DATA COLLECTION SURVEY
ON GEOTHERMAL ENERGY DEVELOPMENT
IN EAST AFRICA

FINAL REPORT
(UGANDA)

February 2014

JAPAN INTERNATIONAL COOPERATION AGENCY
WEST JAPAN ENGINEERING CONSULTANTS, INC.
MITSUBISHI MATERIALS TECHNO CORPORATION

Acronyms and Abbreviations

AfDB	Africa Development Bank
ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUC	African Union Commission
BGR	Federal Institute for Geosciences and Natural Resources of Germany
BMZ	The German Federal Ministry for Economic Cooperation and Development
CER	Certified Emission Reduction
DEM	Digital Elevation Model
DGSM	Department of Geological Survey and Mineral Development
DOE	Division of Environmental
EAGP	East Africa Geothermal Partnership
EIA	Environmental Impact Assessment
EIB	Europe Investment Bank
EIS	Environmental Impact Statement
ERA	Electricity Regulatory Authority
ERC	Energy Regulatory Commission
ETM+	LANDSAT Enhanced Thematic Mapper Plus
FIT	Feed in Tariff
GIS	Geographic Information System
GIZ	German Society for International Cooperation
GRMF	Geothermal Risk Mitigation Facility
IAEA	International Atomic Energy Agency
ICEIDA	The Icelandic International Development Agency
IPP	Independent Power Purchase
JEPIC	Japan Electric Power Information Center
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaubau
MEMD	Ministry of Energy and Mineral Development
NDVI	Normalized Difference Vegetation Index
NEMA	National Environment Management Authority
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PPA	Power Purchase Agreement
SIDA	Swedish International Development Cooperation Agency
SRTM	Shuttle Radar Topography Mission
SWECO	Sweden Consulting Group
SWIR	Short Wave Infrared
TICAD	Tokyo International Conference on African Development
TIR	Thermal Infrared
UEB	Uganda Electricity Board
UEDCL	Uganda Electricity Distribution Company Limited
UEGCL	Uganda Electricity Generation Company Limited
UETCL	Uganda Electricity Transmission Company Limited
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNUGTP	United Nations University Geothermal Training Programme
USAID	United States Agency for International Development
USGS	United States Geological Survey
VNIR	Visible and Near Infrared

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I Framework and Policy of the Survey

I-1 Objectives of the Survey

This study will be conducted to obtain the fundamental information necessary to consider JICA's future contribution to geothermal development in Uganda. For this purpose, "Situation Analysis Study on Geothermal Development in Africa (2010)", in the following, shorten to "Situation Analysis Study" will be updated through this study, collecting the latest information about the situation and condition of geothermal development in Uganda. In this study, hot spring water and rock samples will be collected and analyzed, when necessary, to enable detailed consideration of the geothermal potential of the country.

I-2 Survey Area

Republic of Uganda (Fig. I-1)

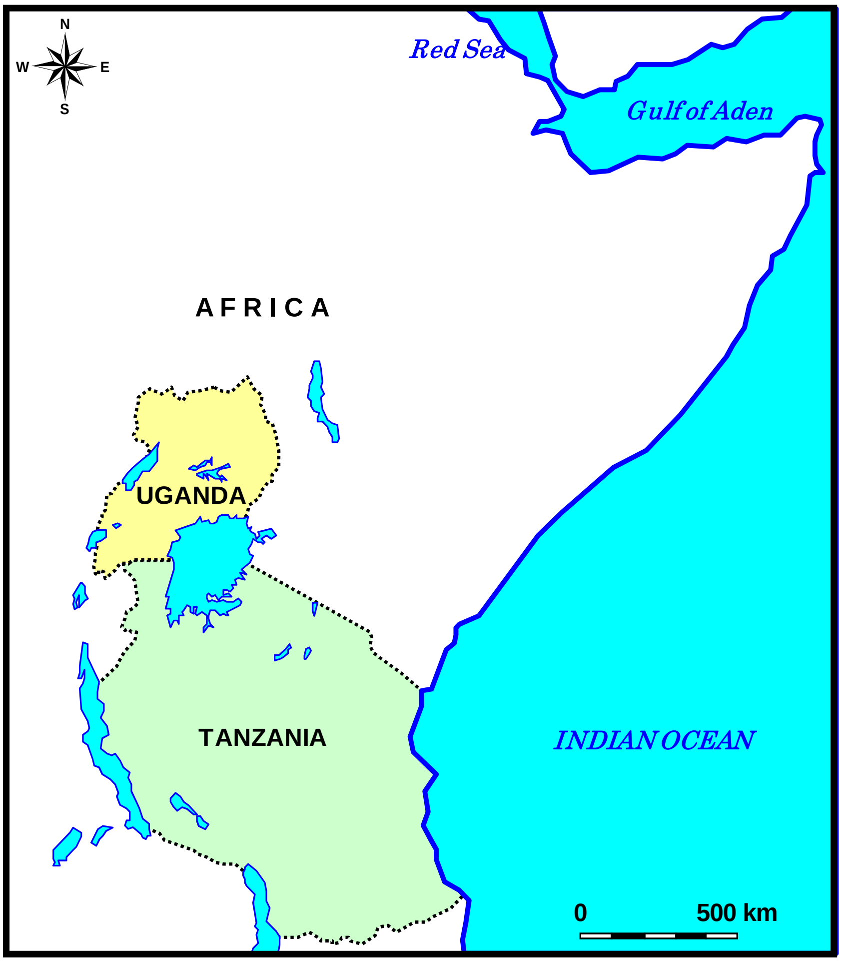


Fig. I-1 Survey area

I-3 Background of the Survey

In Africa, a stable electric power supply corresponding to increasing demand, offering power at a price that consumers can afford, is required for economic and social development. In the face of increasing electricity demand together with the need to reduce greenhouse-gas emissions and ensure energy security, the utilization of renewable energy for power generation, like hydropower, geothermal power and so on, is recognized to be important in Africa. This recognition of the importance of renewable energy is a worldwide trend. At the Tokyo International Conference on African Development (TICAD) V that was held in June 2013, geothermal power development in the Rift Valley area, where considerable geothermal resources is exist, was discussed as one of the important subjects to focus on in the workshop devoted to it.

Although geothermal power plants have been installed in Kenya and Ethiopia, there are no geothermal power plants in the other countries in Africa. The installed geothermal power plants in Kenya are in the Olkaria and the Eburru geothermal fields (See Fig. I-2), with total installed capacities of respectively 209 MW and 2.5 MW (Omenda, 2010). The installed geothermal power plant in Ethiopia is in the Aluto-Langano geothermal field, and its installed capacity is 7.3 MW (Chandrasekharam and Chandrasekhar, 2012). It is considered that geothermal resources in the Rift Valley area, including these two countries, will be developed for power generation in the near future. However, existing fundamental information about geothermal resources was not sufficient to plan geothermal power development. To remedy this situation, “Situation Analysis Study”, studying conditions of geothermal power development in Kenya, Ethiopia, Djibouti, Tanzania, and Uganda, was conducted by JICA in 2010. However, the additional information collected in that study was still not sufficient for the consideration of a suitable supporting program for geothermal power development in this area. In order to elaborate a suitable contribution to future geothermal power development in Uganda, it is necessary to collect the latest information about geothermal resources and geothermal development in these countries and to systematically review the newly collected information together with the previous information.

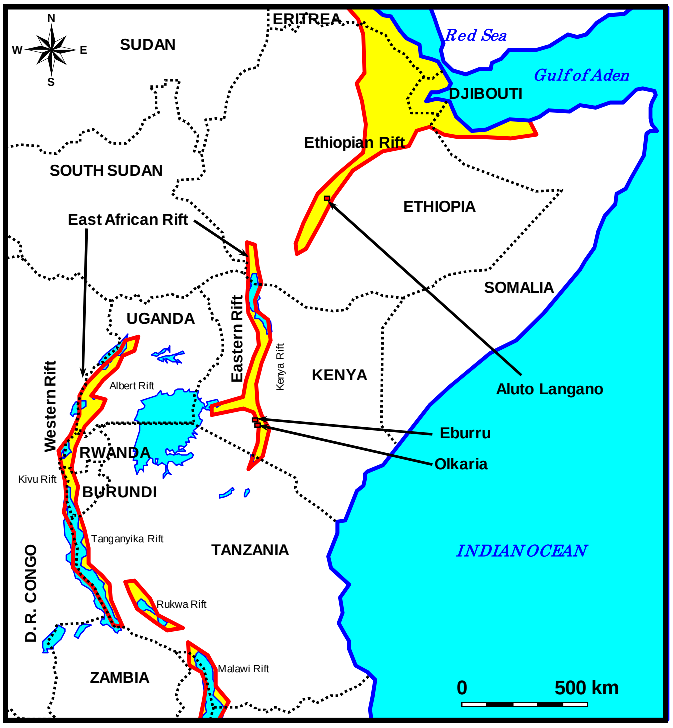


Fig. I-2 Northern and central areas of the rift valley and developed fields

I-4 Strategy and Methodology of Study

I-4-1 Study Strategy

Most of the geothermal areas in Uganda remain in the site reconnaissance phase. Moreover, little nationwide exploration for geothermal resources has been conducted, and adequate topographic maps cannot be obtained. To remedy this situation, remote sensing technology using satellite images and geographic information systems (GIS) has been applied in this study, together with geological and geochemical surveying in several selected geothermal areas to further examine the information obtained.

I-4-2 Study Methodology

1. First year of Study (FY 2012/2013)

a) Update of the Basic Information

The following data and information concerned with geothermal power development in the objective countries are collected in Japan and used to update the information obtained in the "Situation Analysis Study".

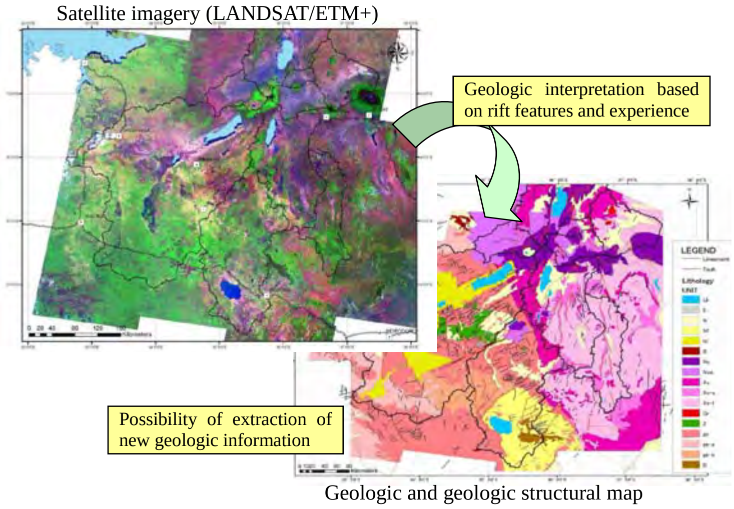
- Potential of primary energy sources and their utilization plan
- Information about geothermal development
- Information about geothermal development by donors
- Environmental and social regulation of geothermal development

b) Geological Survey

For the fundamental evaluation of geothermal resources necessary to consider a suitable geothermal development plan, the study of satellite imagery and elaboration of a geographic information system (GIS) will be very helpful. A combination of these techniques enables rapid interpretation of the potential of an extensive area such as Uganda, which the East African Rift runs through from north to south. Reconnaissance surveying using remote sensing data is first carried out over the area, and then the survey results are stored in a GIS database. The GIS has functions designed to display, superimpose and output various results, elaborating thematic maps of geothermal resource potential. For instance, comparison between the distribution of geothermal potential sites and social and/or economic conditions on the map helps to determine targets and establish priority among them.

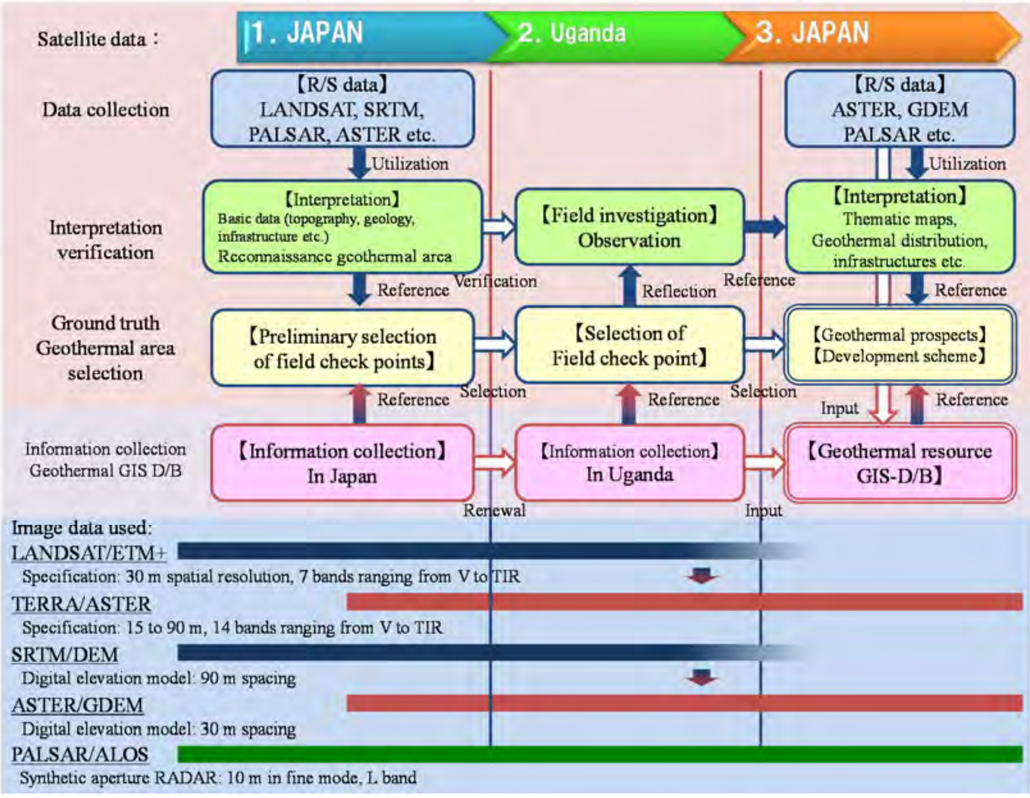
An example of satellite imagery analysis over the East African Rift in Tanzania is shown in Fig. I-3, which includes the very promising area of Arusha. When interpreting this satellite imagery, knowledge about and experience with various rift features is indispensable for applying the remote sensing procedure in advance. In addition, given the current state of digital progress in the east African countries, comprehensive interpretation combining remote sensing techniques with GIS is a great help for further study. A flowchart for the utilization of satellite imagery analysis is shown in Fig. I-4.

In the first year of the study, data collection was conducted in Japan. The data collected included satellite imagery and existing data regarding geothermal features and promising areas, including their actual in situ conditions, with all relevant information being integrated into a GIS database. LANDSAT/ETM+ and SRTM/DEM, ASTER, ASTER/GDEM and PALSAR (if necessary) satellite imagery data will be used throughout this study. Interpretation work will be carried out on this material in the form of lineament extraction identifying fractures, thermal anomalies, the distribution of alteration minerals, groundwater springs and so forth in the images.



(Study team)

Fig. I-3 An example of satellite imagery analysis over the East African Rift in Tanzania



(Study team)

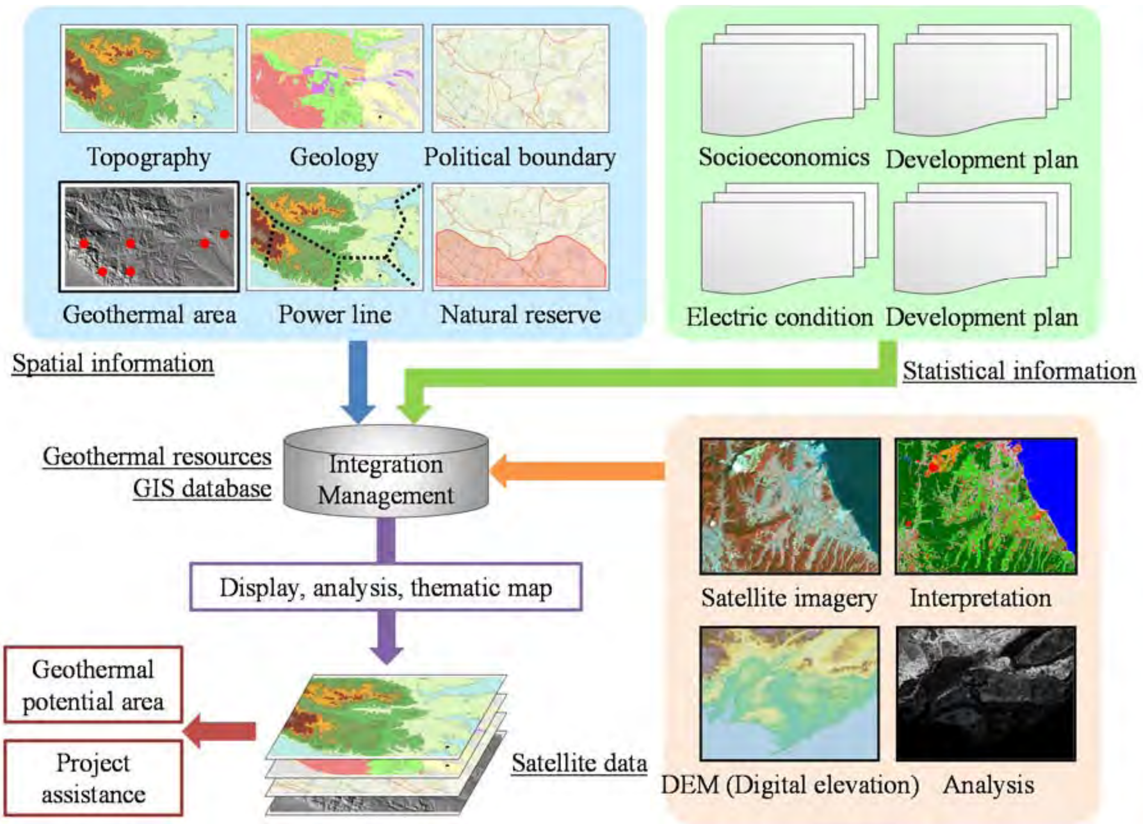
Fig. I-4 A flowchart for the utilization of satellite imagery analysis in Phase I and Phase II

c) Geochemical Survey

Continuing the work of the "Situation Analysis Study", chemical data for the geothermal fluids in Uganda were mainly collected. From these data together with those obtained from the previous study, the following items were examined to evaluate the geothermal resource: origin of geothermal fluid, heating process, reservoir temperature and fluid flow pattern in prospective fields.

d) GIS

Various data must be integrated in considering future geothermal development projects. They include not only natural condition data reflecting such things as topography, geology, geologic structure and distribution of possible geothermal areas, but also socioeconomic data concerning infrastructure, existing and planned electric power development, etc. A GIS provides just such an integrated database package of the data mentioned above, organized around the spatial data that record positional information. In addition, a variety of interpretations and visual output of data are made possible by the GIS spatial analysis functions. In the first year, a fundamental GIS database called 'Geothermal resources GIS database' was designed, and the relevant geothermal related data, satellite imagery and interpretation maps were input. The concept of the 'Geothermal resources GIS database' is illustrated in Fig. I-5.



(Study team)

Fig. I-5 Concept of 'Geothermal resources GIS database'

e) Planning for 2nd year work

Prospective areas for geothermal development are selected mainly through consideration of the updated and complemented information, together with consideration of the current situation of prospective areas and local security

2. Study in the second year (FY 2013/2014)

a) Collection of the Basic Information

The following items will be collected in the field survey to update and complete the preliminary work:

- Information about and survey of accessibility to the prospective area
- Information about donors, private sector enterprises and electric power company which have experience in geothermal development
- Information about geothermal development plans and power development and distribution system plans
- Information about the capacity of the executing agency for geothermal development

b) Geological Survey

Field investigation will be conducted in the selected areas. Geological factors such as geology, geologic structure, occurrence of secondary minerals resulting from hydrothermal alteration and thermal anomalies, which were estimated through imagery interpretation in the first year, will be examined in the field investigation. As ASTER data have a high spectral resolution, the detailed occurrence of secondary minerals can be mapped using spectral analysis. In addition, thermal anomalies related to hot springs are mapped by their TIR E-T separation. The target area selection will be conducted through GIS procedures using existing data and field investigation results. In this process, a GIS database with the relevant geothermal information will be elaborated as well. Hand specimens of rock will be sampled in the field and the following laboratory analysis will be conducted in Japan. These analytical results will contribute to understand characteristics of geothermal activity in the fields.

- Microscopic observation: 6 samples
- X ray diffraction analysis: 7 samples
- Spectral analysis: 9 samples

c) Geochemical Survey

To examine and complement chemical data on hot spring water described in the collected manuscripts, hot spring and surface waters will be sampled in situ. Sampling points, chemical components to be analyzed and number of samples (totalling about 10) will be determined finally based on the data review results and discussion with the Department of Geological Survey and Mines (DGSM).

Samples will be sent to Japan to be analyzed. Provisonally, the chemical components to be analyzed are pH, EC, Na, K, Li, NH_4, Ca, Mg, Cl, SO_4, HCO_3, F, B, T-SiO_2, $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$. From the chemical data of hot spring waters, the following factors will be estimated.

- Presence of a deep geothermal reservoir; occurrence of neutral-pH and Cl-type water
- Estimation of reservoir temperature; geo-thermometry based on chemical composition
- Extent of geothermal reservoir; distribution of hot springs and fumaroles with high discharge or geochemical temperature
- Corrosion potential, scaling potential, etc.

d) GIS

The data mainly collected by field investigation will be added to the GIS database constructed in the first year. This data will include information about topography, geology, geologic structure and distribution of possible geothermal areas, infrastructure, natural reserves and so forth. Geothermal areas with sufficient potential will be selected from this data by using the GIS functions. This process allows the establishment of a basic ‘Geothermal resources GIS database’ and profiles each geothermal area that is promising for further development work.

e) Geothermal Resource Evaluation

The resource potentials will be calculated, mainly based on the collected data. The methods applied to evaluate the potential will be determined on the basis of the quality and quantity of the collected data.

The Study Team will provide the following reports:

Inception Report

In English and in Japanese

Progress Report

In English and in Japanese

Draft Final Report

In English and in Japanese

Final Report (This Report)

In English and in Japanese

I-5 Process of the Survey

The main schedule of the survey is as follows:

The main schedule of the survey is as follows:

Preliminary Work in Japan	Contract (February 7th) - Early March 2013
Inception Report	March 8th, 2013
Field Trip	October 5th-20th, 2013
Progress Report	November 12th, 2013
Wrap-up Work in Japan	Middle of November 2013- February 2014
Draft Final Report	January 31st, 2014
Final Report	February 20th, 2014
End of Work	March 2014

I-6 Work Schedule

The work schedule of this survey is shown in Table I-1.

Table I-1 Work Schedule

Month	FY2012		FY2013											
Service Item	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1. The 1st Work in Japan														
①Collection and Review of Available Data and Information														
・Storage and Utilization situation of primary energy														
・Local Information about Geothermal Development														
・Information about Geothermal Development held by local agencies														
・System of Environmental and Social Considerations														
②Planning and discussion of the field trip														
③Preparation, discussion and submission of Inception Report		△												
Contracting for the survey in the 2nd fiscal year														
2. Field Trip														
①Preparation for Field Trip														
②Field Trip (Explanation for JICA local office, Sampling of hot spring water and rock)							■		■					
③Preparation and Submission of Progress Report									△					
3. The 2nd Work in Japan														
①Analysis (Hot spring water, rock sample)														
②Analytical work (Geology, Geochemistry, GIS)														
③Preparation, discussion and Submission of Draft Final Report												△		
④Preparation and Submission of Final Report													△	

Legend : ——— Preparation Work; ▬ Work in Uganda; ▭ Work in Japan; △——△ Explanation of Report; - - - - - Other task

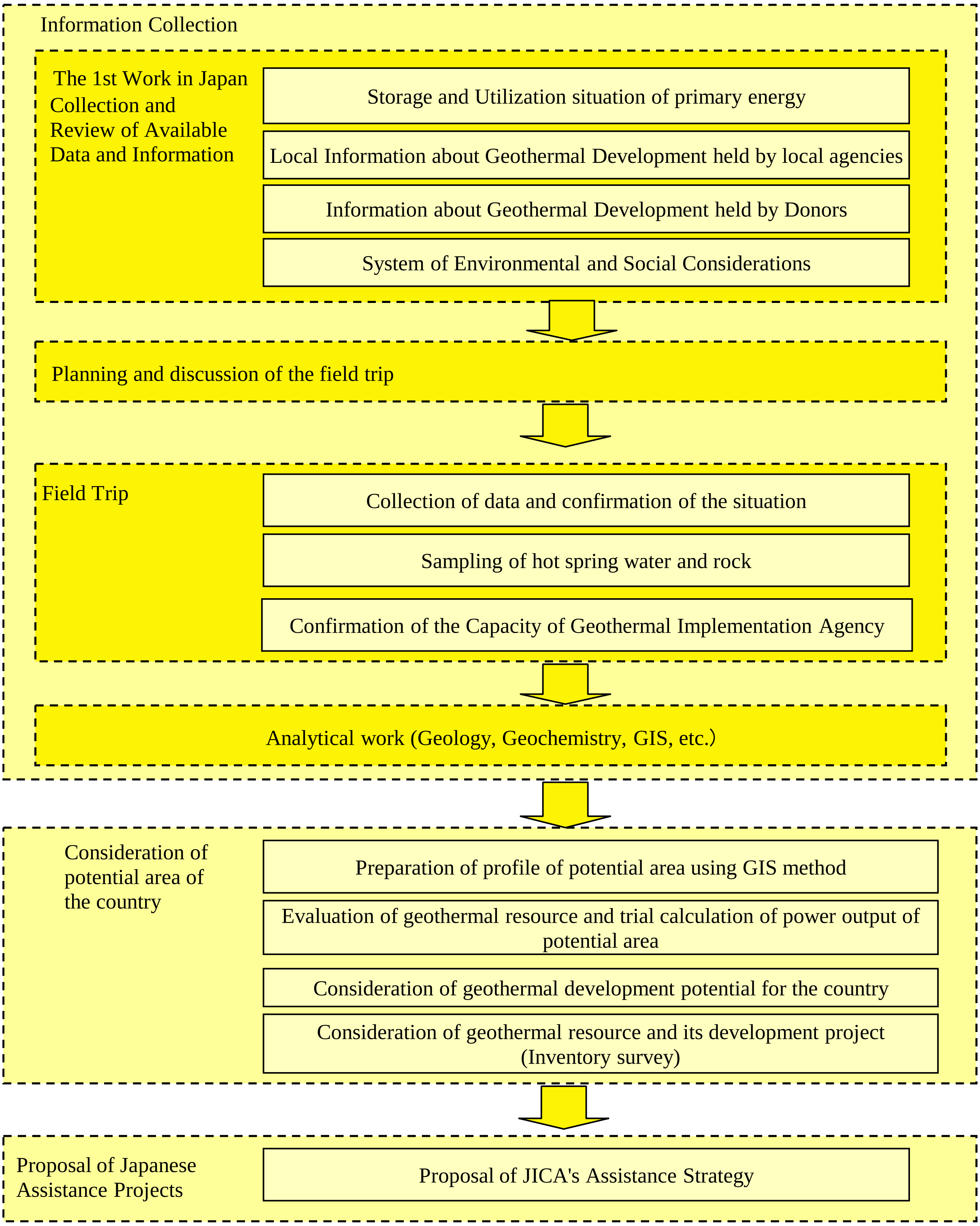


Fig. I-6 Study Flow Chart

I-7 Team of Analysts

Members of the study team are listed in Table I-2 together with their specialties and assignments.

Table I-2 Members of the Study Team

Name	Specialty	Assignment
Hideo AKASAKO	Team Leader, Analyst of Geothermal Development Planning	Team Leader, Project Management, Technical Supervisor of Geothermal Development
Tetsuya YAHARA	Sub-Leader, Analyst of Geothermal Development Planning	Team Sub-Leader, assisting Project Management, Technical Supervisor of Geothermal Development
Koji MATSUDA	Geochemist	Data collection and review of geothermal exploration (geochemistry), and resource evaluation
Noriaki UCHIYAMA	Geochemist	Data collection and review of geothermal exploration (geochemistry), study on environmental and social regulation
Tadashi YAMAKAWA	Geologist	Data collection and review of geothermal exploration (geology), remote sensing
Yoshio SOEDA	Geologist	Data collection and review of geothermal exploration (geology)
Shigeaki MATSUO	GIS Analyst	Construction of GIS for objective areas

II Results of the Survey

II-1 Energy Situation

Uganda is blessed with water resources in the form of Lake Victoria (the third largest lake in the world), the White Nile River, and other sources. As oil was identified in neighbouring Kenya in the early 1980s, oil exploration has been carried out in Uganda, too. Oil was identified in 1998, and oil development projects have been progressing in several fields. Since 2008, Uganda and China National Petroleum Co., China Petroleum & Chemical Co., and also China National Offshore Oil Co. in a joint venture with Heritage Oil Co. have been moving towards oil production in Toro near Lake Albert. Oil reserves in this area were estimated to be approximately 600 million barrels as of February 2009. However, the oil reserves of the country as a whole have not yet been estimated. In order to reduce the amount of imported oil, the Ministry of Energy and Mineral Development (MEMD) plans to construct an oil refining facility near Lake Albert (in the Hoima district near the oil drilling site). The plan is to export oil to other countries, including Kenya. To facilitate this plan, a roughly 1,500 km long pipeline to Mombasa Port, in the eastern part of Kenya has been investigated. MEMD plans to construct an oil-thermal power plant (of 50 to 100 MW) together with a transmission line from the oil field to Kampala city to ease the power shortage there brought on by increasing demand.

II-2 Electric Power Situation and Power Supply System

The Ugandan government approved the Electricity Act of 1999, under which an Electricity Regulatory Authority (ERA) was established as a regulatory agency for the power industry. MEMD is responsible for industrial development policy. Based on an amendment to the Electricity Act of 1999, a state-owned enterprise known as the Uganda Electricity Board (UEB) was divided into three entities: Uganda Electricity Generation Company Limited (UEGCL), Uganda Electricity Transmission Company Limited (UETCL), and Uganda Electricity Distribution Company Limited (UEDCL). Moreover, the power generation and distribution business has been assigned through long-term contracts to Eskom Company and Umeme Company, respectively (although ownership of existing facilities has not been transferred, the two companies are responsible for the operation and maintenance of these facilities). New power development projects are carried out by Independent Power Producers (IPP), mainly in partnership with government.

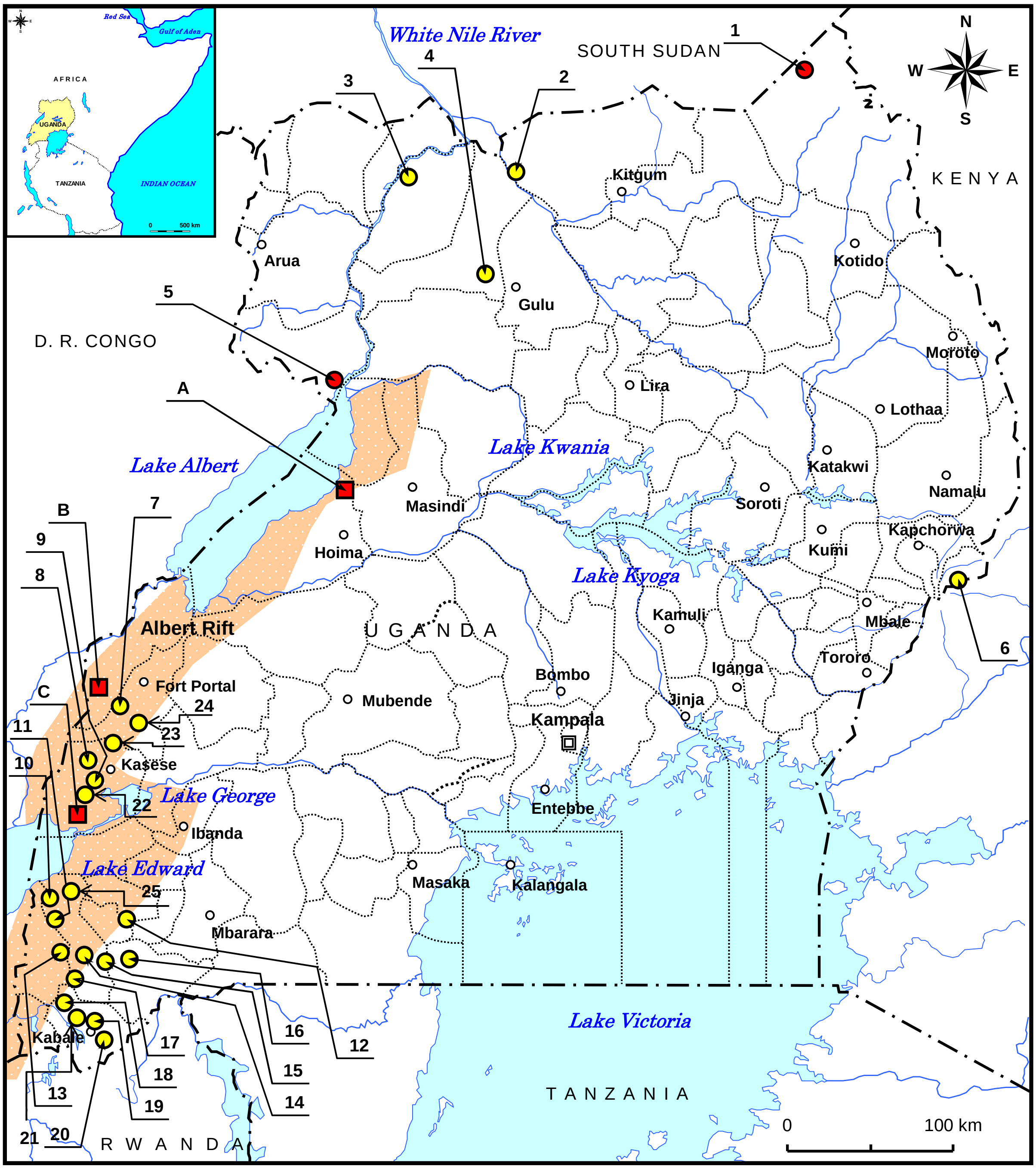
According to Bahati (2012), the total installed capacity in Uganda is 778.5 MW, among which 682.5 MW is hydro power (about 80%), 70 MW is heavy oil-thermal power and 26 MW is co-generation by the Sugar Industry. As a short-term response to rising electricity demand, the Ugandan government is planning to construct two hydro power plants (a 600 MW plant at Karuma and 140 MW plant at Isimba) along the Nile River by 2015. Moreover, the government is moving ahead to construct small hydro power plants in the western region. As a medium-term response, the construction of a 600 MW hydro power plant at Ayago, along the Nile River, has been considered. As a long-term response, the government is planning construction of a 600 MW hydro power plant at Murchison Falls and a 400 MW plant at Oriang.

As stated above, the power supply in Uganda is highly dependent on hydro power plants. The utilization factor of a hydro power plant is greatly affected by changes in water level in Lake Victoria. The water level of Lake Victoria is reduced by drought in the upstream regions in Kenya, Tanzania, and Rwanda, and so the utilization factor falls when there is drought in the upstream region. For example, in 2006 when the water level was quite low, energy production was only 1,178 GWh, compared to 2004, when the water level was high, and energy production reached 1,896 GWh, approximately a 60% difference in production. For this reason, the utilization of peat, solar, biomass, and geothermal energy is being considered as a complement to existing forms of generation. Japan Electric Power Information Center (JEPIC) reports that the renewable energy potential, excluding hydro power, is 1,650 MW from biomass (focusing on agricultural waste), 450 MW from geothermal, 200 MW from solar energy (a power source promoting rural electrification), and 800 MW from other sources (mainly wind power) (Electric power industry of overseas, Part 2, 2010). According to data from the government, a 25 MW geothermal power plant and 45 MW geothermal power plant will be constructed in 2012 and in 2017, respectively. According to the electric power sector master plan drawn up by PB Power Company in December 2009, operation of a geothermal power plant will be started in 2020 (30 MW), 2021 (30 MW), and 2022 (30 MW). In this master plan, it is noted that a 100 MW thermal power plant planned for 2013 could be replaced by geothermal power plants in the next revision of the master plan, if geothermal development progresses favorably and the total potential of geothermal resources can be identified.

II-3 Outline of Geothermal Resources

The governmental agency responsible for geothermal exploration, including exploration drilling in Uganda is the Department of Geological Survey and Mineral Development (DGSM), named Geological Survey of Uganda (GSU) for short. In terms of geothermal projects, DGSM has conducted geothermal exploration in the Kibiro area and in the Katwe area, with supporting funds from ICEIDA, and geothermal exploration in the Buranga area, with support from BGR.

Most of the geothermal areas in Uganda are situated along the Rift Valley (Albert Rift, see Fig. II-1). Although a nationwide geothermal survey has not been conducted yet, a research agency of the United States estimated a geothermal potential of about 450 MW in a survey by UNDP in the 1980s (McNitt, 1982). The following three areas are recommended as major potential areas: Kibiro, Buranga and Katwe. A high thermal gradient has also been identified in the course of oil exploration in the Panyimur area. Geothermal exploration has been focused on these four areas.



Legend

- Main Licensed Geothermal Area
- Other Licensed Geothermal Area
- Other Geothermal Area

A: Kibiro B: Buranga C: Katwe

1: Kanangarok	2:Amorpi	3: Amuru (Pakele)	4: Amuru
5: Panyimur	6: Kaitabosi	7: Rwagimba	8: Kibenge
9: Kabuga	10: Kiruruma	11: Ihimbo	12: Kitagata
13:Birara	14: Rubabo	15: Minera	16: Rabaare
17: Kisiizi	18: Karungu	19: Bubale	20: Kagamba
21: Murole	22: Muhokya	23: Ndugutu	24:Rwimi
25: Kanyinabolongo			

Modified from Bahati (2012)

Fig. II-1 Geothermal Fields in Uganda

II-4 Situation of Geothermal Development

II-4-1 Geothermal Development

According to "East Africa Geothermal Energy: Review of Donor Initiatives and Current Regulatory Framework", published by Economic Consultants Associated Ltd. in October 2012, many donors have been supporting geothermal development projects over the past 20 years. However, the actual progress of geothermal development in Uganda has been very minimal. Perhaps one reason for this dismal progress in geothermal development has been that Uganda is endowed with huge hydropower potential along the Nile River estimated at over 2000MW. More recently, discoveries of oil, and lack of clear and attractive results from the geothermal investigations done to date have played a role. Lack of government funds to finance aggressive exploration work has also been a major factor. However, the Government would like to have an energy mix in its electric power system in order to protect the country from power deficits caused by the now more frequent droughts and unpredictable price variations in the oil market.

The Kibiro geothermal area is one of the three geothermal areas in Uganda (Kibiro, Buranga and Katwe) that have received exploration attention. The area is located on the eastern side of Lake Albert. In 1993, UNDP, the Government of Iceland and OPEC funded geological and geochemical exploration work (Gislason et al, 1994) during which subsurface temperatures in the range of 200-220^{O}C were estimated from the geothermometry of hot springs. In 1997-2002, Isotope work was conducted with funding by IAEA which predicted a lower subsurface temperature of 140ºC (IAEA, 2003). The oxygen and sulfur isotope ratio of sulfuric acid in the sampled waters suggests a contribution of magmatic fluids. In 2004, ICEIDA conducted a TEM survey, while gravity and magnetic surveys were done by the Petroleum Exploration and Development Department of Uganda. The interpretation of these geophysical data was integrated with the rest of the available data and led to the drilling of six 300m thermal gradient holes. The geothermal gradient in this area was determined to be about 16ºC/km on the eastern side of the escarpment, while it was slightly higher at about 30ºC/km in the escarpment near Kibiro village (Árnason and Gíslason, 2009). This study recommended that MT surveying be undertaken, followed by a deep exploration well, as there was a possibility of striking fluids suitable for power generation. Moberge Finance Limited acquired the exploration license for this area in 2012.

In the Buranga prospect area, geological, geochemical, isotopic and geophysical surveys have been carried out, followed by drilling of thermal gradient holes (with a maximum drilled depth of 349 m). The results of these surveys are summarized in Árnason (1994), Árnason (2003) and Árnason and Gíslason (2009). The maximum measured hot spring temperature was 98.3ºC. The chemical composition of the hot spring water suggests that this water is contaminated by magmatic fluid and that the reservoir has a temperature of about 120-150ºC. Isotope surveys predict a higher temperature of 200ºC. The highest thermal gradient determined from drilling was about 31ºC/km. BGR undertook further work under their GEOTHERM project beginning late in 2004, which included DC resistivity, TEM, and gravity and microearthquake measurements (Ochmann et al 2010; BGR, 2007). All these results lead to the conclusion that the most suitable area is confined within a fault zone and should be investigated further with deep drilling. GIDS Consult Limited obtained the exploration license for this area in 2011.

The Katwe-Kikorongo geothermal prospect area is situated in Queen Elizabeth National Park. Geothermal manifestations occur in the Kitagata Crater. Various surveys have been carried out in this area. These include geological and geochemical surveys made by UNDP (Armannsson 1994) and which predicted subsurface reservoir temperatures of about 200°C, isotopic studies which predicted subsurface reservoir temperatures of 140-160°C (Bahati et al, 2005), and TEM and gravity measurements funded by ADF and ICEIDA (Gíslason et al, 2009). The World Bank funded the drilling of six shallow thermal gradient holes (about 300 m deep), and the results were analyzed by ICEIDA. Hot spring water in the area has high salinity, four (4) times more saline than seawater. These hot springs are a source of salt mining in the area at Lake Katwe. The measured thermal gradient in the shallow temperature gradient wells is also disappointingly low at about 15-36ºC/km. Given the low temperatures encountered in all three drilled areas, there was general doubt whether the shallow thermal gradient wells could be relied on to predict temperatures at the main exploitable depth of 2000-3000 m. Cozumel Energy Ltd acquired the exploration licenses for the western part of this area in 2010, while the exploration license for the eastern part was acquired by Katwe Geothermal Power Project Limited in 2011.

The Panyimur area is located near the northern tip of Lake Albert. Preliminary geological, geochemical, magnetic and gravity surveys have been conducted in this area by GSMD since 2011, under the ongoing 3-year "Uganda Geothermal Resources Development Project (No. 1199)" funded by the Government of Uganda. The area initially attracted attention when several oil exploration wells were found to have a high temperature gradient. The temperatures of hot springs found in the area are 35-60ºC and they are high in hydrogen sulphide gas (Bahati, 2012). The geothermometers of these waters predict a reservoir temperature of 100-140ºC. Pawakom International Limited received the exploration license for this area.

Realizing that Uganda was not receiving any assistance from donors for geothermal development after the BGR survey at Buranga in 2006, the Government of Uganda decided to fund on its own the Uganda Geothermal Resources Development Project (1199), which commenced in 2011. Under this project pre-drilling studies have concentrated mainly on four geothermal resource sites; Kibiro, Katwe, Panyimur, and Buranga (Table II-1). Although Exploration Licenses have been granted to private companies for these four fields, no effective exploration has been conducted by them. Consequently, DGSM is conducting geoscientific studies in the four fields in anticipation of reacquiring exploration rights to the areas from the IPPs due to non-performance. The recent mapping has identified thermal manifestations which had not been previously discovered and which imply that these systems are larger than previously thought. Review of airborne magnetic data acquired under the Sustainable Management of Mineral Resources Project, which covers a large part of the country, has identified low magnetic areas believed to be associated with geothermal systems at Kibiro, Katwe-Kikorongo and Panyimur. Structural analysis using DTM images, and Environmental Baseline Studies have been carried out, particularly at Kibiro for the latter. In addition, DGSM is also carrying out geoscientific studies in other geothermal prospects under this project, though they are of limited extent.

Table II-1 Present status of geothermal exploration by the Government of Uganda

Site	Airborne data interpretation	Ground magnetic & gravity surveys	Geological Mapping	Geochemistry & Isotopic studies	Environmental Baseline studies
Kibiro	Undertaken	Completed, MT recommended	Completed but incremental improvements can be made. Hydrothermal alteration studies undertaken	Sufficient data collected	On-going
Katwe	Undertaken	Pending	Completed but incremental improvements can be made	Sufficient data collected	On-going
Panyimur	Undertaken	A few line kilometers covered and group is planning for more exploration	Completed but incremental improvements can be made	Sufficient data collected	Pending
Buranga	Undertaken	A few line kilometers covered	On-going, surface manifestations quite extensive.	Sufficient data collected	On-going

(Study team prepared based on DGSM data. as of August 2013)

Since the IPPs are still having the licenses over the four most promising geothermal areas, the geological and geochemical survey in this JICA study targeted other areas with a view of finding whether there exists other sites which could equally be promising for further detailed studies.

II-4-2 Geothermal Licenses

The Government of Uganda started issuing geothermal Exploration Licenses under the Mining Act in 2010, when the first license was issued to Cozumel Energy (U) Limited at Katwe. Currently a total of ten (10) Exploration Licenses have been granted to eight private companies (Fig. II-2, Table II-4). In May 2013, one of these companies, Katwe Geothermal Power Project Ltd, in a joint venture with AAE Systems Inc, was granted a Power Purchase Agreement (PPA) of 8.0USCts/kWh to develop an initial 150MW. However, it appears that no effective exploration work has been undertaken by these private companies, as required by the law. It seems that, as happened in Tanzania as well, the licenses were acquired for speculative purposes only. Due to the slow progress of development by these companies, DGSM intends to carry out exploration activity itself in these licensed fields after the expiry of the licenses. It is understood that DGSM has stopped issuing any new geothermal exploration licenses. It also plans to terminate the Morbege Finance Ltd license at Kibiro because the ARGeo Project is ready to send its team of experts to carry out a detailed survey in October 2013. Notice to terminate the license has already been issued, but the license holder has not responded. A second Notice was to be issued before termination could be completed. Clean Source Energy Partners Ltd has indicated that it is willing to terminate its Yumbe license, as it has found that there are no geothermal manifestations in that area. It did, however, obtain a new license at Amuru in May 2013. FCN Energy Ltd was the last IPP to receive an exploration license, on 23rd May 2013, but it has not undertaken any work, either.

The 2009 Least Cost Master Plan for power expansion formulated by Parsons Brinckerhoff (PB 2009) calls for 90MW from geothermal to be installed between 2021 and 2023 (30MW per year), allowing plenty of time for the country to carry out exploration, drilling and power development and also to develop the relevant technical capacity. In order to promote investment in renewable energy, in June 2012 ERC published Developments and Investment Opportunities in Renewable Energy Resources in Uganda (ERC, 2012). The government policy for renewable energy is to make modern renewables a substantial part of the energy mix. In this regard, the policy is to increase the use of renewables from the current 4% to 61% by 2017. The renewable energy potential in the country which can be called upon to achieve this policy goal totals about 5,300MW, as given in Table II-2 below.

Table II-2 Renewable resources potential in Uganda

	Energy Source	**Estimated Potential (MW)**
1	Hydro	2,000
2	Mini-Hydro	200
3	Solar	200
4	Biomass	1,600
5	Geothermal	450
6	Peat	800
7	Wind	-
	Total	5300

(ERC 2012)

The government also published feed-in tariffs (FIT) for renewable energy in order to encourage rapid investment in this sector as shown in Table II-3 below:

Table II-3 Feed-in tariff of various renewable resources

	Technology	**Tariff (US Cents/kWh)**
1	Hydro (0.5-1MW)	10.9
2	Hydro (1-8MW	9.1
3	Hydro (9-20MW)	7.9
4	Bagasse	8.1
5	Biogas	11.5
6	Land fill gas	8.9
7	Geothermal	7.7
8	Solar PV	36.2
9	Wind	12.4

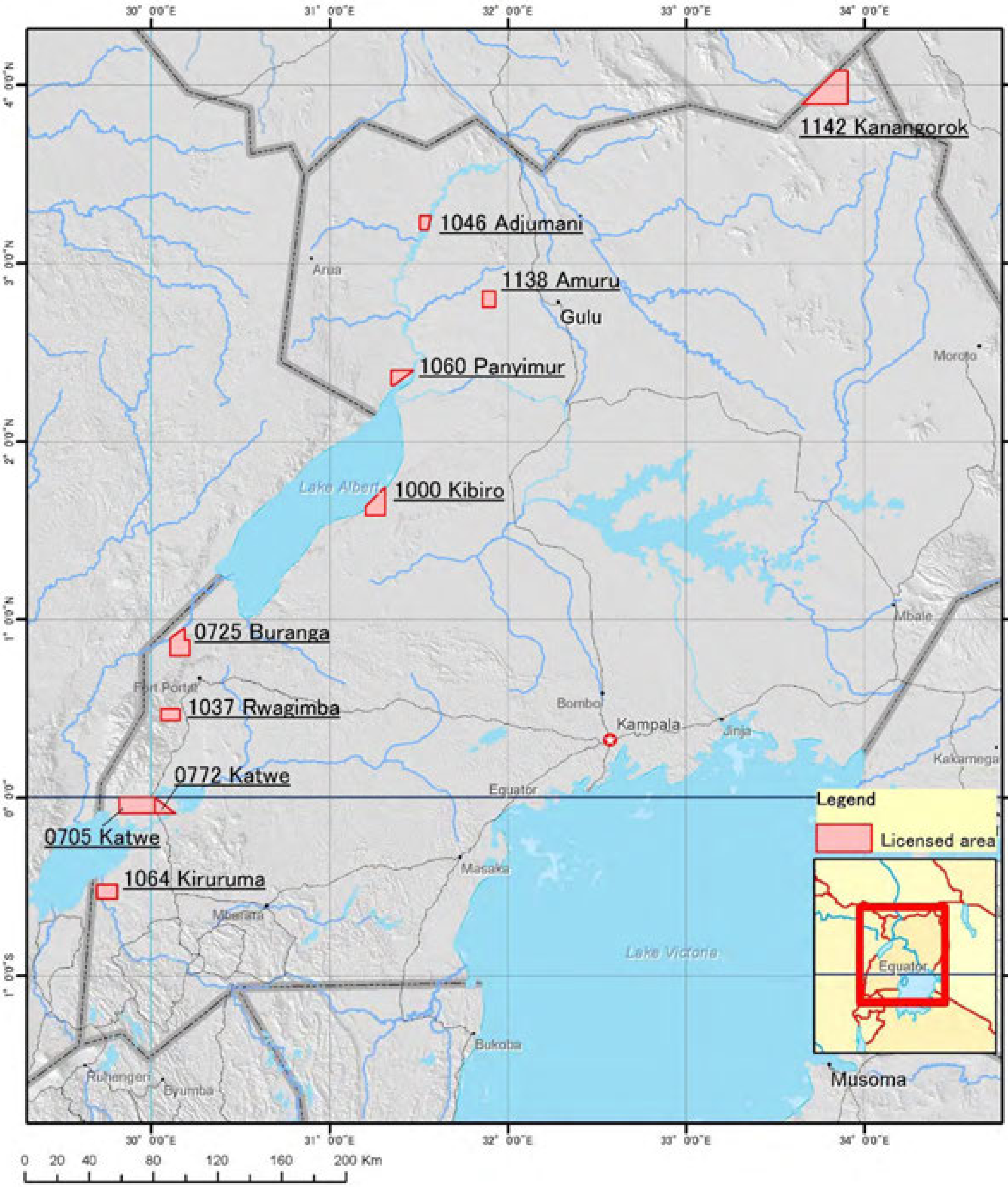
(ERC 2012)

The FIT covers geothermal generation up to 20MW. Plants larger than this will require a negotiated price. There would be 20-year PPA between the generator and Uganda Electricity Transmission Company Limited (UETCL).

The purpose of FITs is to encourage and support greater private sector participation in renewable power generation. Some of the risks addressed in the FIT are:

- Automatic grid interconnection and pricing flexibility
- Off-take risks for a 20-year period addressed through a PPA with UETCL
- Price and currency risks which are borne by the UETCL through long-term PPAs.
- Hedging against inflation risks is provided through escalation factors
- Gains in Certified Emission Reduction (CERs) when sold.

It is understood that geothermal power can be taken up by the system as soon as it is available, without regard to the National Power Master Plan.



(Study team)

Fig. II-2 Location of the licensed geothermal areas

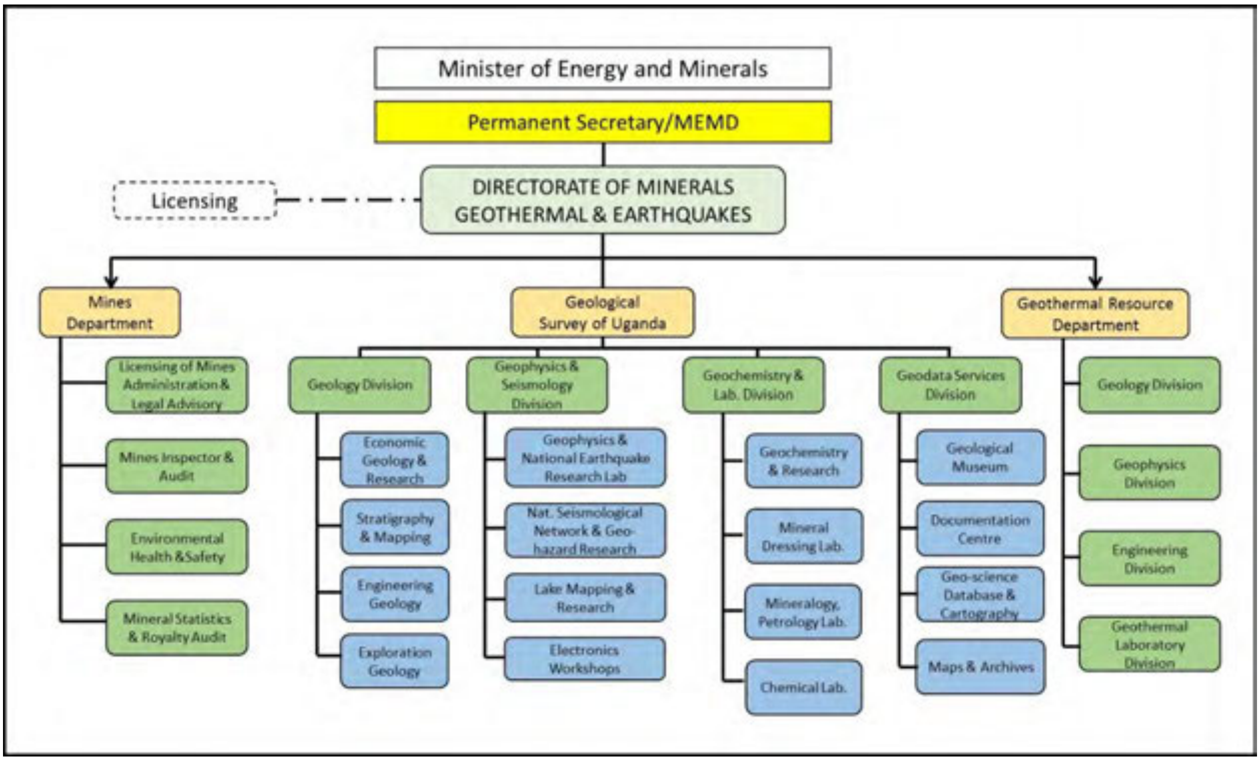
Table II-4 Licensed Geothermal areas

Number	License Holder	Field	Effective Date	Expiry Date
0705	Cozumel Energy (U) Limited	Katwe	2010.11.29	2013.11.28
0725	Gids Consults Limited	Buranga	2011.2.10	2014.2.9
0722	Katwe Geothermal Power Project Ltd	Katwe	2011.6.27	2014.6.26
1000	Moberge Finance Ltd	Kibiro	2012.7.24	2015.7.23
1037	Clean Source Energy Partners Ltd	Rwagimba	2012.8.20	2015.8.19
1046	Clean Source Energy Partners Ltd	Adjumani	2012.9.4	2015.9.3
1060	Pawakom International Ltd	Panyimur	2012.10.15	2015.10.14
1064	Ascot Associates	Kiruruma	2012.11.23	2015.11.22
1138	Clean Source Energy Partners Ltd	Amuru	2013.5.2	2016.5.1
1142	FCN Energy Ltd.	Kanangorok	2013.5.23	2016.5.22

(Study team prepared based on DGSM data. as of August 2013)

II-4-3 Establishment of Geothermal Department

The Government of Uganda realizes that in order to move forward with geothermal development more effectively, there is a need to restructure the relevant authorities. The Government has decided to form a department to handle geothermal development by forming a new Directorate of Minerals and Geothermal Resources (Fig. II-3), The Directorate will have three departments: one for geological surveys, another for Mining and a third for Geothermal Resources. The plan has yet to be put into operation, but a meeting was held with the Public Service Commission to discuss the final details of the new structure. The current staff with geothermal training in the Department of Geological Survey and Mineral Development (DGSM) at Entebbe will be absorbed into the new department of Geothermal Development. Staffing of the department will then be increased as the workload increases and more geothermal resources are developed. It was understood that the Directorate will be established in the current 2013/2014 fiscal year. In addition to conducting geothermal studies (MT geophysical survey equipment will be procured this year), the new Geothermal Resources Department will prepare a legal framework suitable for geothermal development, issue geothermal Exploration Licenses under the new law and develop a clear geothermal development roadmap. The Exploitation Licenses will be handled by the Department of Energy, whereas PPAs will be handled by ERA. In order to do this, the Government will certainly need both financial and technical assistance from donors to augment the local funding available for its annual budget.



(DGSM)

Fig. II-3 Proposed Organization structure of the new Directorate of Minerals and Geothermal Resources.

II-4-4 Support from International Institutions

The present status of support by other donors is as follows:

- The DGSM submitted a request to AfDB in December 2012 for US$ 51.865m to fund geothermal exploration work, and is still waiting for a response. The funds were to cover detailed exploration work in the four priority sites of Katwe, Buranga, Kibiro and Panyimur, particularly MT surveys, the drilling of three deep exploration wells in the most promising site, the installation of a 5MW wellhead generator, the development of legal and policy frameworks for the country and the training of staff.
- The ICEIDA – the World Bank is considering the possibility of providing a geothermal exploration grant of US$700,000 from its Compact project funds for extra work in Katwe on condition that the Katwe licenses already issued should be terminated.
- ARGeo-UNEP is planning to carry out a geothermal exploration project in Kibiro geothermal prospect. UNEP and DGSM held a workshop in Entebbe to review currently acquired data and identify uncertainties and data gaps in order to design a new project proposal for funding. The assistance was on condition that the current exploration License to Morbege Financial Ltd is terminated.
- Uganda is one of the East African countries covered by the GRMF managed by AUC from Addis Abba. GRMF is funded by BMZ (EUR 20million) and the EU-Africa Infrastructure

Trust Fund (EUR 30million). Uganda did not submit any proposal for consideration in the first round, in which US$22m was approved for three drilling and one surface exploration projects. GRMF has now increased the number of countries eligible for GRM assistance to 11 countries, and total spending of USD 163million (Mayer 2013) is expected to be allocated in the second and third round of applications, if all the projects are approved. In the second and third rounds, Uganda is expected to submit four surface exploration proposals for Katwe, Buranga, Kibiro and Panyimur and one drilling proposal for Kibiro.

- UNUGTP, KenGen and GDC continue to sponsor Ugandans for the 4-week short courses held in Kenya since 2005. UNUGTP offers a 6-month geothermal course in Iceland. Admission to both these courses is granted upon submission of suitable candidates by the recipient countries.
- GIZ and USAID-East Africa Geothermal Partnership (EAGP) had indicated earlier their willingness to assist in the development of a legal and environmental policy framework. EAGP was also willing to assist American companies already holding geothermal licenses. However, nothing concrete has come of this intention.

II-5 Promising Area for Geothermal Development

II-5-1 Preliminary Survey

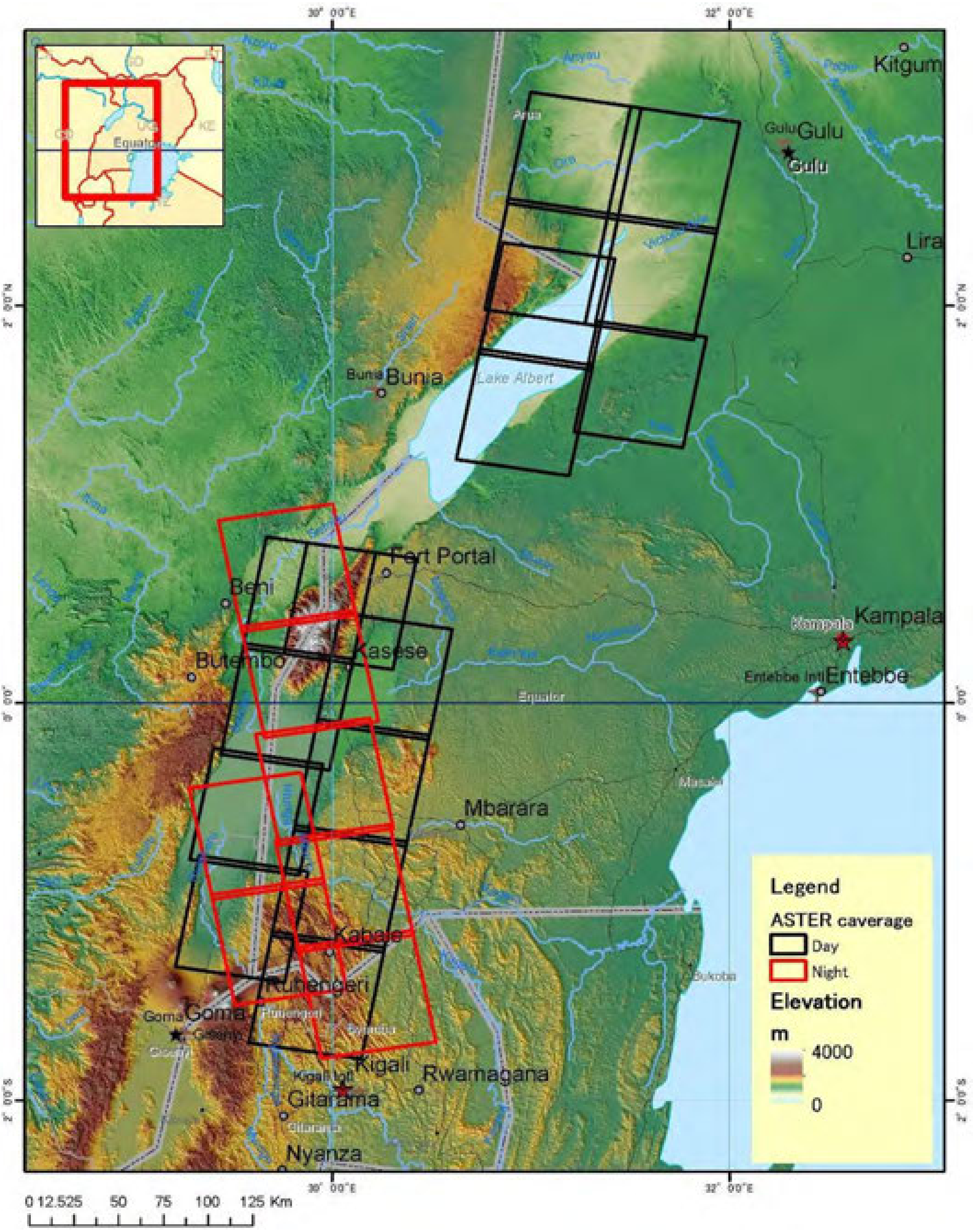
1. Remote Sensing Data Collection

a) Data Collection

Remote sensing data collected in this study are listed in Table II-5, and a coverage map of ASTER data is shown in Fig. II-3.

Table II-5 Remote sensing data collected in the Phase I study

Data used	Specification	Numbers	Remarks
LANDSAT/ETM+ Pan-Mosaic image (Optical)	-7 bands ranging from VNIR to TIR through SWIR -15m in spatial resolution	as required	USGS Earth Resources Observation and Science (EROS) Center
Terra/ASTER (Optical)	-14 bands ranging from VNIR to SWIR -15 to 90 m in spatial resolution -60 km in swath -Pointing -Stereoscopic view along track	23	Product Level1B; 16scenes 3B temperature; 7scenes From Japan Space Systems
SRTM (DEM)	-90 m in spatial resolution -Data released in 2002	as required	USGS Earth Resources Observation and Science (EROS) Center

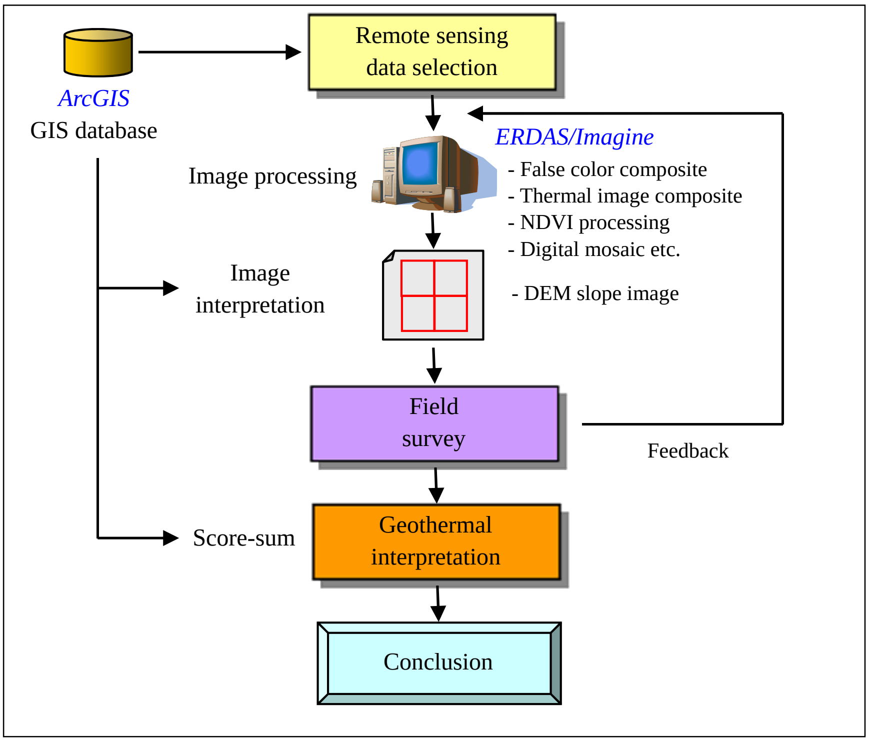


(Study team)

Fig. II-4 Coverage map of ASTER data

b) Methodology of the field survey

The methodology of the Study comprises six elements; namely, remote sensing data selection, image processing, image interpretation, field investigation, geothermal interpretation and final integration and conclusion. Series of these studies should be established through GIS database generated in this survey. A flow chart of the survey is shown in Fig. II-5.



(Study team)

Fig. II-5 Flow chart of the survey

The image data used for the Study are LANDSAT/ETM+ data and EOS/ASTER data, together with SRTM (Space-Shuttle Radar Terrain Model) data. The SRTM is a kind of DEM (Digital Elevation Model) generated from a specially modified radar system and is used to recreate the topographic features through a variety of digital processing techniques.

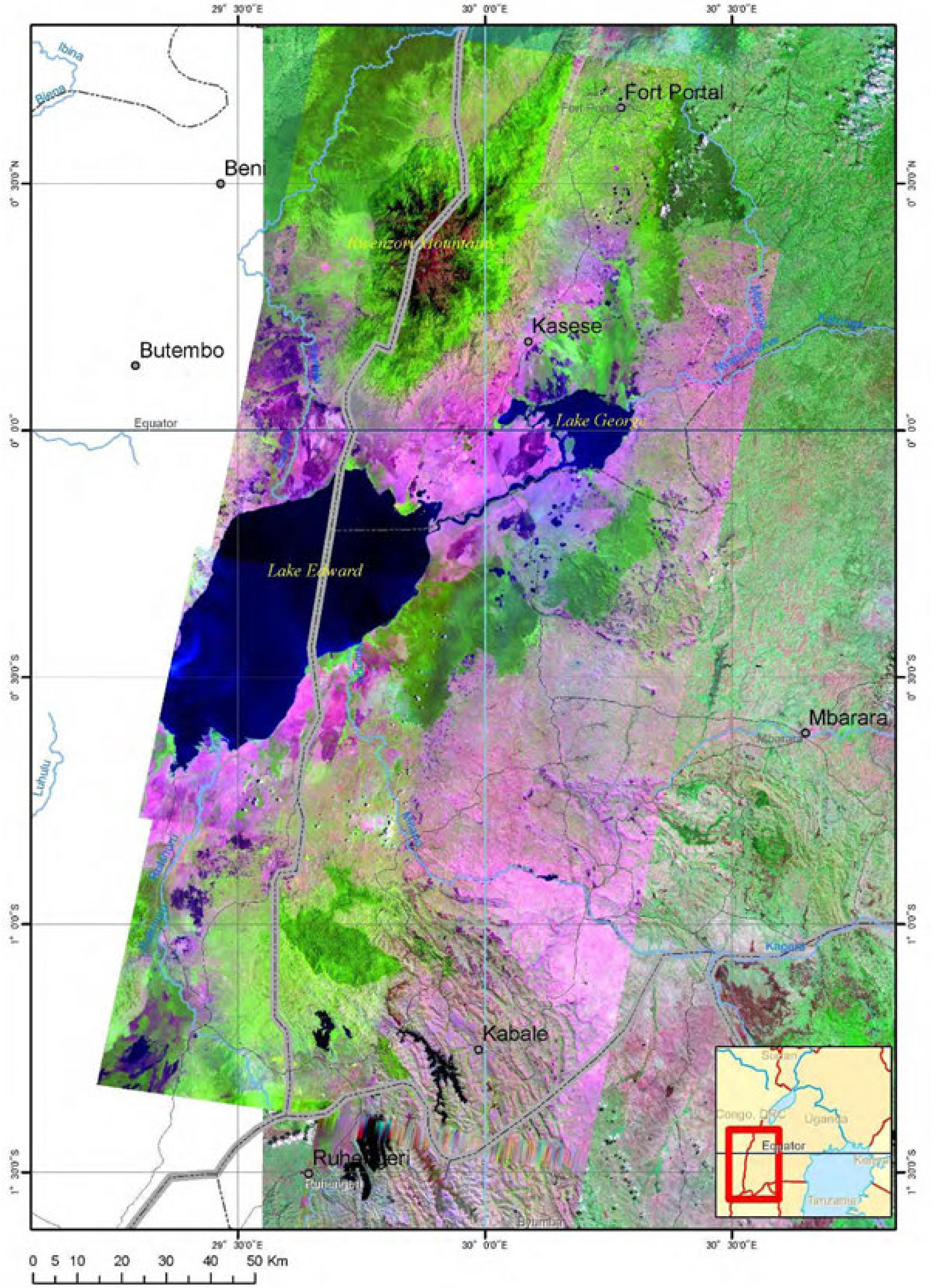
c) Processed Image Data

Processed image data of the Study are listed in Table II-6. False color composite, thermal image composite, NDVI processing and digital mosaics are the main processing techniques applied to the original images. The false color image is a composite using the appropriate 3 bands assigned the color blue, green and red (Fig. II-6). NDVI (Normalized Difference Vegetation Index) is one of the techniques used to the enhance the presence of vegetation in the images (Fig. II-7). The thermal image is generated from ASTER Level 2B03 product which clarifies surface kinetic temperature data (Fig. II-8). Higher temperature is generally expressed by a higher grey level in the images.

On the other hand, SRTM is processed by calculating slope values in each 3x3 rectangular window and shaded relief also (Fig. II-9 and Fig. II-10). These images are superimposed on the various false color data.

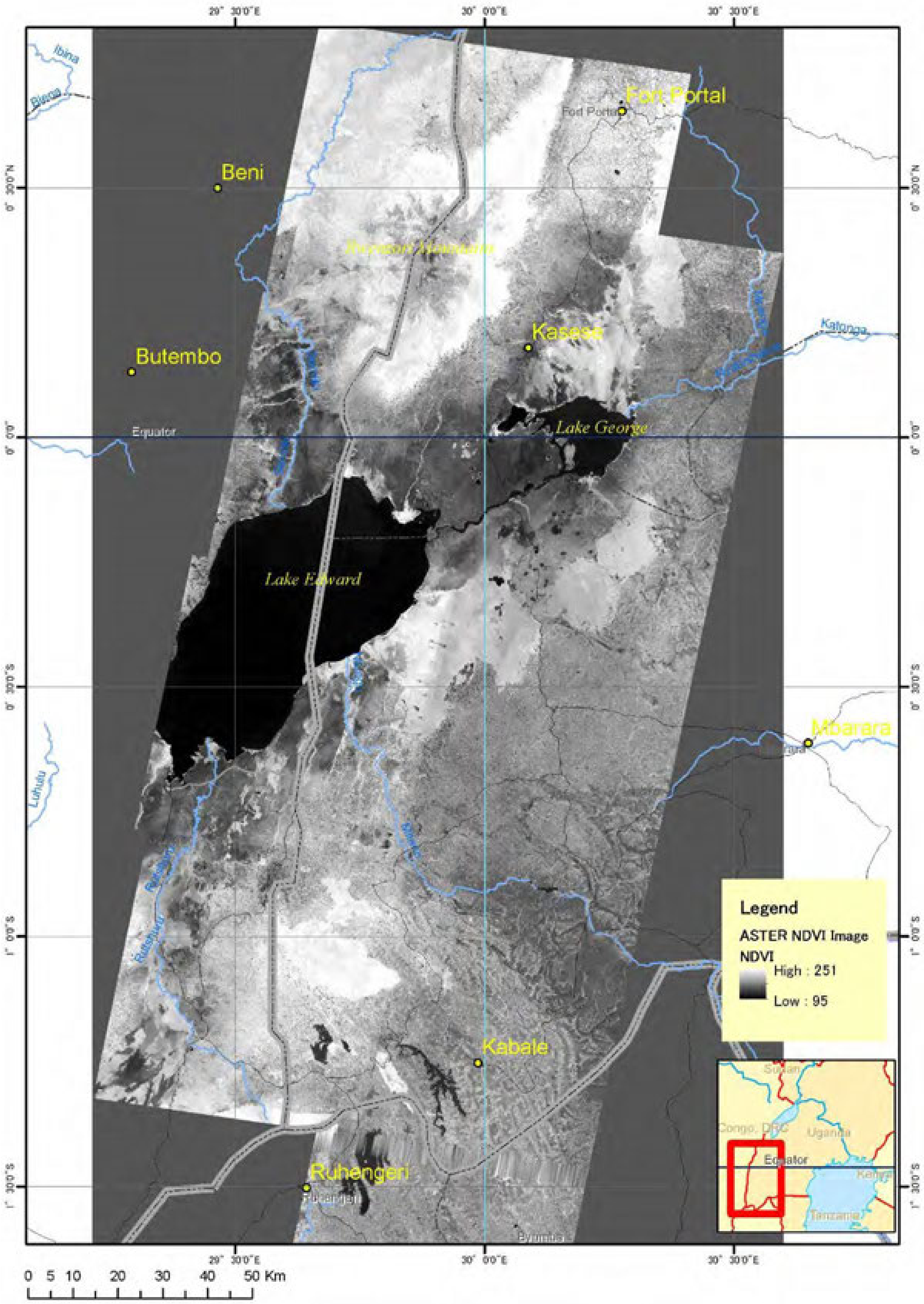
Table II-6 List of image data used

Generated imagery	Scale
ASTER false color image combined with LANDSAT/ETM+	1:250,000
SRTM slope image superimposed on ASTER false color image	1:250,000
SRTM shaded image superimposed on ASTER false color image	1:250,000
ASTER NDVI (Normalized Vegetation Index image)	1:250,000
ASTER Level 2B03 product (surface kinetic temperature)	1:250,000



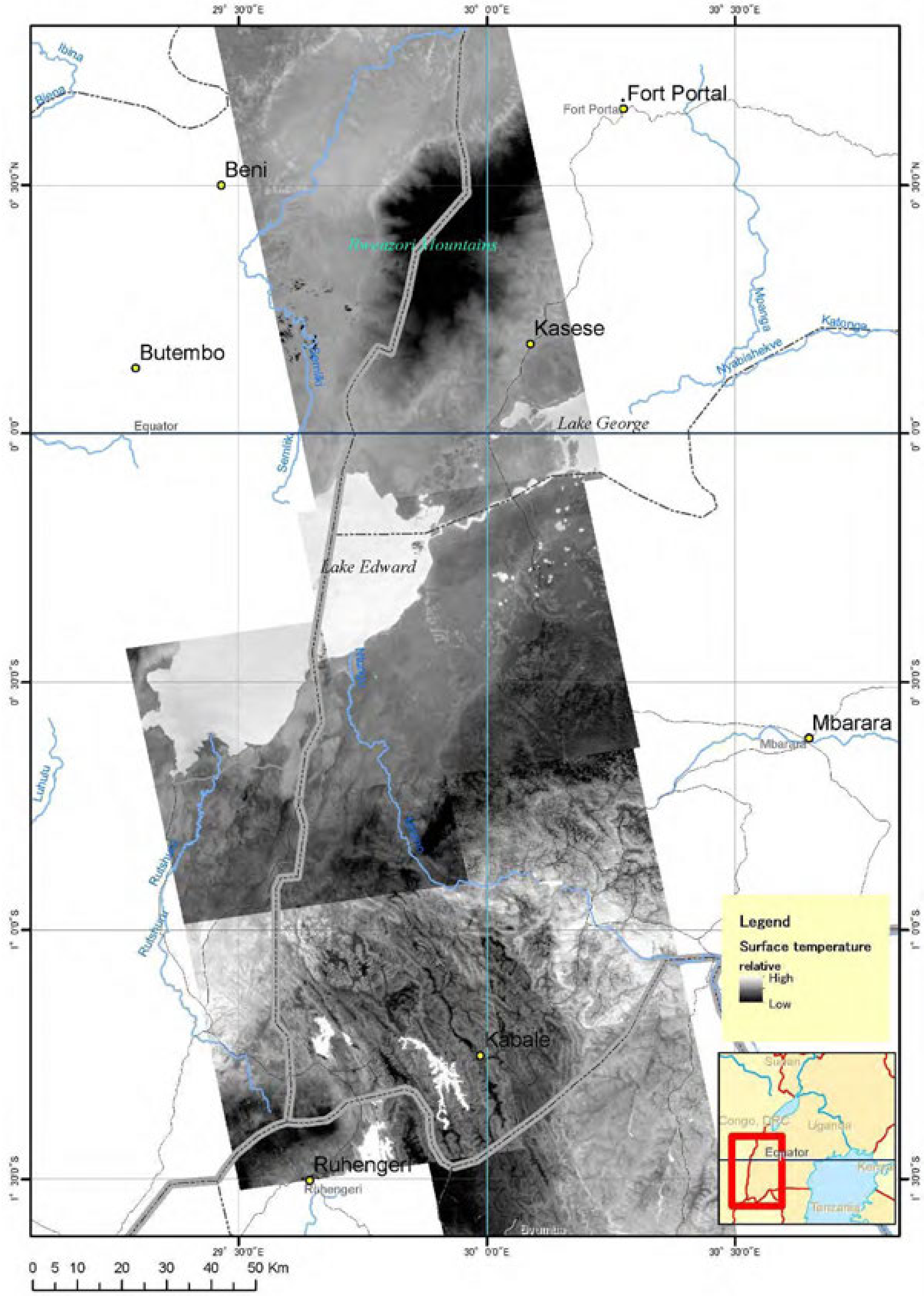
(Study team)

Fig. II-6 ASTER false color image combined with LANDSAT/ETM+



(Study team)

Fig. II-7 ASTER Normalized Difference of Vegetation Index (NDVI) Image



(Study team)

Fig. II-8 ASTER Level 2B03 product (surface kinetic temperature)

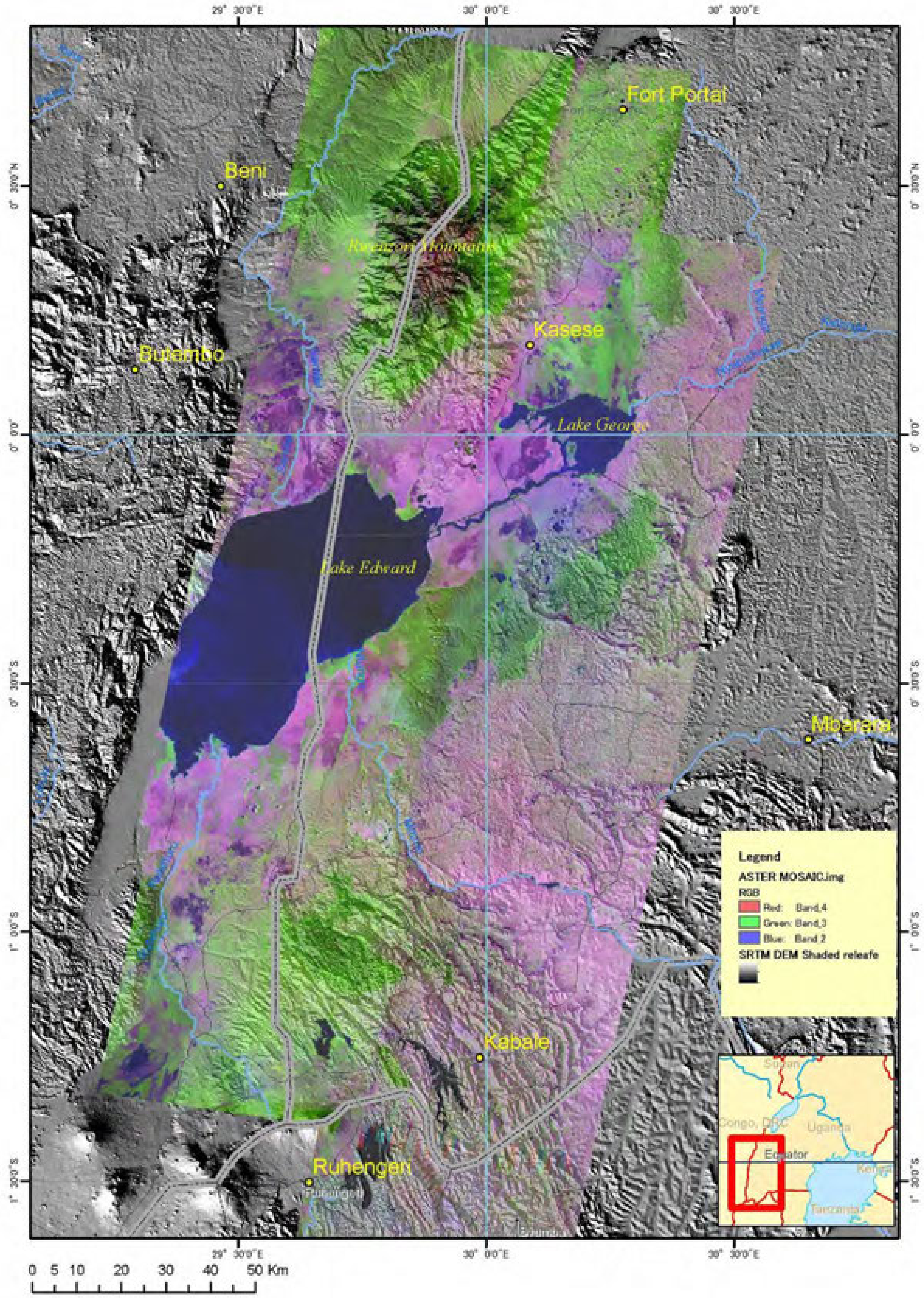


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Fig. II-9 SRTM shaded image superimposed on ASTER false color image

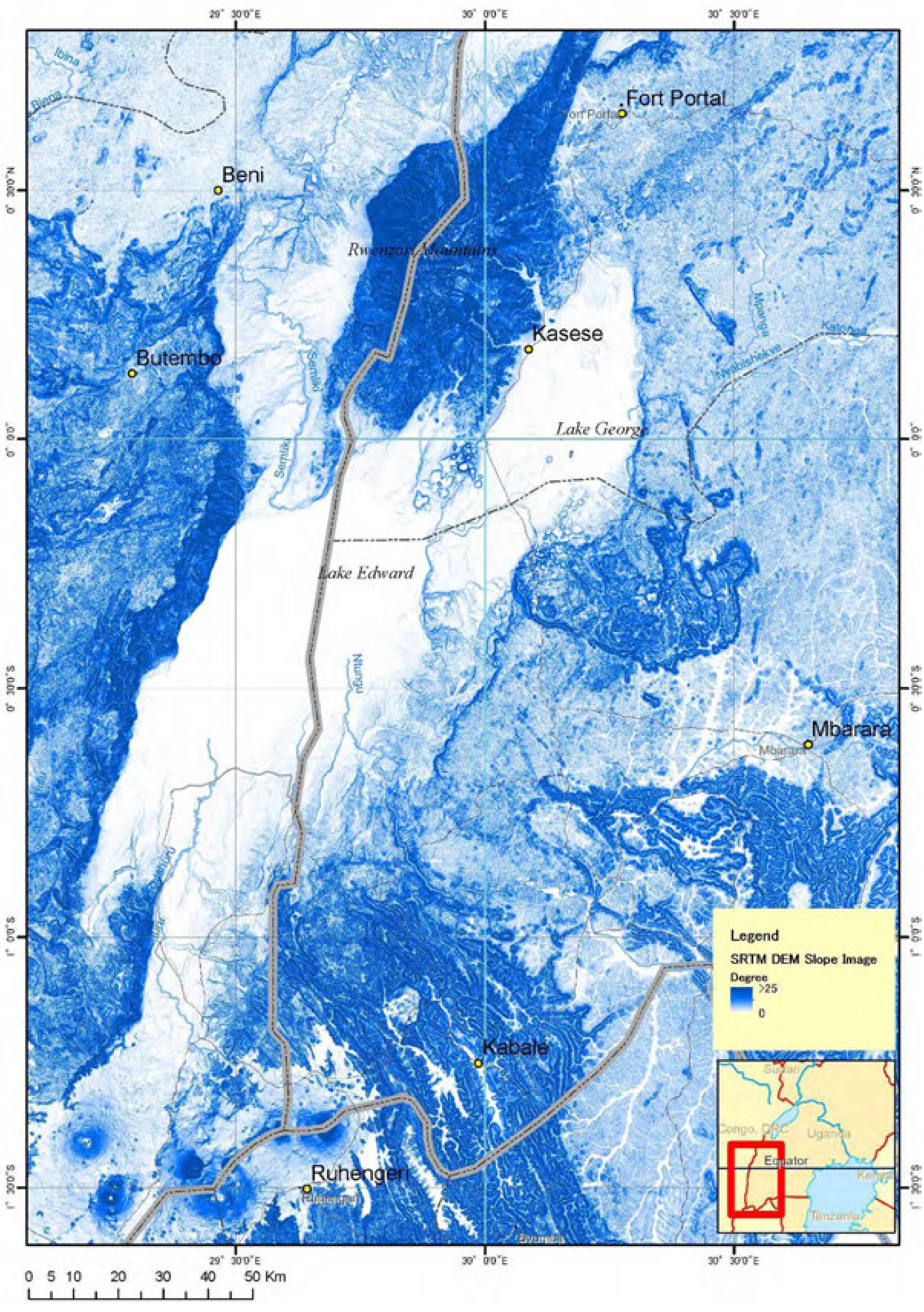

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Fig. II-10 SRTM DEM Slope Image

d) Image Interpretation

(a) Targets and Methods of Image Interpretation

1) Finding the geothermal energy potentials

Indicators of geothermal energy potential are considered through interpretation of the images. In general, the main indicators of geothermal energy potentials in the study areas are as follows:

- Heat source: Quaternary volcanic activity plays a crucial role in terms not only of thermal gradients under the surface but also of their lateral extension. In particular, areas intersected by large-scale faults may display a higher thermal gradient, indicating a heat source.
- Geological structures: relevant geological structures consist of two features, namely calderas and paths for recharging groundwater.
- Cap rock: Volcanic lava flows can form cap rock sealing a geothermal reservoir beneath them.
- Other aspects: Such categories as environmental aspects, engineering aspects, socio-economic aspects and others, are focused on.

2) Image interpretation

Image interpretation should be carried out based on the photo geological method, focusing on the following surface features:

- Distribution of Quaternary volcanic rocks over the area indicating volcanic activity including craters, lava flows, volcanic cones, etc.
- Extraction of geological structures such as lineaments related to faults.
- Identification of zones in which hot springs are active on the basis of water flow, vegetation density, high surface temperature, etc.

Other items are also important in defining geothermal development potential, such as the location of natural reserves, power lines, concessions, as well as population, accessibility, groundwater flow and so forth.

(b) Results of Image Interpretation

The geological image interpretation map of the field survey area is shown in Fig. II-10. The geological image interpretation map of Lake Albert area is shown in Fig. II-11.

The south-western area

This covers an area ranging from Kabale city to Kitagata town through Kagamba, Karungu, Bubale, Rubaare, Kisiizi, Rubabo, Birara, Minera, Ihimbo, Kanyinabarongo, Kiruruma and Kitagata hot springs.

The basement is mainly composed of metasedimentary rocks and gneiss over the entire area. The meta-sedimentary rock shows strongly folded structure extending in NNW-SSE direction. Generally, there is a tendency for the big rivers to lie on a synclinal structure and the lakes on an anticlinal structure. The gneiss is distributed in the northern part of this area, expressing a homogenous texture. Major lineaments are developed in NNW-SSE direction parallel to the folding axis, and minor lineaments also extend in an ENE-WSW direction. Some circular structures a couple of kilometers in diameter are also extracted from some parts of the basement area.

Quaternary volcanic rocks are distributed in a limited part of the westernmost area. A considerable number of volcanic cones and craters are observed in the images. Lineaments which are considered to be a marginal fault on the eastern side of the rift are clearly present in the enhanced images. The volcanic rocks are distributed successively to the further west.

The western area

This covers an area ranging from Rubirizi town to Fort Portal city through Muhokya, Kibenge, Ndugutu, Rwagimba and Rwimi hot springs.

The basement is mainly composed of gneiss and granitic rocks in the eastern part and the western part, where a series of summits of the Rwenzori Mountains forms the western border of the country. Many minor E-W and N-S lineaments, which cannot be mapped on a 1: 250,000 scale, are observed in the images. They seem to represent a structure older than Quaternary volcanism according to the existing geological maps. The Rwenzori Mountains display a very rough topographic texture, where E-W, NW-SE and NE-SW lineaments are very well developed.

The west branch of the rift is divided into two sub-branches, the eastern and western sub-branches, divided by the Rwenzori Mountains. The eastern sub-branch develops east of the Rwenzori Mountains. The N-S to NE-SW trending lineaments, which are considered to be marginal faults of the eastern sub-branch, are clearly extracted from the images, especially the DEM imagery. Muhokya, Kibenge, Ndugutu and Rwagimba hot springs are aligned in an almost N-S direction along the marginal fault. There are four Quaternary volcanic fields in this region. They are the Lake George south, Lake George west, Rwimi and Fort Portal fields. A great number of cones and craters are extracted from both the ASTER and DEM imagery. The western sub-branch, stretches out to the west of the Rwenzori Mountains and continues beyond the border of the country.

Lake Albert Area

This area covers Kibiro and Panyimur geothermal areas at side of Lake Albert. Kibiro geothermal area is located on the southeast shoreline of Lake Albert. Panyimur geothermal area is located at the west side of outlet of Albert Nile, the northernmost tip of the Albert Lake.

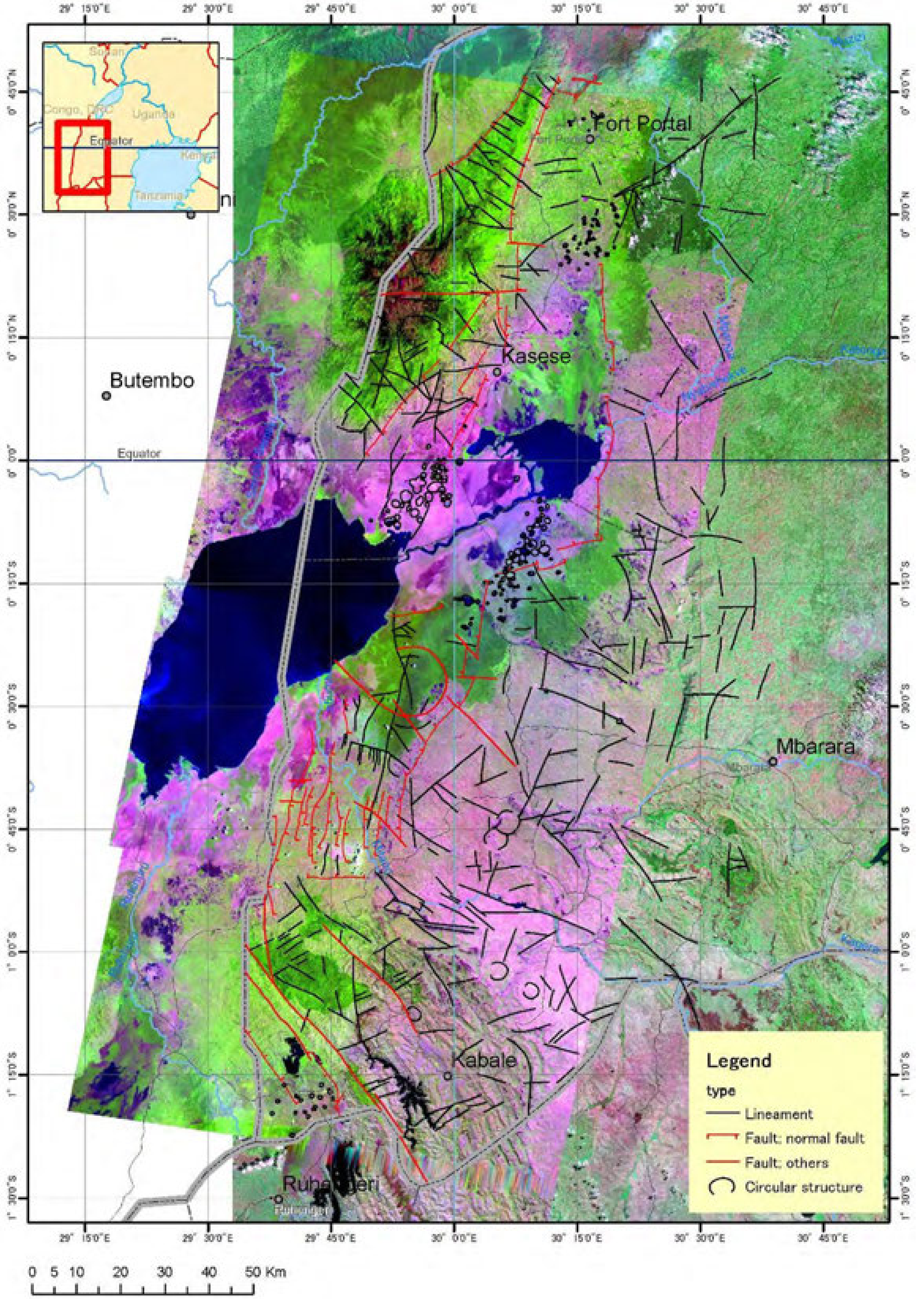
The southeast side of Lake Albert is underlain by Proterozoic meta-sedimentary rocks and, the northwest side of the lake is underlain by Archean metamorphic rocks and Proterozoic metamorphic rocks. The northeast side of the lake where rift zone is elongated is covered by Neogene and Quaternary rift related sediments. Accordingly, a low land is widespread in this northeast area.

The two major NE-SW fault escarpments which are considered to be marginal faults of Albert rift, are elongated on both side of the Lake Albert. The southeast side fault is elongated to northeast on the straight and separates the rift related sediments and the basement rocks. The southwest side fault is elongated to approximately 15km north of Panyimur and become to be unclear there.

In the southeast side area of Lake Albert, NE-SW, NW-SE, E-W, N-S trending lineaments are extracted. The NE-SW trending lineaments are parallel to the marginal fault of Albert Rift. Kibiro geothermal area is located on this marginal fault and N-S and NW-SE trending lineaments cross there.

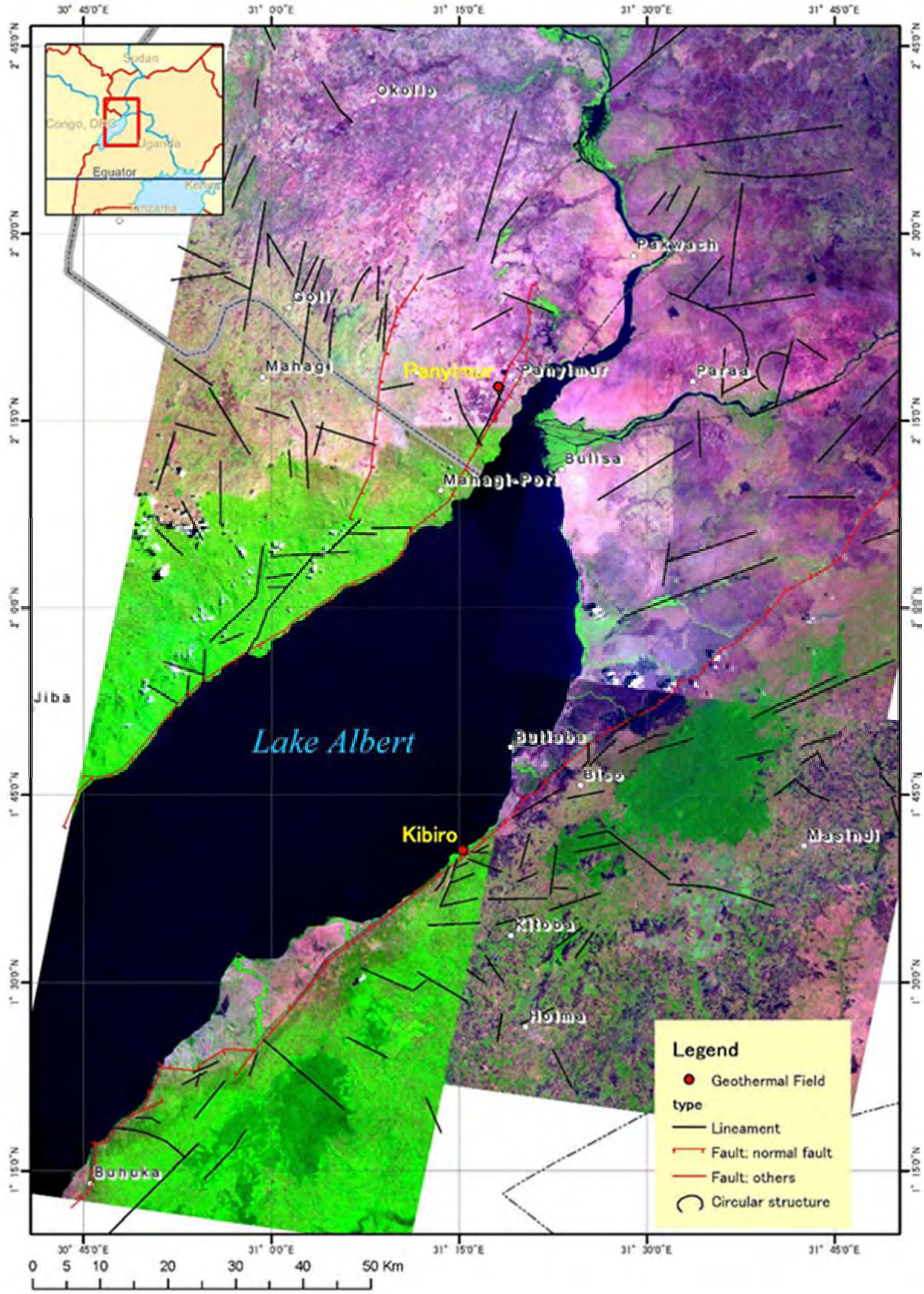
In the north side area of Lake Albert, mainly NE-SW, E-W and N-S trending lineament are extracted. In northern part of this area, N-S trending lineaments which reflect the basement structures are extracted. Panyimur geothermal area is situated in the two set of NNE-SSW marginal faults and a small lineament is developed parallel to these faults.

In Rift related sediments area northeast side of the lake, NE-SW and N-S tending lineaments are extracted.



(Study team)

Fig. II-11 Geological Interpretation Map



(Study team)

Fig. II-12 Geological Interpretation Map (Lake Albert)

2. Preliminary analysis based on the existing data

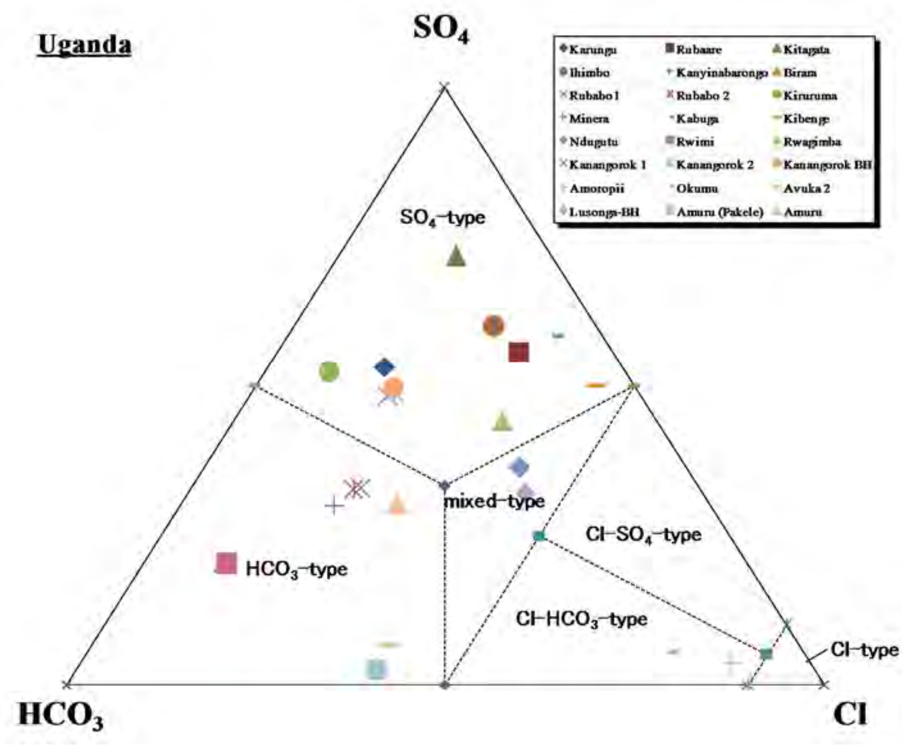
The chemical compositions of hot spring and surface water are described in the reports of Armannsson et al. (2007) supported by ISOR and those of BGR (2007). The former surveyed 28 hot springs (analyzing 24 constituents including isotopes for each hot spring) in 2005 (see Table II-10). The latter surveyed 44 hot springs in the Buranga area (analyzing about 60 constituents, including even trace elements which usually not used for geochemical analysis). It is uncertain whether a more recent survey has been conducted since these surveys or not, but we could not obtain any new chemical data. As the chemical data reported by BGR (2007) are only for hot springs in the (already licensed) Buranga area, We conducted preliminary geochemical review based on the data from Armannsson et al. (2007), covering most of Uganda (the chemical data are listed in the Appendix).

Considering the (unbalanced) charge valance between cations and anions that is reported, the reliability of analytical data from Armannsson et al. (2007) is deduced to be low. Therefore, additional geochemical surveying (water sampling and chemical analysis) is required to complete our chemical review based on the data from Armannsson et al. (2007). According to Armannsson et al. (2007), hot spring waters are mostly neutral to weak alkaline. Most of hot spring waters in Uganda are classified as HCO_3 type or SO_4 type (see Fig. II-13). It is well known that hot spring water affected by deep reservoir fluid is usually Cl-type, Cl-HCO_3 type or Cl-SO_4 type, but there is no sample classified as one of these types. However, one sample from the Rwagimba area shows a relatively high Cl concentration (exceeding 200mg/L), and its discharging temperature exceeds 60ºC (see Fig. II-14). This raises the possibility that the Rwagimba area is an area with geothermal potential. On the other hand, the Cl concentrations of samples from the Lusonga and Ndugutu areas are quite high (exceeding 3,000mg/L). These high Cl concentrations may result from evaporation (with possible heating of the high salinity water after evaporation).

Applying geothermometry based on the chemistry of hot spring water, the following areas are temporarily designated as promising areas on the basis of their geothermometric temperatures (estimated reservoir temperatures for all samples are given in Appendix): Rubaare (134ºC to 140ºC), Kitagata (120ºC to 140ºC) and Kanangorok (140ºC to 160ºC). There is no description of the chemistry of hot spring water in the Katwe, Kikorongo, Buranga or Kibiro areas in Armannsson et al. (2007). However, these are already licensed areas.

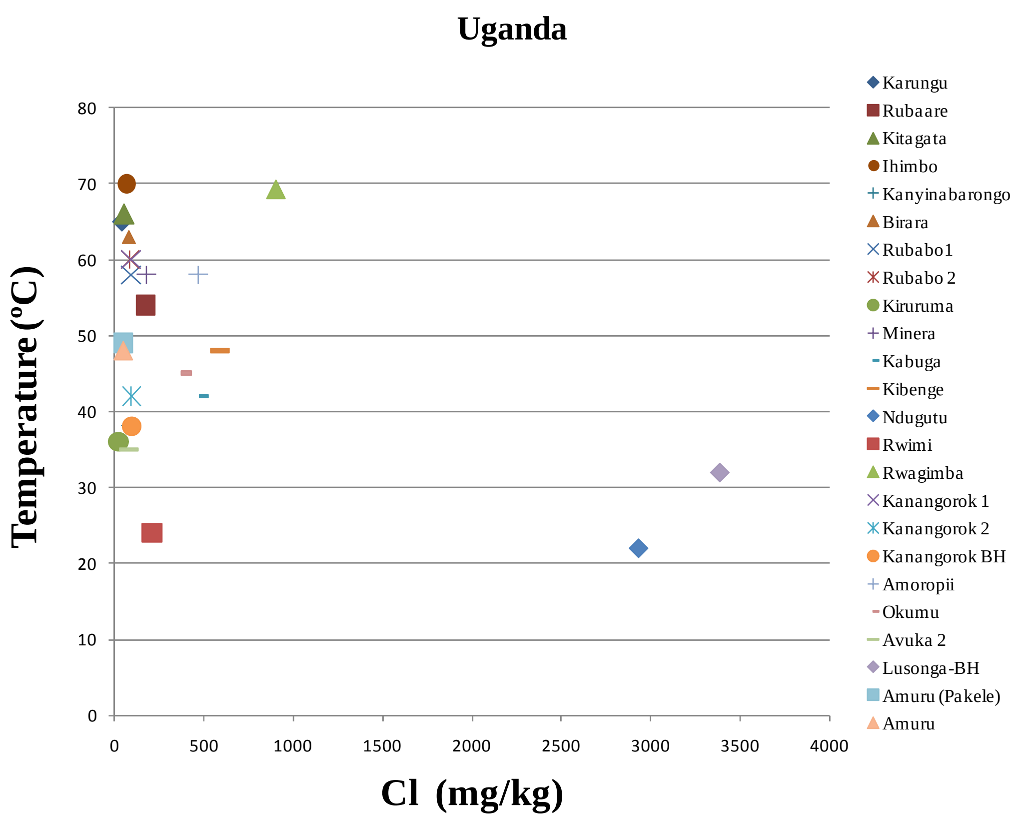
Table II-7 Referenced existing hot spring chemical data

Reference	Sampled year	Analyzed constituents	Sampled area	Reliability of data
Armannsson et al. (2007)	2005	24 constituents including isotope	28 hot springs all over Uganda	Charge imbalance
BGR(2007)	Around 2006	64 constituents including trace elements	44 hot springs in Buranga	Almost no problem



(Created from Armannsson et al., 2007)

Fig. II-13 Ternary diagram of major anions of hot spring water in Uganda



(Created from Armannsson et al., 2007)

Fig. II-14 Cl-temperature diagram of hot spring water in Uganda

3. Selection for the field survey

Based on the existing data concerning discharge temperatures of hot springs and reservoir temperatures estimated from chemical analysis, promising geothermal areas are selected. Geothermal hot spring areas with a discharge temperature greater than 50ºC are shown in Table II-8. Leaving out those hot springs in geothermal licensed areas, the following are singled out: Ihimbo, Kitagate and Karungu in the Albert rift area (Fig. II-15). Based on the website of the Ministry of Foreign Affairs of Japan, there seem to be no security problems with the above areas, and the JICA study team should be safe during the field survey.

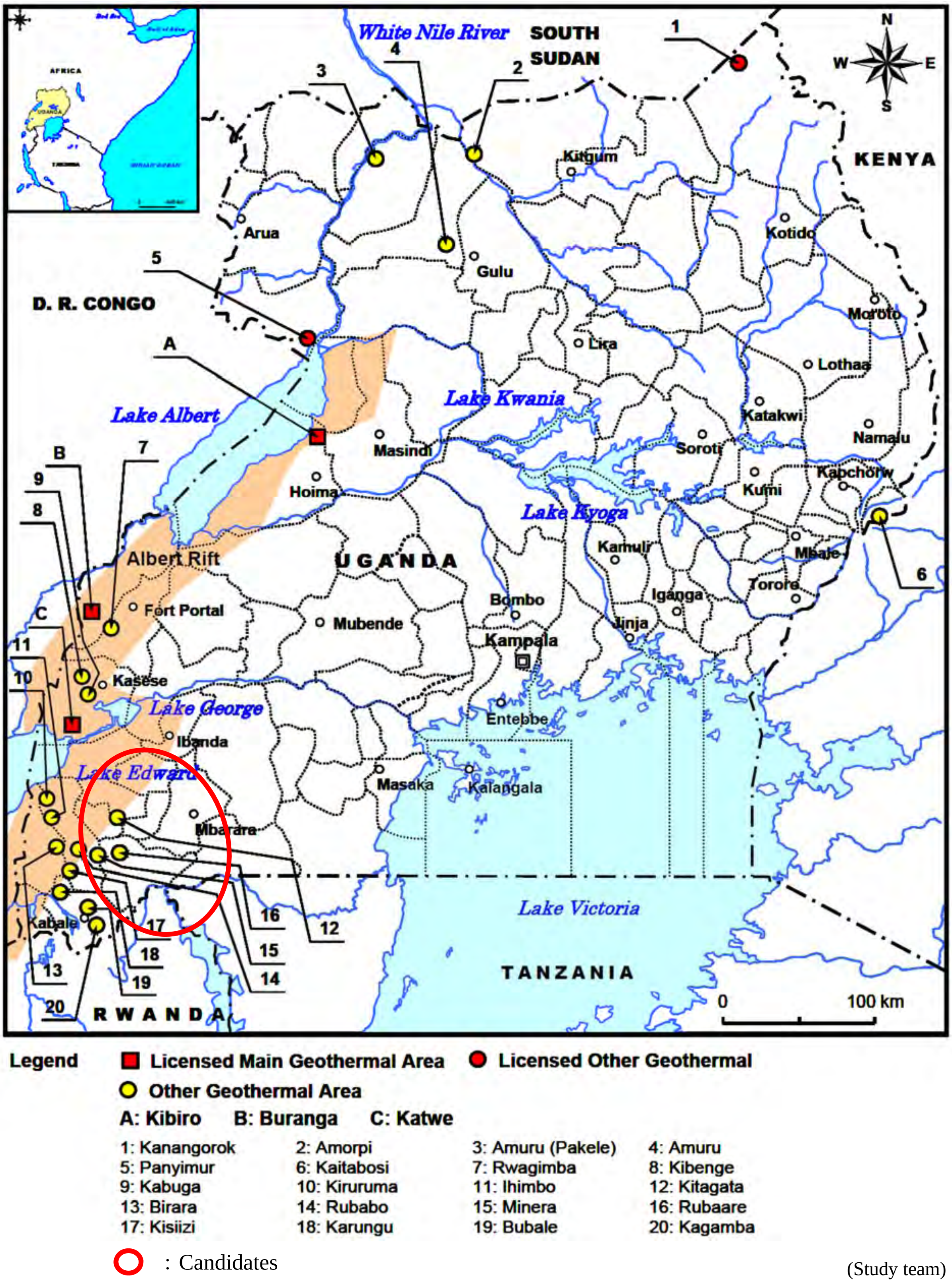
Table II-8 Temperature of Geothermal Areas (Uganda)

Location	**District**	**Discharging Temperature (^oC)**	**Estimated Reservoir Temperature (^oC)*1**	**Remarks**
Kibiro	Hoima	86.4	150, 200 - 220*2	Licensed
Ihimbo	Rukungiri	50 - 70	52	
Rwagimba	Kabarole	69.2	85	Licensed
Kitagata	Bushenyi	66	91	
Karungu	Kabale	34.4 - 65	71	
Birara	Rukungiri	63	109	
Rubabo	Rukungiri	58 - 60	94.9 - 96.9	
Kanangorok	Kotido	38 - 60	111.6 - 119	Licensed
Minera	Rukungiri	58	99	
Amoropi	Kitung	58	82	
Rubaare	Ntungamo	54	112	

Reservoir temperature is estimated by geothermometer applying chemistry of hot spring water
Geothermal areas are listed in order of temperature, where measured highest temperature of hot spring is higher than 50^oC

*1: Silica Temperature (Chalcedony)

*2: Silica Temperature (Quartz)



(Study team)

Fig. II-15 Candidates for geothermal field surveys in Uganda

II-5-2 Field Survey

1. Field survey

The areas visited in the survey had been selected for their geothermal potential in the first year stage of the study based on the existing data. These areas were also discussed with MEMD and DGSM. One area located inside a national park was eliminated at JICA's request, but no areas were eliminated because of JICA's security regulations. The list of sites visited in the field survey is shown in Table II-9. The location map of hot springs visited in the field survey is shown in Fig. II-16.

The sample lists for water and rock are shown in Table II-10 and Table II-11, respectively. Temperatures were measured with a thermistor thermometer, and then pH and electric conductivity were measured with a portable pH meter and electric conductivity meter, respectively.

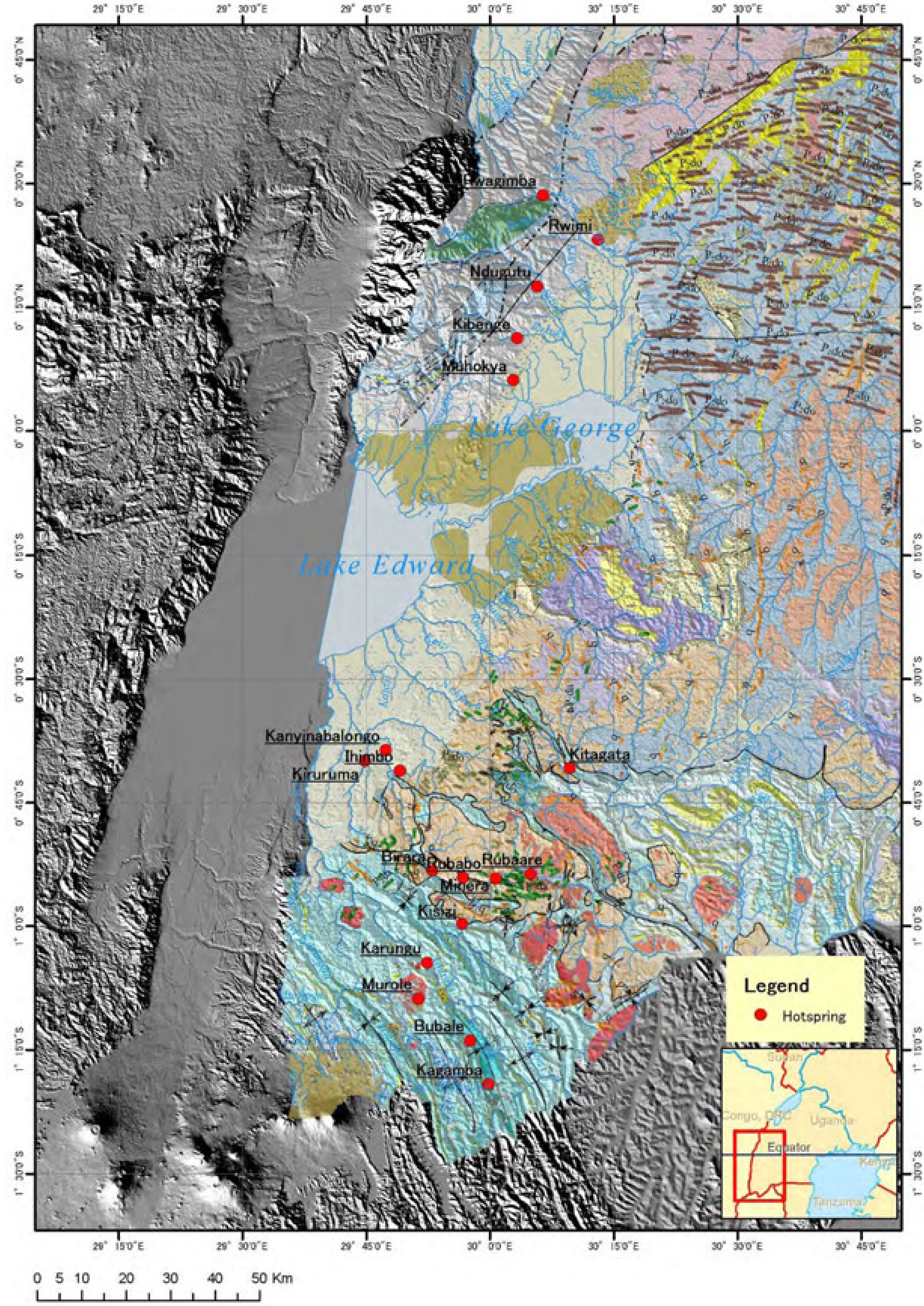
The features of each hot spring location are described as follows:

Table II-9 List of site visited in the field survey

Location No.	Date	Place	District	Longitude	Latitude	Elevation	Geology
				degree(E)	degree(N)	m	
Ka01	9-Oct	Kagamba	Kabale	29.99716	-1.32024	1805	Meta-sediments
Kr01	9-Oct	Karungu	Kabale	29.87281	-1.07401	1831	Meta-sediments
Bu01	9-Oct	Bubale	Kabale	29.95998	-1.23178	1811	Meta-sediments
Mu01	9-Oct	Murole	Kabale	29.85442	-1.14709	1971	Quaternary volcanics
Ru01	9-Oct	Rubaare	Ntungamo	30.08225	-0.89426	1377	Granitic rocks
Ki01	10-Oct	Kisiizi	Rukungiri	29.94384	-0.99533	1662	Meta-sediments
Rb01	10-Oct	Rubabo	Rukungiri	29.94488	-0.90198	1309	Granitic gneiss
Bi01	10-Oct	Birara	Rukungiri	29.88278	-0.88771	1288	Meta-sediments
Mi01	10-Oct	Minera	Rukungiri	30.01129	-0.90385	1344	Gneiss
Ih01	11-Oct	Ihimbo	Rukungiri	29.81719	-0.68512	1019	Quaternary sediments
Kn01	11-Oct	Kanyinabalongo	Rukungiri	29.78933	-0.64318	989	Quaternary sediments
Km01	11-Oct	Kiruruma	Kanungu	29.74691	-0.66558	1013	Quaternary sediments
Kt01	11-Oct	Kitagata	Sheema	30.16074	-0.68038	1478	Gneiss
Mh01	12-Oct	Muhokya	Kasese	30.04698	0.10264	1001	Quaternary sediments
Kb01	12-Oct	Kibenge	Kasese	30.0546	0.18739	1071	Gneiss
Nd01	13-Oct	Ndugutu	Kasese	30.09586	0.29324	1230	Gneiss
Rw01	13-Oct	Rwagimba	Kabarole	30.10631	0.47695	1556	Gneiss
Rm01	13-Oct	Rwimi	Kabarole	30.21778	0.38668	1109	Quaternary sediments

Map Datum: WGS 1984

(Study team)



(Study team)

Fig. II-16 Location Map of Site Visits

Table II-10 Water chemistry data from the field survey

sample name	date	place	air temp	water temp	pH	EC
			℃	℃	- (℃)	mS/m
Ka01	9-Oct	Kagamba	17.4	28.4	7.1 (29)	50
Kr01	9-Oct	Karungu	22.0	61.7	6.7 (59)	86
Bu01	9-Oct	Bubale	20.0	29.5	6.1 (29)	76
Ru01	9-Oct	Rubaare	19.5	52.0	7.3 (52)	165
Ru02	9-Oct	Rubaare	-	52.0	-	-
Ki01	10-Oct	Kisizi	21.5	29.1	7.4 (29)	32
Rb01	10-Oct	Rubabo	22.0	57.5	7.0 (53)	124
Bi01	10-Oct	Birara	23.4	61.0	6.7 (50)	141
Mi01	10-Oct	Minera	24.0	56.2	6.9 (49)	240
Mi02	10-Oct	Minera	24.0	42.3	7.0 (25)	240
Mi03	10-Oct	Minera	-	55.0	-	-
Ih01	11-Oct	Ihimbo	22.0	69.0	8.7 (61)	98
Ih02	11-Oct	Ihimbo	-	67.3	8.7 (59)	98
Kn01	11-Oct	Kanyinabalongo	31.6	36.3	6.7 (36)	104
Km01	11-Oct	Kiruruma	-	36.0	7.3 (35)	112
Km02	11-Oct	Kiruruma	-	33.0	-	130
Kt01	11-Oct	Kitagata	21.4	64.0	7.7 (57)	118
Mh01	12-Oct	Muhokya	22.3	42.0	7.2 (42)	360
Mh02	12-Oct	Muhokya	-	37.6	-	410
Mh03	12-Oct	Muhokya	-	40.0	7.2 (39)	350
Kb01	12-Oct	Kibenge	25.0	46.6	7.2 (46)	370
Kb02	12-Oct	Kibenge	-	44.0	-	-
Kb03	12-Oct	Kibenge	-	42.3	7.3 (42)	380
Rw01	13-Oct	Rwagimba	27.0	68.7	6.6 (68)	650
Rw02	13-Oct	Rwagimba	-	68.0	-	-
Rw03	13-Oct	Rwagimba	-	68.7	-	-
Rw04	13-Oct	Rwagimba	-	59.0	-	530
Rm01	13-Oct	Rwimi	28.0	25.0	6.3 (26)	420
Rm02	13-Oct	Rwimi	-	24.3	-	-

(Study team)

Table II-11 Rock sample list from field survey

sample name	date	place	Rock name	Thin section	X-ray	Spectrum
Ka01	9-Oct	Kagamba	meta-conglomerate	○	○	○
Kr01	9-Oct	Karungu	phyllite	○	○	○
Bu01	9-Oct	Bubale	-			
Mu01	9-Oct	Murole-nyakabungo	limburgite	○	○	○
Ru01a	9-Oct	Rubaare	travertine	○	○	○
Ru01b	9-Oct	Rubaare	pegmatite			○
Ki01	10-Oct	Kisizi	-			
Rb01	10-Oct	Rubabo	schist	○	○	○
Bi01	10-Oct	Birara	-			
Mi01	10-Oct	Minera	bio-gneiss	○	○	○
Ih01	11-Oct	Ihimbo	-			
Kn01	11-Oct	Kanyinabalongo	-			
Km01	11-Oct	Kiruruma	-			
Kt01	11-Oct	Kitagata	-			
Mh01	12-Oct	Muhokya	-			
Kb01	12-Oct	Kibenge	-			
Nd01	13-Oct	Ndugutu	travertine		○	○
Rw01	13-Oct	Rwagimba	-			
Rm01	13-Oct	Rwimi	travertine			○

(Study team)

(a) Outline of surveyed areas

1) The south-west area

Kagamba; Ka01

This site is located at the roadside of the Kabale–Katuna road in the Kagamba area, approximately 8km south of Kabale Town. The hot spring gushes out from unconsolidated sediment at the site. A small pond and wet land are developed in the vicinity. The maximum temperature, pH and electric conductivity of the hot spring are 28.4°C, pH 7.1 and 50mS/m, respectively. The basement rocks are composed of Mesoproterozoic meta-sandstone and meta-conglomerate. The foliation of the rocks distributed at this site strikes N45°W and dips 90°W. The lineaments are developed in ENE-WSW and NE-SW directions.

The Kagamba, Bubale and Karungu hot springs are aligned in a NW-SE direction, which is almost the same alignment as the foliation of basement. According to the existing geological map, whose scale is 1:250000, this site is located in a NW-SE trending synclinal structure.

Photo II-1 Kagamba (Ka01) site

Karungu; Ku01

This site is located in the Ishasha River valley in the Karungu area, approximately 20km northwest of Kabale Town. The hot springs gush out from unconsolidated sediments or through fractures developed in the phyllite outcrop of the river bottom. The maximum temperature, pH and electric conductivity of the hot springs are 61.7°C, pH 6.7 and 86mS/m, respectively. The hot springs are utilized as a spa.

The rock is composed of Mesoproterozoic phyllite and meta-sediments. The foliation of these rocks strikes N35°W and dips 80°W. This site is located at the intersection between a clear NW-SE trending lineament and a minor NE-SW trending lineament. A hot spring flows out from a N60E trending joint at the site.

The Kagamba, Bubale and Karungu hot springs are aligned in a NW-SE direction, which is almost same alignment as the foliation of basement. According to the existing geological map, whose scale is 1:250000, this site is located in a NW-SE trending synclinal structure.

Photo II-2 Karungu (Ku01) site

Bubale; Bu01

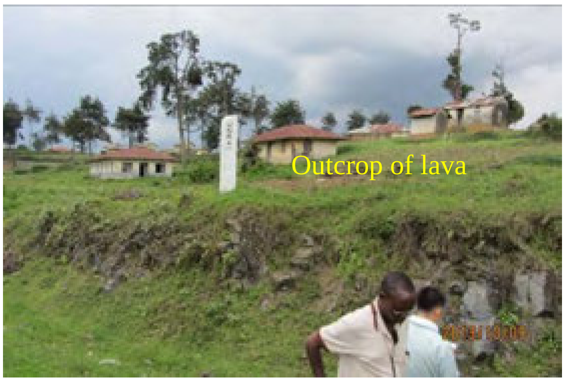
This site is located at the roadside of the Kabale–Kisoro road in the Bubale area, approximately 4km southwest of Kabale Town. The hot spring gushes out from unconsolidated sediment in the end of a slope. A small pond is developed in the vicinity. The maximum temperature, pH and electric conductivity of the hot spring are 29.5°C, pH 6.1 and 76mS/m, respectively. The rock is considered to be composed of meta-sandstone and conglomerate. No lineaments are developed at this location.

The Kagamba, Bubale and Karungu hot springs are aligned in a NW-SE direction, which is almost same alignment as the foliation of basement. According to the existing geological map, whose scale is 1:250000, this site is located in a NW-SE trending synclinal structure.

Photo II-3 Bubale (Bu01) site

Murole-Nyakabango; Mu01

The Mulore-Nyakabango area is underlain by Quaternary limburgite lava. The lavas have a vesicular texture and contain granitic xenoliths which were derived from basement rocks.



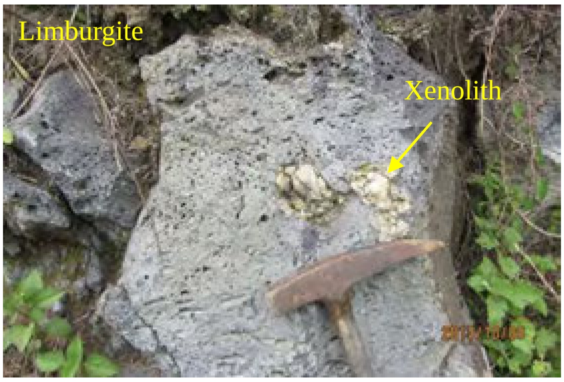


Photo II-4 Murole (Mu01) site

Rubaare ; Ru01

This site is located on the left side of a wide valley in Rubaare area, approximately 20km west of Utungamo Town. The valley is approximately 1km wide and trends WNW-ESE. The hot spring gushes out from the foot of slope on the south side of valley. Several small ponds are developed in the vicinity. The maximum temperature, pH and electric conductivity of the hot spring are 52.0°C, pH 7.3 and 165mS/m, respectively. There is a huge amount of travertine limestone around the hot spring.

The rock consists of massive, foliated granitic rocks with a great number of pegmatite veins. A WNW-ESE trending lineament is developed at this location.

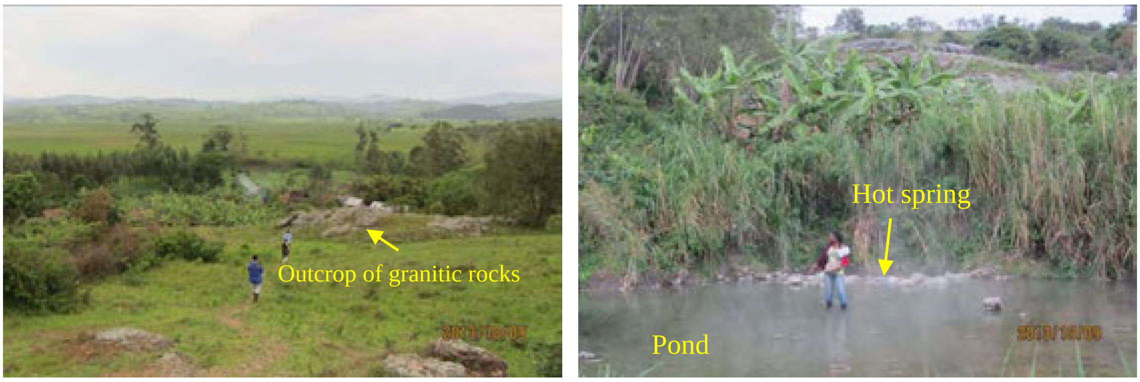


Photo II-5 Rubaare (Ru01) site

Kisiizi; Ki01

This site is located in the Kisiizi area, approximately 20km south of Rukungiri Town. The hot spring gushes out from scree deposits which are made up of gneiss. The maximum temperature, pH and electric conductivity of the hot spring are 29.1°C, pH 7.4 and 32mS/m, respectively.

The rocks are strongly silicified gneiss affected by quartz-dominant pegmatite intrusions. In particular, there are a lot of big boulders ranging from 1 to 5 m in size in the vicinity. An E-W trending lineament is developed at this location.

Rubabo; Rb01

This site is located on the left bank of a river valley in the Rubabo area, approximately 12km east-southeast of Rukungiri Town. The hot spring gushes out through fractures developed in schist. The maximum temperature, pH and electric conductivity of the hot spring are 57.5°C, pH 7.0 and 124mS/m, respectively. The rock consists of schist corresponding to the basement. The foliation of the rock distributed at this location strikes N35°W and dips 80°W. The site is located at the intersection of minor WNW-ESE and NE-SW trending lineaments.

Photo II-6 Rubabo (Rb01) site

Birara; Bi01

This site is located in Birara area, approximately 12km west-southwest of Rukungiri Town. The hot springs flow out from the bottom of a gorge. There are 4 hot springs on both sides of the river. Gneiss and granitic gneiss are distributed at this location. The maximum temperature, pH and electric conductivity of the hot springs are 61.0°C, pH 6.7 and 141mS/m, respectively.

A major NW-SE trending lineament running parallel to the river is very well developed

.

Photo II-7 Birara (Bi01) site

Minera; Mi01

This site is located in the Minera area, approximately 15km southeast of Rukungiri Town. The hot spring gushes out through fractures in the gneiss. The maximum temperature, pH and electric conductivity of the hot spring are 56.2°C, pH 6.9 and 240mS/m, respectively. The rock is composed of biotite gneiss whose foliation strikes N40°W and dips 80°W. A minor WNW-ESE trending lineament crosses the location.

Photo II-8 Minera (Mi01) site

Ihimbo;Ih01

This site is located in the Ihimbo area, approximately 15km northwest of Rukungiri Town. The area is located at a boundary between basement rocks and Quaternary rift sediments in the western Rift Valley. Hot waters seep out from Quaternary alluvial rift sediments.

The hot springs gush out from unconsolidated sediments at the bottom of the river. The maximum temperature pH and electric conductivity of the hot springs are 69.0°C, pH 8.7 and 98mS/m, respectively. The hot springs are utilized as a spa. This area is a forest reserve area.

There are two hot springs aligned in a N10°E direction. There are no discernable structural features in the imagery.

Photo II-9 Ihimbo (Ih01) site

Kanyinabalongo; Kn01

This site is located in the Kanyinabalongo area, approximately 20km northwest of Rukungiri Town. The site is located in a Quaternary rift sediment area of the western Rift Valley. Hot waters seep out from Quaternary unconsolidated sediments. A wet land and a small pond are developed in the vicinity. The maximum temperature, pH and electric conductivity of the hot spring are 36.3°C, pH 6.7 and 104mS/m, respectively.

There is a minor NE-SW trending lineament at this location.

Photo II-10 Kanyinabalongo (Kn01)

Kiruruma; Km01

This site is located in the Kiruruma area, approximately 5km west-southwest of Kanyinabalongo hot spring. The site is located in a Quaternary rift sediment area of the western Rift Valley. Hot waters seep out from Quaternary unconsolidated sediments. There is a 20m high cliff consisting of stratified sediments behind the hot spring. The maximum temperature, pH and electric conductivity of the hot spring are 36.0°C, pH 7.3 and 112mS/m, respectively.

There is a minor NNE-SSW trending lineament situated near this location.

Photo II-11 Kiruruma (Km01) site

Kitagata; Kt01

This site is located in the Kitagata area of the western part of Sheema district. The hot spring gushes out through fractures in the gneiss. The maximum temperature, pH and electric conductivity of the hot spring are 64.0°C, pH 7.7 and 118mS/m, respectively. The rock is composed of banded gneiss. The foliation of these rocks strikes N45W and dips 90. A major NE-SW trending lineament is very well developed.

This hot spring is utilized as one of the biggest public spas in the region.

Photo II-12 Kitagata (Kt01) site

2) Western area

Muhokya; Mh01

This site is located in the Muhokya area, approximately 10km southwest of Kasese Town. The hot springs gush out from unconsolidated slope deposits on a gentle hill. This site is overlain by Quaternary colluvium sediments. There are gneiss boulders on the surface. The maximum temperature, pH and electric conductivity of the hot springs are 42.0°C, pH 7.2 and 360mS/m, respectively. A great amount of lacustrine limestone, which is not classified as travertine limestone, is distributed around the site.

A major NE-SW trending lineament is developed, which is considered to be a rift margin fault.

A lime factory was established in this location.

Photo II-13 Muhokya (Mh01) site

Kibenge ; Kb01

This site is located in the Kibenge area, approximately 5km west of Kasese Town. The hot springs gush out from unconsolidated deposits. This site has a gneiss basement and there are gneiss boulders on the surface. The maximum temperature, pH and electric conductivity of the hot springs are 46.6°C, pH 7.2 and 370mS/m, respectively. The hot spring is utilized as a public spa.

A major NE-SW trending lineament is developed, which is considered to be a rift margin fault.

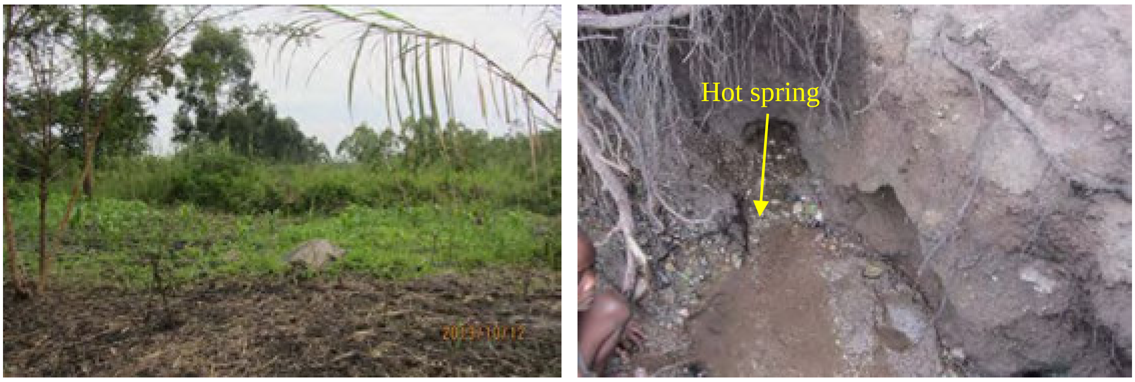


Photo II-14 Kibenge (Kb01) site

Ndugutu; Nd01

This site is located in Ndugutu, approximately 10km north of Kasese Town. Travertine limestone (old spring deposits) forming various sizes of pools is very well developed on the surface. Cold springs flow out from this travertine. This site has a gneiss basement, and there are gneiss boulders on the surface. A major N-S trending lineament is developed, which is considered to be a rift margin fault.

The Ndugutu and Rwagimba hot springs are aligned in a N-S direction controlled by the rift margin fault.

Rwagimba; Rw01

This site is located on the bottom of a V-shaped valley in the Rwagimba area, approximately 30km southeast of Kasese Town. The hot springs gush out from unconsolidated deposits in the river. The maximum temperature, pH and electric conductivity of the hot springs are 68.7°C, pH 6.6 and 650mS/m, respectively. This site has a gneiss basements, and there are gneiss boulders along the stream. Hot springs are found on both sides of the river. The site is in a very remote area, far from the village.

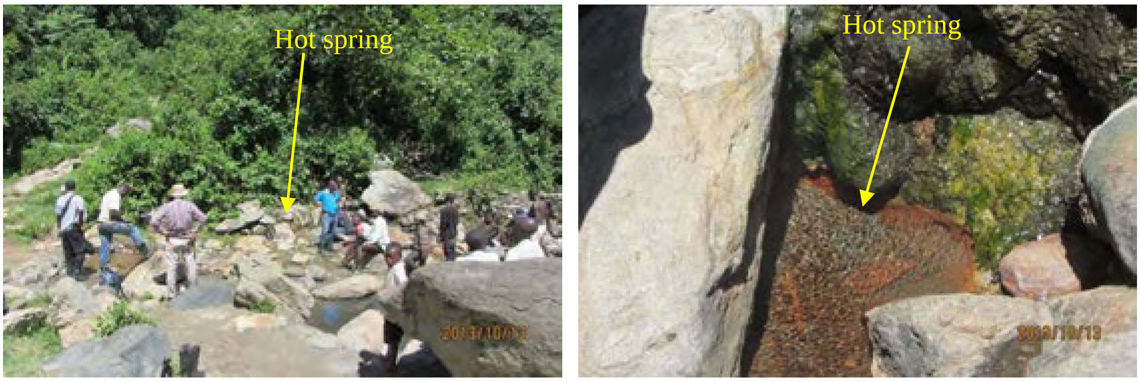


Photo II-15 Rwagimba (Rw01) site

Rwimi; Rm01

This site is located in the Rwimi area, approximately 25km northeast of Kasese Town. The hot springs gush out from unconsolidated deposits. The maximum temperature, pH and electric conductivity of the hot springs are 48.7°C, pH 6.3 and 26mS/m, respectively. This site has a gneiss basement. Quaternary lapilli tuff is widely distributed just north of this site.

The hot spring is located in a banana field. A1 m high mound of travertine limestone is observed close to the current hot spring.

Photo II-16 Rwimi (Rm01) site

(b) Tentative analysis of field data collected

The data distribution maps for temperature, pH and electric conductivity of the hot spring water are shown in Fig. II-17, Fig. II-18 and Fig. II-19, respectively. Correlations between the data collected in the field for these hot springs are shown in Fig. II-20.

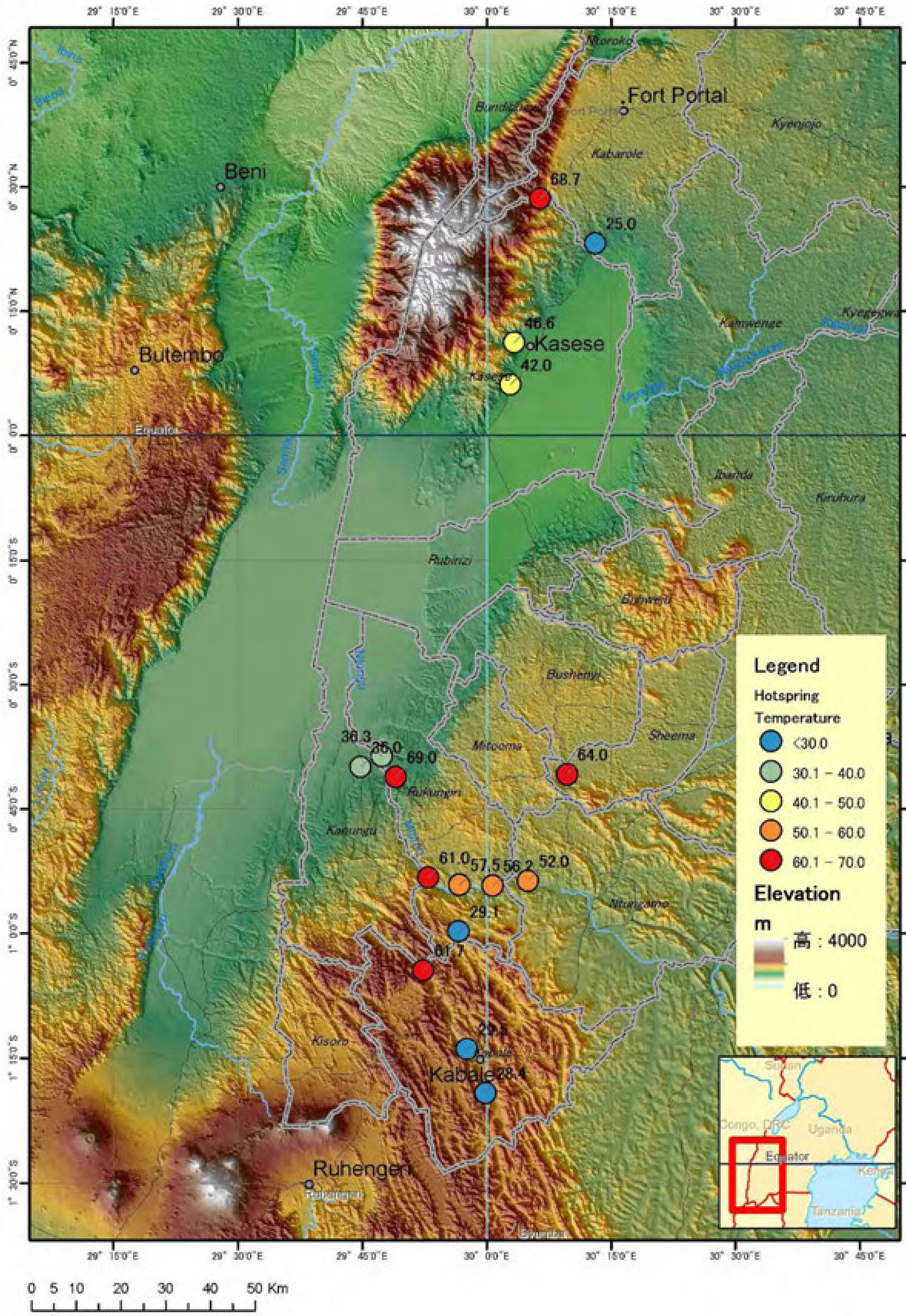
The highest hot spring temperatures are 69.0 °C at the Ihimbo site in Rukungiri District, 68.7 °C at the Rwagimba site in the Kabarole District and 64.0°C at the Kitagata site in Sheema District. In the western area, Quaternary volcanic rocks, which have the potential to act as heat sources for these hot springs, are widely distributed along the Rift Valley. On the other hand, most hot springs in the southwestern area are situated over Precambrian basements, and there are no volcanic rocks to act as a heat source. The Bufumbira volcanic rocks are distributed mostly in the southwest, about 20km from any hot springs. However, a small amount of limburgite lava occurs on basement granitic rocks in the

Murole area, approximately 8km southwest of the nearest Karungu hot spring. These observations imply the possibility that igneous rocks at greater depth are acting as the heat source.

The pH of the hot springs ranges from 6.1 at Bubale to 8.7 at Ihimbo. The regional tendency of pH values is not clear. Anyway, no hot spring shows an acid pH contributed by high-temperature volcanic gas.

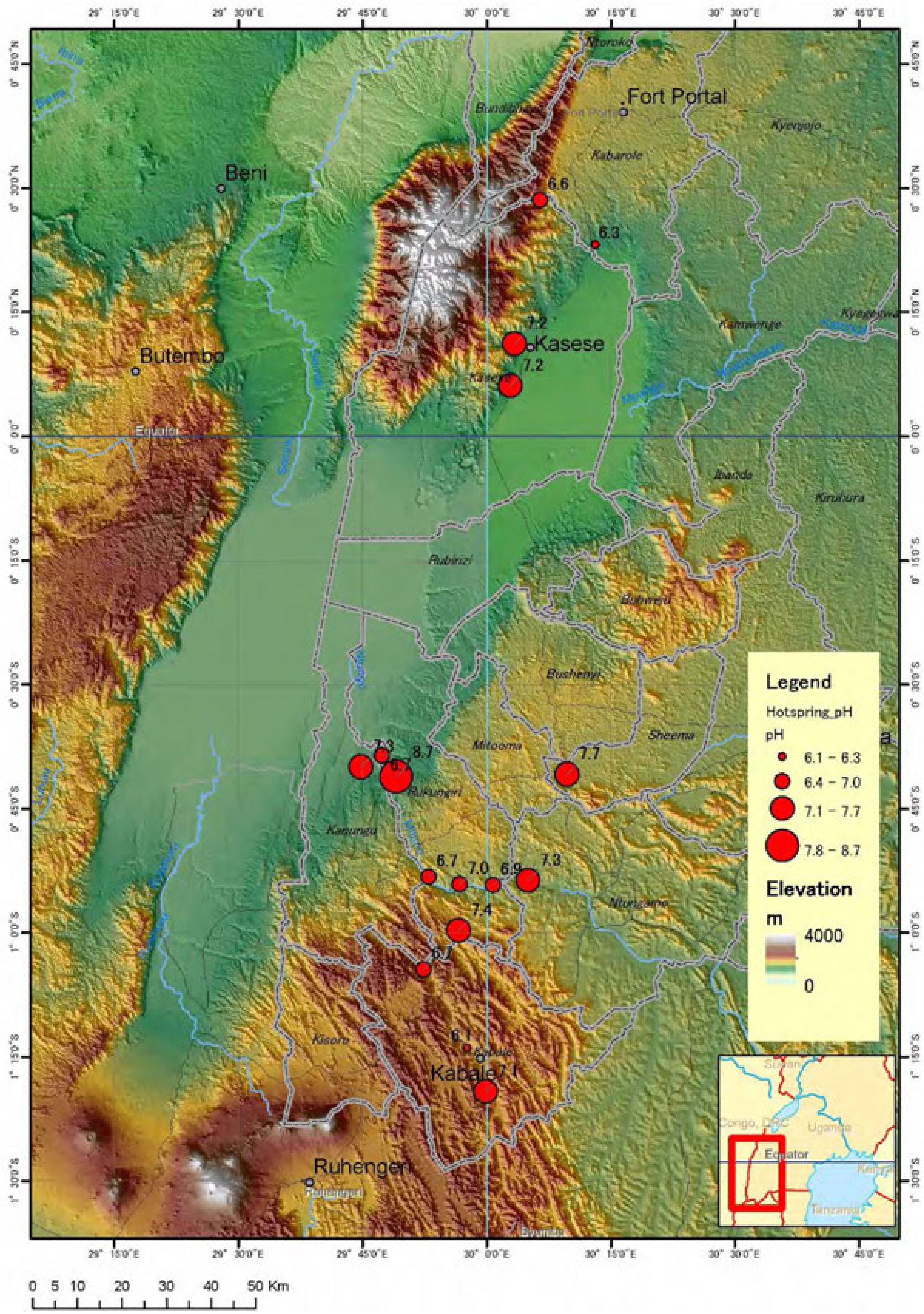
The electric conductivity (EC) of the hot springs ranges from 32mS/m at Kisiizi to 650mS/m at Rwagimba. Generally, the western area shows higher EC values than the southwestern area. Some of the hot spring EC values show an inverse correlation with temperature (Fig. II-20). This implies HCO_3-dominated waters, suggesting that those hot springs have been heated conductively, because HCO_3 concentration usually shows an inverse correlation with temperature. Otherwise, the EC at Rwagimba shows a positive correlation with temperature, implying the contribution of a Cl-dominated deep reservoir.

Analytical results will appear in section ‘II-5-2 Geological information’ and ‘II-5-3 Geochemical information’ after chemical analysis of the samples in Japan.



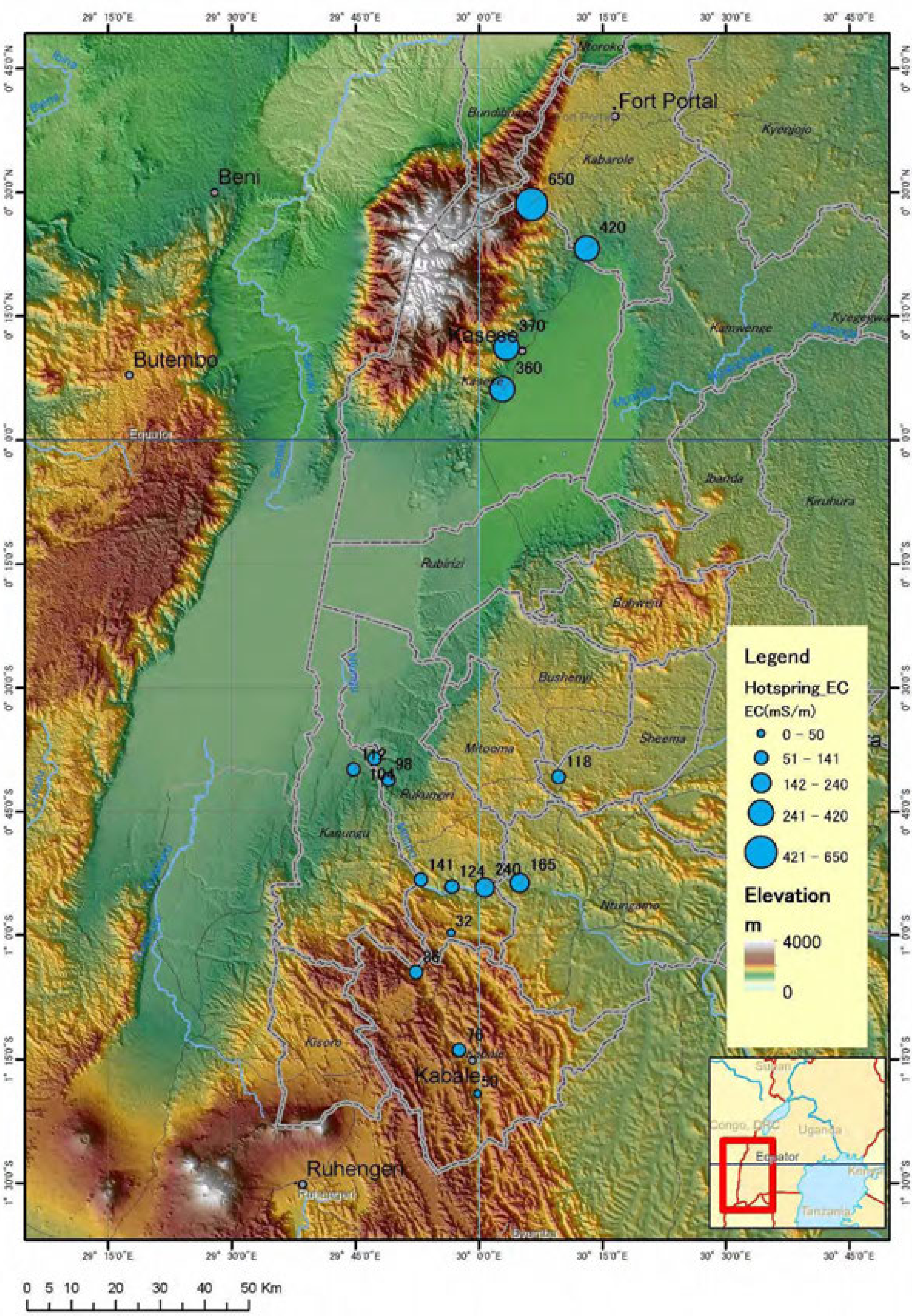
(Study team)

Fig. II-17 Temperature Distribution map of Hot Spring Water



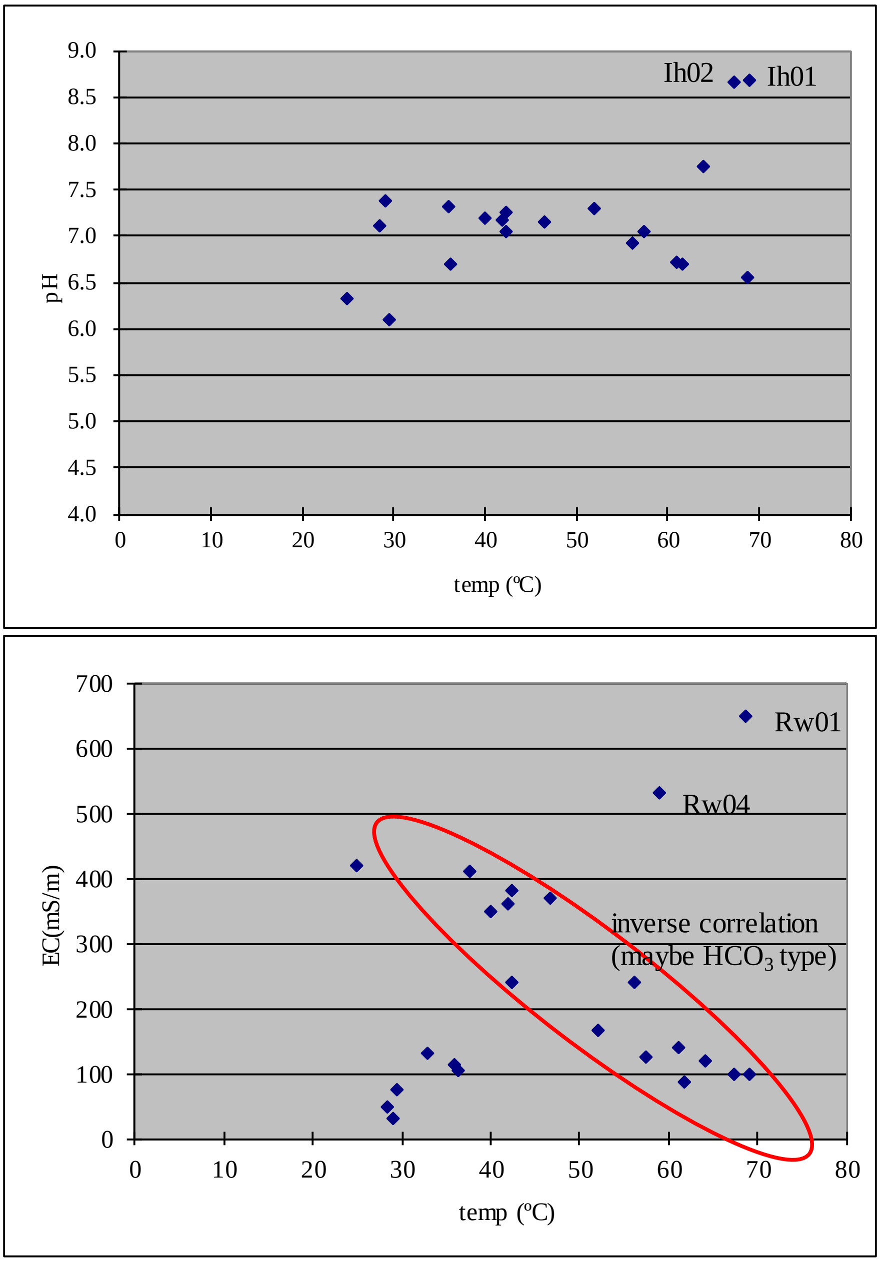
(Study team)

Fig. II-18 pH distribution map of Hot Spring water



(Study team)

Fig. II-19 Electric conductivity distribution map of hot spring water



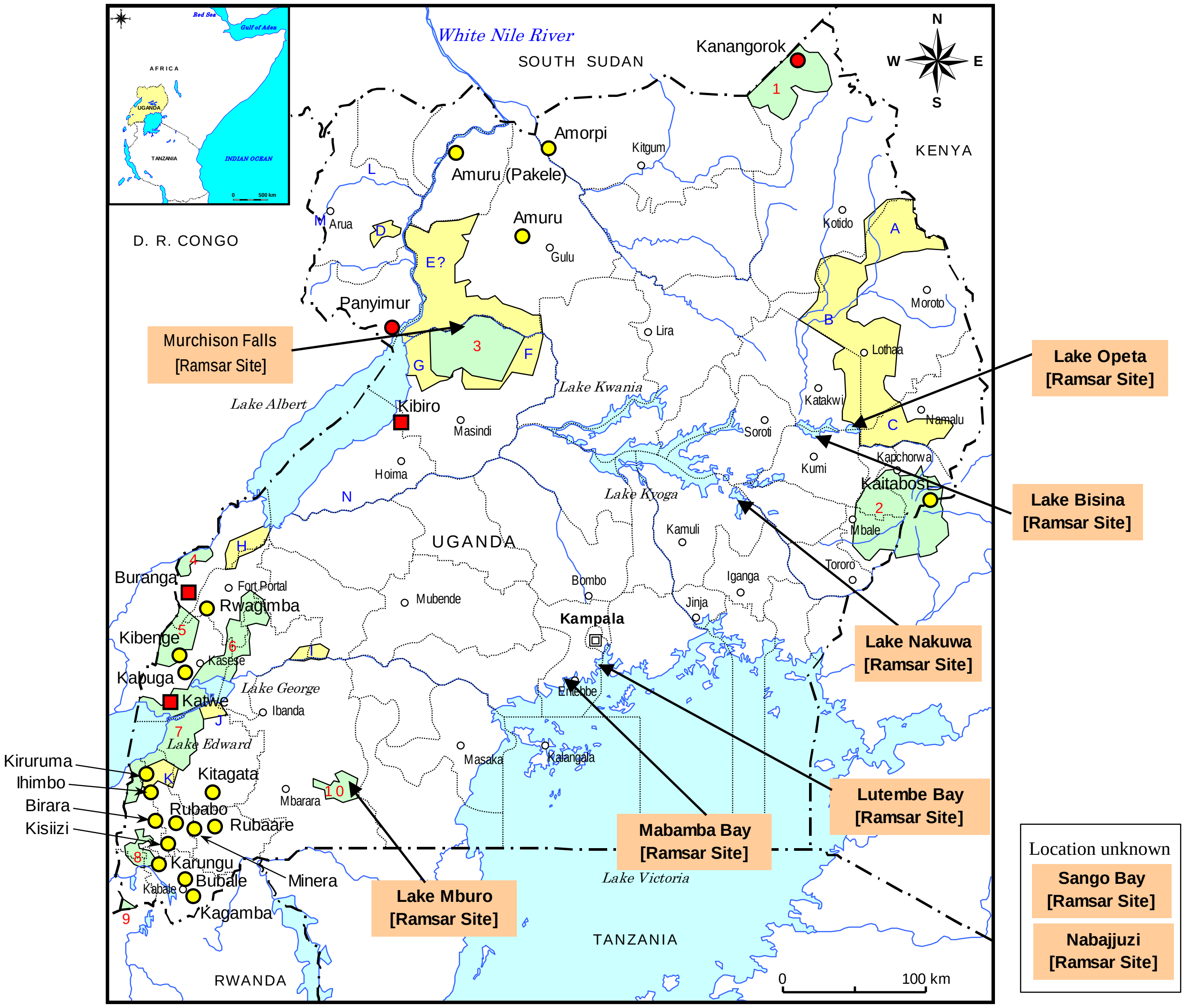
(Study team)

Fig. II-20 Correlation diagram for hot spring data collected in the field

2. Information about Natural Reserves

In evaluating geothermal potential in terms of environmental impacts, it is important to consider the natural reserves. There are two categories of natural reserve: National parks and Game reserves. These natural reserves are shown in Fig. II-21.

However, national park areas were not included in this field survey, because those areas are really difficult to develop.



Legend ■ Licensed Main Geothermal Area ● Licensed Other Geothermal Area ● Other Geothermal Area

National Park 1 = Kidepo Valley 2 = Mt. Elgon 3 = Murchison Falls 4 = Semuliki 5 = Rwenzori Mountains 6 = Kibale 7 = Queen Elizabeth 8 = Bwindi Impenetrable 9 = Mgahinga Gorilla 10 = Lake Mburo

Game Reserve A = Matheniko B = Bakora Corridor C = Pian Upe D = Ajai E = Aswa-Lolim? F = Karuma G = Bugungu H = Toro-Semliki I = Katonga J = Kyambura K = Kigezi L = Lomunga M = East Madi N = Kabwoya

(Modified from Wikipedia)

Fig. II-21 Location of Natural Reserves

II-5-3 Geological Information

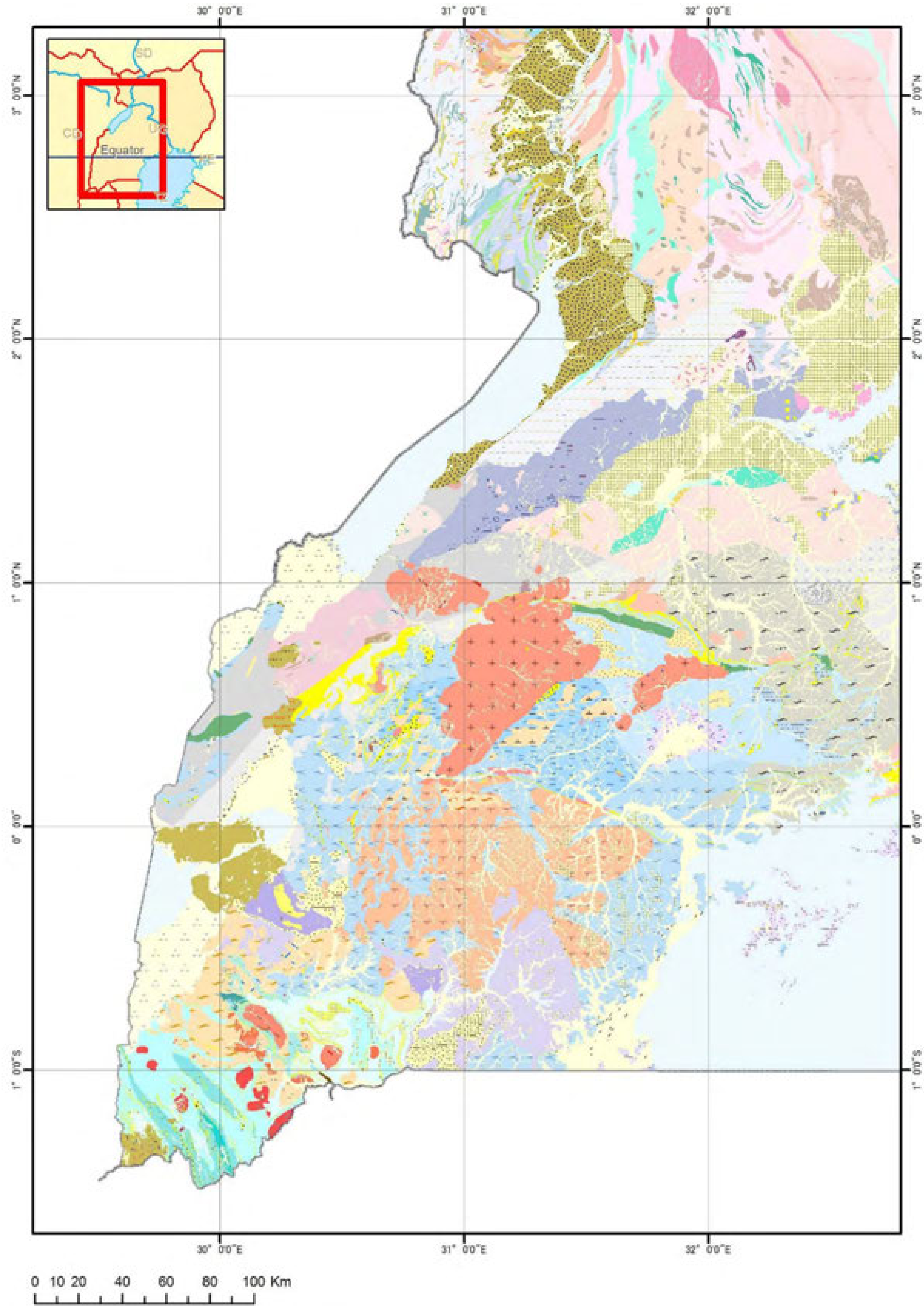
Fig. II-22 and Fig. II-23 show a geological map of the study area and a simplified legend of the geological map, respectively. This map was modified from The GEOLOGICAL MAP of UGANDA 1:250,000.

The geology of Uganda consists of an exposed Precambrian basement dissected by the western branch of the East African Rift System in the western part of the country. The Western branch, the Albertine Rift, starts to the north along the Sudan border, then curves to the west and then southwest along the border with the Democratic Republic of Congo, finally running south to Rwanda, Burundi and western Tanzania. Spreading began at least 15 million years ago in the Miocene. The western Rift is considered to be at an early stage of development, and is younger (late Miocene-Recent) than the more mature eastern branch (Morley and Westcott, 1999). The Albertine Rift is seismically active, characterized by deep-seated (27–40km) large earthquakes. The region of the Rift has a markedly higher heat flow than the surrounding Precambrian terrain. Two different en echelon strands are found in the Western Rift Valley, separated by the Rwenzori Mountains, which rise from a base of less than 1,000m in the Rift to an elevation of over 5,000m. Within the Rift Valley there are thick layers of late Tertiary and Quaternary sediments, fresh water and saline crater lakes, and volcanic and plutonic bodies have been identified beneath Lake Albert and Lake Edward (EDICON, 1984).

The four main Ugandan geothermal fields are located in the Albertine Rift at Kibiro, Katwe, Buranga and Panyimur. The general strike of the Albertine Rift is NE-SW. Geophysical surveys indicate a 2,500 to 3,000m thickness for the Pleistocene sediments in the rift floor.

1. Kibiro area

The Kibiro geothermal prospect, which is located on the eastern escarpment of the Albertine Rift is comprised of hot springs that emerge at the base of the escarpment at the intersection of three oblique faults. The escarpment forms a boundary between the old basement rocks (to the east) and the young sedimentary formation of the rift (to the west). The basement consists of Precambrian granites, granitic gneisses, gneisses and N-S striking basic amphibolite intrusives. Mylonitic gneisses occur in the fault-controlled valleys. The NE striking faults in the area are oblique to the main rift fault and crosscut E-W striking faults. All rocks are heavily fractured with crosscutting joints. Geothermal manifestations such as hot springs and solfatara are identified, together with products from hydrothermal alteration such as argillized ground and secondary hydrothermal minerals (gypsum and calcite) filling joints in altered mylonitic gneisses on the escarpment, among others. The measured maximum temperature of the hot springs is 86.4^{o}C.



(Modified from GEOLOGICAL MAP of UGANDA 1:250,000)

Fig. II-22 Geological Map of Study Area

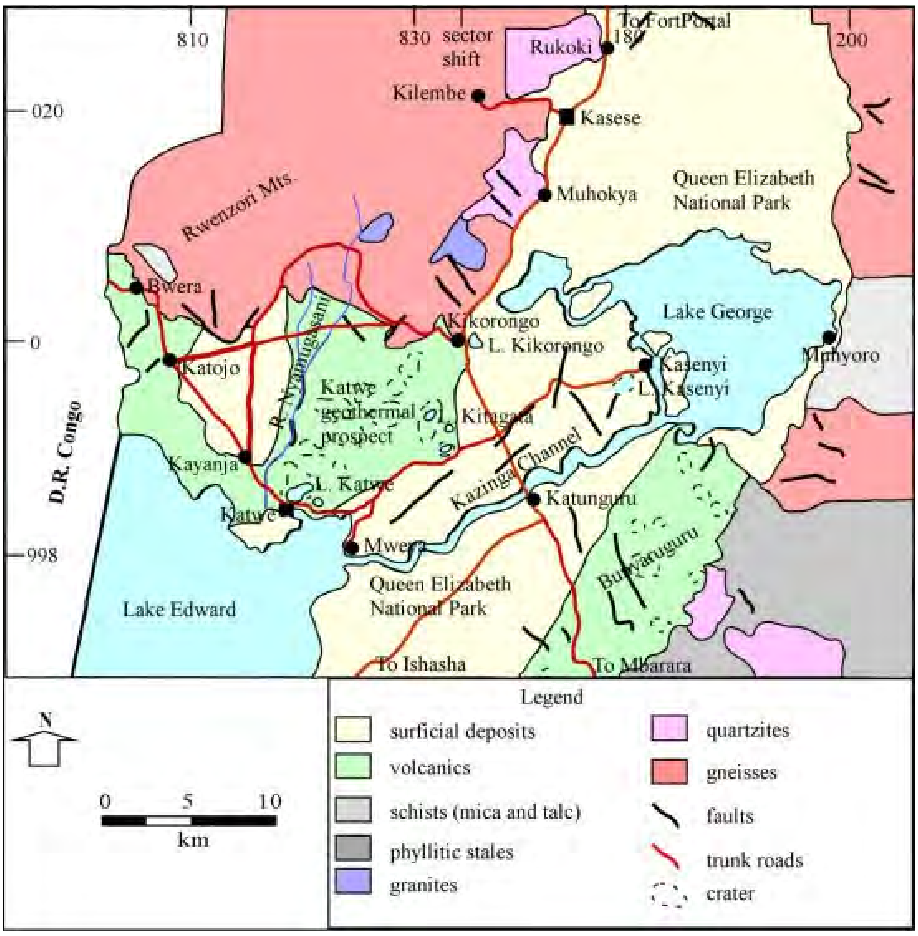
	Unit	SEDIMENTARY VOLCANIC ROCK AND METAMORPHIC COMPLEXES		PLUTONIC ROCKS AND DYKES	
QUATERNARY		QHu	Alluvium, swamp, lacustrine deposits		
		QHc	Colluvium		
		QHr	Rift alluvium		
		QHtc	Terrace conglomerate		
		QHl	Laterite		
	Albertine	QFPt	Lapilli tuff		
		QGtl	Tuff and lava		
		QGpv	High-K volcanics, also carbonatite lava		
MESOPROTEROZOIC	Akanyaru-Ankole	P_3ACsqg	Sandstone, quartzite, grit	P_3tg	Tourmaline biotite granite
		P_3ACs	Mudstone, shale, slate, phyllite	P_3Rpg	Rubaale pegmatite granite (~1.12 Ga)
		P_3APqs	Sandstone, quartzite, grit	P_3Kpgr	Bwindi porphyritic granite
		P_3APiq	Quartzite	P_3Kbgr	Porphyritic biotite granite
		P_3APfg	Feldspathic grit	P_3dh	Dolerite, hornblende bearing
		P_3APgq	Garnet quartzite	P_3do	Dolerite, pyroxene bearing (1368±41 Ma; 1374±42 Ma)
		P_3APbq	Border quartzite	P_3um	Kafunzo ultramafic rock, geophysical interpretation
		P_3APs	Mudstone, shale, slate, phyllite	P_3Ngr	Ntungamo granite
		P_3AGsqg	Sandstone, quartzite, grit	P_3Cgr	Chitwe granite
		P_3AGqg	Sandstone, quartzite, grit intercalated with shale, phyllite and schist		
		P_3AGqs	Quartzitic sandstone		
		P_3AGs	Mudstone, shale, slate, phyllite		
		P_3AGt	Mudstone, slate, turbiditic		
		P_3AGms	Mica schist, muscovite quartzite		
		P_3AGcs	Calc-silicate rock		
PALEOPROTEROZOIC	Kagera-Buhweju	P_1KRq	Quartzite with minor pelitic layers	P_1gb	Metagabbro
		P_1KRp	Pelites with minor quartzite beds	P_1do	Metadolerite
		P_1KRmq	Mylonitised and brecciated quartzite	P_1pg	Pegmatite and pegmatite granite
		P_1KRqs	Quartzitic sandstone	P_1Sgrc	Kasagama granite (1964±4 Ma)
		P_1KRc	Conglomerate, grit	P_1Sgrh	Rwamasha granite (1987±5 Ma)
		P_1KMms	Mudstone, shale, phyllite, oncolite and stromatolite in places		
		P_1KMqs	Quartzite, conglomerate, with algal fossils in places		
	Buganda	P_1BNms	Mica schist with quartzitic interbeds	P_1Rqgn	Quartzofeldspathic gneiss
		P_1BNqs	Sericite quartzite and quartzite	P_1Rmmg	Muscovite-bearing granite gneiss, porphyritic in part
				P_1Rmpg	Porphyritic granite gneiss
				P_1Rvgg	Variable granitic gneiss (2147±16 Ma)
ARCHAEAN				AWtg	TTG gneiss

(Modified from GEOLOGICAL MAP of UGANDA 1:250,000; KABALE)

Fig. II-23 Simplified Legend of Geological Map

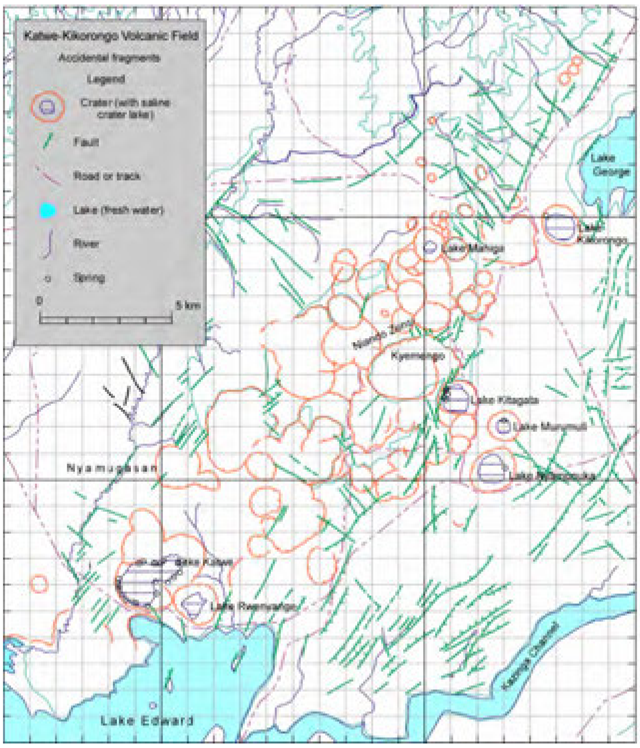
2. Katwe area

The Katwe area is on the southeastern slope of the Rwenzori massif, and includes 78 randomly distributed craters. The volcanic rock covers Pleistocene sediments. Though these directly cover Precambrian rocks of the Toro system around the western marginal part of their extent, the Pleistocene sediments are underlain by the Karagwe-Ankolean (K-A) metasediments in the eastern part. The Bunyaruguru volcanic field extends in the southeastern part of this area, where tuffs mixed with K-A rock fragments are identified. The Katwe volcanic rocks are mainly phreatomagmatic pyloclastic deposits consisting of ash, tuff, lapilli, volcanic bombs and basement rock xenoliths. Basaltic lava flows and ejected lava blocks occur around the Kyemengo and Kitagata craters. The volcanic material pile rises up to 420m above surrounding sediments. NE-SW striking faults parallel to the strike of the main rift fault are dominant in this area. Carbon dating shows the period of volcanism to be Pleistocene to Holocene. Travertine deposits resulting from geothermal activity indicate extinct hot springs, warm springs (30ºC) at Lake Katwe and hot springs (70ºC) at Lake Kitagata area. A geologic map of the Katwe area and its surroundings and of the Katwe-Kikorongo volcanic field are shown in Fig. II-24 and Fig. II-25, respectively.



(Bahati, 2012)

Fig. II-24 Geologic map of Katwe area and its surroundings



(ICEIDA, 2010)

Fig. II-25 The Katwe-Kikorongo volcanic field

3. Buranga area

The Buranga area is located at the northwestern end of the Rwenzori massif near the base of the Bwamba escarpment. Hot springs occur in the area covered by Pleistocene sediments. Precambrian rocks underlie the sediments. The main rift fault strikes N45°E and dips 60°-65°. The three hot spring areas of Mumbuga, Nyansimbe and Kagoro lie on a line striking N40°E, sub-parallel to the main rift fault. Precambrian rocks form the northern half of the Rwenzori massif that consists of migmatites and gneisses striking N10°E to N30°E. The sediments consist of fine to medium-grained sands and clays. They are poorly consolidated, and some of them are coated with calcareous material. The measured maximum hot spring temperature is 98ºC, and travertine cones and some sulphur deposits are identified at the Kagoro spring area. This area is seismically active and the frequent earthquakes reactivate and create new geothermal manifestations, like the new hot springs near the Nyansimbe pool.

4. Southwestern Uganda

Eleven geothermal areas in southwestern Uganda were investigated by Armannsson et, al. (2007). A field survey involving these geothermal areas was conducted by this study team.

The geology of this region is characterized by widespread Precambrian basements and the Bufumbira volcanics in southwesternmost part of the region. The Bufumbira volcanic field is part of the larger Virunga volcanic field extending into the Congo and Rwanda. There are active volcanoes in this volcanic field, such as Nyiragongo volcano. The main volcanoes in the Bufumbira volcanic field are Sabinyo (3415 m), Mgahinga (3475 m) and Muhavura (4126 m), though they are all extinct. These volcanoes are arranged on a line trending east to west, though the trend of the rift valley is SE-NW. It is believed that the volcanism generating these volcanoes is controlled by basement faulting (Thomas, 1997).

5. Results of Laboratory Analysis

Petrography, X-ray diffraction analysis and spectral analysis were conducted in this study to clarify the hydrothermal alteration process in geothermal areas.

1) Petrography

In the petrography, country rocks from geothermal areas show no evidence of apparent hydrothermal alteration. The results of petrography are as follows. The petrography sheets are shown in Appendix-2.

Ka01; Kagamba

The rock is conglomerate and consists of quartz grain and pebble of quartz and muscovite. The matrix mostly consists of opaque mineral and looks dark reddish purple to the naked eye. It is considered to be hematite from the results of XRD analysis. The maximum grain size is around 1cm, and a lot of particles of around 0.5mm are included.

Kr01; Karungu

The rock is phyllite, mainly consisting of quartz, muscovite and hematite. The quartz and muscovite are less than 0.1mm in diameter. Pseudomorph laths consist of fine opaque minerals. The intergranular regions of quartz and muscovite are filled up by very fine opaque minerals. The cleavage is developed with the orientation of mica.

Mu01；Murole-nyakabungo

The rock is olivine-pyroxene basalt. The phenocrysts are less than 1.5-2.0mm in diameter. The porous groundmass consists of volcanic glass, plagioclase and opaque mineral. The rock shows no evidence of hydrothermal alteration.

Ru01a；Rubaare

The rock is travertine, and consists of calcite and a matrix of brown clay mineral. The calcite is less than 0.5mm in diameter. The rock shows a porous texture.

Rb01; Rubabo

The rock is schist, and consists of mainly quartz, biotite and muscovite. The biotite and the muscovite show parallel alignment. The quartzes are around 0.2-2mm in diameter and show mosaic texture and undulatory extinction. The muscovite and the biotite are 0.2-0.5mm in length. The cleavages are developed.

Mi01; Minera

The rock is gneiss, and consists of quartz and microcline with biotite and a small amount of muscovite. The rock shows an equigranular texture with a grain size of around 0.5mm. The mica is oriented. A small amount of chlorite is observed.

2) X-ray diffraction analysis

Table II-12 shows the results of XRD analysis. The detected clay minerals are kaolinite, smectite, illite chlorite and mixed layer mineral.

Kaolinite and illite are detected in Ka01 (conglomerate) and Kr01 (phyllite) of Proterozoic meta-sedimentary rocks. Chlorite, illite and smectite are detected in Rb01 (schist). Illite, kaolinite and smectite are detected in Mi01 (gneiss). Illite is detected in Quaternary basalt Mu01, although it shows a low intensity of X-ray diffraction. Mixed layered mineral is detected in travertine Ru01a and is related to hot spring activity.

In general the hydrothermal process, the presence of kaolinite shows acid alteration, and the presence of smectite and illite indicate neutral alteration. The results of field observation and petrography showed no evidence of apparent hydrothermal alteration, and moreover kaolinite occurs in abundance in soils that have formed from the chemical weathering of rocks. So this kaolinite is inferred to originate from chemical weathering. The presence of a small amount of smectite of metamorphic rocks (Rb01 and Mi01) suggests a low-grade water-rock interaction product. The illite is formed by higher-grade alteration than smectite and is the main mineral contained in sedimentary rocks and low to intermediate-grade metamorphic rocks. Although illite is detected in Rb01and Mi01, their petrography and field observations show no evidence of apparent hydrothermal alteration. Therefore, the origin of the illite is considered to be unrelated to Quaternary hydrothermal activity.

Table II-12 Results of X-Ray diffraction analysis

Sample No.	Rock name	Bulk specimen (Quartz index)									Oriented specimen					
		quartz	feldspar	mica	pyroxene	chlorite	kaolinite	calcite	ankerite	hematite	chlorite	illite	kaolinite	smectite	mixed layer	other
Ka01	Conglomerate	22.6		3.2						5.8		○	○			
Kr01	Phyllite	19.0		9.7			0.7					○	○			
Mu01	Basaltic rock (Limburgite)		2.0		3.8							○				
Ru01a	Travertine							11.0							○	○ (calcite)
Rb01	Schist	16.2	2.1	13.7		1.3					○	○		○		
Mi01	Gneiss	16.7	9.6	1.5				1.1				○	○	○		○ (quartz, feldspar)
Nd01	Travertine							14.9	0.9					○		○ (calcite)

(Study team)

3) Spectral measurement

Infrared reflectance spectral measurements were conducted to clarify the clay and carbonate mineralogy of rock samples, Table II-13 shows the list of identified minerals. The reflectance curves of each sample are shown in Appendix-3.

SWIR (short wave infrared region) reflectance spectroscopy is a very sensitive analytical method for the investigating clay mineral groups and carbonate mineral groups. The wave length of SWIR ranges from 1,300 to 2,500nm. Fig. II-26 shows the reflectance curves of kaolinite, smectite and sericite (illite) from the USGS spectral library. In SWIR, clay minerals and carbonate minerals have specific absorption features. These absorption features are caused by water and the $Al\text{-}OH^-$ molecular vibration process in the minerals, making it possible for spectroscopy to identify the type of mineral and chemical component. For example, kaolinite is identified by the absorption feature of a doublet or shoulder shape in the 2,200nm region. Some of the absorption band of smectite overlaps with that of illite (sericite).

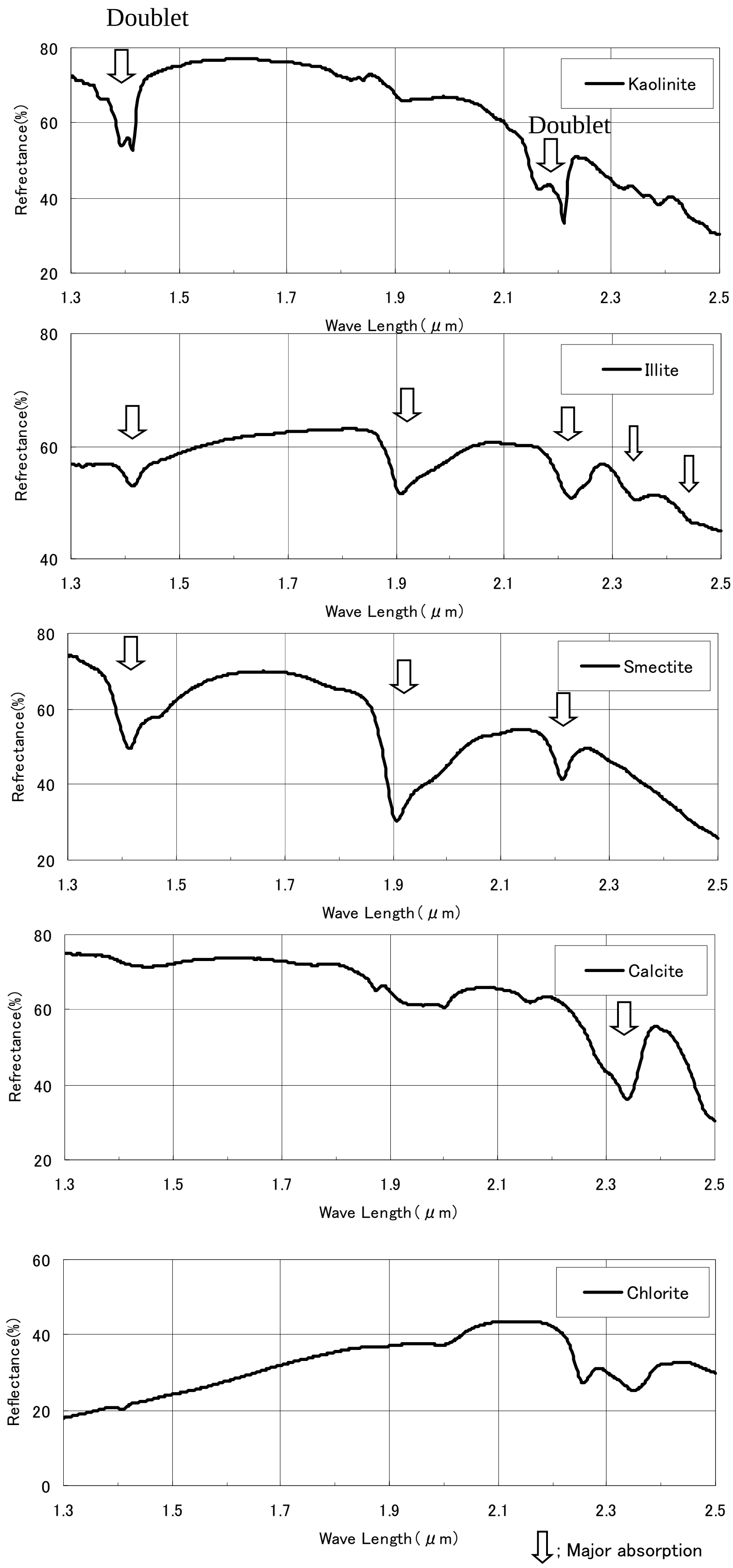
The minerals detected by spectral measurement are kaolinite, illite (sericite), smectite, chlorite, calcite and tourmaline (Table II-13) Typical spectral curves of Ka01, Rb01 and are shown in Fig. II-27. The kaolinite is presumed to originate in the weathering process, because kaolinite is detected from the weathered portion of conglomerate Ka01. Smectite is detected in Rb01 and Mi01. Illite is detected in Ka01, Rb01 and Mi01, but the spectral absorption for Rb01 and Mi01 are very weak. Mu01, in which illite is detected by XRD analysis, shows no sign of spectral absorption.

Calcite and clay minerals are detected in the travertine samples. These clay minerals are considered as being of soil origin, based on their petrography.

Table II-13 Results of spectral measurement

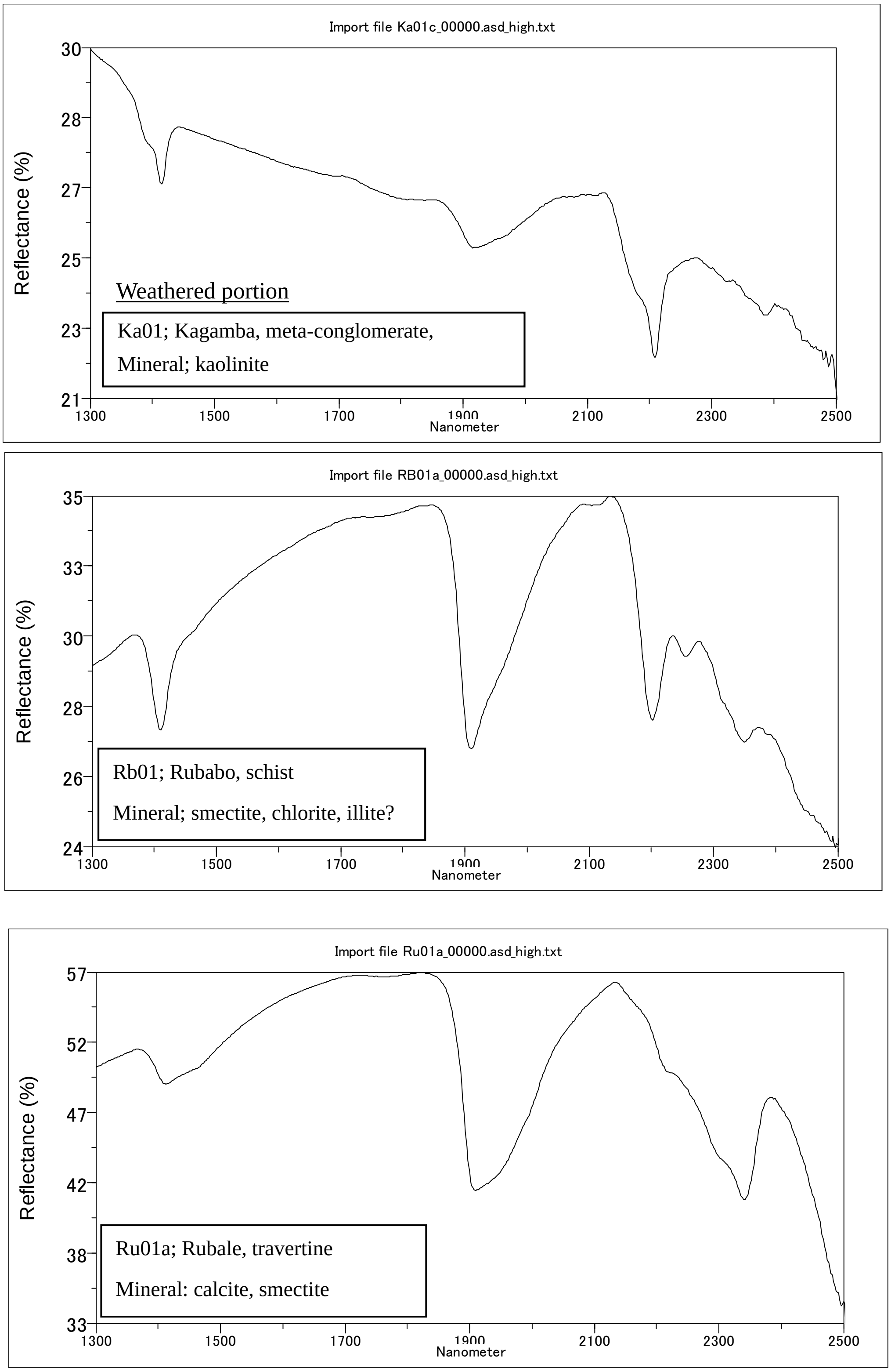
Sample name	Place	Rock name	kaolinite (halloysite)	smectite	illite (sericite)	chlorite	calcite	tourmaline	Remark
Ka01	Kagamba	meta conglomerate	○						weathered portion
					○				unweathered portion
Kr01	Karungu	phyllite							undetected
Mu01	Murole-nyakabungo	limburgite							undetected
Ru01a	Rubaare	travertine		○			○		
Ru01b	Rubaare	pegmatite						○	
Rb01	Rubabo	schist		○	○?	○			
Mi01a	Minera	bio-gneiss		○	○?	○?			
Nd01	Ndugutu	travertine					○		
Rm01	Rwimi	travertine		○	○?	○?			

(Study team)



(Study team)

Fig. II-26 Spectral Reflectance of Typical Clay Minerals and Calcite



(Study team)

Fig. II-27 Results of spectral measurement

II-5-4 Geochemical Information

The chemical analysis methods applied to the samples mentioned in “II-5-2 Field Survey” are shown in Table II-14, and the analysis results are shown in Table II-15. Geochemical analysis figures are shown in Fig. II-28 to Fig. II-31. The results of the calculated geothermometers are shown in Fig. II-33 to Fig. II-35 and Table II-16 (Equations are shown in Appendix-6).

Table II-14 Chemical/isotopic analysis method

	Analysis Method	Detection limit/accuracy
pH	pH-meter (glass electrode method)	-
EC	Conductivity meter	-
Na	Flame Atomic Absorption Spectrometry	0.02mg/L
K	Flame Atomic Absorption Spectrometry	0.02mg/L
Li	Flame Atomic Absorption Spectrometry	0.01mg/L
Ca	ICP Atomic Emission Spectroscopy	0.01mg/L
Mg	ICP Atomic Emission Spectroscopy	0.001mg/L
Cl	Volumetric method/Ion chromatography	10/0.01mg/L
SO_4	Ion chromatography analysis	0.1mg/L
HCO_3	Volumetric method	1mg/L
T-SiO_2	Molybdenum yellow method	2mg/L
B	ICP Atomic Emission Spectroscopy	0.04mg/L
$\delta D(H_2O)$	Mass spectrometry	±1‰
$\delta^{18}O(H_2O)$	Mass spectrometry	±0.1‰

(Study team)

Table II-15 Results of geochemical analysis (This Study)

Sample name	Data	Chemical component														Isotope Component	
		pH	EC	Na	K	Li	NH4	Ca	Mg	Cl	SO_4	HCO_3	F	B	T-SiO_2	$\delta D(H_2O)$	$\delta^{18}O(H_2O)$
		(-)	(mS/m)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(‰)	(‰)
Ka01	2013/10/9	-	-	-	-	-	-	-	-	6.0	-	-	-	-	-	-17	-4.0
Kr01	2013/10/9	7.39	79.2	134	8.77	0.38	0.02	28.8	3.69	46.8	207	149	5.00	0.37	51	-12	-3.3
Bu01	2013/10/9	6.53	71.8	58.8	5.54	0.23	0.19	60.5	35.9	20.3	70.1	376	0.60	0.18	19	-11	-3.4
Ru01	2013/10/9	7.92	154	270	14.3	0.29	0.24	72.8	1.56	170	410	145	5.43	0.72	108	-16	-3.7
Ki01	2013/10/10	-	-	-	-	-	-	-	-	12.0	-	-	-	-	-	-11	-3.2
Rb01	2013/10/10	7.50	115	203	10.6	0.08	0.08	42.1	8.03	91.0	181	334	3.52	0.20	80	-11	-3.2
Bi01	2013/10/10	7.11	132	203	13.6	0.21	0.19	82.8	12.0	82.9	213	442	5.99	0.20	107	-10	-2.8
Mi01	2013/10/10	7.09	236	478	21.0	0.72	0.19	72.6	21.8	180	362	824	2.74	0.58	83	-15	-3.6
Ih01	2013/10/11	9.14	90.5	173	5.25	0.01	0.03	3.99	0.088	71.8	220	66	5.41	0.22	68	-10	-3.1
Kn01	2013/10/11	6.72	101	158	8.38	0.02	0.37	32.0	4.36	92.2	294	54	2.46	0.30	36	-10	-2.7
Km01	2013/10/11	7.32	108	198	8.76	0.04	0.82	28.4	2.76	92.7	254	161	5.14	0.58	63	-12	-3.2
Kt01	2013/10/11	7.94	113	190	10.2	0.52	0.18	35.9	0.315	59.0	350	95	7.13	0.52	77	-9	-2.7
Mh01	2013/10/12	7.45	354	608	19.0	0.04	<0.01	214	12.5	470	1050	143	2.85	0.36	50	-14	-3.8
Kb01	2013/10/12	7.36	354	582	24.8	0.22	0.01	242	5.95	610	887	89	3.79	0.47	45	-19	-4.4
Rw01	2013/10/13	7.31	620	1490	44.3	0.47	0.05	76.0	5.14	860	1470	784	7.58	0.70	67	-17	-4.2
Rm01	2013/10/13	6.80	413	442	62.6	0.06	0.32	419	215	250	684	2120	2.23	0.24	93	-4	-2.3

(Study team)

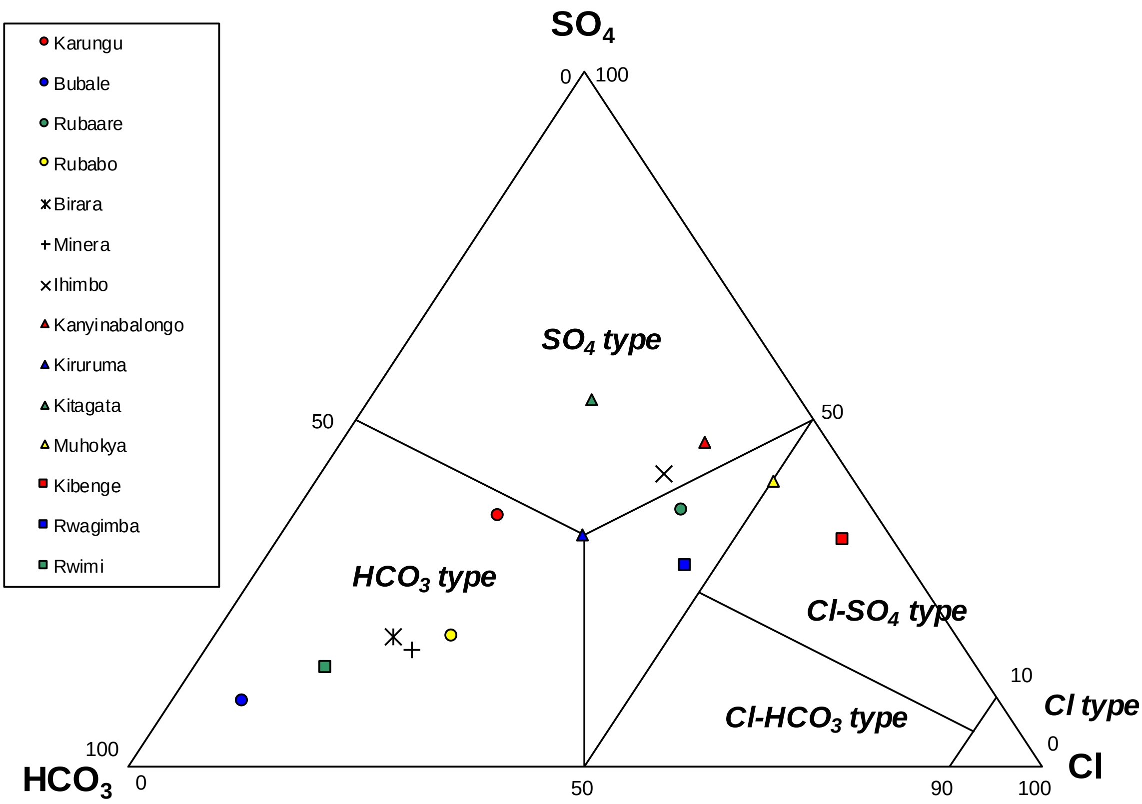
In the following, the south-west area and western area are each given separate geochemical interpretations.

a) The south-west area

This covers an area ranging from Kabale city to Kitagata town through Karungu, Bubale, Rubaare, Rubabo, Birara, Minera, Ihimbo, Kanyinabarongo, Kiruruma and Kitagata hot springs. Hot spring water from this area has a relatively low Cl concentration of 20 to 180 mg/L (Table II-16), and is mainly classified as being of the conductively heated type (HCO_3 type) while some springs are of the steam-heated type (SO_4 type) (Fig. II-28). Judging from the Cl-B diagram (Fig. II-29), the hot spring waters are stored in volcanic rocks. However, no volcanic rocks were observed in this vicinity in the geological survey. The isotopic composition is almost the same as for meteoric water, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig. II-30). In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig. II-31). So based on the Na-K-Ca temperature, taking Ca into account, the underground temperature was estimated to be 52 to 93 degrees C for the Kabale – Ntungamo area (Fig. II-32, Table II-16), 85 to 124 degrees C for the Rukungiri area (Fig. II-33, Table II-16), and 94 to 95 degrees C for the Kanungu – Sheema area (Fig. II-34, Table II-16).

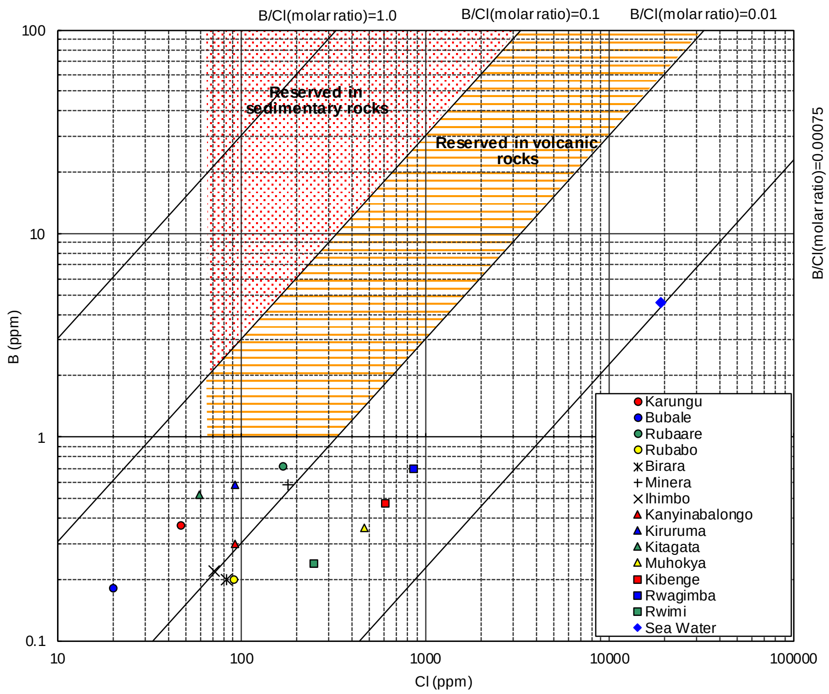
b) The western area

This covers an area ranging from Rubirizi town to Fort Portal city through Muhokya, Kibenge, Rwagimba and Rwimi hot springs. Hot spring water from this area has a relatively high Cl concentration of 250 to 860 mg/L (Table II-16), and is mainly classified as Cl-HCO_3 type or intermediate type while only Rwimi falls into the HCO_3 type (Fig. II-28). This implies mixing of deep high-temperature reservoir water. The boron concentration was lower than the Cl concentration, in contrast to normal hot springs (Fig. II-29), and evaporites seem to play some role for those hot springs. The isotopic composition is almost the same as meteoric water, as in the south-western area, and there is no oxygen shift that would indicate water-rock interaction under high temperature (Fig. II-30). In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig. II-31). So based on the Na-K-Ca temperature, taking Ca into account, the underground temperature was estimated to be 88 to 145 degrees C for the Kasese – Kabarole area (Fig. II-35, Table II-16).



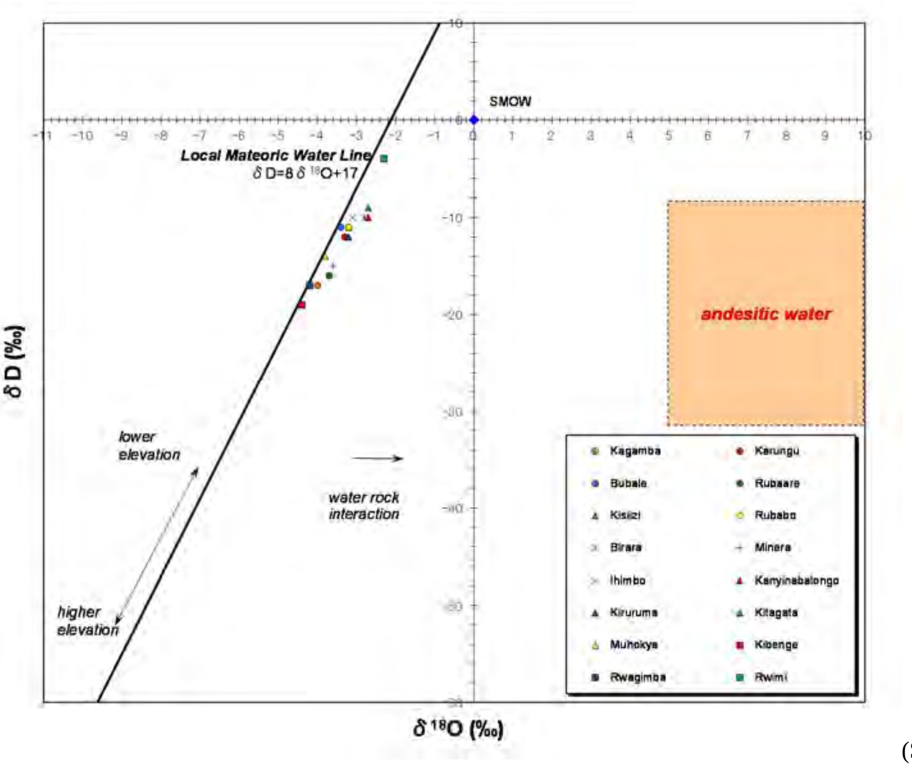
(Study team)

Fig. II-28 Ternary diagram of the major anions



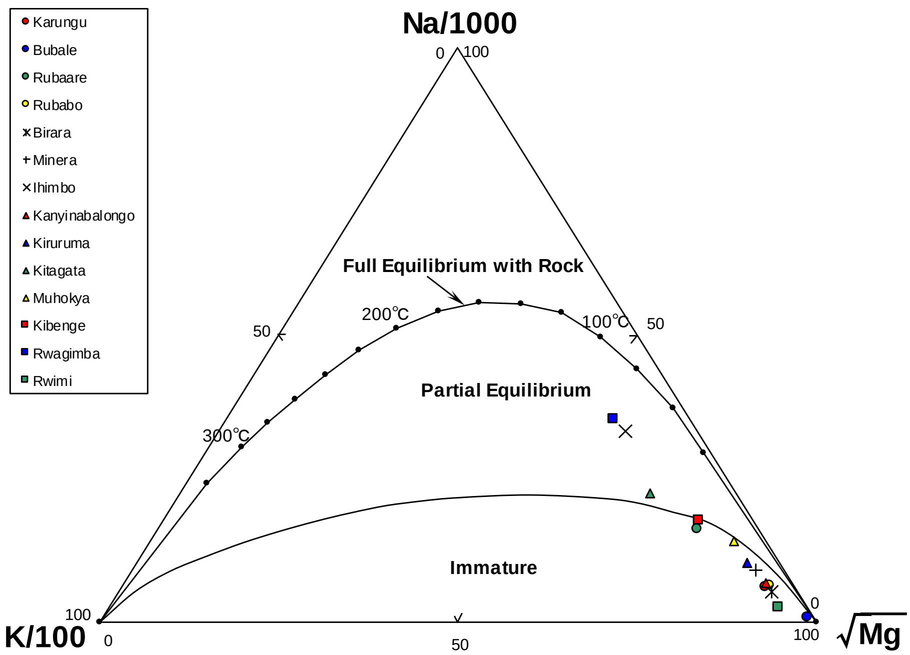
(Study team)

Fig. II-29 Cl-B diagram of hot spring waters



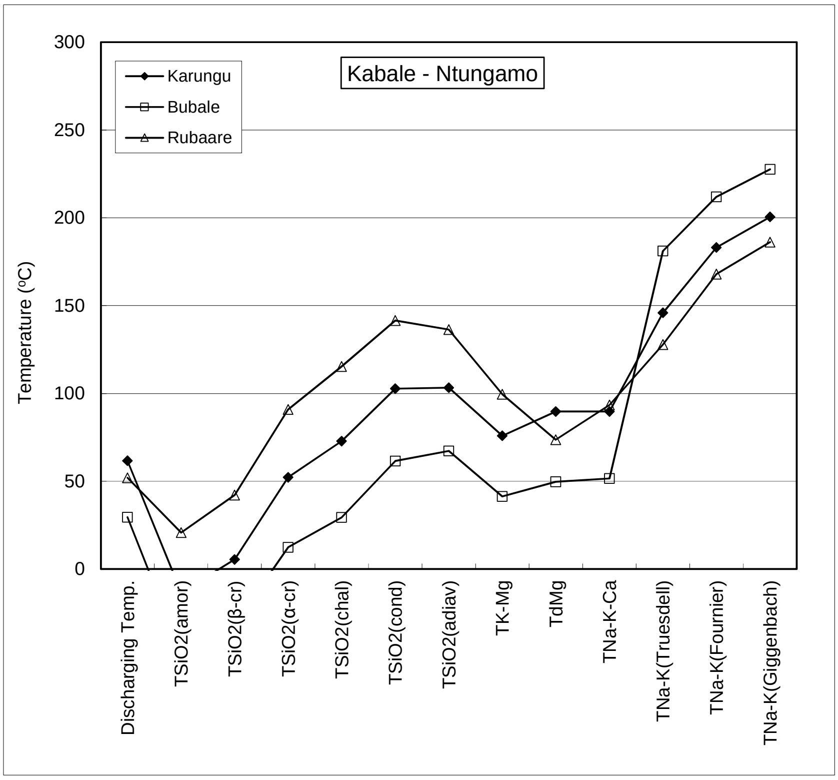
(Study team)

Fig. II-30 Delta-D and Delta-18O diagram of waters



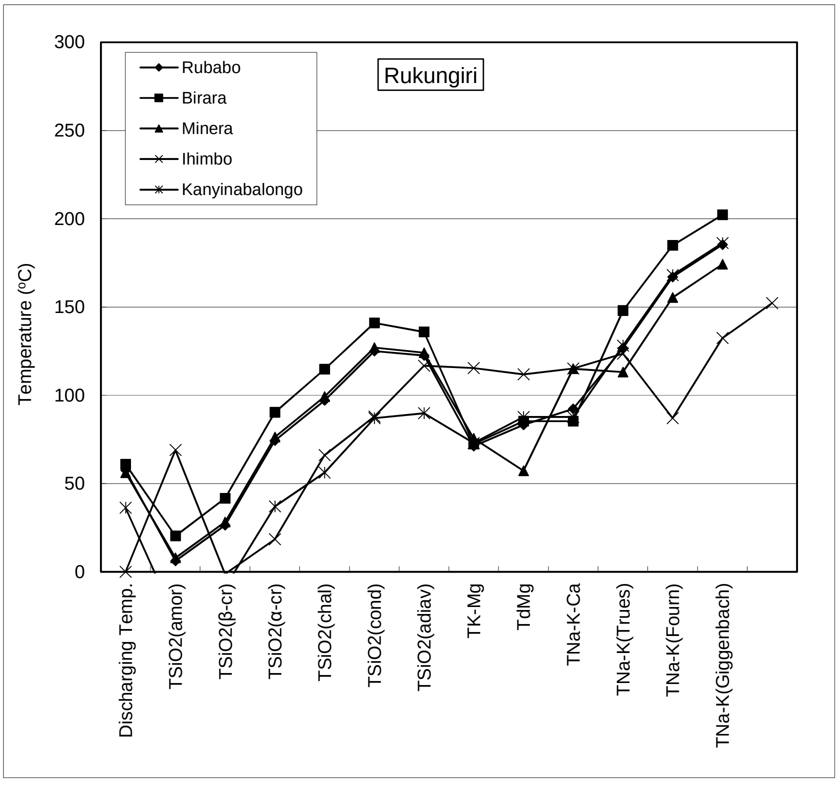
(Study team)

Fig. II-31 Ternary Na-K-Mg diagram



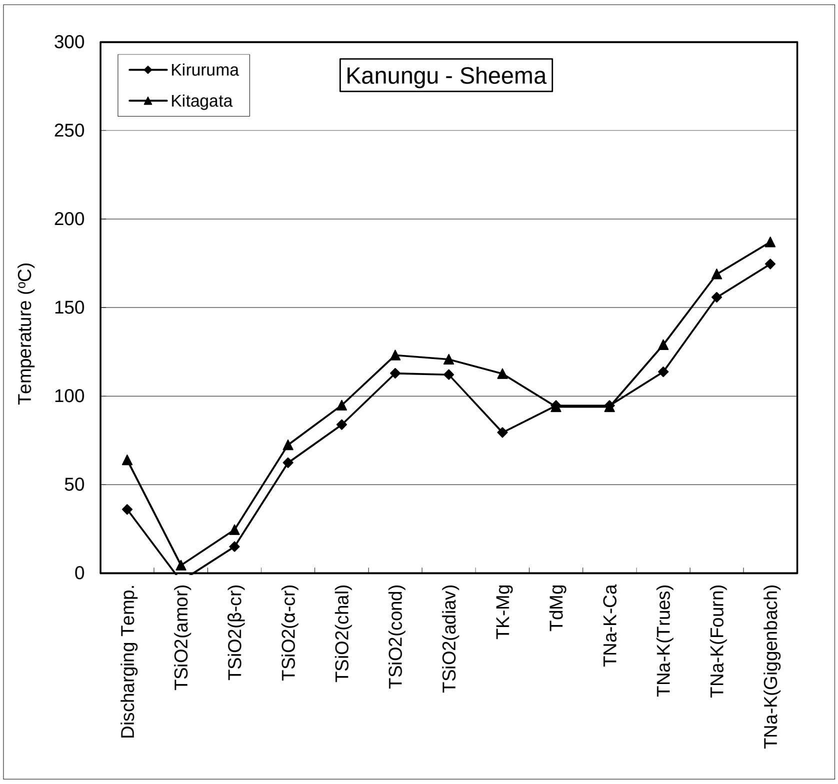
(Study team)

Fig. II-32 Calculated geothermometers for Kabale – Ntungamo



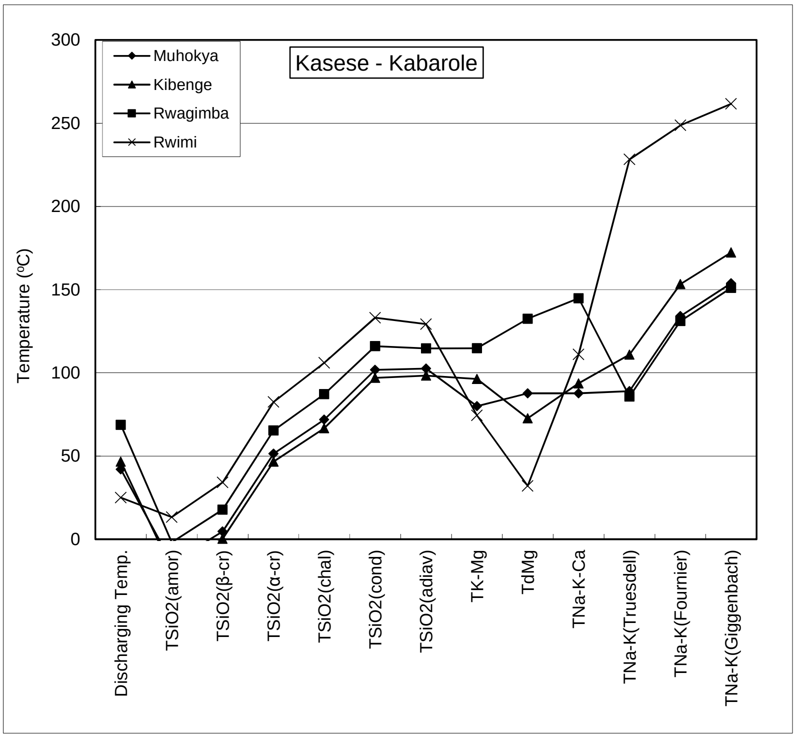
(Study team)

Fig. II-33 Calculated geothermometers for Rukungiri



(Study team)

Fig. II-34 Calculated geothermometers for Kanungu - Sheema



(Study team)

Fig. II-35 Calculated geothermometers for Kasese – Kabarole

Table II-16 Calculated geothermometry results

Area		Kabale-Ntungamo			Rukungiri				
Site		Kagamba	Bubale	Rubaare	Rubabo	Birara	Minera	Ihimbo	Kanyinabalongo
Sample No.		Kr01	Bu01	Ru01	Rb01	Bi01	Mi01	Ih01	Kn01
Discharging Temp. (℃)		61.7	29.5	52	57.5	61	42.3	69.0	36.6
Geothermometry (℃)	$TSiO_2$ (amor)	-13	-48	21	6	20	8	-1	-26
	$TSiO_2$ (β-cr)	6	-31	42	26	42	28	19	-9
	$TSiO_2$ (α-cr)	52	12	91	74	90	76	66	37
	$TSiO_2$ (chal)	73	29	115	97	115	99	88	56
	$TSiO_2$ (cond)	103	62	142	125	141	127	117	87
	$TSiO_2$ (adiav)	103	67	136	122	136	124	115	90
	TK-Mg	76	41	100	71	72	76	112	73
	TdMg	90	50	74	83	85	57	115	88
	TNa-K-Ca	90	52	93	92	85	115	124	88
	TNa-K(Truesdell)	146	181	128	127	148	113	87	128
	TNa-K(Fournier)	183	212	168	167	185	155	132	168
	TNa-K(Giggenbach)	201	228	186	185	202	174	152	186

Area		Kanungu	Sheema	Kasese		Kabarole	
Site		Kiruruma	Kitagata	Muhokya	Kibenge	Rwagimba	Rwimi
Sample No.		Km01	Kt01	Mh01	Kb01	Rw01	Rm01
Discharging Temp. (℃)		36	64.0	42	46.6	68.7	25
Geothermometry (℃)	$TSiO_2$ (amor)	-4	4	-14	-18	-2	-18
	$TSiO_2$ (β-cr)	15	25	5	0	18	0
	$TSiO_2$ (α-cr)	62	72	51	47	65	47
	$TSiO_2$ (chal)	84	95	72	67	87	67
	$TSiO_2$ (cond)	113	123	102	97	116	97
	$TSiO_2$ (adiav)	112	121	103	98	115	98
	TK-Mg	79	113	80	96	115	0
	TdMg	95	94	88	73	132	4
	TNa-K-Ca	95	94	88	94	145	3
	TNa-K(Truesdell)	114	129	89	111	86	111
	TNa-K(Fournier)	156	169	134	153	131	153
	TNa-K(Giggenbach)	175	187	154	172	151	0

(Study team)

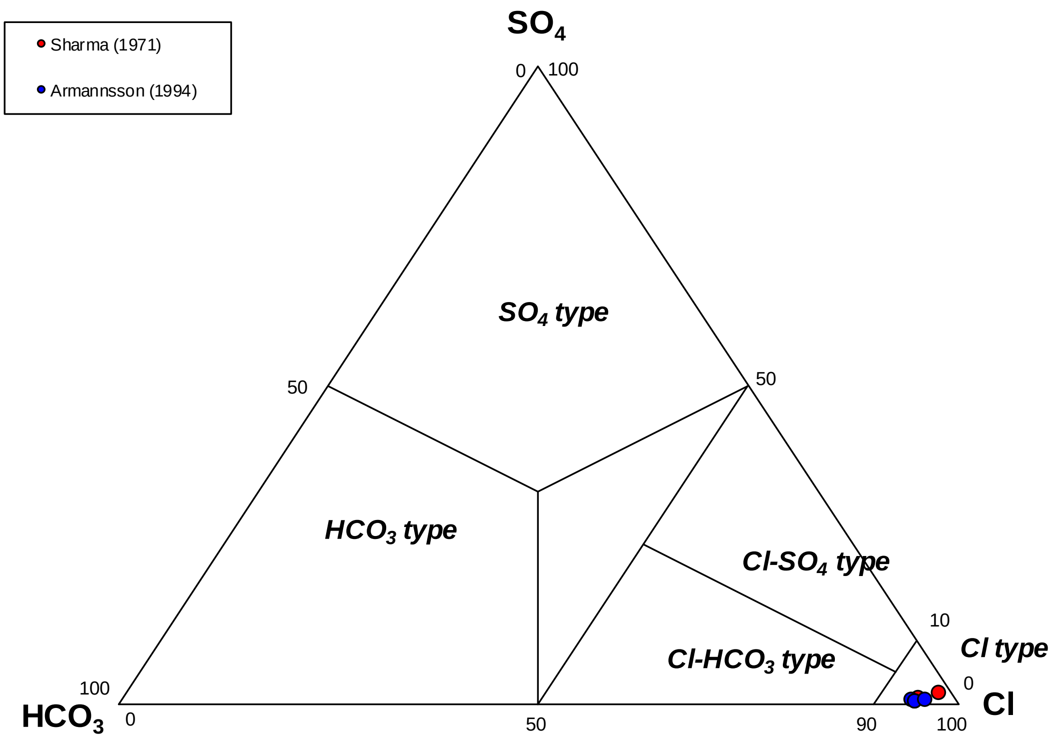
c) Kibiro area

The geochemistry of hot spring waters at Kibiro was studied on the basis of the existing data. The Cl concentration is high at about 2,500 mg/L (Table II-17), and the waters are classified as deep reservoir type (Cl type) (Fig. II-36). Concerning the Cl and Boron concentrations, Bahati et al. (2010) mentions that relatively low B values compared to Cl and Li suggest that the fluids are more likely to originate from volcanic basement rocks than from the young overlying sediments (Fig. II-37). In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in equilibrium, but showed a high Mg concentration (Fig. II-38). So based on the Na-K-Ca temperature, taking Ca into account, the underground temperature was estimated to be 217 to 229 degrees C (Fig. II-39, Table II-18).

Table II-17 Chemical composition of Kibiro (existing data)

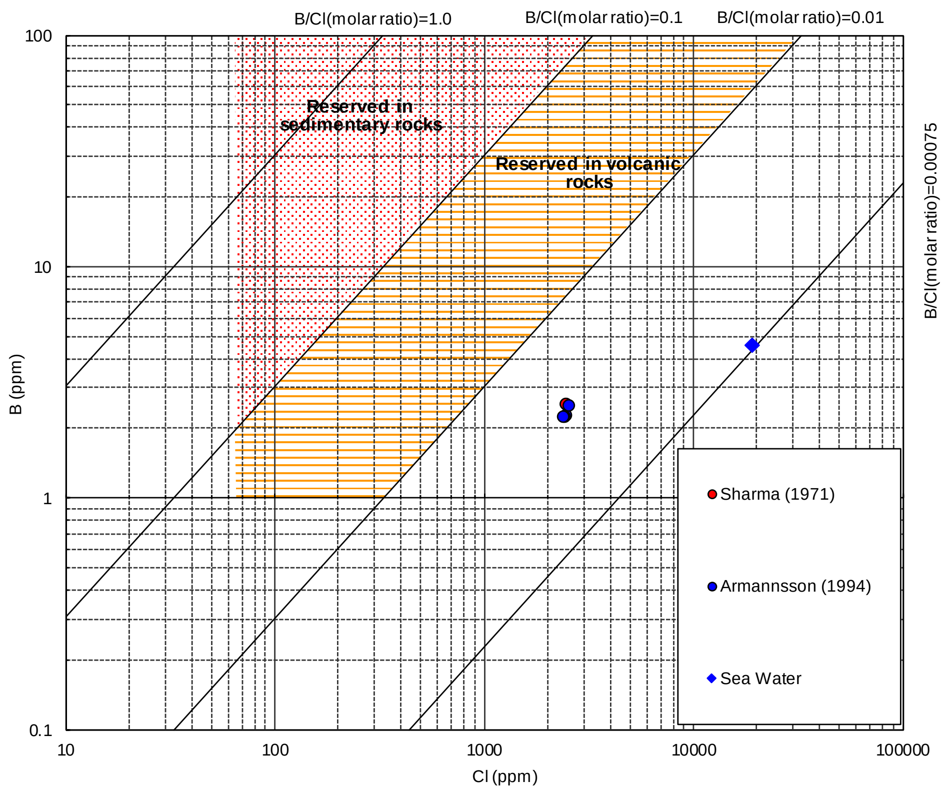
Chemical composition																	Reference
pH	Na	K	Li	Ca	Mg	T-Fe	Al	Cl	SO_4	HCO_3	F	B	SiO_2	Mn	δD (H_2O)	$\delta^{18}O$ (H_2O)	
7.5	1539	188	-	60	16	-	-	2500	57	188	-	2.5	166	-	-	-	Sharma (1971)
7.5	1620	200	-	50	20	-	-	2500	120	60	-	2.5	21	-	-	-	Sharma (1971)
7.06	1530	169	1.5	62	8.14	-	0.037	2500	46.7	227	5.12	2.26	129	0.004	-11.3	-2.0	Armannsson (1994)
7.14	1490	164	1.48	62.69	7.96	0.02	0.041	2450	26.4	215	5.02	2.23	125	0.004	-11.8	-2.1	Armannsson (1994)
7.14	1480	165	1.46	65.7	9.12	-	0.044	2440	15.4	215	4.74	2.21	122	0.007	-10.6	-2.0	Armannsson (1994)
8.05	1570	182	1.53	75.9	8.71	0.03	0.029	2580	49.9	159	5.37	2.47	135	0.006	-3.9	-1.0	Armannsson (1994)

(Compile from Sharma (1971) and Armansson (1994))



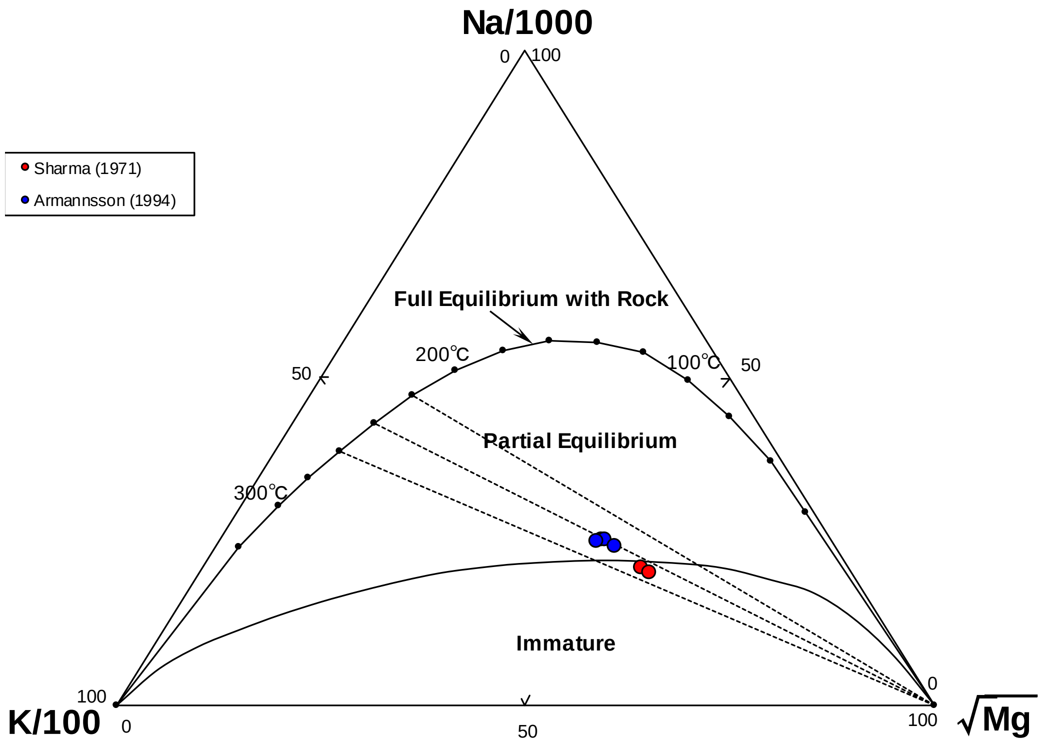
(Study team)

Fig. II-36 Ternary diagram of the major anions (Kibiro area)



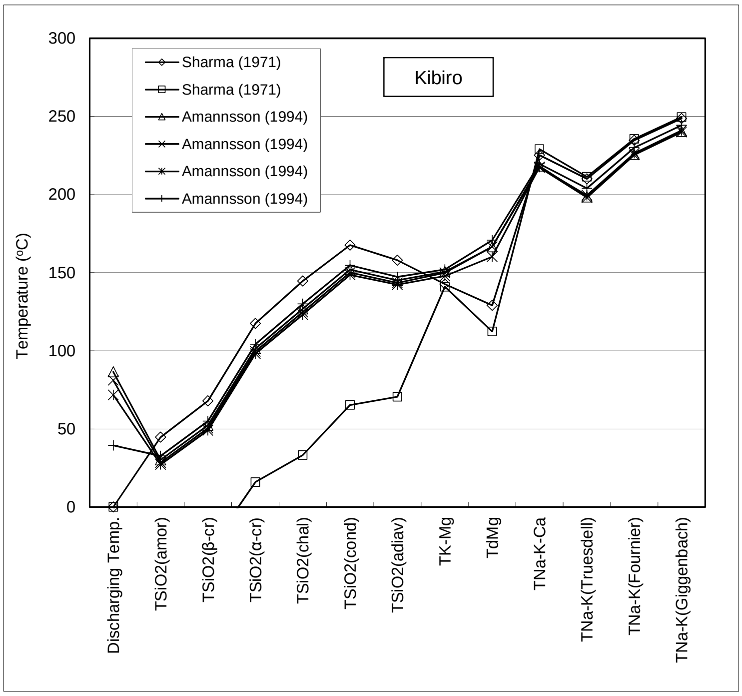
(Study team)

Fig. II-37 Cl-B diagram of hot spring waters (Kibiro area)



(Study team)

Fig. II-38 Ternary Na-K-Mg diagram (Kibiro area)



(Study team)

Fig. II-39 Calculated geothermometers for Kibiro

Table II-18 Calculated geothermometry results (Kibiro area)

Area		Kibiro					
Site		Sharma (1971)		Armannsson (1994)			
Sample No.		Sharma (1)	Sharma (2)	Amannsson (1)	Amannsson (2)	Amannsson (3)	Amannsson (4)
(℃)	Discharging Temp.	no data	no data	86.5	81.1	71.8	39.5
Geothermometry (℃)	TSiO2(amor)	45	-45	30	29	27	33
	TSiO2(β-cr)	68	-28	52	51	49	55
	TSiO2(α-cr)	117	16	101	100	98	104
	TSiO2(chal)	145	33	127	125	123	130
	TSiO2(cond)	168	65	152	150	149	155
	TSiO2(adiav)	158	71	145	143	142	147
	TK-Mg	143	141	151	150	148	152
	TdMg	129	112	167	167	160	171
	TNa-K-Ca	225	229	218	217	218	220
	TNa-K(Truesdell)	210	211	198	198	200	204
	TNa-K(Fournier)	235	236	226	225	226	230
	TNa-K(Giggenbach)	249	250	240	240	241	244

(Study team)

II-5-5 GIS

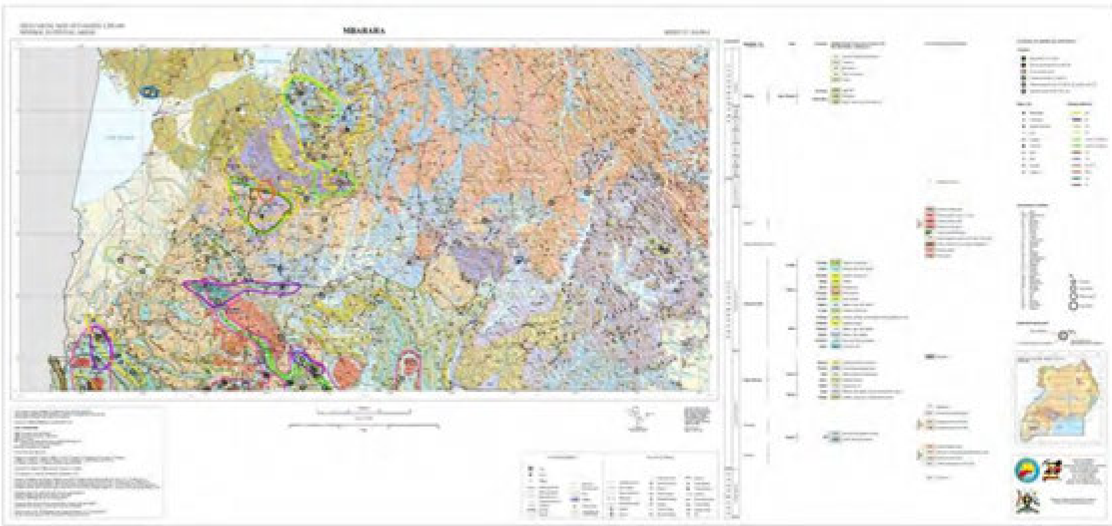
GIS data consisting of remote sensing data, geological maps, natural reserve and power line maps and the coordinates of concession areas were collected in this survey.

Remote sensing data were collected in the first year study. These data are mentioned in chapter II-5-2. Geological Maps and the power line map are considered below.

1. Geological Maps

Seven geological maps were provided by DGSM. The digital data format is the Arc GIS shape file format.

- Geological Map of Uganda 1:250,000, FORT PORTAL, sheet No.NA-36-13.
- Geological Map of Uganda 1:250,000, MBARARA, sheet No.SA-36-1.
- Geological Map of Uganda 1:250,000, KABALE, sheet No.SA-36-5.
- Geological Map of Uganda 1:250,000, KAMPALA, sheet No.NA-36-14.
- Geological Map of Uganda 1:250,000, JINJA, sheet No.NA-36-15.
- Geological Map of Uganda 1:250,000, MASAKA, sheet No.SA-36-2.
- Geological Map of Uganda 1:250,000, HOMEBAY, sheet No.SA-36-3.

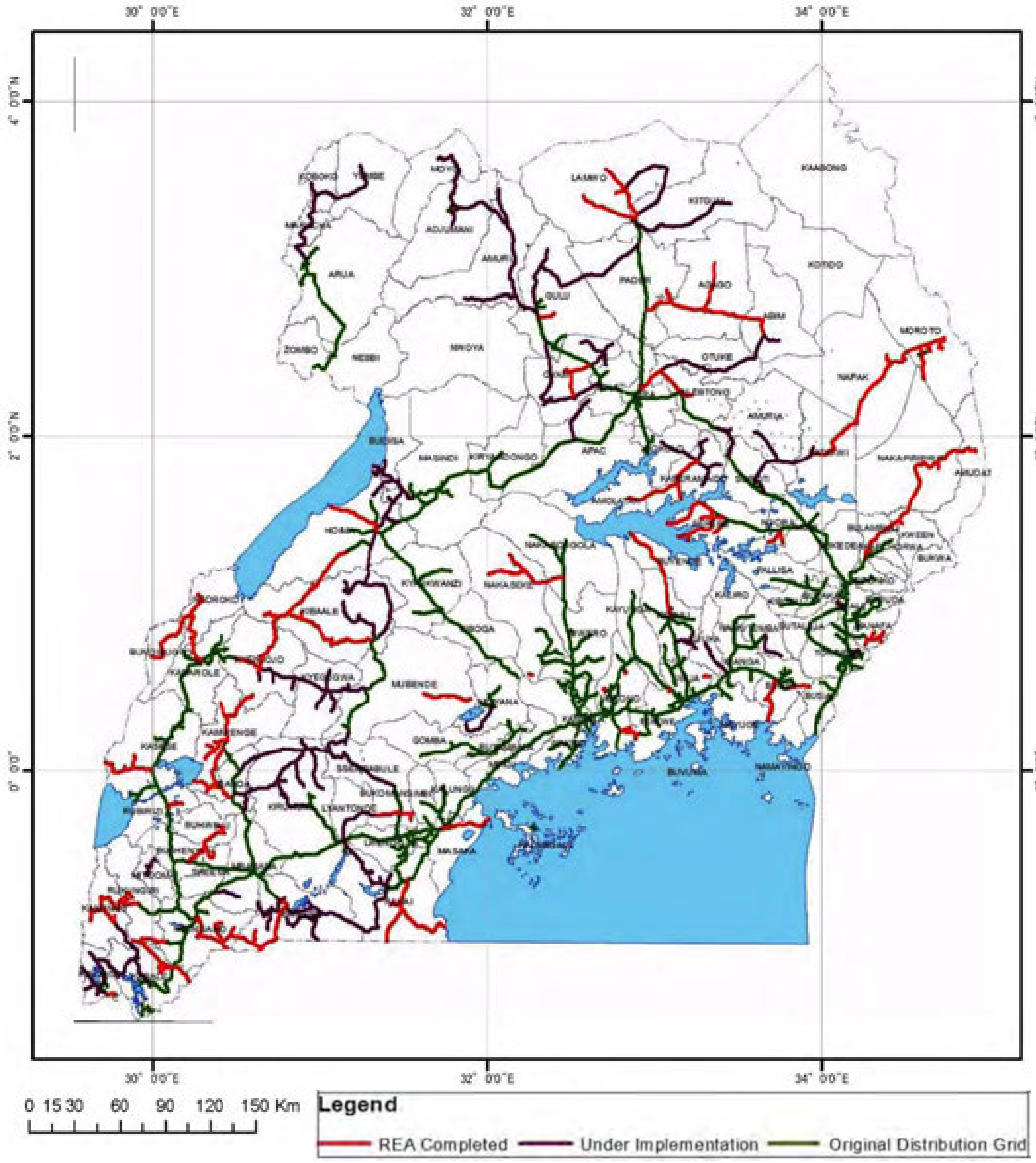


(DGSM)

Fig. II-40 Sample Geological map of Uganda

2. Power line Map

The current grid distribution map is shown in Fig. II-41. This map refers to MEMD (2012) Joint Sector Review.



(MEMD, 2012)

Fig. II-41 Current grid distribution network of Uganda

II-5-6 Selection of Promising Areas

In order to identify promising geothermal areas, a 'score-sum' method, which is generally used in the earliest stage of a geothermal survey, is applied to each surveyed site on the basis of the field survey results (Table II-19 and Table II-20). This identification method follows a simple addition formula, and offers a precise total score enabling an objective evaluation of the field. This method has the advantages of selecting appropriate items under each category and of score traceability. On the other hand, there is some difficulty in determining the criterion for each item and/or category. The score should be determined by applying GIS functions to thematic maps.

There are two steps to the examination of a field undertaken in this survey. The first step is to consider its geological aspects, and the second is to take account of its environmental aspects. After the field has passed through the first step, its environmental aspects are examined in the second step.

In the first step, information about geothermal manifestations such as surface geology and hot spring data from this field survey were used for resource evaluation. The reservoir temperatures of almost all of the fields were less than 200 ^{o}C, so it is likely that a binary generation system will be applied. Therefore, the weighting of the points for each category was set in view of the likelihood of the application of a binary system.

The following criteria were used for the evaluation.

- Geological aspects
  - ☐ Volcanic heat source : Quaternary volcanic rocks

    Generally, magma is the main heat source for a geothermal system in a volcanic area. Promising geothermal areas are often located around volcanos, though it depends on the scale of the volcano (activity of magma). The presence of volcanic rocks formed by volcanic activity is an indicator of volcanic activity. However, if the distributed volcanic rocks are older than Quaternary, the magma may already be cold. Therefore, it's important to ascertain whether the volcanic rocks are Quaternary or not. Furthermore, if the volcano is too young, the geothermal system may not yet have matured. A tentative weighting based on the presence of Quaternary volcanic rocks is as follows.

    Distribution of Quaternary volcanic rocks: weight 6
    Within 10km of Quaternary volcanic rocks: weight 4
    Over 10km from Quaternary volcanic rocks: weight 2

  - ☐ Permeable zone : Faults and/or lineaments

    In many geothermal areas, a highly permeable zone along a fault is the major path for geothermal fluid. Thus, the presence of a large-scale fault is an indicator of a geological structure providing a pathway for the geothermal fluid. Further, it is expected that water permeability will be high in areas where several faults intersect. Thus, the following tentative weighting was given to the presence of faults and lineaments.

    Presence of a large fault and/or intersection of faults: weight 6
    Presence of a fault and/or lineament: weight 4
    No structure: weight 2

- Cap rock formation

  In most geothermal areas, cap rock forms between the geothermal reservoir and low-temperature shallow groundwater and prevents reservoir cooling caused by the inflow of shallow groundwater. In general, argillated rocks formed by hydrothermal alteration in the deep portion constitute the cap rock in many cases. However, the data is insufficient to estimate underground conditions at this stage. There is a possibility, though, that low permeability rock such as lava plays an important role in sealing the geothermal reservoir from shallow groundwater. Thus, the following tentative weighting is given to the presence of a formation which may function as a cap rock.

  Presence of lava: weight 6

  Presence of overburden: weight 4

  No seal: weight 2

- Hot spring features
  - Fumaroles

    The presence of fumaroles with a boiling point or higher temperature is always an important indicator of a high-temperature geothermal reservoir under the ground. Thus, the presence of fumaroles is given the following tentative weighting.

    Presence of fumaroles: weight 10

    No fumaroles: weight: 0
  - Hot spring temperature

    Hot spring temperature can also indicate a high-temperature geothermal reservoir under the ground. The following tentative weighting is proposed, considering the possibility of the development of a binary plant.

    Hot spring temperature above 80ºC: weight 8

    Hot spring temperature below 80ºC but not lower than 60ºC: weight 4

    Hot spring temperature below 60ºC: weight 1
  - Estimated reservoir temperature (fluid geothermometry)

    The following tentative weighting was given to the estimated reservoir temperature (fluid geothermometry).

    Estimated (fluid geothermometry) reservoir temperature is above 200ºC: weight 10 (There is a possibility of flash-type generation)

    Estimated (fluid geothermometry) reservoir temperature below 200ºC but not lower than 170ºC: weight 8

    Estimated (fluid geothermometry) reservoir temperature below 170ºC but not lower than 140ºC: weight 6

    Estimated (fluid geothermometry) reservoir temperature below 140ºC but not lower than 100ºC: weight 4

    Estimated (fluid geothermometry) reservoir temperature below 100ºC: weight 1

- ☐ Surface extent

  The surface extent of geothermal manifestations sometimes reflects the distribution of geothermal activity. It is tentatively weighted as follows.

  Extent on the surface exceeds 0.01 km2: weight 2

  Extent on the surface does not exceed 0.01 km2: weight 1

- ☐ Composition of a Deep reservoir

  The chemical composition of hot spring water (such as the major anion composition, for example) can indicate the possibility of mixing of deep high-temperature geothermal fluid. The tentative weighting of this factor is as follows.

  Mixing of deep high-temperature geothermal fluid is remarkable: weight 3

  Mixing of deep high-temperature geothermal fluid is not remarkable: weight 2

  Mixing of deep high-temperature geothermal fluid is not indicated: weight 1

In addition, since there are no geothermal fields that have reached the stage of power plant construction in Uganda, it's impossible to verify which indicators are most suitable for determining promising areas. In the above proposed weightings, therefore, the weightings are tentatively set based on the experience of geothermal development in Japan. It will be necessary in the future to verify the validity of the indicators and weightings described above, when Uganda has accumulated greater geothermal development experience. There is also the possibility that new promising data may be obtained in some future research, since only representative geothermal fields have been the focus of this survey. Therefore, it is desirable that the evaluation criteria set out above should be updated in the future on the basis of further geothermal surveying.

In the second step, the environmental aspects of the fields selected in the first step are examined.

The following criteria were used for the environmental evaluation.

- ➢ Natural reserves : National parks

  Development in environmentally protected areas such as national parks and game reserves will face certain difficulties in the form of additional environmental regulations. A tentative weighting as for this factor is as follows.

  No reserve: weight 10

  Game reserve: weight 4

  National park and/or conservation area: weight 1

- ➢ Power line : Distance from the site

  If the geothermal development field is far from existing power lines, a new power line must be constructed, involving a certain amount of additional work. So, this factor is tentatively weighted as follows.

  Distance to power line is less than 5 km: weight 4

  Distance to power line is 5 – 10 km: weight 2

  Distance to power line is greater than 10 km: weight 1

- Concessions

  If a geothermal development field is already covered by a private sector concession, the Ugandan government will face additional difficulty in developing it. So, this factor is tentatively weighted as follows.

  No concession: weight 8
  Other land uses: weight 4
  Concession already established: weight 1

- Population

  The distance from the main power consumption areas to the geothermal development field, has a certain influence on the priority of development. This factor is tentatively weighting as follows.

  Close to a large city (capital of the state or following): weight 3
  Close to a town or village (smaller than the above): weight 2
  In a remote area: weight 1

- Social acceptance

  If there is social opposition to a geothermal development, it will make development more difficult. This factor is tentatively weighted as following, referring the behavior of the chief when the study team met one.

  Socially accepted: weight 3
  Unknown: weight 2
  Not socially accepted: weight 1

- Accessibility

  If there is no access road to the geothermal development field, it will make development more difficult. This factor is tentatively weighted as follows.

  Access road less than 1 km: weight 3
  Access road from 1 – 3 km: weight 2
  Access road greater than 3 km: weight 1

The results from the first evaluation step determined the selection as promising fields of fields with over 15 points (although the prospectivity of fields with less than 15 points is not ruled out.)

- Minera (15 pts)
- Ihimbo (15 pts)
- Muhokya (17 pts)
- Kibenge (15 pts)
- Rwagimba (22 pts)
- Rwimi (17 pts)

When the points for evaluating environmental aspects were added in the second step to the fields determined to be promising in the first step, the following 2 fields achieved the highest score of 45 points.

- Muhokya (45 pts)
- Rwimi (45 pts)

Rwagimba, which had high scores in the resource aspects of the first step, had low scores in the environmental aspects, so Muhokya and Rwimi was achieved higher total score than Rwagimba. No single outstanding field was found in this survey.

Table II-19 Geothermal resource evaluation of surveyed area

Category	Item	Criteria	Point	Score																
				Southwestern area												Western area				
				Kagamba	Karungu	Bubale	Rubaare	Kisiizi	Rubabo	Birara	Minera	Ihimbo	Kanyina-barongo	Kiruruma	Kitagata	Muhokya	Kibenge	Ndugutu	Rwagimba	Rwimi
Geological aspect	Heat source	Distribution of Quaternary volcanic rocks Within 10 km far from volcanic rocks Over 10 km far from volcanic rocks	6 4 2	2	2	2	2	2	2	2	2	2	2	2	2	4	2	2	2	4
	Structure	Large fault and/or intersection of faults Fault and/or lineamet No structure	6 4 2	4	6	2	4	4	4	4	4	2	4	2	4	6	6	6	6	2
	Seal	Lava Overburden No seal	6 4 2	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	3
Hot spring features	Fumarole	Existence of fumarole	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Hot spring temperature	Not lower than 80ºC Lower than 80ºC and not lower than 60ºC Lower than 60ºC	8 4 1	1	1	1	1	1	1	1	1	4	1	1	1	1	1	1	4	1
	Estimated reservoir temperature (fluid geothermometry)	Not lower than 200ºC Lower than 200ºC and not lower than 170ºC Lower than 170ºC and not lower than 140ºC Lower than 140ºC and not lower than 100ºC Lower than 100ºC	10 8 6 4 1	-	1	1	1	-	1	1	4	4	1	1	1	1	1	-	6	4
	Extent on the surface	Exceeding 0.01 km^2 Not exceeding 0.01 km^2	2 1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1
	Composition	Deep Intermediate Shallow	3 2 1	1	1	1	2	1	1	1	2	1	1	1	1	2	2	-	2	2
Subtotal score in 1st step				10	13	9	12	10	11	12	15	15	11	9	11	17	15	13	22	17
Remarks				Floats of travertine limestone			Travertine limestone		Travertine limestone	hot springs are located in both side of the river						Lacustrine limestone Marginal fault	Marginal fault	Travertine limestone Marginal fault	Marginal fault	Travertine limestone Volcanic area

Footnote: Area size is apploximately 5 km in diameter centerd each hot spring sampling point.
( ) : guessed from nearby field because not analysed
- : No hot water

(Study team)

Table II-20 Social and environmental evaluation of surveyed area

Category	Item	Criteria	Point	Score																
				Southwestern area												Western area				
				Kagamba	Karungu	Bubale	Rubaare	Kisiizi	Rubabo	Birara	Minera	Ihimbo	Kanyina-barongo	Kiruruma	Kitagata	Muhokya	Kibenge	Ndugutu	Rwagimba	Rwimi
Environmental aspect	Natural reserves	No reserve Game reserves National parks and/or Conservation	10 4 1	10	10	10	10	10	10	10	10	4	10	10	10	10	10	10	10	10
Engineering aspect	Power line	<= 5 km 5-10 km >=10 km	4 2 1	1	2	4	1	1	1	1	1	1	1	1	4	4	1	2	1	4
Socio-economic aspect	Concession	None Other landuses Already established	8 4 1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	1	8
	Population	Close to large city Close to town or village Remote area	3 2 1	2	1	3	1	1	1	1	1	1	1	1	2	1	3	1	1	1
	Social acceptance	Yes Yes or No No	3 2 1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Others	Accessivility	<= 1 km 1-3 km >= 3 km	3 2 1	3	3	3	1	3	2	1	2	3	2	2	2	3	3	3	1	3
Subtotal score in 2nd step				26	26	30	23	25	24	23	24	19	24	24	28	28	27	26	16	28
Subtotal score from 1st step				10	13	9	12	10	11	12	15	15	11	9	11	17	15	13	22	17
Total score				36	39	39	35	35	35	35	39	34	35	33	39	45	42	39	38	45
Remarks						Close to Kabale city						Forest reserve area			Close to Kitakata town		Close to Kasese city		Concession	

(Study team)

II-5-7 Estimation of the geothermal resource potential

The volumetric method for estimating geothermal resource potential uses a single-phase extraction model. The thermal energy contained in the rock and in the water extracted under exploitation is computed. The recovery factor, which represents a small fraction of the total recoverable heat content of the rock and water, approximates the resource that can be harnessed at the surface. The recovered thermal energy is then converted to electrical energy using conversion efficiency, a function of geothermal temperature. For a specified plant life, the generating potential of the field in MW can be derived.

Power Capacity [MW] $=(Tr-Ta)\times\{(1-\phi)\times Cpr\times\rho r+\phi\times Cpw\times\rho w\}\times V\times RF\times CE/(LF\times PL)$

ρr, ρw	: rock density and fluid density(kg/m^3)
Cpr, Cpw	: rock specific heat and fluid specific heat (kJ/kg-ºC)
Tr, Ta	: reservoir temperature and abandonment temperature (ºC)
ϕ	: porosity (%)
V	: reservoir volume (km^3)
RF	: recovery factor (%)
CE	: conversion efficiency (%)
LF	: load factor (%)
PL	: plant life (years)

Using a distribution of the probable values for each of the parameters relevant to the estimation of the geothermal potential, Monte Carlo analysis is used to statistically estimate, by trying all possible combinations of these parameters, the most probable power capacity of the field. The distribution of parameters involved may include values that are not precisely known but can be part of the probability distribution. Triangular distribution or rectangular distribution (see Fig. II-42) are the probability distributions usually applied in this estimation.

Reservoir Volume

The thickness of each field is assumed to be as follows: the minimum is 1,800m, the medium is 2,000m and the maximum is 2,200m. The assumed maximum and minimum area of a given field can be estimated from the distribution of geothermal manifestations. The reservoir volume can then be obtained by multiplying the thickness by the area. Later verification of the reservoir volume based on further detailed surveying will be necessary, however, because the values used here are just estimates.

Reservoir Temperature and Abandonment Temperature

The minimum, medium and maximum values for reservoir temperature are based on geothermometry. Basically, the minimum temperature is the alkaline geothermometer (Na-K-Ca) value, and the medium and maximum temperatures are established by adding 20 and 40 ºC, respectively, to the minimum value.

The abandonment temperature is assumed to be 80 ºC for a binary type plant. (Generally, this rises to 180

°C for a flash type.)

Rock Density

2,400kg/m^3, 2,500kg/m^3 and 2,600kg/m^3 are assumed as the minimum, median and maximum for an area of Cenozoic formation, while 2,600kg/m^3 and 3,000kg/m^3 are the minimum and maximum for an area of pre-Mesozoic formation.

Rock Specific Heat

The rock specific heat is assumed to range from 0.7 to 1.0 kJ/kg- °C based on the general value for rock given by rectangular distribution.

Porosity

5% and 10% are assumed as minimum and maximum values for areas of Cenozoic formation. 1% and 5% are similarly assumed for areas of pre-Mesozoic formation.

Fluid Density and Specific Heat

The fluid density and specific heat are obtained from the steam tables by rectangular distribution.

Recovery Factor

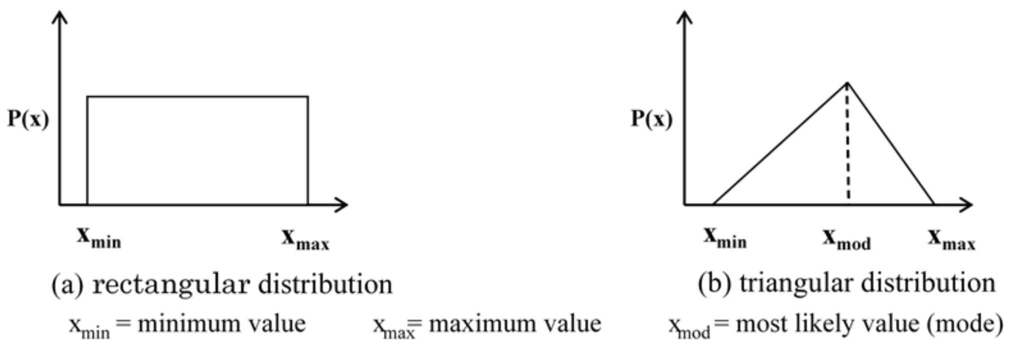
In general, the recovery factor is assumed to be 2.5 times the porosity value from rectangular distribution. Thus, the recovery factor ranges from 2.5% to 12.5%.

Conversion Efficiency

Minimum, median and maximum values for conversion efficiency are assumed to be 1.9%, 6.3% and 11.4% for a binary type plant. (Generally, 12% is the minimum and 14% the maximum for a flash type.)

Plant Life and Load Factor

The plant life and load factor are assumed to be 30 years and 85%, respectively.

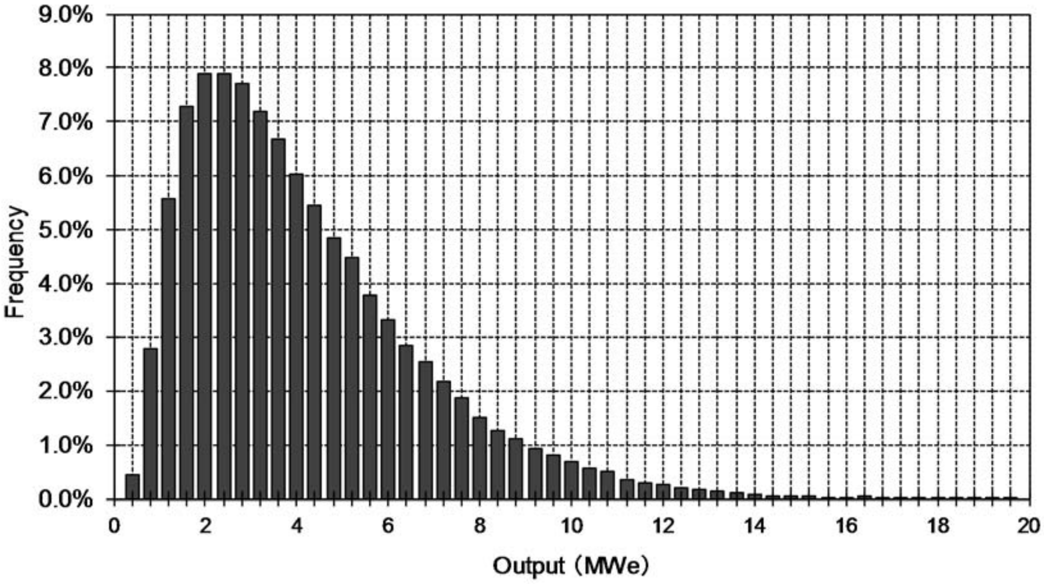


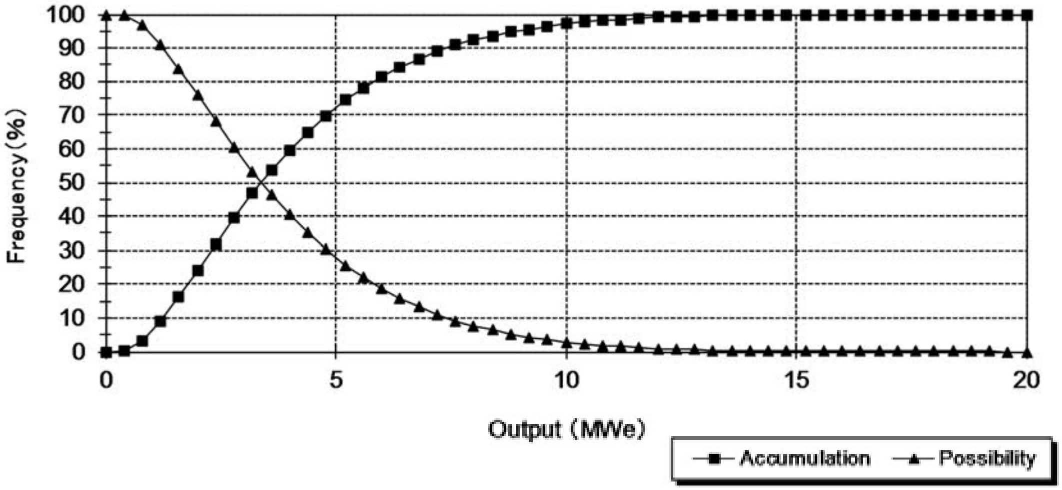
(Study team)

Fig. II-42 Assumed Probability Distribution

An example of input parameters and the results of geothermal resource potential calculation (for Minera) are shown in Fig. II-43. The geothermal resource potential of Minera is calculated to be 2.00MW with an 80% probability. The temperature of the hot water used as a heat source for binary system plants should be higher than 100°C. Therefore, fields with a reservoir temperature of less than 100°C were eliminated from the resource calculation because it's impossible to utilize them for generation, given the present technology (although direct use is possible). Calculation results for 3 fields other than Minera with a reservoir temperature over 100°C (Ihimbo, Rwagimba and Rwimi) are attached in Appx -7. The reservoir temperature of Kibiro is over 210°C based on the geothermometry of the fluid, so flash-type power generation will be possible in that field, though it's in a concession area that we therefore did not survey. A potential of 39 MW was calculated for flash-type power generation at Kibiro (Table II-21). The total potential of these 4 fields with an assumed binary system plant and Kibiro with an assumed flash-type plant is about 50MW. In the above, only the geothermal resource potential of the southern part of Lake Albert in Uganda was considered. Major geothermal fields in the study area at Katwe and Buranga were eliminated from the calculations because of environmental issues impeding a JICA project. Given these facts, the calculated geothermal resource potential is thought to be really small compared with the estimated total for Uganda (about 450MW). The reservoir temperature of Buranga is expected to be over 210°C based on the geothermometry of the fluid. For Katwe, it's difficult to estimate reservoir temperature from the geothermometry of the fluid because of the anion-cation imbalance, but a reservoir temperature of over 210°C is expected. Therefore, both of these fields may have an equal or greater potential than Kibiro.

The geothermal data that have been surveyed in this study are limited, and many fields seem to remain at the regional survey stage (requiring additional investigation). Therefore, the possibility remains that fields where the reservoir temperature is presently estimated to be below 100°C will be reevaluated and shown to be over 100°C with the discovery of new hot springs in future investigations.





Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	1.50	-	3.75
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg°C)	0.70	-	1.00
Reservoir Average Temperature (°C)	115	135	155
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	1.9%	6.3%	11.4%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (°C)	-	80	-

Probability Distribution of the Geothermal Potential for Minera

(Study team)

Fig. II-43 Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis (Minera)

Table II-21 Results of geothermal resource potential calculation

	Field Name	Estimated Potential (MW)	Remarks
Surveyed areas	Minera	2.00	Assuming binary system plant
	Ihimbo	2.38	Assuming binary system plant
	Rwagimba	4.52	Assuming binary system plant
	Rwimi	1.81	Assuming binary system plant
Unsurveyed areas	Kibiro	14.90	Assuming binary system plant
		38.89	Assuming flash type plant
Total		25.61	Assuming binary system plant at Kibiro
		49.60	Assuming flash type plant at Kibiro

(Study team)

II-6 Environmental and Social Considerations

Uganda has had the National Environmental Act since 1995. The Environmental Impact Assessment Regulations were issued in 1998 and the Guidelines for Environmental Impact Assessment in 1997. In addition to the EIA guidelines, sectoral guidelines for the EIA and some other relevant Acts and regulations are listed in Table II-22. The National Environmental Management Authority (NEMA) coordinates and issues all environmental permits according to the National Environmental Act.

Annex 3 of the EIA guidelines details the projects that are covered under these laws. Geothermal power development projects are covered under electrical infrastructure projects (item No. 11) and also under mining (item No. 6), because the drilling of wells to extract steam or hot water is a mining process. However, since conditions on project scale are not prescribed, the requirement for a full-scale EIA is determined during the EIA screening process.

A flow chart for the EIA procedures is shown in Fig. II-44. It takes a maximum of 180 days to obtain an EIA decision after the project proponent submits an EIA report to NEMA. On average, this period is shorter than 180 days. During the assessment process, feedback is provided by NEMA to the project proponent within 21 business days in the case of an IEE and within 30 business days in the case of a full-scale EIA. Expenses for the EIA assessment are based on the standard costs prescribed in the EIA regulation of 1998. EIA studies are carried out by companies or individual professionals registered with NEMA.

Review of EIA reports is conducted by NEMA. Upon receipt of an EIA report from the project proponent, NEMA sends the report to the lead agency for the project and the relevant district office where the project is located, seeking their comments as a part of the stakeholder consultation. In the case of controversial projects, an ad hoc technical committee is formed to prepare comments. Public hearings are held in the case of such controversial projects. In non-controversial cases, a summary of the EIA report is made public and opened for comments. The summary of the EIA report is translated into the local language and made available at NEMA, in public libraries, at Makerere University, and in the Environmental Division of the relevant District Office.

Though land acquisition and resettlement are required to be considered as a social environmental issue in an EIA, there are no detailed requirements in the current EIA guidelines. Since there is no other regulations/guidelines on land acquisition and resettlement separate from the EIA guidelines, the guidelines of the World Bank on this issue are used in practice. The District Land Board in the project area is responsible for handling land acquisition and resettlement issues.

The number of EIAs which require a full-scale EIA has gone up, and some 300 EIAs are filed for approval every year. Among those EIAs, around 30 projects are related to the energy sector, mainly the oil exploitation industry.

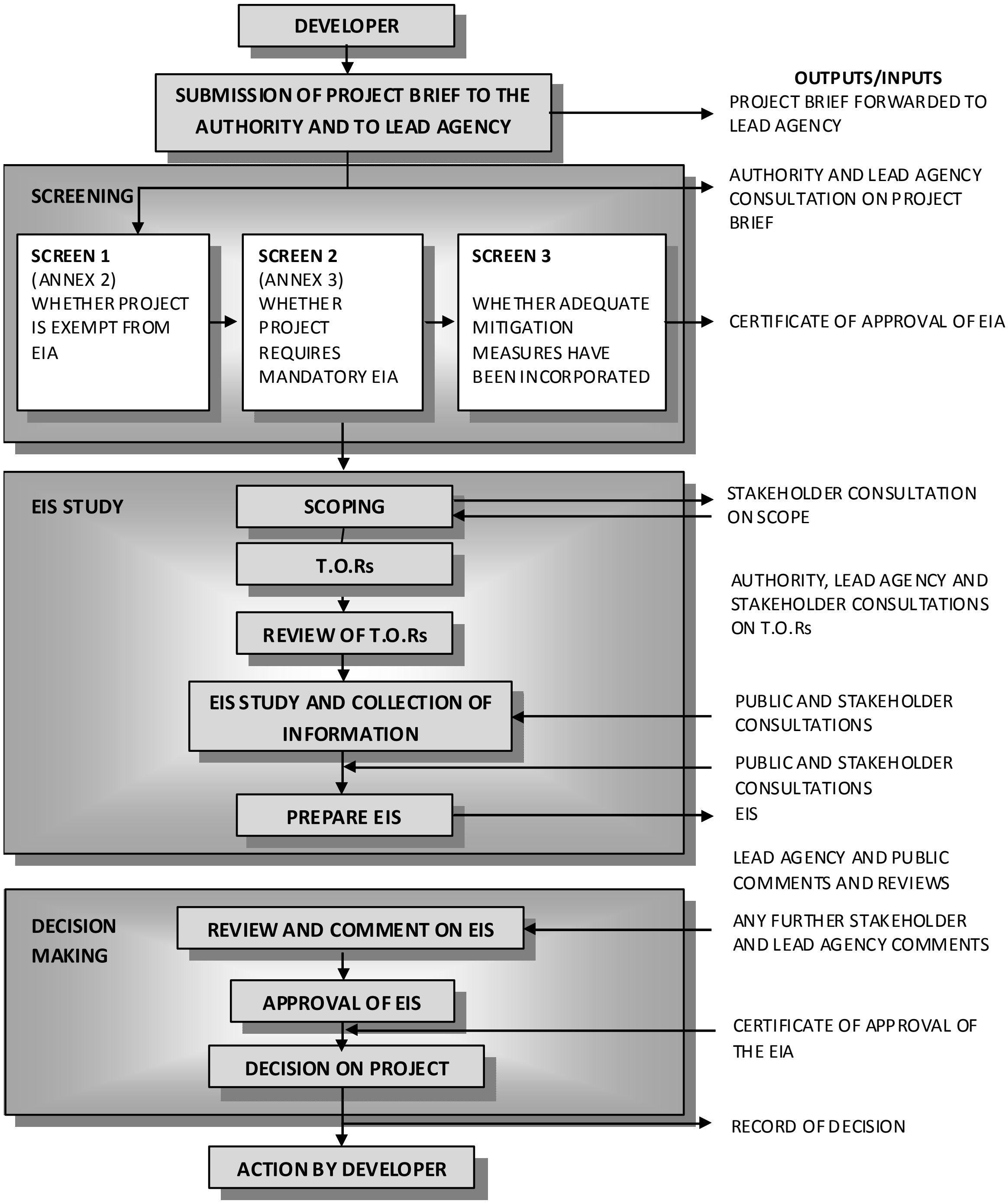
The major environmental issues related to development projects are resettlement, pollution-related health damage, and trans-boundary impacts on the natural environment. NEMA believes that the issues to be addressed in the geothermal development are well drilling, well exploitation and power plant construction.

Table II-22 Relevant Environmental Legislation and Standards in Uganda

No.	Name of Legislation
1	The National Environmental Act, Cap 153 (Commencement 19 May, 1995)
2	The Environmental Impact Assessment Regulation, S.I. No. 13/1998
3	Guidelines for Environmental Impact Assessment in Uganda, NEMA, 1997
4	Sectoral Guidelines for the Environmental Impact Assessment Process for the Mining Sector in Uganda (Draft under review process), NEMA
5	The National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, S.I. No 5/1999
6	The National Environment (Noise Standards And Control) Regulations, 2003
7	The National Environment (Hilly And Mountainous Area Management) Regulations, 2000
8	The National Environment (Management Of Ozone Depleting Substances And Products) Regulations 2001
9	The National Environment (Access to Genetic Resources and Benefit Sharing) Regulations, 2005
10	The Mining Act, 2003
11	The National Forestry and Tree Planting Act, 8/2003
12	The Water Act, Cap. 152
13	Uganda Wildlife Act (Cap 200) of 2000

(NEMA)

DGSM has approval from the Uganda Wildlife Authority, which is in charge of National Parks, to carry out surface exploration work in the National Parks. However, IPPs are required to seek approval from the Authority. It was further reported that NEMA has sought an individual consultant to develop EIA guidelines specifically for geothermal activities. Proposals have been received but no decision has been made as yet.



(NEMA, 1997)

Fig. II-44 Process of EIA Report Preparation and Assessment Process

III Proposal of Future Assistance Plan

III-1 Characteristic of Geothermal Resource

Geothermal resources are a form of domestic renewable energy that does not depend on imports from other countries. It's a bit difficult to expect a single unit to deliver a large power capacity, but geothermal power plants worldwide operate with very little downtime and can function continuously at capacity for up to 90% of the time, so they are one of the base load power sources. It's also possible for a geothermal facility to generate power stably for many years with appropriate operation and maintenance centered on reservoir maintenance.

The presence of water (as a carrier of heat energy) is an important factor in the utilization of geothermal resources for power generation, together with an elevated temperature (heat energy) and a reservoir where heated water is stored or flows. For power generation in a conventional system, a temperature higher than 200^{o}C is usually required and for generation in a binary system, a temperature higher than 100^{o}C. A layer near the ground surface composed of unconsolidated coarse grain materials (sand, pebbles, etc.) usually has good permeability and can store water. However, the permeability of rock bodies extending under the ground is generally not so good, though there are some exceptions. Moreover, the presence of an impermeable layer lying over the geothermal reservoir is desirable. When a reservoir is associated with an overlying impermeable layer, it is expected that the impermeable layer will prevent the reservoir from being cooled by the inflow of cold groundwater.

Identified geothermal reservoirs in the world are roughly classified into two categories according to the medium storing the geothermal fluid: "fracture type" and "porous media type". A fracture type geothermal reservoir lies in a fractured zone where the constituent rocks are fractured (see Fig. III-1). Faulting and intrusion of rock bodies will cause fracturing in existing rock formations. Considering the geological conditions around the identified geothermal reservoirs in the world, it can be seen that the majority of fracture type geothermal reservoirs occur in a fractured zone associated with a fault. The impermeable layer lying over the reservoir is usually composed of argillized rocks characterized by the occurrence of smectite. This argillization results from a water-rock interaction under relatively low temperature conditions (lower than 200^{o}C). This impermeable layer is often detected as a low resistivity layer (zone) by resistivity surveying.

A porous media type geothermal reservoir lies in a permeable stratum and has a greater lateral extent (see Fig. III-2). The overlying impermeable stratum is usually composed of a compact formation such as intensively welded tuff. On the whole, occurrence of this type reservoir is rather rare. Moreover, geothermal fluid stored in such a reservoir is generally supplied by a fracture type reservoir.

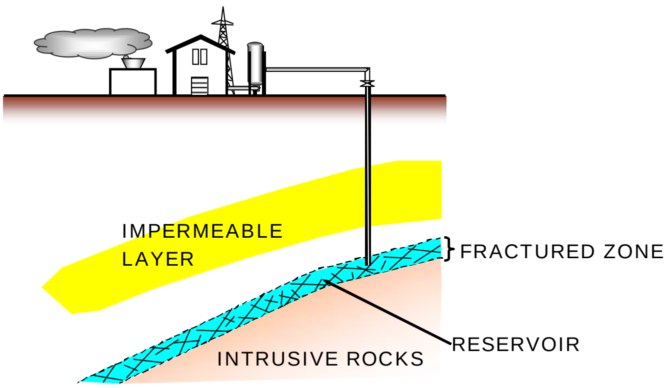
For successful geothermal development and geothermal well drilling, geological and geothermal structures should be clarified mainly through the use of geological and geophysical techniques. Delineation of geothermal reservoirs based on the surface survey results is vital work for estimating the distribution and extent of the reservoirs. The results of these studies, namely the geothermal structures and reservoir extents, are used as working assumptions for exploratory well drilling. These assumptions concerning the geothermal structure and reservoir extent are ascertained using exploratory wells.

Geothermal reservoirs are sometimes categorized by the phase of the stored geothermal water (H_2O) into a water-dominated type, a vapor-dominated type and so on. The majority of geothermal reservoirs are of the water-dominated type. In a water-dominated reservoir, the water is present in the liquid phase. In a vapor-dominated reservoir, water in the liquid phase and water in the gas phase (steam) coexist in the reservoir (a two-phase reservoir). In rare cases, a reservoir may consist of superheated steam.

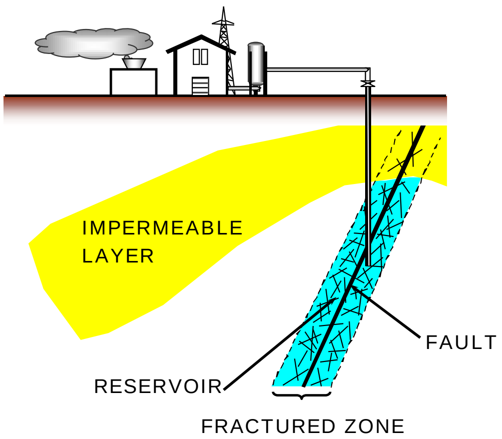
In consideration of the interference problems and decline problems attendant on steam production and brine reinjection, a water-dominated reservoir is favored for geothermal development. However, a vapor-dominated reservoir has the advantage of scarcely requiring reinjection wells for waste brine. A vapor-dominated reservoir is sometimes identified above a water-dominated reservoir, as shown in Fig. III-3. In such a case, the vapor-dominated reservoir is often called a "steam cap". In some geothermal fields, the steam cap has a considerable extent and high potential. Steam caps have been identified underneath impermeable layers.

The fluid type a well discharges is a critical factor in geothermal field operation. The fluid type of geothermal reservoirs is usually studied using geochemical methods and confirmed by exploratory well drilling and flow tests.

The chemical characteristics of the geothermal fluids are controlled by water-rock interactions under high temperature conditions and/or chemical reaction with gases such as H_2S, CO_2 etc. These chemical components provide vital clues for assessing the reservoir characteristics, its temperature, and other information that is crucial during the pre-drilling exploratory stages of geothermal resource development. In particular, high-temperature, chloride-type hot water is regarded as most important, because this type of water is usually derived from a water-dominated reservoir with a temperature higher than 200^{o}C. Acidic sulfate-type hot water and fumaroles are also important, because this water and the fumarolic gases may originate from high-temperature geothermal reservoirs. Detecting these manifestations and clarifying the reservoir characteristics using geochemical techniques provide crucial information concerning the geothermal reservoirs.



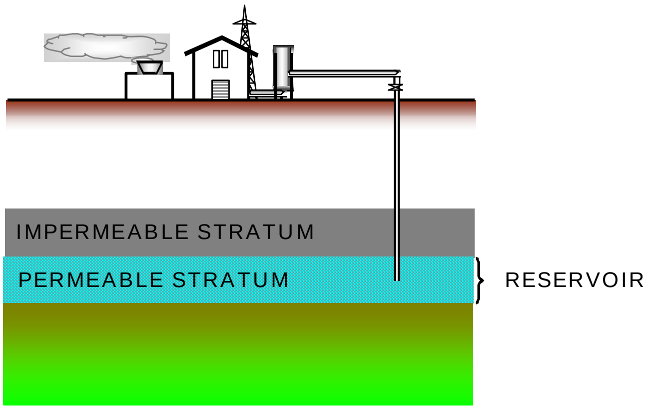
(a) Fractured zone associated with intrusive body



(b) Fractured zone associated with fault

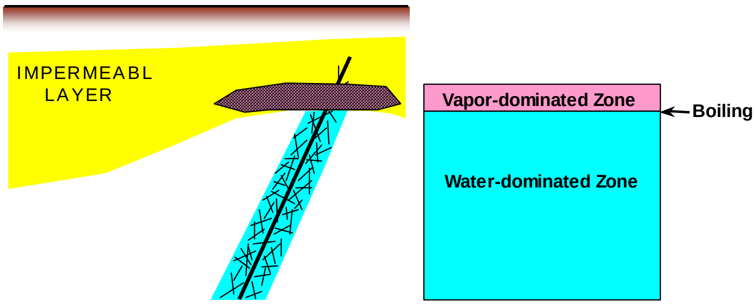
(Study team)

Fig. III-1 Example of fracture type geothermal reservoir



(Study team)

Fig. III-2 Example of porous media type geothermal reservoir



(Study team)

Fig. III-3 Example of vapor-dominated reservoir above a water-dominated reservoir

III-2 General Flow of Geothermal Resource Development

As development risk (leading to an unfavorable result) is not negligible in steam field development, a phased process of steam field development is usually adopted. One typical process of steam field development is shown in Fig. III-4. The development process is composed of the following four stages:

1st Stage Exploration Stage
2nd Stage Feasibility Study Stage
3rd Stage Project Implementation Stage
4th Stage Operation and Maintenance Stage

The goal of the First Stage (Exploration Stage) is to confirm the presence of a geothermal resource, to identify the chemical and physical properties of the geothermal resource and to estimate the resource capacity (optimum output to maintain sustainable operation). The exploration stage is subdivided into the following three phases:

Phase 1 Regional Exploration Phase, to select a prospective area (or areas)
Phase 2 Detailed Exploration Phase, to clarify the presence of a geothermal resource, to identify the geothermal structure and to select drilling targets
Phase 3 Resource Evaluation Phase, to identify the chemical and physical properties of a targeted geothermal reservoir by well drilling and to evaluate resource capacity

In Phase 1 (Regional Exploration Phase), exploration is carried out over the whole of an objective field to select a prospective area (first priority area to study in detail). In Phase 2 (Detailed Exploration

Phase), detailed exploration of sufficient accuracy to permit selection of drilling targets is carried out. In Phase 3 (Resource Evaluation Phase), several exploratory wells (more than three wells is desirable) are drilled to tap the selected targets, and production (discharge) tests are carried out. Moreover, resource evaluation to estimate the optimum sustainable geothermal power generation output is conducted through reservoir simulation using a 3-D numerical model based on the results of the production tests and exploration.

A conceptual model of geothermal resources is usually constructed at the end of each phase, to draw up a revised strategy for the development. In this model, information about the distribution of geological elements controlling geothermal activity, the extent of high temperature anomalies and the flow pattern of geothermal fluid, which are sometimes referred to as "geothermal structure", are represented in a way that is easy to understand. There are many kinds of geothermal exploration technologies contributing to this estimation of geothermal structure for modeling, but no single technology is sufficient on its own.

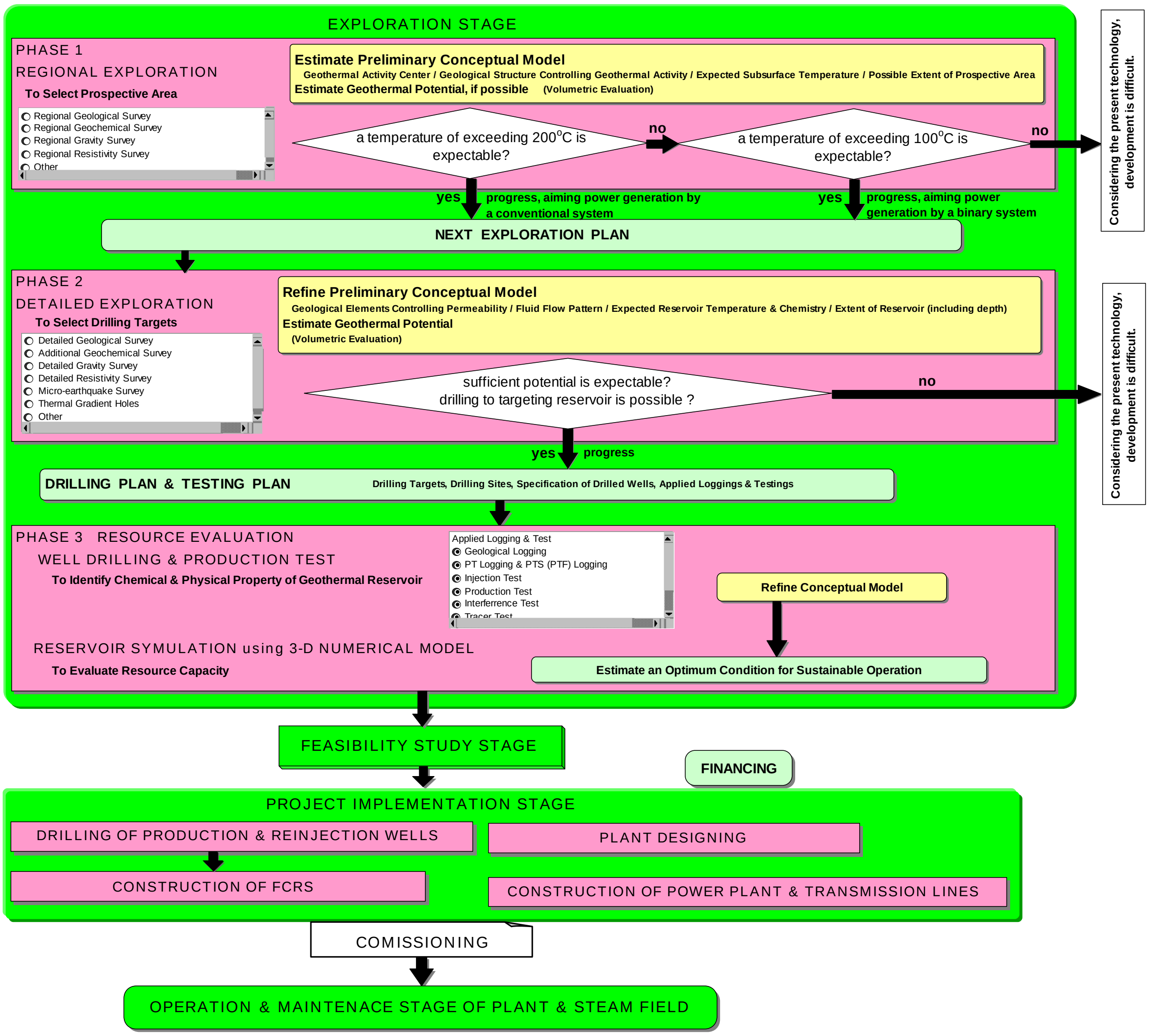
Therefore, a variety of exploration technologies must be applied in order to prepare an adequate model for geothermal development. However, the best combination of technologies to be applied depends on the particular field, as an objective field has unique geothermal resource characteristics and surrounding geological conditions differing from other fields. Although geological, geochemical and MT surveying are rather commonly conducted, consideration of the suitable combination of technologies for the objective field is required at the planning stage. Furthermore, comprehensive analysis and integrated interpretation of the obtained geothermal exploration results will be required.

The work of Phases 1 and 2 in private geothermal development can be undertaken either by the Government or by the private sector. Phase 2 work is of particular importance and is believed to significantly affect the outcome of the geothermal power development project.

In the Second Stage (Feasibility Study Stage), the conceptual design of the future geothermal power station is elaborated, based on estimated optimum output and steam quality as clarified by production tests. At this stage, economic and financial evaluation of the proposed geothermal project is also carried out. It is desirable that a full environmental assessment, including the power plant and associated transmission line, should be completed before the inception of the following stage (Project Implementation Stage).

In the Third Stage (Project Implementation Stage), a detailed design of the power plant and FCRS (Fluid Collection and Reinjection System) is prepared. If the power plant, including pipelines, is constructed using a competitive tendering system to select an EPC contractor, bidding documents for procurement are prepared based on information in the detailed design. Then, the power plant and FCRS are constructed. During construction, the necessary number of additional production and reinjection wells to meet the power plant operation requirements are constructed. Those wells are also subject to long term production tests, following which a review of the geothermal reservoir simulation is conducted.

In the Fourth Stage (Operation and Maintenance Stage), ongoing refinement of the conceptual model on the basis of data accumulated through steam field operation will be required to maintain sustainable steam production (reservoir management).



(Study team)

Fig. III-4 General Flow of Geothermal Resource Development

III-3 Proposed JICA Support

A geothermal power development project is a typical example of a high-risk, low return project. It also characterized by a relatively long lead time. In order to establish the optimum output for sustained and stable power generation for the field, the following investigative steps are necessary. First, in order to identify promising areas, a regional survey (Phase 1) is necessary. Next, a detailed survey of areas shown to be promising in the regional survey is carried out, establishing drilling targets and the extent of the geothermal resource (Phase 2). The geothermal potential of the target area is roughly estimated by applying the stored-heat or volumetric method to the survey results. The estimated geothermal potential value is set as the provisional development goal. However, this provisional estimate does not always correctly indicate the sustainable optimum power output at that point. Geothermal resource evaluation based on exploration well drilling and production testing in the next stage (Phase 3) is required to identify the optimum sustainable power output.

As indicated above, the expected power output is usually unknown at the early stage of development study. The three stages of investigation outlined above are required to ascertain the optimal sustainable power output, and a budget is necessary for these investigations. However, a project sometimes fails, even when the investigation is carried out stage by stage. Such development risks present a barrier to private sector entry. Most geothermal areas in Uganda are still in Phase 1. So the initial development risks constitute a significant factor interfering with private sector participation in geothermal development projects. Some countries have introduced incentives to promote the participation of the private sector (for example, tax incentives in the Philippines). In Japan, surveys corresponding to the Phase 1 to Phase 3 stage have been carried out by government. In other words, government surveys reduce the development risk for the private sector and facilitate its entry. Even in Indonesia, surveys corresponding to phases 1 and 2 have been carried out by government, so the risk is reduced for the private sector, and this promotes development.

Table III-1 General schedule for geothermal development

				1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year
Exploration Stage	Selection of consultant			░								
	Phase 1	Regional Survey		■								
	Phase 2	Detailed Survey		■	■							
	Phase 3	Well Drilling and Testing	Topographical survey		■							
			Drilling contractor selection		░							
			Site preparation of access road and drilling site		■	■						
			Well drilling (3 wells)			■	■					
			Well Testing				■					
		Resource Assessment					■					
F/S Stage		Basic Design of Plant・F/S					■					
Construction Stage	Production Well Injection Well	Drilling contractor selection						░				
		Production/Injection Well Drilling/Well Testing						■	■	■		
		Piping for brine and steam							░	░■	■	
	Power Plant	Selection of Consultant						░				
		Selection of EPC Contractor						░	░			
		Design, Manufacturing, Shop Inspection, Delivery of Equipments & Materials							■	■	■	
		Commissioning									■	
	Transmission Plant	Vendor selection						░				
		Construction work							■	■	■	

Loan Negotiation？ (at the start of the 5th year)

(Study team)

Note: Period for land acquisition, EIA and other legal proceedings are not considered.

As mentioned above in sections II-5-6 and II-5-7, no fields with great geothermal potential or environmentally suitable fields were observed in this study. On the other hand, as mentioned in section II-4-1, there are 4 major geothermal fields in Uganda (Kibiro, Katwe, Panymur and Buranga) and concessions for these have been granted to the private sector, but the license holders are carrying out almost no development. In addition, the government of Uganda is conducting its own geothermal surveying in preparation for the expiration of these concessions (Table II-1). Supporting geothermal surveying of these fields by the Uganda government for is a possibility for JICA after the concessions, for which the period is 3 years, expire. Therefore it's important for JICA to watch the progress of these concession fields closely.

It is recommended that support by JICA in this situation is best directed to enabling these early-stage surveys by the government or governmental agencies. In addition, support for capacity-building among policy makers and/or survey staff involved in early stage development is important because Uganda suffers from a serious lack of geothermal development expertise. Considering the present situation of Uganda and environmental factors like national parks, the following projects are listed up here as possible JICA projects (Table III-2). There also remains the possibility that fields where the reservoir temperature is presently estimated to be below 100^{o}C will be shown to have a temperature over 100^{o}C with the discovery of new hot springs by future investigations.

Many geothermal fields in Uganda appear to still be at the regional survey stage. So, when the Uganda government conducts additional investigation of some fields with a view to promoting geothermal development, support for resource exploration surveying, including technical capacity formation in the form of on-the-job training, is also recommended.

Table III-2 Possible projects of JICA

Project No.	1		
Project Name	Resource Exploration Survey in Kibiro (Table III-3) (When the current concession expires and the situation permits development by the Uganda government)		
Project Outline	To carry out an exploration survey including drilling two (2) to four (4) exploration wells in the Kibiro field.		
Beneficiary	Geological Survey and Mines Department of Uganda (GSMD-MEMD)		
Scheme	Development Study	Category	Resource survey
Project Scale	Approx. 3 years Approx. USD 10-20 million		
Remarks			

Project No.	2		
Project Name	Regulatory Framework Study		
Project Outline	To develop a regulatory framework for geothermal policy, the following are to be studied: - Drawing up a Development Road Map, - Institutional arrangements - Review of regulatory framework, etc.		
Beneficiary	Ministry of Energy and Minerals (MEMD)		
Scheme	Development Study	Category	Policy
Project Scale	Approx. 1-2 years Approx. USD 1 million		
Remarks			

(Study team)

Table III-3 Information about promising geothermal area

1	Country		Uganda
2	Geothermal field name		Kibiro
3	Area name (hot spring name)		Kibiro
4	Local government name		Kibiro village, Hoima district
5	Location/access		Southeast shoreline of Lake Albert, 30km NNW of Hoima
6	Survey/Development status		Surface survey (Geology, geochemistry, airborne and ground magnetic, gravity)
		Stage	Phase1-2 (Table III-1)
7	Information about geothermal resource		
	1) Geology/Structure		Located just under the fault escarpment of eastern edge of the Albertine Rift where a lineament oblique to the fault is observed. The basement consists of Precambrian granites and metamorphic rocks. Argillized ground is reported in the vicinity.
	2) Geochemical	Temperature, chemical properties	Hot spring temperature 86.5ºC, pH7.1, TDS 4,600mg/kg, Cl type (Bahati et al., 2010)
		Geothermometry	Approximately 220ºC（Na-K-Ca temperature）
	3) Geophysical survey		airborne and ground magnetic, gravity
	4) Well Drilling		Not yet
	5) Geothermal structure model		Not constructed yet
	6) Geothermal resource potential		39MW (this survey)
8	Social environment		
	1) Environmental constrains/National park		None (to be confirmed)
	2) Infrastructure, etc.	Transmission line/electrification	30km from major transmission line (field survey is necessary)
		Road/Land use	Unknown (field survey is necessary)
		Population density/Distance from houses	Unknown (field survey is necessary)
		Industry	Unknown (field survey is necessary)
9	Survey problems		Social environment is to be confirmed
10	Proposed geothermal surveying		MT survey, exploratory well drilling
11	Field survey		Not conducted (because it is a concession area)
12	Remarks		

(Study team)

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Appendices

1. Field sheets for each surveyed site

2. Petrograpic analysis of rock samples

3. Results of spectral measurements

4. Chemical Analysis Data for Hot Spring Water (Existing data)

5. Compilation of Geo-thermometers for Hot Springs (Existing data)

6. List of geothermometers for hot springs

7. Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis

1. Field sheets for each surveyed site

Location No.	Ka01		DATE	9-Oct-13		
Place Name	Kagamba		DISTRICT	Kabale		
Cordination;						
Longitude (E)	29.99716	Latitude (N)	-1.32024	Elevation	1805	m
Water sample No.	Ka01					
Temperature	28.4 ℃		Air Temp	17.4 ℃		
pH	7.1 (29℃)		Remark;	pond, diluted		
Electric conductivity	50 mS/m					
Rock sample No.	Ka01	conglomerate				

Geological condition;
The basement rocks are composed of MesoProterozoic meta-sandstone and meta-conglomerate. The foliation of these rocks strikes N45°W dips 90°W is distributed around this place.
The lineaments are developed in ENE-WSW and NE-SW directions.

Discription;
This place is located at the roadside of the Kabale–Katuna road of Kagamba area, being approximately 8km south of Kabale Town. The hot spring is gushing out from unconsolidated sediment in the place. The small pond and wet land are developed in the vicinity.

Location No.	Kr01		DATE	9-Oct-13	
Place Name	Karungu		DISTRICT	Kabale	
Cordination;					
Longitude (E)	29.87281	Latitude (N)	-1.07401	Elevation	1831 m
Water sample No.	Na02				
Temperature	61.7 ℃		Air Temp	22.0 ℃	
pH	6.7 (59℃)		Remark;	bubbling	
Electric conductivity	86 mS/m				
Rock sample No.	Na02	phylite			

Geological condition;

The rock is composed of Mesoproterozoic phyllite and meta-sediments. The foliation of these rocks strikes in N35°W, dips 80°W. This place is situated in the intersection between NW-SE trending clear lineament and NE-SW trending minor lineament.

Discription;

This place is located at the Ishasha River valley in Karungu area, being approximately 20km nouthwest of Kabale Twon. The hot springs are gushing out from unconsolidated sediments or through the fractures developed in phyllite outcrop of the river bottom. A hot spring is flow out of N60E trending joint in situ.

Location No.	Bu01			DATE	9-Oct-13		
Place Name	Bubale			DISTRICT	Kabale		
Cordination;							
Longitude (E)	29.95998		Latitude (N)	-1.23178	Elevation	1811	m
Water sample No.	Mn01						
Temperature	29.5 ℃			Air Temp	20.0 ℃		
pH	6.1 (29℃)			Remark;	bubbling		
Electric conductivity	76 mS/m						
Rock sample No.	-						

Geological condition;
The rock is considered to be composed of meta-sandstone and conglomerate. No lineament is developed in this place.

Discription;
This place is located at the roadside of the Kabale–Kisoro road of Bubale area, being approximately 4km southwest of Kabale Town. The hot spring is gushing out from unconsolidated sediment in the end of slope. The small pond is developed in the vicinity.

Location No.	Mu01		DATE	9-Oct-13		
Place Name	Mulore-Nyakabungo		DISTRICT	Kabale		
Cordination;						
Longitude (E)	29.85442	Latitude (N)	-1.14709	Elevation	1971	m
Water sample No.	-					
Temperature	- ℃		Air Temp	- ℃		
pH	-		Remark;	-		
Electric conductivity	- mS/m					
Rock sample No.	Mu01	limbergite				

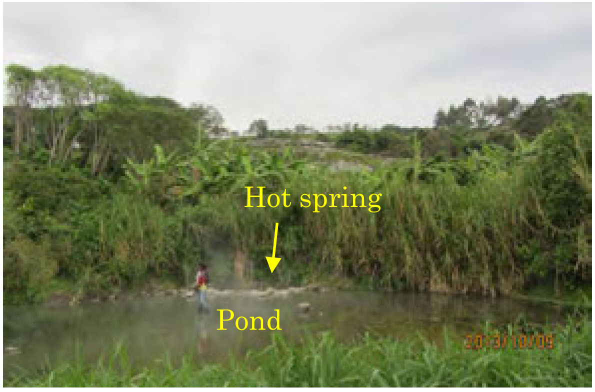
Geological condition;
This area is underlain by Quaternary limburgite lava. The lavas have vesicular texture and contains granitic xenoliths which derived from basement rocks.

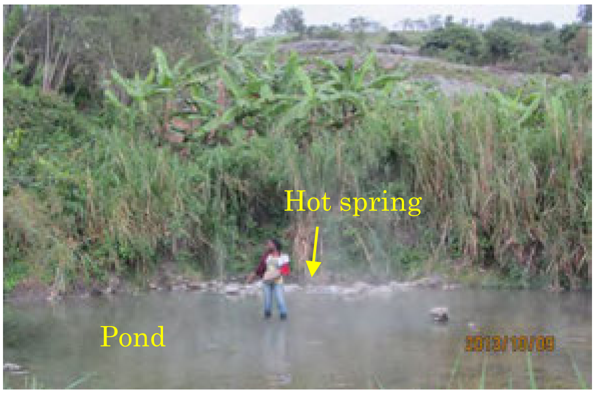
Discription;
No spring.

Location No.	Ru01		DATE	9-Oct-13		
Place Name	Rubaare		DISTRICT	Ntungamo		
Cordination;						
Longitude (E)	30.08225	Latitude (N)	-0.89426	Elevation	1377	m
Water sample No.	-					
Temperature	52.0 ℃		Air Temp	19.5 ℃		
pH	7.3 (52℃)		Remark;	bubbling		
Electric conductivity	165 mS/m					
Rock sample No.	Ru01a	travertine				
	Ru01b	pegmatite				

Geological condition;
The rock is foliated and massive granitic rocks with a great amount of pegmatite vein. WNW-ESE trending lineament is developed in this place.

Discription;
This place is located in Rubaare area the left bank of wide valley, being approximately 20km west of Utungamo Town. The valley is approximately 1km width, WNW-ESE trending. The hot spring is gushing out from foot of slope south side of valley. The small ponds is developed in the vicinity.
There are huge amount of travertine limestone around the hot spring.





Location No.	Ki01			DATE	10-Oct-13	
Place Name	Kisizi			DISTRICT	Rukungiri	
Cordination;						
Longitude (E)	35.25440		Latitude (N)	3.57560	Elevation	1045 m
Water sample No.	-					
Temperature	29.1 ℃			Air Temp	21.5 ℃	
pH	7.4 (℃)			Remark;	no smell, no tastes	
Electric conductivity	32 mS/m					
Rock sample No.	-					

Geological condition;
The rocks are silicified gneiss very much by affected quartz dominant pegmatite intrusion. In particular, there are a lot of big boulders ranging 1 to 5 m in size in its vicinity. E-W trending lineament is developed in this place.

Discription;
This place is located in Kisizi area, being approximately 20km south of Rukungiri Town. The hot spring is gushing out scree deposits made up of gneiss.The hot spring is utilized as daily use.

Location No.	Rb01			DATE	10-Oct-13		
Place Name	Rubabo			DISTRICT	Rukungiri		
Cordination;							
Longitude (E)	29.94488		Latitude (N)	-0.90198	Elevation	1309	m
Water sample No.	Na01						
Temperature	57.5 ℃			Air Temp	22.0 ℃		
pH	7.0 (53℃)			Remark;	bubbling		
Electric conductivity	124 mS/m						
Rock sample No.	Rb01	schist					

Geological condition;
The rock is schist of the basement. The foliation of these rocks strike N35°W, dips 80°W is distributed in this place. The place is situated in the intersection of WNW-ESE and NE-SW trending minor lineaments.

Discription;
This place is located in the left bank of river valley of Rubabo area, being approximately 12km east-southeast of Rukungiri Town. The hot spring is gushing out through the fractures developed in schist.

Location No.	Bi01		DATE	10-Oct-13	
Place Name	Birara		DISTRICT	Rukungiri	
Cordination;					
Longitude (E)	29.88278	Latitude (N)	-0.88771	Elevation	1288 m
Water sample No.	-				
Temperature	61.0 ℃		Air Temp	23.4 ℃	
pH	6.7 (50℃)		Remark;	bubbling	
Electric conductivity	141 mS/m				
Rock sample No.	-				

Geological condition;
Gneiss and granitic gneiss are distributed in this place.
NW-SE trending major lineament parallel to the river is developed very well.

Discription;
This place is located in Birara area, being approximately 12km west-southwest of Rukungiri Town. The hot springs are flow out from bottom of gouge. There are 4 hot springs in both sides of the river.

Location No.	Mi01		DATE	10-Oct-13		
Place Name	Minera		DISTRICT	Rukungiri		
Cordination;						
Longitude (E)	30.01129	Latitude (N)	-0.90385	Elevation	1344	m
Water sample No.	-					
Temperature	56.2 ℃		Air Temp	24.0 ℃		
pH	6.9 (49℃)		Remark;	bubbling		
Electric conductivity	240 mS/m					
Rock sample No.	Mi01	biotite-gneiss				

Geological condition;
The rock is composed of biotite gneiss, having foliation strikes N40°W and dips 80°W. WNW-ESE trending minor lineament crosses the place.

Discription;
This place is located in Minera area, being approximately 15km southeast of Rukungiri Town. The hot spring is gushing out through the fractures of gneiss. The hot spring is utilized as daily use and a small facility was made for that.

Location No.	Ih01			DATE	11-Oct-13		
Place Name	Ihimbo			DISTRICT	Rukungiri		
Cordination;							
Longitude (E)	29.81719		Latitude (N)	-0.68512	Elevation	1019	m
Water sample No.	Ih01						
Temperature	69.0 ℃			Air Temp	22.0 ℃		
pH	8.7 (61℃)			Remark;	bubbling		
Electric conductivity	98 mS/m						
Rock sample No.	-						

Geological condition;
The place area is located at a boundary between basement rocks and Quaternary rift sediments the western Rift Valley. There is no specific structural feature on the image.

Discription;
This place is located in the Ihimbo area, being approximately 15km northwest of Rukungiri Town. Hot waters are seeping out from Quaternary alluvial rift sediments.There are two hot springs aligned in N10°E direction.
The hot spring are utilized as a spa. This area applies to the forest reserve area.

Location No.	Kn01		DATE	11-Oct-13		
Place Name	Kanyinabalongo		DISTRICT	Rukungiri		
Cordination;						
Longitude (E)	29.78933	Latitude (N)	-0.64318	Elevation	989	m
Water sample No.	Kn01					
Temperature	36.3 ℃		Air Temp	31.6 ℃		
pH	6.7 (36℃)		Remark;	sulfate tastes?		
Electric conductivity	104 mS/m					
Rock sample No.	-					

Geological condition;
The place is located on Quaternary rift sediments area of the western Rift Valley.
NE-SW trending minor lineament is situated in this place.

Discription;
This place is located in the Kanyinabalongo area, being approximately 20km northwest of Rukungiri Town. Hot waters are seeping out from Quaternary unconsolidated sediments. The wet land and the small pond are developed in the vicinity.

Location No.	Km01		DATE	11-Oct-13	
Place Name	Kiruruma		DISTRICT	Kanungu	
Cordination;					
Longitude (E)	29.74691	Latitude (N)	-0.66558	Elevation	1013 m
Water sample No.	Km01				
Temperature	36.0 ℃		Air Temp	- ℃	
pH	7.3 (35℃)		Remark;	bubbling	
Electric conductivity	112 mS/m				
Rock sample No.	-				

Geological condition;
The place is located on Quaternary rift sediments area of the western Rift Valley.
NNE-SSW trending minor lineament is situated near this place.

Discription;
This place is located in the Kiruruma area, being approximately 5km west-southwest of Kanyinabalongo hot spring. Hot waters are seeping out from Quaternary unconsolidated sediments. 20m high cliff which consists of stratified sediments is behind the hot spring.

Location No.	Kt01		DATE	11-Oct-13		
Place Name	Kitagata		DISTRICT	Sheema		
Cordination;						
Longitude (E)	30.16074	Latitude (N)	-0.68038	Elevation	1478	m
Water sample No.	Kt01					
Temperature	64.0 ℃		Air Temp	21.4 ℃		
pH	7.7 (57℃)		Remark;	no smell, no tastes		
Electric conductivity	118 mS/m					
Rock sample No.	-					

Geological condition;
The rock is composed of banded gneiss. The foliation of these rocks strikes N45W, dips 90. NE-SW trending major lineament is developed very well.

Discription;
This place is located at Kitagata area, western part of Sheeme district. The hot spring is gushing out through the fractures of gneiss.
This hot spring is utilized as one of the biggest public spa.

Location No.	Mh01		DATE	12-Oct-13		
Place Name	Muhokya		DISTRICT	Kasese		
Cordination;						
Longitude (E)	30.04698	Latitude (N)	0.10264	Elevation	1001	m
Water sample No.	Mh01					
Temperature	42.0 ℃		Air Temp	22.3 ℃		
pH	7.2 (42℃)		Remark;	taste SO4		
Electric conductivity	360 mS/m					
Rock sample No.	-					

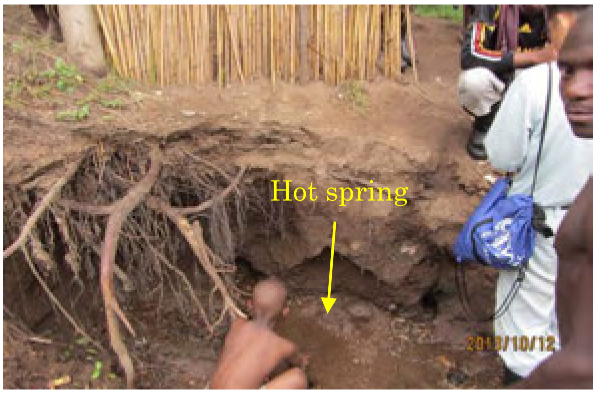
Geological condition;
This place is consisting of Quaternary colluviums sediments. There are gneiss boulders on the surface. A great amount of lacustrine limestone, which is not travertine limestone, is distributed around the place.

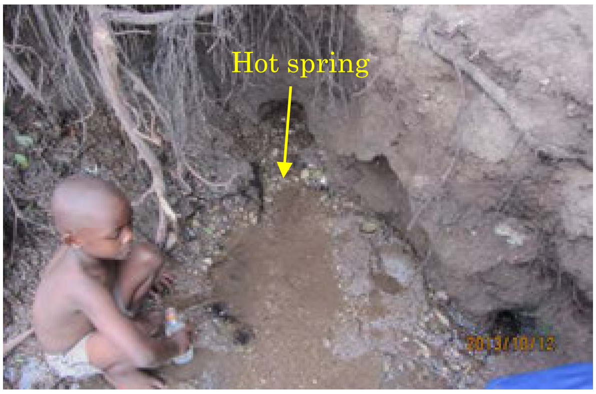
Discription;
This place is located in Muhokya area, being approximately 10km southwest of Kasese Town. The hot springs are gushing out from unconsolidated slope deposits on the gentle hill.
Lime factory was established in this place.

Location No.	Kb01		DATE	12-Oct-13		
Place Name	Kibenge		DISTRICT	Kasese		
Cordination;						
Longitude (E)	30.0546	Latitude (N)	0.18739	Elevation	1071	m
Water sample No.	Kb01					
Temperature	46.6 ℃		Air Temp	25.0 ℃		
pH	7.2 (46℃)		Remark;	no smell, no tastes		
Electric conductivity	370 mS/m					
Rock sample No.	-					

Geological condition;
This place is consisting of gneiss basements. There are gneiss boulders on the surface. NE-SW trending major lineament is developed, which is considered to be rift margin fault.

Discription;
This place is located in Kibenge area, being approximately 5km west of Kasese Town. The hot springs are gushing out from unconsolidated deposits.
The hot spring is utilized as a public spa.





Location No.	Nd01			DATE	13-Oct-13		
Place Name	Ndugutu			DISTRICT	Kasese		
Cordination;							
Longitude (E)	30.09586		Latitude (N)	0.29324	Elevation	1230	m
Water sample No.	-						
Temperature	-	℃		Air Temp	- ℃		
pH	-	(℃)		Remark;	-		
Electric conductivity	-	mS/m					
Rock sample No.	Nd01	travertine					

Geological condition;

This place is consisting of basement gneiss. There are gneiss boulders on the surface. N-S trending major lineament is developed, which is considered to be rift margin fault.

Discription;

This place is located in Ndugutu, being approximately 10km north of Kasese Town. Travertine limestone (old spring deposits) making various sizes of pools develops very well on the surface. The cold springs are flow out from these travertines.

Hot springs, Ndugutu and Rwagimba, are aligned in N-S direction controlled by the rift margin fault.

Location No.	Rw01		DATE	13-Oct-13		
Place Name	Rwagimba		DISTRICT	Kabarole		
Cordination;						
Longitude (E)	30.10631	Latitude (N)	0.47695	Elevation	1556	m
Water sample No.	Rw01					
Temperature	68.7 ℃		Air Temp	27.0 ℃		
pH	6.6 (68℃)		Remark;	a little salty tastes		
Electric conductivity	650 mS/m					
Rock sample No.	-					

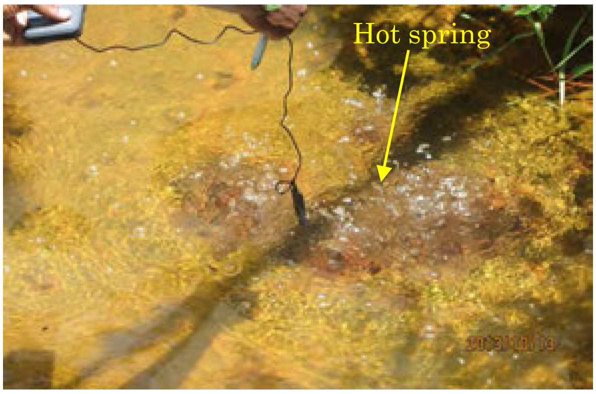
Geological condition;
This place is consisting of gneiss basements. There are gneiss boulders along the stream.

Discription;
This place is located on the bottom of V-shaped valley in Rwagimba area, being approximately 30km southeast of Kasese Town. The hot springs are gushing out from unconsolidated deposits of river. Hot springs sit both side of the river. The place is very remote area far from the village.

Location No.	Rm01			DATE	13-Oct-13		
Place Name	Rwimi			DISTRICT	Kabarole		
Cordination;							
Longitude (E)	30.21778		Latitude (N)	0.38668	Elevation	1109	m
Water sample No.	Rm01						
Temperature	25.0 ℃			Air Temp	28.0 ℃		
pH	6.3 (26℃)			Remark;	bubbling hard, red soil		
Electric conductivity	420 mS/m						
Rock sample No.	Rm01	Cemented pebbly deposite(travertine)					

Geological condition;
This place is consisting of gneiss basements. Quaternary lapilli tuff is distributed widely just north of this place.

Discription;
This place is located in Rwimi area, being approximately 25km northeast of Kasese Town. The hot springs are gushing out from unconsolidated deposits.
Hot spring sits banana field. The mound 1 m high of travertine limestone is observed close to the current hot spring.

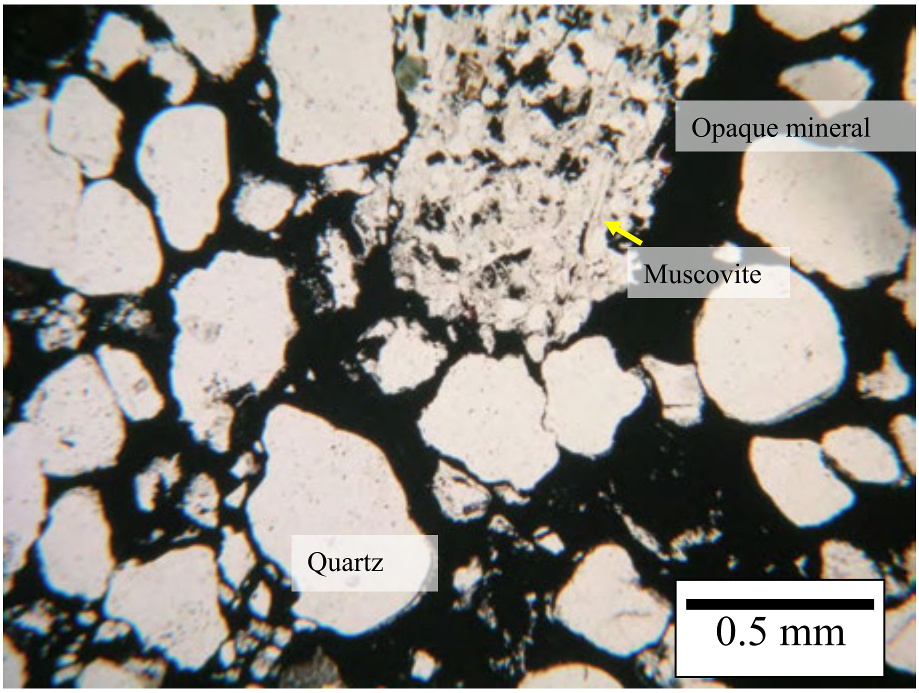


2. Petrography analysis for rock samples

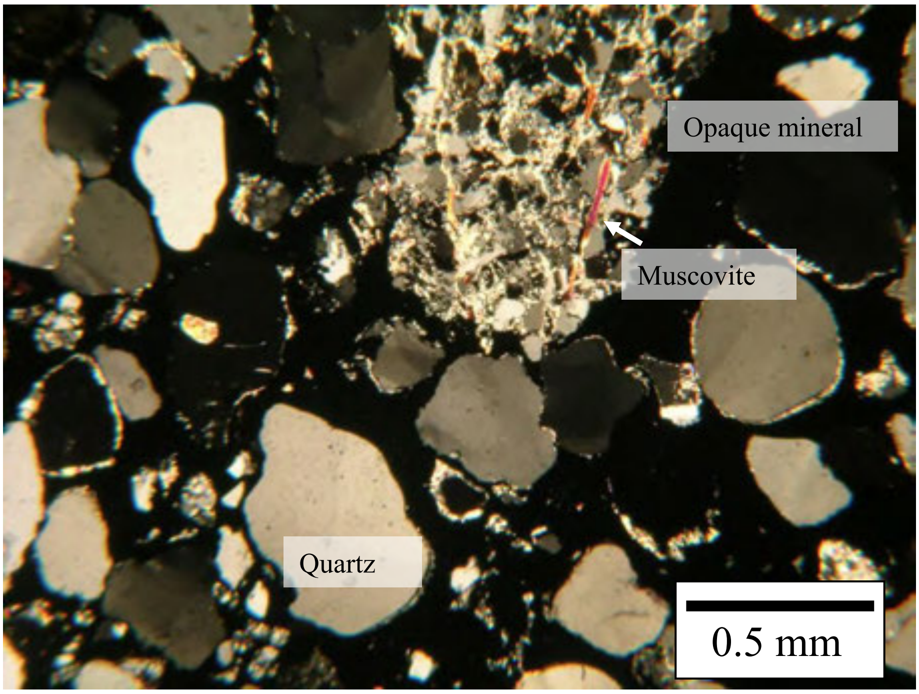
Petrography sheet No.1

Field	**Kagamba(Ka01)**

Plane-polarized light



Crossed-polarized light



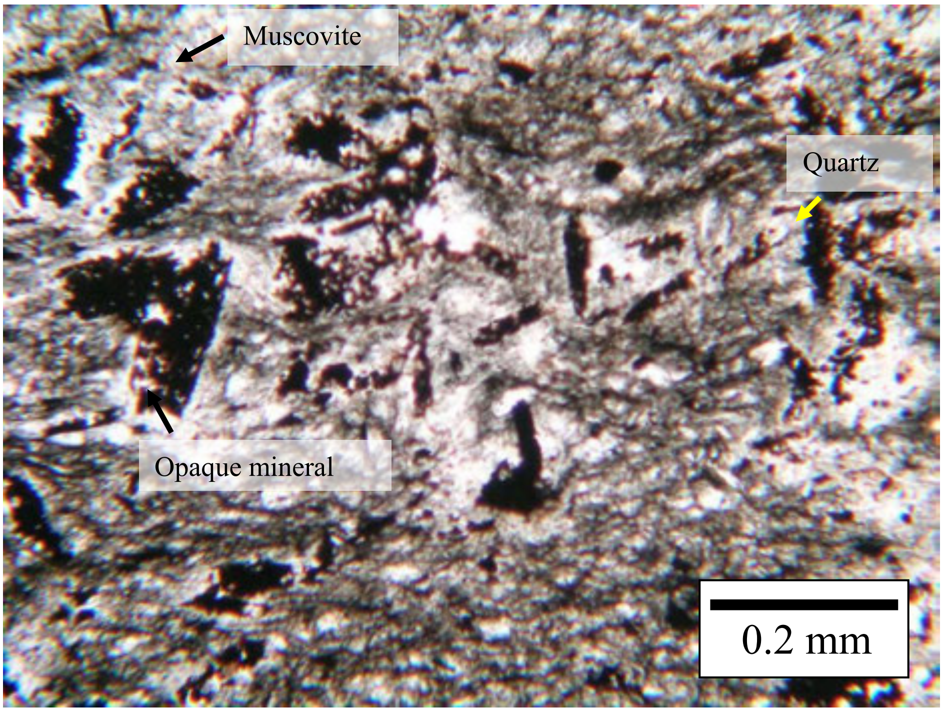
Description

Rock name：Conglomerate

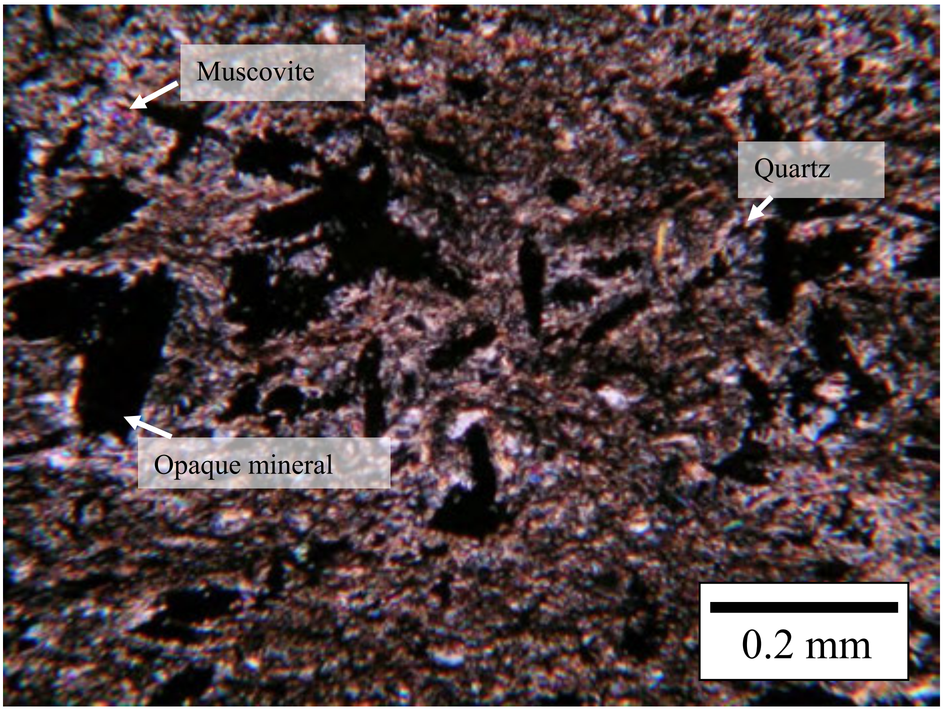
- This rock consists of quartz grain, pebble of quartz and muscovite.
- The matrix mostly consists of opaque mineral and looks like dark reddish purple to naked eye. It is considered hematite from result of XRD analysis. The maximum grain size is around 1cm, and a lot of particles of around 0.5mm are included.

Petrography sheet No.2	
Field	**Karungu(Kr01)**

Plane-polarized light



Crossed-polarized light



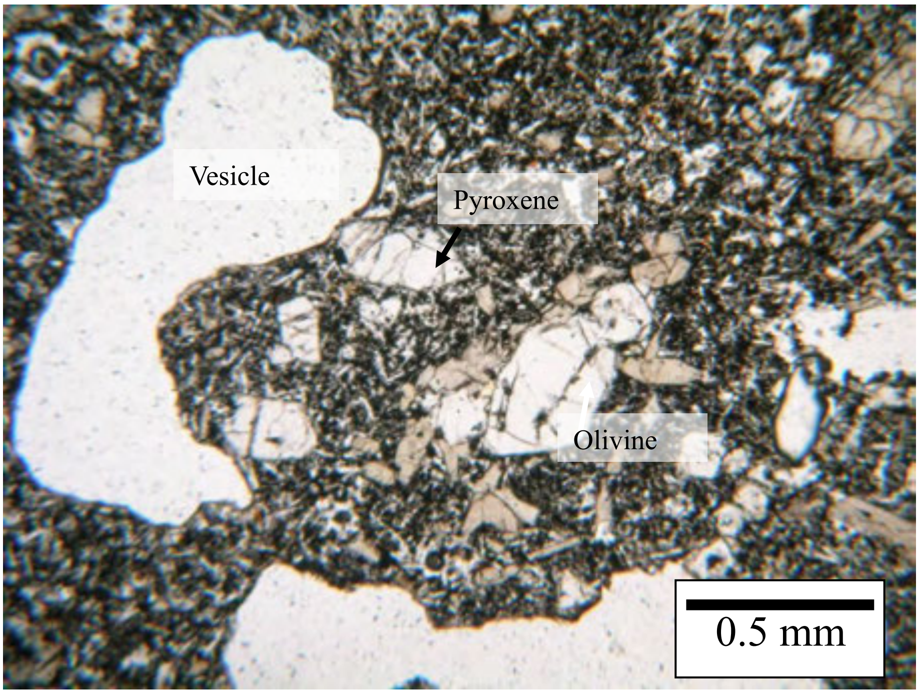
Description

Rock name：Phyllite

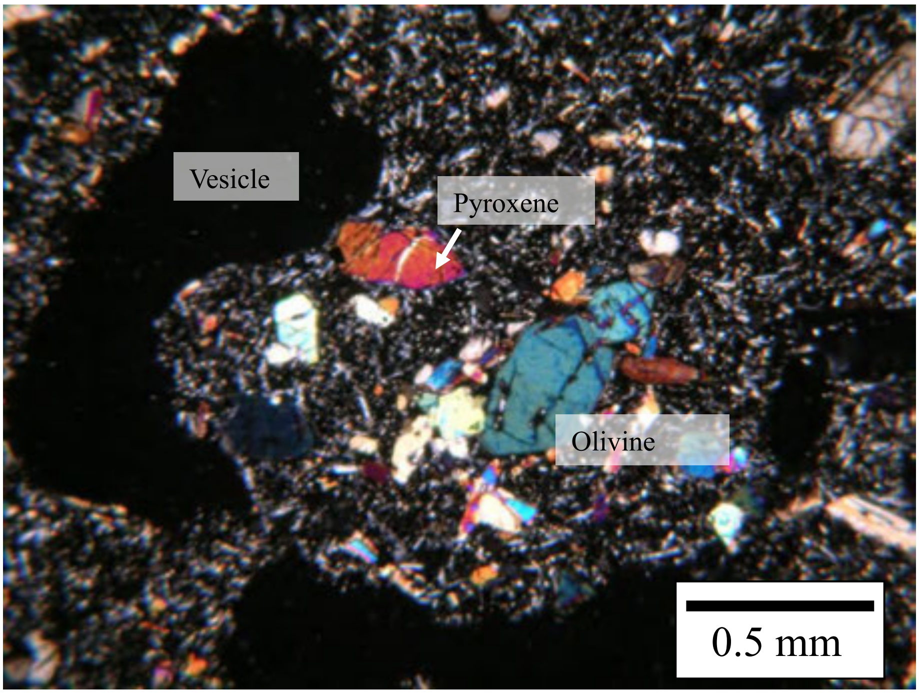
- The rock mainly consists of quartz, muscovite and hematite.
- Quartz and muscovite are less than 0.1mm in diameter.
- Pseudomorph laths consist of fine opaque minerals. The intergranuler of quartz and muscovite are filled up by very fine opaque minerals.
- Cleavage with orientation of mica is developing.

Petrography sheet No.3	
Field	**Murole-Nyakabungo(Mu01)**

Plane-polarized light



Crossed-polarized light



Description

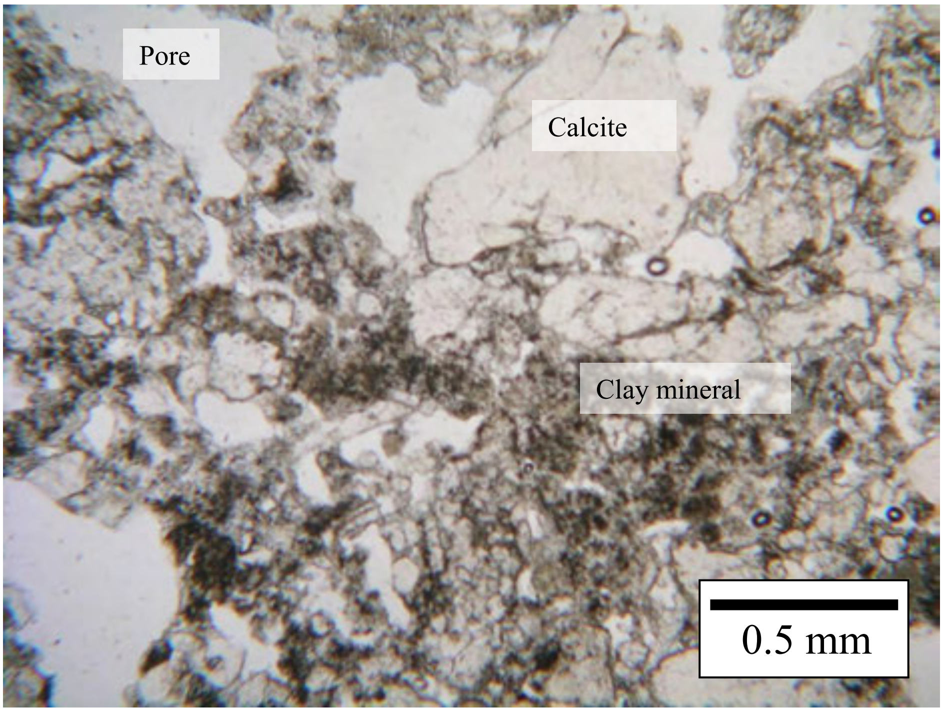
Rock name：Basalt

- The rock is olivine-pyroxene basalt. Phenocrysts are less than 1.5-2.0mm in diameter. The porous groundmass consists of volcanic glass, plagioclase and opaque mineral.

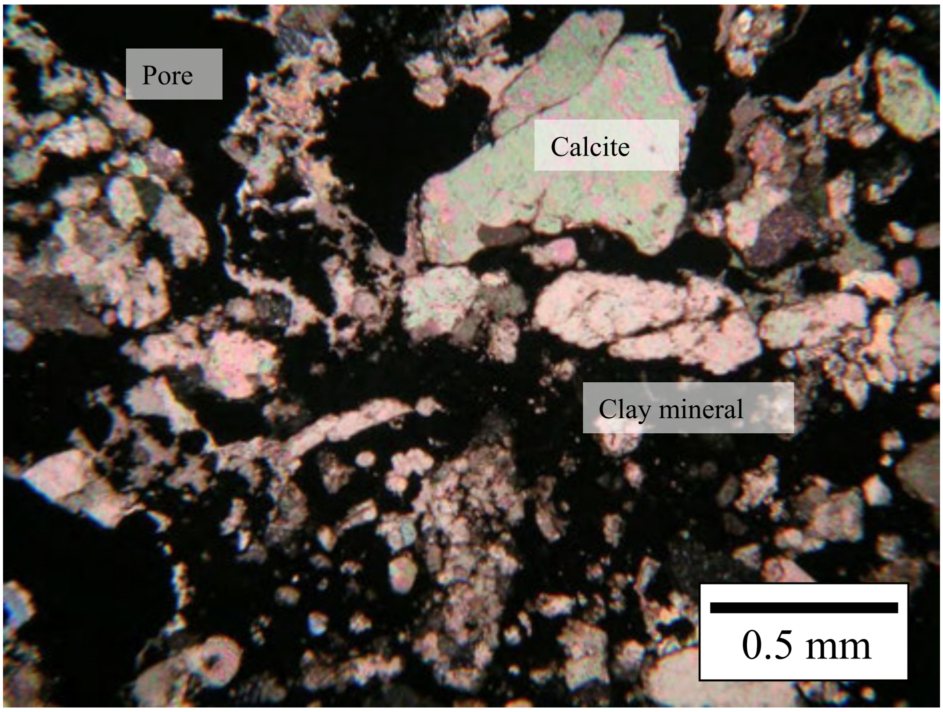
Petrography sheet No.4

Field	**Rubaare(Ru01a)**

Plane-polarized light



Crossed-polarized light



Description

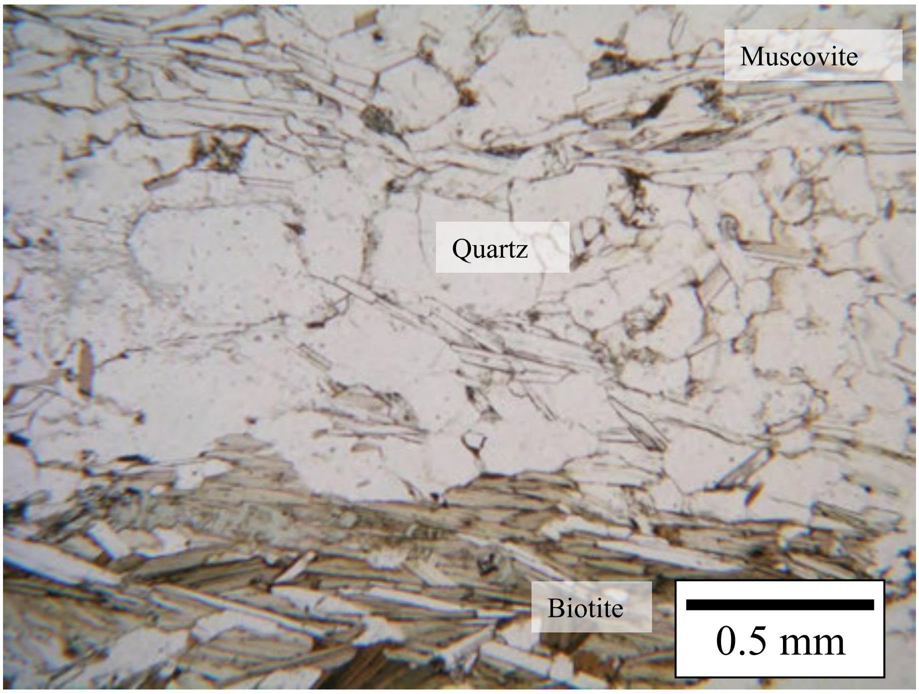
Rock name：Travertine

- The rock consists of calcite and matrix of brown clay mineral.
- Calcite is less than 0.5mm in diameter.
- The rock shows porous texture.

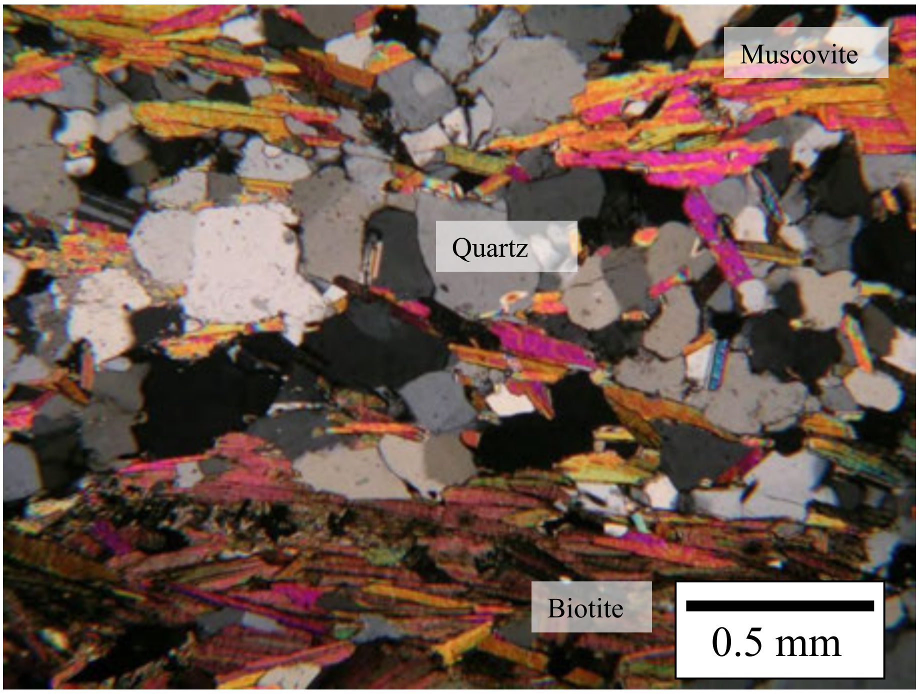
Petrography sheet No.5

Field	Rubabo(Rb01)

Plane-polarized light



Crossed-polarized light



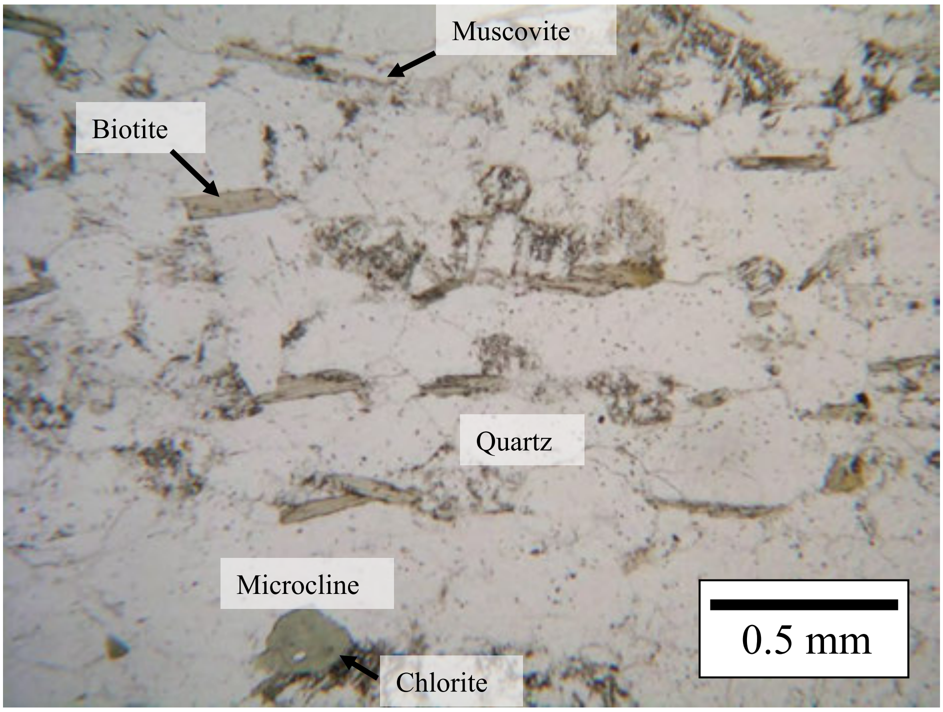
Description

Rock name：Schist

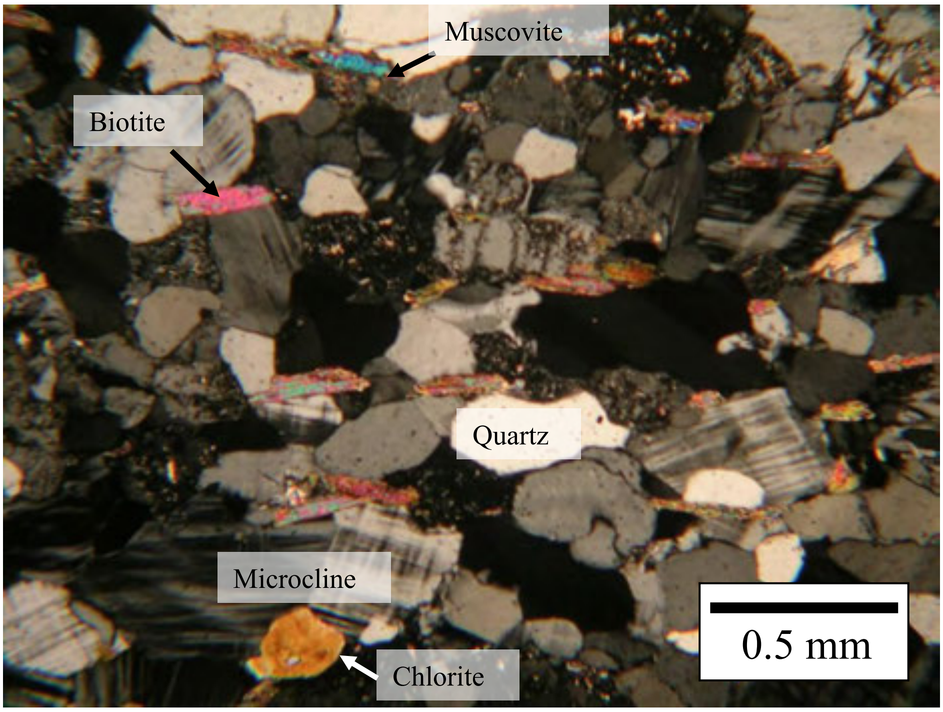
- The rock consists of mainly quartz, biotite and muscovite. Biotite and muscovite show parallel alignment.
- Quartz are around 0.2-2mm in diameter, show mosaic texture and undulatory extinction.
- Muscovite and biotite are 0.2-0.5mm in length and cleavages are developed.

Petrography sheet No.6	
Field	**Mineral(Mi01)**

Plane-polarized light



Crossed-polarized light

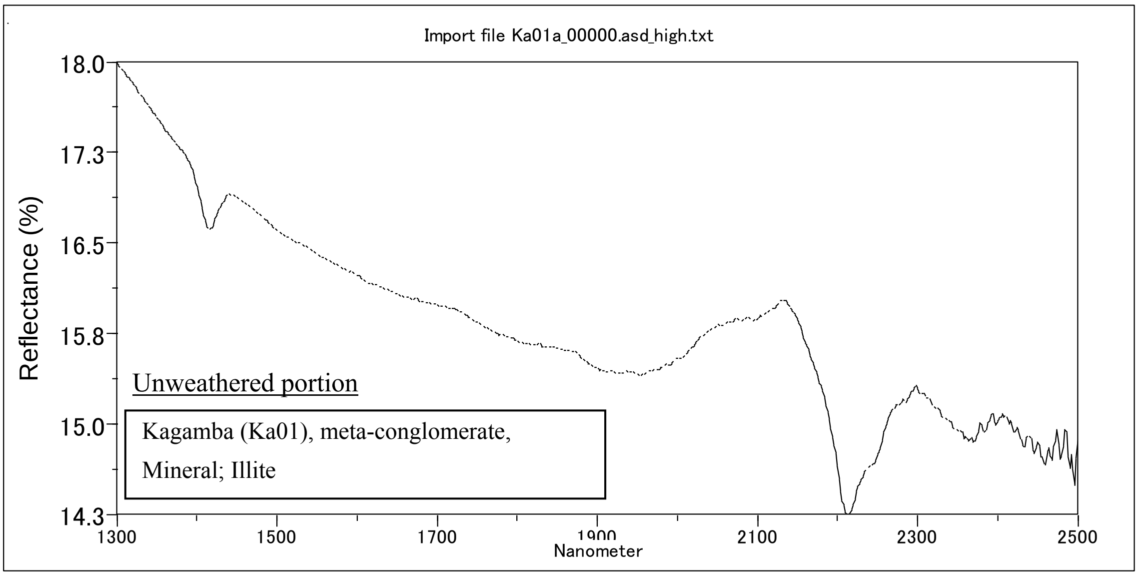


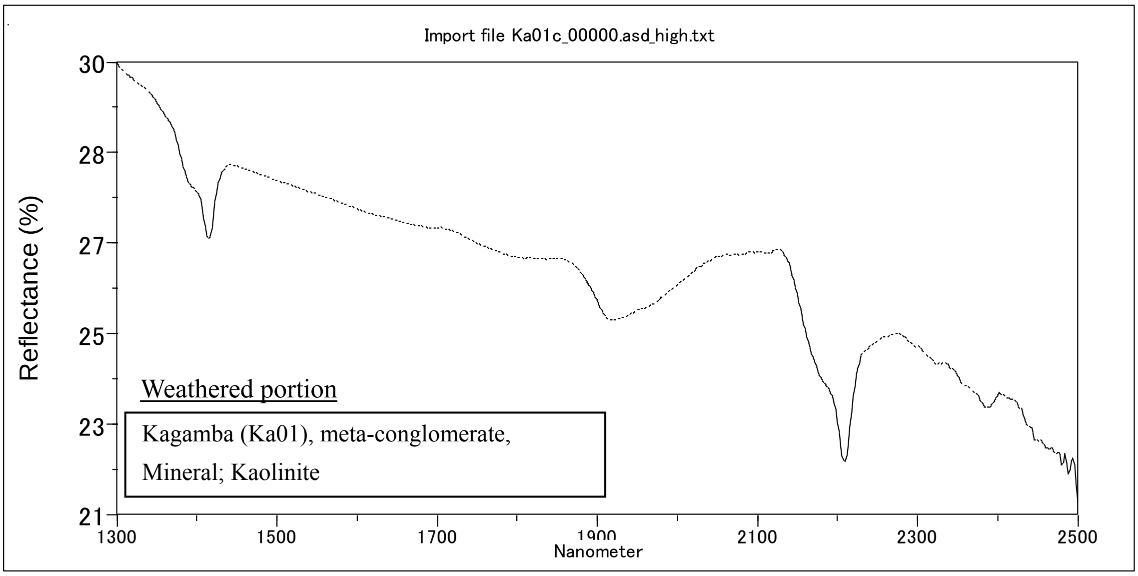
Description

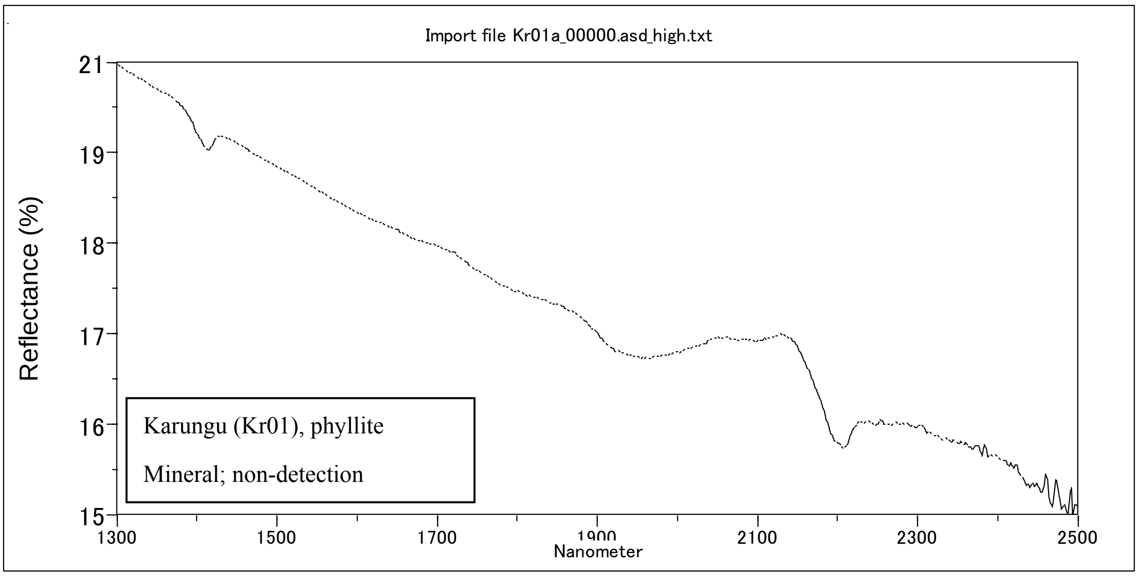
Rock name：Gneiss

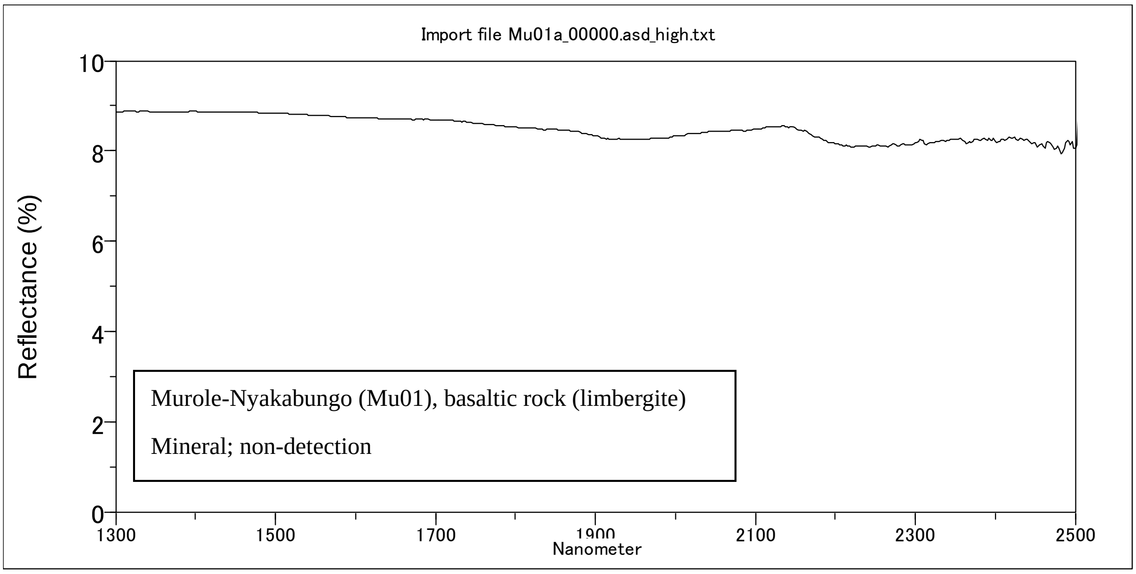
- The rock consists of quartz and microcline mainly with biotite and a little muscovite.
- The rock shows equigranular texture around 0.5mm grain size. Mica has orientation.
- Small amount of chlorite are observed.

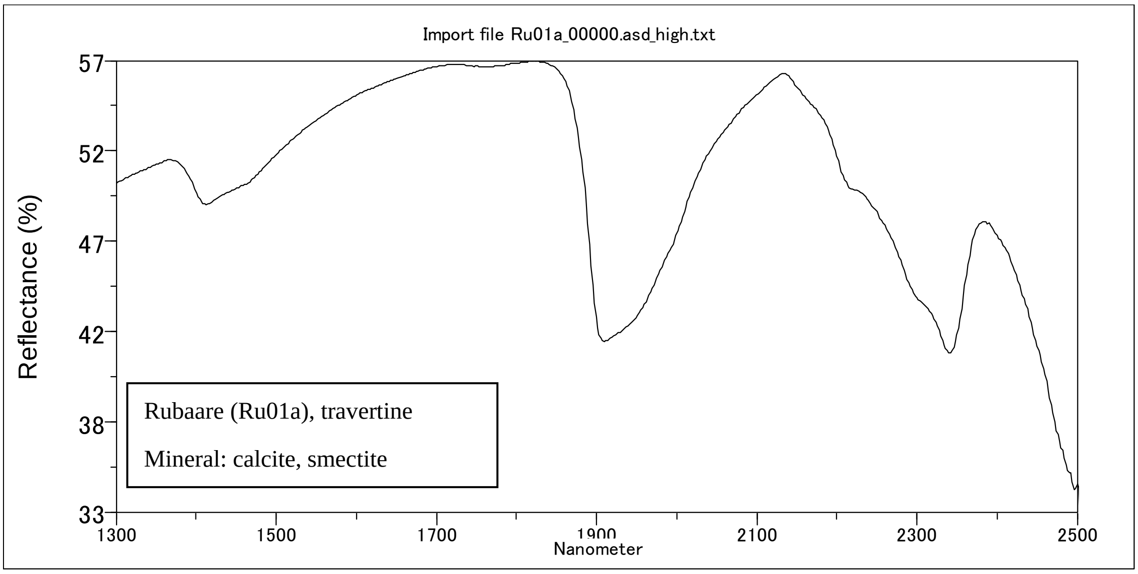
3. Spectral measurement result

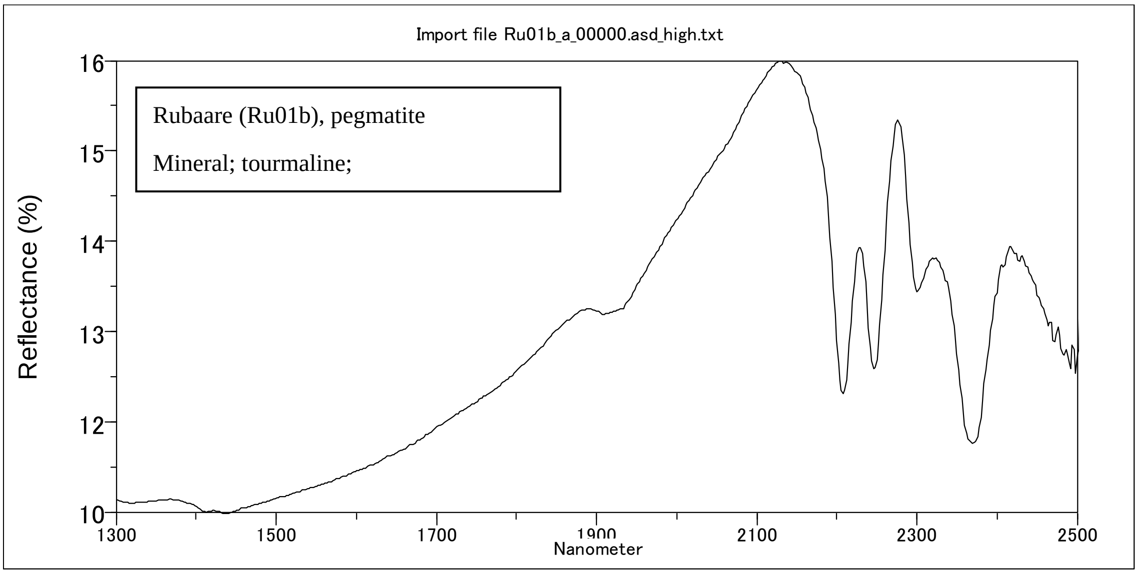


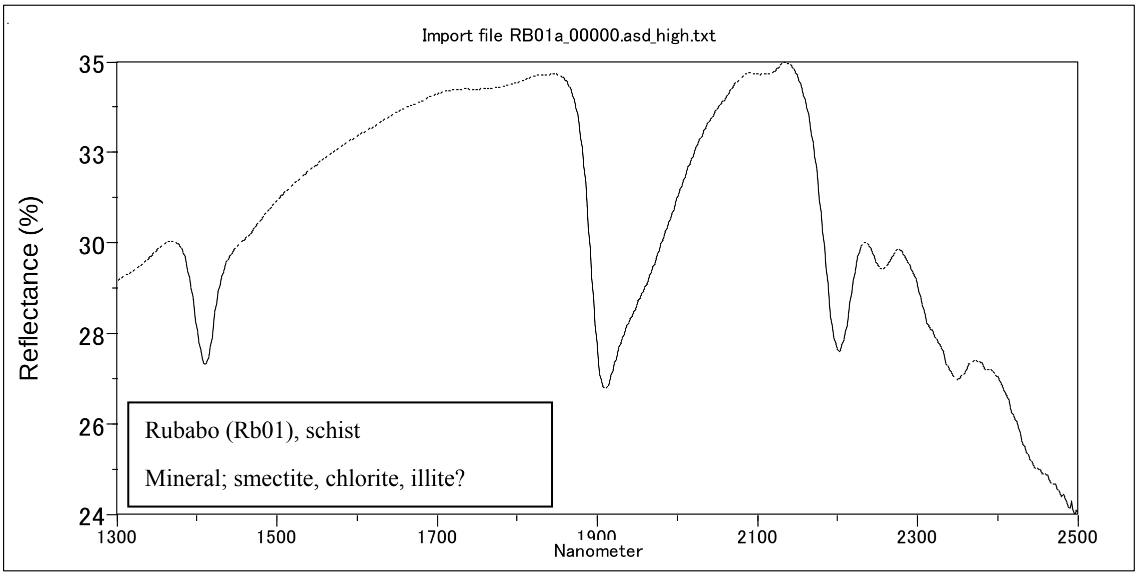


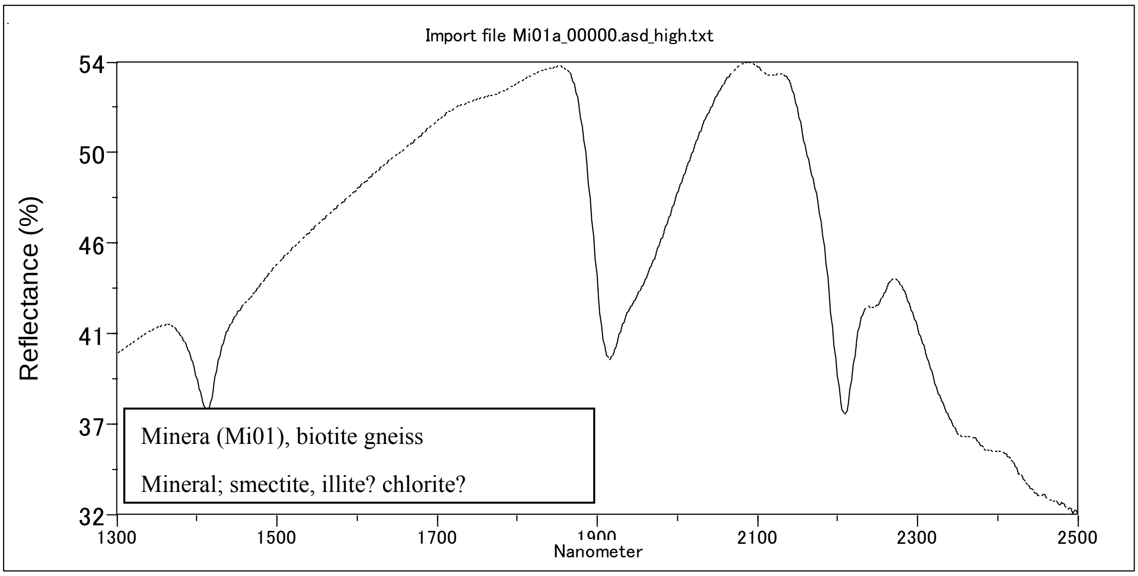


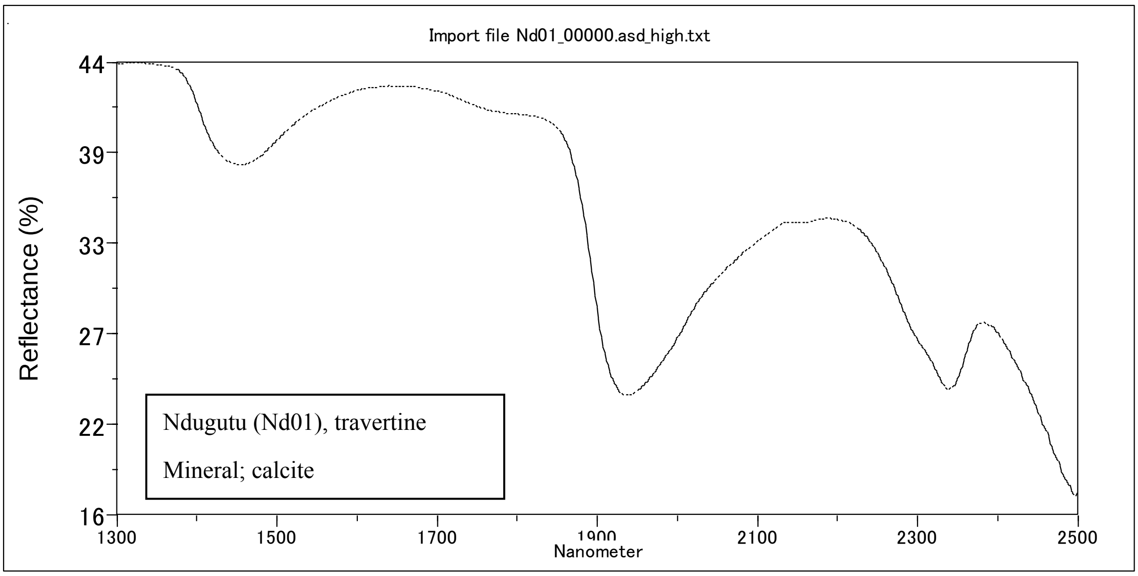

Import file Mu01a_00000.asd_high.txt
Reflectance (%)
Nanometer
10
8
6
4
2
0
1300
1500
1700
1900
2100
2300
2500
Murole-Nyakabungo (Mu01), basaltic rock (limbergite)
Mineral; non-detection

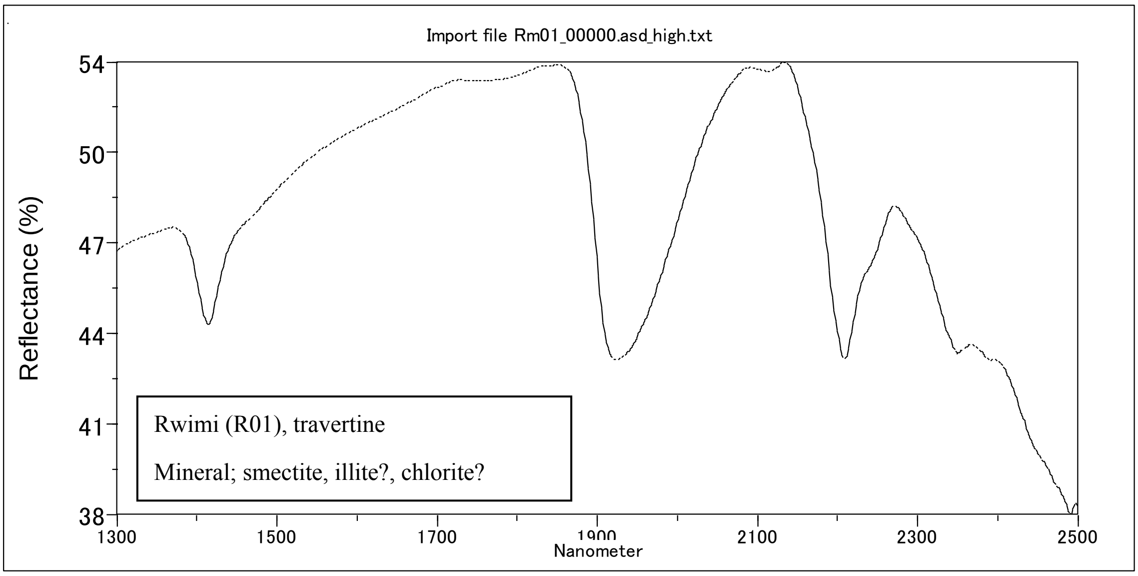

Import file Ru01a_00000.asd_high.txt
Reflectance (%)
Nanometer
57
52
47
42
38
33
1300
1500
1700
1900
2100
2300
2500
Rubaare (Ru01a), travertine
Mineral: calcite, smectite


Import file Ru01b_a_00000.asd_high.txt
Reflectance (%)
Nanometer
16
15
14
13
12
10
1300
1500
1700
1900
2100
2300
2500
Rubaare (Ru01b), pegmatite
Mineral; tourmaline;


Import file RB01a_00000.asd_high.txt
Reflectance (%)
35
33
30
28
26
24
1300
1500
1700
1900
2100
2300
2500
Nanometer
Rubabo (Rb01), schist
Mineral; smectite, chlorite, illite?


Import file Mi01a_00000.asd_high.txt
Reflectance (%)
54
50
46
41
37
32
1300
1500
1700
1900
2100
2300
2500
Nanometer
Minera (Mi01), biotite gneiss
Mineral; smectite, illite? chlorite?


Import file Nd01_00000.asd_high.txt
Reflectance (%)
44
39
33
27
22
16
1300
1500
1700
1900
2100
2300
2500
Nanometer
Ndugutu (Nd01), travertine
Mineral; calcite


Import file Rm01_00000.asd_high.txt
Reflectance (%)
54
50
47
44
41
38
1300
1500
1700
1900
2100
2300
2500
Nanometer
Rwimi (R01), travertine
Mineral; smectite, illite?, chlorite?

4. Chemical Analysis Data of Hot Spring Water (Existing data)

Location	Temp.	pH	EC	Na	K	Ca	Mg	Cl	SO_4	HCO_3	F	B	CO_2	H_2S	SiO_2	Fe	Sr	NH_3	Li	Br	$\delta^{18}O$	δD
	℃		µs	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	‰	‰	‰	‰	‰	‰
Kagamba	35	7.49	467	13.2	4.7	29	44	<20	37		1.8	0.3	186	0	26	<0.02	0.2	0.13	<0.05	<0.2	-4.7	-17.1
Karungu	65	7.09	846	149	9.4	29	3.8	44	206		5.4	0.44	111	0	49	0.9	1.5	<0.1	0.38	<0.04	-3.97	-9.6
Bubale	34	6.29	578	61	5.7	60	38	<20	73		0.69	0.27	406	0	19.2	1.8	0.5	0.1	0.23	<0.02	-3.93	-9.1
Rubaare	54	7.52	1600	285	14.9	70	1.4	177	417		6	0.78	85	0	106	0.08	1.1	0.48	0.29	1.2	-4.2	-12.1
Kitagata	66	7.92	1110	203	10.7	36	0.28	55	346		7.4	0.61	56	0	76	0.05	0.77	0.41	0.5	0.36	-3.3	-3.1
Ihimbo	70	9.2	893	186	5.6	3.8	0.02	71	219		6	0.27	45	0.92	66	0.08	0.24	0.58	<0.05	0.42	-3.45	-4.1
Kanyinabarongo	38	7.37	992	173	9	31	4.5	92	280		2.6	0.66	58	0	34	6.8	0.74	0.63	0.05	0.54	-3.45	-5
Birara	63	7.44	1072	210	13.6	70	10.5	80	208		6.2	0.33	647	0	103	0.25	1.1	0.25	0.21	0.35	-3.51	-7.2
Rubabo 1	58	7.14	1069	216	11.2	41	8.3	93	184		3.9	0.27	230	0	81	0.04	1.2	0.19	0.09	0.4	-3.61	-8.5
Rubabo 2	60	7.5	1077	216	11.3	41	8.3	90	183		3.9	0.26	235	0	80	0.09	1.2	0.25	0.09	0.39	-3.58	-7.2
Kiruruma	36	7.09	609	110	9.4	36	2.9	22	182		2.7	0.34	124	0	57	0.4	0.79	0.95	0.08	<0.2	-3.28	-4.7
Kisiizi	30.1	7.43	292	5.8	3.8	30	18.9	<20	14.7		0.18	<0.10	106	0	17.5	0.04	0.07	0.15	<0.05	<0.04	-3.69	-7.9
Minera	58	6.88	2180	482	23	70	22	181	361		2.5	0.65	547	0	83	0.23	1.5	0.21	0.7	0.88	-4.13	-10.7
Kabuga	42	7.42	3290	622	21	208	13.2	474	1071		2.7	0.42	110	0	53	0.38	1.5	<0.1	0.1	3.5	-4.33	-11.4
Kibenge	48	7.5	3300	581	26	233	6.5	589	889		4.2	0.52	79.2	0	46	0.15	3.3	0.1	0.26	3.9	-4.9	-15.7
Ndugutu	22	8.5	17580	4482	268	25	11.2	2931	3469		16.5	3	1918	0	40	0.04	2.9	0.43	1.9	<0.2	-2.94	-4.4
Rwimi	24	7.09	3160	382	61	384	191	211	523		1.3	0.53	1620	0	94	7.5	8.9	0.25	0.11	1.3	-2.61	1.9
Rwagimba	69.2	6.87	6400	1481	46	75	5.1	905	1527		8	0.94	651	0	65	0.8	3.3	<0.1	0.59	4.1	-4.8	-14.7
Kanangorok 1	60	8.35	1631	322	17.7	24	2.7	95	341		12	0.18	216	0	118	0.08	0.77	<0.1	0.19	<0.2	-4.92	-18.8
Kanangorok 2	42	8.39	1627	323	19.2	21	1.5	97	343		13.8	<0.1	207	0	129	0.18	0.71	<0.1	0.2	<0.2	-4.83	-17.2
Kanangorok BH	38	8.44	1658	342	22	21	1.5	96	352		13	0.76	207	0	129	0.32	0.73	0.15	0.22	<0.2	-4.88	-16.6
Kaitabosi	48	10.55	1038	248	7	0.52	0.014	<20	36		22	0.17	155	8.3	157	0.03	0.1	0.15	0.08	<0.2	-5.91	-25.3
Amoropii	58	8.66	1790	352	10.9	4.5	0.36	470	26		5.2	0.65	71	5.61	73	0.06	0.27	2.1	0.12	1.5	-3.52	-7.7
Okumu	45	8.45	1590	321	9.5	8.5	0.68	379	36		4.7	0.58	109	2.48	69	0.02	0.2	1.6	0.08	0.93	-3.29	-5.5
Avuka 2	35	7.56	676	138	7.3	8.4	3.1	83	19		2.4	0.22	142	0	54	0.23	0.07	0.25	<0.05	0.17	-2.5	1.9
Lusonga-BH	32	7.57	46300	42	316	163	243	3385	3313		0.32	0.85	2218	0	53	1.2	2.4	10.7	0.18	22	-3.42	-7.3
Amuru (Pakele)	49	9.06	449	110	2.6	1.4	0.04	53	4.4		6.6	<0.1	95.5	0	70	0.1	0.02	<0.1	<0.05	0.29	-2.48	-1.9
Amuru	48	8.23	508	111	3.9	6.6	0.76	51	73		8	0.2	91.1	0	68	0.04	0.07	<0.1	<0.05	0.45	-1.95	2.5

(From Armannsson et al, 2007)

5. Compilation of Geo-thermometers from Hot Springs (Existing data)

Location	Sample No.	Measured temp. (ºC)	Quartz temp. (ºC)	Chalcedony temp. (ºC)	Na/K temp. (ºC)
Kagamba	UG-05-15	35	73.9	41.8	338.9
Karungu	UG-05-16	65	101.1	70.7	153.9
Bubale	UG-05-17	34	62.6	30.3	194.7
Rubaare	UG-05-18	54	138.8	112.1	134.6
Kitagata	UG-05-19	66	120.1	91.4	136.1
Ihimbo	UG-05-20	70	83.8	52.2	96.0
Kanyinabarongo	UG-05-21	38	85.0	53.4	136.4
Birara	UG-05-22	63	136.1	109.1	155.8
Rubabo1	UG-05-23	58	125.0	96.9	136.2
Rubabo2	UG-05-24	60	123.2	94.9	137.0
Kiruruma	UG-05-25	36	108.2	78.4	183.9
Kisiizi	UG-05-26	30.1	58.6	26.4	n.a.
Minera	UG-05-27	58	126.8	98.8	128.1
Kabuga	UG-05-29	42	104.0	73.8	100.2
Kibenge	UG-05-30	48	97.5	66.8	121.6
Ndugulu	UG-05-31	22	79.7	47.9	141.3
Rwimi	UG-05-32	24	133.2	105.9	250.3
Rwagimba	UG-05-33	69.2	114.3	85.0	93.1
Kanangorok-1	UG-05-58	60	138.4	111.6	139.4
Kanangorok-2	UG-05-59	42	145.0	119.0	146.0
Kanangorok-BH	UG-05-60	38	144.9	118.9	153.2
Kaitabosi	UG-05-61	48	26.9	-3.1	93.7
Amoropii	UG-05-62	58	111.3	81.8	98.5
Panyimur (Okumu)	UG-05-63	45	112.9	83.6	95.4
Panyimur (Avuka-2)	UG-05-64	35	104.6	74.5	139.6
Panyimur (Amuru)	UG-05-117	49	78.7	46.7	82.5
Amuru	UG-05-118	48	114.0	84.7	106.8

(From Armannssonn et al, 2007)

*Note: It's important to consider the co-existing silica minerals (silica, chalcedony) for silica geothermometer and concentration of Ca and Mg for alkali geothermometer, so they should be validated.

6. List of geothermometers of hot springs

T-SiO_2 (adia.)	$\frac{1522}{5.75 - \log(T-SiO_2)} - 273.15$	T-SiO_2: mg/L	Fournier (1977)
T-SiO_2 (cond.)	$\frac{1309}{5.19 - \log(T-SiO_2)} - 273.15$	T-SiO_2: mg/L	Fournier (1977)
T-SiO_2 (chal.)	$\frac{1032}{4.69 - \log(T-SiO_2)} - 273.15$	T-SiO_2: mg/L	Fournier (1977)
T-SiO_2 (α-crist.)	$\frac{1000}{4.78 - \log(T-SiO_2)} - 273.15$	T-SiO_2: mg/L	Fournier (1977)
T-SiO_2 (amor.)	$\frac{731}{4.52 - \log(T-SiO_2)} - 273.15$	T-SiO_2: mg/L	Fournier (1977)
TNa-K (Truesdell)	$\frac{856}{0.857 + \log(Na/K)} - 273.15$	Na, K: mg/L	Truesdell (1976)
TNa-K (Fournier)	$\frac{1217}{1.483 + \log(Na/K)} - 273.15$	Na, K: mg/L	Fournier (1977)
TNa-K-Ca	$\frac{1647}{\log(Na/K) + \beta \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15$		Fournier and Truesdell (1973)

$$For \sqrt{Ca}/Na < 1 \, or \, \frac{1647}{\log(Na/K) + 4/3 \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15 > 100$$

$\beta = 1/3$, *for the others* $\beta = 4/3$ Na, K, Ca: mol/L

Tna-K-Ca-Mg	$\frac{1647}{\log(Na/K) + \beta \times \log(\sqrt{Ca+Mg}/Na) + 2.24} - 273.15$		Fournier and Truesdell (1973)

$$For \sqrt{Ca}/Na < 1 \, or \, \frac{1647}{\log(Na/K) + 4/3 \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15 > 100,$$

$\beta = 1/3$, *for the others,* $\beta = 4/3$ Na, K, Ca, Mg: mol/L

TΔMg

$R = \frac{Mg}{Mg + Ca + K}$ □100

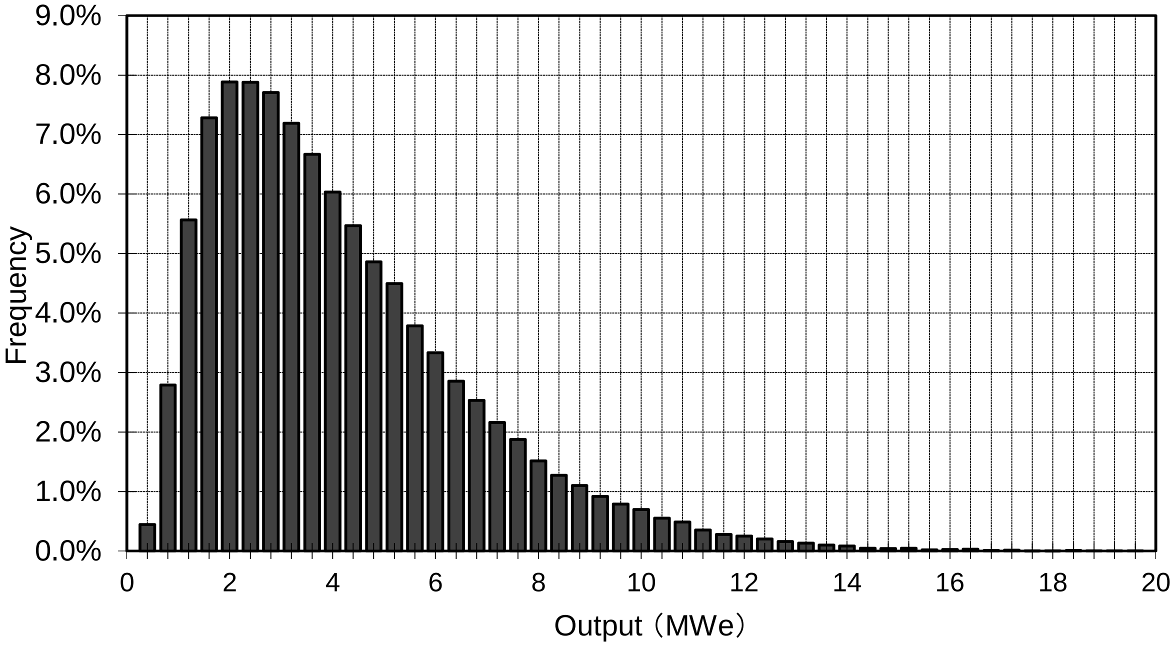
1) Mg correction is needed to the Na-K-Ca geothermometer.
2) The Mg correction is applicable only for waters which have TNa-K-Ca<70℃
3) If R>50, the geothermometer calculation is not applicable. K, Ca, Mg: meq/L
4) For 5≦R≦50, ΔtMg=10.66-4.7415×R+325.85×$(\log R)^2$-1.032×10^5×$(\log R)^2$/T-1.968×10^7×$(\log R)^2/T^2$+1.605×10^7×$(\log R)^3/T^2$
T=TNa-K-Ca (K)
5) For 0.5<R<5, ΔtMg=-1.03+59.971×logR+145.05×$(\log R)^2$-36711×

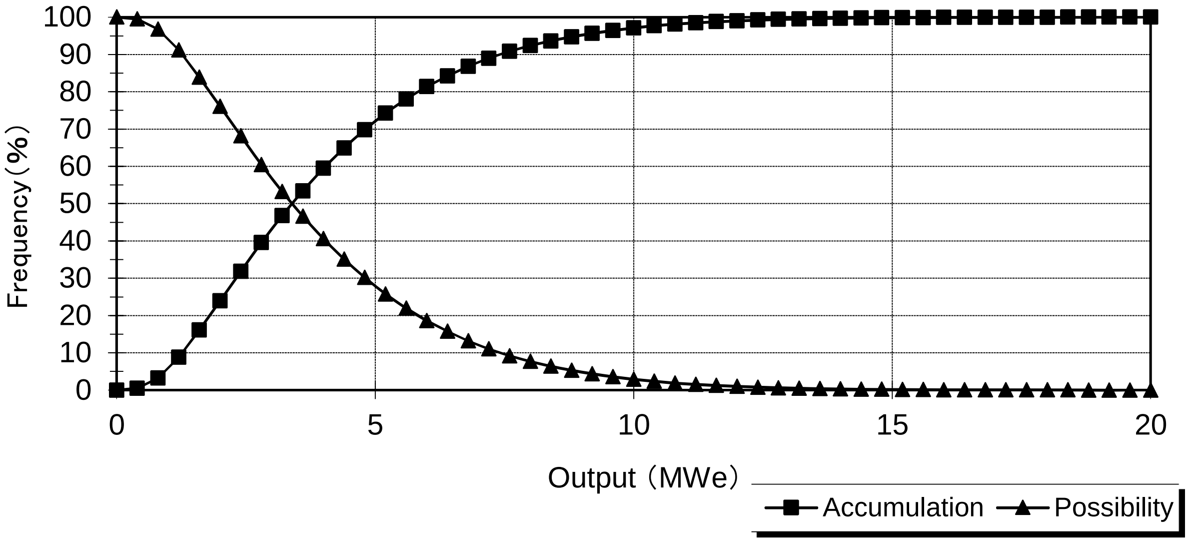
Fournier and Potter (1979)

6) In calculation 4), 5), for ΔtMg<0, or R<0.5, this geothermometer is not applicable.
7) TΔMg="TNa-K-Ca"-ΔtMg

TKMg	$\frac{4410}{13.95 - \log(K^2/Mg)} - 273.15$	K, Mg: mg/L	Giggenbach (1988)

7. Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis

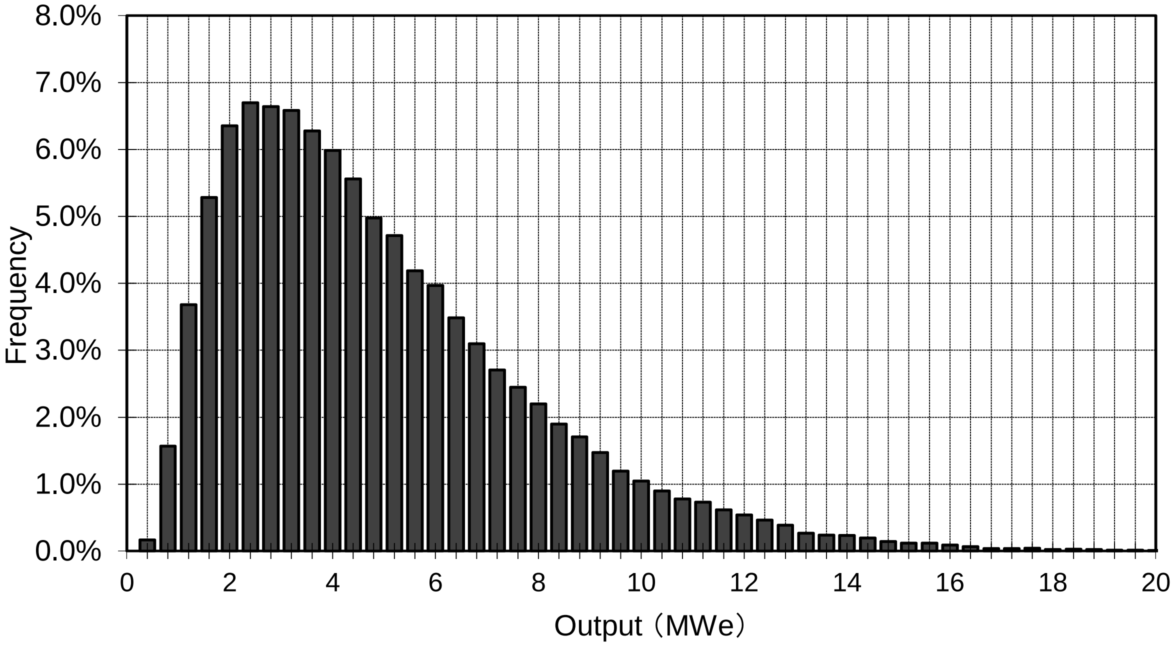


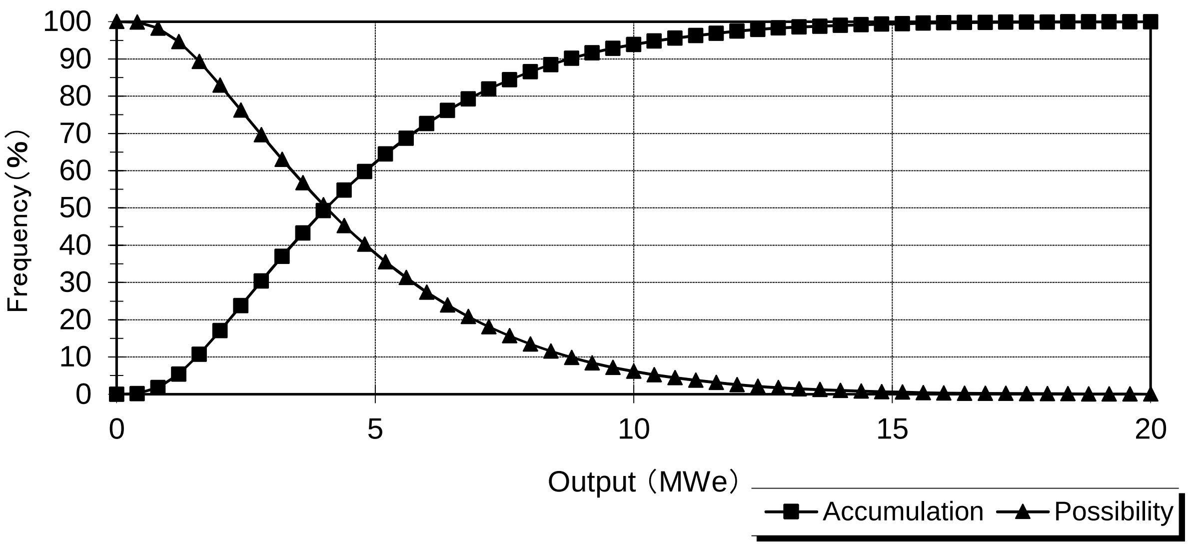


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	1.50	-	3.75
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	115	135	155
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	1.9%	6.3%	11.4%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (^oC)	-	80	-

Probability Distribution of the Geothermal Potential for Minera

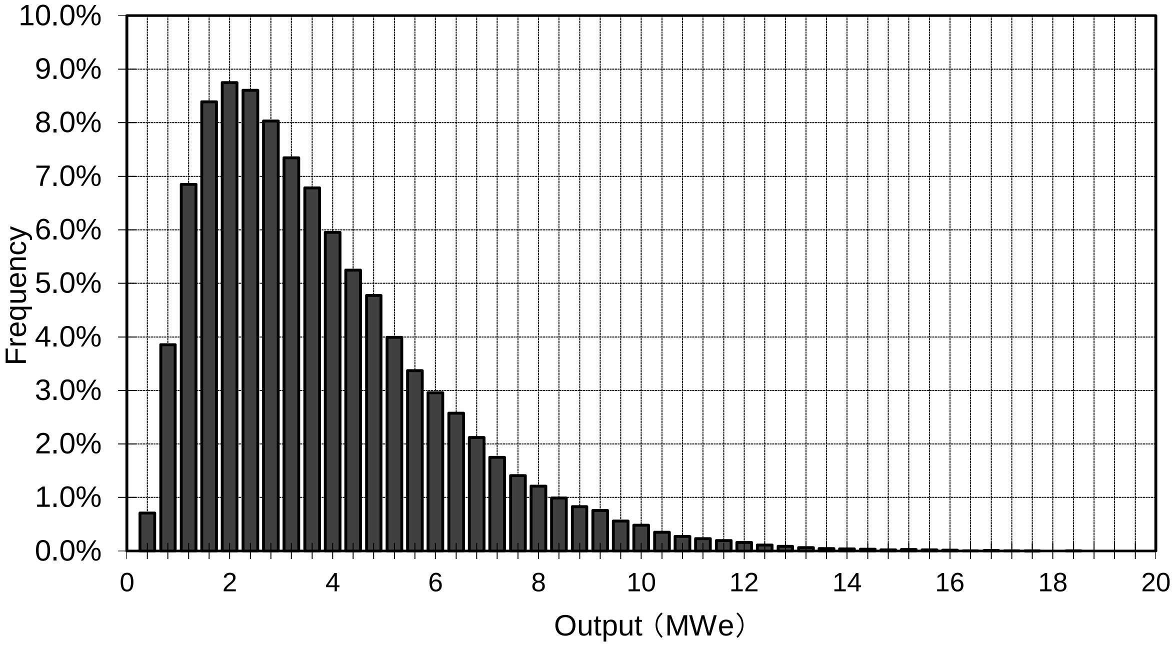


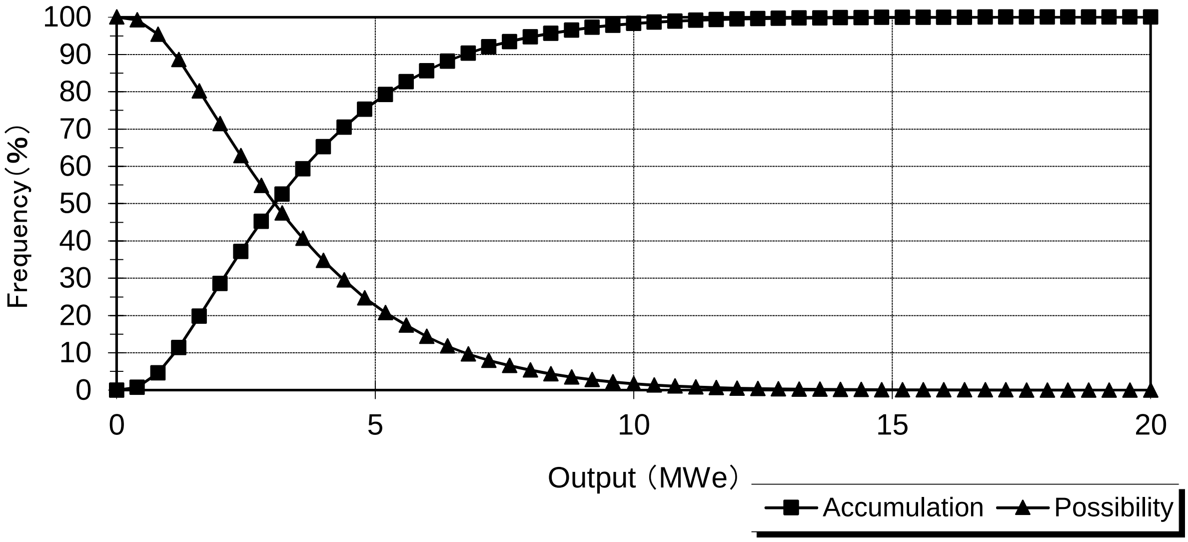


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	1.50	-	3.75
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	125	145	165
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	1.9%	6.3%	11.4%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (^oC)	-	80	-

Probability Distribution of the Geothermal Potential for Ihimbo

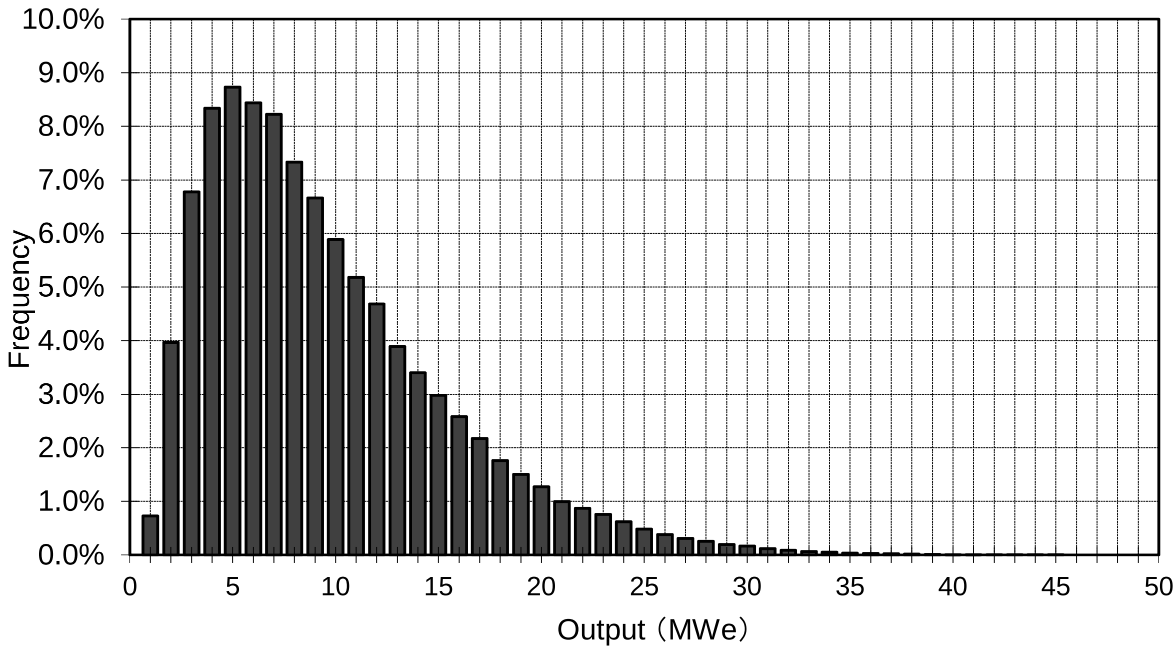


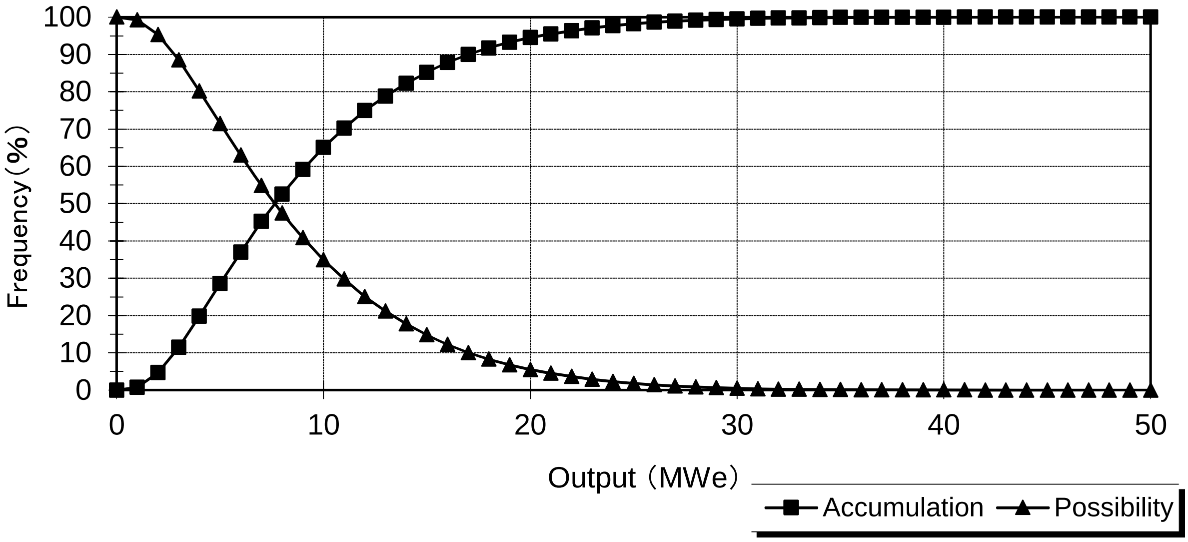


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	1.50	-	3.75
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^{o}C)	0.70	-	1.00
Reservoir Average Temperature (^{o}C)	110	130	150
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	1.9%	6.3%	11.4%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (^{o}C)	-	80	-

Probability Distribution of the Geothermal Potential for Rwimi

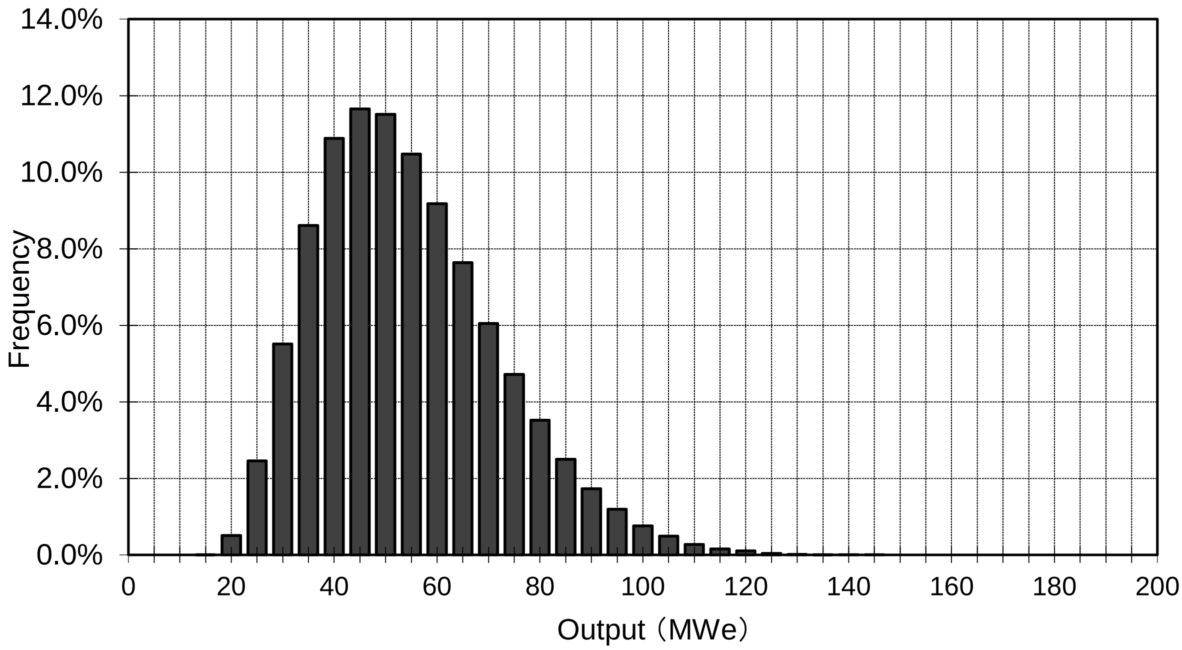


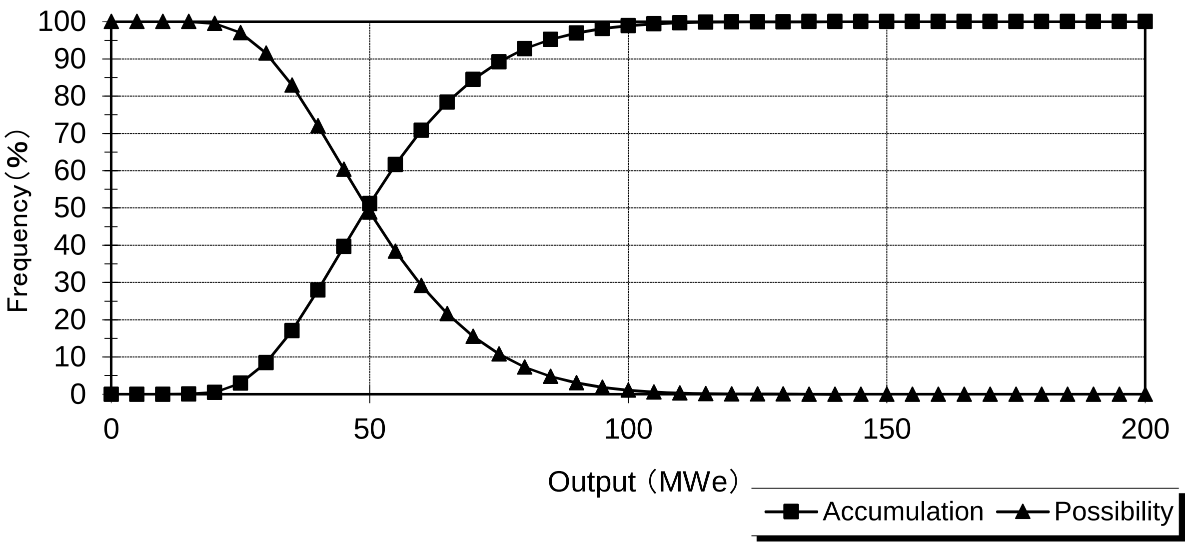


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	1.50	-	4.50
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	170	190	210
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	1.9%	6.3%	11.4%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (^oC)	-	80	-

Probability Distribution of the Geothermal Potential for Rwagimba





Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	4.40	-	8.30
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2400	2600	3000
Porosity (-)	0.01	0.05	0.10
Recovery factor (-)	0.125	-	0.250
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	220	240	260
Reservoir Average Pressure (MPa)	-	10.0	-
Heat-Electricity Conversion Factor (%)	12.0%	-	14.0%
Plant Life (year)	-	30	-
Load Factor (-)	-	0.85	-
Abandonment Temperature (^oC)	-	180	-

Probability Distribution of the Geothermal Potential for Kibiro