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Geophysical Exploration and Drilling for Thermal Gradient Distribution Study: Joint Project at Bugarama Geothermal Graben Located Between Rwanda, R.D Congo and Burundi

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ABSTRACT

Our geoscientific observations in Bugarama Geothermal Graben show that Low Geothermal temperatures can yield significant potentials in direct uses or small to medium geothermal power plants. Geothermal manifestations that appear at surface in that part of the Western Rift, among other geological features, are a signature of what the Earth underneath holds and that there is a geothermal resource to be tapped whether for direct uses (i.e. rice drying, fish farming, geothermal spas for tourism etc.) or small-scale power generation. This paper describes the work done in Bugarama Graben so far since 2016 and potentiality of these geothermal resources. In conjunction with three countries, Rwanda, DRC and Burundi, a joint exploration project was conducted at Bugarama Graben, a continuation of the Western Geothermal Rift System. The graben has got geothermal manifestations at the surface such as hot springs, normal faults and several other geological indications of past tectonic activities. Surface Geophysical exploration were conducted such as TEM (transient Electromagnetic), Magnetics, of which a detailed report has been done, followed by shallow drilling activities to map the temperature gradients distributions. Description of retrieved geological core samples were studied and analyzed as well for clear geological settings of the drilled area. The project is set to enlighten scientists and decision makers of energy authorities of the three countries on the geothermal potential and possible future geothermal energy development at Bugarama Geothermal Graben. The analysis from these surveys showed a relatively low to medium temperature geothermal system of which a heat source is yet to be identified. Temperatures were ranging between sixty-three and seventy-five degrees at a depth of one hundred and two meters with an increasing trend as we drill down; in one of the wells. Temperature gradients can build up from surface down deep and future shallow drilling are recommended in Bugarama Graben for delineating the geothermal potential underneath and of which three countries Rwanda, DRC and Burundi can tap together for their energy or geothermal direct uses needs.

1. INTRODUCTION

Detailed surface geothermal explorations are the prior steps to drilling for temperature gradient studies. The purpose of these surveys was to understand the geothermal resources in Rusizi graben, with an aim to use them for electricity generation or direct uses.

Temperature gradient distribution study was set after surface exploration surveys, to gain information on thermal gradient in the area and locate anomalies which would indicate up-flow zones. The main goal is to reach down into rocks that are not thermally disturbed by surface or ground water to be able to estimate the geothermal gradient from temperature measurements. These drilling activities were carried out first, in Bugarama and Ruhwa geothermal prospects. Results of shallow drilling will be used to determine the siting of deep wells which would delineate the size, distribution of geothermal heat in the areas of each prospect.

The drilling started in Bugarama, Rwanda, where first wells were sited. In Ruhwa geothermal prospect, RU-TG-04 was drilled and unexpectedly, it resulted in a blow-out discharging over 10 meters with hot geothermal water, mud, steam and gravel. These were dangerous drilling circumstances to both drilling workers as well as local population. The well was controlled and mastered without any damage to the crew and population.

For future drilling activities in Ruhwa, Kavimvira and Bugarama, there is need of prior studies for environmental impact assessment and mitigations to cater for these geohazards events met at Ruhwa, well RU-TG04.

1.1. Geothermal History in Rusizi Graben countries

Rwanda, Burundi and Democratic Republic of Congo have been conducting geoscientific explorations that started two to three decades ago, to build geothermal power plants in their respective countries, because energy is a strategic priority sector to these nations. Accordingly, an integrated geoscientific work has been carried out there, which includes geology, geochemistry, geophysics and soil temperature and CO2 gas measurements and geothermometers.

1.1.1. Rwanda

Geothermal investigations in Rwanda started in 1980's. In Rwanda there are two prospective areas for geothermal energy. These are found in the north western region, which is associated with intensive volcanism in the area. It is also found in the southern Region (Bugarama graben) associated with faults in East African Rift System. Among these prospect areas, the development activities in North-Western Geothermal fields are much better known considerably to the South-Western prospects, Bugarama and Ruhwa which are at early stage of exploration surveys.

Since 2006, Rwanda have increased research effort, in quest for potential of geothermal energy resource. A brief summary of research projects carried out before this study can be seen here:

- In 1983, the French Bureau of Geology and mines identified Gisenyi and Bugarama as potential sites for geothermal energy with estimate reservoir temperature over 100 C;

- In 2006, Chevron carried out Geochemistry studies in the Bugarama and Gisenyi geothermal prospects and estimated the reservoir temperature to be more than 150 C;

- In 2008, the German institute for Geosciences and Natural Resource (BGR), in collaboration of the Kenya Electricity Generating Company (KenGen), the Icelandic Geo Survey (ISOR) and Spanish Institute for Technology and Renewable Energies (ITER) carried out surface explorations in the North-Western Geothermal prospect area. The results from this study concluded that a high temperature geothermal system (>200 C) may exist. The medium temperature geothermal system (150-200C) may also exist in other parts of the prospect.

- In 2009, KenGen (Kenya Electricity Generating Company) in collaboration with local geoscientists acquired additional surface studies (geochemistry and geophysics) and carried out baseline environmental impact assessment (EIA) in North-Western geothermal prospects.

- In 2011, an additional geothermal survey was done by the Institute of Earth Science and Engineering (IESE) and local geoscientists.

From this brief review of geothermal research in Rwanda, can be seen that most effort, to date, has been focused on the north-western geothermal prospects. It is in this regard; emphasis has now been given to deepen geoscientific research and exploration on South-Western geothermal prospects.

1.1.2. Burundi

Descriptions of geothermal activity in Burundi can be found in documents dating back to 1968. However, much less effort has been put into geothermal research in Burundi compared to the work done in Rwanda. In the 20th century four studies on geothermal potential of the country were carried out (McNitt et al., 1969; Deelstra et al., 1972; Edeline et al., 1981, Ármannsson and Gíslason, 1983).

- In 1968, the first description of Geothermal manifestation is given by Stanley

- In 1968, the first specific investigation activity was carried out by UNDP and the study covered eight geothermal locations

- In 1972, 15 hot springs have been described

- In 1982, 14 geothermal locations have been described and reported chemical analysis from 13 of them. All reported geothermal resources are hot springs, no record of surface steam (fumaroles) or mud pools.

The highest temperature is 68 °C at Ruhwa and geothermometers indicate reservoir temperature as high as 110 -120 °C, in two places in Rusizi Valley. Most geothermal areas are in central and Western Burundi.

1.1.3. Democratic Republic of Congo

Before this study, there was no systematic work on geothermal potential in South Kivu, unlike in the neighboring countries, Rwanda and Burundi. For those countries, several known geothermal manifestations are the well-known in the region. Spring temperatures range from 35 to 90 ºC, with flow rate averages ranging from 11 to 162 littles.

The geological mapping was of 5x5 km area of each of the three geothermal targets under study, with special attention on how the geothermal occurrence relates to the structural pattern of the areas. The regional geology of the current study covers the area between Lake Kivu in the north and Lake Tanganyika in the south.

2. REGIONAL GEOLOGICAL SETTINGS OF KAVIMVIRA (DRC), BUGARAMA (RWANDA), RUHWA (BURUNDI).

The geology of the Rusizi Geothermal Graben consists of Precambrian metasediments, limestone rocks, Mio-Pliocene, basaltic lavas and Quaternary sediments. The western branch of EARS (East Africa Rift System) is primarily a sedimentary rift, with several large volcanic zones. Geothermal surface manifestations are widely distributed throughout the Rift, most commonly known as warm or hot springs. The Rift is set in Precambrian geological formations, and there is a strong relation between the tectonics of the rifting and the location of geothermal surface manifestations.

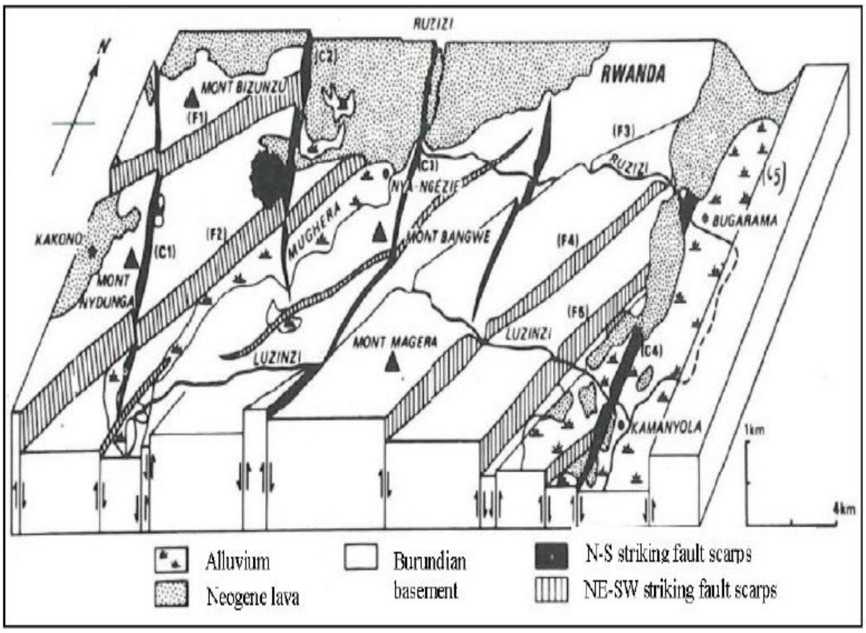


Figure 1: Fault structures of Nyangezi area (from Figure 5 in Villeneuve, 1950). Note that Nyangezi is located on the southern margin of the Bukavu lava field.

The study area is dominated by Burundian metamorphic sedments. The two rock units comprise quartzites, biotite and muscovite schists and other only moderately metamorphosed clastics as stated above in figure 1. Being of Neoproterozoic age, this formation is affected by the Cenozoic formation of the Western Rift. The age of the formation excludes any stored ancient heat source, but the younger Cenozoic are believed to have re-activated structural weaknesses in the Burundian Group.

The youngest rock formation within the area are limestone deposits which occur adjacent to the geothermal area in Bugarama. The deposit forms a low layer, rising 30 – 40 m higher than the valley floor, stretching 1000 m along the escarpment and 600 m. The deposits form thin, loose layers, often broken and fragmented. The limestone deposit is used a source of calcium for cement production, both by the cement factory and by the local people.

Figure 2: Calcium carbonate scaling

3. RESISTIVITY SURVEYS

Field method and measuring instrumentation- Transient Electromagnetic Method (TEM) uses the artificial pulse, electromagnetic field, to generate vortex currents that penetrate down deep into the ground. As a source of primary Electromagnetic field, the ungrounded loop is used and that is energized with pulse current. The secondary Electromagnetic transient is measured during off time (when the current in the transmitter loop is off) on the output of the receiver loop or multi-turn coil.

As vortex currents penetrate deeper into the ground with time, the measured Electromagnetic Magnetic (EM) transient can be interpreted as a sounding curve to reveal geoelectrical structure underneath. (see figure 3).

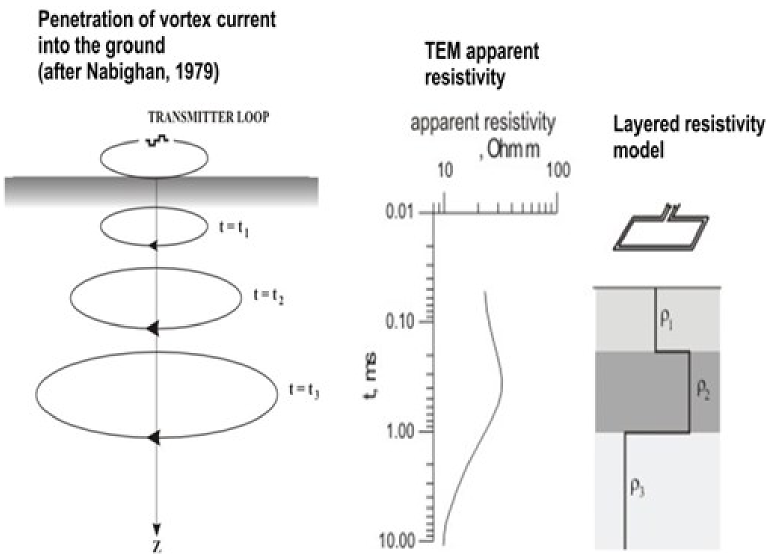


Figure 3: Main principles of the TEM sounding

The multifunctional AIE-2 system was used for TEM measurements. In TEM configuration, AIE-2 system comprises TEM/TDIP receiver with the control PDA computer and TEM-200 transmitter (see figure 4). Additionally, the multi-turn receiver coil (20 m2 effective area) with a preamplifier (x100) can be used as a sensor.

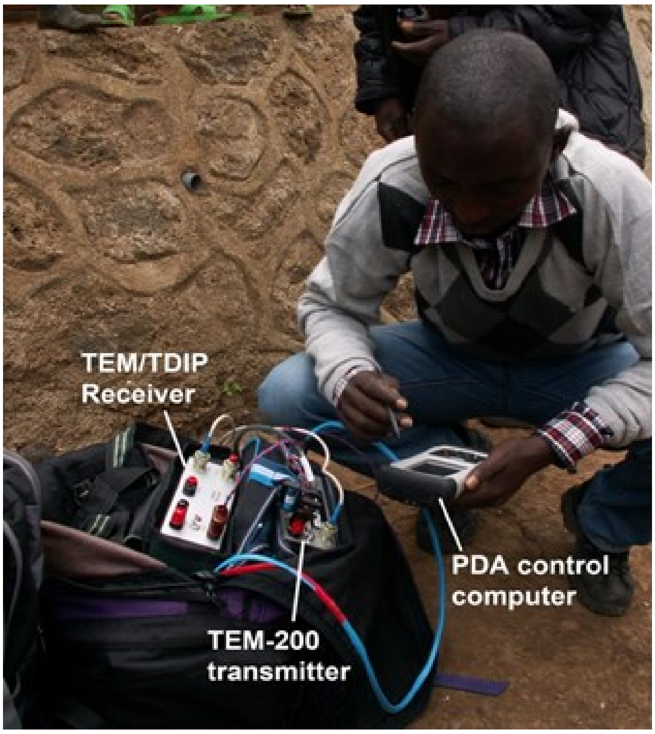


Figure 4: Field TEM measurement with the AIE-2 system.

In TEM mode the receiver takes readings of the EM transient voltage within several time windows with increasing duration (see figure 5). Number of time windows during time-off depends on its duration and varies between 42 (10 ms time-off) and 74 (1 s time off). The receiver also provides stacking (Nx100-1000 times typically) to improve signal-to-noise ratio.

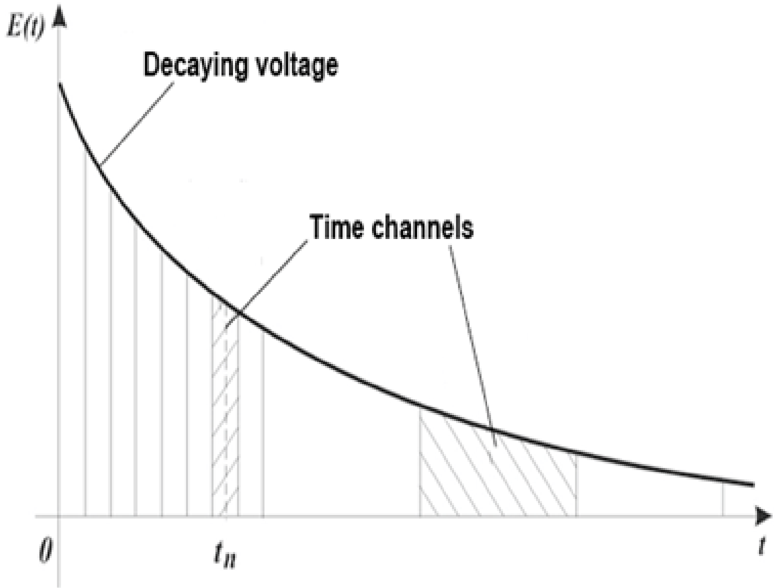


Figure 5: TEM-IP receiver time-diagram.

3.1. TEM Surveys in Kavimvira, Ruhwa and Bugarama Geothermal Prospects

Geophysical survey conducted in these areas, especially the TEM (Transient Electromagnetic) soundings done west of the fault, show only high resistivity. This confirms that the fault is the main feature of the geothermal reservoir and reflects an upward flow of geothermal flow along these prospects.

Based on the outcome of the study five temperature gradient wells were recommended first in Bugarama. The purpose was to detect a suitable near surface temperature gradient structure on which deeper exploratory wells could be sited. This section describes the resistivity and magnetic surveys conducted in three countries, prior to shallow drilling for temperature gradient wells.

3.1.1. TEM surveys in Bugarama

An investigation with Transient Electromagnetic Method (TEM) was performed at Bugarama site (south-west of Rwanda) on 22nd – 24th of September 2016. The main objective of this survey was estimation of capabilities of TEM with the AIE-2 measuring system for investigation of geothermal sites and exploration of geothermal resources in Rwanda. Bugarama site was chosen for these investigations because of the known geothermal springs and several boreholes revealed hot water sources down deep.

In the course of our field soundings at Bugarama site we tried one-loop and central loop TEM configurations with 100x100 m square loop (see Figure 6). For one-loop configuration the same loop is used both as transmitter and receiver. For central loop configuration an additional separate sensor (multi-turn coil) is placed within the center of the transmitter loop to measure the transient decay. Central loop measurements allow to avoid the distorting, so called "superparamagnetic effect", that is typical for highly magnetic African topsoil and could badly affect one-loop TEM data. For that reason, we mainly used central loop data for interpretation.

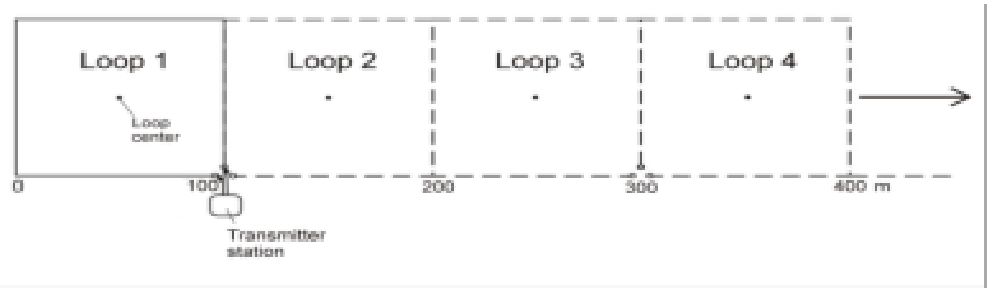


Figure 6: Laying out 100x100 loops for one-loop and central loop TEM soundings.

3.1.1.1. Data processing and interpretation

Results of measurements (raw binary data files) were copied from PDA memory to a PC host computer for further processing and interpretation. On the first stage, TEMBIN program was used. This provided reading raw binary data files, averaging of the results of the repeated measurements, sorting data and creation of an output profile data file. Additionally, time smoothing of TEM transients was made.

The TEMIMAGE program provided 1D inversion of the TEM data into resistivity distribution with depth and graphical presentation as TEM multichannel plots and resistivity cross-sections. Among different inversion algorithms available within TEMIMAGE program, we used Smoothing Imaging Inversion algorithm that provided 1D inversion model with about 50 layers of fixed thickness and smooth resistivity distribution. This algorithm is quite stable, flexible and does not need any prior information about number of layers beneath.

For final presentation of the inversion results SURFER program by Golden Software was used.

3.1.1.2. TEM results

First parametric TEM sounding was made directly at the borehole TG-06, to compare TEM inversion results with revealed geological layers (generalized model). According to this verification the most electrically conductive layers (1-10 Ohm m) correspond to clay soils, tuffs and highly altered basalts (see Figure 7). Fresh basalts, limestone and sandstone have quite high resistivity. Thus, according to these data, TEM method (being quite sensitive to highly conductive layers) can be used effectively for sounding of basaltic shields to delineate highly altered horizons, tuffs and clay layers.

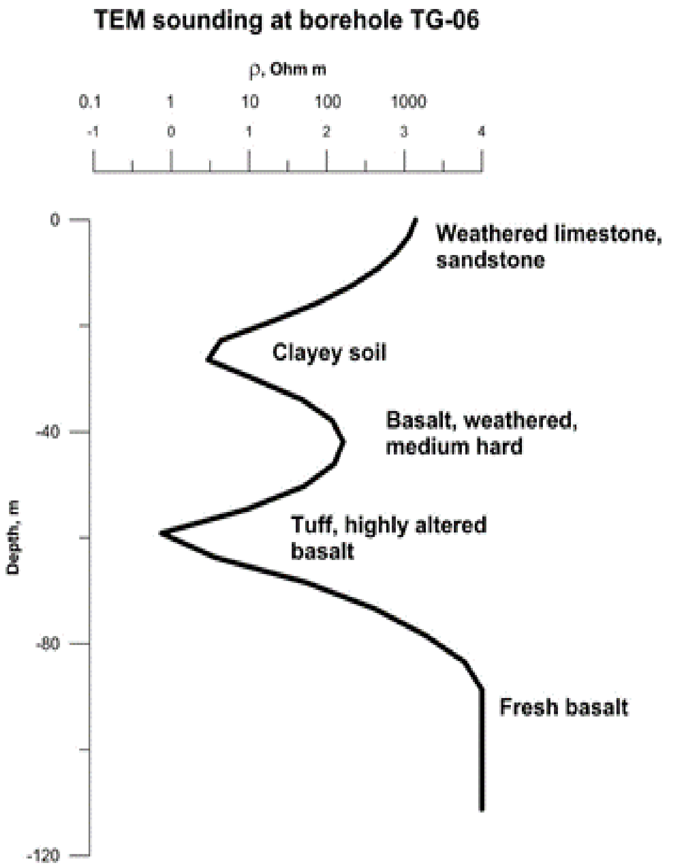


Figure 7: TEM sounding at the borehole TG-06 in Bugarama Geothermal Prospect.

Moreover, we performed TEM soundings along two lines: Line 1 crossing Ru-TG-04 borehole revealed hot water (72.5 C) at about 100 m depth and Line 2 across the Rubyiro river valley.

TEM sections (see Figure 8) along lines 1 and 2 also revealed electrically conductive altered layers in the upper part of the basaltic shield. In the bottom of the sections the resistivity typically grows up detecting fresh basalt or quartzite layers most likely. In the central part of the TEM line 1 where resistivity values in the bottom part are lower (10 Ohm m approx.) that could point to a more fractured zone.

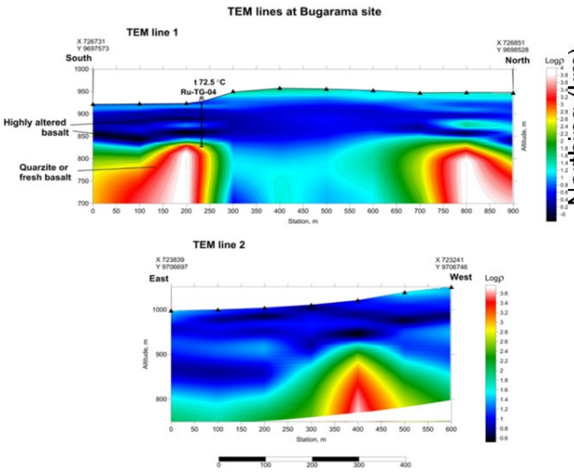


Figure 8: TEM resistivity sections at borehole Ru-TG-04.

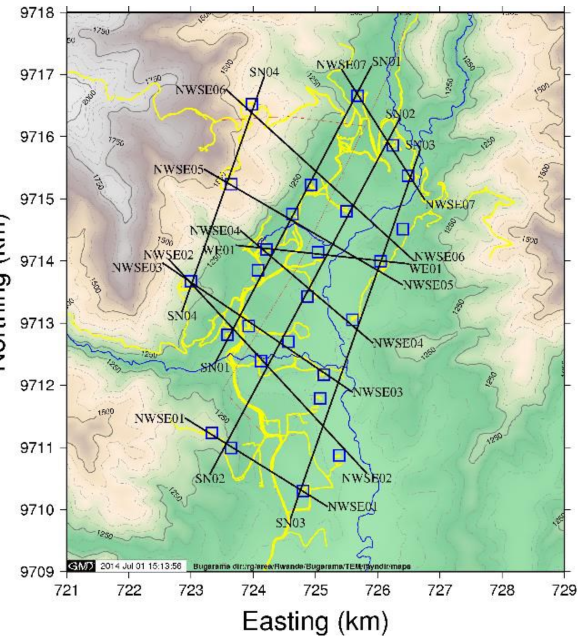


Fig. 9: Location of TEM soundings in Bugarama (RG, 2014)

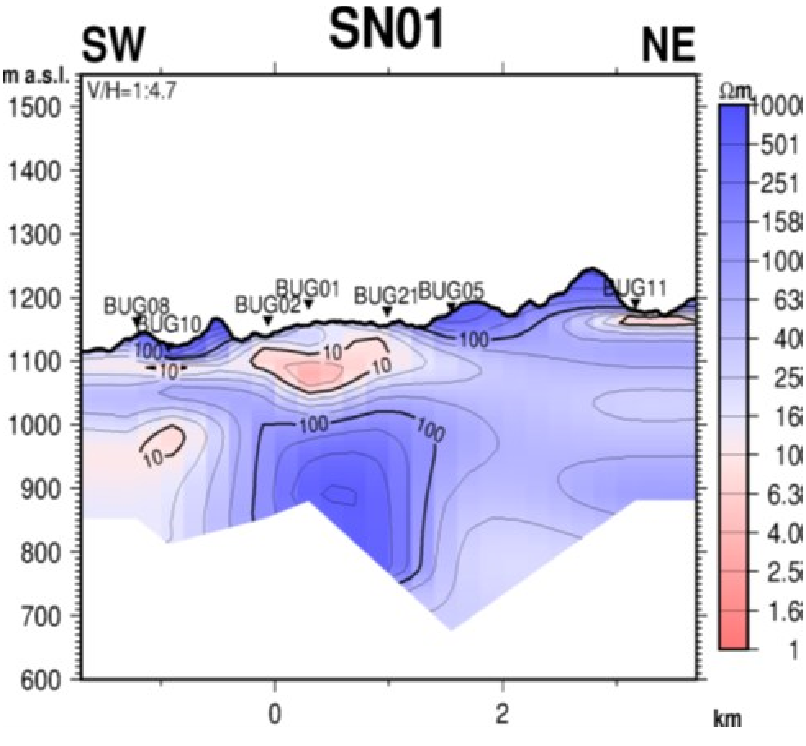


Figure 10: Resistivity cross section SN01 from SSW to NNE through the geothermal area in Bugarama (site BUG01). Black triangles show location of TEM soundings and their name is above it. (RG, 2014). (See also Figure 9 for map/data location)

Summing up, presented TEM results here, take us to a conclusion that TEM method might effectively assist in exploration for geothermal sources at Bugarama geothermal prospect and other similar sites in Rwanda. TEM might be used for estimation of depth of hydrothermally altered layers and for exploration of fractured zones filled with hot water down deep. For the more reliable sounding of deep geothermal sources we would recommend using larger loops (200x200 up to 500x500 m size) and more sensitive sensors (multi-turn coils).

3.1.2. TEM surveys in Ruhwa

The location of Ruhwa is in the middle of mountainous at the confluent of Rusizi rivers. In that region, main rivers follow main faults that are oriented N-S and controls the main tectonic of the region. There are plenty of warm springs with waters up to 65 degrees celicius or more.

The TEM (Transient Electromagnetic) resistivity surveys indicate a vertical boundary with S-N to SSW-NNE direction with conducive part to the West and resistive to the East. The low resistivity anomalies that extends from 200m depth down to the resolution depth of the TEM soundings, may show the geothermal reservoir (See figure 8, 10). The resistivity and magnetic surveys at Ruhwa suggest a N-S to SSW-NNE fault with downfall towards West that controls the deep up-flow of geothermal fluid. This N-S oriented up flow line is located West of the geothermal manifestations in Ruhwa. This up-flow zone is transited by some E-W oriented geological structures shown in the magnetic data which controls shallower part of the up-flow and the surface geothermal activity in Ruhwa (RG, 2016). An extensive low resistivity anomaly at depth could indicate a large geothermal reservoir.

A total number of 30 soundings were done in Ruhwa. Emphasis was made to the data points performed along the Ruhwa normal fault of which a low resistivity anomaly has been mapped. There is clearly a vertical resistivity boundary close to sounding RUH19. This boundary is interpreted to reflect a major fault, in a similar way as the sharp vertical resistivity boundary in Bugarama. The resistivity structure of sounding RUH19 which lies by the fault, has a character of up flow, a clear high resistivity to the East of the fault and low resistivity at depth to the West of the fault. This is different from the Bugarama area as there, the low resistivity anomalies were rather confined to a layer (sediments) or a narrow fracture system.

The low resistivity anomaly extends from approximately 200 meters depth under the surface down to the penetration depth of the TEM soundings. The low resistivity anomaly also has a sharp boundary to the south as displayed on the resistivity cross sections. To the south of SWNE 03 there is high resistivity at depth whereas the low resistivity anomaly extends under all the North-Western part of the survey area.

It must be kept in mind that low resistivity can be caused by other parameters than high temperatures. Sediments with conductive clay minerals may be reflected as low resistivity anomaly. Whether the low resistivity anomaly in Ruhwa reflects geothermal activity or not will only be found out by drilling, but we here suggest that given the fist shallow well drilled in the area. At a depth of 102 m, and of which a discharge of hot water mixed with mud and gravel were ejected up to 12 m from well head. This is clear indication that geothermal resource in Ruhwa might be viable than thought previously.

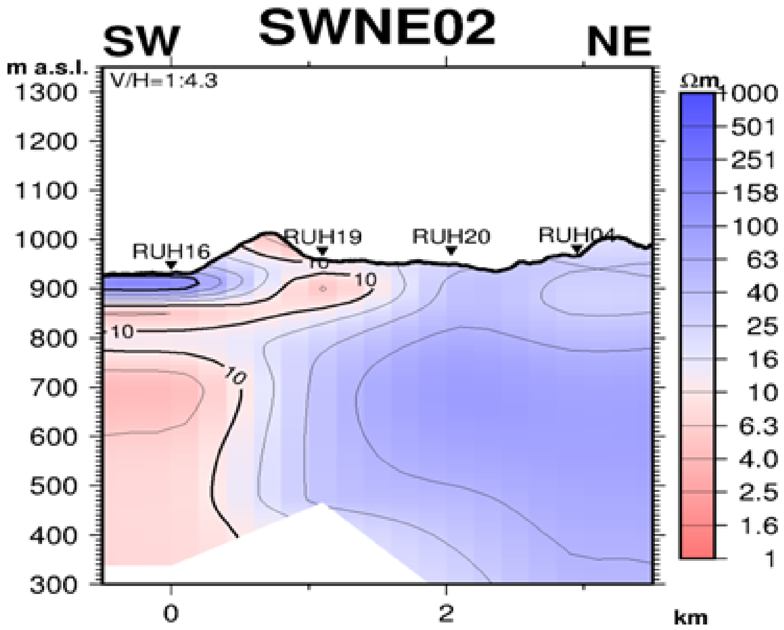
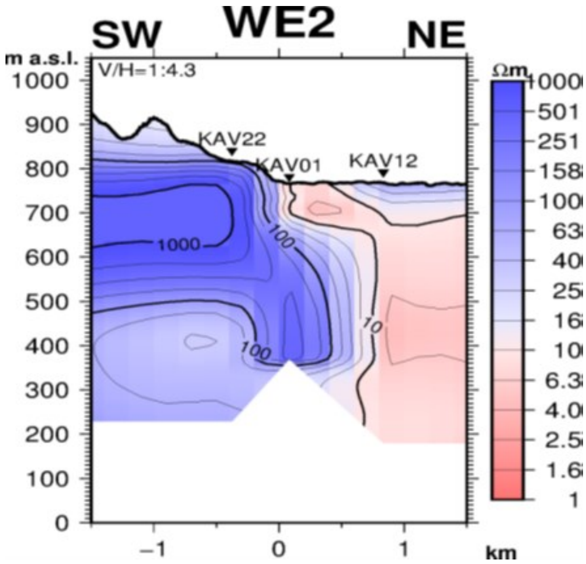


Figure 11: Resistivity cross section SWNE02 from SSW to NNE, through the geothermal area in Ruhwa. Black triangles show location of the TEM soundings with their name above it. (RG, 2014) (See also Figure 9 for map/data location)

3.1.3. TEM Surveys in Kavimvira

A total of 27 TEM soundings where measure. As in the other two previously described geothermal areas, the Kavimvira geothermal location is on normal fault system, where the sharp edge of the mountains to the west marking the escarpment edge, with the downward site of the graben to the east.



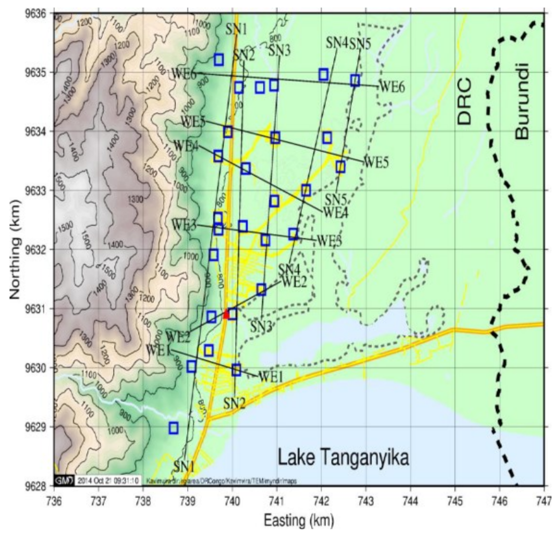


Figure 12: Vertical resistivity cross-section at KAV01. **Figure 13: Location of vertical resistivity cross-sections, in Kavimvira**

The nature of the low resistivity region is not clear, it may be a geothermal reservoir, showing increased amount of ion strength (charged particles) in the hot water. Other explanation such as saline water or clay zones in sediments could also explain the low resistivity. Only drilling into the low resistivity zone can reveal its true nature.

A typical resistivity structure for a high enthalpy geothermal reservoir is high-low-high from surface and downwards, where the low resistivity zone is commonly less than 10 Ωm. This zoning is a result of thermal alterations due to water-rock interaction and is temperature dependent. The low resistivity zone is called clay cap zone that occurs in the temperature range of about 100-250 °C. The high resistivity below, is then an indication of temperature higher than 250 °C. The low resistivity East of the escarpment is showing resistivity less than 10 Ωm and as such it could represent the clay cap layer. However, that possibility is unlikely, mainly due to the low temperature.

3.2. Magnetic surveys

3.2.1. Magnetics in Bugarama Geothermal Prospect

Magnetic surveys were conducted in an area of one km square around the geothermal pool in Bugarama. The requirements where to measure the magnetic field at least at 5 m interval along a survey lines with 50 m spacing in a one km square area. The total of 21 km of survey lines were planned.

The total length of the survey is about 30 km but 21.5 km along the predefined lines. The average distance between data points is about 1.8 meters. The data is scrutinized and short anomalies that are believed to be originated from man-made magnetic materials such as iron roofs of houses, vehicles are eliminated.

Three lines where measured perpendicular to the main survey lines. The purpose of those lines was to check for possible narrow anomalies between lines, as well as checking for cross over errors. In short no such narrow E-W anomalies where found and the cross over check showed error usually only few nT (1nT = 0.001µT).

The minor geothermal pool located at 500 m east of the main pound, coincide with the main E-W positive magnetic anomalies. It is not known what this anomaly reflects but suggested here that it controls the up flow of hot water to the western geothermal manifestation.

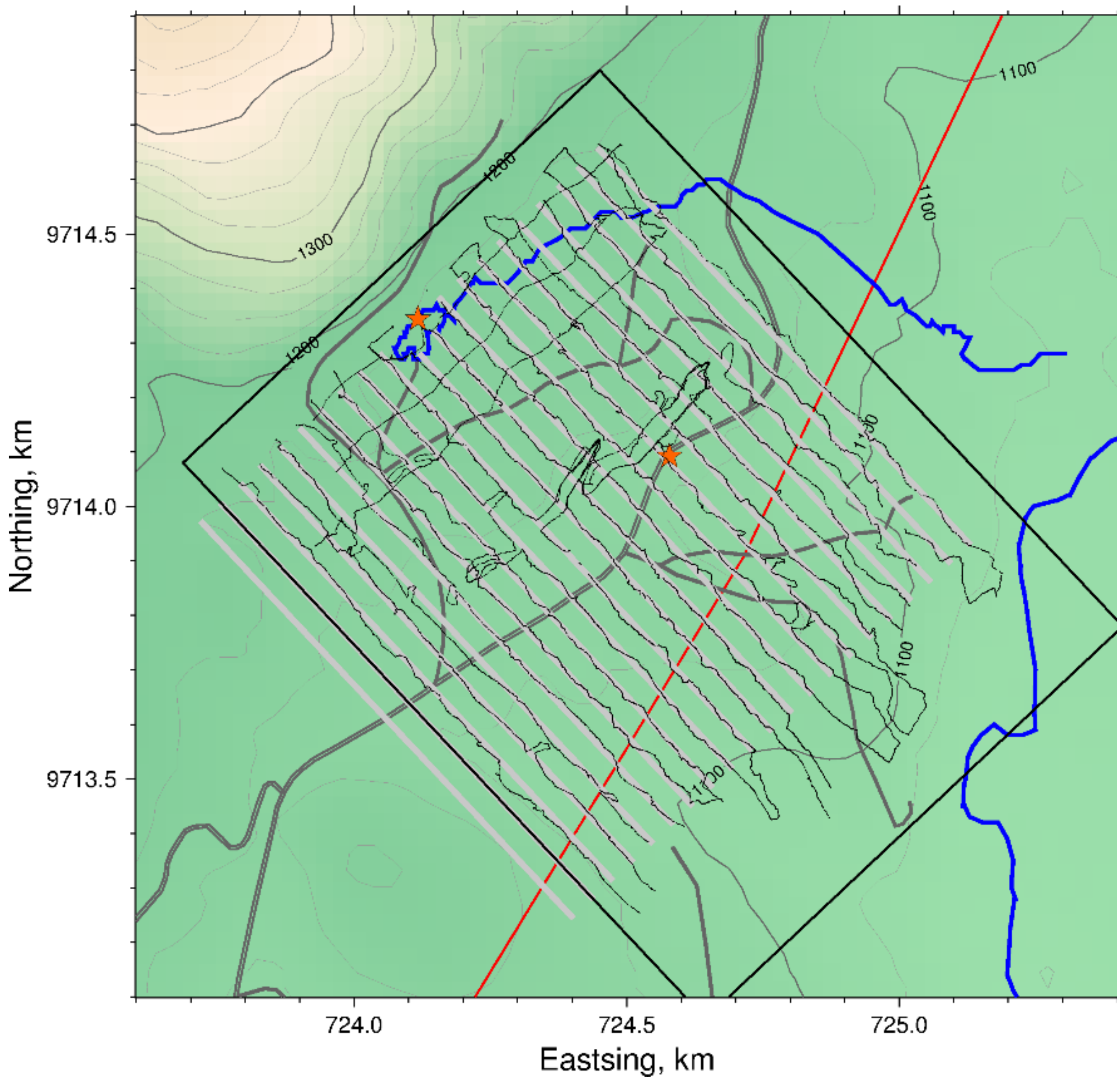


Figure 14: Location of magnetic survey lines in Bugarama. Grey paths are roads and tracks, red line is a power line and blue paths are rivers. Red stars show geothermal manifestations, the western one in the geothermal pond and the main spring. The easting and northing are UTM coordinates in km. (RG, 2014).

3.2.2. Magnetics in Ruhwa Geothermal Prospect

The resistivity and magnetic surveys at Ruhwa support the following model:

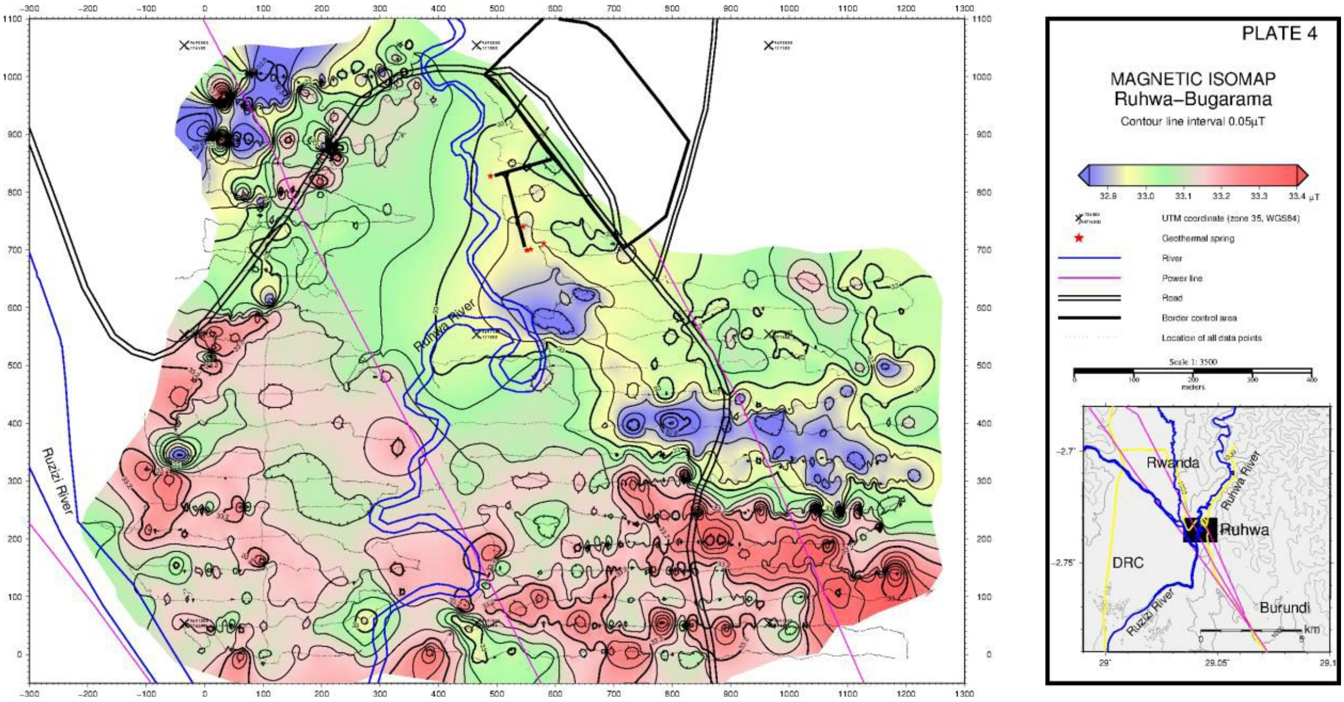


Figure 15: A magnetic map of the Ruhwa area (RG, 2014).

- A NS to SSW-NNE fault with downfall towards west that controls the deep up-flow of geothermal fluid.
- This NS oriented up-flow line is located west of the geothermal manifestations in Ruhwa
- This up-flow zone is transited by EW oriented geological structures shown in the magnetic data, which controls shallower part of the up-flow and the surface geothermal activity in Ruhwa.
- An extensive low resistivity anomaly at depth could indicate a large geothermal reservoir.
- The size of the reservoir must be taken with caution and only drilling will decide if the low resistivity is only caused by geothermal activity or partly by the existence of clays in sediments.
- The drilling target would be in the fault in the area of alleged up-flow along the fault, preferably by the geothermal springs.

3.2.3. Magnetics in Kavimvira Geothermal Prospect

There are no magnetic anomalies that can be traced on magnetic maps of Kavimvira. The magnetic field is constant at 33 µT and the deviations from that value are probably all due to local cultural noise. Thus, the magnetic field is not giving any information on the origin of the geothermal field in the Kavimvira area.

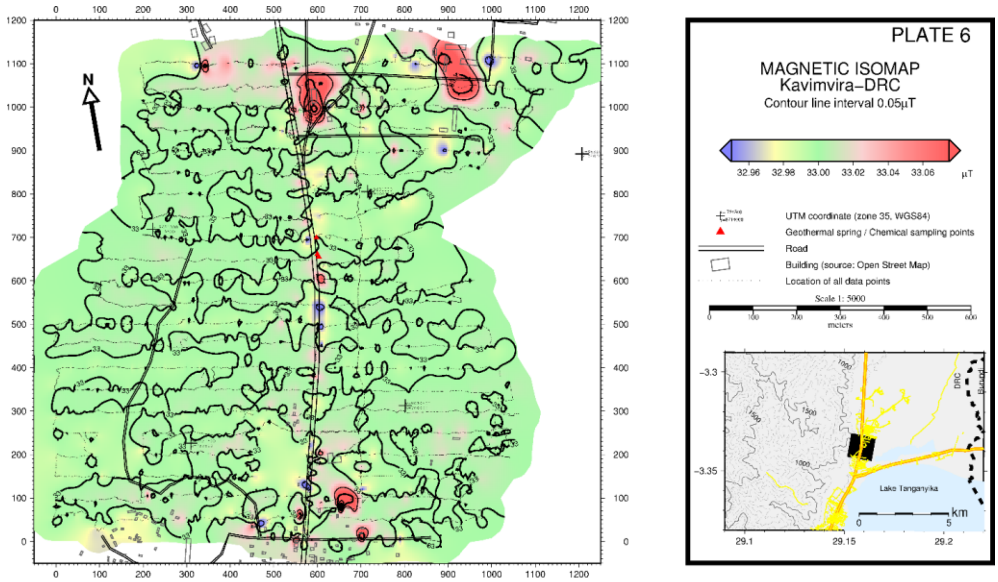


Figure 16: Magnetic iso-map. Positive anomalies are shown by red colour and negative anomalies by blue colour. (RG, 2014)

Bugarama geothermal prospect sits in Rusizi Graben, a narrow N-S to NE-SW trending valley. There are warm springs at the foot of western escarpment of the Graben, that denote the fault most intensely on a 100 m long line along the western shore of a small pond fed by the several 45-55 ˚C warm springs, with extensive gas flow, located at the bottom of the pool.

3.3. Drilling exploration at Bugarama geothermal prospect, Rwanda

During this phase, 3 wells TG-01, TG-02 and TG-03 were drilled using hammer air drilling technology. However, due to soft formations and geology of the area this method has been changed to coring drilling technology.

The drilling activities and wells characteristics are described below:

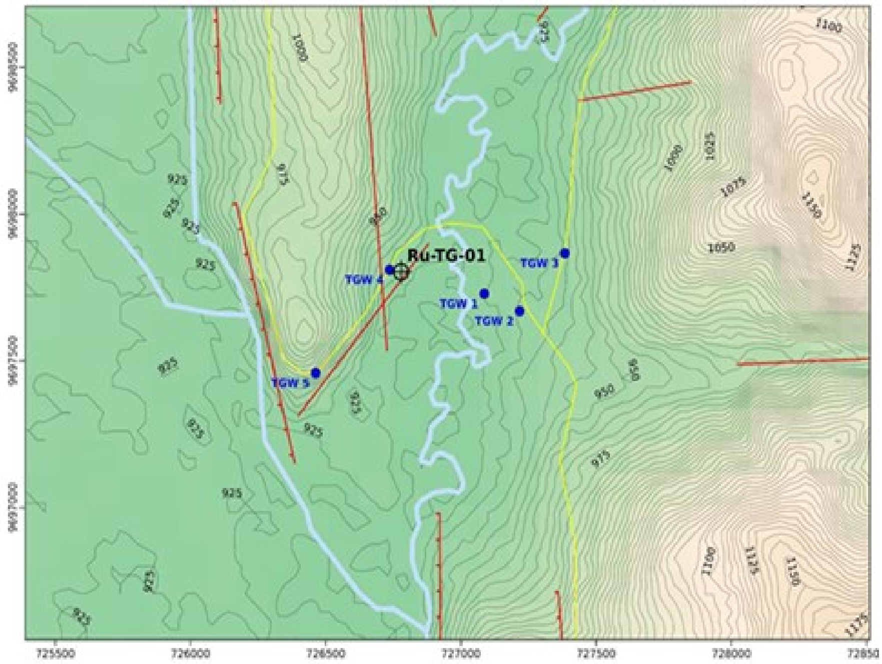


Figure 17: Location of temperature gradient well in Ruhwa. Blue circle is the planned drilling location of the five temperature gradient wells and black mark is the drilled well Ru-TG-01.

Subsurface Stratigraphical units from wells of TG-01, TG-02 and TG-03 were drilled in very soft formations and they collapsed instantly as drilling continues. The drilling crew decided to change drilling method and proceeded with TG-04, TG-05, TG-6 and TG-04-Ru in Ruhwa.

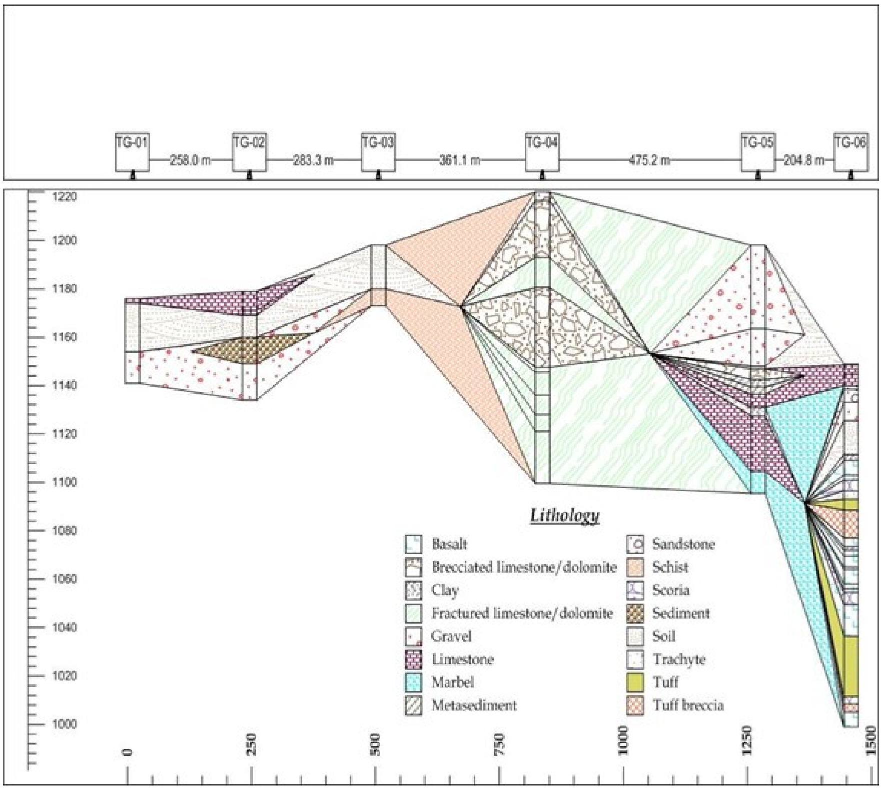


Figure 18: A Cross-section of wells drilled in Bugarama geothermal prospect.

3.3.1. Drilling at TG 04

Recommenced on March 02, 2016. New 76 mm and new diamond core bit were inserted and drilled to 9 m. Water/foam was used as a drilling fluid. At 9 m depth total loss occurred. Drilling continued till 15.5 m and penetration rate decreased and tripped out for bit inspection. The bit was worn out. Tripped in another diamond bit, which was used before but in good condition and drilled down to 17.7 m with total circulation loss. Due to the collapsing nature of the formation, tripped out to run casing. Inserted 90 mm reamer with casing down to 13 m.

Inserted new bit and continued drilling down to 25.5m and complete loss of circulation occurred. Drilled down to 28.5 m. Pause in the drilling and continued reaming down to 15m with no return of circulation fluid. Continued reaming but the rate of penetration (ROP) was very low.

Tripped out the reamer for inspection, the outside of the bit was completely worn out and continued reaming slowly. Tripped out the reamer for inspection, the outside of the bit was completely worn out. Continued reaming with new reamer down to 26m and run casing. Drilling continued down to 37.5m.

Between 115-118.5 m depth intervals retrieving core was not possible. Tripped out for bit inspection and the bit and the core barrel turned out to be cracked. Tripped in new bit and core barrel and continued drilling down to 121.5m and the bit was stuck. Tried to release it but was not possible. Tripped in new reamer bit and reamed down to 73 (three reamer bits were totally worn out). During the drilling and reaming, there was no return of circulation fluid.

The water table was encountered at 30 m and continued drilling down to 73.5m. Changed new and continued drilling down to 118.5 m with total loss of circulation fluid.

Temperature logging down to 120 m and the maximum reading was 55.5 ˚C after 14 hours of heating. Water level in the drilling rod was at 36m. It was decided by the drilling company to stop drilling and retrieve the drilling rods. About 20 m length of drilling rods and core barrel remained in the hole and the rest were tripped out. The depth of the clear well is down to 101.05m. The reaming couldn´t pass 73 m. The plan was to run 2" galvanized pipe, but the rig was not equipped with pipe holder. Therefore, it was sent to Bukavu, DR Congo workshop. In the meantime, six of the pipes were perforated randomly using a grinder. 2" galvanized pipe holder arrived from Bukavu, DR Congo workshop. Rods and the reamer were removed (73 m) but the bit was totally worn out. Two-inch galvanized pipes were installed down to 80 meters. It was not possible to push it down further. Drilling ended on 18/02/2016 after two weeks of drilling at total depth of 121.5 m.

3.3.2. Drilling at TG 05

Started on 20/02/2016 and drilled down to 31.5 m. Encountered the water table at 10 m and the well started to collapse. In order to overcome the caving, the well was cased down to 24 m. The caving of the formation and collapsing of the boulders and cobbles and at the same time increasing inflow of water to the well made the drilling very difficult. Continued drilling down to 34.55 m but there was decrease in the ROP (rate of penetration). Tripped out for bit inspection and the bit was broken and the core barrel has cracked completely. Core barrel is not at site and wait till it comes from Kigali.

Tripped in with new core bit and core barrel. Continued drilling down to 50 m. Tripped out and reamed and run casing down to 33 m and drilled to 102 m. Stopped drilling and started tripping out for bit inspection. The bit was worn out.

In the meantime, conducted temperature logging down to 100 m. The maximum temperature was 28 °C after 12 hours heating. During the measurement, the water was pressurized (artesian flow) and overflowing on the surface. Tripped in new bit and drilled down to 100 m and the drill string was stuck and tried to release it but without success. Tried to trip out the casings but stuck too. Efforts were made to release the casings but were not successful. Waiting for crane to assist the rig in pulling out the stuck casings from Cimerwa cement factory, which is in the vicinity of the drilling site.

Still efforts were made to release the casings but were not successful. Waiting for crane to assist the rig in pulling out the stuck casings from Cimerwa cement factory, which is the only available crane in the area. In the meantime, temperature and pressure logging was conducted on TG-4.

Crane from Cimerwa arrived at site. After several hours struggle the casing was released. Tripped in the reamer which was at 44 m depth and continued reaming down to 87 m and the bit was freed.

Still water was overflowing to the surface through the casing. Conducted temperature and pressure measurements the maximum temperature was 27.5˚C. Tripped out casing and drilling terminated on 03/03/2016 to a total depth of 87 m.

3.3.3. Drilling at Well TG-06

It was started on March 4, 2016. Drilling started in gravel formation down to 23.5 m and then down to 37.5 m in soft clay and boulders. Then from 37.5 to 50.0 m in soft and medium hard formation. No loss of circulation fluid. Tripped out reamer/bit and started running casing. Drilling continued down to 70 m in soft and medium formation. No loss of circulation fluid. In the meantime, tripped out for bit inspection but the bit was alright. There was problem with the core catcher and maintained it and continued drilling 71 m in soft formation and the top part of the well collapsed. Tripped out the casings and an old reamer. Reamed for 3 m, down to 53 m (casing shoe is at 50 m) and it couldn't ream further. There was no extra reamer on site. Wait for reamer to come from India (07/03/2016).

Conducted temperature and pressure measurements. The water level was 1 m above the ground level in the drill pipe when conducting the measurement. The maximum temperature was 28.6˚C after 18 hours heating.

Reamer arrived on 09/03/2016 and inserted new reamer bit and continued reaming down to 71 m. While reaming, the formation above was collapsing and much of the time is spent in hole washing (clearing the cuttings). Started drilling, but the collapse material was too much. Hole washing and cleaning the ponds took much time. A gas kick was encountered at 72 m depth. It was safe and there was no smell (possibly CO2 gas). Drilling continued down to 82 m without loss of circulation fluid. Changed new bit and continued drilling down to 112.5 m. Drilling continued down to 112.5 m. Changed new bit and continued drilling down to 121.5 m and terminated drilling.

Started running the 2" galvanized pipes and unfortunately some of the connectors were not fitting the pipes. Therefore, it was decided to look for connectors available in the vicinity towns but only very few were found. Other alternates are being sought. The connectors were bought from Bukavu, DR Congo. Started running the 2" galvanized pipes and reached at a depth of 122.3 m. Installed the well head and drilling terminated on 17/03/2016.

3.4. Drilling exploration at Ruhwa Geothermal Prospect

Ruhwa is in the middle of mountains at the confluent of Rusizi and Ruhwa Rivers. In that area, the main rivers follow the main faults that are oriented N-S and control the main tectonic of the region. There are several warm springs with waters of 65 ˚C. The geochemical study was conducted; especially chalcedony geothermometer indicates reservoir temperature of 66 – 72 ˚C.

The purpose of drilling actvities was to detect a suitable near surface temperature gradient structure on which deeper exploratory wells could be sited.

Ruhwa Ru-TG-04 well discharges hot pressurized fluid (67 °C) which erupts up to 10 m when the well is fully open. The closing pressure is 2.1 bar. When discharging the well the water is clear at first but after few seconds it becomes muddy and throws stones (<5 cm). The discharge is driven by a perched gas (possibly CO2) and degassing. There is a minor smell of H2S, and pyrite is observed in several locations in the core. The discharge is driven by a gravel aquifer at 101 m. On top is basalt from 80 to 100 m, altered to clay at the bottom forming a clay cap preventing the gas flow to the surface. The discharged fluid is forming scaling on the pipes and in a small stream, reddish-brown in color. Degassing will result in highly oversaturation of carbonates. During compilation of the report the gauges were calibrated, and the oil pressured gauge gave good reading.

3.5. Drilling exploration at Kavimvira Geothermal Prospect

Due to unexpected technical challenge in drilling exploration at Bugarama and Ruhwa, the activities of drilling in Kavimvira were postponed to another phase of the project, given the challenges of carrying out these works in Democratic Republic of Congo and the attention it requires.

4. TEMPERATURE GRADIENT DISTRIBUTION STUDY IN BUGARAMA, RUHWA GEOTHERMAL PROSPECTS

Thermal gradient drilling is a regular tool used in geothermal exploration, usually carried out as a first step after surface exploration reports are completed. This method is more used in low enthalpy resources than in high enthalpy studies. In case of the current project, the surface exploration confirmed that the surface manifestations are closely linked to the main youngest fault structures of each of the three areas under investigation.

For down-hole logging two different tools were used. During the first drilling session a Hobo temperature sensor was used. After Christmas the logger was replaced by P/T sensor.

This is due to the unforeseen stratigraphic conditions. Drilling in this condition would require larger budget to get larger drilling rig and a drilling and casing programme to enable to drill the formations. Such an undertaking would not secure a useable result as the indications from the boreholes is that the groundwater flow disturbing the conditions for gradient measurement.

TG-03 gave no temperature data. The temperature profiles from wells TG-01, TG-02 and TG-05 are to short (TG-01: 25 m, TG-02: 25 m) and/or disturbed by downflow (TG-01 and TG-02 or up flow (TG-05) to give usable data.

Only wells TG-04 and TG-06 have logs where temperature gradient study can give accurate measurements.

4.1. Temperature gradient calculations of TG-04 and TG-06

The temperature and pressure data from well TG-04 used for gradient calculation is the log from March 16, 2016 (Figure 17). The log is log is 78 m and the water level are at 37 m depth. The water table is at ~1184 m a.s.l. which is the same elevation as the warm springs of Bugarama. The temperature at the surface (52.7 °C) compared to 55 °C in the warmest springs. For the gradient calculation the deepest four data points (50, 60, 70 and 78 m) are used. The fit is reasonably good (R2=0.906) and the calculated is 20.8 °C.

Temperature gradient wells will be drilled for the sole purpose of gaining information on thermal gradient in the area and to try to locate anomalies in the regional geothermal gradient which may indicate up-flow zone or zones. The main goal is to reach down into rocks that are not thermally disturbed by surface or ground water to be able to estimate the geothermal gradient from temperature measurements.

4.2. Characteristics of Well Ru-TG-04 drilled in Ruhwa

Name	Drilling Time		Coordinates (UTM)					Temperature °C
Ru-TG-04	Start Date	End Date	Easting	Northing	Zone	Elevation (m) (a.s.l)	Total depth (m)	72.5
	30.3.2016	10.4.2016	726779	9697803	35 N	938	102	

Table 1: Well Logging table of Ru-TG04 in Ruhwa Geothermal Prospect

Drill log and stratigraphy of Well Ru-TG-04 of Ruhwa Geothermal prospect - The mineralogy of the collected drill cuttings was analyzed visually by a geologist loupe. This gives an image of the stratigraphy of the area, as well as secondary mineral assemblage and alteration can act as indicators of geothermal activity in the area.

The alteration minerals assemblages of chlorite, carbonates, silica and rare disseminated pyrite indicate the presence of low temperature hydrothermal process and deposition driven by degassing, which was proven by the discharging fluid.

It is our evaluation that any future blow-outs might result in:

- A blow-out which could be harmful for the crew.
- Cause hazardous conditions for the local population with flowing hot water.
- Cause a financial damage to the project, such as more lost casings and damage to hardware.
- The height of the discharging hot water and steam reached over 10m throwing mixed mud and gravel. The temperature of the fluid was 67.5 C which is ~ 2°C hotter than measured in the surface manifestations.

5. COMPARISON AND TEMPERATURE GRADIENT PROJECTIONS IN GREATER DEPTHS OF WELLS TG-04 AND TG-06

For well TG-06 the selected logging data for gradient calculation is from March 17, 2016. It is 70 m long and the water table is at 14.95 m which equals ~1169 m a.s.l. or 15 m lower than the warm spring elevations. Four data points (30, 40, 50 and 60 m) are usable for linear fit calculation, the fit is good (R2=0.999) and the calculated thermal gradient is 46.5 °C/km. The gradient in the two wells vary greatly but can be explained. both horizontally from the aquifers feeding the springs as well as from buried faults. Here the temperature increases faster with depth, hence higher gradient.

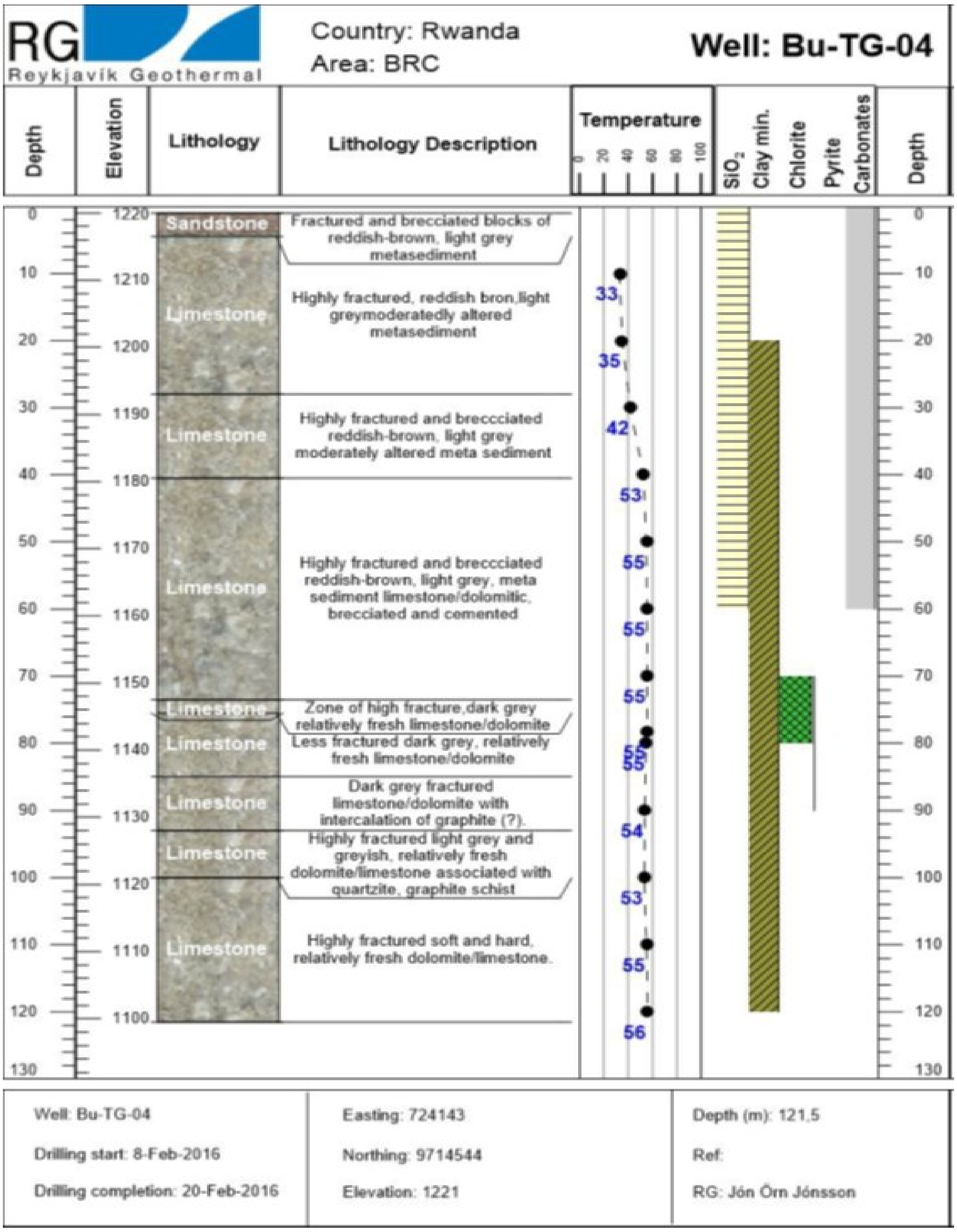


Figure 19: Stratigraphy of the Bu-TG-04 temperature gradient well in Bugarama, Rwanda.

Well TG-04 is drilled in the faulted escarpment of the Bugarama Graben. The fault zone is the upflow channel feeding the Bugarama springs. In the upflow zone the heat transfer from the resource is mainly with mass transport (water flow). Cooling is slow in the main upflow, leading to a low gradient but relatively high temperature at shallow depth as experienced in TG-04. Well TG-06 is on the other hand located east of the escarpment in a sedimentary and basaltic environment. The warm groundwater flow is dominated by an outflow from the faultzone of the escarpment, more of a horizontal flow than upflow. This leads to lower temperature farther from the escarpment,

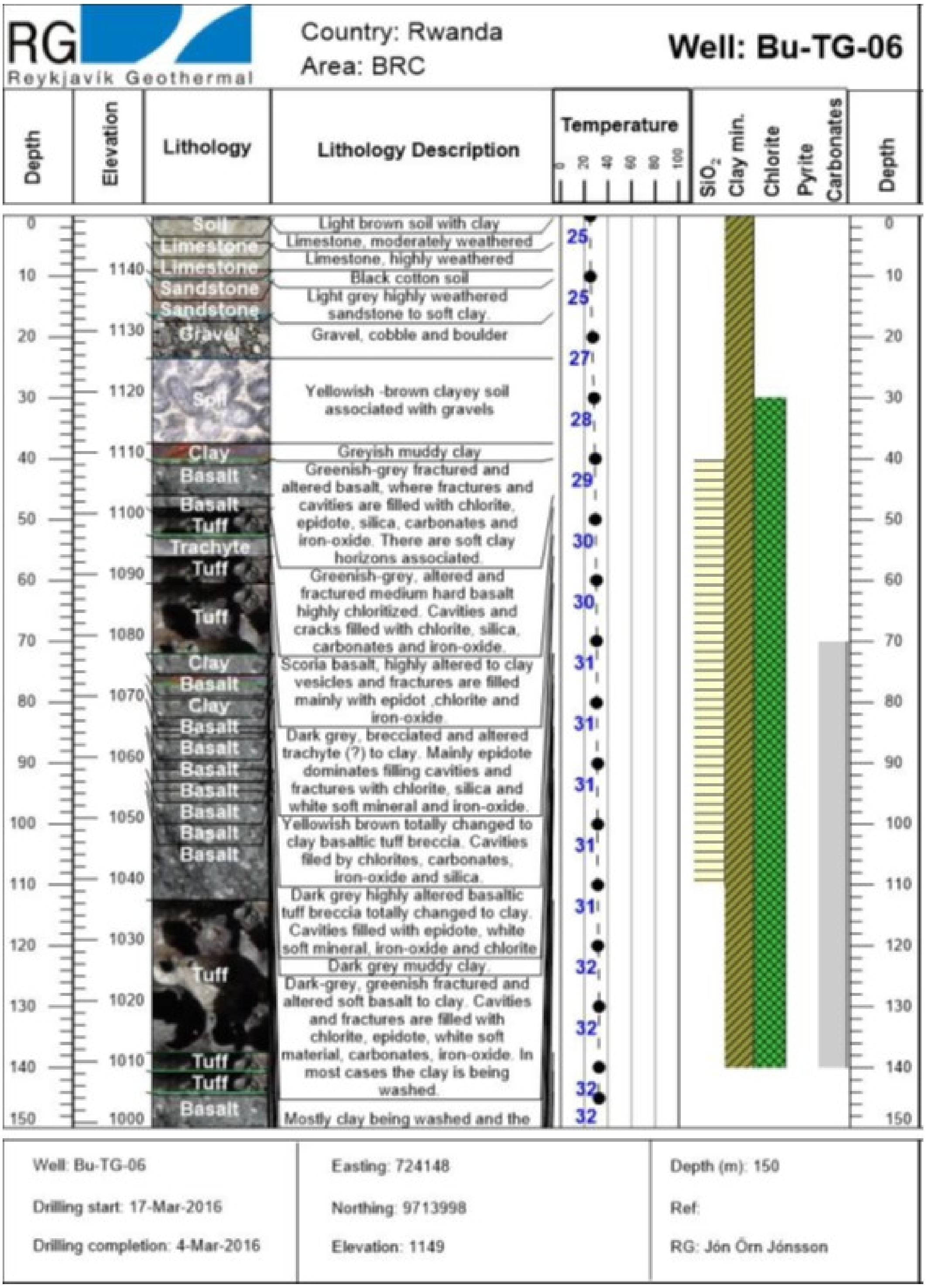


Figure 20: Stratigraphy of the Bu-TG-06 temperature gradient well in Bugarama, Rwannda

After drilling of temperature gradient wells in Bugarama, well TG-04 and TG-06 presented some similarities of originality. These two wells seem to have gradients that are controlled by same resource. These finding were encountered when temperature gradient logs of two wells seem to intersect each other at a temperature of 75 oC and depth of 1500 m (see Figure 20).

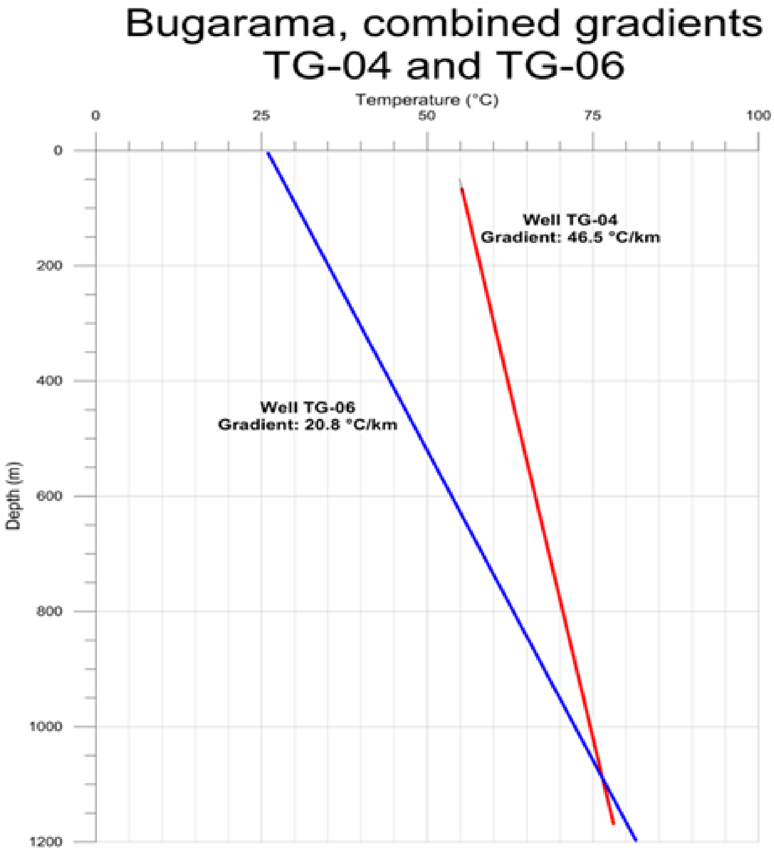


Figure 21: Combined gradient for TG-04 and TG-06 (RG, 2016)

6. CONCLUSIONS

Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC is set to bring more understanding of geothermal resource in Bugarama, Ruhwa and Kavimvira Graben. These finding are important in advancement of the project to the next steps of exploration. After drilling Temperature Gradient Wells, it was confirmed that Ruhwa-Bugarama yields a resource of low enthalpy and it is what surface studies expected. Therefore, drilling of temperature gradient wells is a favorable method to explore the Bugarama/Ruhwa and Kavimvira geothermal prospects.

Direct uses are set to be more favorable for farming activities in the Rusizi graben, plus touristic attractions that geothermal hot springs and other geological features, offer. What is only needed is for Authorities of the three countries to foster these resources for productive uses that benefit the people of these countries.

Electricity Generation can also be obtained from these resources, but there is much more to be done in understanding the Rusizi Geothermal Potentials. More studies such as shallow drilling, delineation and estimation of the reservoir size are to be done in the future, if these countries are to tap into geothermal energy resources.

It is also suggested that for next exploration projects in the Rusizi graben, three countries should deploy sufficient funding so that all approaches of geothermal energy exploration are tried and results are obtained for accurate planning and development.

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