

The Geology and Potential of Kibiro Geothermal Field in Albertine Graben, Western Uganda

Peter Mawejje, Vincent Kato, Jacqueline Nnakirija, Keith Tunde, Unity Birungi, Henry Mulindwa and Mebra M. Tamuwa.

Geological survey and Mines Dept. P.O Box 9 Entebbe, Uganda

Mawejje.p@gmail.com

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ABSTRACT

Kibiro is one of the main geothermal prospects of Uganda. Work in this geothermal prospect started way back in 1993 around the hot spring area of Kibiro, but the reservoir and the heat source have not been established. In the year 2011 a project called Uganda Geothermal Resources Development Project 1199 (UGRDP) sponsored by government of Uganda, was inaugurated to do further work on main geothermal areas of Uganda which included Katwe, Kibiro, Buranga and Panyimur geothermal fields. Based on geological explorations so far done over Kibiro, several observations and findings have been made. Maximum surface temperature of 85 degrees Celsius has been measured in the hot springs. Findings show that geothermal surface manifestations cover a much wider area than previously thought. Several hundreds of observation points were made and the area covered by surface manifestations was delineated. All the geographical spatial data was compiled into a geo-database including the old datasets for spatial analysis in GIS environment. Zonation within the manifestation area was done based on three minerals to identify areas which are likely to have high or low temperature zones, as well as up flow zones. The zonation was based on silica, sulphur and calcite or travertine. Two areas of interest including the hot spring area have been identified. According to observations made, the geothermal system is primarily along boarder faults of the rift and subordinate volcanism has been observed elsewhere within the rift. Since sediment-filled grabens exist in this environment, strata bound aquifers are also likely. The hydrothermal fluids are directly controlled by the main fault scarp. Up flow zones along the escarpment are more pronounced at intersections with other smaller faults, especially where the fault density is higher, which also increases secondary permeability. The data available is now being used to make geothermal geological model, but further studies of structures need to be done. After the geological model is out, the next stage will be integrating data from other exploration disciplines i.e. geophysics and geochemistry. Information from oil wells and companies is being scrutinized so as to throw some more light on seismic layering, lithology and temperature gradient.

1. INTRODUCTION

1.1 Background

Uganda is one of the developing countries whose population has been growing over the years. This population growth has been in line with growing energy demand which stands at 8% per annum. The total access to electricity for the whole country stands at only 12% whereas that of rural areas is only at 6%. Climatic fluctuations have resulted into change in water levels in most of the rivers not only in Uganda but also in the whole East African region. This has affected on the quantities of electricity generated from hydro which has been the main source of power generation in Uganda.

The government of Uganda therefore committed itself to looking at alternative sources of energy which are renewable and clean in their nature. Geothermal energy is one of such energy sources that is renewable, very clean and is not affected by climatic fluctuations. Uganda Geothermal Resources Development Project 1199 was initiated (fully funded by the Government of Uganda) to help Uganda develop her geothermal resources by taking upfront risks to attract potential investors to develop the resources. The project has been used to do further exploration work on most of the major geothermal prospects of Uganda (Buranga, Kibiro and Panyimur).

Using airborne magnetic data, a magnetic low anomaly was observed to extend to the North-east of Kibiro hot springs. Further analysis for fault systems in the area also proved an intersection of faults in the same area suggesting a possible area of high permeability hence possibility to have surface manifestations that extend from Kibiro into this area.

1.2 Location and accessibility

Kibiro area is located in the west side of Uganda on the shores of Lake Albert at the edge of the Western arm of the East African rift valley (Fig. 1). It is situated on topographic sheet 38/4 – Kigorobyia in the administrative district of Hoima.

Kibiro can be accessed by driving on good tarmac road Kampala – Kiboga – Hoima for a distance of about 202 km. From Hoima you drive along good marram road to the north-west via Kigorobyia and branch off to the left either at Kibengeya trading centre or at Kapapi trading centre. The area of study is about 35 km from Hoima town. Kibiro hot springs are best accessed by taking a left turn at Kigorobyia trading centre.

1.3 Physiography

Being in a rift environment, the area of study is characterised by step faulted topography. Several steps exist at the franks of the main fault scarp with varying altitude above sea level. The lowest altitude at Bikunyu landing site on Lake Albert is 630 m a.s.l, as opposed to the highest observed altitude of about 1136 m a.s.l at Hoima town. Generally the area of study is low lying due to the fact that it is within the rift zone (Average altitude of 800 m a.s.l). At the upper terraces of the rift, there are some gently sloping to fairly steep hills with intermittent valleys of variable depth. Many of these valleys are fault controlled. Most of the valleys are

perpendicular to the main fault scarp, but there are also those which are parallel as well as those which are oblique to the main escarpment. Within the rift floor is Lake Albert and at times it is so close to the main rift wall. In most of the valleys there are seasonal rivers, but a few of them are permanent streams. Vegetation is thickest close to the banks of such streams up to their flood plains at the floor of the rift valley in sediments. The vegetation varies from scanty grasses up to thick shrubs of various plant species.

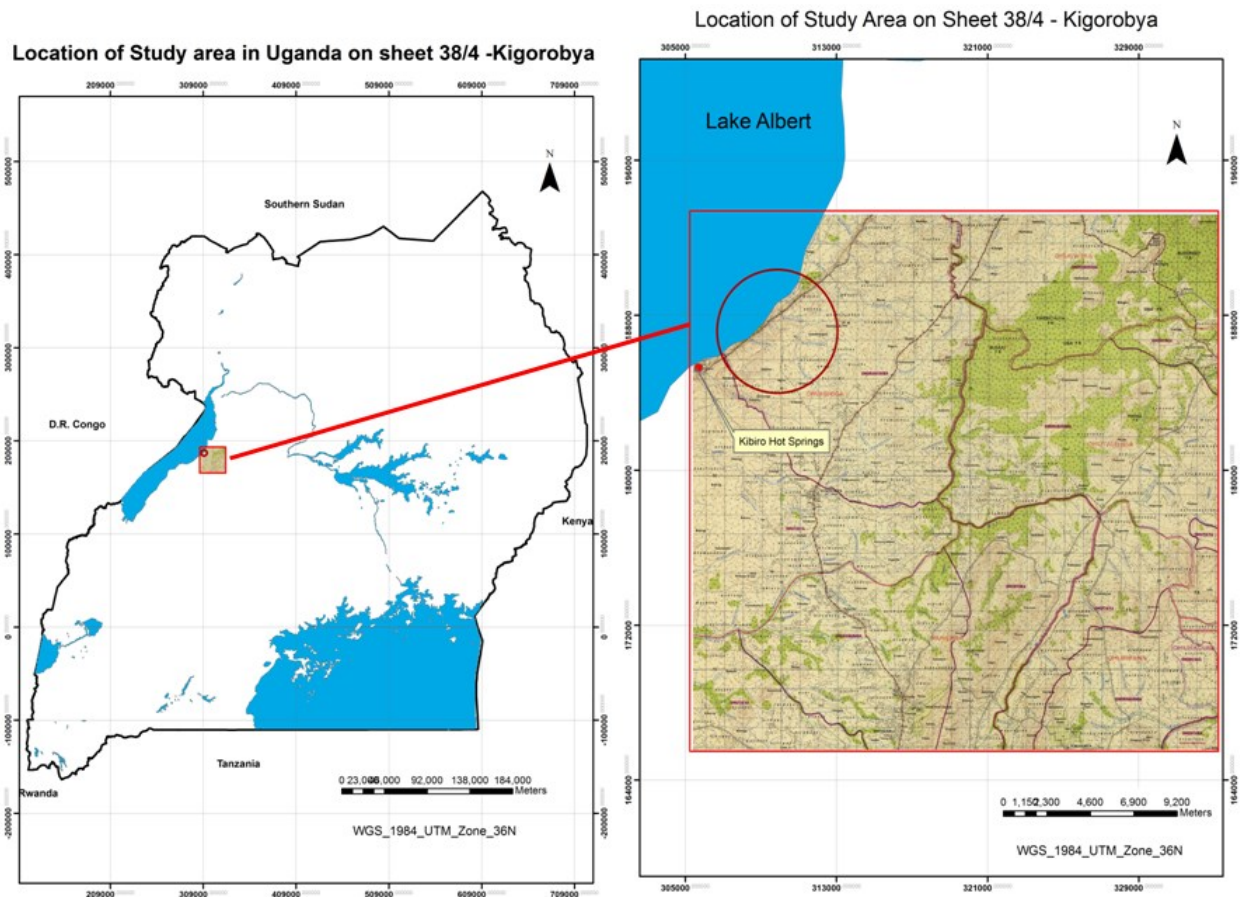


Figure 1: Location of the study area in Uganda and on sheet 38/4 in relation to Kibiro hot springs.

1.4 Previous work

Geothermal investigations at Kibiro started way back in 1993 by the Department of Geological Survey and Mines (DGSM) in co-operation with UNDP under a project called Geothermal Exploration UGA/92/002 & UGA/92/E01, a project co-funded by the Government of Uganda, UNDP, the Government of Iceland and OPEC (Gislason, 1994). The project was primarily focused on geochemistry and geology in the areas of Katwe, Buranga and Kibiro, and the main conclusion was that although the surface manifestations were not extensive, the chemistry of the spring water indicated sub-surface temperatures in the range of 200°C (Armannsson 1994). No clear indication was found on the nature of a heat source, but the main attention for a reservoir was directed towards the thick sediments of the tertiary rift system.

A new DGSM project, Isotope Hydrology for Exploring Geothermal Resources, UGA/8/003, then in co-operation with International Atomic Energy Agency (IAEA), was initiated in 1999 and completed in 2002 (IAEA, 2003). Under the project work was carried out in the same three areas as the earlier project and the findings regarding the Kibiro area showed that the sources of recharge was meteoric water, and originated from higher ground than in the immediate escarpment area, pointing inland away from the rift. The isotope geothermometer pointed towards lower reservoir temperature than conventional geothermometer (140°C), and the isotope research implies water-rock interaction, old age of the system, or low water/rock ratio. The study suggests that the reservoir rock in Kibiro is granitic gneiss.

In 2002 ICEIDA prepared a status report, where the current situation in geothermal survey was reviewed, and recommended further actions to be taken to complete a pre-feasibility study in the three above-mentioned geothermal areas (Gislason 2002). Since then the Africa Development Fund (ADF) funded a project to complete the study in two of the areas, Katwe – Kikorongo and Buranga, but ICEIDA agreed to assist DGSM 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.

Mawejje et al (2012) carried out geological investigations over a low magnetic anomaly north east of Kibiro hot spring. Altered ground with silica, clayey grounds and calcite were discovered. In 2013 further investigations were made and gap between magnetic anomaly and Kibiro hot springs filled up. An area covered by geothermal surface manifestations was delineated and zonation based on Silica, sulphur and calcite was also finished.

2. GEOLOGY AND MINERALIZATION

Regionally, in the area of study there is a clear contrast in geology ranging from Quaternary sediments to basement gneiss. At the escarpment itself, there is mylonitic rocks formed during the formation of the rift. It is in this zone that permeability has been enhanced and most of the geothermal surface manifestations are found either at the escarpment or in these mylonitic zones.

Due to limited number of days allocated for this work, most of the time was dedicated to trying to find as much geothermal manifestations as possible. Mapping of geological boundaries could not be finished in such a short time. However, most of the rock types that were encountered were noted and will be briefly discussed in this section.

2.1 Mylonite

Close to the escarpment, there exist a zone in which rocks have been sheared leading to formation of mylonite. The mylonite appears to be of different types depending on the type of the parent rock. Bright-coloured mylonite are believed to have originated from felsic parent rocks. Many of these felsic mylonite may be confused to be quartzite. There are those ones which are darker in colour and these ones are believed to have a source of a more mafic parent rocks. In some cases mixed mylonite was observed in which the more competent feldspars have been preserved in a dark matrix of less competent mafic rocks. The fragments or crystals of feldspars in many cases were observed to be elongated by shear stress.

2.2 Quartzite

Quartzite rocks were mapped in the Northeast side of the study area. At some point these quartzite was observed to be highly sheared and iron rich fluids have been introduced into weak zones of the sheared quartzite giving it a brownish tint.

2.3 Pyroxene-bearing rocks

Pyroxene-bearing plutons were observed at the Southwest of the target area. Here no alteration was observed. Within the same locality there was quartz rock and fragments which were suspected to be of beryl and / or moonstone type.

2.4 Quartz–Feldspar Rocks

In many places in the study area, quartz-feldspar rocks were encountered. These rocks though coarse in texture; they do not necessarily conform to the composition of a usual pegmatite. Probably they are pegmatite very poor in micas. Many of these have been mapped as quartzite in the old geology map compiled by Petroleum Exploration and Production Department (PEPD).

2.5 Dolerites and meta-dolerite

Metadolerite were encountered in of fault-guided valley now a seasonal stream. In this valley there were also sheared boulders of quartzite, but those of the metadolerite were the dominant ones. There is not enough time to map insitu outcrops of such meta-dolerite.

In the third phase of mapping over Kibiro geothermal prospect, young dolerites were also mapped in the area of study. The young dolerites were observed to be not sheared or tectonically altered in any way. At some point meta-dolerites were observed to be sheared like the old gneiss which means they already existed when rifting and shearing occurred (although they are not the same age as gneiss). The young dolerites need to be studied further to see if their existence may be associated with magmatic chamber that may likely to be heat source for Kibiro geothermal prospect.

3. WORK CARRIED OUT

3.1 Desktop studies

The work carried out in this area started when airborne magnetic and gravity data was analyzed to come up with an anomalous area that extended from Kibiro hot springs up to this area of interest. Desktop studies also involved reviewing old reports including those ones for petroleum exploration. SRTM data was also looked at, clipped area of interest, buffered, projected and hill shaded to enhance structure in a grey tone of SRTM. From analysis for fault systems and also from old maps, a target area was established. Old maps as well as the necessary topo-sheets were assembled in preparation for the field. Google Earth images were used to help plan for accessibility up to the targeted area.

3.2 Methodology

Coordinates for the target area were generated and fed into Global Positioning System (GPS) so as to guide us within the field by tracking back to pre-determined points. Geological traverses were made in the area to map all surface geothermal manifestations and all rock units encountered. A total of one hundred and forty nine (149) geological observations were made in this mapping exercise. Photographs of interesting sites were taken in the field and are inserted appropriately in the text.

The spatial positions of observation points were fixed by the use of Global Position System (GPS) and recorded in the UTM Coordinates System (Datum of WGS 1984 and UTM Zone 36 projection). Where possible, certain geothermal and geological entities were tracked using GPS to map the lateral extent, length or width for example for altered grounds, faults or dykes. From the data gathered as well as that one collected in the past, a tentative map has been compiled. The map now has been improved because the approximate area where surface manifestations occur has been delineated. The distribution of mineral assemblages which are indicators for high or low temperature zones has also been highlighted. All the data that has been collected and compiled has been stored in geothermal geo-database and can readily be available for use in GIS environment. From such data different maps may be produced depending on the final use and type of questions to be answered.

3.3 Geothermal Surface Manifestations

Several geothermal surface manifestations were mapped around Kibiro ranging from extinct ones to active ones. Salt gardens area (which is a direct utilisation of geothermal system) were also tracked and now presented on the map. Gas emanations may have

existed where some of the manifestations were observed, but the team never had any tools to measure or detect some of the gases. However for gases such as hydrogen sulphide it is easy to detect it because of its characteristic smell. When the geochemistry team visits Kibiro, the data collected will be integrated to enrich information about the prospect.

3.3.1 Alteration with amorphous silica

Alteration with a lot of amorphous silica was observed at a point where an oblique fault (trending NE - SW) and other faults intersect with the main escarpment. As one gets away from this intersection area less quartz is observed. Quartz is only found in joints of fractured rocks. There are small shear zones in some places where more hydrothermal fluids resulted in precipitation of more quartz as well as intense alteration (Fig.2).



Figure 2: A small shear zone containing silica and altered mylonite.

3.3.2 Travertine and calcite precipitation

Travertine and calcite were encountered in Kibiro. They occur in such a way that calcite and travertine is more common close to Kibiro hot spring. As you move away to the north east direction there tends to be less calcite / travertine until a bit outside the intersection of faults (NE direction) where calcite starts to appear again. (See maps below). One of the travertine was found side at an intersection of a minor perpendicular fault to the main escarpment. The minor fault can clearly be observed from a distance because of its open fracture in the mylonite at the intersection point. Both the travertine and precipitated calcite are easy to identify because they readily react with dilute hydrochloric acid (with effervescence).

3.3.3 Altered grounds

In the area of study there were altered grounds of variable degree of alteration ranging from very weak to strong. There was also variation based on the nature of hydrothermal fluids. In areas where the fluids were rich in iron it resulted into reddish-brown appearance of the altered grounds (after oxidation of iron through the weathering process).

Close to the floor of the rift at a point where quartz precipitation was mapped, there was clayey alteration which implies that the degree of alteration was higher at this point.

3.3.4 Complete clay alteration

Complete clay alteration was mapped in this area close to Kibiro hot springs. The clays were seen to comprise of bentonite and other clays with fragments of gypsum. One can use the presence of gypsum to suggest that in this area there has been a lot of sulphur which was later oxidised to gypsum after long exposure to oxidising environments. In some places a close look at the manifestation suggested that at one point there were strong manifestations but they have been covered by scree and outwash over the years from raised terraces of the escarpment zone.

3.3.5 Hot springs

In this geothermal field, hot springs are only found at Kibiro. At least two hot springs have been mapped in this area. One of them appears as hot spring 1 and it has maximum surface temperatures of 60°C. It is found in an area where salt gardens occur. The second one is the main spring close to the wall of escarpment. It has a measured maximum surface temperature of 84°C. All around these hot springs, there is sharp hydrogen sulphide smell, and gas emanations are observed to bubble out of the water especially at the main spring. The water is observed to contain hot water algae and damp soils close by are covered with white salt efflorescence rich in sodium chloride (Fig. 3).

3.3.6 Sulphur and hydrogen sulphide fumaroles

These fumaroles were mapped to south west of Kibiro main spring. The fumaroles are located along a lineament of about 300 metres and strike to the north east within the escarpment zone oblique to the main fault scarp. This zone is characterised with baked mylonite that has been stained by hydrocarbons giving mylonite a black tone of colour. There is no observable water flow or steam, which means there is less recharge especially during dry seasons. Gas emanations can only be detected due to hydrogen sulphide smell. The ground itself is hot in some places, and elemental sulphur was seen to occur close to rims of small fumaroles.



Figure 3: On the left is main spring with gas bubbling, white efflorescence and some white algae. To the right is the smaller spring in area with salt gardens. Also note hot water algae of different species.

3.3.7 Salt gardens–Direct utilisation

Close to Kibiro hot spring, there is an area where salt (common salt) has been extracted for so many years. There are two areas where salt gardens are found. The salt is extracted from soils by dissolution in water, followed by filtration. The resultant brines are then taken for evaporation to concentrate the salt which is heaped and sold as small piles.

3.3.8 Oil seepages

In recent years a lot of oil discoveries have been made in the Albertine graben. In the process of geothermal mapping, oil seepages and old shallow exploration wells have been encountered. One of the oil seepages was encountered mid-way between Bikunyu and Kyamwana fishing villages along the shores of Lake Albert (Map. 5). Close by, there were also two old oil wells, one of them dormant, while the other one discharges black hydrocarbons especially during dry season. Only a small part of the discharging well can be viewed because most of the pipe is now submerged in water. At the natural oil seepage all the surrounding sediments have been stained black. Locals reported that the seepage is more active during dry seasons. The stained sediments and rocks have a characteristic kerogeneous smell.

3.4 Structure and fractured zones

The main structure within the study area is the rift itself and of course its escarpment (main fault scarp) which has NE – SW trend. The escarpment is associated with a narrow band of mylonitic rocks which correspond to a zone of enhanced permeability.

There are points along the escarpment where there is a higher density of faults which tend to intersect at the same point. These are very interesting areas in terms of permeability and surface manifestations. They constitute highly fractured zones that may be the zones of recharge, outflow or upflow. One of such areas is in north east side of the mapped area, where at least three major faults and two minor ones intersect.

Many of the small faults are shallow in their nature but they enhance upflow of hydrothermal fluids where they intersect with the main fault scarp. Some of such faults have been preserved as open fractures which can even be recognised from a distance (Fig. 5). Some fault planes have been preserved both for the minor and major fault scarp. At one point on the escarpment a slickenside (Fig. 5) was recognised and mapped whose dip was $302^{\circ}/52^{\circ}$ (Azimuth of dip direction and dip amount respectively). Therefore the main escarpment dips to the Northwest.

Local shear zones were observed to exist perpendicular but close to the main rift scarp. Where they occur, surface manifestations tend to go a bit further up the escarpment. It was also noticed that some of the escarpment steps are not only due to down throw, but also due to erosion because of highly fractured zones that run parallel to the main escarpment (Fig.4).



Figure 4: A step which is thought to be not down thrown but erosional because of high degree of fracturing and alteration. Hydrothermal fluids here were rich in iron and traces of calcite cited.



Figure 5: On the left is open fracture of a minor fault as it joins the main escarpment. At the junction was mapped travertine. Right: Remnants of a slickenside at the main fault scarp whose dip is $302^{\circ} 52'$.

4. RESULTS

From this work, several active and extinct surface manifestations were mapped and several lithological units were also identified. In this mapping exercise lithological unit boundaries were not mapped. However, the area of study was overlaid over regional geology layer to get the regional geology of the area (see Kibiro regional geology maps below). Most of time was used to try and map as many surface manifestations as possible. A map (1:70'000) showing all observation points for available data about Kibiro was compiled (Map. 1). All easily-mapped faults have already been included in this map.

From the data base, all observation points which are in the category of geothermal surface manifestations were selected for and a zone (polygon) showing extent of surface manifestation has been created to delineate area of manifestations (see Kibiro geothermal area map 3 below). From this map it can be noticed that the distribution of geothermal surface manifestation is guided and controlled by the main fault scarp. The zone of surface manifestations widens at points where secondary permeability has been enhanced, that is, at points where many faults intersect (like close to yellow and white circles – see map 4 below).

Zonation based on three minerals in geothermal environments was made to see their distribution in mapped area of this geothermal prospect. The zonation was based on silica, sulphur and travertine/calcite. Gypsum was taken to be indicative of sulphur. It was noted that calcite and/or travertine occur outside the silica and sulphur zones, and there are no situations where calcite exists in zones with sulphur or silica (Map. 4).

4.1 Recent findings

The third phase of geological mapping of Kibiro geothermal area was able to cover up the gaps east and south of Kibiro hot springs. The observation points made during the phase are shown in green colour in the bottom left corner of figure 13 on next page. More manifestations were discovered which include altered grounds, calcite, hydrogen sulphide and sulphur fumaroles.

The sulphur-hydrogen sulphide fumaroles were observed to be distributed along a linear structure that strikes north east within the escarpment zone oblique to the fault scarp. Many of them still emanate hydrogen sulphide and elemental sulphur fills rims of the fumaroles.

Dolerite dykes of different ages were also discovered and have been discussed in the geology section. Grab sample for age dating were also collected. Well and seismic data sets have been obtained from Petroleum Exploration and Production department so that information about seismic layering and temperature gradient can be understood. A team has been assigned this work and results are almost out.

5. CONCLUSIONS AND RECOMMENDATIONS

Out of this work it has been found out that for sure there are surface manifestations in this area. The manifestations cover a wider area than previously thought. Now the linkage between Kibiro hot and the targeted magnetic anomaly is known.

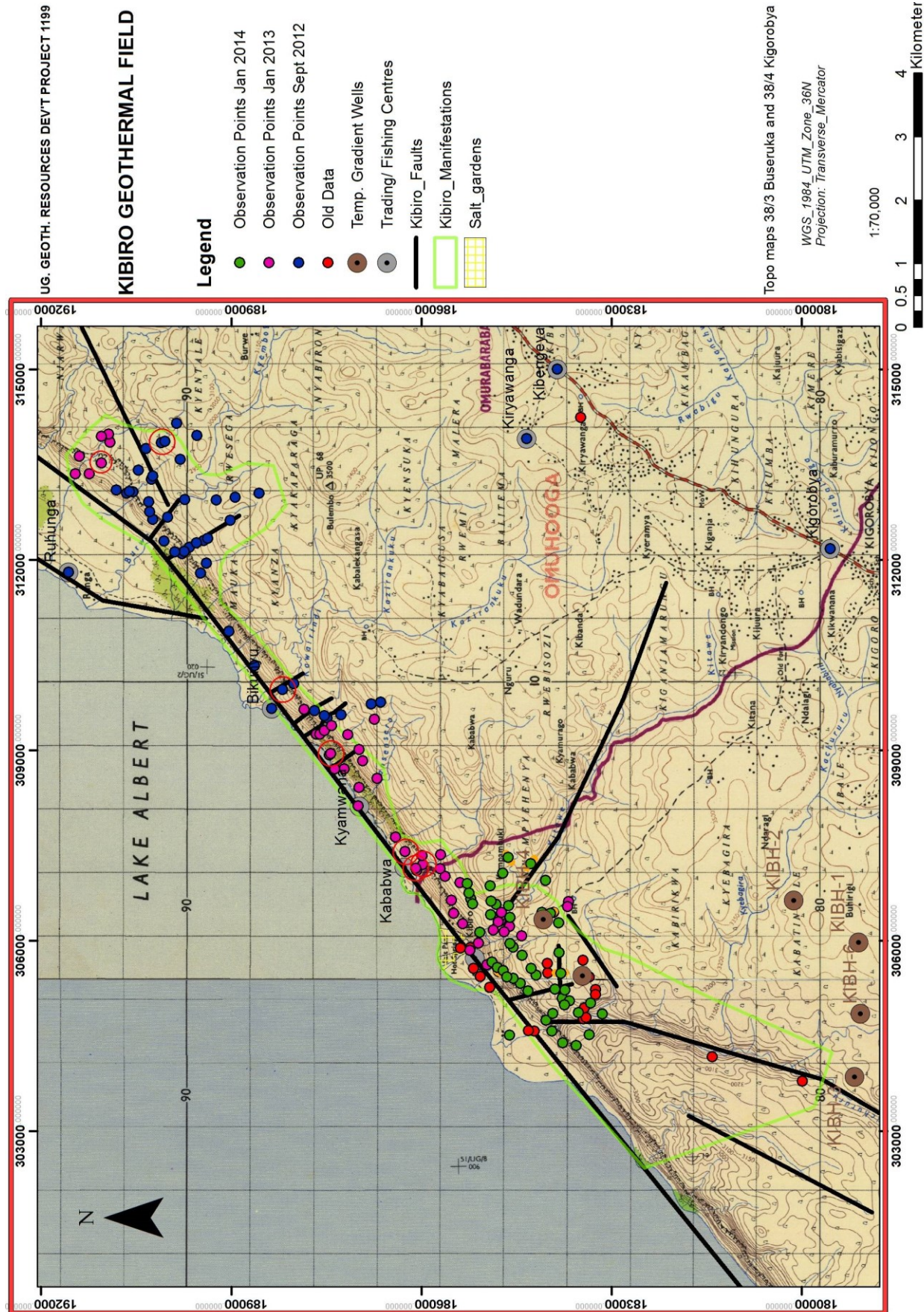
The distribution of geothermal surface manifestation has a northeast - southwest trend, in the same direction like the main escarpment of the western arm of the east African valley. There are areas where the hydrothermally altered grounds thin out and only close to escarpment, but widen out at intersection points of fault systems.

In the whole geothermal field, there are two areas which are more promising as up flow zones. The areas marked by the yellow and white circles, because silica and sulphur are indicative of fluids coming from deep sources and high temperature hydrothermal fluids. These two points are also interesting because they are located in zones of enhanced secondary permeability i.e. intersection of several faults.

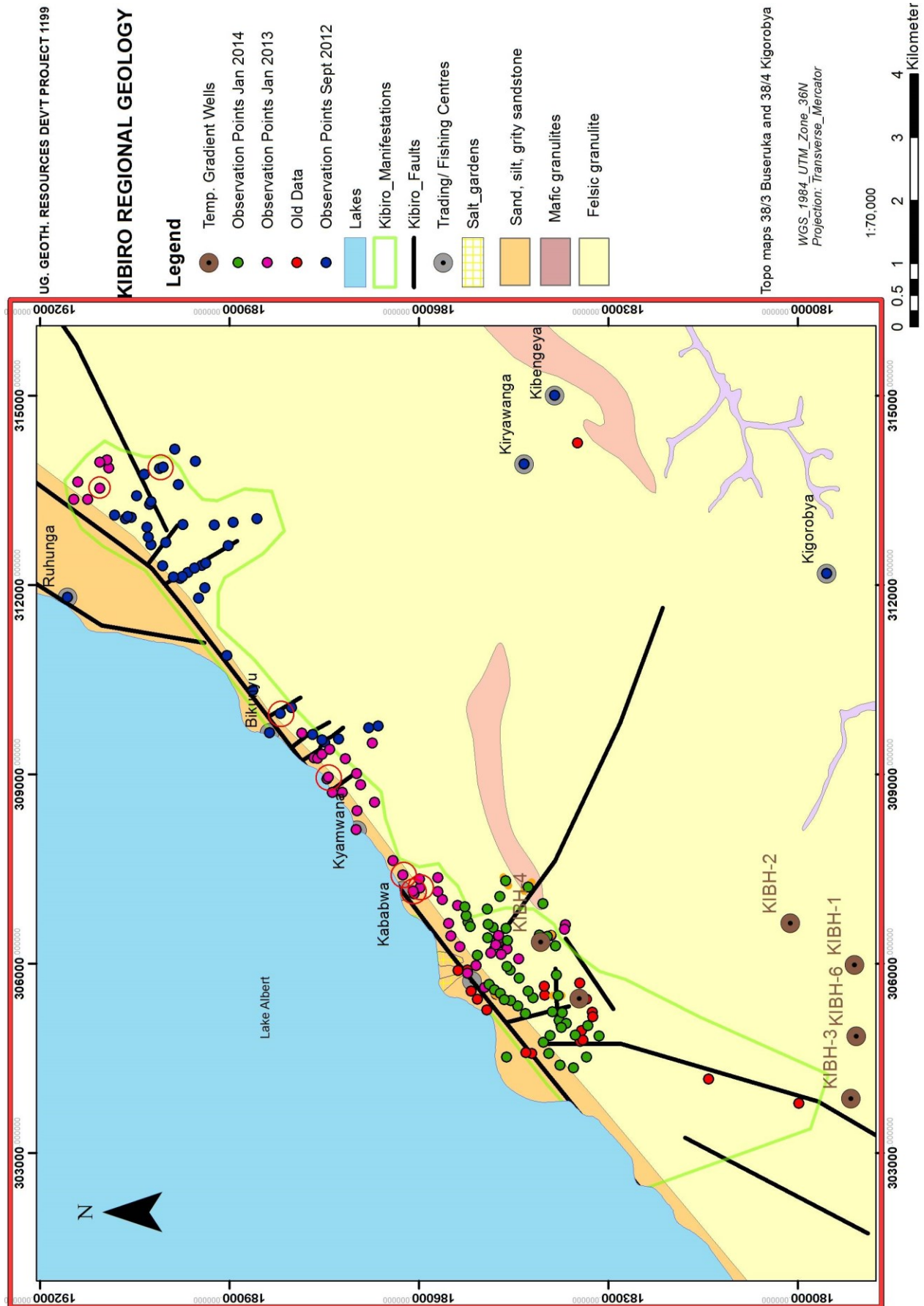
By the fact that an area has been observed to have silica precipitate, it indicates that this geothermal field has a potential for high temperature fluids if it has not been cooling down (there is a possibility of geothermal systems cooling down due to excessive recharge with cold water).

From observations made, it seems the up flow of geothermal fluids is directly associated with the main fault scarp which dips to the Northwest. Having this in mind, it seems geothermal systems within the Western arm of the E.A rift system need careful directional

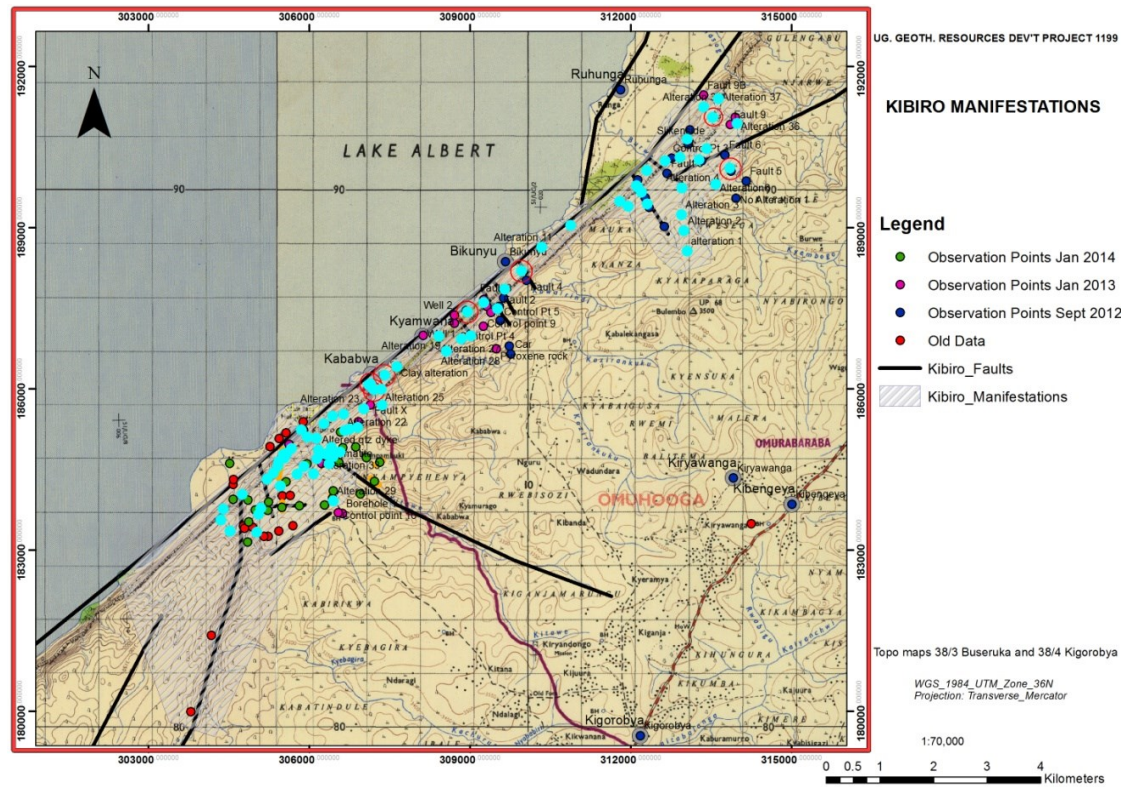
drilling to be able to intercept the seemingly narrow and deep reservoir. In future a lot of structural studies should be made before any drilling can be made.



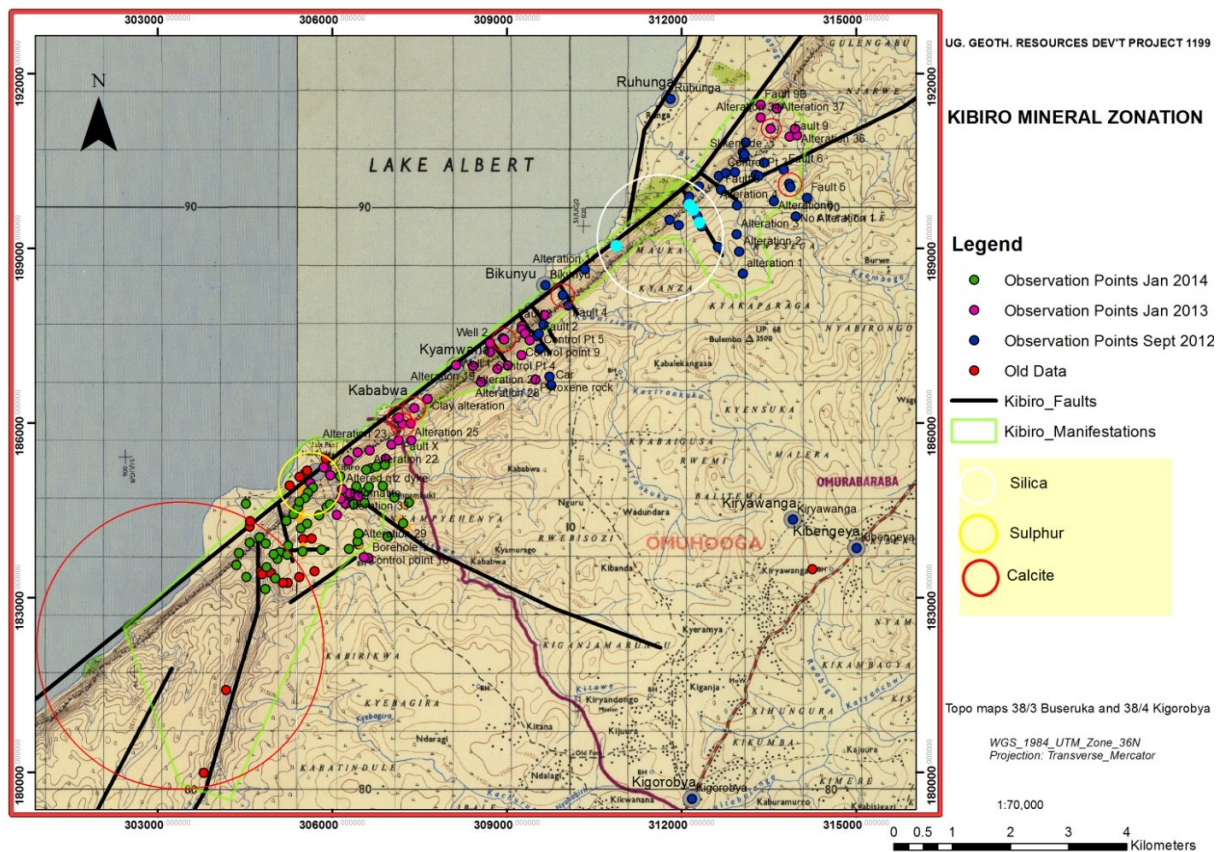
Map 1: Showing Kibiro Geothermal area.



Map 2: Kibiro Geothermal field over regional Geology.

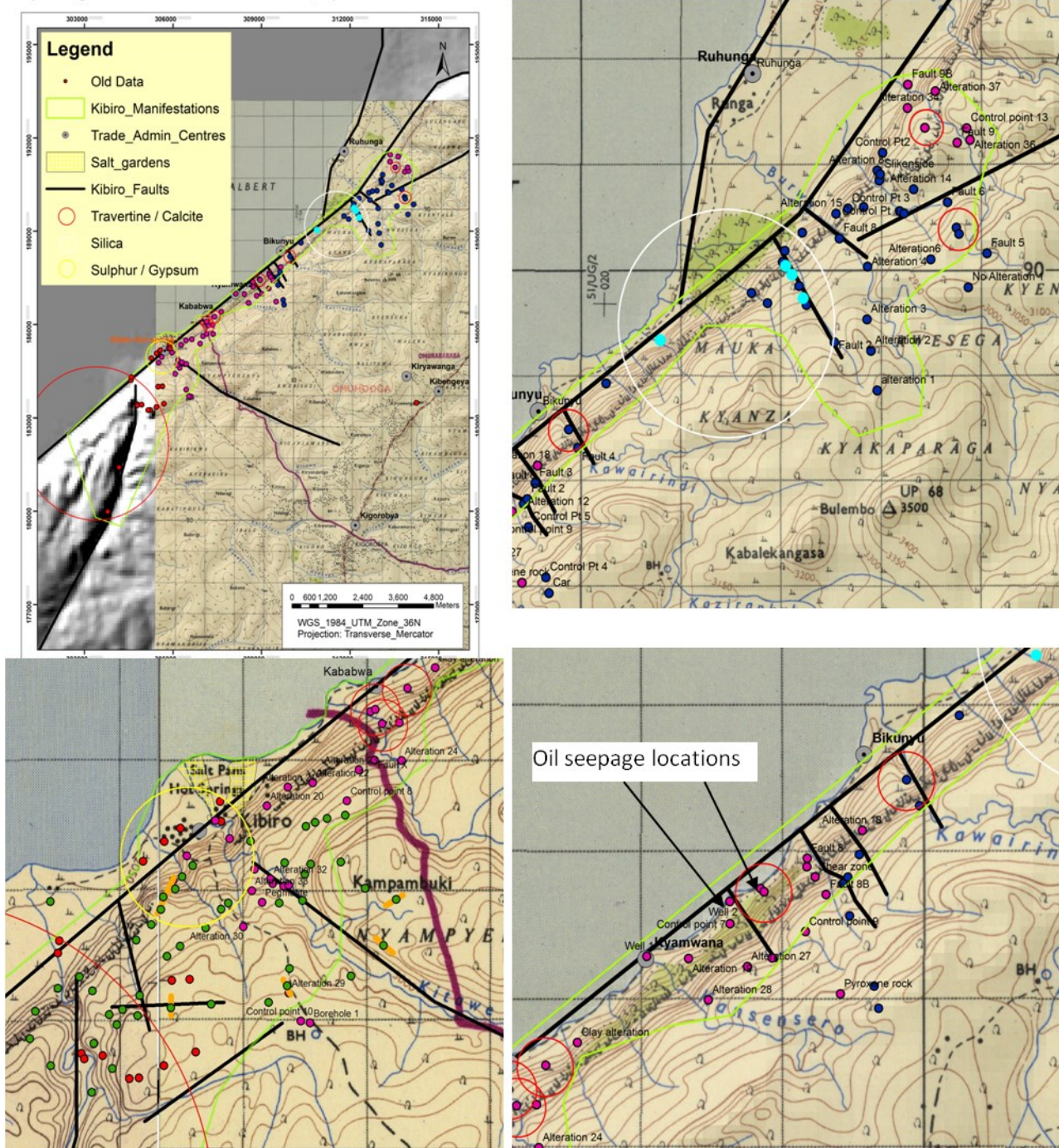


Map 3: Polygon of surface manifestations was done by selecting for all way points for geothermal surface manifestations in the database. The selected way points appear light blue. Old way points were included because they all occur in manifestation area. The manifestations widen where fault densities are higher.



Map 4: Zonation is based on three minerals; Calcite, sulphur and silica. It is assumed that silica and sulphur are indicative of high temperatures, while calcite or travertine is indicative of low temperatures. Note the smaller red circles around way points.

Map showing zonation of manifestations based on Silica, sulphur and Travertine/Calcite



Map 5: Showing portions of zoomed in mapped area with labeled way points.

The western rift is not as volcanically active as the eastern rift. The occurrence of a lot of calcite / travertine is maybe due to presence of a lot of limestone in the sedimentary basin which may be mobilised by hydrothermal fluids and then later precipitated at lower temperatures at the surface. However, even all volcanics of western Uganda are all carbonatitic.

The data available in now being used to make geothermal geological model, but further studies of structure need to be done. After the geological model is made out, the next stage will be integrating data from other disciplines i.e. geophysics and geochemistry.

There is need for further investigations on the dolerite dykes to get its age to see if they are young enough to be associated with heat source in Kibiro geothermal system.

Continuous monitoring of temperature gradient well should be carried out. Routine temperature measurements should be carried to get trend for temperature gradients. The last time temperature measurements were made was after drilling, and there is a likely that there was a cooling effect then due to cold circulation from drilling circulation.

Consultation of drilling information from oil exploration wells, seismic data and any other petroleum exploration information should be consulted so that some more light is thrown to the subsurface temperature as well as the possibility of having strata bound geothermal reservoir.

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