

THOUGHTS ABOUT TECHNIQUES APPLICABLE IN EXPLORATION OF GEOTHERMAL RESOURCES OF UGANDA

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ABSTRACT

Some thoughts about the most important geophysical techniques used in geothermal exploration are presented. The exploration methods are Passive seismic, Transient Electromagnetic Magnetic (TEM) and Magnetotelluric (MT) and Gas geochemistry. Integrating the models from these techniques with geological and terrain models benefits the exploration strategy to the next step of prefeasibility and feasibility studies of the prospects respectively.

In Uganda, only surface exploration of the geothermal resources has been limited in extent and exploration techniques. Over the years, of all the available geothermal surface manifestations sites, only three prospects at Kibiro, Buranga and Katwe-Kikorongo have been studied using the geological and geochemistry methods but geophysical techniques were limited in extent and scope. TEM was used to explore the three prospects above, and covered extensively Katwe-Kikorongo. In Kibiro, fieldwork focused in the south, whereas very few TEM soundings are located in the northern part of the prospect. In Buranga, the TEM field work plan was inadequate and terrain is complex and mountainous. The results from the prospects caused the drilling of shallow wells for temperature gradient measurements in only Katwe-Kikorongo and Kibiro. Buranga was not subjected to temperature gradient measurements because the results from passive seismic and Direct Current resistivity methods alone were insufficient.

The geothermal techniques used in exploration of geothermal resources in Uganda are inadequate. The prospects need to be re-investigated using Gravity, TEM and MT.

Key words: Techniques, Geophysical Exploration, Geothermal Resources

INTRODUCTION

Geothermal resources (fig.1) in Uganda are located in the most seismically active western branch (fig.2) of the East African Rift System (EARS). On average more than 100 earthquakes are felt per year in Uganda. Its west border lies almost entirely in the western branch of the Rift System. Other tectonic features that have a great influence on earthquake occurrences and geothermal system in Uganda include:

- a) The Ruwenzori Mountain: The Ruwenzori massif and tectonic movements cause stress accumulation that is released along the border and boundary faults to the mountain. The faults include:- the Nyamwamba, Kicwamba, Bwamba, and Kitimbi-Semuliki, Ruimi-wasa and Bunyoro –Toro.
- b) Katonga Fault: This fault starts from foothills of the Ruwenzori Mountain, traverses Lake Victoria and connects to Kavirondo Gulf in western Kenya and Speke Gulf south of Lake Victoria in Tanzania.
- c) Aswa Shear Zone: the shear zone is observed in Uganda from Nimule at Uganda –Sudan Border and joins Mt Elgon in the north-east (see Kiatabosi Hotspring). The north – eastern volcanic fields are part of an array of tertiary and pre-tertiary that is composed of Mts. Moroto, Kadam and Napak (see Kanagorok hot spring fig.1).

The tectonic setting provides potential for geothermal resources and high seismic activity. Catastrophic earthquakes include the:

- 9th July 1912 Kitgum earthquake measured magnitude 6.7 (on Richter scale), with partial destruction of buildings in Northern Uganda;
- 18th March 1945 Sembabule earthquake measured 6.0, killed five people and destroyed buildings;
- 20th March 1966 Toro earthquake measured 6.6 and killed 150 people, injured 1,300 people and economic loss of 1million dollars;
- 5th February 1994 Kisomoro-Toro earthquake measured 6.2, killed 8 people and caused destruction of property worth 61 million dollars.
- 7th September 1990 Lake Victoria earthquake measured 5.0 destroyed semi-permanent buildings;
- 18th March 1945 Sembabule earthquake measured 6.0, killed five people and destroyed buildings.

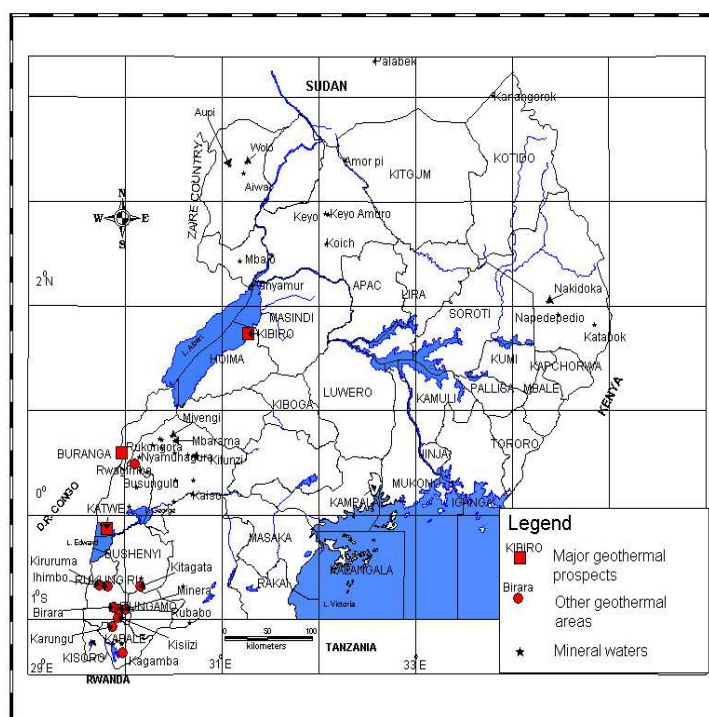


Fig.1: Geothermal prospects of Uganda

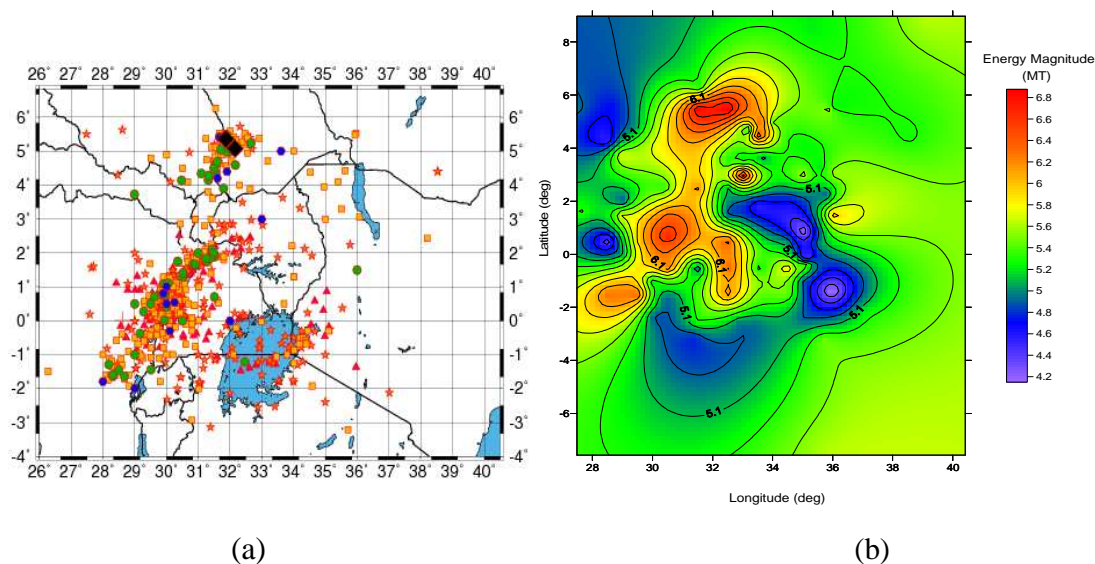


Fig. 2: (a) Earthquakes (1840-1999). Earthquake magnitude is shown in range by symbols: $1.0 \leq M \leq 1.9$ red cross; $2.0 \leq M \leq 2.9$ red triangle; $3.0 \leq M \leq 3.9$ red star; $4.0 \leq M \leq 4.9$ orange square; $5.0 \leq M \leq 5.9$ green circle; $6.0 \leq M \leq 6.9$ blue hexagon; $7.0 \leq M \leq 7.9$ black diamond symbols (b): Seismic energy release.

Katwe –Kikorongo (Katwe) Prospect:

Katwe is located in the Kasese district (fig.1). It is within the Queen Elisabeth National Park, south of the Rwenzori Massif and north of Lake Edward. Katwe is a volcanic area with many phreatic craters but very little lava on surface. Some of the craters have crater lakes. The most pronounced hot spring is on bottom of the Crater Lake in the Kitagata crater. As being

in a national park, the Katwe area is mostly uninhabited, except for the Katwe village, south of the saline lake Katwe. Considerable salt mining takes place in Lake Katwe.

Kibiro Prospect

Kibiro is situated in Hoima district, on the eastern shore of Lake Albert (fig.1). Kibiro is located at the foot of the escarpment of the western branch of the East African Rift System (EARS), and is connected by a rough but motorable track up the escarpment from Kigorobyia town council, which has road connection to Hoima in the south and Masindi to the north through Biiso. The escarpment, which rises over 300 m above Lake Albert, has a profound influence on land use in the area.

Buranaga Prospect

Buranga is situated at the western foot of the northern part of Rwenzori Mountains (fig.1) within the rift sediments of Semliki basin in the Semuliki National Park in Bundibugyo district.

PREVIOUS WORK

Geothermal investigations in Uganda were revived by the Ministry of Energy and Mineral Development (formerly Ministry of Natural Resources) in 1993 in co-operation with United Nations Development Programme (UNDP) under a project called Geothermal Exploration UGA/92/002 & UGA/92/E01. The project was co-funded by the Government of Uganda, UNDP, the Government of Iceland and Organisation of Petroleum Exporting Countries (OPEC) primarily focused on geochemistry and geology.

Isotope Hydrology for Exploring Geothermal Resources, UGA/8/003 & 005, in co-operation with International Atomic Energy Agency (IAEA), was initiated in 1999 and completed in 2007 Under the project, hydrological studies were carried out in the same three areas, Katwe, Buranga and Kibiro, as the earlier project and the findings regarding the Katwe area showed that the recharge is from the Rwenzori Mountains, subsurface temperature of 140 - 160°C predicted by geothermometry.

In 2002 the Icelandic International Development Agency (ICEIDA) prepared a status report, where the current situation in the geothermal survey was reviewed, and recommended further actions to be taken to complete a pre-feasibility study in the three above-mentioned geothermal areas. Since then the Africa Development Fund (AfDF) funded a project to complete the study in two of the areas, Katwe and Buranga, but ICEIDA agreed to assist the Ministry of Energy and Mineral Development (MEMD) to complete the study in Kibiro. A project agreement was signed in 2003 and a work plan agreed upon, based on the recommendation set forward in the status report (ICEIDA 2004).

In 2004 and 2005 a geological and geophysical survey were carried out by professionals from Iceland and the DGSM in Kibiro. The surface exploration was later followed by a temperature gradient survey where the drilling cost was financed by the World Bank.

The AfDF funded project started in Katwe in 2003 and was continued in 2004. No work was however done in Buranga under that AfDF project. Later (2005 - 2006) The Germany Federal Institute for Geosciences and Natural Resources (BGR) financed and carried out a geothermal survey in Buranga in cooperation with the MEMD (BRG-MEMD, 2007).

The AfDF project in Katwe comprised geological investigation, TEM resistivity measurements, gravity- and ground magnetic measurements (Uganda-ARRDP 2004). The survey was mainly focused on three profiles. Densely spaced magnetic and gravity (271 stations) measurements were done along the profiles. TEM soundings were done along the profiles and some soundings spread over the whole crater area.

The AfDF survey gave some clear structural information but since the survey was mostly limited to three profiles, it was not considered as very conclusive and hence as insufficient geophysical survey of the area. The magnetic measurements did not provide any readily usable information but the gravity measurements and TEM soundings did.

GEOPHYSICAL TECHNIQUES

The geophysical methods presented here are the major ones useful in prospecting for heat source and associated structures in geothermal surveys.

Total Magnetic Field

The magnetic field is a dynamic entity and varies significantly on all temporal and spatial scales. The largest component 80 to 90% of the earth's magnetic field is believed to originate from convection of liquid iron in the earth's outer core. The remaining component of the field originates in rocks near the surface where temperatures are low, being less than 580°C in a region of upper crust (20-30) km (Nabighian et al., 2005, p. 34NB).

The magnetic method is discussed by many scholars for instance (Telford et al., 1976, pp.105-215; Nabighian et al., 2005, pp. 33ND-53ND). Magnetic method developed based on the earth's magnetic environment, because the earth has its own internally generated magnetic field, the bulk (99%) of which arises from a self-sustaining dynamo that operates in the liquid outer part of the core, and the remaining 1% arises from electric currents from ionosphere (radiation of particles) and solar winds due to the Sun. The method involves the measurement of earth's magnetic field and the interpretation of its variation in the survey area. The variations cause anomalies due to the field produced by the magnetic material within the earth.

The magnetic anomalies of geologic interest are of two types: induced magnetisation and remanent magnetisation. Induced magnetic anomalies are as a result of magnetisation induced in a body by the earth's magnetic field. The anomaly produced is dependent on the geometry, orientation and magnetic properties of the body as well as the direction and intensity of the earth's magnetic field.

Remanent magnetic anomalies are as a result of permanent magnetization of the body and are controlled by the direction of remanent magnetisation, and the geometry of the disturbing mass. Most magnetic anomalies are a combination of both types; however, usually one type is dominant and is used to interpret the results.

Gravity

Gravimetry is a geophysical method that measures the acceleration due to gravity. It 'involves measurement of variation of earth's gravitational field' (Telford et al., 1976, pp. 7-103). Gravimetry as a geophysical method is based on the universal law of gravitation. The law states that: every particle of matter exerts a force of attraction on every other particle that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. The other instrumental law in Gravimetry is Newton's second law which can be stated as: a body experiences an acceleration that is directly proportional to force and inversely proportional to the mass when a force is applied. The gravity variations associated with geologic bodies is measured in milligals. A gravity meter thus measures the maximum vertical component gravity difference between the earth's field (the main gravity of reference spheroid) and that is actually observed on the surface (gravity meter). The difference of the gravity value is the gravity anomaly and reflects the lateral density variations in rocks extending to a depth.

Resistivity method

Telford et al., (1976, pp. 632-700) discusses the resistivity method. This method uses electrical properties of the rocks, which also depend on the amount of water or pore-fluids within the rock, the salinity of the water and the distribution of water in the vicinity. The higher porosity of rocks saturated with water lowers the resistivity. High salinity of the saturating fluids too lowers the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock. Thus saturated rocks have lower resistivities than unsaturated and dry rocks. The resistivity method is primarily facilitated by the ability of rocks to conduct electrical current and also the polarisation which occurs when electrical current is injected in the ground or the rocks. By injecting current into the earth, the electrical conductivity of the material that make up the earth are revealed by measuring the induced voltage between two potential electrodes by choosing appropriate array configuration. However, most commonly the geothermal water lowers the resistivity, but in some cases the resistivity increases again at very high temperatures.

Transient Electromagnetics

In the transient electromagnetics (TEM) method, the earth is excited by injecting electric current into the ground using a transmitter. A loop of wire is laid on the ground and a constant current is injected through the loop to build up a constant magnetic field of known strength. The current is turned off in a controlled manner by adjustments on the transmitter; the magnetic field starts to decay and, at the same time, induces secondary electrical currents in the ground. In turn, the induced a secondary magnetic field also decaying with time. The decay rate of the secondary magnetic field is then monitored by measuring the voltage induced in a receiver coil or a small receiver loop at the centre of the current transmitting loop. The distribution of the current and the rate of decay of the secondary magnetic field both depend on the resistivity structure of the earth.

Magnetotelluric

The Magnetotelluric (MT) method is a passive frequency-domain electromagnetic sounding technique that measures the earth's response to natural electric (telluric) and magnetic fields to investigate the resistivity structure of the subsurface. The electromagnetic waves (EM) of the MT signals are mainly caused by distant lightning (above 1 Hz), and electric currents flowing in the ionosphere (below 1 Hz). The EM field caused by changing currents radiates around the earth,

reflected repeatedly between the conductive ionosphere and the relatively conductive earth. The MT method exploits naturally varying EM fields, spanning from 0.0001 Hz to 10 kHz. These primary fields induce secondary electric and magnetic fields in the conductive earth.

Telluric currents are caused to flow in the earth by the earth's varying magnetic field. As an electromagnetic wave propagates through the earth, its amplitude decays exponentially with depth at a rate dependent on the conductivity of the medium and the frequency of the wave. Longer periods (low frequencies) decay more slowly with depth and therefore penetrate deeper. The EM fields recorded at the surface of the earth are, therefore, diagnostic to the electrical properties of the earth. Hence, information about the near-surface and deep structure is deduced from high-frequency and low frequency variations, respectively.

MT surveys are conducted by measuring two perpendicular horizontal, x and y components of the electric and magnetic fields (E and H), and the vertical, z component of H as a function of time. The time series recorded are then Fourier transformed to the frequency domain for further processing, determining the impedance tensor, apparent resistivities and phases.

In the field, a typical layout of a five component MT unit consists of five (5) electrodes, four (4) of which measure two (2)-perpendicular horizontal components of the electric field (E_x, E_y), and the fifth electrode is used to ground the MT unit data logger at the centre. For magnetic field measurement, three (3) induction coils are involved, two (2) of which measure two (2)-horizontal perpendicular components (H_x, H_y), and one (1)-coil measures the vertical component (H_z) of the magnetic field. The MT sounding method, like all resistivity methods that are based on measuring the electric field in the subsurface, suffers the so called telluric or static shift problem. The static shift is caused by shallow resistivity inhomogeneities close to the electric dipoles, and can cause severe problems in the interpretation of MT data by shifting the apparent resistivity sounding curves (on a log scale) by a scale factor, which is independent of frequency. Telluric shift correction in the MT is achieved by jointly inverting the MT and TEM sounding data collected at the same location (Nyago 2009).

Seismic

Seismic methods are divided into two: (a) Passive seismic methods deal with the detection and recording of natural seismicity and induced seismicity due to ground fracturing associated with geothermal fluid extraction or injection. The seismic activity gives information about active faults and therefore permeable zones in geothermal systems. (b) Active seismic methods are concerned with seismicity generated by artificial wave sources. The propagation of the generated waves is used to study the geological structures and strata.

INSTRUMENTS FIELD PROCEDURE

TEM: Protem-67 instruments from Geonics Ltd. in Canada was used. The system comprises a PROTEM digital receiver, TEM67 transmitter with motor generator, a receiver coil with the effective area of 100 m² and 800 m of cables for the source loop. The source loop used, was a single turn 200*200 m² square loop. The transmitter transmitted 23 A half duty square wave current at the repetition rate of 2.5 Hz, with two 100 ms current off intervals in each cycle. The receiver and the transmitter are synchronised by connecting them by a signal cable such that the receiver records the induced voltage in the receiver coil, during the current off intervals, at 30 time gates, logarithmically spaced from 0.09 to 69.8 ms after the current turn-off. During recording, 75 to 150 transients were stacked in order to reduce external electromagnetic noise. Several tens of stacked transients were recorded and stored in an internal memory in the receiver, to be later downloaded to a PC computer.

Gravity: The gravity surveys were taken using Scintrex CG-3 Model-110196 Autograv gravimeter that was operating at a resolution of 0.005mGal. Positioning and determination of the elevation was done by differential GPS technique, using a pair (base and a rover) of Magellan Promarc x-cm (10 channels, single frequency, and carrier phase data) GPS system.

Magnetics: The instrument used was two Portable Invimag Proton Precession total field magnetometers from Scintrex. One of the magnetometers was used as a reference station to correct for diurnal variations. The reference station was placed in the survey area at the coordinates 0308457E and 0181866N (UTM, Arc 1960). The rover was used to measure the total field at 5 m interval along profiles. The positioning was performed by a hand held GPS instrument and a measuring tape. Pre-calculated coordinates of stations at 50 m intervals along the profiles were loaded into the GPS instrument, which was used to navigate to these points. The absolute accuracy of these locations is of the order of +/-5 m.

DATA ACQUISITION

Katwe: TEM data was collected using Protem 67 Transmitter and Receiver reported here were collected under two projects: AfDF project from 4th to 13th April 2003 and 19th to 25th November 2004 (see red dots). ICEIDA/MEMD project started on August 19th to September 23th 2005 (blue dots in fig.3).

Kibiro: The fieldwork started on 16th of February and was continued until March 26th 2004. The TEM soundings were starting to reveal a N-S trending low-resistivity anomaly to the south of Kibiro emphasis was put on that region and six relatively densely spaced E-W profiles (M6 to M11) were measured in order to see if a magnetic anomaly was associated with the resistivity anomaly. A total of about 80 km were traversed amounting to over 16,000 magnetic stations. During the first days two gravity new base stations were established one at Kigorobya Health Centre and the other at Kabiribwa at the top of the escarpment above Kibiro. The gravity values at these reference stations were determined by connecting to an already established base station in Hoima. The new base stations were used for the GPS measurements and time dependent drift corrections for the gravimeter.

Large parts of the survey area are covered with dense bushes and some places the accessibility was further limited by deep gullies. Despite the difficult conditions a total of 75 soundings were made, amounting to an average performance of about three soundings a day.

Buranga

Ground geophysical field survey at the Buranga geothermal prospect started on 11th of February and ended on 4th of March 2005. Geoelectrical, TEM and gravity measurements were carried out. BGR installed seismic stations and between May 2005 and August 2006, earthquakes were registered at several seismological stations.

FIELD RESOURCES AND PLANNING

The field crew consisted of three experts from GSMD, one driver and two local helpers. ICEIDA expert supervised the fieldwork during the first week, but after that the field crew was properly trained and the ICEIDA expert could concentrate on data processing, interpretation and survey planning. The recorded data were downloaded to a PC computer at the end of each day and inspected and processed by the ICEIDA expert.

RESULTS

Katwe TEM

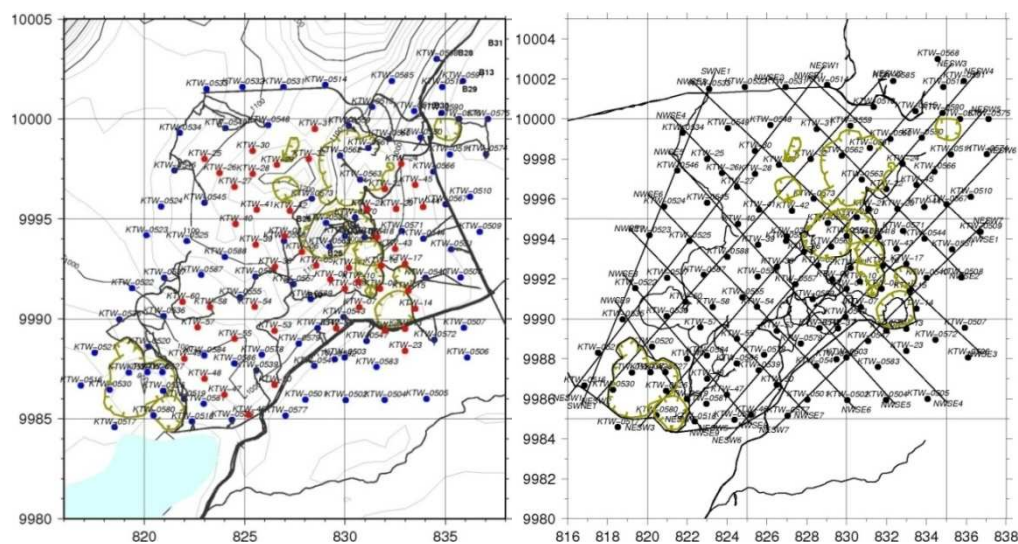


Fig. 3: Location of TEM stations in the Katwe area. Red points are stations from the ADF project and blue are stations from the ICEIDA/MEMD project.

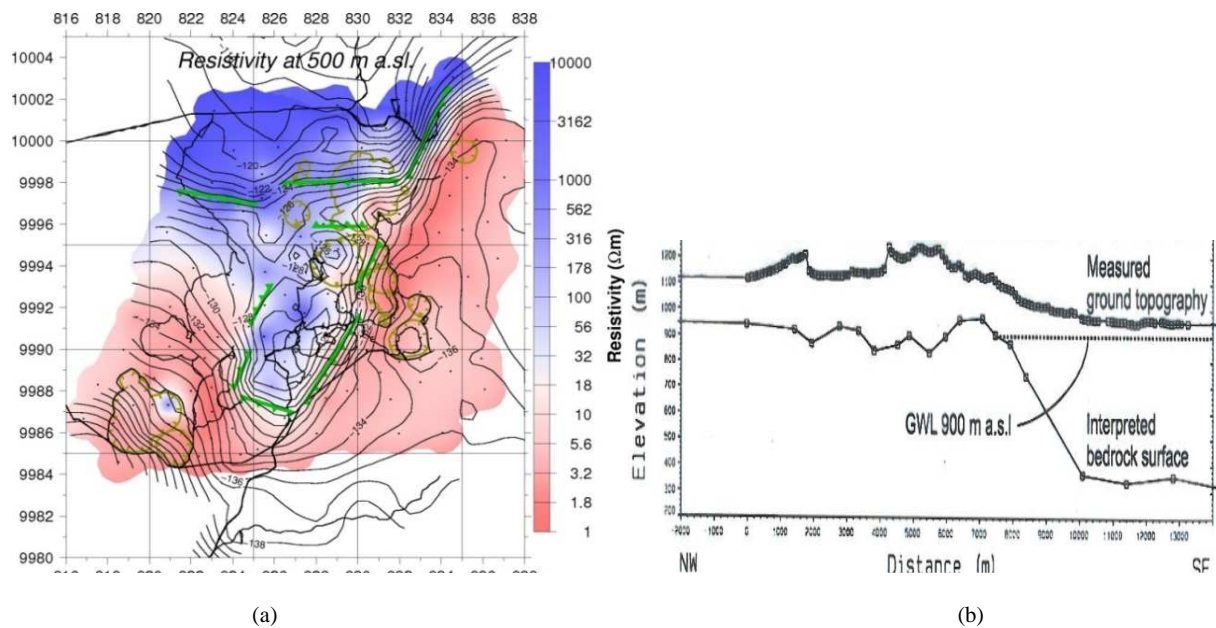


Fig.6: Resistivity at 500 m a.s.l; Bouguer gravity contours and inferred faults. (b) Model of sediment thickness and elevation of basement rocks (Uganda-AERDP 2004). Note that the thickness of the sediments is over 700m and all the drilling was done in the sediments.

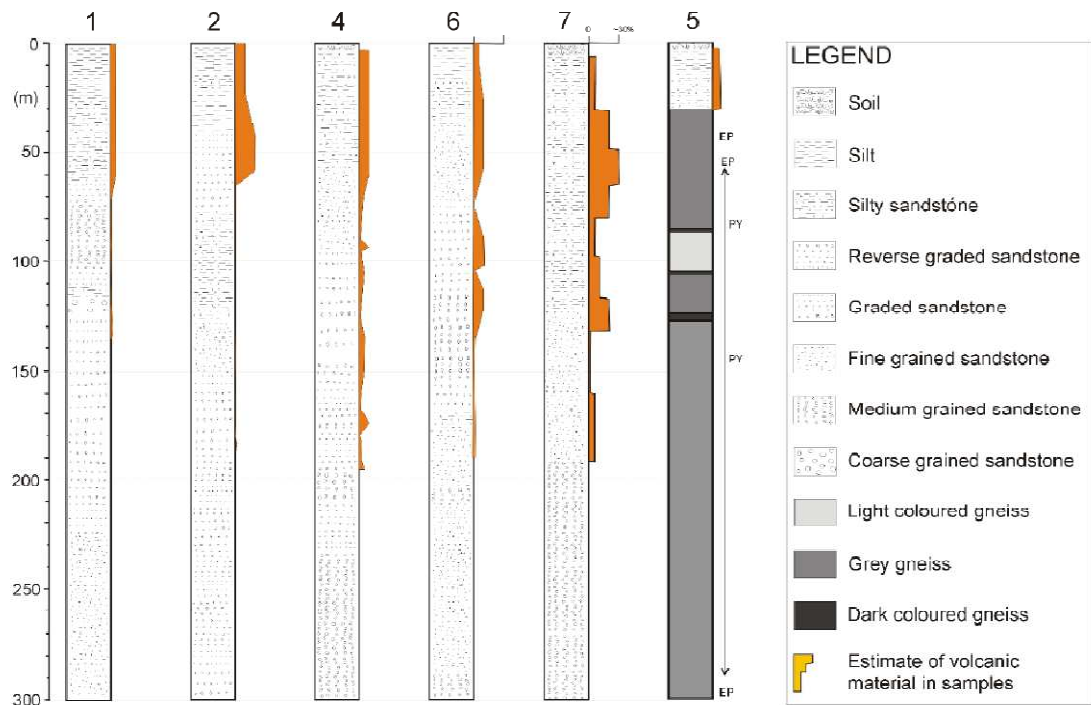


Fig.7: Katwe Stratigraphy of temperature gradient wells (ICEIDA 2008b). Note that drilling encountered rift sediments and volcanic except in borehole 5 in the north west of the prospect.

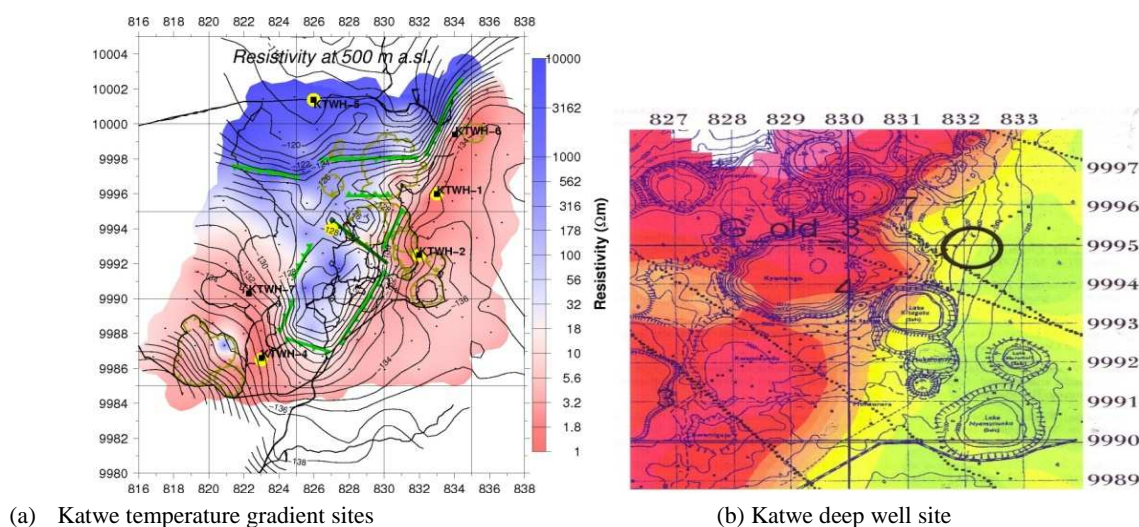


Fig. 8: Locations of temperature gradient holes (yellow circles) and actual locations of the holes (black squares) (ICEIDA 2004) (b) Black Circle is a site recommended for drilling by Uganda-AERDP in 2004.

Table. 1: Temperature gradients in the boreholes in Katwe and extrapolated surface temperature.

Borehole	Gradient °C/km	Surf. temp. °C
KTWH-1	36.0	29.3
KTWH-2	36.0	27.8
KTWH-4	28.3	28.4
KTWH-5	13.0	24.7
KTWH-6	30.0	27.8
KTWH-7	33.5	28.2

The extrapolated surface temperatures are consistently about 28-29 °C at the lower altitudes and somewhat lower, about 25°C, for KTWH-5, which is at higher altitude. The extrapolated surface temperatures are consistently about 28-29 °C at the lower altitudes and somewhat lower, about 25°C, for KTWH-5, which is at higher altitude. The temperature gradients are all rather low, especially in KTWH-5. The temperature gradients in KTWH-5 and the other holes are not directly comparable. KTWH-5 is drilled into the granitic basement but the other holes are mainly drilled in sediments. The heat conductivity of granite is higher than that of sediments and equal heat flow would consequently have lower gradient in granite than in sediments (ICEIDA 2008b).

The temperature gradients are highest in holes KTWH-1 and 2, which are in the low resistivity anomaly South East of the main graben fault. This might indicate that the observed lower resistivity is due to slightly elevated temperatures. But the temperature gradients and estimated heat flow do not indicate that high temperatures are found in the uppermost few kilometres in the Katwe area (ICEIDA 2008b).

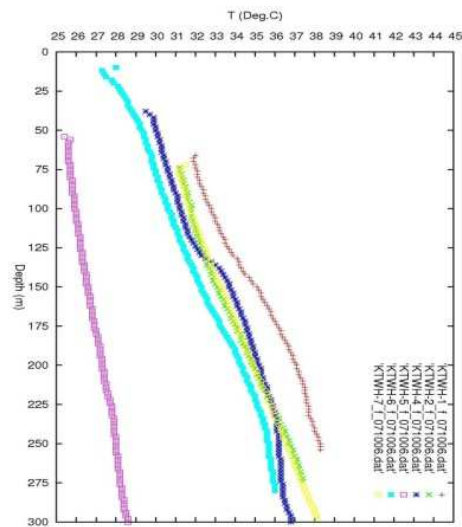


Fig. 9: The final temperature measurements in all the boreholes. Measurements in different holes are shown with different colours. The borehole numbers (KTWH-x) are shown in the lower right corner (ICEIDA 2008b).

Kibiro TEM results

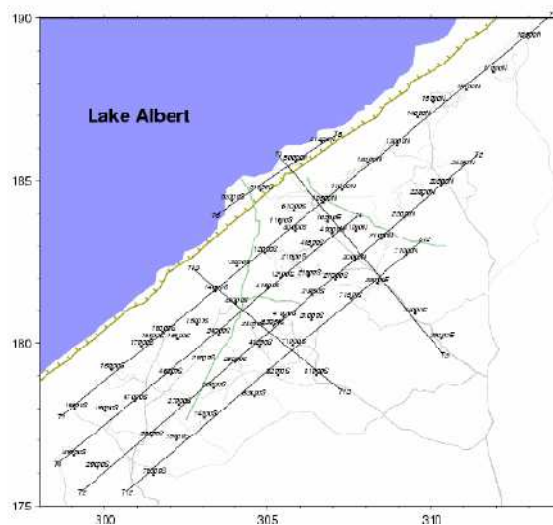
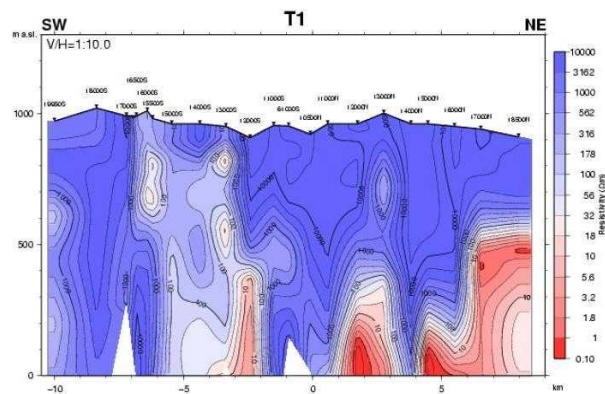


Fig 10: Location of TEM soundings and section lines in Kibiro Prospect



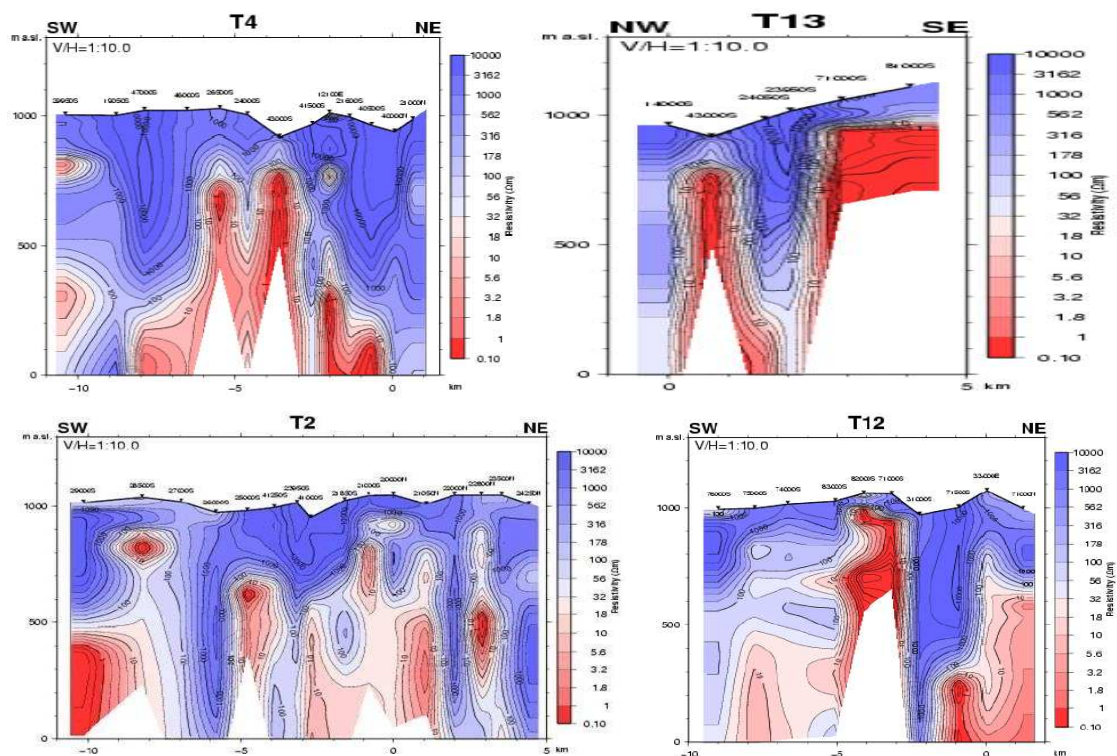


Fig.11: Various TEM sections in Kibiro prospect. Note that the weak resolution at depth and gaps in the data. TEM only resolved the anomalies in few hundreds of metres above sea level (m. a. s. l). The observed low resistivity anomaly in shallow depth may be due to conductive minerals.

Kibiro Gravity

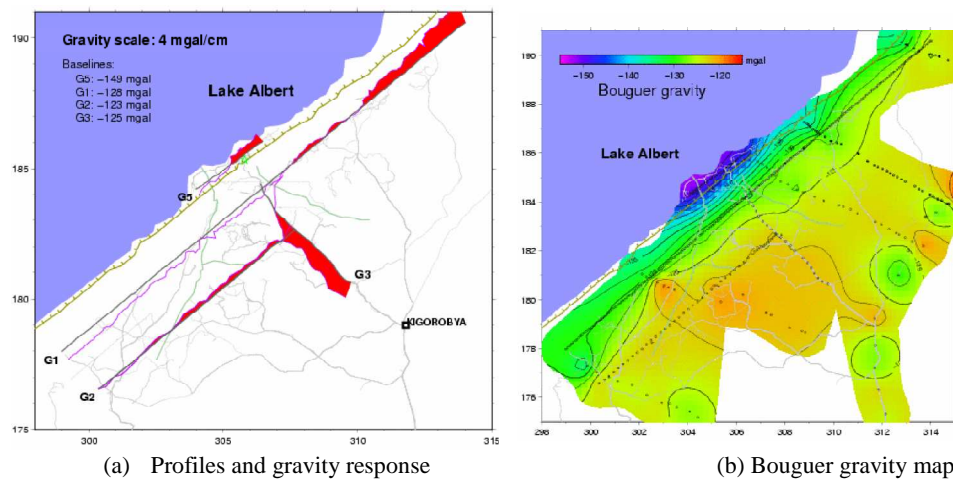


Fig.12: The geothermal anomalies (b) are weakly resolved due to the few data samples (dots) collected and small gravity survey coverage.

Kibiro Magnetics

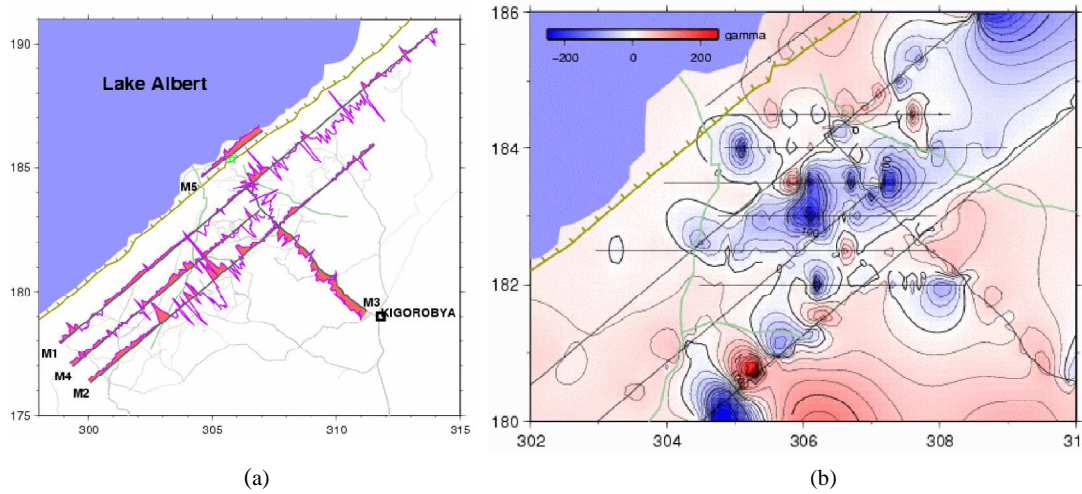


Fig. 13: (a) Magnetic profiles and magnetic field (b) total field magnetic anomaly and major structures. The magnetic field strongly correlates with structural geology.

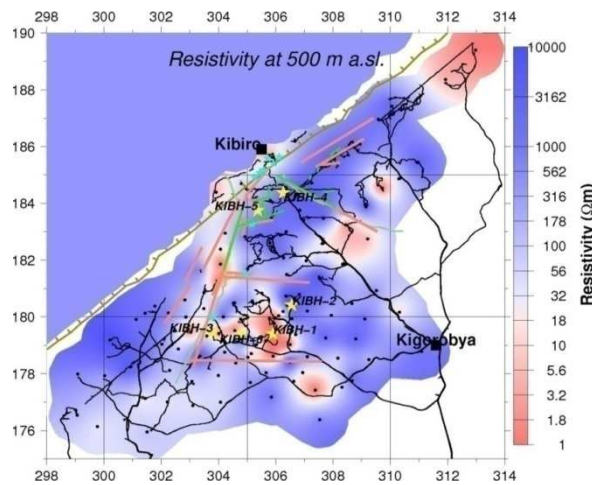


Fig.14: Locations of temperature gradient holes (yellow stars) and resistivity at 500 m above sea level. Inferred faults and fractures (pink lines), gullies (light green lines) and indications (Calcite, sulphur etc.) of geothermal activity (light blue stars).

Table. 2: Temperature gradients in the boreholes in Kibiro and extrapolated surface temperature.

Borehole	Gradient °C/km	Surf. temp. °C
KIBH-1	16.0	24.7
KIBH-2	16.0	24.4
KIBH-3	16.0	24.9
KIBH-4	27.3	27.9
KIBH-5 (deep)	31.3	25.7
KIBH-5 (shallow)	22.0	27.7
KIBH-6	16.0	24.8

The extrapolated surface temperatures are consistently between 24 and 25 °C for the holes away from the escarpment (KIBH-1, 2, 3 and 6). The holes at the escarpment (KIBH-4 and 5) have higher temperature gradients and extrapolated surface temperature.

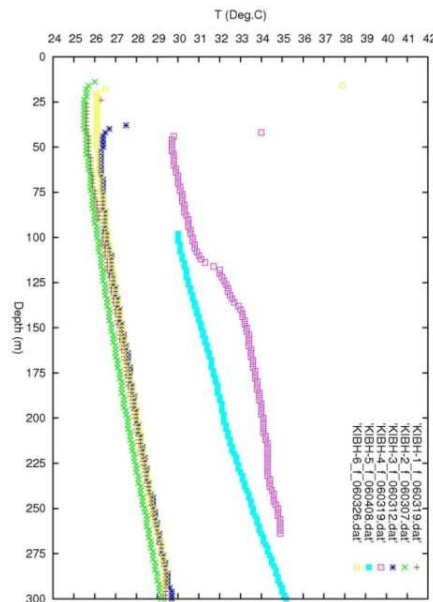


Fig. 15: Temperature gradient measurements in all the holes in the Kibiro area. The date is shown in the lower right corner [year month day] (ICEIDA 2004). Note that the wells can be categorised in two groups (KIBH-1, 2, 3 and 6) low temperature and (KIBH-4 and 5) high temperature.

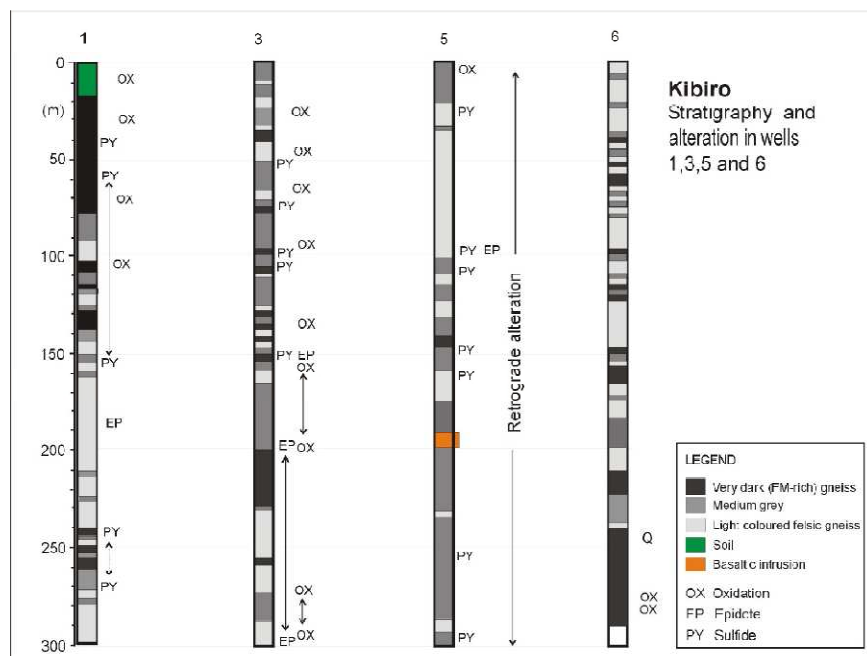


Fig. 16: Kibiro Stratigraphy of temperature gradient wells (ICEIDA 2008b). Note that the minerals Epidote and Sulfide are associated with high temperature.

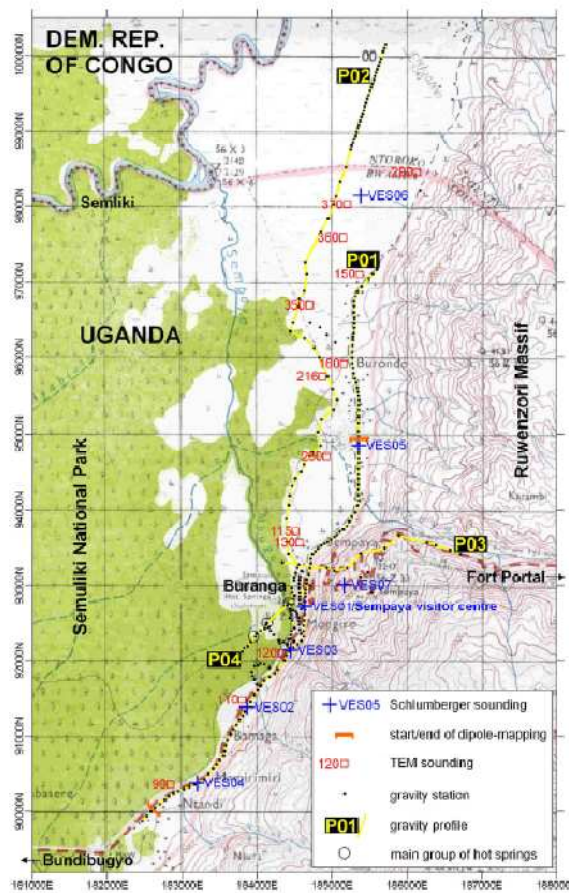


Fig. 17: Topographic map of Buranga Geothermal prospect and ground geophysics coverage. Note the limited extent in coverage of the geophysical surveys.

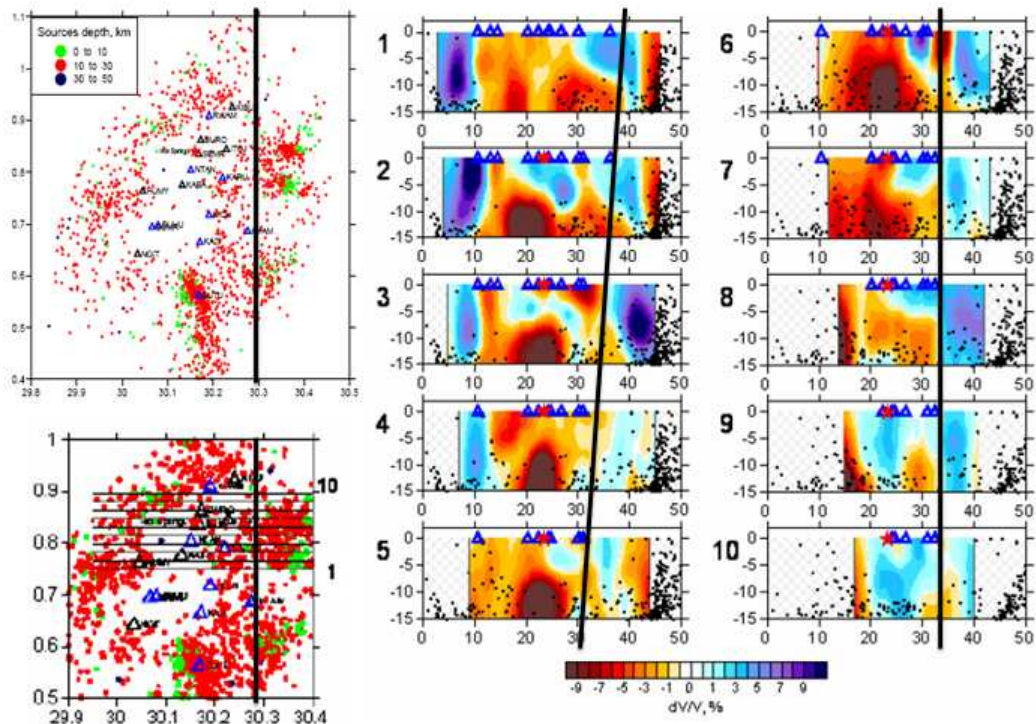


Fig. 18: Seismic activity and vertical topographic sections numbered from top 1 to 10. The thick black line sets a boundary of network coverage and limitation of the ray path to resolve a representative model and most of the data was left out. Red star is the location of Buranga hot spring. Brown-red show low velocities due to high heat flow and blue cold rocks.

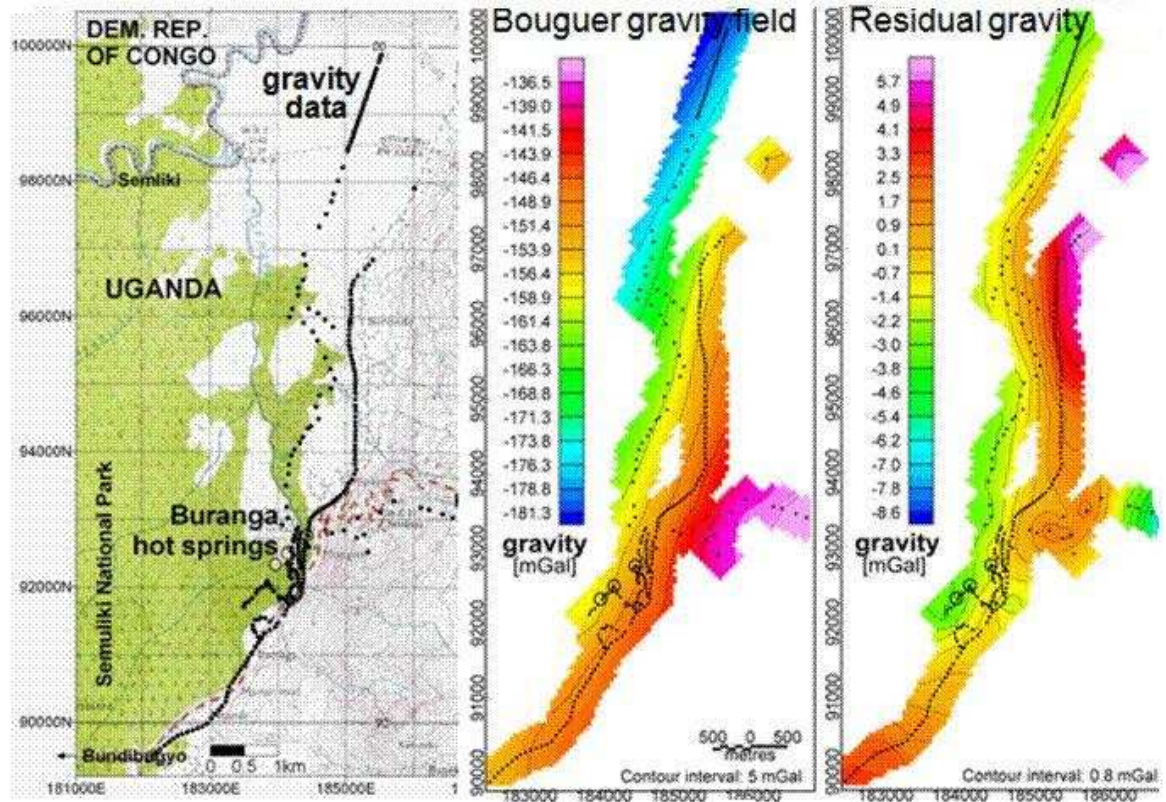
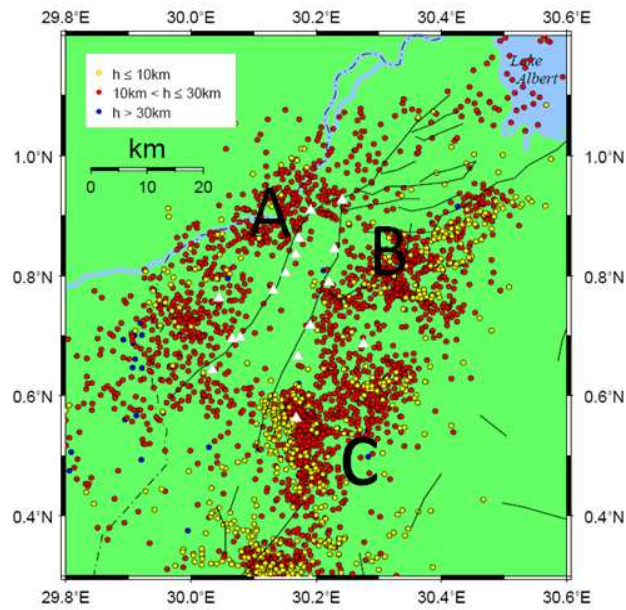
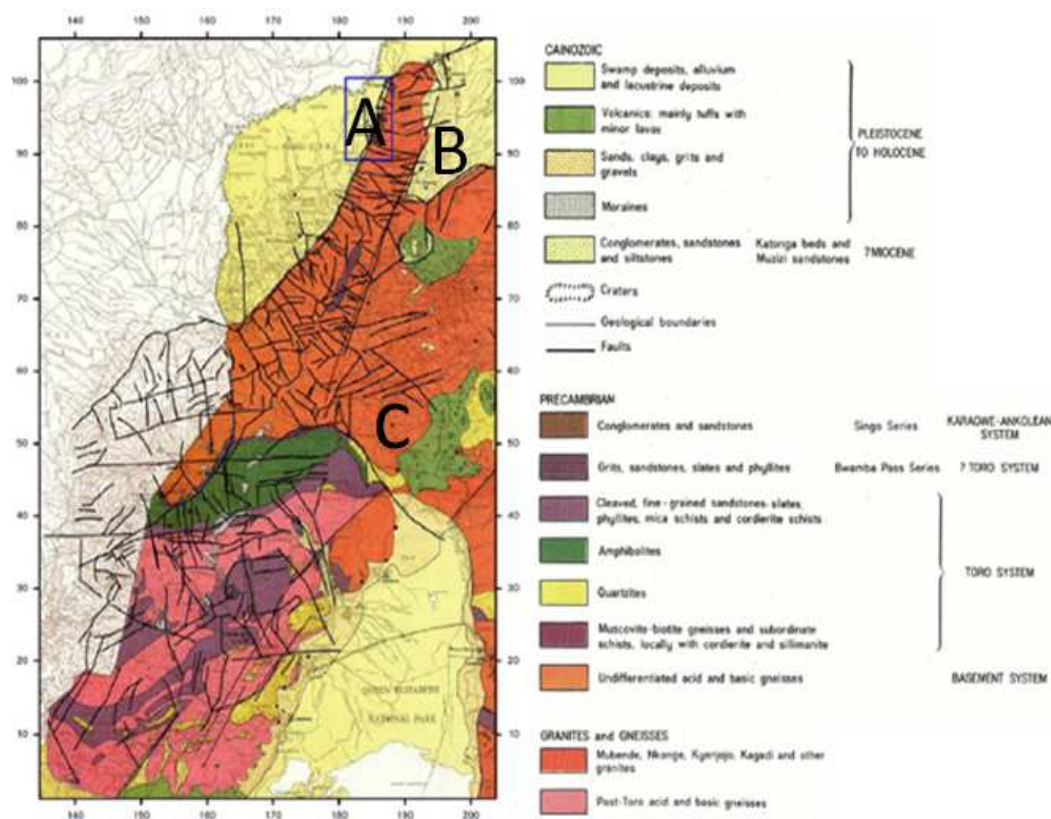


Fig. 19: Bouguer and residual gravity of Buranga. The gravity data coverage was not enough to resolve the geothermal anomaly.



(a) Epicenters of natural earthquakes in Buranga



(a) Geological map of Rwenzori region and known faults

Fig.20: The seismic activity gives information about active faults and thus permeable zones in geothermal systems. However, in this case, there is no correlation between the known faults and the epicenter locations in (a). The observation may be due to geothermal activity in regions marked with A, B and C, because the seismic activity is clustered and diffuse.

Case study using Passive Seismic Method

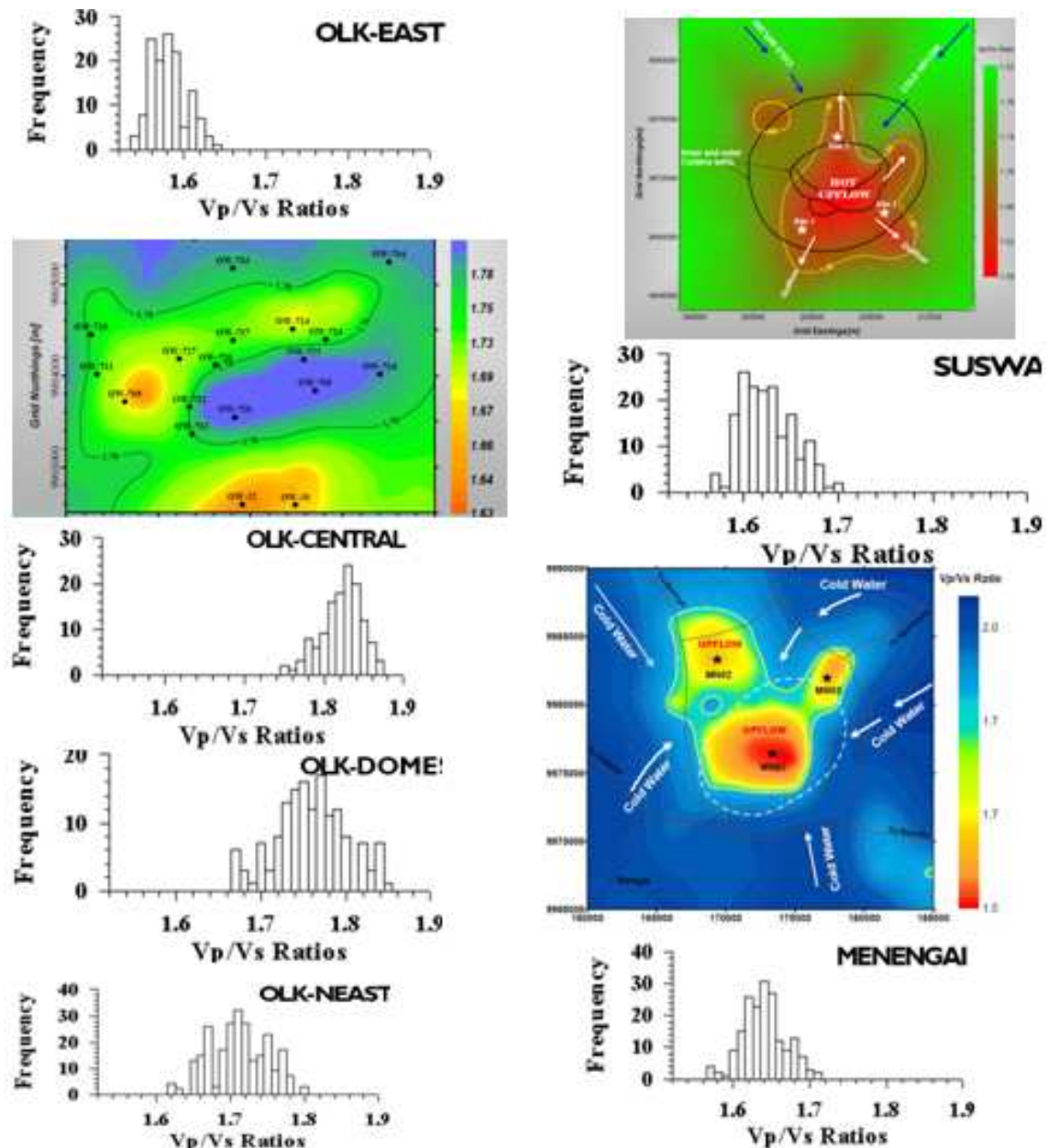


Fig. 21: P-wave and S-wave velocities ratios for Olkaria, Suswa and Menengai geothermal fields in Kenya Rift. Note a strong correlation of low velocity ratios with zones of high thermal anomalies. However such analysis was not carried out for Buranga Geothermal Prospect in Uganda.

LESSONS FROM CASE STUDIES OF OTHER GEOTHERMAL PROSPECTS

1. The geothermal resources in Uganda are largely located in the western branch of the rift which is volcanic and sedimentary as compared with Kenya, Ethiopia rifts which are highly volcanic.
2. The work done so far suggests that the heat source could be deep seated or off set from surface manifestation in Katwe, Kibiro and Buranga.
3. The current findings suggest that more detailed studies need to be done to map up flow zones and identify the heat source.
4. The geothermal fields in Uganda are different from most of the proven fields elsewhere so appropriate models should be developed.
5. The existing knowledge on the geothermal systems in Uganda is still limited and needs to be further expanded.

6. The concluded study has identified other areas which have geothermal potential and should be investigated further.

WAY FORWARD

The way forward is to continue investigating the geothermal resources

1. Carryout detailed geological, geochemical, hydrological geophysical including seismological and magnetotellurics investigations to probe deeper and identify the heat source.
2. Study in detail the structures that control the fluid flow mechanisms in geothermal areas.
3. Expand the areas of study to correlate extinct and active surface manifestations of geothermal systems.
4. Integrate the available geophysical and geological data at DGSM and PEPD to improve the existing knowledge, including the mineral content of the fluids.
5. Foster regional and international collaboration to enhance capacity building such as on-job training, short courses and formal qualifications, field attachments, equipment sharing and expertise.
6. Disseminate the results of the above initiatives at appropriate fora.
7. Funds should be mobilised both locally and through our Development Partners to support the above initiatives.

CONCLUSION

The geothermal studies in Uganda covered small areas and geothermal resources seem to be extensive with deep seated heat source.

Previous studies indicate that the heat source is deep seated in all cases. The geothermal anomalies are not adequately resolved to warrant the drilling of deep wells.

The prospects need to be re-investigated using good network coverage for Seismic, Gravity, TEM and MT techniques that can probe deeper to map the thermal anomalies for drilling.

The proposed geophysical techniques have proven to be the most successful mapping the geothermal system for development into steam production.

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