DATA COLLECTION SURVEY
ON GEOTHERMAL ENERGY DEVELOPMENT
IN EAST AFRICA

FINAL REPORT
(TANZANIA)

January 2014

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

Acronyms and Abbreviations

ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUC	African Union Commission
AfDB	Africa Development Bank
BGR	Federal Institute for Geosciences and Natural Resources of Germany
DECON	Deutsche Energie-Consult Ingenieurgesellschaft mbH
DEM	Digital Elevation Model
DFID	Department for International Development
DOE	Division of Environmental
EIA	Environmental Impact Assessment
EIB	Europe Investment Bank
EIS	Environmental Impact Statement
ESIA	Environmental and Social Impact Assessment
ESMF	Environmental and Social Management Framework
ESMP	Environmental and Social Management Plan
ETM+	LANDSAT Enhanced Thematic Mapper Plus
EWURA	Energy and Water Utilities Regulatory Authority
FCRS	Fluid Collection and Reinjection System
FEC	First Energy Company Ltd
GDC	Geothermal Development Company
GEF	Global Environment Facility
GIS	Geographic Information System
GPL	Geothermal Power Limited
GPT	Geothermal Power Tanzania Limited
GRMF	Geothermal Risk Mitigation Facility
GST	Geological Survey Tanzania
ICEIDA	The Icelandic International Development Agency
JEPIC	Japan Electric Power Information Center
JICA	Japan International Cooperation Agency
KfW	Kreditanstalt für Wiederaubau
LANDSAT	Land + Satellite
MEM	Ministry of Energy and Minerals
MNRT	Ministry of Natural Resources and Tourism
NDC	National Development Corporation
NDVI	Normalized Difference Vegetation Index
NEMA	National Environment Management Authority
NEMC	National Environmental Management Council
PALSAR	Phased Array type L-band Synthetic Aperture Radar
RAP	Resettlement Action Plan
REA	Rural Energy Agency
REB	Rural Energy Board
REF	Rural Energy Fund
RPF	Resettlement Policy Framework
SIDA	Swedish International Development Cooperation Agency
SREP	Scaling-up Renewable Energy Program
SRTM	Shuttle Radar Topography Mission

Table of Contents

List of Figures

List of Tables

List of Photos

I Framework and Policy of the Survey

I-1 Objectives of the Survey

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

I-2 Survey Area

United Republic of Tanzania (Fig. I-1)

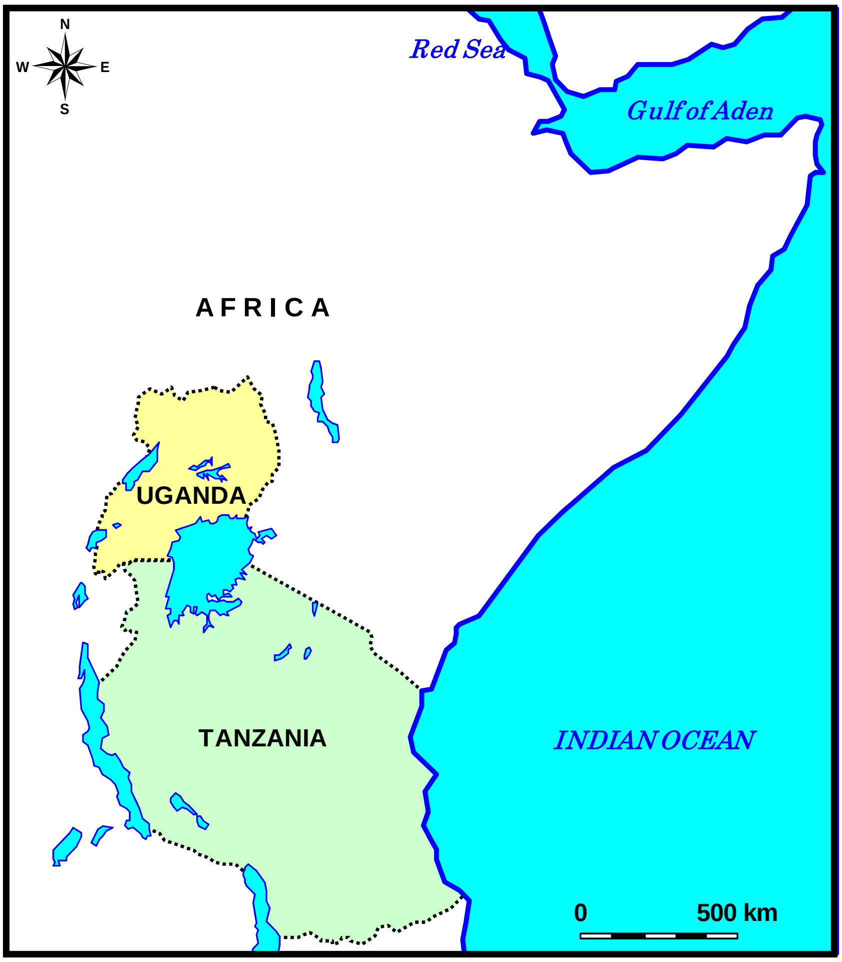


Fig. I-1 Survey area

I-3 Background of the Survey

In Africa, a stable electric power supply able to satisfy increasing demand at a satisfactory price for consumers is a requirement for economic and social development. The utilization of renewable energy for power generation (i.e. hydropower, geothermal power and so on) is recognized to be important in Africa in order to meet increasing electricity demand while addressing the reduction of greenhouse-gas emissions and energy security. This recognition of the importance of renewable energy is part of a worldwide trend. At the Tokyo International Conference on African Development (TICAD) V in June 2013, geothermal power development in the Rift Valley area, where considerable geothermal resources are present, was discussed as one of the important focuses of this workshop.

Although geothermal power plants have been installed in Kenya and Ethiopia, there are no geothermal power plants in the other countries of Africa. The installed geothermal power plants in Kenya are in the Olkaria and the Eburru geothermal fields (see Fig. I-2), and their total installed capacities are 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, fundamental information about geothermal resources is currently insufficient to allow the planning of geothermal power development. As a first step in remedying this state of affairs, a previous study (Situation Analysis Study on Geothermal Development in Africa, studying conditions of geothermal power development in Kenya, Ethiopia, Djibouti, Tanzania, and Uganda) was conducted by JICA in 2010. However, the information collected at that time is not yet sufficient to allow the formulation of a suitable supporting program for geothermal power development in this area. To elaborate a suitable contribution to the future geothermal power development of Tanzania it is necessary to collect the latest information about geothermal resources and geothermal development in these countries and to systematically review the collected information together with the information acquired previously.

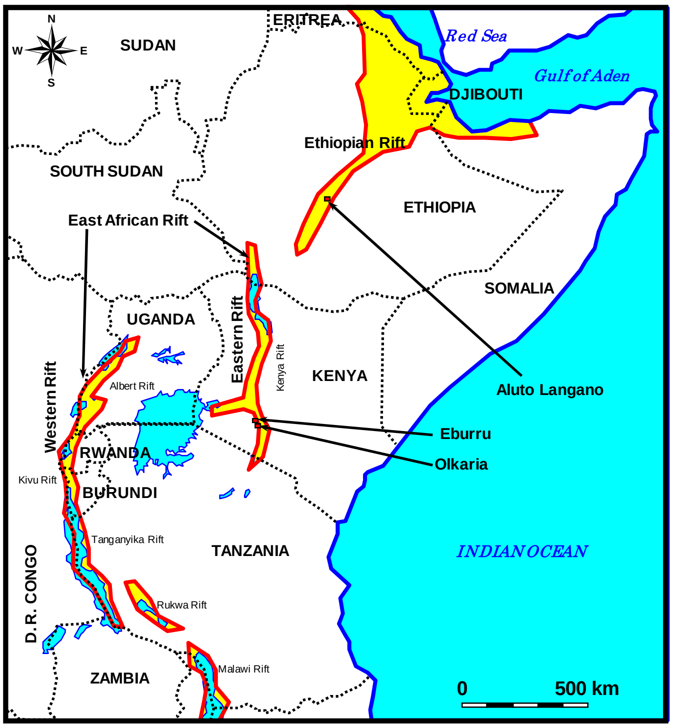


Fig. I-2 North and middle of the rift valley and developed field

I-4 Strategy and Methodology of Study

I-4-1 Strategy of Study

Most of geothermal areas in Tanzania still remain in the site reconnaissance phase. Moreover, nationwide explorations for geothermal resources are scarcely conducted, and adequate topographic maps cannot be obtained. To address this state of affairs, remote sensing technology using satellite images and geographic information systems (GIS) will be applied in this study, together with geological and geochemical surveying of several selected geothermal areas to further refine the obtained information.

I-4-2 Methodology of Study

1. Study in the first year (FY 2012/2013)

a) Update of the Basic Information

The following data and information concerning geothermal power development in the objective countries is collected in Japan and the information obtained in the previous study is updated.

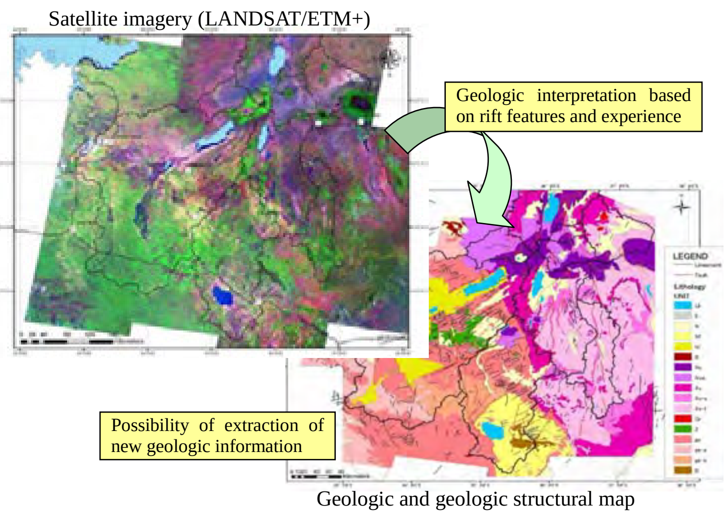
- Potential of primary energy sources and their utilization plan
- Information about geothermal development
- Information about geothermal development by donors
- Environmental and social regulation limiting geothermal development

b) Geological Survey

For the fundamental evaluation of geothermal resources to elaborate a suitable geothermal development plan, satellite imagery and geographic information systems (GIS) will give helpful information. A combination of these techniques enables fast interpretation over such a wide area as Tanzania, where the East African Rift extends from north to south. Reconnaissance surveying using remote sensing data is carried out over the area at the beginning, and then the study results are stored in a GIS database. A GIS has functions designed to display, superimpose and output various results, focusing thematic maps of geothermal resource potential. For instance, a comparison between the distribution of geothermal potential sites and social and/or economic conditions on the map will lead to the determination of exploration intent and priority.

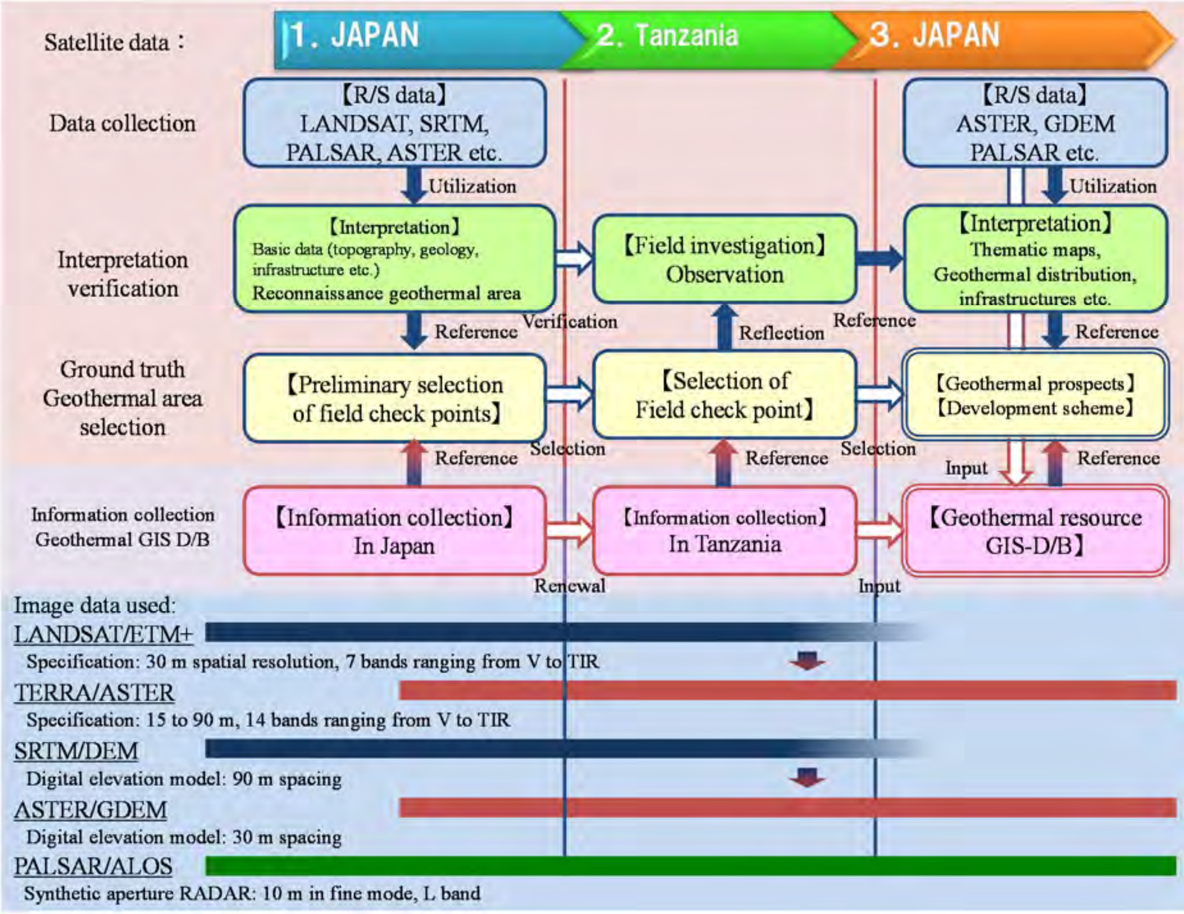
For an example of satellite imagery analysis of the East African Rift in Tanzania, where Arusha appears to be a very important promising area, see Fig. I-3. When interpreting this satellite imagery, knowledge and experience concerning various rift features is indispensable for applying the remote sensing procedure in advance. In addition, taking current conditions of digital progress in the east African countries into consideration, comprehensive interpretation which combines remote sensing techniques with GIS will play a very useful role in further study. The flowchart for utilization of satellite imagery analyses is shown in Fig. I-4.

In the first year of the study, data collection was conducted in Japan. This phase consisted of satellite imagery collection, collection of existing data regarding geothermal features, selection of promising areas including its ground truth in situ and GIS database design. Satellite imagery data from LANDSAT/ETM+ and SRTM/DEM, ASTER, ASTER/GDEM and PALSAR (if necessary) will be used through this study. Interpretation work will be carried out to extract lineaments such as fractures, thermal anomalies, distribution of alteration minerals, groundwater springs and so forth on the images.



(Study team)

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



(Study team)

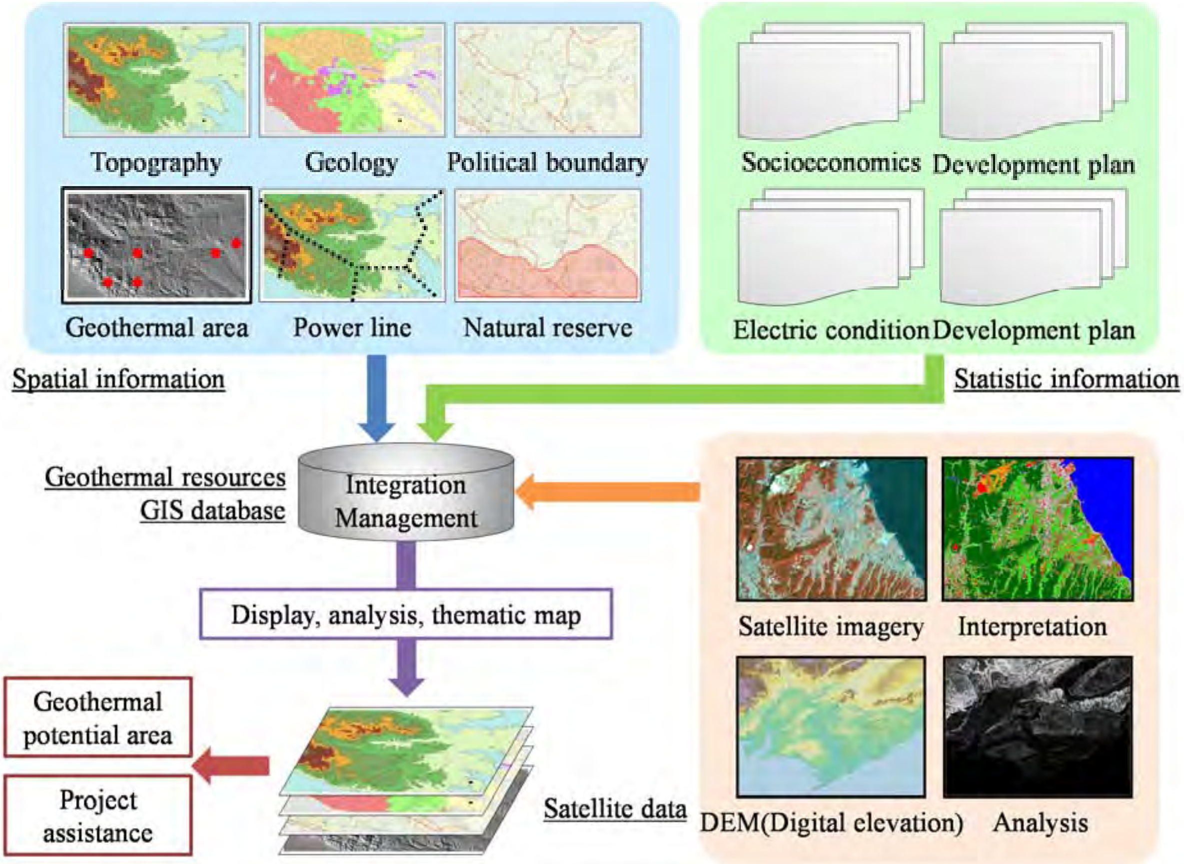
Fig. I-4 The flowchart for utilization of satellite imagery analyses in Phase I and Phase II

c) Geochemical Survey

Following on the previous study by JICA (2010), chemical data concerning geothermal fluids in Tanzania were mainly collected. From these data together with those obtained in the previous study, the following items were examined for evaluation of geothermal resources: origin of geothermal fluid, heating process, reservoir temperature and fluid flow pattern in prospective fields.

d) GIS

Various data must be examined in considering future geothermal development projects. They include not only natural condition data concerning items such as topography, geology, geologic structure and the distribution of possible geothermal areas, but also socioeconomic data concerning infrastructure, the development plan for electric power etc. A GIS provides such a database as a package of the data mentioned above, particularly the spatial data that include positional information. In addition, miscellaneous interpretations and optical outputs can be achieved by using its spatial analysis functions. In the first year, a fundamental GIS database called ‘Geothermal resources GIS database’ was designed, and the existing geothermal-related data were input, including the satellite imagery and its interpretation maps. The ‘Geothermal resources GIS database’ is shown in Fig. I-5.



(Study team)

Fig. I-5 Concept of the '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 Basic Information

The following items will be checked in the field survey to update and complete the preliminary data

- Collect information about and survey the accessibility of the prospective area
- Collect information about donors, private sector entities and electric power companies which have experience in geothermal development
- Collect information about the geothermal development plan and power development and distribution system plan
- Collect information about the capacity of executing agencies for geothermal development

b) Geological Survey

Field investigation will be conducted in the selected areas. The following geological factors estimated through imagery interpretation in the first year will be examined in the field investigation: geology, geologic structure, occurrence of secondary minerals resulting from hydrothermal alteration and thermal anomalies. As ASTER data have a high spectral resolution, the detailed occurrence of secondary minerals can be mapped by means of its spectral analysis. In addition, thermal anomalies related to hot springs will be mapped by means of its TIR E-T separation. The target area selection will be conducted through GIS procedures using existing data and field investigation results. In these procedures, a GIS database closely related to geothermal information will be elaborated as well.

Hand specimens of rock will be sampled in the field, and the laboratory analysis specified below will be conducted in Japan. These analytical results will contribute to the understanding of the characteristics of geothermal activity in the fields.

- Microscopic observation: 8 samples
- X ray diffraction analysis: 13 samples
- Spectral analysis: 13 samples

c) Geochemical Survey

To examine and complement the chemical data concerning hot spring water described in the collected literature, hot spring and surface waters will be sampled at the sites. A final determination of sampling points, chemical components to be analyzed and the number of samples (totaling about 20) will be made based on the data review results and discussion with the Geological Survey of Tanzania (GST).

Samples will be sent to Japan for analysis. Provisionally, 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 conditions 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 collected mainly by field investigation will be added to the GIS database constructed in the first year. These are data concerning topography, geology, geologic structure and distribution of possible geothermal areas, infrastructure, natural reserves and so forth. Geothermal areas with sufficient potential will be selected by applying GIS functions to these data. This process allows for the establishment of a basic ‘Geothermal resources GIS database’ and profiles each promising geothermal development area for further work.

e) Geothermal Resource Evaluation

The resource potentials will be calculated, mainly based on the collected data. Applied method to evaluate the potential will be determined on the basis of 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:

Preliminary Work in Japan	Early February - Early March 2013
Inception Report	March 8th, 2013
Field Trip	Early August 2013 - Early September 2013
Progress Report	October 7th, 2013
Wrap-up Work in Japan	Middle of October 2013- January 2014
Draft Final Report	December 3rd, 2013
Final Report	January 31st, 2014
End of Work	January 2014

I-6 Work Schedule

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

Table I-1 Work Schedule

Month / Service Item	FY2012		FY2013								
	2	3	4	5	6	7	8	9	10	11	12
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 Donors											
・ 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 Japan; - - - - - Other task; Work in Tanzania; △——△ Explanation of Report

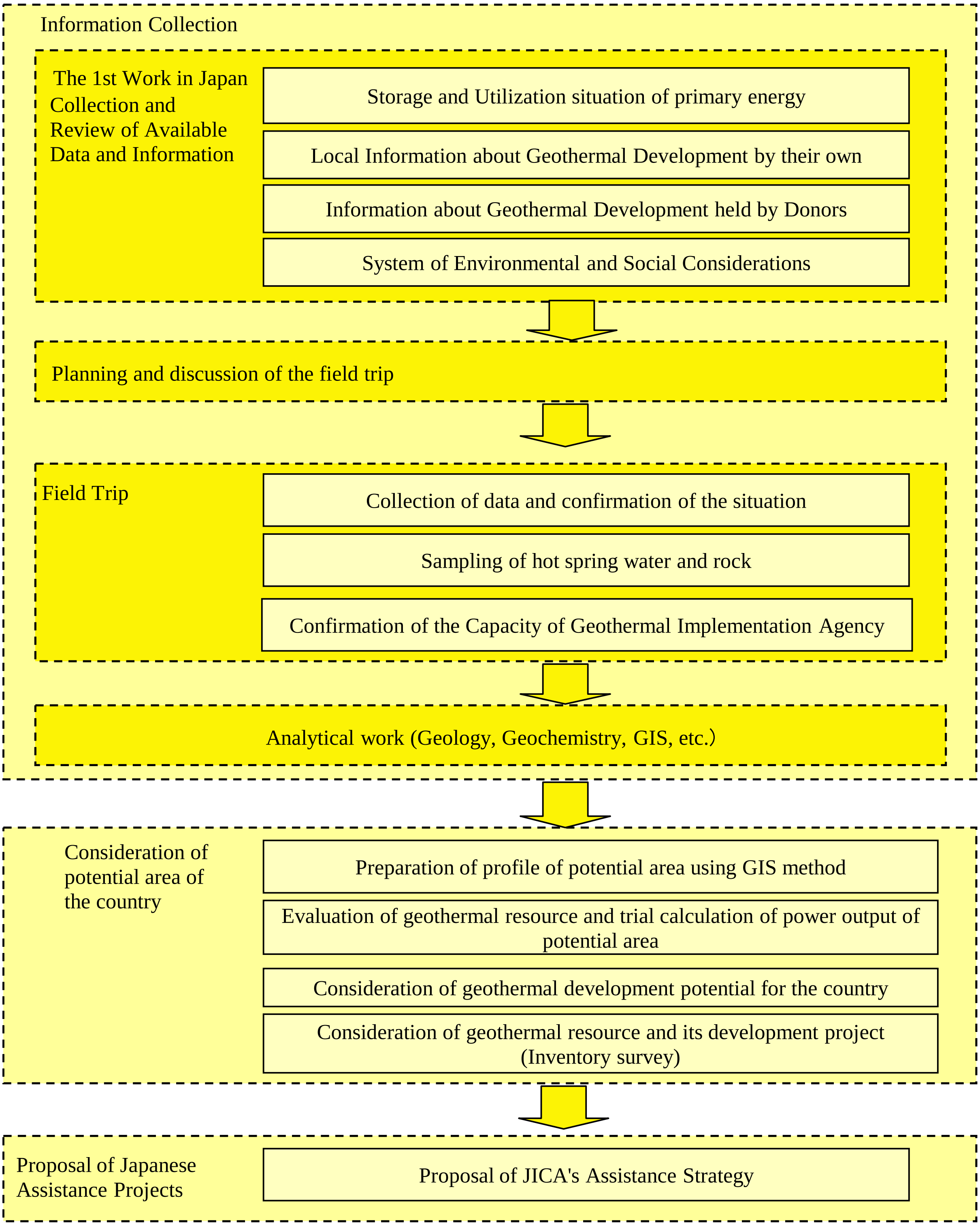


Fig. I-6 Study Flow Chart

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, Planning of Geothermal Development	Team Leader, Project Management, Technical Supervisor of Geothermal Development
Tetsuya YAHARA	Sub-Leader, Planning of Geothermal Development Analyst	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 of 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

According to JICA (2010, Situation Analysis Study on Geothermal Development in Africa), the amount of primary energy supply in Tanzania in 2007 was 18,287,000 toe. Among these, domestic energy (coal, natural gas, hydropower, fuel, etc) amounts to 16,902,000 toe. On the other hand, final energy consumption is 15,806,000 toe, consisting of 2,013,000 toe for industrial, 1,005,000 toe for transportation, and 12,788,000 toe for other (commercial, agricultural, etc) purposes. The main energy resources in Tanzania are hydro power, natural gas, coal and renewable energy (solar energy, wind energy, geothermal, biomass). Their potentials are estimated as follows: 5,000 MW of hydro power, 45 billion m^3 of natural gas, approximately 300 million tons of coal, and 187 kW/m^2 of solar energy. With financing from the World Bank, Europe Investment Bank (EIB), and Swedish International Development Agency (SIDA), a natural gas development project in the Songo Songo Island area, located in the Indian Ocean, is in progress and production in the gas field began in 2004. Songas Company (a joint venture of more than 20 companies, such as Canadian and Tanzanian investment firms) is responsible for this natural gas project, though it is also carrying out improvements to the power plant and constructing a pipeline for this natural gas project. The 186 MW power plant for this project was completed in 2002 before the pipeline was constructed. In the beginning, jet fuel was used for power generation, but since the pipeline system from the gas field to the power plant was established in 2004, natural gas has been used for power generation.

II-2 Electric Power Situation and Power Supply System

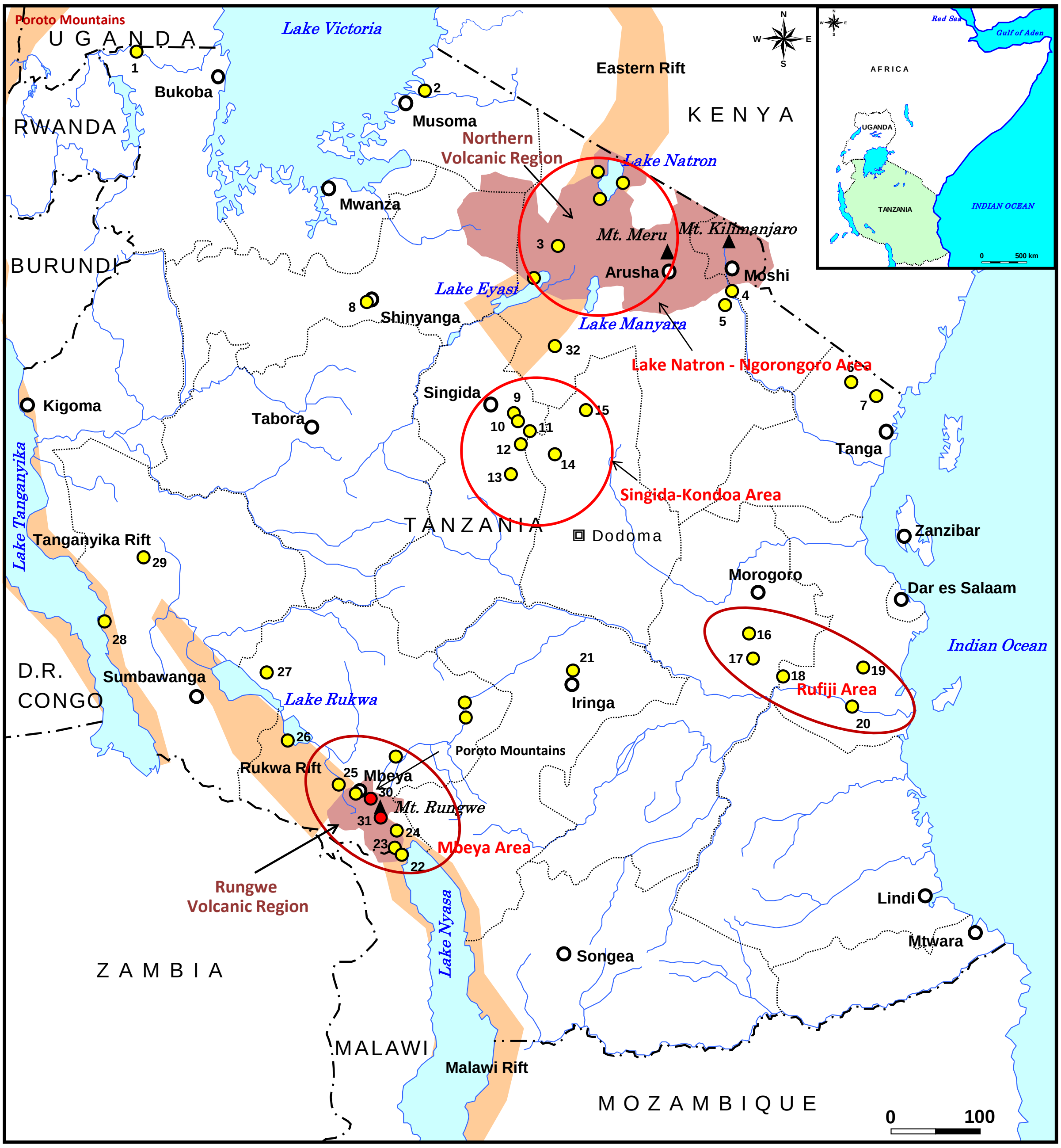
The electric power sector in Tanzania is composed of the Ministry of Energy and Minerals (MEM), Tanzania Electric Supply Company (TANESCO), Rural Energy Board (REB), Rural Energy Agency (REA), Rural Energy Fund (REF), and Energy and Water Utilities Regulatory Authority (EWURA). TANESCO had been established under MEM by the private sector and government in the early 1930s, but the Tanzanian government held all the shares by 1957. TANESCO's undertakings covered the whole spectrum of the power business from power generation through power transmission to power distribution in Tanzania, and it was the only large-scale electricity supplier in Mainland Tanzania. From 1980, TANESCO supplied 45 MW of electricity via submarine cable (about 38 km in length) with a capacity of 132 kV to Zanzibar Electricity Corporation (ZECO), which was responsible for power distribution in Zanzibar Island and Pemba Island. However, TANESCO's monopoly position ended when participation of the private sector in the electricity business became possible in June 1992. According to the 2003 revised energy policy, the national development goals are ensuring a stable, reliable and sustainable supply of energy at reasonable cost. In addition, it is pointed out that current supply capacity must be increased three-fold by 2023, because of increasing demand due to industrial, agricultural and commercial expansion, population growth, etc.

According to the previous report by JICA (2010), TANESCO has a power generation capacity of 1,039 MW in total, comprising 561 MW of hydropower and 478 MW of thermal power. According to Mnjokava (2012), the electrical generation capacity of Tanzania is 1,320 MW in total; its constituent sources are hydropower, gas and thermal power. As the current power supply is highly dependent on hydropower, the power supply system is easily affected by climatic factors, such as drought. For this reason, the government of Tanzania is committed to developing alternative power sources and achieving the best mix among energy sources. As mentioned above, the possible sources of power in Tanzania are hydro power, heavy oil, coal, wind power, solar energy, ocean wave power, natural gas, geothermal, biomass, etc. Geothermal energy is regarded as an important alternative energy source.

II-3 Outline of Geothermal Resources

Geothermal development projects in Tanzania are under the control of the Division of Renewable Energy, Department of Energy and Oil, MEM. The Division of Renewable Energy is currently managing 5 fields where solar, wind, small hydro, geothermal and biomass power is being developed. Another actor is the Geological Survey of Tanzania (GST), a national agency regulating geothermal exploration. TANESCO has not been given responsibility for geothermal development, but is a member of the geothermal development working group, together with GST and the Division of Renewable Energy of MEM. In addition, REA is investigating the development of small-scale geothermal power plants for rural electrification.

Although there has been little geothermal exploration in Tanzania, it has been conducted since 1949. Preliminary studies have yielded results in the areas of ground temperature measurement, chemical analysis of hot spring water and gas, flow rate measurement of hot spring water, etc. These preliminary studies have become basic information for planning geothermal exploration. Most of the hot springs identified are in the Rift Valley. These hot spring areas are mostly distributed in the northern volcanic regions such as Kilimanjaro, Mel and Ngorongoro, near the border with Kenya, and in the Rungwe volcanic region in the southwestern part of Tanzania (see Fig. II-1).



Legend

Geothermal Area   Licensed Geothermal Area

1 : Mitagata	7 : Amboni	13 : Hika	19 : Rufiji (Nyongoni)	25 : Songwe	31 : Mbaka
2 : Maji Moto	8 : Usangori	14 : Gonga	20 : Utete	26 : Ivuna	32: Masware
3 : Ngorongoro	9 : Isanja	15 : Kondoa	21 : Daraja ya Mungu	27 : Mapu	
4 : Ukindu	10 : Mnyeghi	16 : Kisaki	22 : Kasimulo	28 : Bulongwe	
5 : Njoronoli	11 : Takwa	17 : Maji ya Weta	23 : Mampulo	29 : Kabango	
6 : Bombo	12 : Mponde	18 : Tagallalla	24 : Kilambo	30 : Ngozi	

(Modified from Mnjokava, 2012)

Fig. II-1 Geothermal Fields in Tanzania

II-4 Situation of Geothermal Development

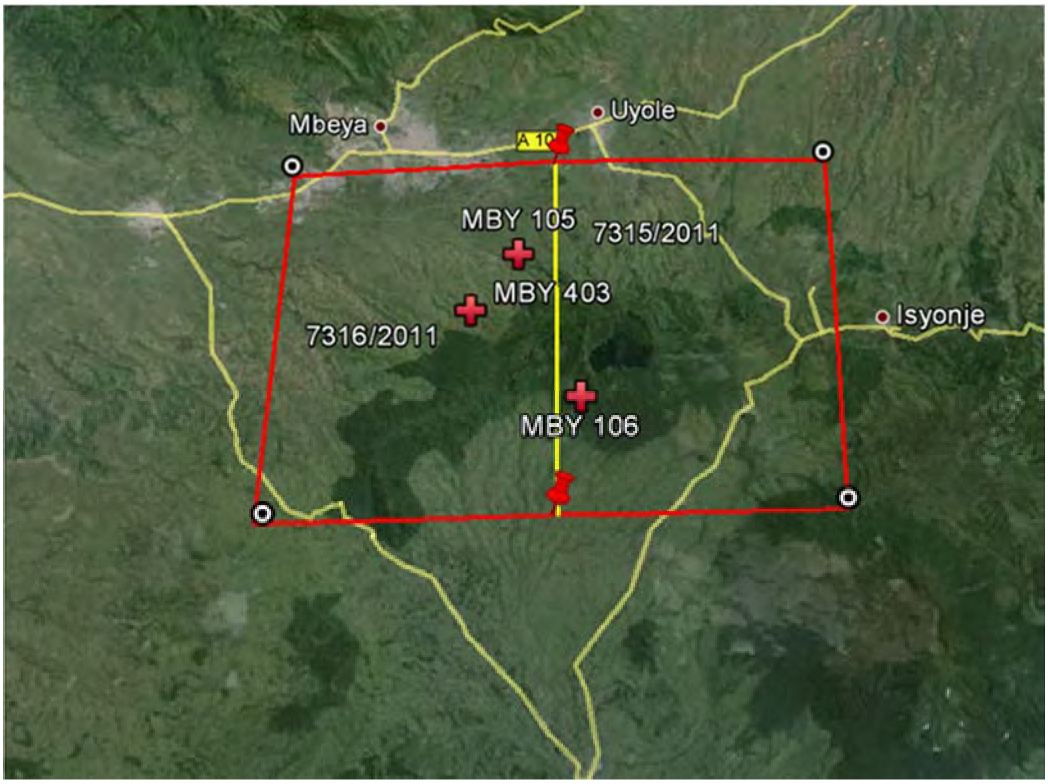
II-4-1 Geothermal Development

Sweden Consulting Group (SWECO) and Virkir-Orkint Consulting Group of Icenad (SWECO, 1978) conducted geothermal reconnaissance exploration in Tanzania from 1976 until 1978 funded by Swedish International Development Agency (SIDA). In that survey, a total of 50 hot springs in the northern part of Tanzania (Arusha and its vicinity, Lake Natron, and Lake Manyara) to in the southwestern part of the country (Mbeya), were investigated by taking temperature of hot discharging springs. As relatively high temperatures were identified around Lake Manyara, Lake Natron, Ngorongoro crater and Mbeya, these areas were therefore regarded as prospective areas for further studies.

Hochstein and others (2000) reviewed some reconnaissance data of some 15 geothermal hot springs with temperatures >40ºC. Ten of these hot springs are located within the Quaternary volcanics associated with the Eastern and Western Rift systems and the other are located within the Tanzanian Archean craton and Precambrian rocks. They concluded that the most attractive prospects were to be found in the reservoirs Songwe, Kilambo and Mampulo/Kasimolo hot springs associated with Rungwe Volcanic complex located in the Mbeya region. The springs were indicative of the outflows of some system to be located elsewhere to be determined by detailed scientific investigations.

From 1997 to 2004, based on reconnaissance surveying conducted by First Energy Company Ltd. (FEC), at Luhoi (Nyongoni) in the Rufiji River basin, approximately 160 km south of Dar es Salaam, it is expected that a geothermal reservoir is present in this area as well. In 2004 and 2005, with the funding from the African Development Bank (AfDB), Deutsche Energie-Consult Ingenieurgesellschaft mbH (DECON) conducted another survey for the purpose of rural electrification. In this survey, geothermal energy was regarded as one local renewable energy source for future power supply for rural development. The survey covered Lake Natron and Mbeya areas and employed geological and geochemical and geophysical methods of limited coverage. The survey concluded that Mbeya region and Utete area which had been licensed to FEC were better prospects than Lake Natron for further detailed surveys. At Lake Natron, the areas towards Oldonyo Lengai volcano and to the east of Gelai volcano were suggested to be covered for more understanding of those areas.

Based on the recommendations of earlier reconnaissance surveys, between 2006 and 2009 Federal Institute for Geosciences and Natural Resources of Germany (BGR) conducted in collaboration with the staff from MEM, GST and TANESCO geological, geochemical and geophysical surveying (TEM, MT) in Mbeya region within the Rungwe volcanic complex. The survey was conducted under the GEOTHERM project which was a part of a larger project covering Rwanda, Uganda and Kenya. In Tanzania the project was entitled “Geothermal Energy as an alternative source of energy for Tanzania. These surveys indicated that there are two geothermal systems, the northern one associated with Ngozi volcano which gives rise to the Songwe and other hot springs and the southern one associated with Rungwe and Kiejo volcanos discharging southwards through several hot springs. The northern geothermal system was found to have temperatures in excess of 200^{O}C whereas the southern one less than this (BGR, 2008). Based on this finding, more detailed geophysical work was carried out at Ngozi in 2010 by the same team with the aim of siting three shallow (300-400m) exploration wells. It is understood that the BGR has not submitted a report on this final detailed work. However, based on field data, the Tanzanian project staff proposed location for three shallow drilling sites as shown in Fig. II-2 (Ministry of Energy and Minerals, 2012). It must be noted that proposed shallow wells are located within the two areas license to GPTL.



(Modified from Google map)

Fig. II-2 Proposed shallow drilling sites (MBY105, MBY106 and MBY403 and location of the two geothermal licenses awarded to GPT at Mbeya

Except the detailed studies made by BGR at Ngozi prospect, most of the geothermal exploration conducted in other areas of Tanzania are on a reconnaissance basis. Hence, big risk for development are remaining for many areas. Therefore, in order to develop geothermal resources further in Tanzania, it is important to select other more prospective sites on which detailed exploration work can be conducted followed by exploration drilling. Conducting detail surveys in several areas allows comparison of results to be made before selecting the most suitable site for further development. It is also recommended to maximum on the surface exploration in order to reduce the exploration drilling risk which is much more expensive.

II-4-2 Geothermal Licenses

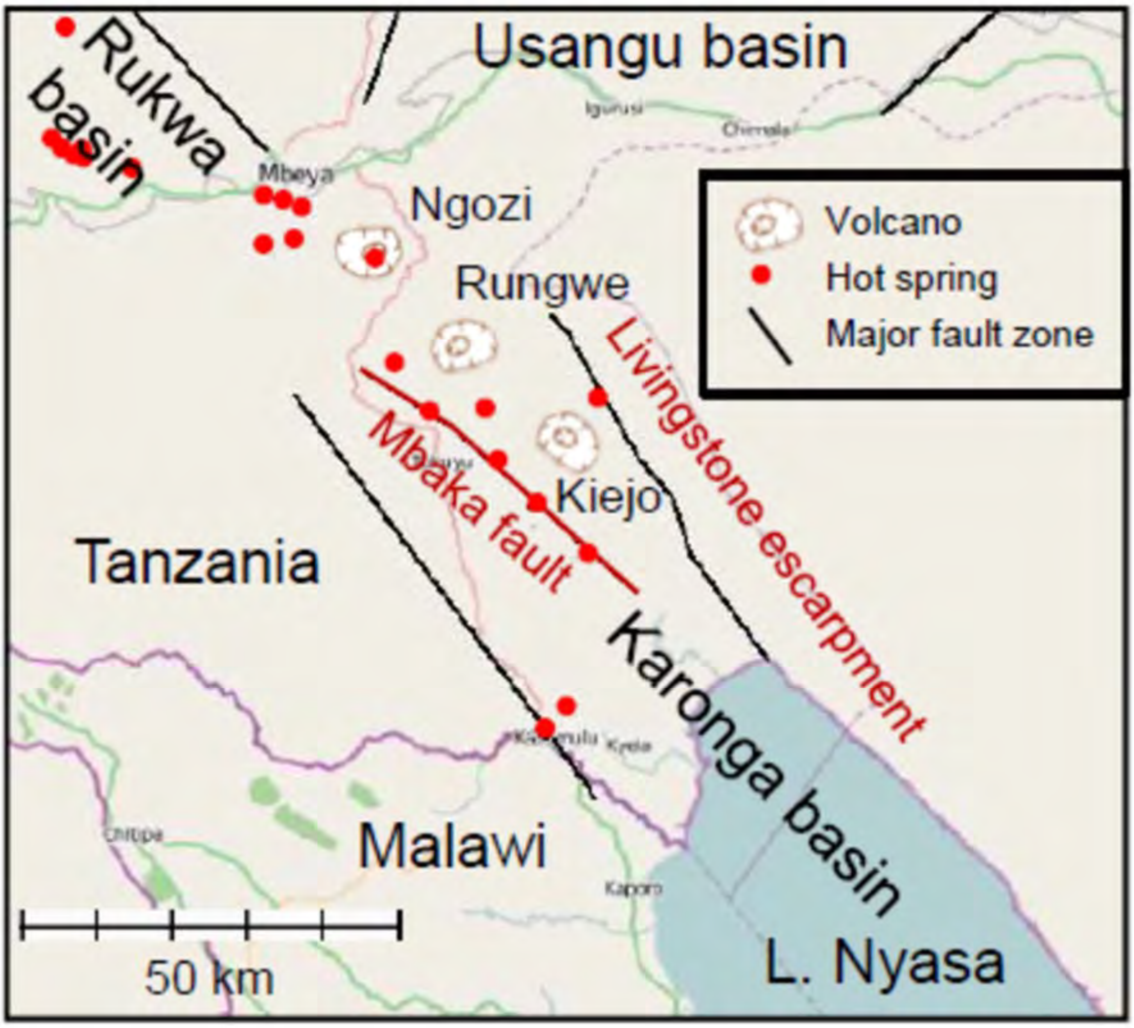
The First Energy Company Limited (FEC), which is a Tanzanian company was the first IPP to be issued with a geothermal license in Tanzania in 1997. The license was for detailed geothermal exploration and development of the geothermal prospect of Luhoi in the Lower Rufiji Basin. FEC compiled studies, based on results and data from petroleum exploration in the area, to assess the prospect. FEC estimated the geothermal potential at Luhoi to be in the order of 100 MW. However, the reports and data of the studies have never been publicly available. The company did not proceed this development and the license has since been cancelled.

Although the Geothermal Staff working with BGR has located three temperature gradient exploration sites at Ngozi area, the Government of Tanzania could not proceed with the exploration drilling due to lack of funds. In order to proceed with further development, the Government decided to issue 30 geothermal licenses from 2011 to various IPPs under the Mining Act.

Geothermal Power Tanzania (GPT) Ltd was registered in 2012 in Tanzania to explore and develop geothermal resources. GPT is 70% owned by Geothermal Power Limited (GPL registered in Mauritius), Interstate Mining & Minerals Ltd (Interstate, 25%) and National Development Corporation (NDC, 5%). GPL is owned by Aspac Mining Ltd, Geothermal Engineering GmbH and some investors from Australia and Singapore. Interstate and NDC are Tanzanian. The geothermal consultants for this venture are GeoThermal Engineering GmbH from German who are also shareholders.

GPT initially obtained six geothermal exploration licenses which were held through Interstate Mining & Minerals limited around Mbeya and Rufiji areas (www.gpl-international.com/projects). Three licenses were at Mbaka (PL7314/2011, PL7312/2011, PL7317/2011), two at Ngozi (PL7316/2011, and PL7315/2011) and one at Rufiji (PL 7261/2011).

In 2012, after acquiring two concessions at Mbaka, GPT carried out surface investigations comprising geological and geochemical in the area (Kraml et al, 2012). It is postulated that the Mbaka fault (Kraml et al, 2012) Fig. II-3 is upflowing hot fluids which mix at near the surface with surface percolating water creating diluted springs hot springs. Currently GPT is drilling three 600-800m exploration wells at Mbaka targeting the Mbaka fault below the dilution zone with the intention of putting a small 10MW wellhead generator to supply Mbeya area. The hot water will be used for drying tea and bananas (Kraml et al, 2012). A bigger rig has now been delivered in Tanzania and will drill a production well at Mbaka (Kraml, personal communication). They also planned to drill three other shallow wells at Ngozi before drilling a deep well exploration well and negotiating a 100MW PPA for the site. Plans for a 5MW power plant had been planned at Rufiji site. However, due to lack of activities in many of these licenses as required by the law (Mining Act), the government cancelled all the other licenses except two at Ngozi (7315/2011, 7316/16) and one at Mbaka (7317/2011) licensed to GPT. The government was reviewing the remaining three concessions with the view of cancelling them if they did not comply.



(Kraml et al., 2012)

Fig. II-3 Map showing the Rungwe volcanic complex with Ngozi, Rungwe and Kiejo volcanic centers with Mbaka fault

II-4-3 Support from International Institutions

Economic Consultants Associated Ltd has published the "East Africa Geothermal Energy Review of Donor Initiatives and Current Regulatory Framework" in October 2012. According to this report, it was proposed that considerable number of donors represent their interest to the geothermal projects in Tanzania. The report was prepared for energy donor partner group led by SIDA. Through the support to the geothermal sector with collaboration of some donors, this group aims to play a role in scaling up renewable energy program (SREP) in Tanzania.

AfDB is and will continue playing an active role in moving forward geothermal development in Tanzania. Buoyed by its successful role in financing GDC in the Menengai project in Kenya, AFDB in collaboration with the DFID and MEM organized and hosted in March 2013 a fruitful stakeholder’s workshop on Geothermal Legal and Regulatory Framework in Dar es Salaam. The workshop provided feedback on “SREP: Investment Plan for Tanzania” proposal before it was submitted to Climate Change Investment Fund for consideration (Ministry of Energy, 2013). These suggestions included developing a geothermal roadmap, legal and regulatory framework instead of the Mining Act, providing clarity on the renewable energy strategy and the role of the private sector, streamlining processes for project development, increasing human capacity for geothermal sector governance and establishing a geothermal section in Department of Energy.

SREP proposal consisted of two major components - Geothermal Development and Renewable Energy for Rural Electrification component. SREP project would develop a total of 147.5MW of renewable energy which was estimated to cost US$719.2m out of which US$ 536.8m would be the geothermal component. AfDB is the lead agency for geothermal component of SREP while the World Bank will be the lead agency for the Renewable Energy for Rural Electrification (Mini and Micro Grid) component. The Ministry of Energy will be the implementing agency for the geothermal component while the Rural Energy Authority would implement the other component. In this regard, the Ministry of Energy was committed to restructure and establish a geothermal section in the Energy Department to handle the project.

The estimated costs for the geothermal component of SREP is shown in Table II-1 below. The project component aims to develop 100MW by 2025 as called in the Power Master Plan (Ministry of Energy and Minerals, 2013). It must be noted that the Master Plan does not specially provide 100MW for geothermal but for renewable energy with the anticipation that it could come from either wind, geothermal or solar. SREP will provide a grant of US$25m which cover project preparation, organization and institutional development at MEM, capacity building, detailed exploration of a field to be identified by the current JICA study followed by exploration drilling and transaction advice services for power station development. The current JICA reconnaissance study is therefore a part of the SREP project to identify a site (s) for detailed study.

On 3rd August, a team of government officials visited geothermal operations in Kenya as one of the capacity building activities of SREP (see item 1.3 of table). AfDB had already drafted the TOR for legal and regulatory framework as one of the components of SREP activity 1.1 in Table II-1.

As soon as the delegation was back from Kenya, MEM was to set up a geothermal section with the existing trained staff. Any future geothermal licenses will be issued and monitored from this new section. The capacity building for the holders of the new institutional arrangement will be based on the staff requirements. It was noted that the new geothermal institution will be responsible for any future geothermal exploration work and exploration drilling before areas are bidden to IPPs for further development. This means that it will be staffed with scientists, engineers and economists and perhaps evolve to Kenya’s GDC type of arrangement dealing with steam supply in the near future.

AfDB will contribute about US$100m in loans form and SREP US$20m of which 25% will be grant and 75% soft loan.

Table II-1 SREP Geothermal development project for 100MW power plant

	Target capacity	100MW						
		SREP	AfDB	Others	GoT	Private Sector	Commercial Banks	Totals
		Unit: Thousands of US$						
0	Project prep grant	700	-	-	-	-	-	700
1	Strategy, Registration and Capacity Building	-	-	-			-	
1.1	Strategy, registration and regulation	-	-	2,300	500	-	-	2,800
1.2	Organization establishment, institutional development and program management	700	-	-	1,000	-	-	1,700
1.3	Capacity building, training, knowledge and lessons sharing	1,600	-	-	-		-	1,600
2	Geothermal Resource Confirmation and feasibility studies of promising sites							
2.1	Satellite and surface exploration and pre-feasibility studies			3,000				3,000
2.2	Test drilling program design, exploration drilling and feasibility studies	20,000						20,000
3	Power generation project development and Transaction Advisory	2,000						2,000
4	100MW Power Plant Project	-	15,000	-	-	142,500	317,500	475,000
5	Partial Guarantee for power plant	-	30,000	-	-	-	-	30,000
	Total	25,000	45,000	5,300	1,500	142,500	317,000	536,800

（MEM, 2013）

SREP will finance the detailed exploration work at a site to be proposed by the current JICA study beginning January 2014. The SREP project will also cover the costs of subsequent exploration drilling.

Although the actual plans have not been well spelt out, DFID was keen to participate in the development of Legal and Regulatory frameworks related to Land Rights and power tariff issues as these would be very critical in attracting IPPs into the geothermal projects.

BGR is considering assistance in the following fields:

- Training for Tanzania's specialist for data acquisition, data analyzing, and result interpreting in geothermal exploration
- Assisting geothermal exploration method based on selected exploration well drilling site in

recent year

- Policy dialogue regarding awareness of policy
- Supporting MEM, GST and TANESCO to continue geothermal resources exploration.
- Promoting information to policy makers regarding the availability of geothermal energy in Tanzania
- Cooperation in financial finding to geothermal shallow drilling.

KfW has already established the Geothermal Risk Mitigation Fund (GRMF) which is being administered by the African Union Commission (AUC) in Addis Ababa to various East African Countries including Tanzania. Although Tanzania has not yet applied for assistance from GRMF, the fund covers exploration assistance and covers the risk of drilling unproductive wells and payment is based on degree of failure. The East African Rift geothermal fund (ARGeo) which was established in 2003 and funded by GEF is also available to Tanzania. However, the facility has had approval and implementation difficulties. Once these challenges are overcome, the funds could be applied for some future exploration work. The funds are however limited and are competed against by six African countries. ICEIDA in collaboration with World Bank (Compact project) has established a fund for East African countries as well. The Compact project will provide assistance in surface exploration and capacity building and will consider extending this assistance in cooperation with other donors to Tanzania once the JICA study is completed. United Nations University Geothermal Training Programme (UNUGTP) has been organizing and funding short courses (4 weeks) every year in Kenya since 2005 to-date in collaboration with KenGen and GDC. Several Tanzania nationals have benefited from this course. UNUGTP has also been offering six months training course in Iceland. JICA has also started sponsoring Tanzanians to the newly reintroduced geothermal cause in Kyushu. In moving forward, JICA could consider tailor-made courses organized specifically for the staff who will be tasked to manage the geothermal section at the Ministry of Energy.

II-5 Promising Area for Geothermal Development

II-5-1 Preliminary Survey

1. Remote Sensing

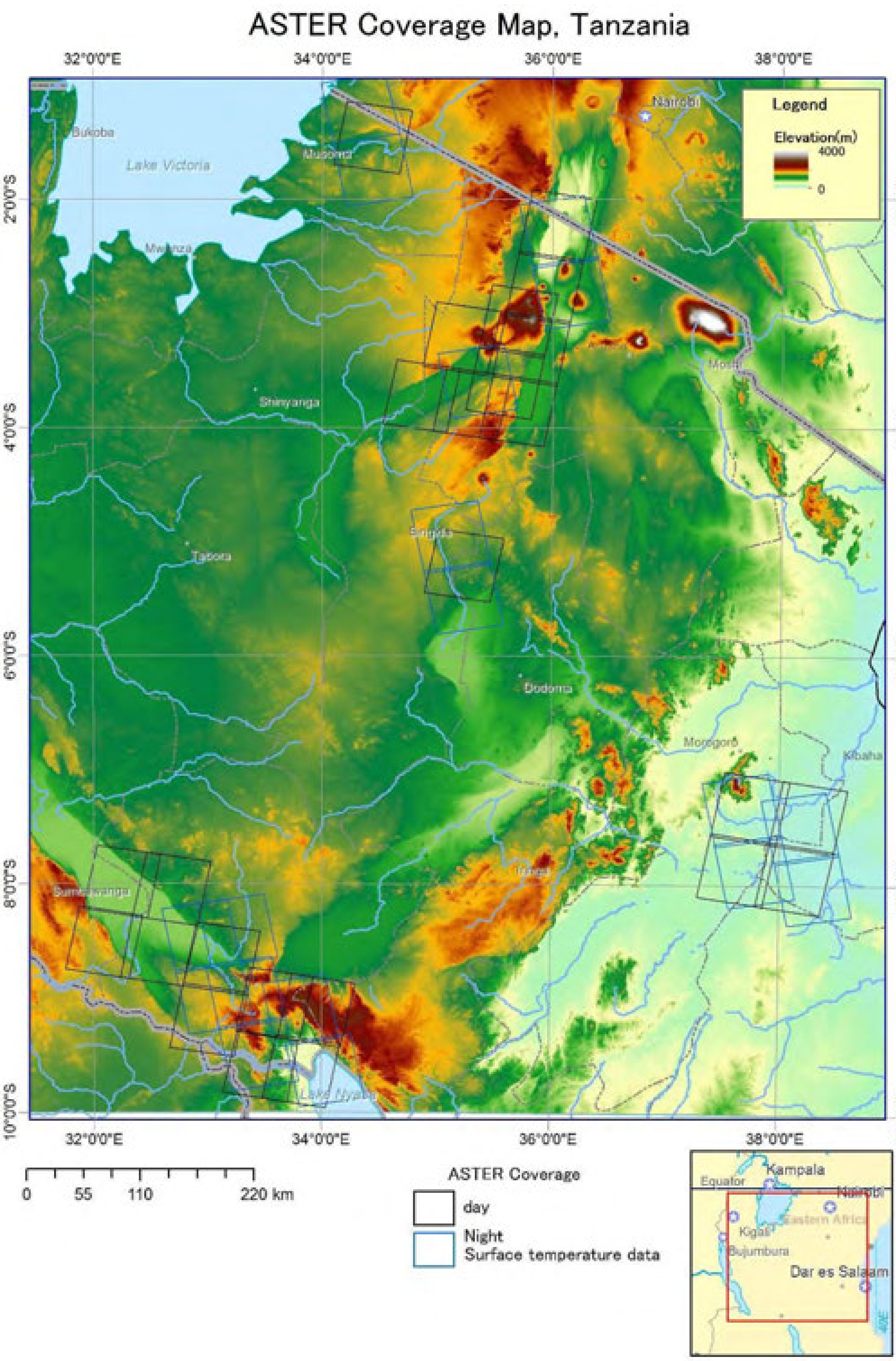
a) Data Collection

Remote sensing data collected in this study are listed in Table II-2, and a coverage map of ASTER data is shown in Fig. II-4. Data has been collected for the following five geothermal potential areas in the first year of the study (Fig. II-1).

- Mbeya
- Near Lake Natron and Manyara
- Maji Moto
- Kisaki
- Southeast of Singida

Table II-2 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: 25scenes 3B temperature: 18scenes From Japan Space Systems
ALOS/PALSAR (SAR)	-L band -10 m in spatial resolution -50 km in swath -20-50^{o} of off-nadir angles	7	Product Level 1.5: 7scenes From Japan Space Systems
SRTM (DEM)	-90 m in spatial resolution -Data opened in 2002	as required	USGS Earth Resources Observation and Science (EROS) Center



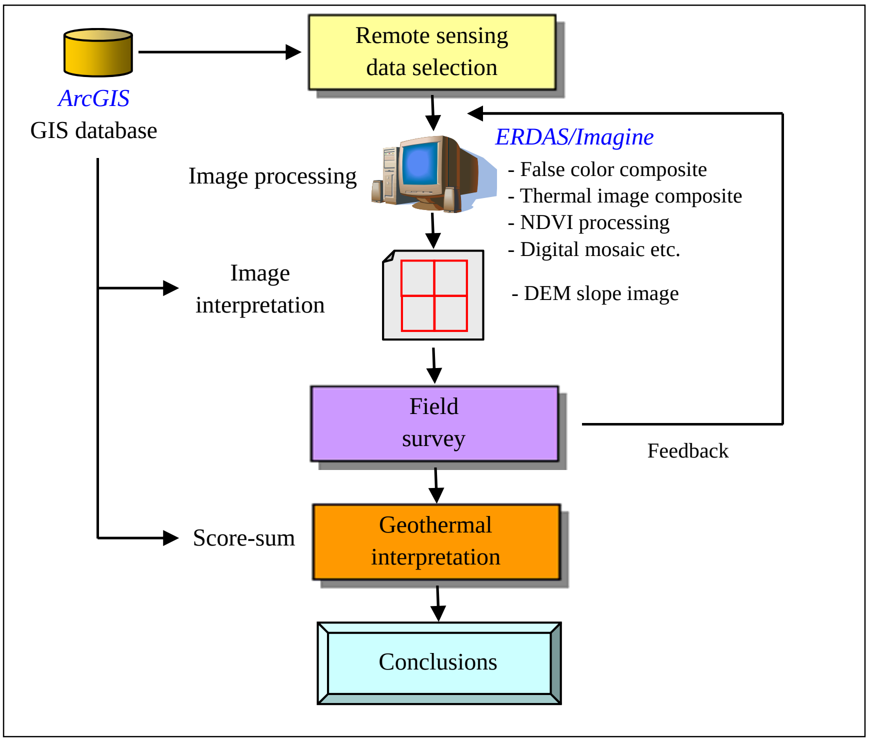
(Study team)

Fig. II-4 Coverage map of ASTER data

b) Methodology

The methodology of the Study includes six items; namely, remote sensing data selection, image processing, image interpretation, field investigation, geothermal interpretation and overall conclusions.

Series of these studies should be established through GIS database generated in this survey. The 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+, EOS/ASTER and ALOS/PALSAR together with SRTM (Space-Shuttle Radar Terrain Model) data. The SRTM is a kind of DEM (Digital Elevation Model) generated from a special modified radar system, and it is used for recreating the topographic features through a variety of digital processing.

c) Processed Image Data

The study's processed image data are listed in Table II-3.

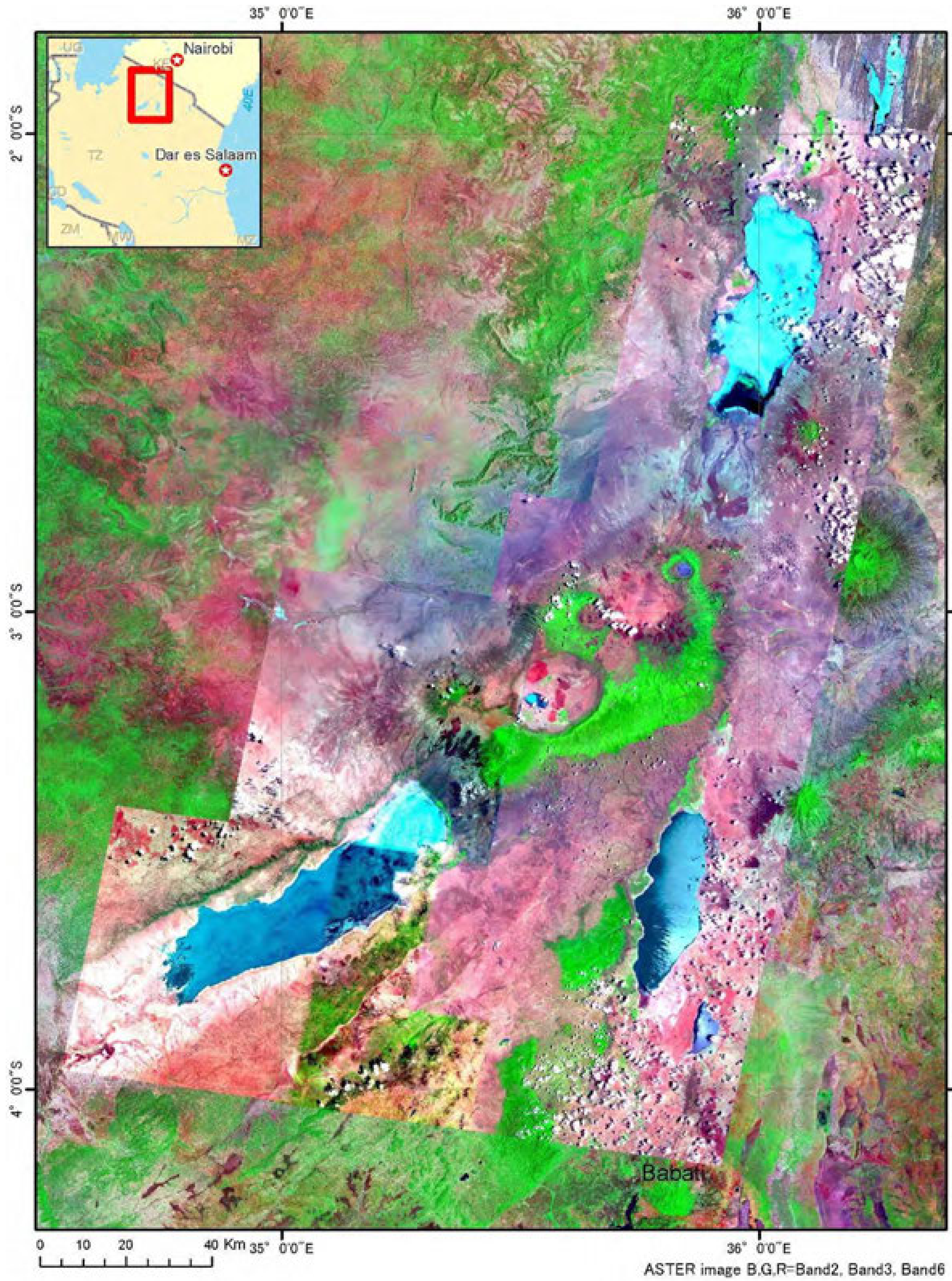
False color composites, Thermal image composites, NDVI processing and digital mosaics are for the main techniques applied to the original images. The false color image is a composite using the appropriate 3 bands assigned the color blue, green or red. The false color image of Northern area (Lake Natron and Lake Manyara area) is shown in Fig. II-6. The false color images of Singida area, Mbeya area, Kisaki and Nyongoni of Rufiji River area are shown in Fig. II-9 ~ Fig. II-12, respectively. NDVI (Normalized Difference Vegetation Index), is a graphic indicator used to confirm and enhance the presence of vegetation in the images. NDVI image of Northern area (Lake Natron and Lake Manyara area) is shown in Fig. II-7. The thermal images are derived from ASTER Level 2B03 product which clarifies surface kinetic temperature data. The thermal image of Lake Natron area is shown in Fig. II-8. The degrees of temperature are generally expressed by pseudo color in the images. Higher temperatures are 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. This image is superimposed on the various false color data.

Table II-3 List of image data used

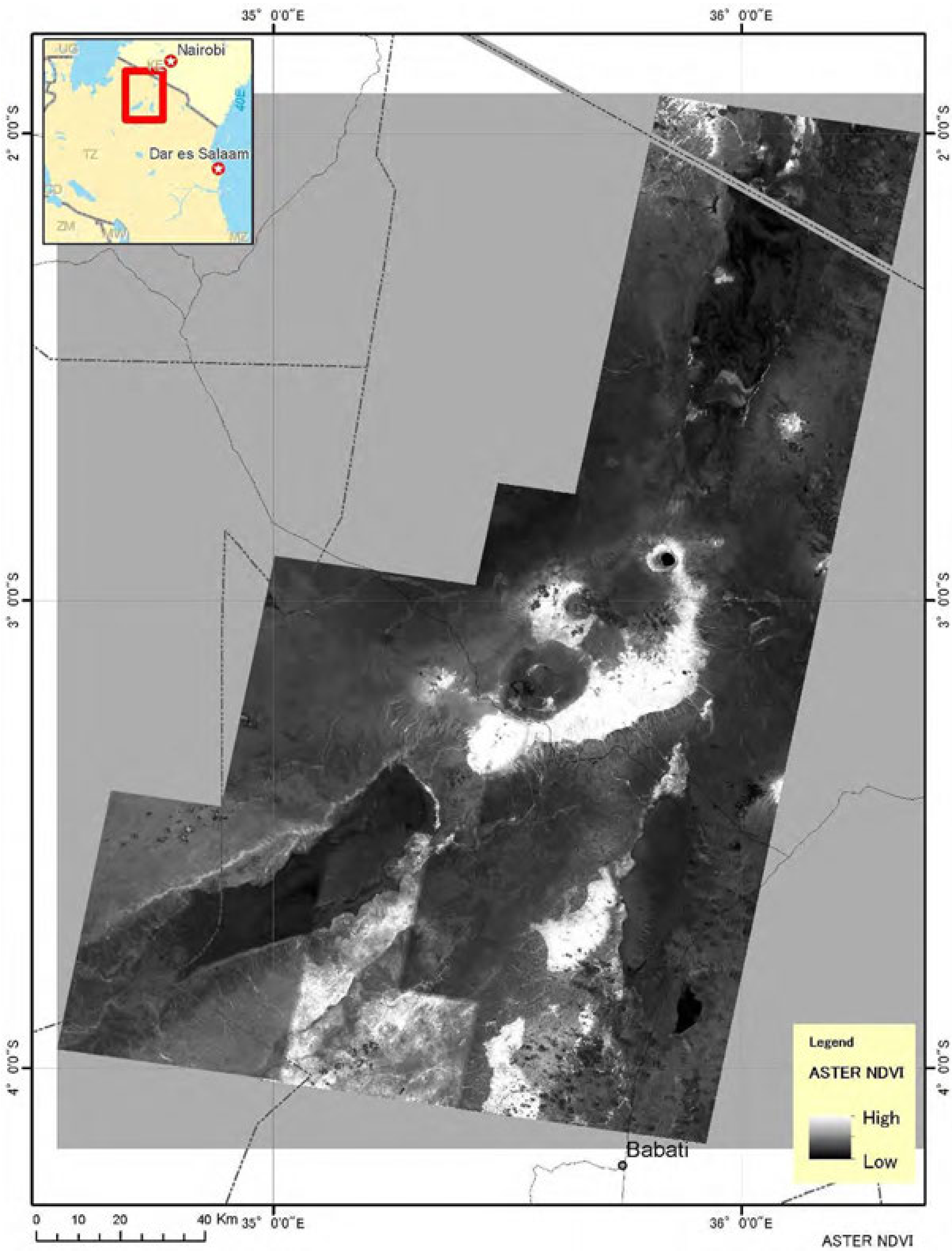
Area name	Generated imagery	Scale
Northern area	ASTER false color image combined with LANDSAT/ETM+	1:250,000
	ASTER false color image combined with LANDSAT/ETM+ (trimmed)	1:100,000
	SRTM slope image superimposed on ASTER false color image	1:250,000
	ASTER NDVI image (trimmed)	1:100,000
	ASTER Level 2B03 product (surface kinetic temperature)	1:100,000
(Shingida area)	ASTER false color image combined with LANDSAT/ETM+	1:250,000
	ASTER false color image combined with LANDSAT/ETM+ (trimmed)	1:100,000
	SRTM slope image superimposed on ASTER false color image	1:250,000
	ASTER NDVI image (trimmed)	1:100,000
Mbeya area	ASTER false color image combined with LANDSAT/ETM+	1:250,000
	ASTER false color image combined with LANDSAT/ETM+ (trimmed)	1:100,000
	SRTM slope image superimposed on ASTER false color image	1:250,000
	PALSAR image	1:100,000
Rufiji area	ASTER false color image combined with LANDSAT/ETM+	1:250,000
	ASTER false color image combined with LANDSAT/ETM+ (trimmed)	1:100,000
	SRTM slope image superimposed on ASTER false color image	1:250,000

(Study team)



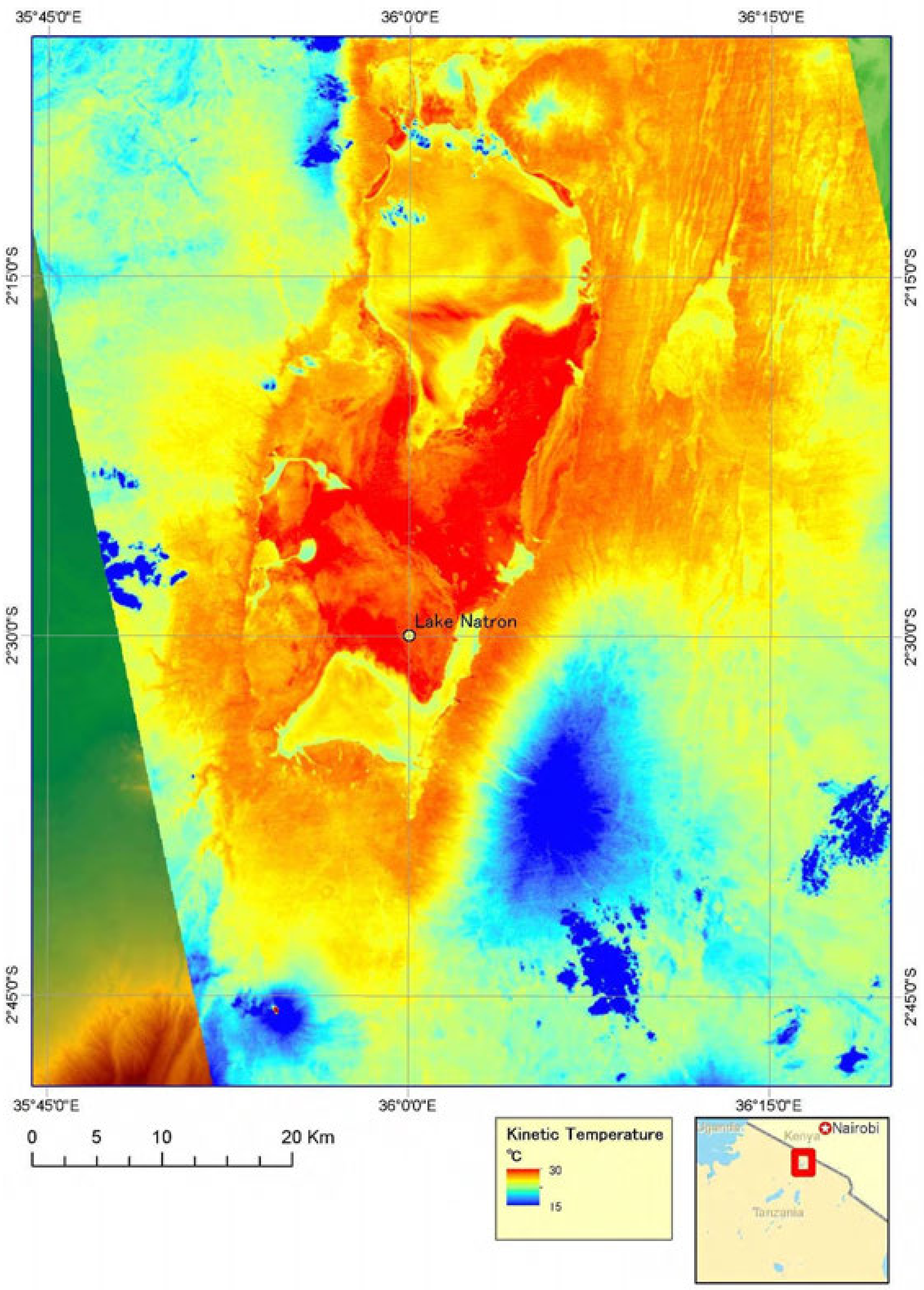
(Study team)

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



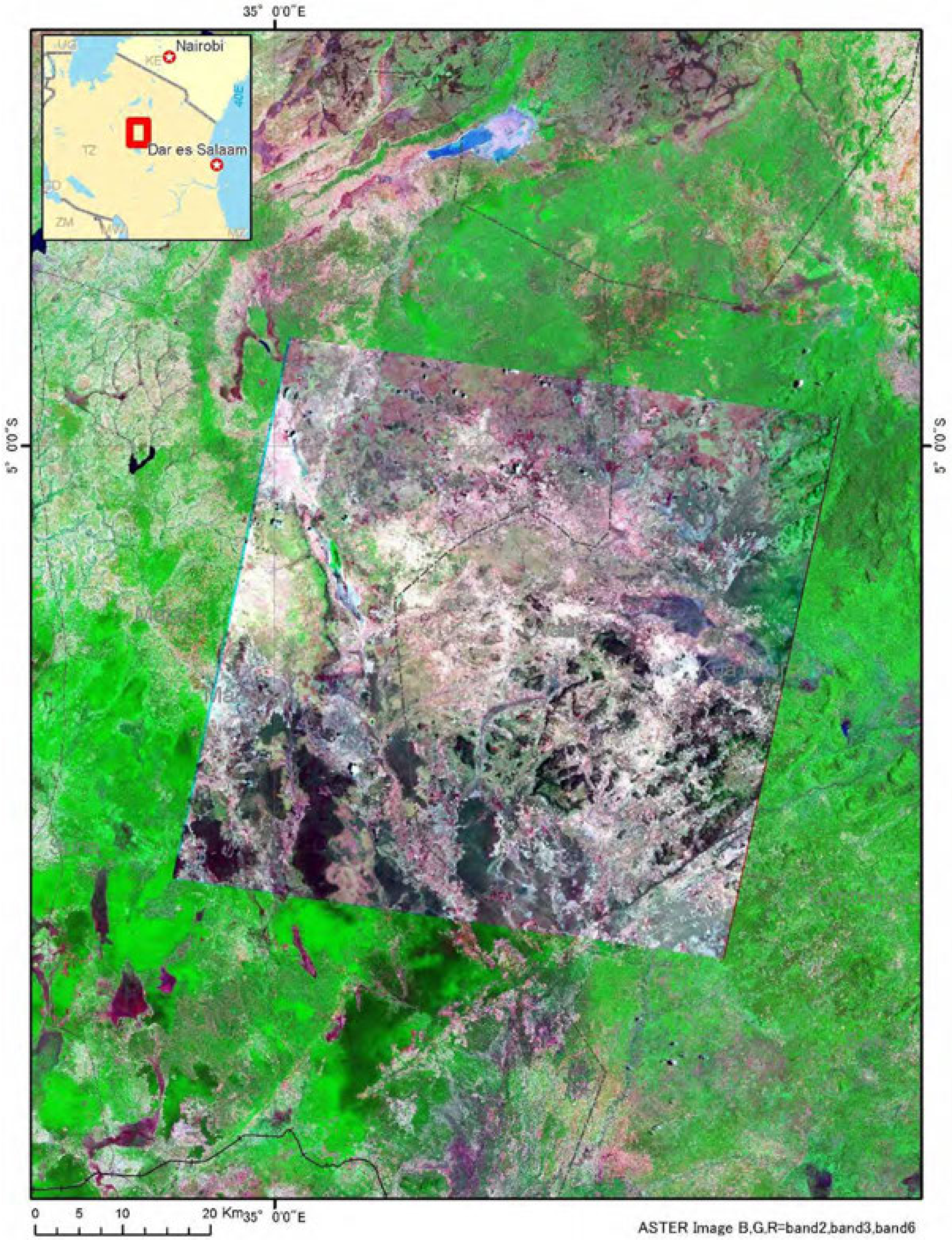
(Study team)

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



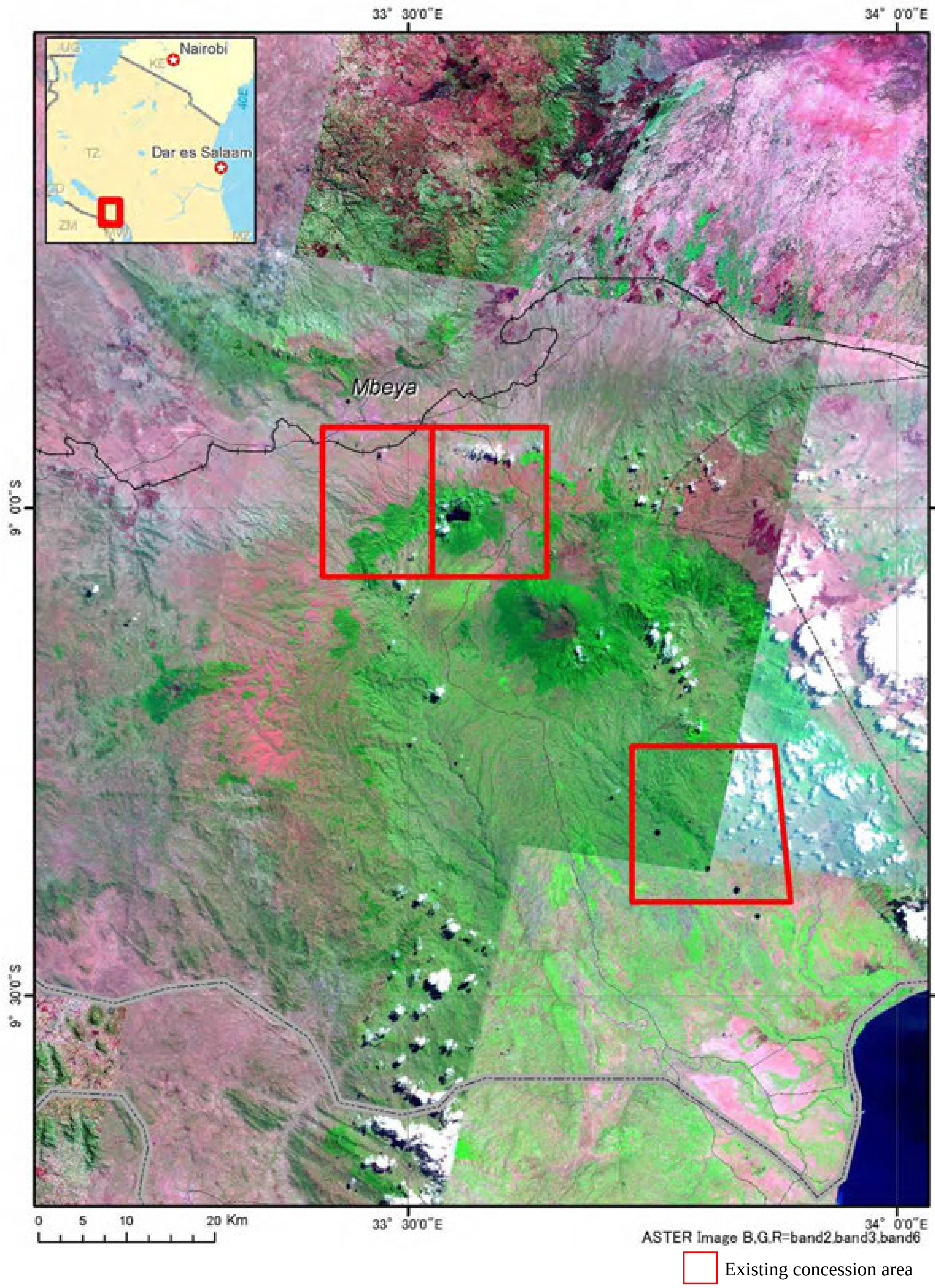
(Study team)

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



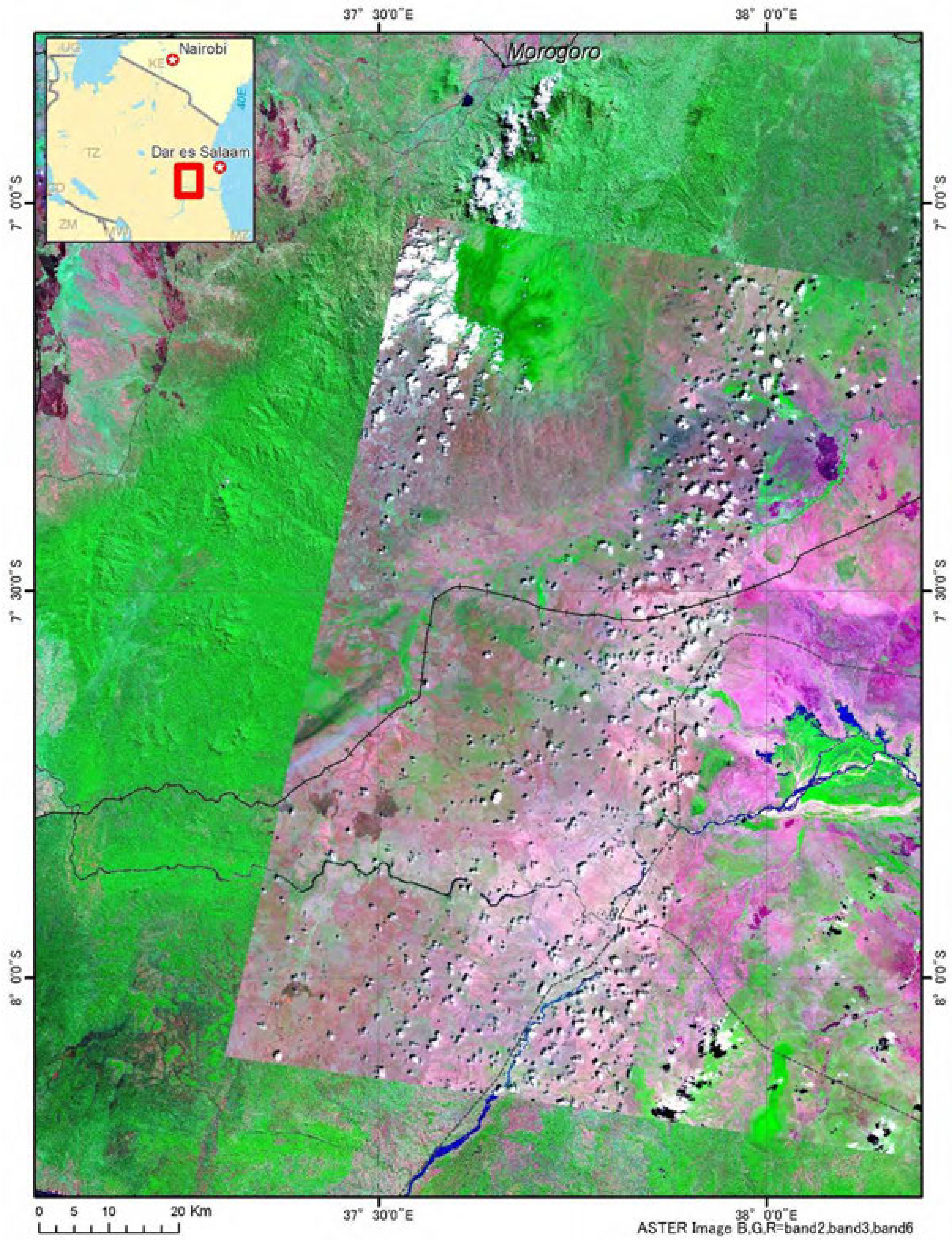
(Study team)

Fig. II-9 ASTER false color image combined with LANDSAT/ETM+, Singida and Kondoa



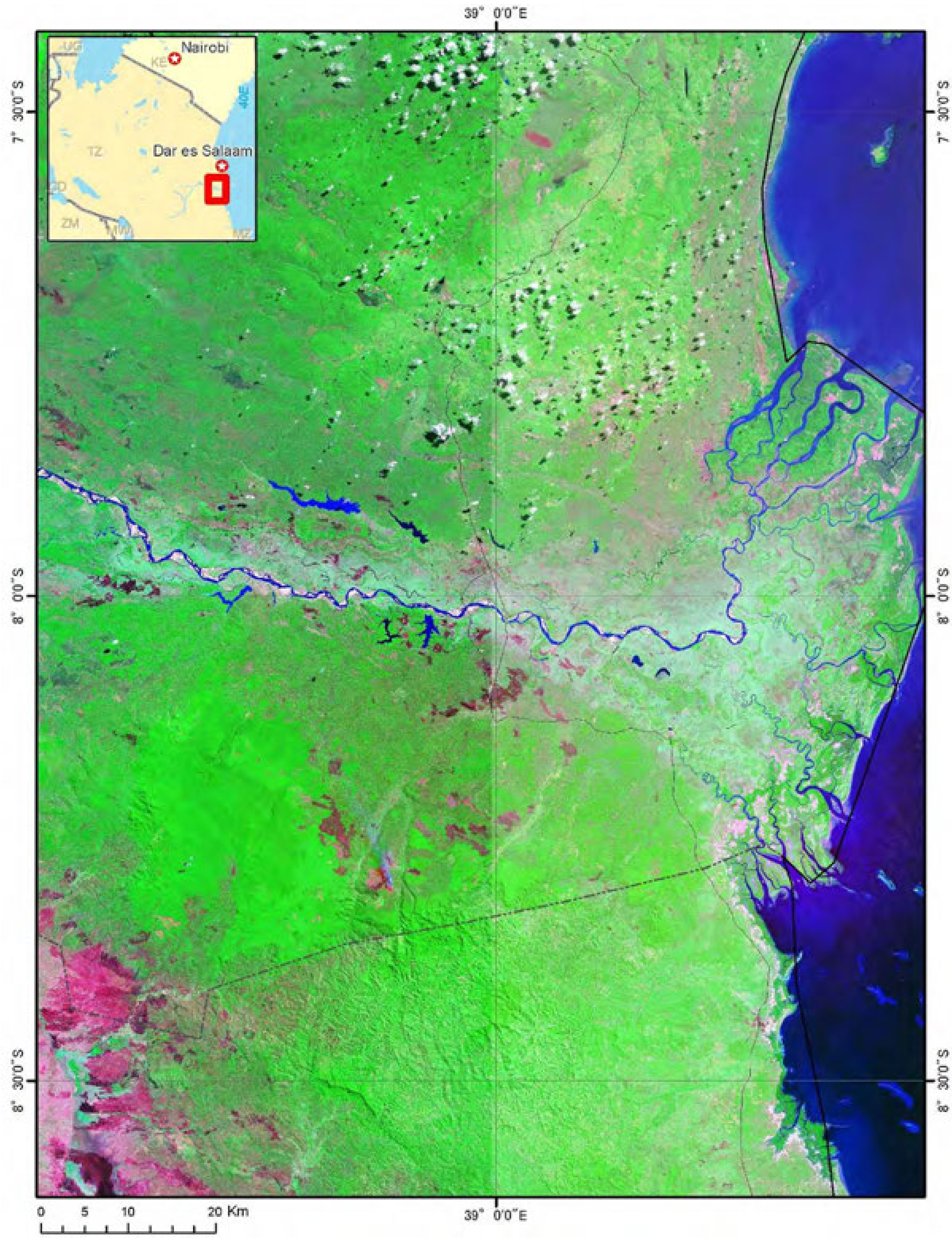
(Study team)

Fig. II-10 ASTER false color image combined with LANDSAT/ETM+, Mbeya Area



(Study team)

Fig. II-11 ASTER false color image combined with LANDSAT/ETM+, Rufiji River Area



(Study team)

Fig. II-12 ASTER false color image combined with LANDSAT/ETM+, Rufiji River Area

d) Image Interpretation

(a) Targets and Method of Image Interpretation

Finding the geothermal energy potentials

The geothermal energy potentials are considered by interpreting the images. The main geothermal energy potentials in the study areas can generally be characterized as follows:

- Heat source: Quaternary volcanic activity plays a crucial role in terms not only of thermal gradient under the surface but also its lateral expansion. In particular, areas intersected by large-scale faults may be found to have a higher thermal gradient as heat source.
- Geological structures: Appropriate geological structures consist of two features, namely kitchen vessel and path recharging groundwater.
- Cap rocks: there is a possibility of volcanic lava flows acting as cap rocks sealing the layers where geothermal energy has accumulated.
- Other aspects: such as the environmental, engineering, socio-economic aspect and among others are considered in interpreting the images.

Image interpretation

Image interpretation should be carried out based on the photo-geological method, focusing on the following variety of surface features;

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

In addition, such items as the following are also important in planning geothermal development: natural reserves, power lines, concessions, population, accessibility, and groundwater flow.

(b) Results of Image Interpretation

Northern Area (and Singida area)

The geological interpretation result for the Northern Area is shown in Fig. II-13 and Fig. II-14.

This covers an area stretching from Lake Natron to the town of Singida through Lake Manyara, Lake Eyasi, Ngorongoro Crater, Lake Balangida Lalu and the town of Kondoa.

Quaternary volcanic rocks are widely found in the area around the Ngorongoro Mountains. The southern margin of the area is bounded Lake Manyara and Lake Eyasi. Except for the higher volcanic mountains and their craters, the area in which volcanic features are distributed is characterized by a smooth texture and purple to red color in the false color imagery. Ngorongoro Crater is the biggest caldera in the area. Numerous volcanic cones approximately 1 to 2 km in diameter are observed in the northeastern part of Ngorongoro Mountains, the eastern coast of Lake Natron and the town of Babati.

The rift valley extends in a NNE-SSW orientation in the northern area, and bends in a NE-SW direction in the southern area. The geological structure is generally marked by the step-like rift valley dipping NW. A large number of faults are found in the western margin of the area, and dislocation is inferred to be approximately 500m laterally. NNE-SSW to NE-SW trending faults and lineaments run parallel to the direction of the rift valley. NNE-SSW trending lineaments are developed in the area east of Lake Natron. Several NW-SE trending faults, which seem to be a result of the most recent geological activity, cut through the NE-SW trending faults as transform faults.

Volcanic lavas functioning as cap rock are distributed in a limited area. The area of the rift valley is widely covered with unconsolidated sediments, including lacustrine deposits.

In terms of environmental regulation, the area includes the Ngorongoro conservation area and Lake Manyara national park.

Mbeya Area

The geological interpretation results for the Mbeya Area are shown in Fig. II-14 and Fig. II-15.

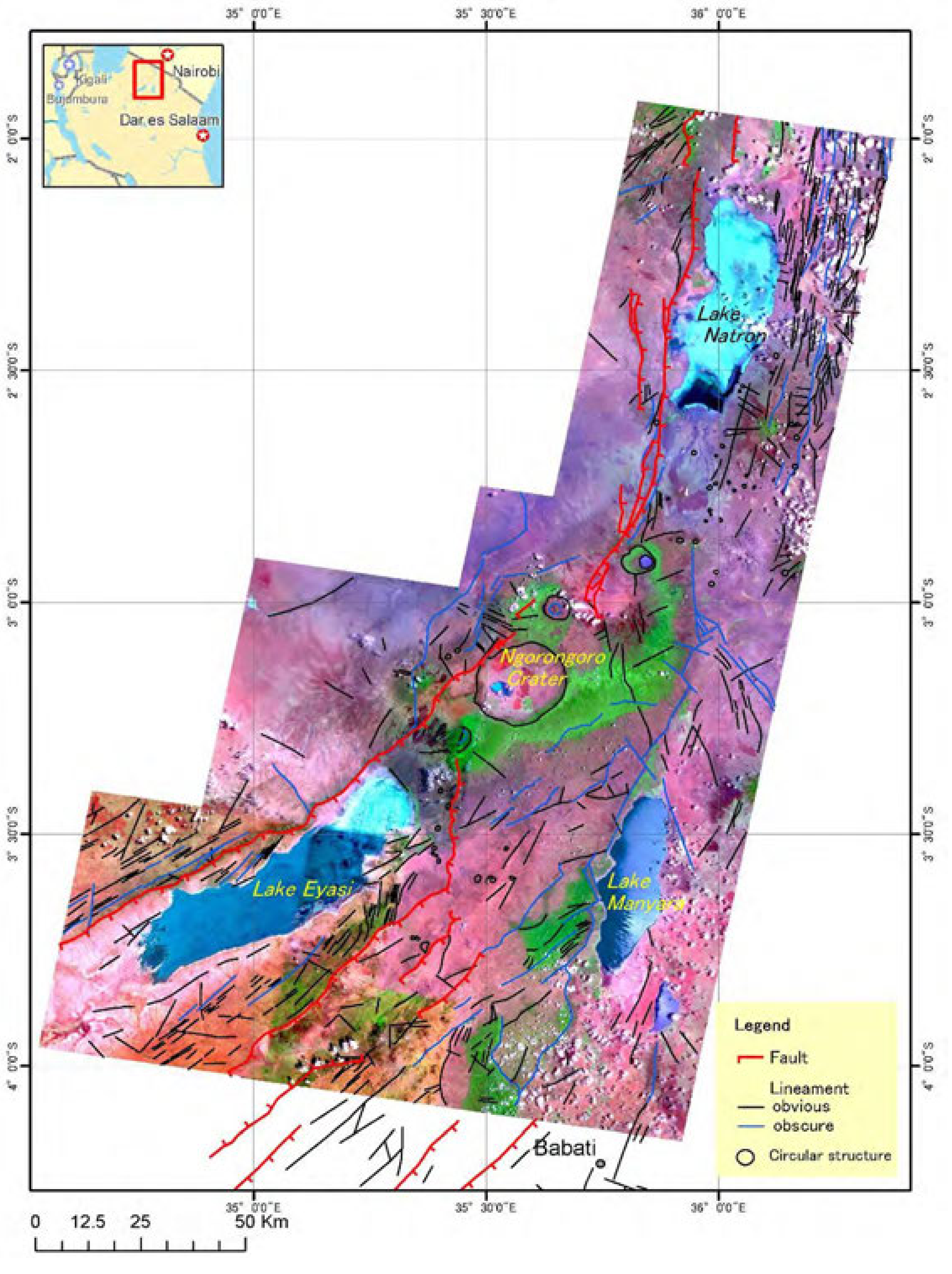
This covers an area extending from Mbeya city to the town of Kyela through Songwe, Ilatile, Rambo, Kilambo, Mampulo and Kasimulu fields.

The Quaternary volcanoes, Ngozi Volcano, Rungwe Volcano, Kyejo Volcano and Mbeya range are situated in the area. There are many volcanic cones around the volcanic mountains, with the cones between Rungwe Volcano and Lake Nyasa, in particular, forming a structural line with a NW-SE orientation. The southeastern part of the line ends around Igurusi Village.

The area is marked by the triple junction of geological structures trending NW, SE and ENE. However, this interpretation has indicated that the NW-SE trending rift valley seems to be dislocated by an ENE-WSW trending rift valley. The eastern margin of the NW-SE trending rift valley is bounded by a large number of faults forming fault scarps. The western margin of the rift valley gives way gradually to basement rock. The basement in the Rongwe, Ilatile, and Rambo fields consists of strongly folded rocks. This expresses a half-graben-like architecture dipping NE.

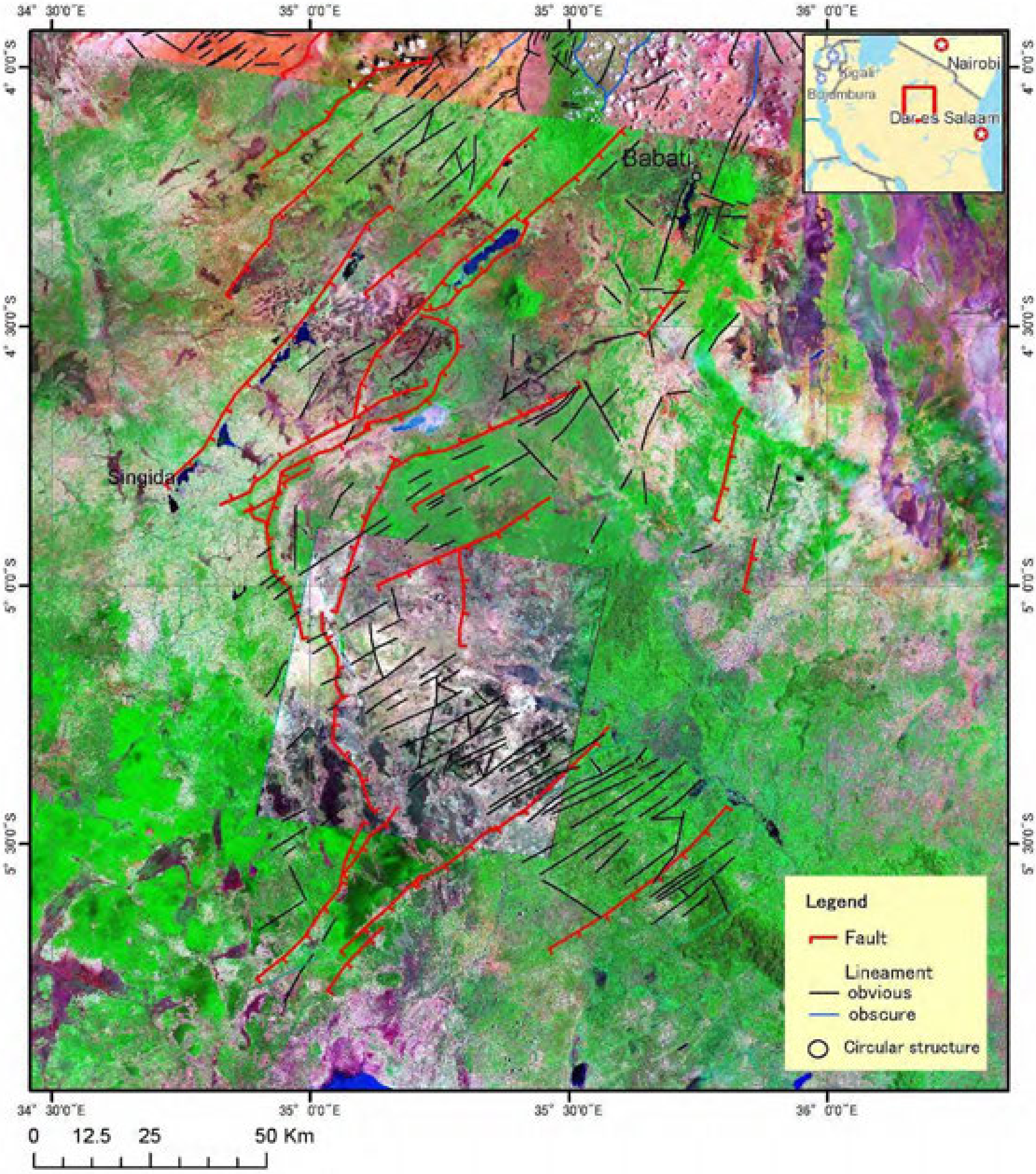
Field observations show that volcanic lava flows are widely distributed and form a mesa topography. Thick lacustrine deposits are found on the lava flows, from basal conglomerate at the bottom to overlying sandstone. A series of these layers might be effective as a geothermal cap rock.

According to local information, two concession areas for geothermal development at the Ngozi volcanic field and in the southern part of Kyejo volcanic field have been licensed.



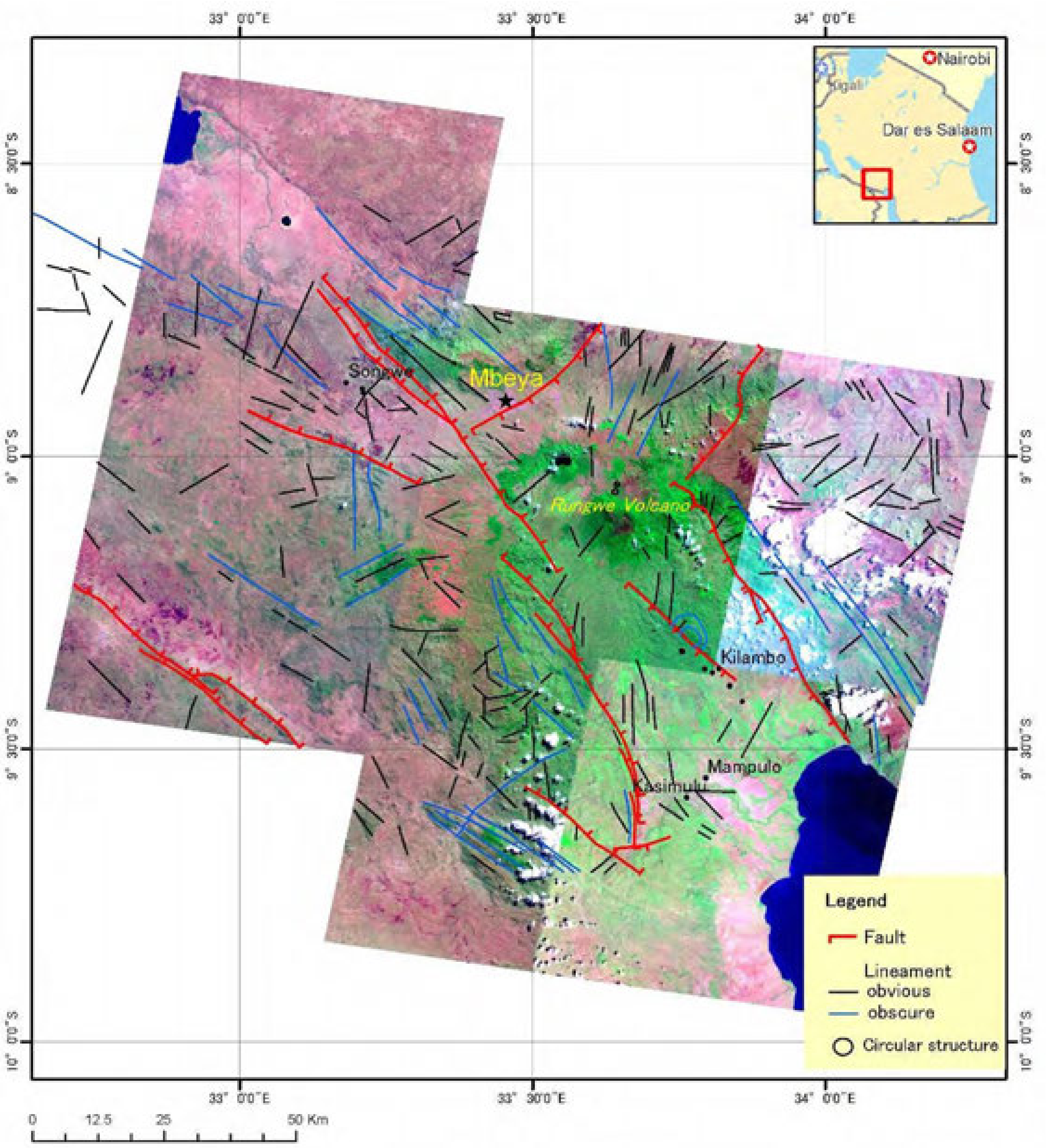
(Study team)

Fig. II-13 Geological Interpretation Map of Northern Area



(Study team)

Fig. II-14 Geological interpretation map of Northern Area (southeast of Singida)



(Study team)

Fig. II-15 Geological Interpretation Map of Mbeya Area

Rufiji area

This is an area ranging from the Uluguru Mountains to Utete town through Kisaki site and Nyongoni site.

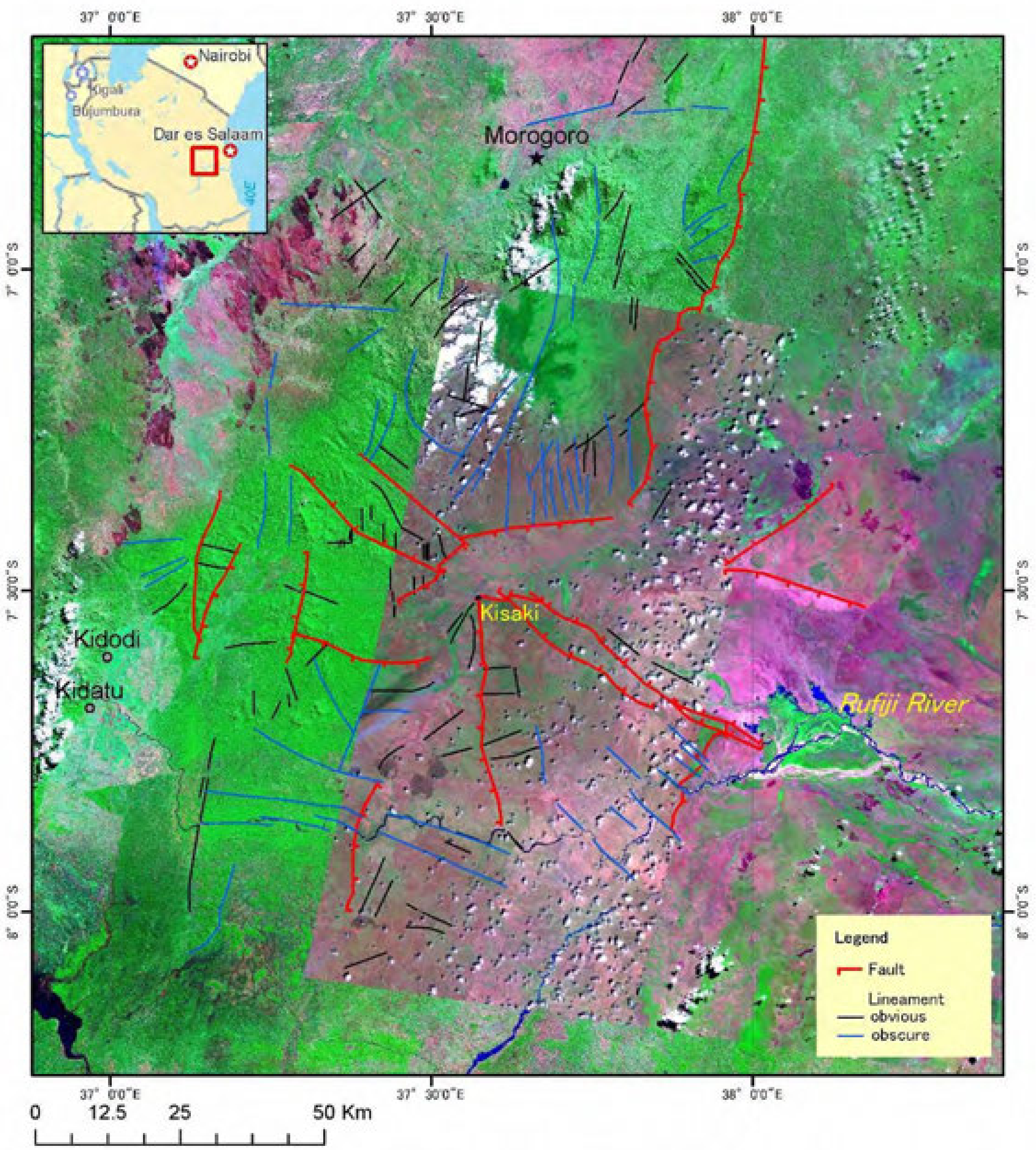
The area is covered with thick Cretaceous to Tertiary marine sediments according to the existing geological map. Generally the geological architecture is a monoclonal structure dipping east. No volcanic activity has been reported in this region. However several hot springs have been recorded in some places.

Kisaki site is a complicated area, where ENE-WSW, NW-SE and N-S trending faults converge. Nyongoni site sits an intersection between unclear NE-SW and NW-SE lineaments. There is no geological structure at the Utete site. However, NE-SW is a dominant orientation, represented by the Mgeta and Luvu plains.

Thick Cretaceous to Tertiary marine sedimentary rocks could play a role as a cap rock, if more intricate geological structure generates a higher thermal gradient than other areas under the surface.

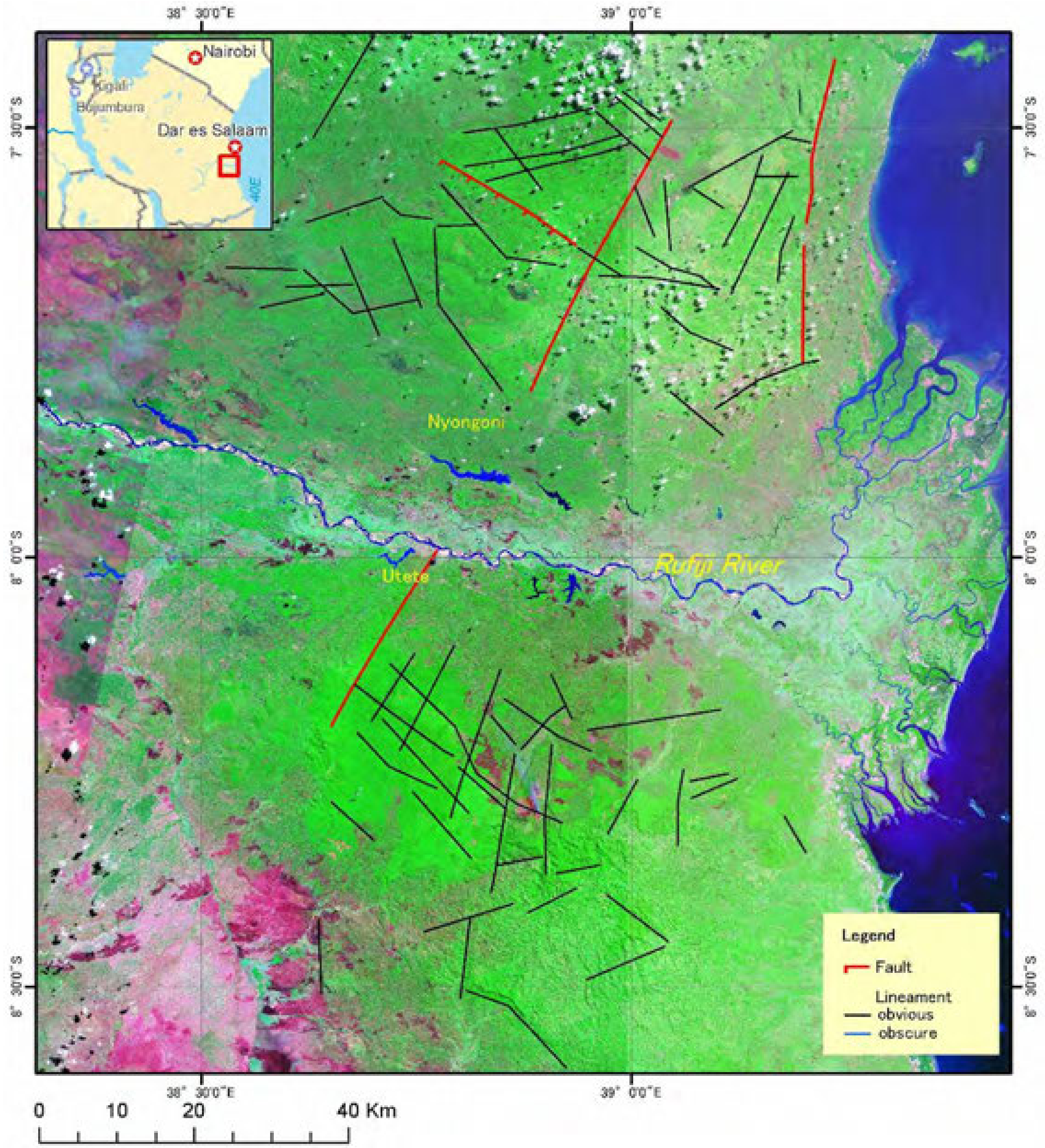
In terms of environmental regulation, Mikumi national park and Selous game reserve cover much of this area.

The geological interpretation results for the Rufiji area are illustrated in Fig. II-16.



(Study team)

Fig. II-16 Geological Interpretation Map of Rufiji Area



(Study team)

Fig. II-17 Geological interpretation map of Rufiji Area (Nyongoni, Utete)

2. Preliminary analysis based on the existing data

Existing chemical analysis data for hot spring and surface water were compiled by DECON-SWECO (2005) and BGR (2008). The former included waters from 28 hot springs on which chemical analysis was conducted from 1951 to 2004 (see Table II-4). Eleven components were analyzed. The latter included waters from 44 hot springs in the Mbeya region on which chemical analysis was carried out from 2006 to 2007. Seventy (70) components (including trace elements) were analyzed. Although it is still uncertain whether a new survey was conducted after BGR (2008) or not, we have been unable to obtain any new chemical data from the BGR website. As the survey by BGR (2008) was conducted only in the Mbeya region and some important components in some samples were not analyzed, we conducted a preliminary geochemical assessment based on the data for all Tanzania adapted from

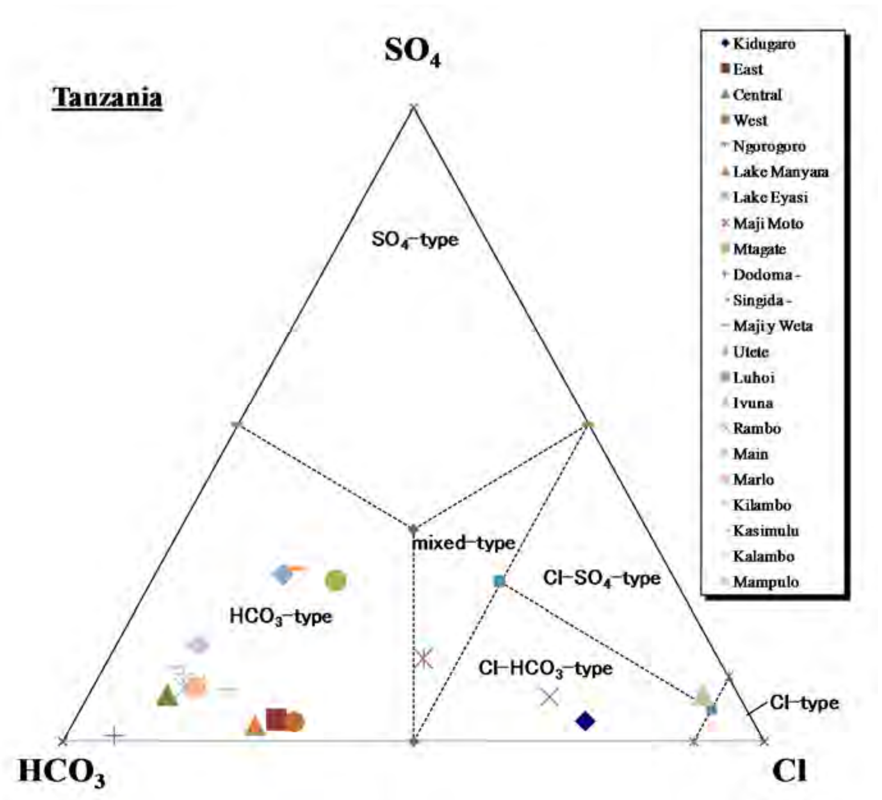
DECON-SWECO (2005). (Chemical data for hot springs are listed in the Appendix.)

In terms of the charge balance of cations against anions, the analytical data given by DECON-SWECO (2005) seems to be reliable. Most of the hot spring waters are neutral to weakly alkaline. When they are classified based on the compositional ratio among the major anions (Cl^-, SO_4^{2-} and HCO^{3-}), most of the hot spring waters are HCO_3-type or SO_4-type (see Fig. II-18). Although no water samples are classified as Cl-type, which indicates the contribution of a deep reservoir, some are classified as Cl-HCO_3 type or Cl-SO_4 type, mixed Cl types. It is well-known that hot spring water affected by deep geothermal fluid resulting from water-rock interaction under high-temperature conditions shows a relatively high Cl concentration. The relationship between the Cl concentration and discharge temperature of hot spring water is given in Fig. II-19. Maji Moto on the southeastern shore of Lake Victoria, and Ivuna, Kasimulu, Mampulo and Kilambo between Lake Rukwa and Lake Nyasa show temperatures of over 60ºC and Cl concentrations of over 200 mg/L, which indicates that they may be geothermal potential areas.

On the other hand, the high Cl concentration in the hot spring water around Lake Eyasi (about 5,000mg/L) is thought to be due to infiltration from Lake Eyasi which is a salt lake.

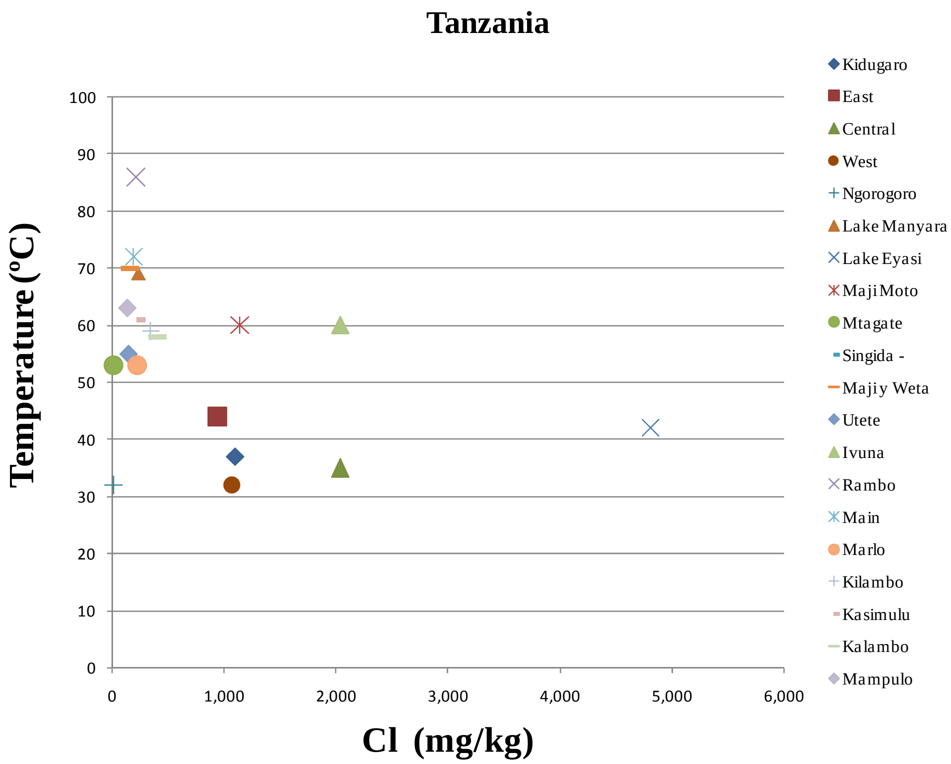
Table II-4 Referenced existing chemical data for hot spring

Reference	Sampling years	Analyzed species	Sampled area	Reliability of data
DECON-SWECO (2005)	1951-2004	11 Major species	28 hot springs all over Tanzania	Almost no problem
BGR (2008)	2006-2007	73 species including trace elements	44 hot springs in Mbeya	Some parts have not been analyzed



(Modified from DECON-SWECO, 2005)

Fig. II-18 Ternary diagram of major anions of hot spring water (existing data)



(Modified from DECON-SWECO, 2005)

Fig. II-19 Cl-temperature diagram of hot spring water (existing data)

3. Selection for the field survey

Based on the existing data of discharging temperature of hot spring and estimated reservoir temperature from chemical analysis, geothermal promising areas are selected. Geothermal hot spring areas with more than 50ºC temperature of discharge are shown in Table II-3. Excepting the geothermal licensed areas, the following are picked up considering site accessibility; around Mbeya region, around Lake Natron and Lake Manyara, and Kisaki along the Rufiji River (see Fig. II-20). Considering of safety of JICA study team during the field survey, based on the website of Ministry of Foreign Affairs of Japan, there seems to be no security problem with the above areas. However, Rufiji is registered as an exploration license area, so Kisaki area may be included in the Rufiji licence area. Therefore, extent of Rufiji license area should be confirmed in the near future.

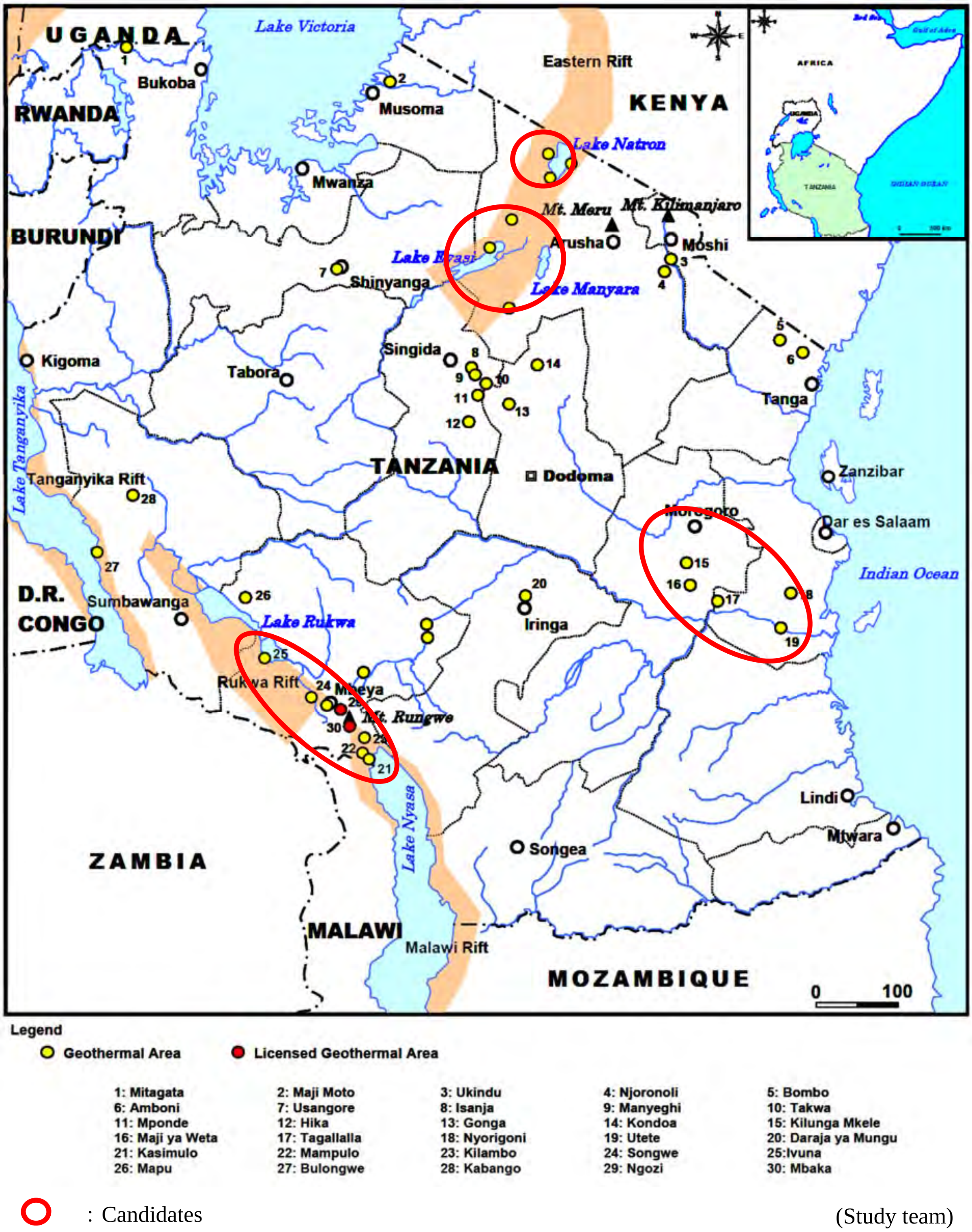
Table II-5 Temperature of Geothermal Areas (Tanzania)

Region	Location	Discharging Temperature (^oC)	Estimated Reservoir Temperature* (^oC)	Remarks
Songwe River	Rambo	86	88	
Nyasa Basin	Ibayi	82.4	99	
Nyasa Basin	Ilatile	65 - 80	88	
Rufiji Valley	Luhoi	50 - 75	n.a.	
Songwe River	Main	72	93	
Rufiji Valley	Maji ya Weta	70	86	
Lake Manyara	Lake Manyara	69	109	
Nyasa Basin	Udindilwa	65.7	92	
Nyasa Basin	Mampulo	61 - 63	125	
Musoma	Maji Moto	60	110	
Lake Rukwa	Ivuna	60	103	
Nyasa Basin	Mahombe	59.7	122	
Nyasa Basin	Kilambo	56.5 - 59	144	
Nyasa Basin	Kalambo	58	125	
Nyasa Basin	Kandete	56.6	61	
Rufiji Valley	Utete	55	127	
Nyasa Basin	Kasimulo	54.7	93	
Nyasa Basin	Mbaka	54.7	72	Licensed
Lake Eyasi	Mtagate	53	89	
Songwe River	Marlo	53	48	
Lake Natron	East	38 - 50	46	

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

*: Silica Temperature (Chalcedony)



(Study team)

Fig. II-20 Candidates for geothermal field surveys in Tanzania

Areas visited in the survey had been selected for their geothermal potential in the first year of the study based on existing data. These candidate areas were also discussed with MEM and GST. No areas were eliminated due to JICA security constraints.

II-5-2 Field survey

1. Results of the field survey

The locations of hot spring areas visited in the field survey are shown in Fig. II-21 and Table II-6. The sample lists for water and rock are shown in Table II-7 and Table II-8 respectively. Temperature was measured with a thermistor thermometer, and then pH and electric conductivity were measured using a portable pH meter and electric conductivity meter, respectively.

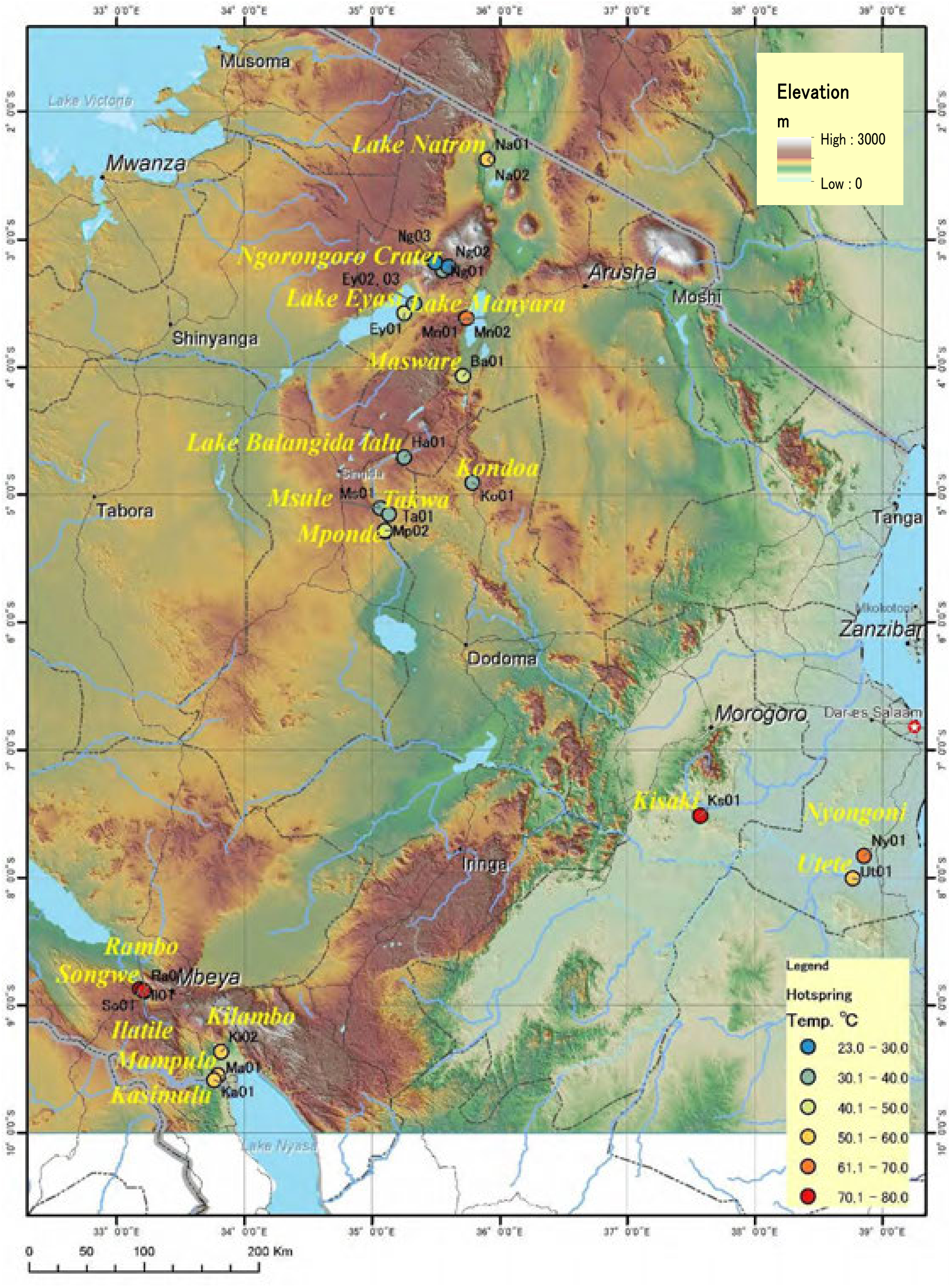
The features at each hot spring location are as follows:

Table II-6 Site visit list for the field survey

Location No.	date	place	Region	Longitude	Latitude	Elevation	Geology	Remark
				degree (E)	degree (S)	m		
Na01	16-Aug	Lake Natron	ARUSHA	35.90563	2.37312	600	volcanics	Ramsar convention
Na02	16-Aug	Lake Natron	ARUSHA	35.90376	2.37392	601	volcanics	Ramsar convention
Mn01	17-Aug	Lake Manyara	ARUSHA	35.73786	3.61676	968	gneiss	Lake Manyara National Park
Mn02	17-Aug	Lake Manyara	ARUSHA	35.74094	3.61712	973	gneiss	Lake Manyara National Park
Ey01	18-Aug	Lake Eyasi	ARUSHA	35.25440	3.57560	1,045	gneiss	
Ey02	18-Aug	Lake Eyasi	ARUSHA	35.33100	3.50276	1,037	gneiss	
Ey03	18-Aug	Lake Eyasi	ARUSHA	35.33057	3.50178	1,106	gneiss	
Ng01	19-Aug	Ngorongoro crater	ARUSHA	35.55775	3.24353	1,168	volcanics	Ngorongoro Conservation Area
Ng02	19-Aug	Ngorongoro crater	ARUSHA	35.60079	3.21050	1,216	volcanics	Ngorongoro Conservation Area
Ng03	19-Aug	Ngorongoro crater	ARUSHA	35.49837	3.17734	1,105	volcanics	Ngorongoro Conservation Area
Ba01	20-Aug	Masware	MANYARA	35.71347	4.06958	1,066	gneiss	
Ha01	20-Aug	Balangida lalu	MANYARA	35.25523	4.70477	1,118	basement	
Ms01	21-Aug	Msule	SINGIDA	35.06760	5.10671	1,212	granitics	
Ta01	21-Aug	Takwa	DODOMA	35.13322	5.15603	1,244	granitics	
Mp01	21-Aug	Mponde	DODOMA	35.10281	5.28361	1,229	granitics	
Mp02	21-Aug	Mponde	DODOMA	35.10293	5.28284	1,214	granitics	
Ko01	22-Aug	Kondoa	DODOMA	35.78966	4.90346	1,385	gneiss	
So01	25-Aug	Songwe	MBEYA	33.18213	8.87427	1,121	travertine	
Il01	25-Aug	Ilatile	MBEYA	33.21126	8.89121	1,072	travertine	
Ra01	25-Aug	Rambo	MBEYA	33.20984	8.88503	899	travertine	
Ki01	26-Aug	Kilambo	MBEYA	33.81793	9.36253	984	volcanics	
Ki02	26-Aug	Kilambo	MBEYA	33.81777	9.36403	1,031	volcanics	
Ma01	26-Aug	Mampulo	MBEYA	33.79546	9.54955	954	sediments	
Ma02	26-Aug	Mampulo	MBEYA	33.79627	9.55239		sediments	
Ka01	26-Aug	Kasimulu	MBEYA	33.76252	9.58319	1,025	sediments	
Ks01	28-Aug	Kisaki	MOROGORO	37.57241	7.51107	525	sediments	
Ut01	30-Aug	Utete	COAST	38.76907	8.00640	5	sediments	
Ny01	31-Aug	Nyongoni	COAST	38.85676	7.82700	70	sediments	

(Map datum: WGS 1984)

(Study team)



(Study team)

Fig. II-21 Location Map of Site Visits

Table II-7 Water chemistry field survey data

sample name	date	place	air temp ℃	water temp ℃	pH - (℃)	EC mS/m
Na01	16-Aug	Lake Natron	32.3	50.5	9.7 (48)	1,050
Na02	16-Aug	Lake Natron	32.3	53.1	9.7 (50)	1,530
Mn01	17-Aug	Lake Manyara	26.1	70.8	9.5 (62)	280
Mn02	17-Aug	Lake Manyara	26.1	62.9	-	-
Mn02'	17-Aug	Lake Manyara	26.1	65.4	-	-
Ey01	18-Aug	Lake Eyasi	17.9	48.6	9.3 (45)	1,010
Ey02	18-Aug	Lake Eyasi	28.3	35.7	9.1 (34)	270
Ey03	18-Aug	Lake Eyasi	28.3	36.6	-	-
Ng01	19-Aug	Ngorongoro crater	23.1	34.4	7.7 (32)	38
Ng02	19-Aug	Ngorongoro crater	23.1	sur21/deep23	7.9 (24)	31
Ng03	19-Aug	Ngorongoro crater	25.0	27.2	8.1 (27)	34
Ba01	20-Aug	Masware	21.2	40.9	7.4 (39)	270
Ha01	20-Aug	Balangida lalu	25.0	32.7	-	-
Ms01	21-Aug	Msule	24.2	37.1	8.1 (36)	350
Ta01	21-Aug	Takwa	31.0	35.9	7.8 (35)	290
Mp01	21-Aug	Mponde	-	43.3	8.3 (33)	241
Mp02	21-Aug	Mponde	-	45.4	8.6 (33)	-
Ko01	22-Aug	Kondoa	26.4	30.3	7.3 (30)	228
So01	25-Aug	Songwe	27.5	74.8	7.0 (65)	730
Il01	25-Aug	Ilatile	-	54.1	6.6 (54)	-
Ra01	25-Aug	Rambo	32.2	79.2	7.0 (68)	728
Ki01	26-Aug	Kilambo	28.3	61.5	6.9 (55)	1,013
Ki02	26-Aug	Kilambo	-	57.4	6.6 (54)	1,030
Ma01	26-Aug	Mampulo	30.9	56.3	7.1 (55)	1,016
Ma02	26-Aug	Mampulo	32.5	52.7	6.9 (47)	-
Ka01	26-Aug	Kasimulu	27.4	52.6	6.8 (40)	1,025
Ks01	28-Aug	Kisaki	36.2	72.3	7.0 (62)	721
Ut01	30-Aug	Utete	43.0	54.4	7.0 (54)	436
Ny01	31-Aug	Nyongoni (Luhoi river)	37.6	67.2	6.7 (66)	2,230

(Study team)

Table II-8 Field survey rock sample list

sample name	date	place	Rock name	Thin section	X-ray	Spectrum
Na01	16-Aug	Lake Natron	basic volcanics	○	○	○
Na02	16-Aug	Lake Natron	basic volcanics	-	-	○
Mn01a	17-Aug	Lake Manyara	gneiss	-	-	○
Mn01b	17-Aug	Lake Manyara	evaporite	-	-	○
Ey01	18-Aug	Lake Eyasi	evaporite	-	-	○
Ng01	19-Aug	Ngorongoro crater	sediment	-	-	○
Ba01a	20-Aug	Masware	gneiss	-	-	○
Ba01b	20-Aug	Masware	sediment	-	-	○
Ba01c	20-Aug	Masware	sediment	-	-	○
Ha01	20-Aug	Balangida lalu	sediment	-	-	○
Ta01a	21-Aug	Takwa	granitic rock	-	-	○
Ta01b	21-Aug	Takwa	sediment	-	-	○
So01a	25-Aug	Songwe	travertine	-	○	○
So01b	25-Aug	Songwe	travertine	○	○	○
Ki01a	26-Aug	Kilambo	travertine	-	○	○
Ki01b	26-Aug	Kilambo	sediment	-	○	○
Ki02	26-Aug	Kilambo	basic volcanics	○	○	○
Ma01	26-Aug	Mampulo	conglomerate	○	○	○
Ka01a	26-Aug	Kasimulu	sandstone	○	○	○
Ka01b	26-Aug	Kasimulu	silicified rock	○	○	○
Ks01a	28-Aug	Kisaki	travertine	-	○	○
Ks01b	28-Aug	Kisaki	travertine	-	-	○
Ks01c	28-Aug	Kisaki	sediment	-	-	○
Ut01a	30-Aug	Utete	sandstone	○	○	○
Ut01b	30-Aug	Utete	travertine	-	○	○
Ny01	31-Aug	Nyongoni	travertine	○	○	○

(Study team)

(a) Outline of surveyed area

1) Northern Area

Lake Natron; Na01, 02

This field is located on the western shore of Lake Natron, where many hot springs well up through the fractures developed in the basalt lava. The maximum recorded temperature in the field was 53.1°C, maximum pH was 9.7 and maximum electrical conductivity was 1,530mS/m. Quaternary basalt lava, which has a largely N-S trending lineament, is widely distributed in the field. The presence of a scarp suggests that the N-S trending lineament is a fault. The porous parts of the volcanic rocks are filled with carbonates forming an amygdaloidal texture.

Hot springs occurring under similar geological conditions to these can be observed in eight sites around Lake Natron thanks to their typical water-slick on the salt evaporates of the lake.

Photo II-1 Na01 site

Lake Manyara; Mn01, 02

This field is located on the western side of Lake Manyara, where several hot springs well up from scree deposits made up of gneiss. The maximum temperature, pH and electrical conductivity of the hot springs were 70.8°C, pH 9.5 and 280mS/m, respectively. Basement rocks mainly consisting of gneiss are distributed in the field, which has NNE-SSW trending lineament and seems to be a fault, as its very well-developed scarp indicates.

Photo II-2 Mn01 site

Lake Eyasi; Ey01, 02, 03

This field is located on the eastern side of Lake Eyasi, where hot springs well up from the unconsolidated sands of lake deposits. The field consists of wetland with sparse vegetation. The maximum temperature, pH and electrical conductivity were 48.6°C, pH 9.3 and 1,010mS/m, respectively. The Gneiss basement rocks show a NE-SW trending lineament, which seems to be a fault, as its very well-developed scarp indicates.

Similar hot springs occurring under these same geologic conditions are observed at four sites around the east coast of Lake Eyasi thanks to their typical water-flow on the salinity evaporates of the lake.

Photo II-3 Ey01 site

Ngorongoro Crater; Ng01, 02, 03

Three hot springs are found inside of Ngorongoro Crater. Hot spring Ng01 is located at the foot of the sommar, welling up from unconsolidated scree deposits. The maximum temperature, pH and electric conductivity were 34.4°C, pH7.7 and 38mS/m, respectively. The geology of the fields is characterized by Quaternary volcanic rocks.

No structural features are observed in the satellite imagery. The hot springs are derived from the flow of groundwater in the outer crater-rim.

Photo II-4 Ng01 site

Masware; Ba01

This field is located to the north of Babati Town. The hot springs gush out from unconsolidated sands on the gentle slope. The vicinity of the hot springs consists of wetland. The maximum temperature, pH and electric conductivity were 40.9°C, 7.4 and 270mS/m, respectively. A gneiss basement, showing a NE-SW trending lineament, is distributed in the field, and seems to be a fault, as its very well-developed scarp indicates.

No geological features are observed in the imagery. This hot spring is newly reported in this preliminary survey.

Photo II-5 Ba01 site

Hanan (Lake Barangida lalu); Ha01

This field is located east of Lake Balangida Lalu, where hot springs well up from unconsolidated sands of sedimentary lake deposits. The field consists of wetland and ponds and is covered with thick vegetation. The maximum temperature was 32.7°C, but pH and electrical conductivity were not measured, because of contamination of the surface water. Gneiss is distributed in the field, trending ENE-WSW, and the lineament appears to be fault, as its very well-developed scarp indicates. In this area, ENE-WSW trending lineaments are found, and these are dislocated by NW-SE lineaments.

Thick vegetation is observed along the watercourse in the satellite image.

South East of Singida; Ms01, Ta01, Mp01, Mp02

These fields are located in Msule Village southeast of Singida Town. Extensive wetland and ponds with thick vegetation are found in the area. The maximum temperature, pH and electrical conductivity of the hot spring were 37.1°C, 8.1 and 350mS/m, respectively. This hot spring is newly reported in this survey.

Basement granitic rocks with NE-SW and NNW-SSE trending lineaments are distributed around Ms01, Ta01, Mp01, and Mp02. The presence of scarps, which intersect one another, suggests that these lineaments are faults. The NE-SW lineaments are older than the NNW-SSE ones.

Dense, grass-like vegetation along the watercourse is a feature of the satellite imagery. All of these fields are located along the Mponde River.

Photo II-6 Ms01 site

Kondoa; Ko01

This field is situated in Kondoa Town. The site of the hot spring is protected by a roofed structure and supplies 3 million L/day to Kondoa Town. The maximum temperature, pH and electrical conductivity of the hot spring were 30.3C, pH 7.3 and 223mS/m, respectively. Gneissic rock from the Usagaran System is distributed in the field, where a NNE-SSW trending fault is well-developed.

Photo II-7 Ko01 site

2) Mbeya Area

Songwe; So01, Il01, Ra01

These fields are located on the left bank of Songwe River, approximately 30km west of Mbeya City. A large amount of travertine (carbonate sinter) is widely distributed in the fileds. The hot springs gush out from a hill composed of travertine. The maximum temperature, pH and electrical conductivity of the hot springs were 79.2ºC, pH 7.0 and 728mS/m, respectively.

Quaternary volcanic rocks are widely distributed in the fields, where NW-SE trending faults are well-developed. Similar hot springs and their white travertine sinter occur in fissures with a similar trend running parallel to the fault.

The huge amount of white travertine characterizes the area. The travertine is more than 10 m thick at its thickest at the quarry site, and it shows likely to be limestone. The microstructure of the layer shows the colloform texture that is developed under the precipitation process at the surface. The base of the travertine is composed of Cretaceous sandstone and mudstone.

Photo II-8 Ra01 site

Kilambo; Ki01, Ki02

This field is located on the left bank of the river, approximately 30 km southeast of Rungwe Volcano. Travertine accumulates where the hot springs gush out from the hillside and riverbed. The maximum temperature, pH and electric conductivity of the hot springs were 57.4°C, pH 6.6 and 1,030 mS/m. Quaternary basic volcanic rocks are widely distributed in the field, where NW-SE trending faults are well-developed. Hot springs well up from fissures with a similar trend.

The hot springs are aligned along the river, over a distance of more than 200 meters. The basalt contains numerous hornblendes up to 1 cm in size.

Photo II-9 Ki01 site

Mampulo; Ma01, Ma02

This field is located in Mampulo Village, where the hot springs well up from fractures in the conglomerate. The maximum temperature, pH and electrical conductivity of the hot springs are 56.3°C, pH 7.1 and 1,016mS/m, respectively. Conglomerate and pebbly sandstone, in which NW-SE trending faults are well-developed, are dominant in the field.

The hot springs are derived from NE-SW trending fissures, which form a dome-like structure with a higher resistance rather than surrounding areas.

Photo II-10 Mn01 site

Kasimulu; Ka01

This field is located in Kasimulu Village close to the border between Tanzania and Malawi. The hot spring is gushing out from sandstone at the foot of a hill. The maximum temperature, pH and electrical conductivity of hot spring are 52.6°C, pH 6.8 and 1,025mS/m, respectively. Grey sandstone is distributed in the field, where NW-SE trending faults are developed. NW-SE trending fracture is strongly silicified, and slickenside are observed on the surface.

Photo II-11 Ki01 site

3) Rufiji River area

Kisaki; Ks01

This field is located in Kisaki Village close to Kisaki Railway Station. The hot springs well up from unconsolidated sediments. The maximum temperature, pH and electrical conductivity of the hot spring were 72.3°C, pH 7.0 and 721mS/m, respectively. Unconsolidated Quaternary deposits (underlain by gneiss basement) cover the field, where NW-SE trending faults are developed.

There are two hot springs aligned along the faults in the Uluguru Mountain and Rufiji area.

Photo II-12 Ks01 site

Utete; Ut01

This field is located in Utete Town, approximately 2km south of the Rufiji River. The hot spring gushes out from light grey sandstone. The maximum temperature, pH and electrical conductivity of the hot spring are 54.4°C, pH 7.0 and 436mS/m, respectively. Tertiary light grey sandstone is widely distributed in the field, and NW-SE trending lineaments in the sandstone are poorly developed. Reddish brown ferruginous irregular veins have developed in the sandstone. There is no Quaternary volcanism in the vicinity.

Photo II-13 Ut01 site

Nyongoni (Luhoi River); Ny01

This field is located in Nyongoni Village, northeast of the Luhoi River of tributary of the Rufiji River. The hot springs well up from unconsolidated sediments with travertine. The field is characterized by wetland and ponds. The maximum temperature, pH and electrical conductivity of the hot springs were 67.2°C, pH 6.7 and 2,230mS/m, respectively. Quaternary unconsolidated sediments cover the field widely, where NE-SW and NW-SE trending lineaments intersect.

The area characterized by hot springs covers a surface area of 300 m by 200 m. There is no Quaternary volcanism in the vicinity.

Another groundwater spring is located approximately 5 km northeast of Ny01 and is found along a NE-SW trending lineament.

Photo II-14 Ny01 site

(b) Tentative analysis of collected field data

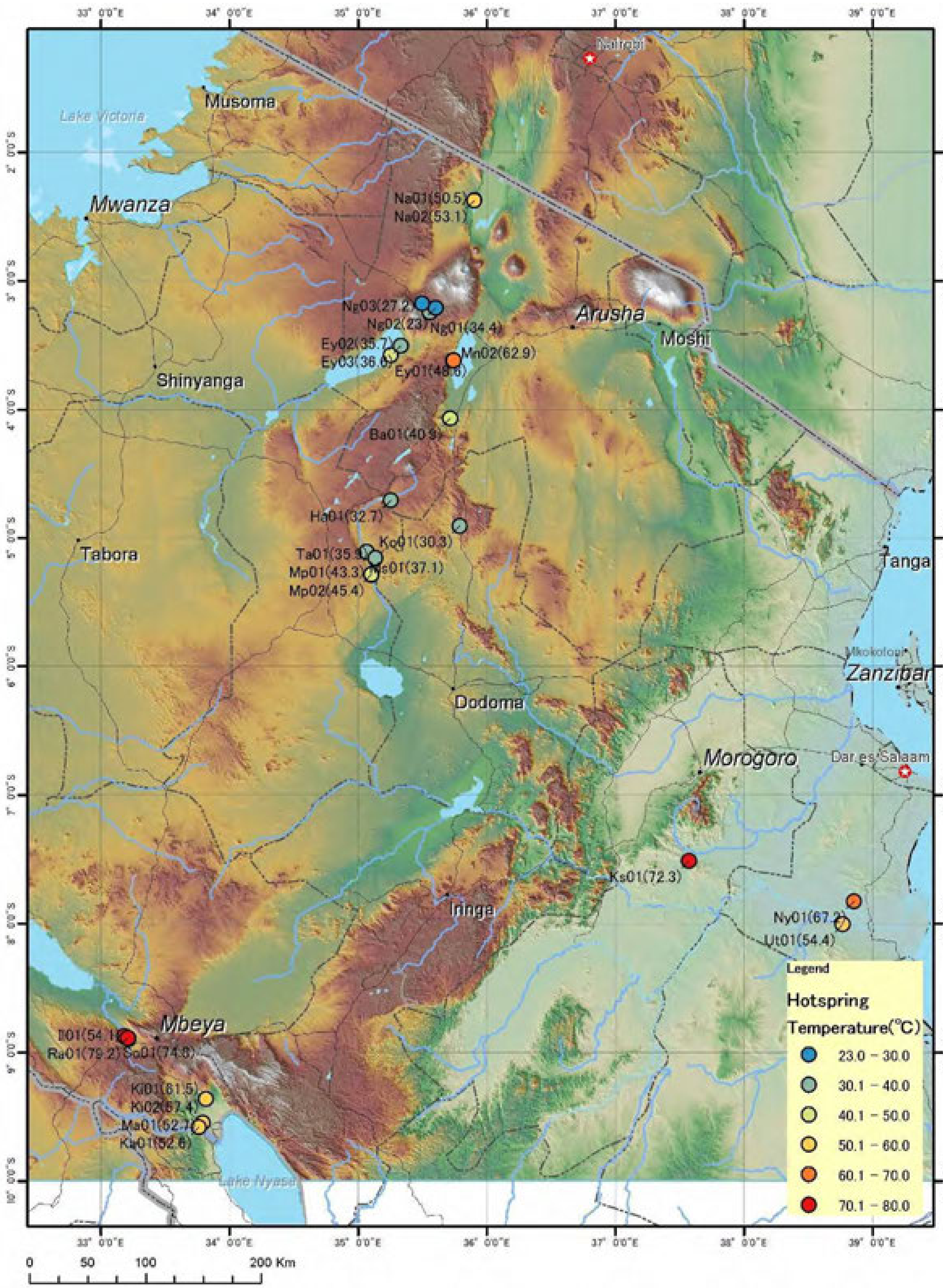
The data distribution maps for temperature, pH and electrical conductivity of the hot spring water are shown in Fig. II-22, Fig. II-23 and Fig. II-24, respectively. The correlation diagrams of the collected field data for these hot springs are shown in Fig. II-25.

The highest hot spring temperature were 79.2 ^{o}C in Rambo field in the Mbeya Area, 72.3 ^{o}C in Kisaki field in the Rufiji Area and 70.8 ^{o}C in Lake Manyara field in the Northern Area. The heat sources of these hot springs are assumed to be Quaternary Volcanic activity such as Oldoinyo Lengai Volcano, Ngorongoro volcanics and others in the Northern Area, and also Rungwe Volcano in Mbeya.

On the other hand, Quaternary volcanic activity in the Rufiji Area has not yet been reported. Only the presence of a volcanic vent which intrudes into the Karoo system is described on the existing geological map of TANGANYIKA sheet series.

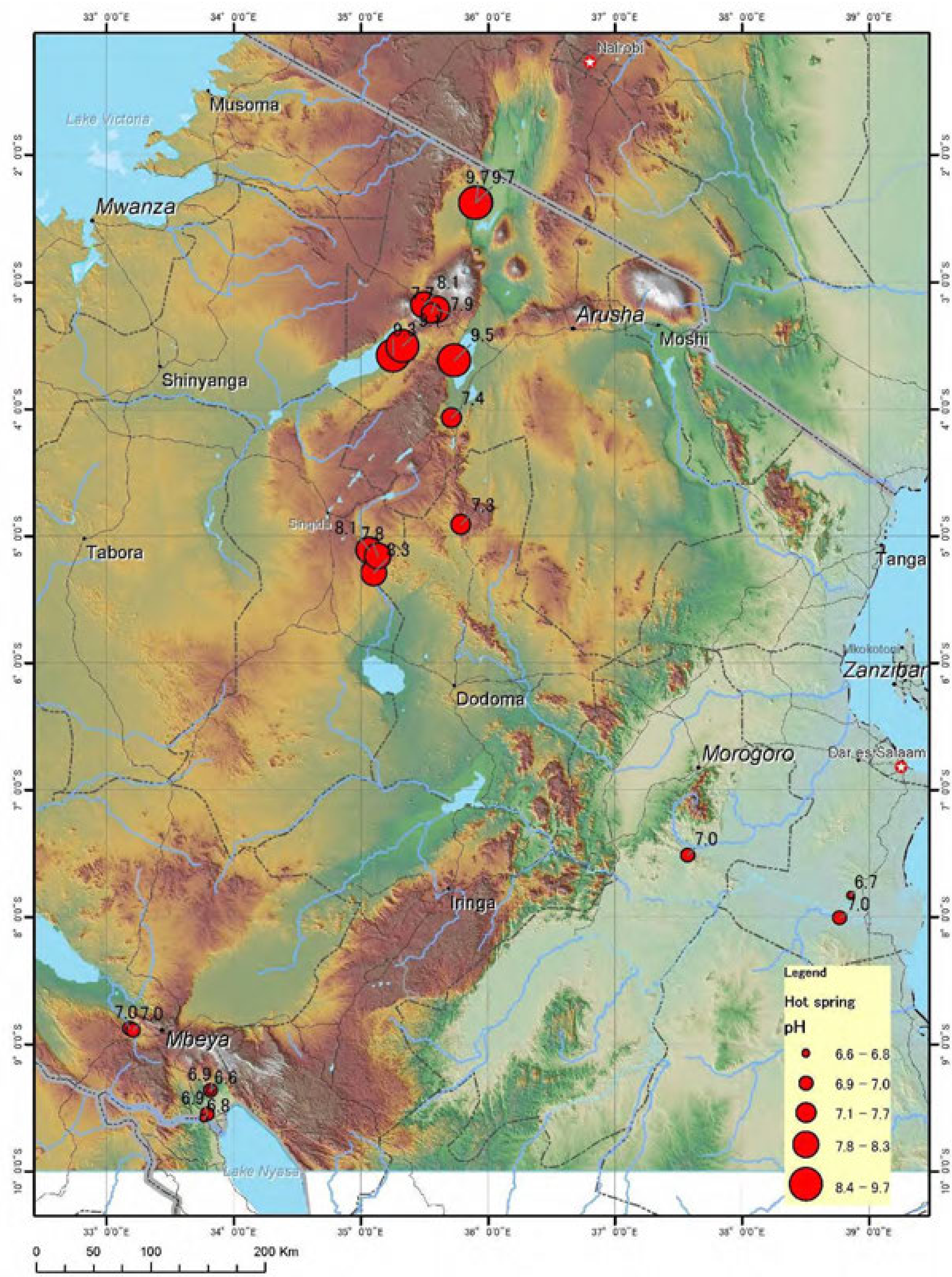
The pH values in the Northern area are relatively higher than in other areas. Mbeya and Rufiji Areas show nearly neutral pH. In any case, no hot spring shows an acid pH contributed by high-temperature volcanic gas.

When the electrical conductivity of hot spring water is high in proportion to the Cl concentration of the hot spring, this indicates water-rock interaction under high temperature conditions. However, the electrical conductivity of hot springs from Lake Natron and Lake Eyasi exceeds 10,000mS/m, implying that those are affected by the brines of salt lakes.



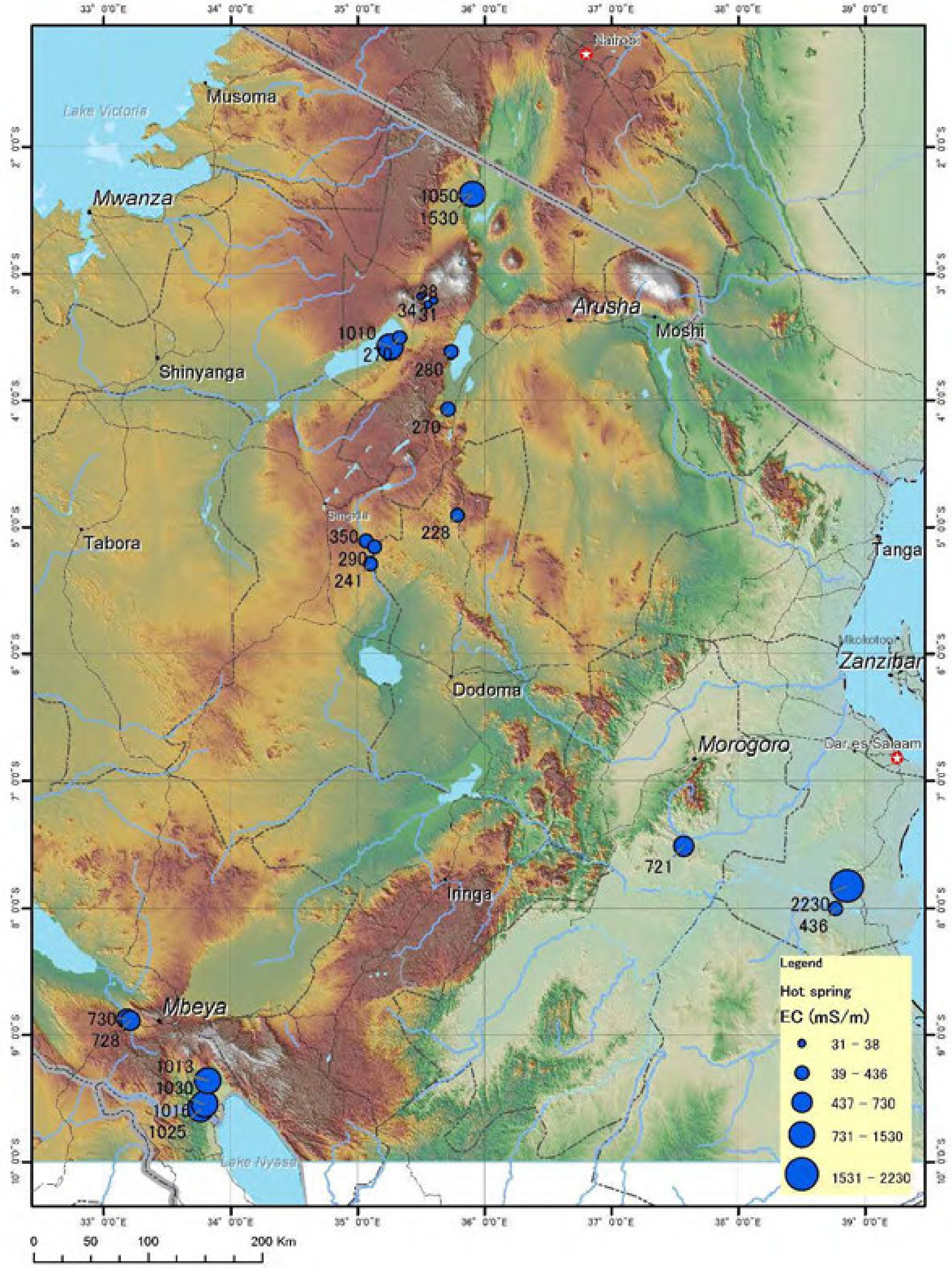
(Study team)

Fig. II-22 Temperature Distribution map of Hot Spring Water



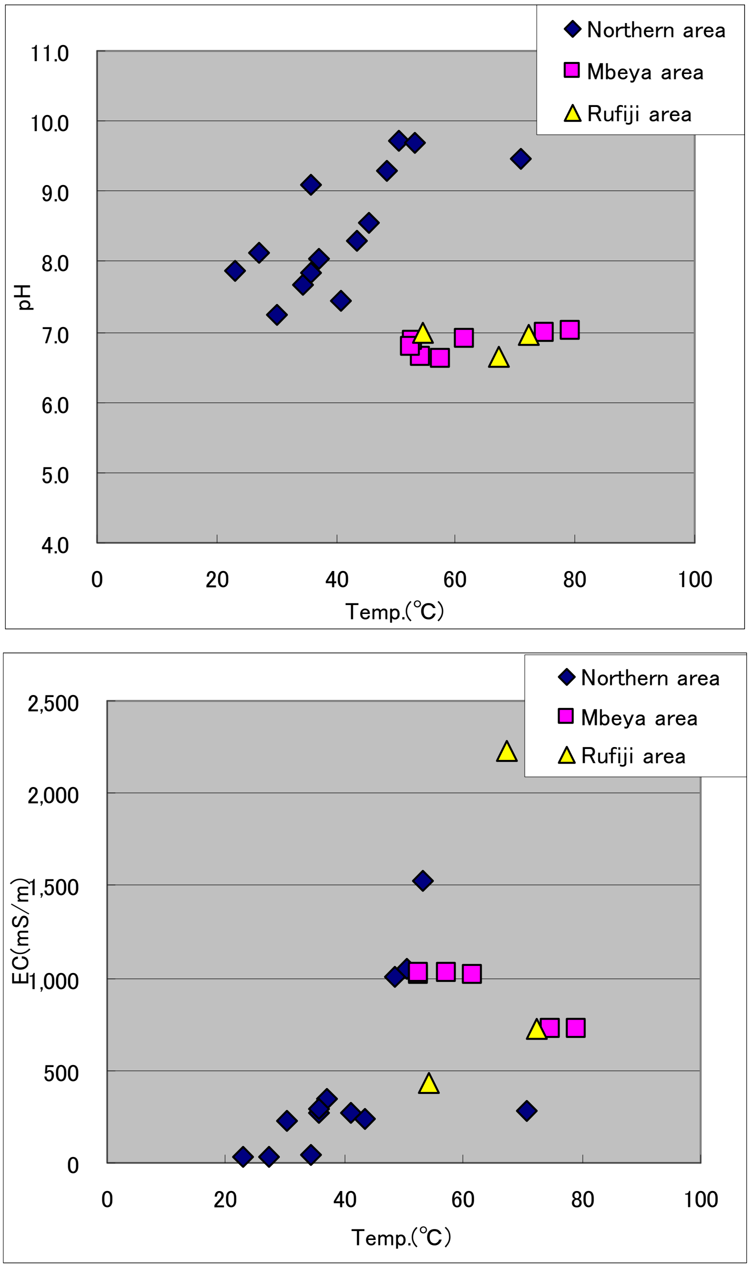
(Study team)

Fig. II-23 pH distribution map of Hot Spring water



(Study team)

Fig. II-24 Electrical conductivity distribution map of hot spring water



(Study team)

Fig. II-25 Correlation diagram of collected field data for hot springs

2. Information about Natural Reserves

In evaluating geothermal potential from the environmental point of view, it is important to consider natural reserves, which are classified into three categories: National parks, Conservation areas and Game reserves.

There are 12 national parks, one conservation area only (in Ngorongoro), and 16 game reserves in the country. In addition, Lake Natron has been inscribed as a registered wetland under the Ramsar Convention. These natural reserves are shown in Fig. II-26.

No human activity at all is allowed in national parks. Ngorongoro Conservation Area has almost the same restrictions on activity as the national parks, except that life activities of the local Masai people are permitted. Some exploration activities are permitted in the game reserves.

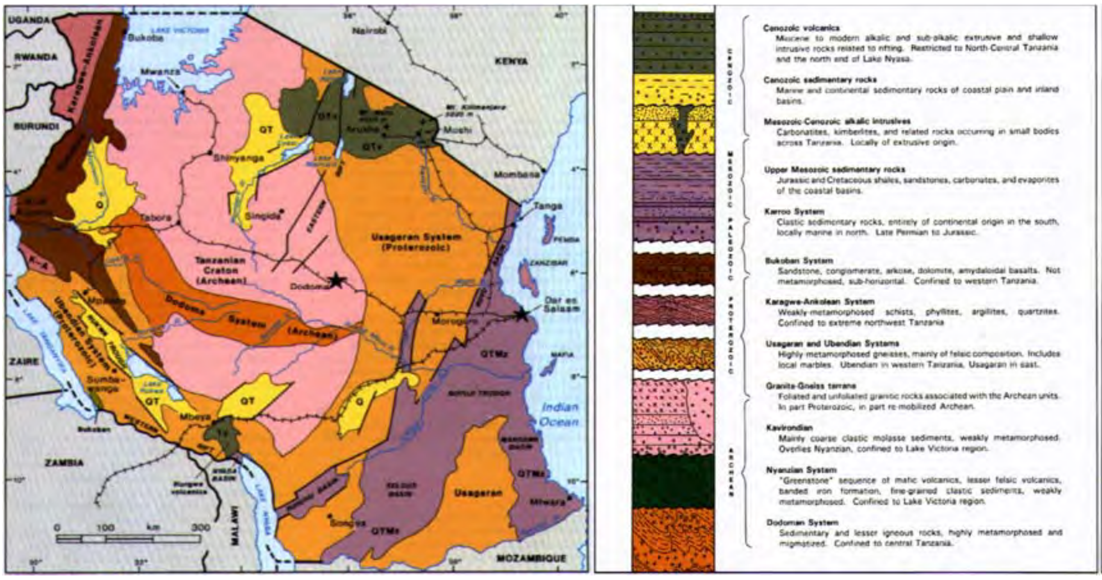
(TANAPA)

1. Ikorongo Game Reserve
2. Grumeti Game Reserve
3. Serengeti National Park
4. Masuwa Game Reserve
5. Lake Natron Ramsar Conv.
6. Ngorongoro Conservation Area
7. Lake Manyara National Park
8. Kilimanjaro National Park
9. Arusha National Park
10. Arangire National Park
11. Mkomazi Game Reserve
12. Buiigi National Park
13. Biharamulo Game Reserve
14. Bubondo Island National Park
15. (unknown)
16. Moyowosi Game Reserve
17. Kigosi Game Reserve
18. Ugalla River Game Reserve
19. Mahale Mountains Nat. Park
20. Katavi National Park
21. Uwanda Game Reserve
22. (unknown)
23. Muhesi Game Reserve
24. Kizigo Game Reserve
25. Rungwa Game Reserve
26. Ruaha National Park
27. Udzungwa National Park
28. Mikumi National Park
29. Selous Game Reserve
30. Sadani Game Reserves
31. Ibanda Game Reserve
32. Rumanyika Orugundu Game Reserve

Fig. II-26 Location of Natural Reserves in Tanzania

II-5-3 Geological Information

Various massifs and a series of strata of pre-Cambrian age cover most regions of Tanzania, with Cambrian and later rocks mainly distributed in the eastern region. The general geology and geologic columnar section are shown in Fig. II-27.

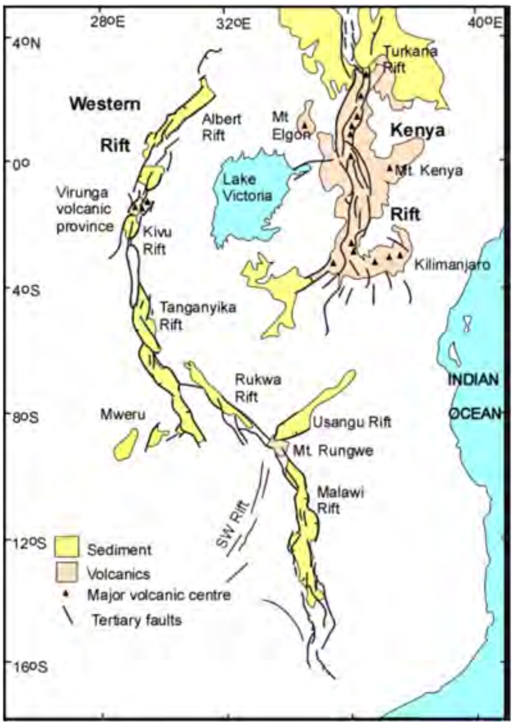


(JOGMEC, 2006)

Fig. II-27 General geology and geologic columnar section of Tanzania

An Archean craton called the 'Tanzanian craton' is composed of complexes of granites and zones of schist and gneiss containing greenstone belts. Proterozoic mobile belts are located in the western, the eastern, the southern and the northwestern regions surrounding the Tanzanian craton. Proterozoic formations distributed in the west and the south consist mainly of gneiss and schist associated with a small amount of amphibolites. Schist, gneiss, granite and a small amount of marble are distributed in the eastern region, and a series of Karoo group formations is distributed in the southwestern region where continental meta-sediments and marine sediments have accumulated successively over the basement. On the other hand, a lot of intrusive rock, ranging from old to young in age shows ultramafic to felsic composition such as gabbro, dolerite, kimberlite, carbonatite, granite, syenite and so forth.

The rift system of Tanzania and its vicinity is shown in Fig. II-28. The system is composed of an Eastern (Kenya) branch and Western branch. The Kenya rift is the segment that extends from Lake Turkana to northern Tanzania. The formation of the Kenya rift started around the early Miocene in the north around Lake Turkana and migrated southwards, with activity in the central segment from about middle to late Miocene. The development of the rift occurred largely within the Late Proterozoic basement of the Mozambique belt and close to the eastern margin of the Tanzanian craton.



(Omenda, 2010)

Fig. II-28 The rift system of Tanzania and its vicinity

The formation of the rift started with up-doming and volcanism on the crest of uplift, which was followed by faulting to form a half graben. The formation of a full graben occurred during the early Pleistocene, when lava flows of basaltic and trachytic composition intercalated with tuffs erupted on the floor. Subsequently, sheet trachytes were grid-faulted with dominant, closely spaced, north-south faults. The Quaternary saw the development of many large shield volcanoes of silicic composition along the axis of the rift.

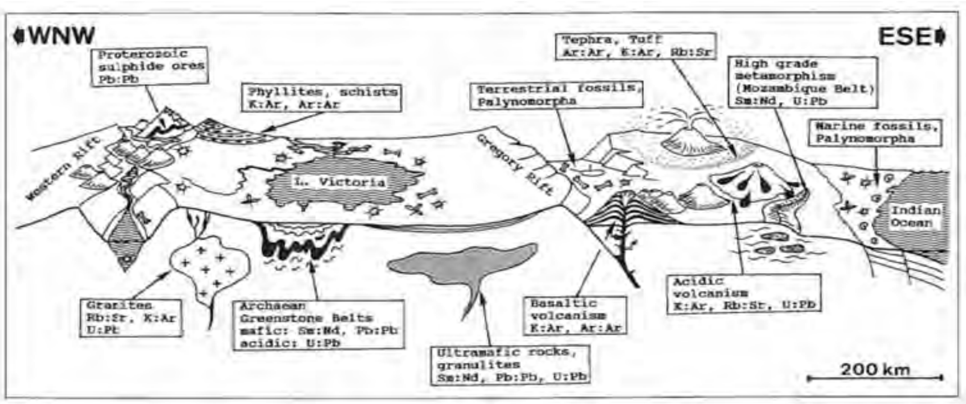
Activity in the southern extreme of the Kenya segment and the northern Tanzania segment of the Kenya rift is dominated by alkaline and carbonatitic volcanism of which Ol Doinyo Lengai is a well-known example. The prevalence of the carbonatites in the region is attributed to the deep source of the lavas occasioned by the thick cratonic crust in the region. Alkaline lavas are predominant in the areas around Kilimanjaro, where micro-rift grabens occur near Arusha and further south.

The entire length of the Kenya rift from Lake Turkana in the north to northern Tanzania has young volcanoes dominantly of silicic composition along its axis. The youthfulness of the volcanoes attests to active magmatism under the rift. Similarly, geothermal manifestations are more abundant and stronger within the rift and in many cases they are associated with young Quaternary volcanoes.

The western branch of the rift runs along the western side of Lake Victoria and along the edge of the East African plateau. The geography of the western branch is typically half-grabens characterized by high-angle normal rift faults. The western branch of the rift displays a paucity of volcanism relative to the Kenyan and Ethiopian rifts. Whereas the volcanism and tectonic activity in the eastern branch commenced about 30 million years ago, volcanic activity in the western branch commenced about 12 Ma in the north near Lake Albert and about 7 Ma in the Tanganyika rift.

The northern zones of the rift comprise several basins that define the Albertine Graben near Lake Albert. The Lake Albert rift was initiated in the early Miocene, and is dominated by a thick sequence of sediments. It is largely non-magmatic except for the southern basins where volcanic products occur. The Albertine basin also has petroleum potential. The western branch is characterized by an abundance of potassic alkaline rocks that consists of carbonatites, ultrapotassic mafic rocks and potassic mafic felsic lava. Volcanic activity is more intense in the Virunga volcanic field.

The Tanganyika–Rukwa-Malawi (TRM) segment of the western branch follows the fabric of the basement structures inherited from the Proterozoic period. The rift is characterized by normal boundary faults, which define half-grabens, horsts and step faults with riftward tiled blocks and monoclinal structures. The Malawi segment extends south to the Urema and Lebombo grabens in southern Mozambique. Lake Tanganyika and Malawi, which are deep sedimentary basins, occur within these rifts. The rift segment has been largely non-magmatic during the Quaternary, with volcanic fields only at Rungwe between Lake Tanganyika and Rukwa. Late Cenozoic volcanism started about 9-7 Ma ago in the Rungwe volcanic province where the rift follows a NE-SW trend in line with the Kenya rift. The volcanic products include Quaternary mafic and felsic rocks. A schematic geological profile along an ESE-WNW axis is illustrated in Fig. II-29.



(Schluter, 1997)

Fig. II-29 Schematic geologic profile along an ESE-WNW axis

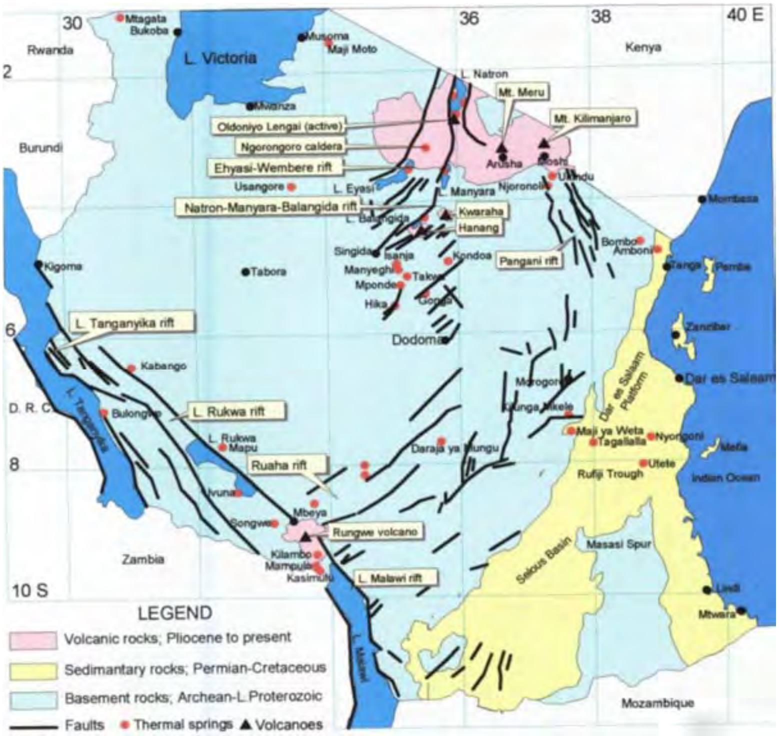
Although there is a paucity of recent volcanism in this segment of the rift, geothermal activity is still evident in many locations. The manifestations in the Tanganyika-Rukwa-Malawi Rift include hot springs and fumaroles with temperatures up to 86^{o}C. These occur at Mbeya where they are closely associated with the Quaternary Rungwe volcanic field. The area is also characterized by high seismicity signifying that the area is still tectonically and magmatically active.

Geothermal areas in Tanzania are shown in Fig. II-30 together with geological structures. In view of the above-mentioned geological features, the following two regions can be nominated as prospective areas for further geothermal explorations.

- The region of Arusha near the Kenyan border in the North (in the Kenya rift)
- The region of Mbeya between Lake Rukwa and Lake Nyasa in the southwest (in the Western rift)

The Luhoi area, situated about 160 km south of Dar Es Salaam, is regarded as prospective. First

Energy Company of Tanzania conducted reconnaissance surveying for preliminary resource evaluation during 1998-2002. From this surveying, a geothermal system with a reservoir temperature higher than 200°C is expected. This area is covered with thick sedimentary rocks of the Karoo group and younger sediments, and NE-SW trending faults, which are parallel to the Usangu rift, are very well developed.

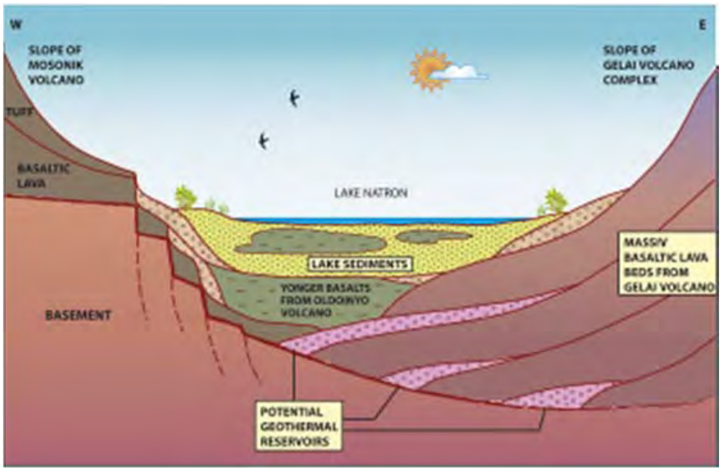


(Omenda, 2010)

Fig. II-30 Geothermal areas and geologic structures in Tanzania

1. The Arusha region

The area is accessible by roads or airways from Dar Es Salaam to Arusha. The geology of the area around Lake Natron is dominated by Cenozoic volcanics, consisting of basalts lava flows and more viscous alkali volcanics. The walls of the rift valley are composed of a number of basalt flows, which are sub-vertical on the more recently faulted western margin. The western rift valley wall appears to consist of at least 10 distinct lava flows. The eastern basin margin has a gentler gradient and appears to be older than the western margin. The initial half-graben boundary fault was presumably on the eastern side of the rift and active faulting has now migrated to the western margin. The western margin boundary fault appears to be the locus of a number of recent volcanoes and volcanic complexes that are located directly over the boundary fault, suggesting that this is a deep crustal fault acting as a conduit for heat flow and lava. One of these volcanoes, Ol Doinyo Lengai, is still active. Lava from this volcano actually overflows the fault escarpment showing that the lava flow from this volcano is younger than the fault. However, the displacement does not appear to be very large. This means that the geological and structural features in the area lead to the following model, a conceptual geologic profile across Lake Natron, which is shown in Fig. II-31.

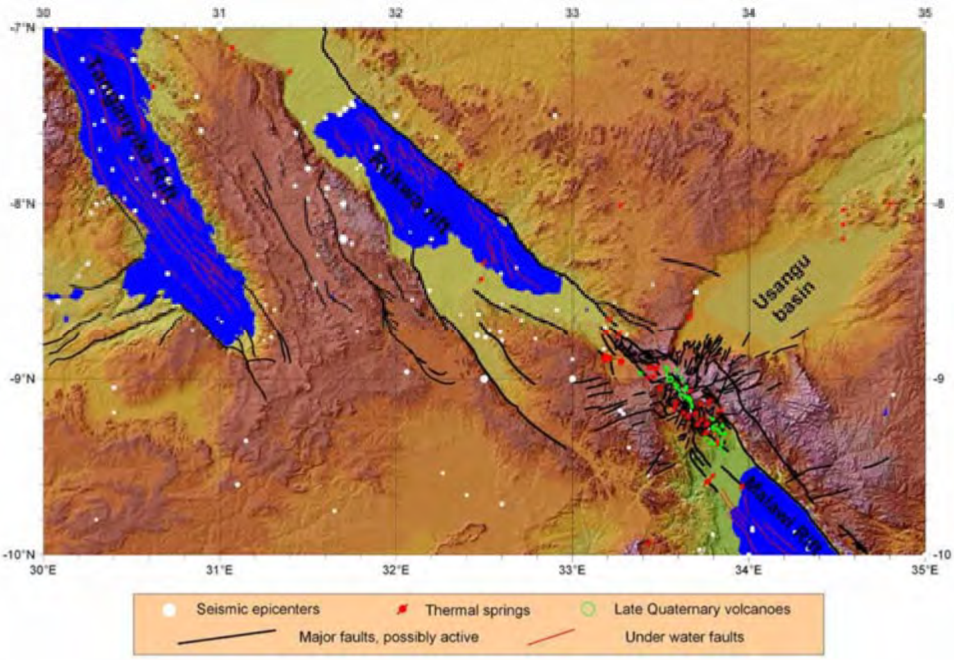


(DECON-SWECO, 2005)

Fig. II-31 Conceptual geologic profile across Lake Natron

2. The Mbeya region

The area is accessible by airways or roads from Dar Es Salaam to Mbeya. The rift system around Mbeya is shown in Fig. II-32.



(Delvaux et. al., 2010)

Fig. II-32 Rift system around the Mbeya region

A detailed investigation combining SRTM DEM90 data, referenced aerial photographs, topographical and geological maps and field observations allow us to refine our knowledge of the tectonic architecture. The Rungwe Volcanic Province is currently affected by a strike-slip to extensional type of tectonic stress regime with both horizontal ENE-WSW maximum compression and NNW-SSE minimum compression (extension) axes. Deformation localizes mainly along high-angle faults that cross-cut the whole volcanic massif and along which significant strike-slip to oblique-slip movements occur. These faults often reactivate older basement structures and/or normal fault systems within Late Quaternary rift sediments and volcanic. They exert strong control on the volcanic vent location and also on the discharge of many hot springs, CO_2, gas vents, bubbling hot springs and cold springs. K-Ar dating of young volcanic rocks and U-Th dating of the Songwe travertine shows that the Ngozi geothermal system started to be active around 360 Ka ago.

The area of investigation belongs to the Rungwe Volcanic Province near Mbeya which is located at the intersection between the western and eastern branches of the East African Rift System, forming a triple junction between the South-Rukwa, North-Malawi (Nyasa) and Usangu rift basins. Its present-day architecture is the product of a long-term rift evolution through several successive stages. The Neo-tectonic period in that area represents the second and still active stage of the Late Cenozoic rifting history, constrained by dated volcanic from the Rungwe massif, to have started 1.5- 1 Ma ago. Tectonic investigations in the area show that fluid flow is controlled by fracture permeability along active faults. Most thermal springs are aligned along the major NW-SE rift trend that controlled the long-term development of the Rukwa and North-Malawi (Nyasa) rift basins. During the last 0.5Ma, the local fault kinematics is dominated by NW-SE horizontal extension and NE-SW horizontal compression leading to a new network of conjugated strike-slip faults.

3. Results of Laboratory Analysis

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

1) Petrography

The petrography rocks in the geothermal areas shows no evidence of apparent hydrothermal alteration. The petrographic results are as follows. The petrography sheets are shown in Appendix-2.

Na01; Lake Natron

The rock is aphyric basalt. The ground mass shows intergranular texture and consists of feldspar lath and pyroxene. The feldspar laths are 0.2-0.3mm in diameter. The pyroxene is under 0.1mm in diameter. The volcanic glasses have been replaced by brown clay minerals.

So01; Songwe

The rock consists almost entirely of calcite which has a dendritic texture with parallel growth.

Ki02; Kilambo

The rock is plagioclase-pyroxene basalt. The maximum diameter of pyroxene is 5mm. The ground mass shows intersertal texture of volcanic glass with fine plagioclase lath and pyroxene. The vesicles (amygdaloidal texture) are filled by intergrowth calcite. The rock shows no evidence of hydrothermal alteration.

Ma01; Mampulo

The rock consists of quartz granules and fine quartz matrix with some admixture of opaque minerals. The quartz granules show a sub-round form and undulatory extinction. The grain size of quartz is mainly

2mm in diameter, sometime 5mm over or 1mm under. The matrix displays a partially reddish brown color. Brown opaque minerals are observed.

Ka01a; Kasimulu

The rock consists mainly of fragments of quartz, biotite and opaque minerals. The quartz fragments have sub-rounded, often angular forms. The matrix consists mainly of fine quartz. Brown opaque minerals and clay minerals are observed in the matrix.

Ka01b; Kasimulu

The grains consist mainly of quartz, displaying an irregular form and undulatory extinction. Few opaque minerals of the matrix consist of aggregate of irregular shape. Clay minerals and brown opaque minerals are observed.

Ut01a; Utete

The rock consists mostly of quartz, which is formed of aggregates of subhedral quartz 1mm in diameter. The grain boundaries of the quartzes show a partially corroded form. Fine quartz, as well as a small amount of fine opaque and clay minerals are observed in the matrix.

UNy01a; Nyongoni

The rock consists of calcite. Fine opaque minerals are observed in the calcite. The rock shows a granular or dendritic texture. A porous texture which is inferred to form during the precipitation process is observed.

2) X-ray diffraction analysis

Table II-9 shows the results of XRD analysis. The detected clay minerals are kaolinite, smectite, illite and mixed-layer mineral. The detected carbonate minerals are calcite and aragonite.

Northern area

The clay minerals contained in the basalt of Na01 (Lake Natron) in the Northern area are composed of kaolinite and smectite.

Mbeya area

The travertine of So01 (Songwe) is composed of calcite and mixed-layer mineral. Aragonite is detected from Ki01 (Kilambo). The clay mineral contained in the basalt of Ki02 (Kilambo) is smectite. The clay minerals contained in the sandstone and conglomerate of Ma01 (Mampulo), and Ka01a (Kasimulu) are illite, kaolinite and mixed-layer mineral.

Rufiji area

The clay mineral contained in the sandstone of Ut01 (Utete) is kaolinite. The travertine of Ks01 (Kisaki), Ut01b (Utete) and Ny01 (Nyongoni) is composed of calcite. Although quartz and feldspar are detected from Ut01b, it is presumed that these are of sedimentary origin.

The detected clay minerals are kaolinite, smectite and illite. In general for hydrothermal processes, the presence of kaolinite shows acid alteration and the presence of smectite and illite indicate neutral alteration. The results of field observations and petrography showed no evidence of apparent hydrothermal alteration. Moreover kaolinite occurs in abundance in soils that have formed from the chemical weathering of rocks, and therefore the kaolinite is inferred have its origin in chemical weathering. The illite in sedimentary rocks is inferred to be of clastic origin. The presences of a small amount of smectite in basalt suggest that it is a low-grade hydrothermal alteration product.

Table II-9 Results of X-ray diffraction analysis

Sample No.	Rock name	Bulk specimen (Quartz index)								Oriented specimen				
		quartz	feldspar	mica	pyroxene	olivine	kaolinite	calcite	aragonite	illite	kaolinite	smectite	mixed layer	other
Na01	basalt		2.7		1.9						○	○		○ (feldspar,pyrite)
So01a	travertine							21.0					○	○ (calcite)
So01b	travertine							18.3						○ (calcite)
Ki01a	travertine							< 0.5	6.0					○ (aragonite)
Ki01b	sediments	19.4	3.4				0.5			○	○	○		○ (quartz, feldspar)
Ki02	basalt		1.6		3.8	1.1						○		
Ma01	conglomerate	49.1	2.9				0.6			○	○			○ (quartz)
Ka01a	sandstone	13.3		0.6			2.2				○		○	
Ka01b	silicified sandstone	35.0								○	○		○	○ (quartz)
Ks01a	travertine							15.4						○ (calcite)
Ut01a	sandstone	67.4	1.0				1.1			○	○			
Ut01b	travertine	3.6	2.7					12.9			○	○		○ (quartz, calcite)
Ny01	travertine							23.8						○ (calcite)

(Study team)

3) Spectral measurement

Infrared reflectance measurements were conducted to clarified clay and carbonate mineralogy of rock samples. Table II-10 shows the list of identified minerals. The reflectance curves of each sample are shown in Appendix-3.

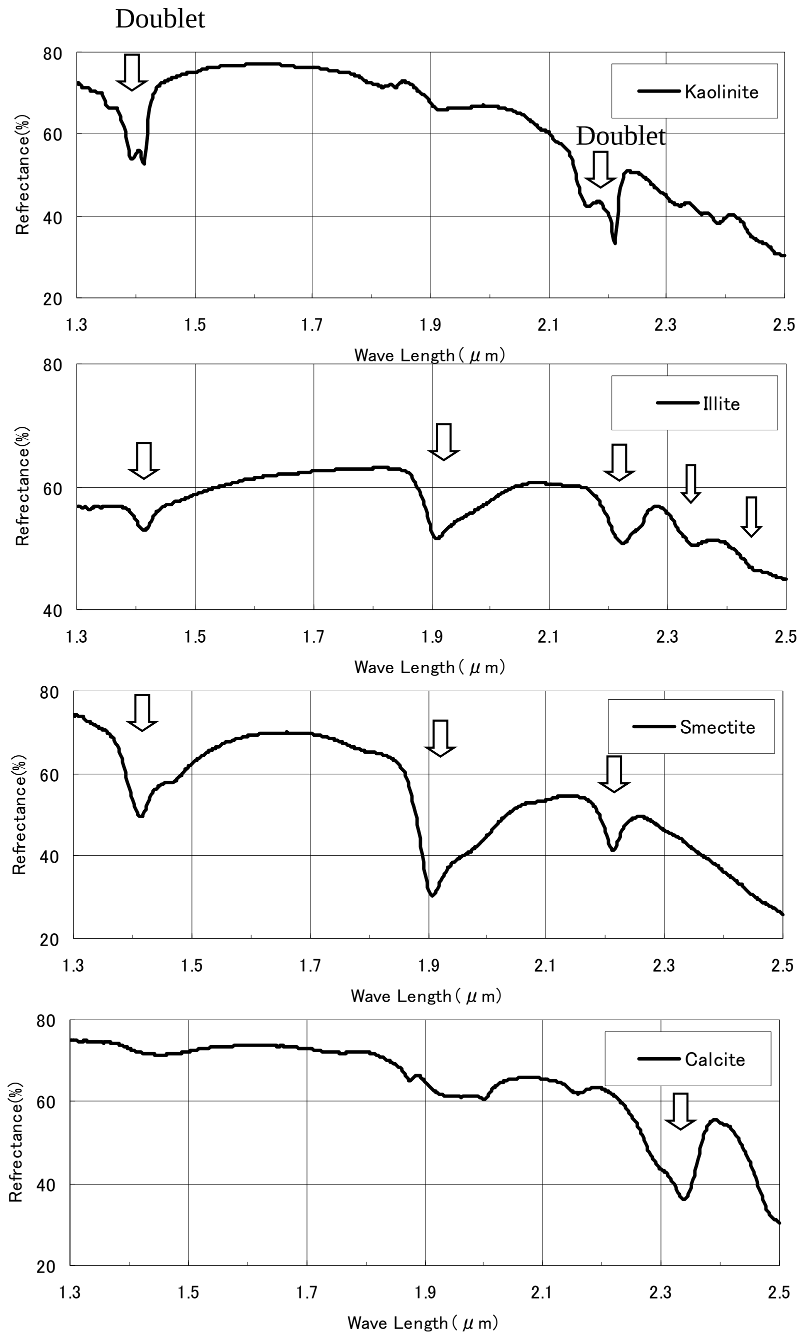
SWIR (short wave infrared region) reflectance spectroscopy is a very sensitive analytical method for the clay mineral groups and carbonate mineral groups. The wave length of SWIR ranges from 1,300 to 2,500nm. Fig. II-33 shows reflectance curves of kaolinite, smectite and sericite (illite) from the USGS spectral library. In SWIR, clay minerals and carbonate minerals have specific absorption features. These absorption features are caused by water and $Al\text{-}OH^-$ molecular vibration processes in the minerals, allowing the spectroscopy to identify the types of minerals and chemical components. For example, kaolinite is identified by the absorption feature of a doublet or shoulder shape in the 2,200nm region. The same absorption band in smectite overlaps with that for sericite (illite).

The detected minerals are kaolinite, sericite (illite), smectite, calcite vermiculite and anhydrite (Table II-10). Some reflectance curves of the travertine of So01a and the kaolinite of Ka01a and Na01a (undetected) are shown in Fig. II-34. Kaolinite is detected in the sandstone and unconsolidated sediments of Ki01b (Kilambo), Ma01 (Mampulo), Ka01a and Ka01b (Kasimulu). All travertine samples show calcite absorption features. These findings are similar to the results of the XRD analysis. Smectite in the basalt of Na01 (Lake Natron) and Ki01 (Kilambo) is not identified by spectral analysis, probably due to weak alteration. Vermiculite formed by the weathering of biotite is detected in the granite of Ta01 (Takwa).

Table II-10 The spectral measurement results

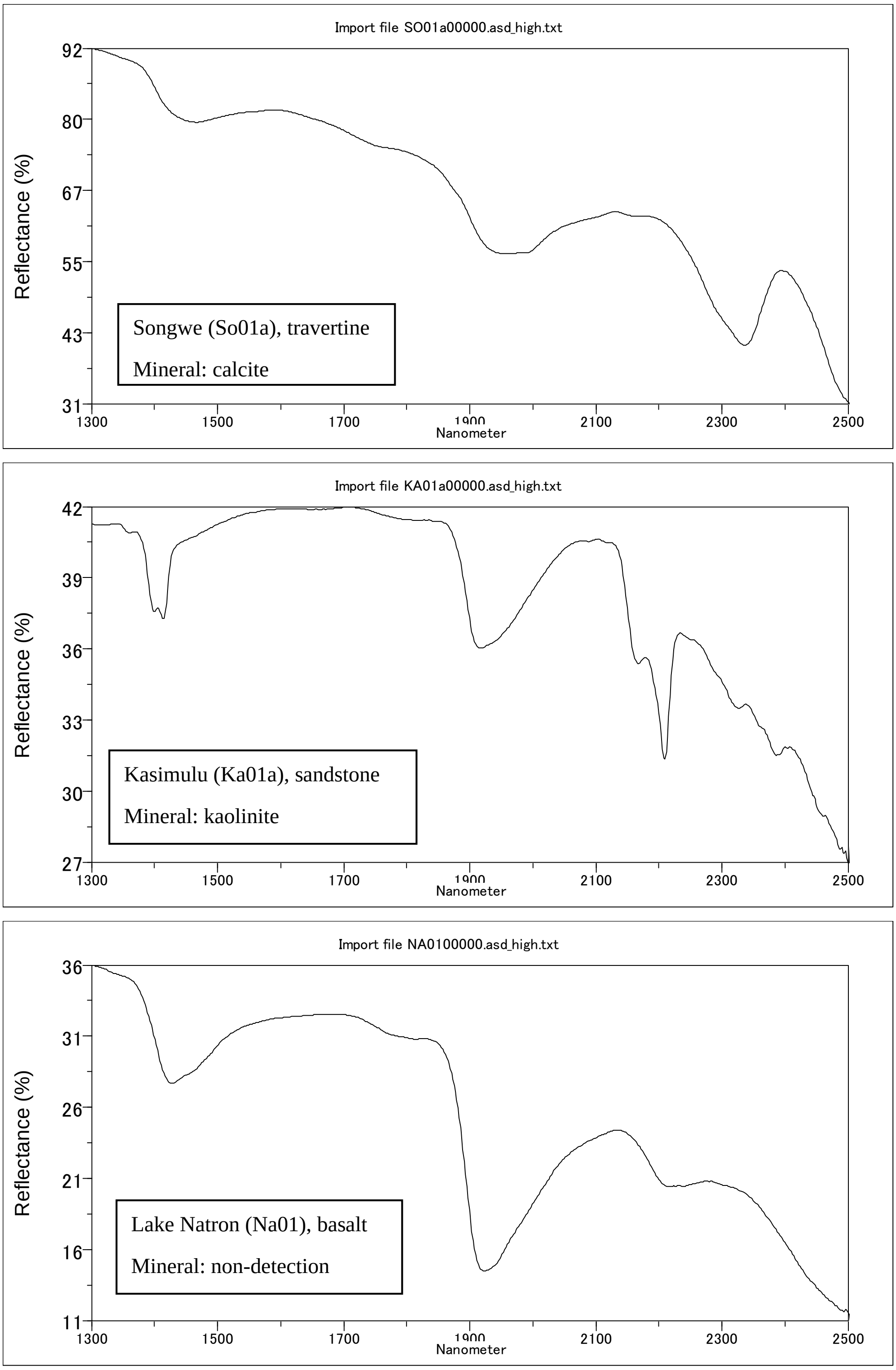
sample name	place	rock name	kaolinite (halloysite)	smectite	illite (sericite)	calcite	vermiculite	anhydrite	remark
Na01	Lake Natron	basalt							undetected
Na02	Lake Natron	basalt							undetected
Mn01a	Lake Manyara	gneiss		○?	○				
Mn01b	Lake Manyara	evaporite						○	
Ey01	Lake Eyasi	evaporite						○	
Ng01	Ngorongoro crater	sediment							2.3μm absorption?
Ba01a	Masware	gneiss		○?	○				2.3μm absorption?
Ba01b	Masware	sediment	○?	○?					2.3μm absorption?
Ba01c	Masware	sediment	○	○?					
Ha01	Balangida lalu	sediment	○						2.3μm absorption?
Ta01a	Takwa	granitic rock		○?	○?		○		
Ta01b	Takwa	sediment		○					
So01a	Songwe	travertine				○			
So01b	Songwe	travertine				○			
Ki01a	Kilambo	travertine				○			
Ki01b	Kilambo	sediment	○						
Ki02	Kilambo	basalt							undetected
Ma01	Mampulo	conglomerate	○						
Ka01a	Kasimulu	sandstone	○						
Ka01b	Kasimulu	silicified rock	○						
Ks01a	Kisaki	travertine				○			
Ks01b	Kisaki	travertine				○			
Ks01c	Kisaki	sediment				○			
Ut01a	Utete	sandstone	○						
Ut01b	Utete	travertine				○			
Ny01	Nyongoni	travertine				○			

(Study team)



(data from USGS)

Fig. II-33 Spectral Reflectance of Typical Clay Minerals and Calcite



(Study team)

Fig. II-34 Spectral measurement results

II-5-4 Geochemical Information

The chemical analysis methods applied to of the samples mentioned in "II-5-2 Field Survey" are shown in Table II-11 and the analysis results are shown in Table II-12. Geochemical analysis figures are shown in Fig. II-35 to Fig. II-38. The results of the calculated geothermometer are shown in Fig. II-40 to Fig. II-43 and Table II-13 (Equations are shown in Appendix-4).

Table II-11 Chemical/isotopic analysis methods

	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	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‰

Table II-12 Results of geochemical analysis (This study)

sample name	date	Chemical component														Isotope component	
		pH	EC	Na	K	Li	NH_4	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)	(‰)	(‰)
Na01	2013/8/16	10.0	2,130	6,600	98.1	<0.01	3.77	0.65	0.037	2,830	270	3,380	66.1	5.57	78	-24	-3.8
Na02	2013/8/16	9.9	2420	-	0	-	-	-	-	3,370	350	4,870	68.3	6.36	-	-	-
Mn01	2013/8/17	9.8	304	676	10.8	0.11	1.00	0.43	0.018	200	151	558	23.0	0.79	146	-24	-4.5
Ey01	2013/8/18	9.4	2,670	7,510	47.4	0.05	< 0.01	0.71	0.095	6,570	869	4,180	80.1	2.63	52	-18	-2.5
Ey02	2013/8/18	8.9	383	948	9.27	0.07	0.15	0.97	0.156	580	161	1,100	14.8	0.70	42	-19	-4.1
Ng01	2013/8/19	7.2	43.5	65.5	8.97	0.01	0.43	29.6	11.8	15	0.5	295	1.16	0.23	104	-26	-5.2
Ng03	2013/8/19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-28	-5.2
Ba01	2013/8/20	7.8	380	939	19.5	0.30	< 0.01	8.64	3.23	280	368	1,560	19.7	0.58	70	-22	-4.2
Ms01	2013/8/21	8.0	485	1,110	8.40	0.12	< 0.01	8.94	3.50	980	462	719	10.5	0.36	36	-27	-4.7
Ta01	2013/8/21	-	-	670	5.57	0.15	0.03	19.4	5.66	-	-	-	-	-	43	-28	-4.7
Mp01	2013/8/21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-26	-4.2
Ko01	2013/8/22	7.3	113	106	8.21	0.02	0.03	111	30.6	118	120	380	0.54	0.11	60	-25	-4.7
So01	2013/8/25	7.4	368	837	99.6	0.88	0.04	40.6	16.0	210	167	1,980	7.12	0.70	75	-35	-6.1
Ra01	2013/8/25	7.3	354	856	88.0	0.94	0.11	20.6	8.39	230	169	1,850	8.58	0.75	70	-34	-6.0
Ki01	2013/8/26	7.3	511	1,190	61.0	0.80	< 0.01	77.1	34.6	430	235	2,600	2.67	0.95	125	-23	-5.2
Ki02	2013/8/26	7.0	515	1,180	60.7	0.80	0.21	89.7	35.0	430	236	2,680	2.59	0.95	122	-24	-5.2
Ma01	2013/8/26	7.6	510	1,300	66.7	0.50	< 0.01	28.6	14.3	280	307	2,820	1.57	0.89	130	-22	-4.7
Ka01	2013/8/26	7.3	511	1,300	72.3	0.45	< 0.01	44.3	17.4	240	367	2,900	1.55	0.87	108	-23	-4.8
Ks01	2013/8/28	7.5	357	819	48.9	0.42	< 0.01	53.4	24.5	180	452	1,650	6.33	0.26	63	-13	-3.3
Ut01	2013/8/30	7.4	205	467	18.5	0.47	1.67	19.2	5.74	160	258	787	3.73	1.93	39	-17	-3.5
Ny01	2013/8/31	7.0	1,090	2,280	120	3.40	19.1	55.9	19.2	3,220	42.8	1,470	2.81	33.8	51	-17	-1.0

(Study team)

In the following, the Lake Natron - Ngorongoro area, the Mbeya area, the Rufiji area and the Singida – Kondoa area are each given separate geochemical interpretation.

a) Lake Natron - Ngorongoro area

In the Lake Natron – Ngorongoro area (Lake Natron, Lake Manyara, Lake Eyasi and Ngorongoro crater), the chemical composition of hot spring water from Ngorongoro crater is diluted (ex. Cl only 14.9mg/L). Judging from the major anions, it's HCO_3-type water (Fig. II-35), and the isotopic composition is almost the same as meteoric water (Fig. II-37), so the hot spring water of Ngorongoro crater seems derive from slightly conductively heated meteoric water. Among the geothermometers the alkaline geothermometer (Na-K) shows over 200ºC (Fig. II-40, Table II-13), but it is not a reliable indicator of underground temperature because it hasn't reached chemical equilibrium (Fig. II-38). As a temperature of only 40 degrees C is estimated from the silica geothermometer, Ngorongoro crater is not promising as a geothermal resource.

Hot spring water from Lake Natron and Lake Eyasi , excluding the single sample Ey02 from Lake Eyasi, shows waters of Cl-HCO_3 type, of an intermediate deep reservoir type (Cl type) and of a conductively heated type (HCO_3 type) (Fig. II-35). The Cl concentrations in those were high at over 3,000mg/L (Table II-12) and the Boron concentration was lower than the Cl concentration, in contrast to normal hot springs (Fig. II-36), so salt lake water from Lake Natron and Lake Eyasi seems to be infiltrating those hot springs, accounting for the high Cl concentrations. Ey02 at Lake Eyasi seems to have formed after waters from Ey01 were diluted with meteoric water, judging from the Cl-B diagram (Fig. II-36). Regarding underground temperatures, the Na concentration is too high compared with the equilibrium condition of Na-K-Mg. So based on the Na-K-Ca temperature, taking Ca into account, the temperature was estimated to be 134 to 174 degrees C (Fig. II-40, Table II-13).

Hot spring water from Lake Manyara was reported to have a very high Cl concentration of 4,810mg/L, and it was expected that this was due to some infiltration from Manyara salt lake, mentioned in the previous section. This survey, however, found that the location of the hot spring has changed and the Cl concentration was only 200mg/L, a normal value for a hot spring, and it was determined to be of the conductively heated type (HCO_3 type) (Fig. II-35). The Cl-B diagram (Fig. II-36), shows that no infiltration of lake water occurs in this hot spring and indicates that the water was stored in volcanic rocks. Based on the Na-K-Ca temperature, taking Ca into account, the estimated underground temperature is 144 degrees C (Fig. II-40, Table II-13).

b) Mbeya area

Hot spring water from the Mbeya area (Songwe, Rambo, Kilambo, Mamplo and Kasimulu) has a Cl concentration ranging from 210 to 430 mg/L, and is classified as water of the conductively heated type (HCO_3 type) (Fig. II-35). Judging from the Cl-B diagram (Fig. II-36), those waters are stored in volcanic rocks. The isotopic composition of the water shows that its origin is meteoric water. In particular, the water from Songwe and Rambo in the northwestern area originates at a higher elevation than the other waters, as the smaller isotope values for Songwe and Rambo indicate (Fig. II-37). In determining the underground temperature, Na-K-Mg thermometry was not applicable, as these three components were not in an equilibrium condition, 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 168 to 215 degrees C (Fig. II-41, Table II-13). A possible reason for the high Mg concentration is that the Mg may be dissolved from travertine (Ca, Mg-bearing carbonate) found in the area.

c) Rufiji area

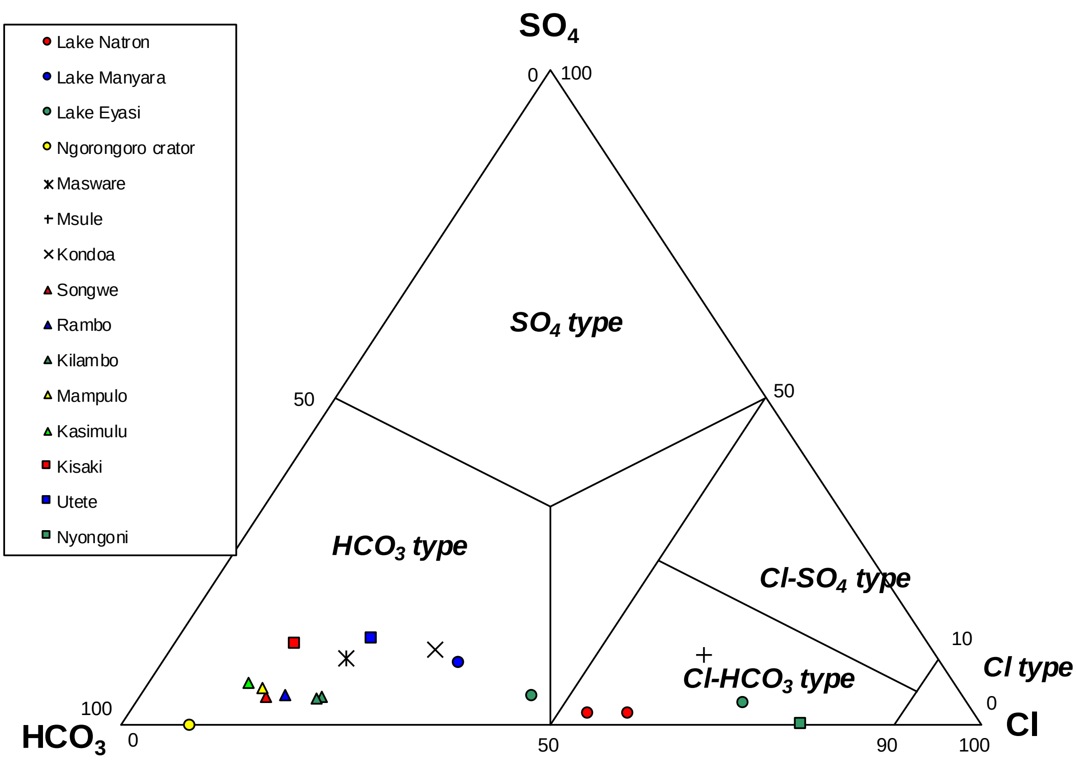
In the Rufiji area (Kisaki, Utete and Nyongoni (Ruhoi river)), hot spring water from Kisaki and Utete has a Cl concentration of 160 to 180 mg/L and is of the conductively heated type (HCO_3 type) (Fig. II-35). Hot spring water from Kisaki may be influenced by evaporites, while that from Utete is stored in volcanic rocks. However, no volcanic rocks were found in our reconnaissance survey of the surface there. The isotopic composition of the water shows that the origin of those hot spring waters is meteoric (Fig. II-37). Regarding underground temperature, three components of Na-K-Mg is not equilibrium condition because Mg concentration is high (Fig. II-38). So based on the Na-K-Ca temperature, Ca was taken into account, estimated underground temperature is 147 to 171 degrees C (Fig. II-42, Table II-13).

Hot spring water from Nyongoni (Ruhoi river) has a Cl concentration of 3,220 mg/L and indicates water of Cl-HCO_3 type, intermediate deep reservoir type (Cl type) and conductively heated type (HCO_3 type) (Fig. II-35). Judging from the Cl-B diagram (Fig. II-36), the high Cl concentration is not due to evaporites but to storage in volcanic rocks. However, no volcanic rocks were found in our reconnaissance survey of the surface there. The shift in the oxygen isotopic condition of the water indicates meteoric water interacting with rocks under high temperature (Fig. II-37). Regarding underground temperature, three components of Na-K-Mg is not equilibrium condition because Mg concentration is high (Fig. II-38). So based on the Na-K-Ca temperature, Ca was taken into account, estimated underground temperature is 183 degrees C (Fig. II-42, Table II-13). The reason for the high

Mg concentration is thought to be the same as in the Mbeya area.

d) Singida – Kondoa area

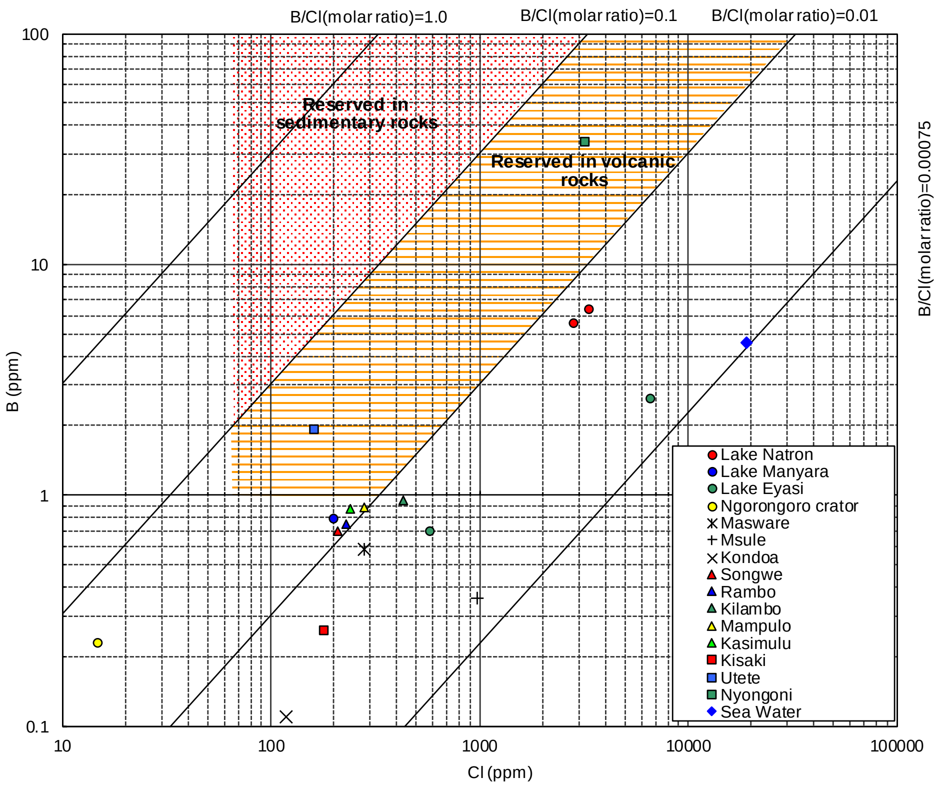
In the Singida – Kondoa area (Masware, Msule, Takwa and Kondoa), hot spring water from Msule has a Cl concentration of 980 mg/L and is classified as Cl-HCO_3 type water while the others were conductively heated type (HCO_3 type) with Cl concentrations of 118 to 280 mg/L (Fig. II-35, Table II-12). However, influence from evaporites must be considered, since the Boron concentration is lower than the Cl concentration unlike normal hot springs (Fig. II-36). The isotopic composition of these waters shows that their origin is meteoric (Fig. II-37). Regarding underground temperature, three components of Na-K-Mg is not equilibrium condition because Mg concentration is high (Fig. II-38). So based on the Na-K-Ca temperature, Ca was taken into account, estimated underground temperature is 57 to 138 degrees C (Fig. II-43, Table II-13).



(Study team)

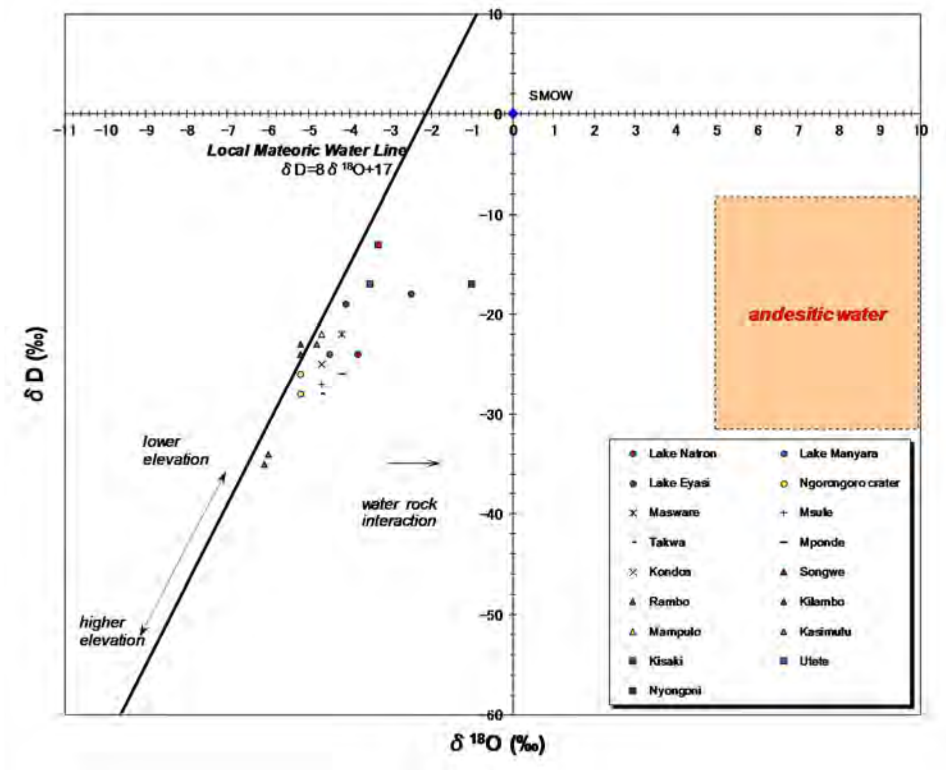
(Legend) ○: Northern area, △ : Mbeya, □: Rufiji, Others: Singida-Kondoa (Below, as well)

Fig. II-35 Ternary diagram of the major anions



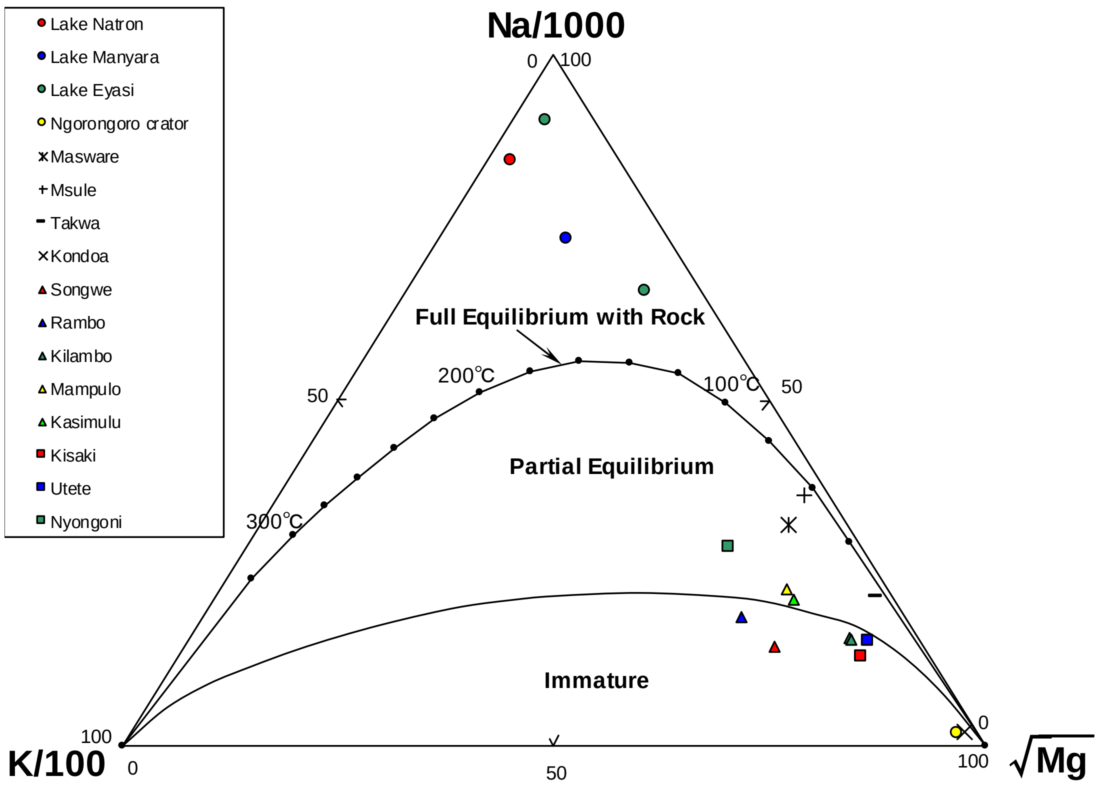
(Study team)

Fig. II-36　Cl-B diagram of hot springs



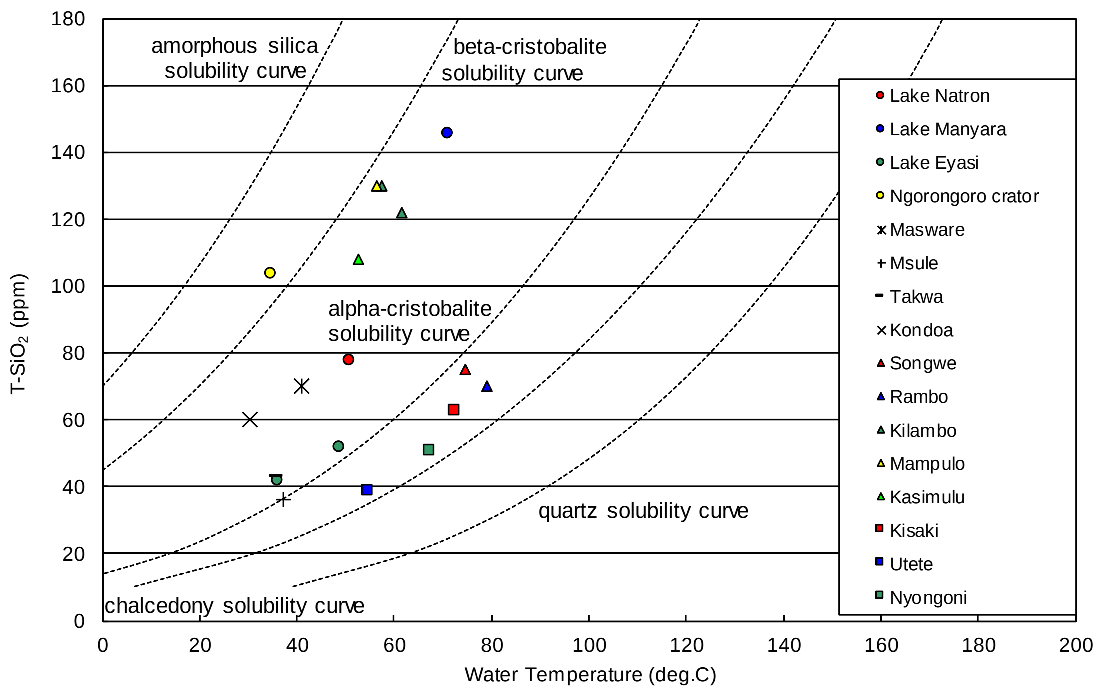
(Study team)

Fig. II-37　Delta-D and Delta-^{18}O diagram of waters



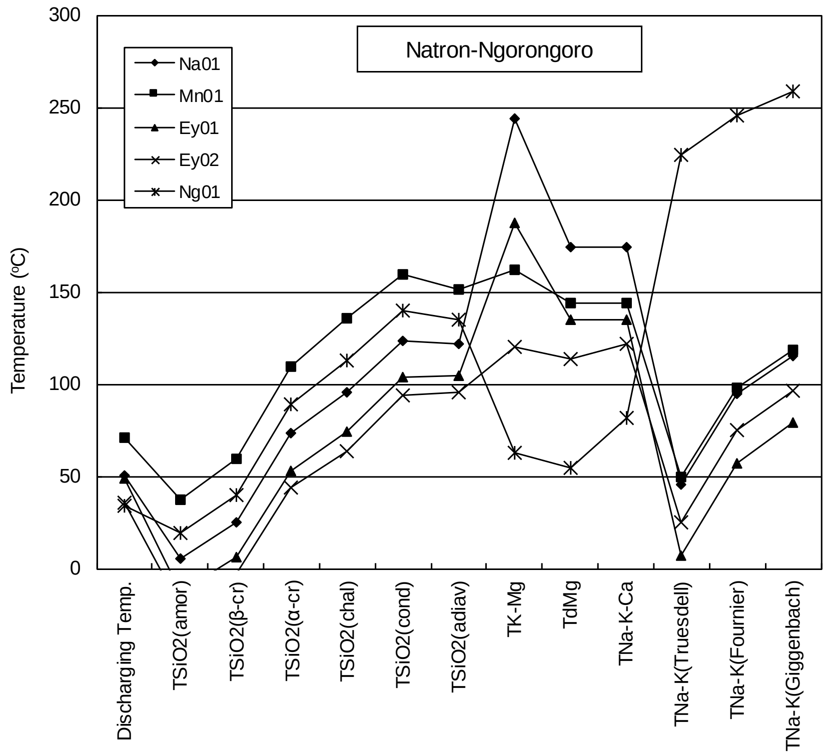
(Study team)

Fig. II-38 Ternary diagram for Na-K-Mg



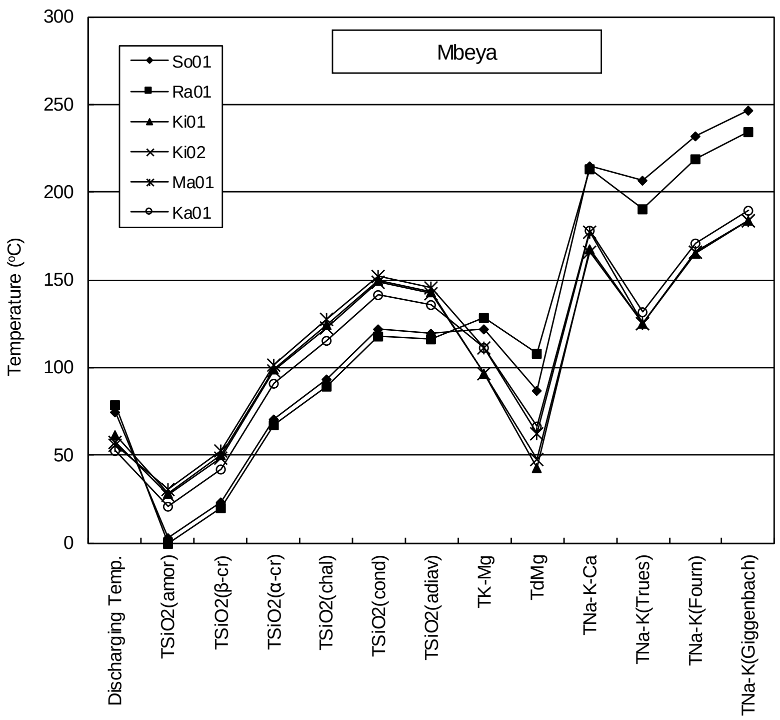
(Study team)

Fig. II-39 Solubility diagram of silica minerals



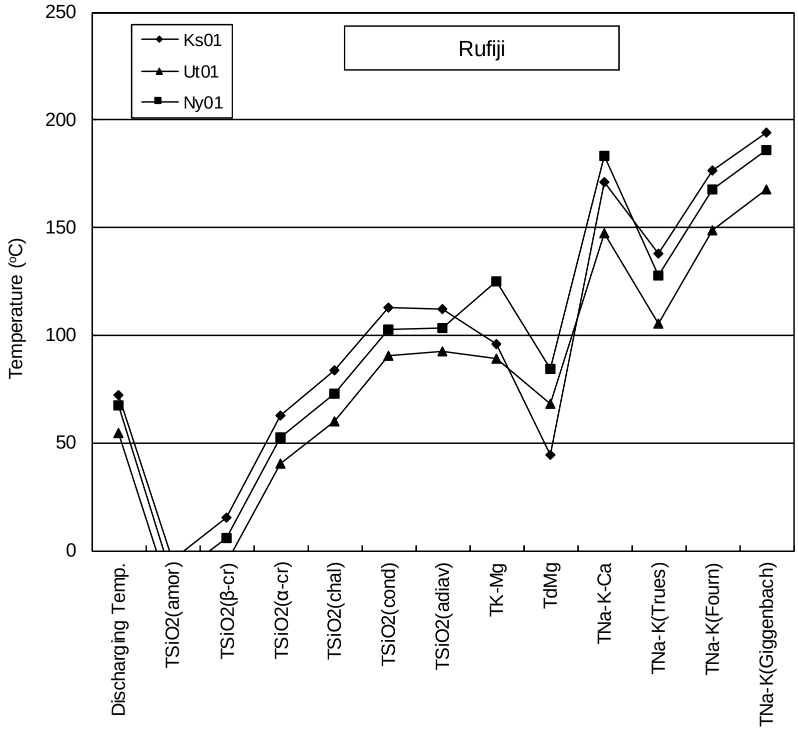
(Study team)

Fig. II-40 Calculated geothermometers in Lake Natron – Ngorongoro area



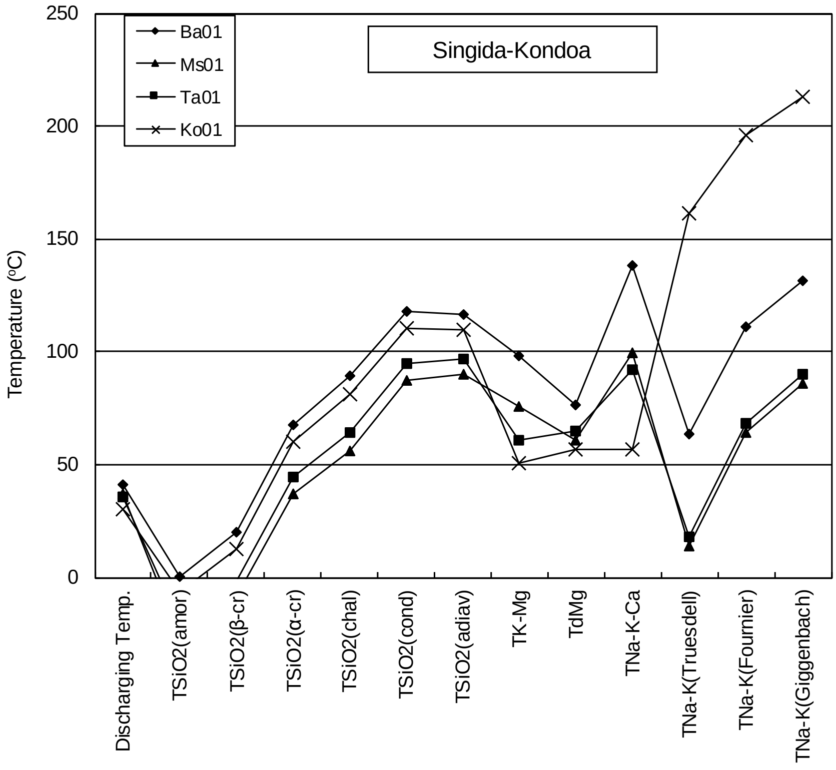
(Study team)

Fig. II-41 Calculated geothermometers in Mbeya area



(Study team)

Fig. II-42 Calculated geothermometers in Rufiji area



(Study team)

Fig. II-43 Calculated geothermometers in Singida-Kondoa area

Table II-13　Calculated results of geothemometry

Area		Natron-Ngorongoro (northeast Tanzania)					Singida-Kondoa (central Tanzania)			
Site		Lake Natron	Lake Manyara	Lake Eyasi		Ngorongoro crator	Masware	Msule	Takwa	Kondoa
Sample No.		Na01	Mn01	Ey01	Ey02	Ng01	Ba01	Ms01	Ta01	Ko01
(℃)	Discharging Temp.	50.5	70.8	48.6	35.7	34.4	40.9	37.1	35.9	30.3
Geothermometry (℃)	$TSiO_2$(amor)	5	37	-12	-21	19	0	-26	-20	-7
	$TSiO_2$(β-cr)	25	60	6	-3	40	20	-9	-2	13
	$TSiO_2$(α-cr)	73	109	53	44	89	68	37	45	60
	$TSiO_2$(chal)	96	135	74	63	113	90	56	64	81
	$TSiO_2$(cond)	124	159	104	94	139	118	87	95	111
	$TSiO_2$(adiav)	121	151	104	96	135	117	90	97	110
	TK-Mg	244	162	187	120	63	98	76	61	51
	TdMg	174	144	134	114	55	76	60	65	57
	TNa-K-Ca	174	144	134	122	82	138	99	92	57
	TNa-K(Truesdell)	45	49	7	25	224	64	14	18	162
	TNa-K(Fournier)	94	98	57	75	246	111	65	68	196
	TNa-K(Giggenbach)	115	119	79	97	259	132	86	90	213
Area		Mbeya (southwest Tanzania)						Rufiji (east Tanzania)		
Site		Songwe	Rambo	Kilambo		Mampulo	Kasimulu	Kisaki	Utete	Nyongoni (Ruhoi river)
Sample No.		So01	Ra01	Ki01	Ki02	Ma01	Ka01	Ks01	Ut01	Ny01
(℃)	Discharging Temp.	74.8	79.2	61.5	57.4	56.3	52.6	72.3	54.4	67.2
Geothermometry (℃)	$TSiO_2$(amor)	3	0	29	27	31	21	-4	-24	-13
	$TSiO_2$(β-cr)	23	20	51	49	53	42	15	-6	6
	$TSiO_2$(α-cr)	71	68	100	98	102	91	62	40	52
	$TSiO_2$(chal)	93	90	125	123	127	115	84	60	73
	$TSiO_2$(cond)	122	118	150	149	152	142	113	91	103
	$TSiO_2$(adiav)	120	117	143	142	145	136	112	93	103
	TK-Mg	122	128	97	97	112	111	96	89	125
	TdMg	87	109	43	48	62	66	44	68	84
	TNa-K-Ca	215	213	168	166	178	178	171	147	183
	TNa-K(Trues)	207	191	125	126	125	132	138	106	127
	TNa-K(Fourn)	232	219	166	166	166	171	176	149	168
	TNa-K(Giggenbach)	247	235	184	184	184	189	194	168	186

(Study team)

II-5-5 GIS

Remote sensing data, geological maps, topographic maps, magnetic interpretation maps, natural reserve maps and power line maps have been collected as GIS data for this survey.

Remote sensing data were collected in the first year study. These data are mentioned in chapter II-5-1. The topographic maps, geological maps and magnetic interpretation maps used are listed below.

1. Topographic Map

   Scale of 1:50,000

   1. Arusha and Manyara Block

      QDS 27/4, 28/3, 39/2, 40/1, 51/4, 52/3, 53/3, 53/4, 67/2, 68/1, 69/1, 69/2, 84/4.

   2. Dodoma and Singida Block

      QDS 104/4, 105/3, 105/4, 121/1, 123/1, 123/3, 127/1, 141/2, 141/4, 142/1, 142/2, 142/3, 143/1.

   3. Mbeya Block

      QDS 244/3, 244/4, 259/4, 272/1, 272/2, 272/3, 272/4.

2. Geological Map
   Scale of 1:1,250,000
   Sheet No. QDS 27, 28, 39, 40, 51, 52, 67, 68, 69, 84, 104, 105, 121, 123, 127, 141, 142, 201, 219, 221, 239, 244, 259, 272.

3. Magnetic Interpretation Map
   Ministry of Minerals, Airborne Magnetic Survey, Magnetic Interpretation Map
   Scale 1:100,000.
   Sheet No.27, No.28, No.39, No.40, No.51, No.52, No.67, No.68, No.69, No.84, No.104, No.105, No.121, No.123, No.127, No.141, No.142, No.201, No.244, No.219, No.221, No.239.

II-5-6 Selection of Promising Areas

In order to identify promising geothermal areas, a 'score-sum' method, which is generally used to the primary stage of geothermal survey, is applied to each surveyed site on the basis of the field survey results (Table II-14 and Table II-15). This identification method follows a simple addition formula, and offers a precise total score to evaluate the field objectively. 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 possibly 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 geothermal system in the volcanic area. Promising geothermal area often locates around the volcano, though it depends on the scale of the volcano (activity of magma). Existence of the volcanic rocks formed by volcanic activity shows the existence of volcanic activity. But, if the distributing volcanic rocks are older than Quaternary, magma maybe already cold. Therefore, it's important whether the volcanic rocks are Quaternary or not. Furthermore, if the volcano is too young, geothermal system may not be matured. Based on the existence of Quaternary volcanic rocks, it was tentatively weighting as follows.

    Distribution of Quaternary volcanic rocks: weight 6

Within 10km far from Quaternary volcanic rocks: weight 4

Over 10km far from Quaternary volcanic rocks: weight 2

- ◻ Permeable zone : Faults and/or lineaments

In many geothermal areas, high permeable zone along the fault is in the major path of geothermal fluid. From this, existence of large-scale fault is an indicator of geological structure for the path of the geothermal fluid. Further, it is expected that water permeability is high portions plural faults intersect. Thus, it was tentatively weighting as follows on the basis of the existence of fault and lineaments.

Large fault and/or intersection of faults: weight 6

Fault and/or lineament: weight 4

No structure: weight 2

- ◻ Cap rock formation

In the most geothermal areas, cap rock are formed between the geothermal reservoir and low temperature shallow groundwater, which prevent reservoir cooling caused by the inflow of shallow groundwater. In general, argillated rocks formed by hydrothermal alteration in the deep portion turn to the cap rock in many cases. However, the data is not enough to estimate the underground condition at this stage. But, there is a possibility that low permeable rock such as lava plays an important role to seal the geothermal reservoir from shallow groundwater. Thus, it was tentatively weighting as follows on the basis of the existence of the formation as may be cap rock.

Existence of lava: weight 6

Existence of overburden: weight 4

No seal: weight 2

- ➢ Hot spring features

- ◻ Fumaroles

Existence of fumaroles with boiling point or higher temperature always shows an important indicator of high temperature geothermal reservoir under the ground. Thus, it was tentatively weighting as follows on the basis of the existence of fumaroles.

Existence of fumaroles: weight 10

No fumaroles: weight: 0

- ◻ Hot spring temperature

Hot spring temperature also possibly shows high temperature geothermal reservoir under the ground. It was tentatively weighting as follows considering the possibility of development of the binary plant.

Hot spring temperature is not lower than 80^{o}C: weight 8

Hot spring temperature is lower than 80^{o}C and not lower than 60^{o}C: weight 4

Hot spring temperature is lower than 60^{o}C: weight 1

- ◻ Estimated reservoir temperature (fluid geothermometry)

It was tentatively weighting as follows on the basis of estimated reservoir temperature (fluid geothermometry).

Estimated reservoir temperature (fluid geothermometry) is not lower than 200^{o}C: weight 10 (There is a possibility for flush type generation)

Estimated reservoir temperature (fluid geothermometry) is lower than 200^{o}C and not lower than 170^{o}C: weight 8

Estimated reservoir temperature (fluid geothermometry) is lower than 170^{o}C and not lower than 140^{o}C: weight 6

Estimated reservoir temperature (fluid geothermometry) is lower than 140^{o}C and not lower than 100^{o}C: weight 4

Estimated reservoir temperature (fluid geothermometry) is lower than 100^{o}C: weight 1

- □ Surface extent

  Surface extent of geothermal manifestation sometime reflects the spread of geothermal activity. It was tentatively weighting as follows.

  Extent on the surface is exceeding 0.01 km^2: weight 2

  Extent on the surface is not exceeding 0.01 km^2: weight 1

- □ Composition of a Deep reservoir

  Chemical composition of hot spring water (such as the major anion composition, for example) shows the possibility of mixing of deep high temperature geothermal fluid. It was tentatively weighting 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 denied: weight 1

In addition, since there is no geothermal field that reached to power plant construction in Tanzania, it's impossible to verify which indicator is suitable for extracting the promising area. In the above, therefore, weighting was tentatively set based on the experience of geothermal development in Japan. It's necessary to verify the validity of the indicator and weighting described above in the future when geothermal development in Tanzania has somehow accumulated. And there is also a possibility of obtaining a new data showing promise in some future research, because only representative geothermal fields were studied in this survey. Therefore, above evaluation is desired to be updated in the future based on the geothermal survey.

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

The following criteria were used for the evaluation.

- ➢ Natural reserves : National park

  The development in the environmentally protected area such as national parks and game reserves will have certain difficulty to overcome the environmental regulations. It was tentatively weighting as follows.

  No reserve: weight 10

  Game reserve: weight 4

  National parks and/or conservation: weight 1

- Power line : Distance from the site

  If the geothermal development field is far from the power line, new power line should be constructed and it will have certain difficulty. So, it was tentatively weighting as follows.

  Power line locates <= 5 km: weight 4

  Power line locates 5 – 10 km: weight 2

  Power line locates > 10 km: weight 1

- Concessions

  If the geothermal development field is already covered with concession of private sector, it will cause certain difficulty for Tanzanian government to develop. So, it was tentatively weighting as follows.

  No concession: weight 8

  Other land uses: weight 4

  Already established: weight 1

- Population

  Distance from the big power consumption area to geothermal development field, have a certain influence on the priority of development. So, it was tentatively weighting as follows.

  Large city (capital of the state or following): weight 3

  Town or village (smaller than the above): weight 2

  Remote area: weight 1

- Social acceptance

  If there is social opposition to geothermal development, it will cause certain difficulty for the development. So, it was tentatively weighting 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 cause certain difficulty for the development. So, it was tentatively weighting as follows.

  Access road locates <= 1 km: weight 3

  Access road locates 1 – 3 km: weight 2

  Access road locates > 3 km: weight 1

The results from the first step determined the selection as promising fields of fields with over 25 points (although the prospectivity of fields with less than 25 points is not ruled out.)

The following fields were selected.

- Lake Natron (32 pts)
- Lake Manyara (28 pts)
- Songwe - Ilatile - Rambo (36 pts)
- Kilambo (30 pts)

- Kisaki (28 pts)
- Nyongoni (29 pts)

When the points for environmental aspects were added in the second step to the fields determined to be promising in the first step, the following fields achieved a score above 50 points.

- Songwe - Ilatile - Rambo (59 pts)
- Nyongoni (52 pts)

Songwe - Ilatile - Rambo, which had high scores in the resource aspects of the first step, also showed high scores in total after the environmental aspects were factored in in the second step. Therefore, Songwe - Ilatile - Rambo are judged to be as the most promising fields among those considered in this survey.

Table II-14 Geothermal resource evaluation of surveyed areas

Category	Item	Criteria	Point	Score: Northern area: Lake Natron Na01,02	Northern area: Lake Manyara Mn01,02	Northern area: Lake Eyasi Ey01,02,03	Northern area: Ngorongoro Crater Ng01,02,03	Northern area: Masware Ba01	Northern area: Balangida lalu Ha01	Northern area: Singida Southeast Ms01,Ta01, Mp01,02	Northern area: Kondoa Ko01	Mbeya area: Songwe Ilatile Rambo So01,Il01, Ra01	Mbeya area: Kilambo Ki01,02	Mbeya area: Mampulo Kasimulu Ma01,Ka01	Rufiji area: Kisaki Ks01	Rufiji area: Utete Ut01	Rufiji area: Nyongoni (Ruhoi Riv.) Ny01
Geological aspects	Heat source	Distribution of Quaternary volcanic rocks Within 10 km far from volcanic rocks Over 10 km far from volcanic rocks	6 4 2	6	4	4	6	4	4	2	2	6	6	4	2	2	2
	Structure	Large fault and/or intersection of faults Fault and/or lineamet No structure	6 4 2	6	6	4	2	6	6	6	2	6	4	4	6	4	6
	Seal	Lava Overburden No seal	6 4 2	4	4	4	6	4	4	4	4	6	6	4	4	4	4
Hot spring features	Fumarole	Existence of fumarole	10	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	4	4	1	4	1	1	4	1	4	4	1	4	1	4
	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	8	6	4	1	4	(1)	1	1	10	6	8	8	6	8
	Extent on the surface	Exceeding 0.01 km^2 Not exceeding 0.01 km^2	2 1	2	2	2	1	1	1	2	1	2	2	1	2	2	2
	Composition	Deep Intermediate Shallow	3 2 1	2	2	2	1	2	(2)	2	2	2	2	2	2	2	3
Subtotal score in 1st step				32	28	21	21	22	(19)	21	13	36	30	24	28	21	29
Remarks							ground-water flow from outer rim					large amount of $CaCO_3$ sinter				fissure	spring alignment

Footnote: Area size is approximately 5 km in diameter centered each hot spring sampling point.
( ) : guessed from nearby field because not analysed

(Study team)

Table II-15 Social and environmental evaluation of surveyed areas

Category	Item	Criteria	Point	Score													
				Northern area								Mbeya area			Rufiji area		
				Lake Natron Na01,02	Lake Manyara Mn01,02	Lake Eyasi Ey01,02,03	Ngorongoro Crater Ng01,02,03	Masware Ba01	Balangida lalu Ha01	Singida Southeast Ms01,Ta01, Mp01,02	Kondoa Ko01	Songwe Ilatile Rambo So01,Il01, Ra01	Kilambo Ki01,02	Mampulo Kasimulu Ma01,Ka01	Kisaki Ks01	Utete Ut01	Nyongoni (Ruhoi Riv.) Ny01
Environmental aspect	Natural reserves	No reserve Game reserves Natural parks and/or Conservation	10 4 1	1	1	10	1	10	10	10	10	10	10	10	4	10	10
Engineering aspect	Power line	<= 5 km 5-10 km >=10 km	4 2 1	1	1	1	2	2	1	1	4	1	2	4	1	1	1
Socio-economic aspects	Concession	None Other landuses Already established	8 4 1	8	8	8	8	8	8	8	8	8	1	8	8	8	8
	Population	Close to large city Close to town or village Remote area	3 2 1	1	2	2	2	2	1	1	3	1	2	3	2	2	1
	Social acceptance	Yes Yes or No No	3 2 1	2	2	2	2	2	2	2	3	2	2	2	2	2	2
Others	Accessibility	<= 1 km 1-3 km >= 3 km	3 2 1	2	2	2	2	1	1	1	3	1	2	2	1	2	1
Subtotal score in 2nd step				15	16	25	17	25	23	23	31	23	19	29	18	25	23
Subtotal score from 1st step				32	28	21	21	22	19	21	13	36	30	24	28	21	29
Total score				47	44	46	38	47	42	44	44	59	49	53	46	46	52
Remarks				Ramsar	National Park		Conserva-tion						Concession				

Footnote: Area size is approximately 5 km in diameter centered each hot spring sampling point.

(Study team)

II-5-7 Estimation of the Geothermal Resource Potential

The volumetric method for estimating the 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. he distribution of parameters involved may include values that are not precisely known but can be part of the probability distribution. As a probability distribution, triangular distribution or quadrilateral distribution (see Fig. II-44) is usually applied on this estimation.

Reservoir Volume

The thickness of each field is assumed to be as follows: the minimum is 1,800m, the most likely is 2,000m and the maximum is 2,200m by triangular uncertainty distribution. The assumed maximum and minimum area of a given field can be estimated by rectangular uncertainty distribution 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

Minimum, most likely and maximum values for reservoir temperature are estimated by geothermometry. Basically, the minimum temperature is the alkaline (Na-K-Ca) geothermometer value, and the most likely and maximum temperatures are established by adding 20 and 40 ºC, respectively, to the minimum value by triangular uncertainty distribution.

Abandonment temperature is assumed to be 80 ºC constant for a binary type installation. (Generally, it is 180 ºC for a flash type installation).

Rock Density

2,400kg/m^3, 2,500kg/m^3 and 2,600kg/m^3 are assumed, respectively, as a minimum, most likely and maximum density for the areas of Cenozoic formation by triangular uncertainty distribution. 2,600kg/m^3 and 3,000kg/m^3 are the assumed minimum and maximum for areas whose formation antedates the Mesozoic by rectangular uncertainty distribution.

Rock Specific Heat

The rock specific heat is assumed to range from 0.7 to 1.0 kJ/kg- ºC based on the general value of rock by rectangular uncertainty distribution.

Porosity

5% and 10% are assumed as minimum and maximum values for areas of Cenozoic formation. 1% and 5% are assumed as minimum and maximum values for areas whose formation antedates the Mesozoic.

Fluid Density and Specific Heat

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

Recovery Factor

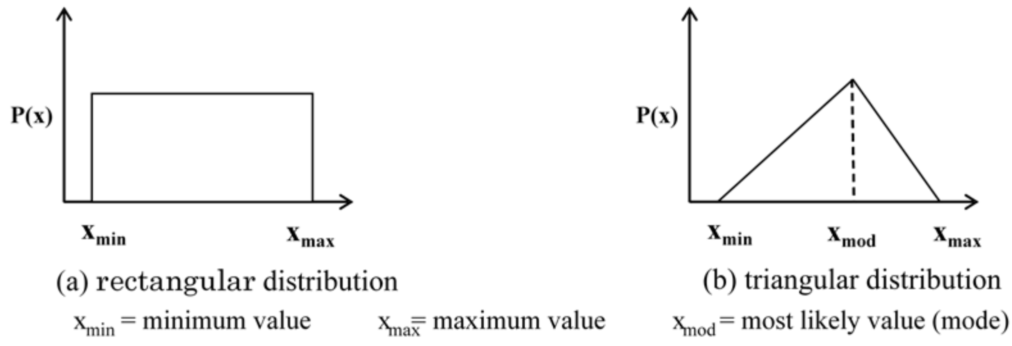
In general, the recovery factor is assumed to be 2.5 times the porosity value from rectangular uncertainty distribution. Thus, the recovery factor ranges from 2.5% to 12.5%.

Conversion Efficiency

Minimum, most likely and maximum values of conversion efficiency are assumed to be 1.9%, 6.3% and 11.4% for a binary type installation by triangular uncertainty distribution (whereas 12% is assumed as a minimum and 14% as a maximum for a general flash type installation).

Plant Life and Load Factor

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



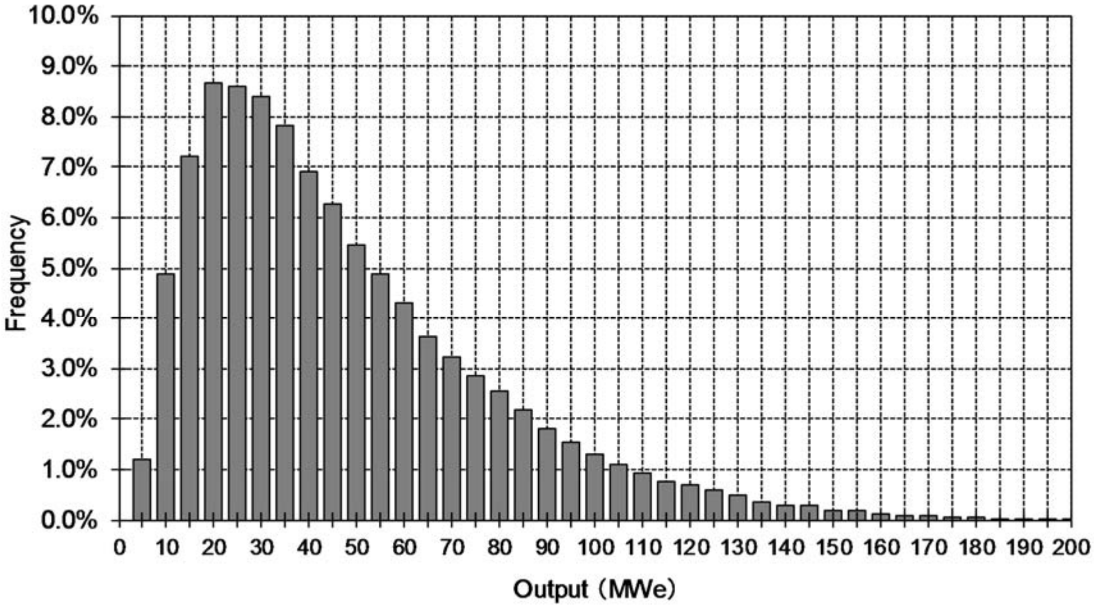
(Study team)

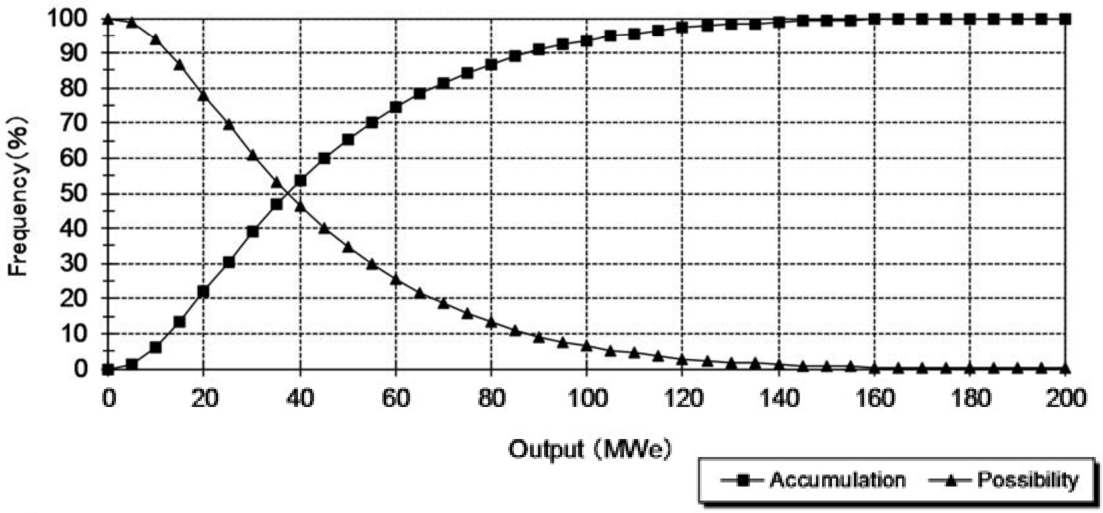
Fig. II-44 Assumed Probability Distribution

An example of input parameters and the results of the geothermal resource potential calculation (for Lake Natron) are shown in Fig. II-45. The results show that Lake Natron has an 80% probability of having a geothermal resource potential of 21MW. The total of these values for individual fields is 359MW

(Table II-16). Subsequently, Ngorongoro was eliminated because its temperature was lower than 80 ^{o}C, which is the abandonment temperature.

Results of the calculations are shown in Appendix-7. The total resource potential of all areas is 359MW (Table II-16). The reservoir temperature of Ngozi in Mbeya will be over 230 ^{o}C based on the geothermometry from the data from BGR (2008). So, if the resource potential of Songwe is assumed to be the same as Songwe, then the total resource potential is rises to 465MW. Moreover, if Mitagata, Maji Moto, Ukindu, Njoronori, Bombo, Amboni, Usangori, Daraja ya Mungu, Ivuna, Mapu, Bulongwe and Kabango are assumed to be the same as Masware, then the total geothermal potential of the whole Tanzania is about 678MW. This estimation of the geothermal potential in Tanzania is close to 650MW, which is the current assumption (Table II-16).





Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	6.00	-	24.00
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	-

(Study team)

Fig. II-45 Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis

Table II-16 Results of geothermal resource potential calculation

	Field	Estimated (MW)	Remarks
Surveyed areas	Lake Natron	21	Assuming binary system plant
	Lake Manyara	15	Assuming binary system plant
	Lake Eyasi	15	Assuming binary system plant
	Masware	18	Assuming binary system plant
	Singida Southeast	23	Assuming binary system plant
	Songwe, Ilatile, Rambo	106	Assuming binary system plant
	Kilambo	36	Assuming binary system plant
	Mampulo	39	Assuming binary system plant
	Kisaki	29	Assuming binary system plant
	Utete	24	Assuming binary system plant
	Nyongoni	31	Assuming binary system plant
	Total	359	Assuming binary system plant

(Study team)

II-6 Environmental and Social Considerations

According to the Energy Policy 2003, (Ministry of Energy and Minerals, 2003) the Government of Tanzania promotes Environmental Impact Assessment (EIA) as a requirement for all energy projects.

The National Environmental Management Council (NEMC) under the Division of Environment (DOE), was established based on the National Environmental Management Act (2004), and is in charge of enforcement of environmental legislations and of EIA approval. DOE was established in 1994 under the Ministry of Natural Resources and Tourism and was placed under the Vice-President's Office in 1994 to enable it to play an inter-ministerial role. The main roles of DOE are to prepare government policy on environmental conservation and to provide guidance and guidelines to the relevant organizations. DOE has establish Regional Offices. Most of the local governmental offices have an Environment Officers. NEMC has Zone Offices spread throughout the country.

EIA guidelines were issued in 2005 based on the National Environmental Act of 2004. There is no plan to revise them at this stage. In addition, although there are no sectoral guidelines, there are sectoral checklists.

The period required for the EIA approval process must not exceed 3 months from submission of an EIA report to NEMC from the project proponent to the issue of a decision. The cost of the EIA approval process varies depending on the number of Technical Committee members required (10 - 12 on average). Only local entrepreneurs who are registered with NEMC can conduct EIA studies. When a foreign firm jointly conducts an EIA study with a local firm, a levy of 200,000 Tanzanian shillings must be paid to NEMC.

The EIA for a development project located in an environmentally protected area, Tanzania National Parks (TANAPA), the Tanzania Wildlife Research Institute and Tanzania Forest Research Institute under the Ministry of Natural Resources and Tourism (MNRT) have to be involved. Management of the environmentally protected areas varies based on the nature of the protected area. The Fishery Dept. is responsible for Marine Protected Areas, the Division of Nature (MNRT) handles Nature Protected Area, and the Division of Forestry (MNRT) deals with Forest Protected Areas.

It is a requirement that a summary of the EIA report in English and Swahili be opened to the public before the public hearing. EIS summaries are mainly disseminated by NEMC offices, District offices, and Project offices. Up-on request, the full EIA report may be consulted. The period and frequency of environmental monitoring are determined on the basis of the project characteristics. Public consultation under EIA procedure means consultation with project-affected persons. According to DOE, though consultation is supposed to be conducted once after the EIA review, additional consultations can be conducted in the timing of EIA scoping process as per the JICA environmental guidelines.

The EIA approval process consists of the following steps; 1) project proponent applies for EIA with submission of an EIS report, 2) NEMC advises DOE based on its review, 3) DOE reviews the application, and 4) The Minister of State grants (or refuses) EIA approval.

Although EIA approval for small-scale development project is supposed to be in the hands of local government, local capacity for EIA review is insufficient at present. There have been cases where the local people have objected to a project after the EIA approval was granted. In such cases, DOE advises the project proponent to ensure adequate communication with the local people as much as possible in order to create the buy-in. Based on local experience, the local people oppose projects in which it has not been made very clear how the project will affect them and what benefits will arise both locally and nationally. Local people hate to be taken for granted.

Land acquisition and resettlement is under the jurisdiction of the Ministry of Land and Human Settlement Development. The land acquisition process is enforced based on the Land Act. Whereas the government can allocate land for national projects, the private land is dealt with on willing-buyer-willing-seller basis. There are many active environmental NGOs in Tanzania who work in cooperation with DOE. However, NGOs require to be registered in order to operate.

In moving forward, SREP project is expected to drive the geothermal development in Tanzania. In this regard SREP expect that Social Management Framework (ESMF) will be prepared that defines the environmental and social planning, review and clearing processes that follow national and donor guidelines. These include:

- **Resettlement Policy Framework (RPF).** A Resettlement Policy Framework will establish the modalities for conducting resettlement action plans (RAPs). The framework will outline components which must be integrated into RAPs, such as legal frameworks, eligibility criteria, the methodology for asset valuations, mechanisms for stakeholder consultations, etc.
- **Detailed E&S Studies.** For each of the components that will be realized under the SREP, separate and comprehensive environmental and social assessments must be undertaken. These assessments must include detailed studies aimed at uncovering the specific environmental and social impacts for each of the subprojects. The detailed E&S studies include an Environmental and Social Impact Assessment (ESIA), an Environmental and Social Management Plan (ESMP) and a Full RAP.

- **Responsibilities.** Project operators will be responsible for compliance with national law and regulations and the donors' E&S policies, guidelines and standards. These operators are also responsible for preparing the required detailed E&S studies (ESIA, ESMP, RAP, etc.), obtaining clearances, implementing all required mitigation and monitoring measures; conducting monitoring activities; providing adequate budgets to sustain mitigation and monitoring activities; and compliance with any directives issued by relevant parties.
- **Stakeholder Consultations**. The ESMF contains detailed checklists and generic mitigation measures to ensure that the potential impacts are addressed in environmental and social assessments and management plans. In preparing the required detailed E&S studies (ESIA, ESMP, RAP, etc.), the operators are required to adhere to the requirements for ensuring participatory stakeholder consultations that are captured in the donors' E&S policies, guidelines and standards. Projects affecting people and other critical stakeholders must be informed and consulted about the nature, timing and scope of the relevant project impacts and the mitigation measures. Participatory approaches must be utilized in organizing and conducting the consultations. Gender considerations must also be factored in.
- **Approval**. The detailed E&S studies must be submitted to NEMC for review and approval based on Tanzanian laws and regulations and to the donors for review and approval based on their respective E&S policies, guidelines and standards. NEMC will be responsible for the review and clearance of ESIAs and ESMPs. NEMC provides a one-stop clearance process by involving all other key governmental agencies in the approval process.

As a part of this survey, field works were conducted at Lake Natron (Ramsar Site), Ngorongoro crater (Ngorongoro Conservation Area) and Lake Manyara (National Park). According to MNRT, the only possibility of the geothermal development in those protected areas (please refer II-5-1 6. "Information about Natural Reserves"), will only be at the Lake Natron. This is because any development in National Parks and Conservation Areas is prohibited except for strategic minerals (oil and gas) according to the current law. Even at the Lake Natron, any power plant will require to be located outside the area and connected to the production wells by long steam pipelines. However, it is believed that based on well prepared ESIA, and considering experiences from Olkaria in Kenya, justifications could be made for developments.

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III Proposal of Future Assistance Plan

III-1 Characteristics 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.

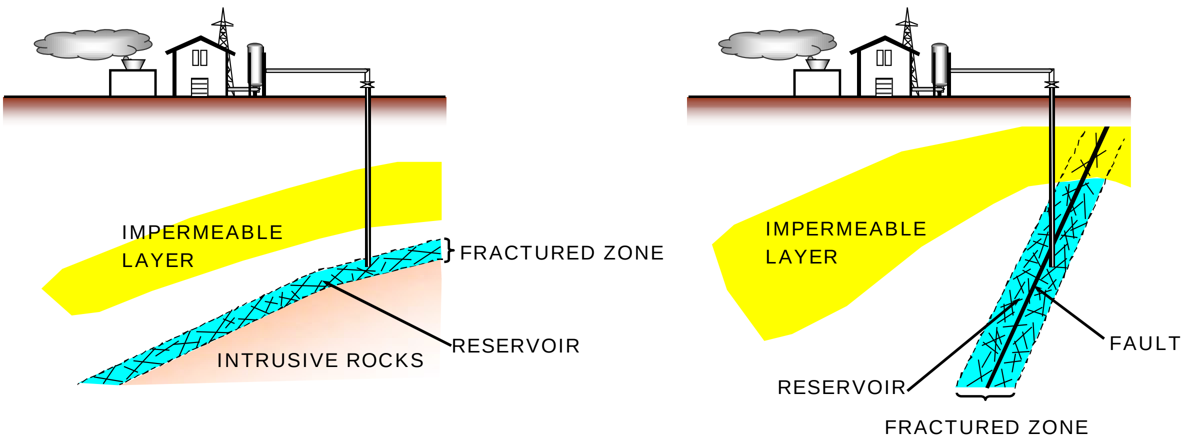
For successful geothermal development and geothermal well drilling, geological and geothermal structures should be clarified mainly through the use of geological and geophysical techniques. Delineation of geothermal reservoirs based on the surface survey results is vital work for estimating the distribution 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.

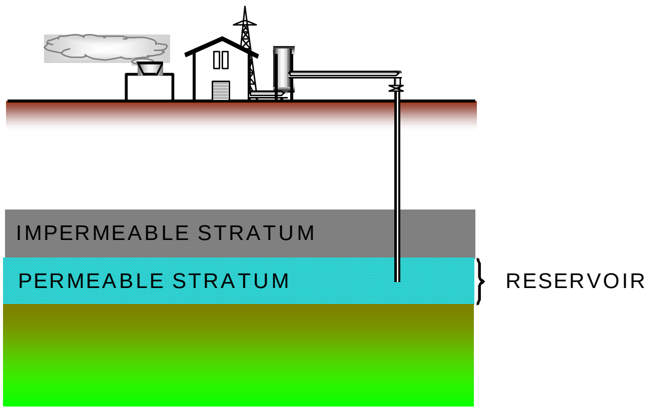
The chemical characteristics of the geothermal fluids are controlled by water-rock interactions under high temperature conditions and/or chemical reaction with gases such as H_2S, CO_2 etc. These chemical components provide vital clues for assessing the reservoir characteristics, its temperature, and 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

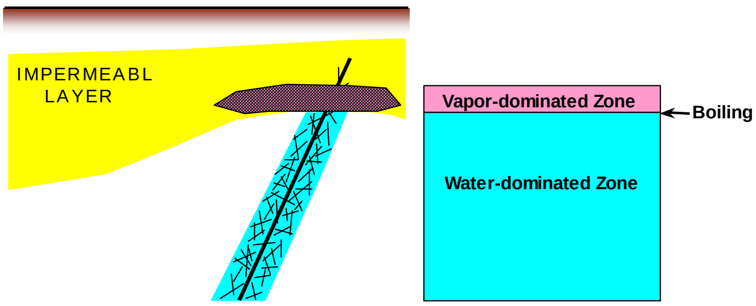
(Study team)

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.

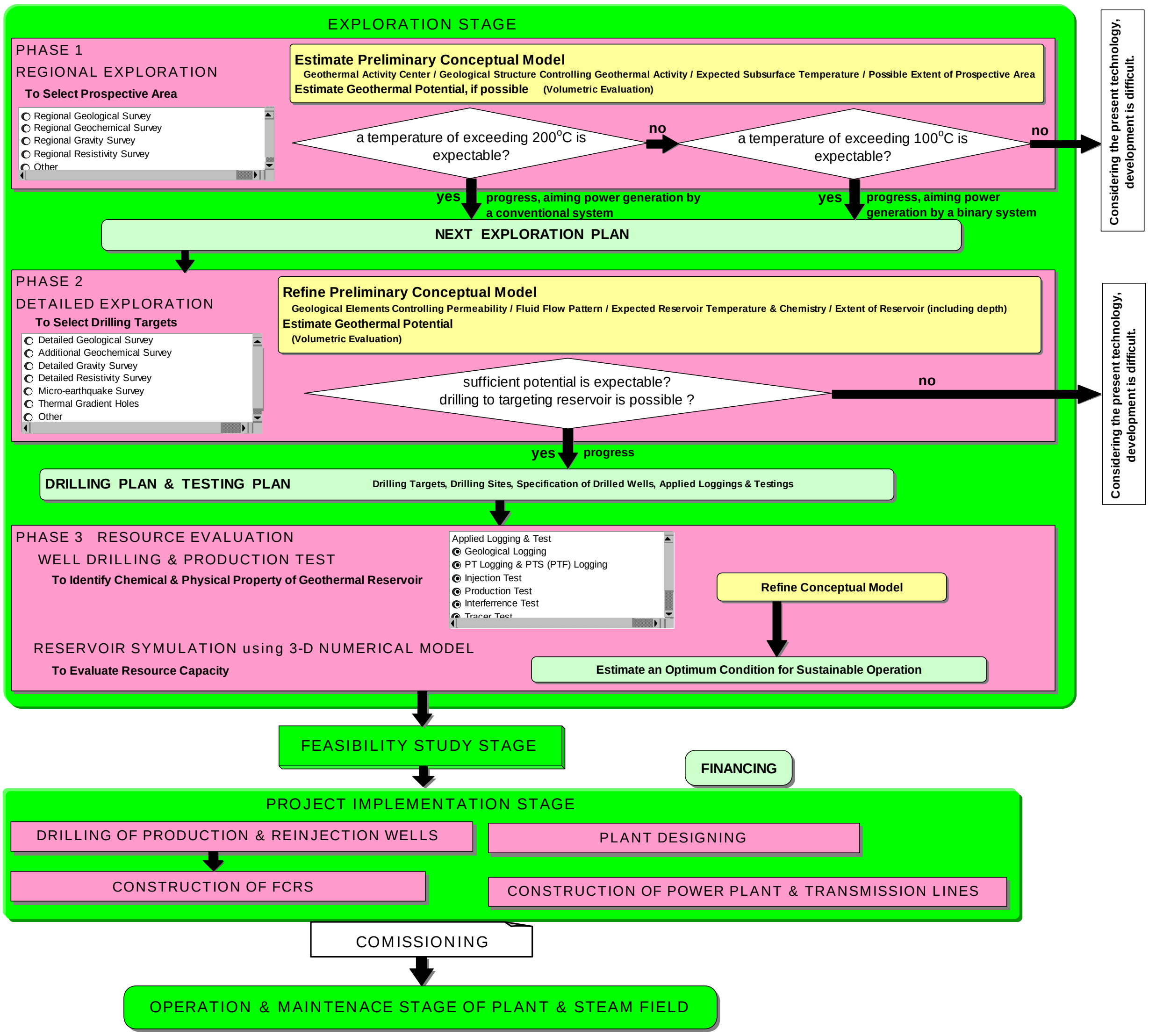
Therefore, a variety of exploration technologies must be applied in order to prepare an adequate model for geothermal development. However, the best combination of technologies to be applied depends on the particular field, as an objective field has unique geothermal resource characteristics and surrounding 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. With the exception of areas such as Ngozi, Songwe - Ilatile - Rambo (which are in the early stages of Phase 3 or Phase 2), most geothermal areas in Tanzania 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

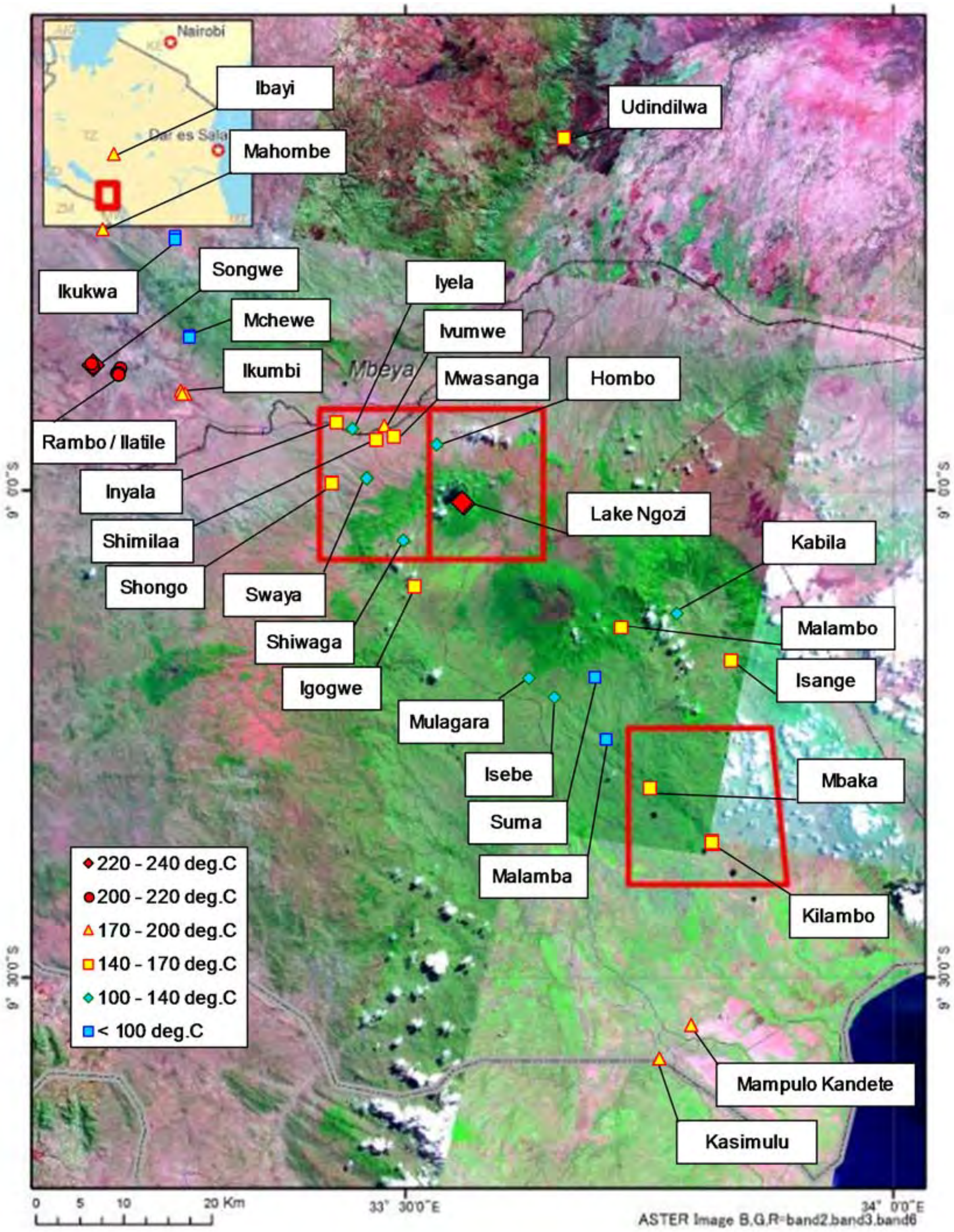
				1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year
Exploration Stage	Selection of consultant											
	Phase 1	Regional Survey										
	Phase 2	Detailed Survey										
	Phase 3	Well Drilling and Testing	Topographical survey									
			Drilling contractor selection									
			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？

(Study team)

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

AfDB is planning a detailed survey for the selection of fields to be conducted after this survey. This survey is expected to assist further promotion of geothermal development in Tanzania. High temperatures are expected at Ngozi, which was eliminated from this field survey, but the concession there has been granted to GPT (the concession areas are shown as red rectangles in Fig. III-5. Therefore, it is recommended to conduct detailed surveying at Songwe - Ilatile - Rambo, which were determined to be the most promising areas in this survey. The information about this area is shown in Table III-1. A geophysical survey (MT survey) to be carried out by AfDB as a Phase 2 survey (Detailed survey) is recommended for geological structure investigation and selection of drilling targets. Basically, an MT survey with a 300 to 500 m interval between measuring points is desirable (1 km is acceptable on the outer edges of the survey area). The costs for this survey will be US$3,500/point for the field work and US$60,000 for analysis (of 80 points). In total, US$340,000 (for 80 points) is thought to be necessary.



(Modified from BGR data)

Fig. III-5 Distribution of Na-K-Ca geothermometers around Mbeya

Table III-2 Information about geothermal promising area

<table>
<tr><td>1</td><td colspan="2">Country</td><td>Tanzania</td></tr>
<tr><td>2</td><td colspan="2">Geothermal field name</td><td>Mbeya site</td></tr>
<tr><td>3</td><td colspan="2">Area name (hot spring name)</td><td>Songwe-Ilatile-Rambo</td></tr>
<tr><td>4</td><td colspan="2">Local government name</td><td>Mbeya</td></tr>
<tr><td>5</td><td colspan="2">Location/access</td><td>30km west of Mbeya city, 10km NW from Songwe airport</td></tr>
<tr><td rowspan="2">6</td><td colspan="2">Survey/Development status</td><td>Surface survey (Geology and geochemistry)</td></tr>
<tr><td></td><td>Stage</td><td>Phase1 (Table III-1)</td></tr>
<tr><td rowspan="9">7</td><td colspan="2">Information about geothermal resource</td><td></td></tr>
<tr><td colspan="2">1) Geology/Structure</td><td>The basement consists of Cretaceous sedimentary rocks, travertine covers the surface of few square kilometers. Quaternary volcanic rocks are widely distributed near the field.</td></tr>
<tr><td rowspan="2">2) Geochemical</td><td>Temperature, chemical properties</td><td>Hot spring temperature (ºC)
<table>
<tr><td></td><td>Songwe</td><td>Ilatile</td><td>Rambo</td></tr>
<tr><td>Previous data</td><td>74</td><td>65-80</td><td>86</td></tr>
<tr><td>This survey</td><td>74.8</td><td>54.1</td><td>79.2</td></tr>
</table>
pH7.0, Electrical conductivity 728mS/m, HCO_3 type (this survey)</td></tr>
<tr><td>Geothermometry</td><td>215 ºC（Na-K-Ca temperature）</td></tr>
<tr><td colspan="2">3) Geophysical survey</td><td>Not yet</td></tr>
<tr><td colspan="2">4) Well Drilling</td><td>Not yet</td></tr>
<tr><td colspan="2">5) Geothermal structure model</td><td>According to BGR, geothermal fluid is flowing out from Ngozi volcano, but restructuring is necessary based on the additional survey.</td></tr>
<tr><td colspan="2">6) Geothermal resource potential</td><td>Estimated 106 MW (Assuming binary system plant)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="6">8</td><td colspan="2">Social environment</td><td></td></tr>
<tr><td colspan="2">1) Environmental constrains/National park</td><td>None</td></tr>
<tr><td rowspan="4">2) Infrastructure, etc.</td><td>Transmission line/electrification</td><td>More than 10 km from existing major transmission line</td></tr>
<tr><td>Road/Land use</td><td>Unpaved road (10 km from main road)/forest</td></tr>
<tr><td>Population density/Distance from house</td><td>Only several houses in the forest</td></tr>
<tr><td>Industry</td><td>About 30km from Mbeya city</td></tr>
<tr><td>9</td><td colspan="2">Survey problems</td><td>Construction of access road</td></tr>
<tr><td>10</td><td colspan="2">Proposing geothermal survey</td><td>MT survey, well drilling (To be held by AfDB)</td></tr>
<tr><td>11</td><td colspan="2">Field survey</td><td>August 25th, 2013</td></tr>
<tr><td>12</td><td colspan="2">Remarks</td><td></td></tr>
</table>

(Study team)

In Tanzania, considering of the lack of experience in geothermal development, government-led surveys corresponding to Phase 1 and Phase 2 are very much desired to promote geothermal development in this country. By reducing development risk, these will facilitate the participation in geothermal development projects by the private sector, leading to an anticipated overall promotion of geothermal development in the country. 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 Tanzania suffers from a serious lack of knowledge regarding geothermal development. Considering the present situation of Tanzania, the following projects are listed up here as possible JICA projects.

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

Project No.	2		
Project Name	Training Support in UNU-GTP (6 months training)		
Project Outline	To provide financing together with UNU-GTP to admit engineers from each country to UNU-GTP for 6 months. Training in UNU-GTP of Iceland is playing a big role in developing skilled engineers not only in Africa, but around the world. The UNU-GTP is planning to expand its training capacity from the current level of 20 trainees to 30 trainees. However, financial support from Icelandic government is limited. Therefore, JICA is expected to support this expansion. (Cost USD 40,000 per trainee; 5 trainees from Africa every year for 5 years)		
Beneficiary	United Nations University (and/or each country)		
Scheme	Technical assistance, Contribution to UN etc.	Category	Technical capacity
Project Scale	Approx. 5 years Approx. USD 1 million		
Remarks	Coordination with UNU and the Icelandic government is needed.		

Reference

BGR (2008) Geothermal Energy as an Alternative source of Energy for Tanzania.

Chandrasekharam, D. and Chandrasekhar, V (2012) Clean Development Mechanism through Geothermal: Ethiopian Scenario. Proceedings of the 4th African Rift Geothermal Conference 2012 Nairobi, Kenya

DECON, SWECO and Inter-Consult (2005) Tanzania Rural Electricity Study -Technical Report on geothermal power Activity 1.4.1

Delvaukx, D., Kraml, M., Sierralta, M., Wittenberg, A., Mayalla, J.W., Kabaka, K., Makene, C. and GEOTHERM working group (2010) Surface exploration of a viable geothermal resource in Mbeya area, SW Tanzania, Part I: Geology of the Ngozi-Songwe geothermal system, Proceedings world geothermal congress 2010.

Fujii, T. (2010) Petroleum exploration in East African Rift basin, Analysis (Japanese).

Geological map of Tanzania, Scale 1:1,250,000.

QDS 27, 28, 39, 40, 51, 52, 67, 68, 69, 84, 104, 105, 121, 123, 127, 141, 142, 201, 219, 221, 239, 244, 259, 272.

Hamlin, T. and Fikre, A. (2004) The African rift geothermal energy development facility (ARGeo), Renewable energy conference.

Hochstein, M.P., Temu, E.P., and Moshy, C.M.A (2000) Geothermal resources of Tanzania, Proceedings world geothermal congress 2000.

JICA (2010) Situation Analysis Study on Geothermal Development in Africa.

JOGMEC (2006) Investigation of investment environment of Tanzania, JOGMEC report.

Kraml M., Kreuter, H. and Robertson, G. (2012) Small scale Rural Electrification and Direct Use of low temperature Geothermal Resources at Mbaka. Proceedings of the 4th African Rift Geothermal conference, Nairobi Kenya 21-23 November 2012.

Kimbara, K. (1992) Geothermal resources in the African Great Rift Valley and its environs, Geothermal energy (Japanese).

McNitt, J.R. (1982): The Geothermal Potential of East Africa. UNESCO/USAID Geothermal Seminar, Nairobi, Kenya, June 15-21, p. 1-9.

Mgejwa, N. (2012) Geothermal energy: A possible source to Light Majimoto Community, Serengeti district, Tanzania, Proceedings of the 4th African rift geothermal conference.

Ministry of Energy and Minerals (2013) Executive Summary of Power System Master Plan 2012 update.

Ministry of Energy and Minerals (2013) Scaling-up Renewable Energy Programme (SREP). Investment Plan for Tanzania, April 2004.

Ministry of Energy and Minerals (2012) Assessment of Drilling sites for geothermal Temperature gradient wells at Lake Ngozi-Songwe Geothermal field, Mbeya –South Western Tanzania. Field Report by the Geothermal Working Group.

Ministry of Energy and Minerals (2003) The National Energy Policy of Tanzania, 2003. A document by Ministry of Energy and Minerals.

Ministry of Energy and Minerals, Airborne Magnetic Survey, Magnetic Interpretation Map, Scale

1:100,000.

Ministry of Energy and Minerals, Geological map of Tanzania, Scale 1:1,250,000.

Ministry of Energy and Minerals, Topographic Map, Scale 1:50,000.

Mnjokava, T.T. (2007) Interpretation of exploration geochemical data for geothermal fluids from the geothermal field of the Rungwe volcanic area, SW-Tanzania, Geothermal training programme.

Mnjokava, T.T. (2008) Geothermal exploration in Tanzania - Status report, presented at short course III on exploration for geothermal resources.

Mnjokava, T.T. (2012) Geothermal development in Tanzania – A country update, Proceedings of the 4th African rift geothermal conference.

Mnzava, L.J., Mayo A. W. and Katima J. H. Y. (2008) Geothermal surface manifestation mapping in south-western Tanzania, ARGeoC2.2008 Entebbe-Uganda.

Muhwezi, D.K. (2009) The potential relationship of some geothermal fields in Uganda, Geothermal training programme.

Mwangi, N.J. (2010) The African rift geothermal facility (ARGEO)-Status, Presented at short course V on exploration for geothermal resources.

Ochmann N., Chiragwile S. A. and Mjokava T. T. (2012) TEM and MT surface exploration at the Ngozi geothermal prospect, Tanzania, Proceedings of the 4th African rift geothermal conference.

Omenda, P.A. (2005) The geology and geothermal activity of the east African rift system, Presented at Workshop for decision makers on geothermal projects and management.

Omenda, P.A. (2007) The geothermal activity of the east African rift, Presented at short course II on surface exploration for geothermal resources.

Omenda, P.A. (2010) The Geology and Geothermal Activity of the East African Rift, Short Course V on Exploration for Geothermal Resources, Kenya

Omenda, P.A. (2010) The geology and geothermal activity of the east African rift, Presented at short course V on exploration for geothermal resources.

Schluter, T. (1997) Geology of east Africa, Gebruder Bornetraeger/Berlin/Stuttgart, Independent book.

TANAPA Website http://www.tanzaniaparks.com/

Telkemariam, M. (2010) Barriers for development of geothermal resource in countries of the EARS: Overcoming these challenges, 11th Annual east African power industry convention.

USGS Digital Spectral Library splib06a (2006) http://speclab.cr.usgs.gov/spectral.lib06/

Appendix

1. Field sheets for each surveyed place
2. Petrography analysis for rock samples
3. Results of the spectral measurements
4. Chemical Analysis Data of Hot Spring Water (Existing data)
5. Compilation of Geo-thermometers from Hot Springs (Existing data)
6. List of geothermometers of hot spring
7. Probability Distribution and Cumulative Probability shown by Monte Carlo Analysis

1. Field Sheets for each surveyed place

Location No.	Na01		DATE	16-Aug-13	
Place Name	Lake Natron		REGION	Arusha	
Cordination;					
Longitude (E)	35.90563	Latitude (S)	2.37312	Elevation	613 m
Water sample No.	Na01				
Temperature	50.5 ºC				
pH	9.7				
Electric conductivity	1,050 mS/m				
Rock sample No.	Na01	Basic volcanic rock			

Geological condition;
Quaternary volcanic zone; olivine basalt of middle Pleistocene age. Being situated on the site where almost N-S trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;
This field is located on the western shore of Lake Natron, where many hot springs well up through the fractures developed in the basalt lava. The temperature in the field was 50.5°C, maximum pH was 9.7 and maximum electrical conductivity was 1,050 mS/m. Quaternary basalt lava, which has a largely N-S trending lineament, is widely distributed in the field. The presence of a scarp suggests that the N-S trending lineament is a fault. The porous parts of the volcanic rocks are filled with carbonates forming an amygdaloidal texture.

Location No.	Na02		DATE	16-Aug-13	
Place Name	Lake Natron		REGION	Arusha	
Cordination;					
Longitude (E)	35.90376		Latitude (S)	2.37392	Elevation 592 m
Water sample No.	Na02				
Temperature	53.1 ºC				
pH	9.7				
Electric conductivity	1,530 mS/m				
Rock sample No.	Na02	Basic volcanics			

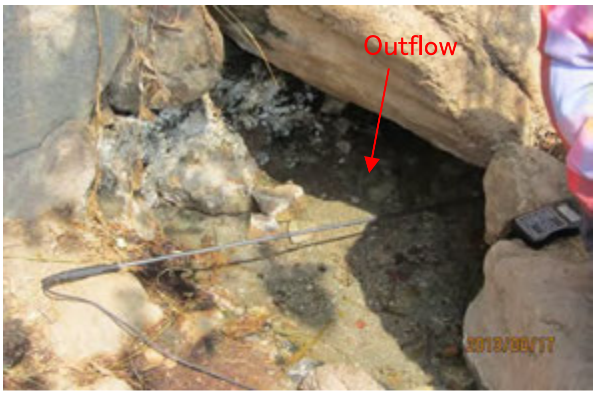
Geological condition;
Quaternary volcanic zone; olivine basalt of middle Pleistocene age. Being situated on the site where almost N-S trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;
This site is located at approximately 200 m west of Na01. This field is located on the western shore of Lake Natron, where many hot springs well up through the fractures developed in the basalt lava. The maximum recorded temperature in the field was 53.1°C, maximum pH was 9.7 and maximum electrical conductivity was 1,530 mS/m. Quaternary basalt lava, which has a largely N-S trending lineament, is widely distributed in the field. The presence of a scarp suggests that the N-S trending lineament is a fault. The porous parts of the volcanic rocks are filled with carbonates forming an amygdaloidal texture.

Location No.	Mn01			DATE	17-Aug-13	
Place Name	Lake Manyara			REGION	Arusha	
Cordination;						
Longitude (E)	35.73786		Latitude (S)	3.61676	Elevation	710 m
Water sample No.	Mn01					
Temperature	70.8 ºC					
pH	9.5					
Electric conductivity	280 mS/m					
Rock sample No.	Mn01a	gneiss				
	Mn01b	evaporite				

Geological condition;
Gneiss of Usagaran system. Being situated on the site where NNE-SSW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;
This field is located on the western side of Lake Manyara, where several hot springs well up from scree deposits made up of gneiss. The maximum temperature, pH and electrical conductivity of the hot springs were 70.8°C, pH 9.5 and 280 mS/m, respectively. Basement rocks mainly consisting of gneiss are distributed in the field, which has NNE-SSW trending lineament and seems to be a fault, as its very well-developed scarp indicates.



Location No.	Mn02			DATE	17-Aug-13	
Place Name	Lake Manyara			REGION	Arusha	
Cordination;						
Longitude (E)	35.74094		Latitude (S)	3.61712	Elevation	973 m
Water sample No.	-					
Temperature	62.9 ºC					
pH	-					
Electric conductivity	- mS/m					
Rock sample No.	-					

Geological condition;

Gneiss of Usagaran system. Being situated on the site where NNE-SSW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;

This field is located on the western side of Lake Manyara, where several hot springs well up from scree deposits made up of gneiss. The temperatureof the hot springs was 62.9°C. Basement rocks mainly consisting of gneiss are distributed in the field, which has NNE-SSW trending lineament and seems to be a fault, as its very well-developed scarp indicates.

Location No.	Ey01			DATE	18-Aug-13	
Place Name	Lake Eyasi			REGION	Arusha	
Cordination;						
Longitude (E)	35.25440		Latitude (S)	3.57560	Elevation	1045 m
Water sample No.	Ey01					
Temperature	48.6 ºC					
pH	9.3					
Electric conductivity	1,010 mS/m					
Rock sample No.	Ey01	evaporite				

Geological condition;
Gneiss of Usagaran system. Being situated on the site where NE-SW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;
This field is located on the eastern side of Lake Eyasi, where hot springs well up from the unconsolidated sands of lake deposits. The field consists of wetland with sparse vegetation. The maximum temperature, pH and electrical conductivity were 48.6°C, pH 9.3 and 1,010mS/m, respectively. The Gneiss basement rocks show a NE-SW trending lineament, which seems to be a fault, as its very well-developed scarp indicates.

Location No.	Ey02		DATE	18-Aug-13	
Place Name	Lake Eyasi		REGION	Arusha	
Cordination;					
Longitude (E)	35.33100	Latitude (S)	3.50276	Elevation	1037 m
Water sample No.	Na01				
Temperature	35.7 ºC				
pH	9.1				
Electric conductivity	270 mS/m				
Rock sample No.	-				

Geological condition;

Gneiss of Usagaran system. Being situated on the site where NE-SW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;

This field is located on the eastern side of Lake Eyasi, where hot springs well up from the unconsolidated sands of lake deposits. The field consists of wetland with sparse vegetation. The temperature, pH and electrical conductivity were 35.7°C, pH 9.1 and 270 mS/m, respectively. The Gneiss basement rocks show a NE-SW trending lineament, which seems to be a fault, as its very well-developed scarp indicates.

Location No.	Ey03			DATE	18-Aug-13		
Place Name	Lake Eyasi			REGION	Arusha		
Cordination;							
Longitude (E)	35.33057		Latitude (S)	3.50178	Elevation	1106 m	
Water sample No.	-						
Temperature	36.6 ºC						
pH	-						
Electric conductivity	- mS/m						
Rock sample No.	-						

Geological condition;

Gneiss of Usagaran system. Being situated on the site where NE-SW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;

This field is located on the eastern side of Lake Eyasi, where hot springs well up from the unconsolidated sands of lake deposits. The field consists of wetland with sparse vegetation. The temperaturewas 36.6°C, pH 9.3 and 1,010 mS/m, respectively. The Gneiss basement rocks show a NE-SW trending lineament, which seems to be a fault, as its very well-developed scarp indicates.

Location No.	Ng01			DATE	19-Aug-13	
Place Name	Ngorongoro crater			REGION	Arusha	
Cordination;						
Longitude (E)	35.55775		Latitude (S)	3.24353	Elevation	1168 m
Water sample No.	-					
Temperature	36.6 ºC					
pH	7.7					
Electric conductivity	32	mS/m				
Rock sample No.	Ng01	sediment				

Geological condition;
Quaternary volcanic zone (Ngorongoro crater)

Discription;
Three hot springs are found inside of Ngorongoro Crater. Hot spring Ng01 is located at the foot of the sommar, welling up from unconsolidated scree deposits. The maximum temperature, pH and electric conductivity were 36.6°C, pH7.7 and 32 mS/m, respectively. The geology of the fields is characterized by Quaternary volcanic rocks.
No structural features are observed in the satellite imagery. The hot springs are derived from the flow of groundwater in the outer crater-rim.

Location No.	Ng02			DATE	19-Aug-13	
Place Name	Ngorongoro crater			REGION	Arusha	
Cordination;						
Longitude (E)	35.60079		Latitude (S)	3.21050	Elevation	1216 m
Water sample No.	-					
Temperature	23 ºC					
pH	7.9					
Electric conductivity	34 mS/m					
Rock sample No.	-					

Geological condition;
Quaternary volcanic zone (Ngorongoro crater).

Discription;
Three hot springs are found inside of Ngorongoro Crater. Hot spring Ng01 is located at the foot of the sommar, welling up from unconsolidated scree deposits. The temperature, pH and electric conductivity were 23°C, pH7.9 and 34 mS/m, respectively. The geology of the fields is characterized by Quaternary volcanic rocks.
No structural features are observed in the satellite imagery. The hot springs are derived from the flow of groundwater in the outer crater-rim.

Location No.	Ng03			DATE	19-Aug-13	
Place Name	Ngorongoro crater			REGION	Arusha	
Cordination;						
Longitude (E)	35.49837		Latitude (S)	3.17734	Elevation	1105 m
Water sample No.	-					
Temperature	27.2 ºC					
pH	8.1					
Electric conductivity	34 mS/m					
Rock sample No.	-					

Geological condition;
Quaternary volcanic zone (Ngorongoro crater)

Discription;
Three hot springs are found inside of Ngorongoro Crater. Hot spring Ng01 is located at the foot of the sommar, welling up from unconsolidated scree deposits. The maximum temperature, pH and electric conductivity were 27.7°C, pH8.1 and 34 mS/m, respectively. The geology of the fields is characterized by Quaternary volcanic rocks.
No structural features are observed in the satellite imagery. The hot springs are derived from the flow of groundwater in the outer crater-rim.

Location No.	Ba01			DATE	20-Aug-13	
Place Name	Masware			REGION	Manyara	
Cordination;						
Longitude (E)	35.71347		Latitude (S)	4.06958	Elevation	1066 m
Water sample No.	Ba01					
Temperature	40.9 ºC					
pH	7.4					
Electric conductivity	270 mS/m					
Rock sample No.	Ba01a	gneiss				
	Ba01b	sediment				
	Ba01c	sediment				

Geological condition;

Gneiss basement zone. Being situated on the site where NE-SW trending lineament, seemed to be fault by the presence of its scarp, is developed very well.

Discription;

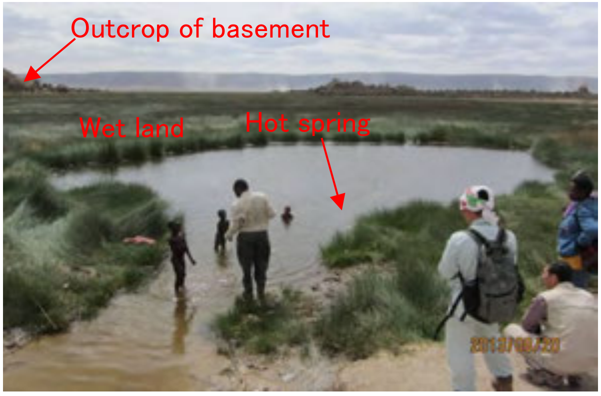
This field is located to the north of Babati Town. The hot springs gush out from unconsolidated sands on the gentle slope. The vicinity of the hot springs consists of wetland. The maximum temperature, pH and electric conductivity were 40.9°C, 7.4 and 270 mS/m, respectively. A gneiss basement, showing a NE-SW trending lineament, is distributed in the field, and seems to be a fault, as its very well-developed scarp indicates.

No geological features are observed in the imagery. This hot spring is newly reported in this preliminary survey.

Location No.	Ha01		DATE	20-Aug-13	
Place Name	Balangida Lalu		REGION	Manyara	
Cordination;					
Longitude (E)	35.25523	Latitude (S)	4.70477	Elevation	1118 m
Water sample No.	-				
Temperature	32.7 ºC				
pH	-				
Electric conductivity	- mS/m				
Rock sample No.	Ha01	sediment			

Geological condition;
Being situated on the site where ENE-WSW trending lineament, seemed to be fault by the presence of its scarp, is developed very well. In this region, ENE-WSW trending lineaments are developed, and are dislocated by NW-SE lineaments.

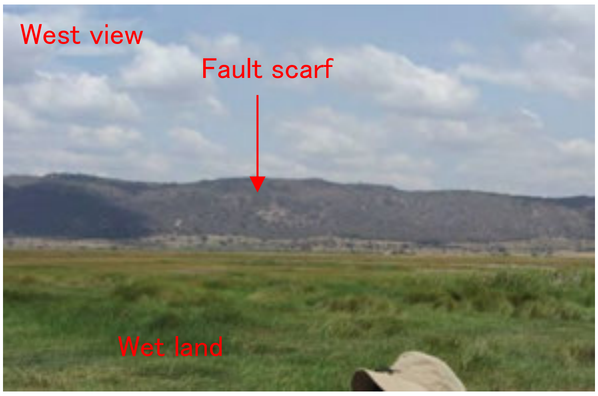
Discription;
This field is located east of Lake Balangida Lalu, where hot springs well up from unconsolidated sands of sedimentary lake deposits. The field consists of wetland and ponds and is covered with thick vegetation. The maximum temperature was 32.7°C, but pH and electrical conductivity were not measured, because of contamination of the surface water. Gneiss is distributed in the field, trending ENE-WSW, and the lineament appears to be fault, as its very well-developed scarp indicates. In this area, ENE-WSW trending lineaments are found, and these are dislocated by NW-SE lineaments.
Thick vegetation is observed along the watercourse in the satellite image.

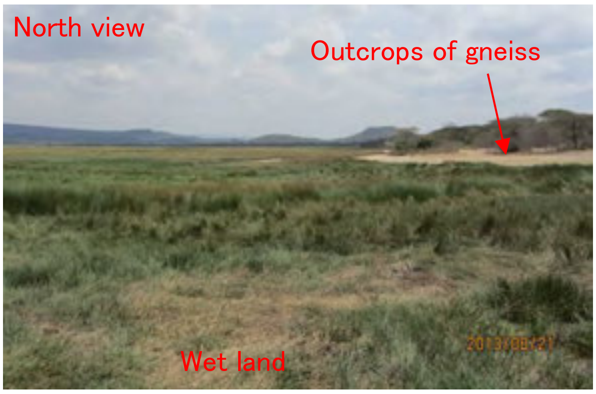


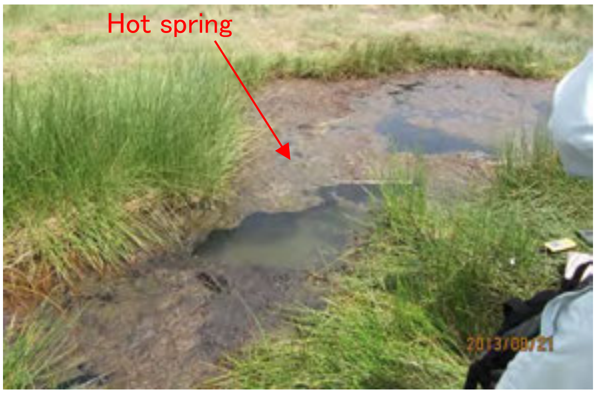
Location No.	Ms01			DATE	21-Aug-13	
Place Name	Msule			REGION	Singida	
Cordination;						
Longitude (E)	35.06760		Latitude (S)	5.10671	Elevation	1212 m
Water sample No.	Ms01					
Temperature	37.1 ºC					
pH	8.1					
Electric conductivity	350 mS/m					
Rock sample No.	-					

Geological condition;
Granitic rock of Precambrian age. Being situated on the site where NE-SW and NNW-SSE trending lineaments, seemed to be faults by the presence of their scarps, intersect each other. The former is elder than the latter in the activity age.

Discription;
These fields are located in Msule Village southeast of Singida Town. Extensive wetland and ponds with thick vegetation are found in the area. The maximum temperature, pH and electrical conductivity of the hot spring were 37.1°C, 8.1 and 350mS/m, respectively. This hot spring is newly reported in this survey.







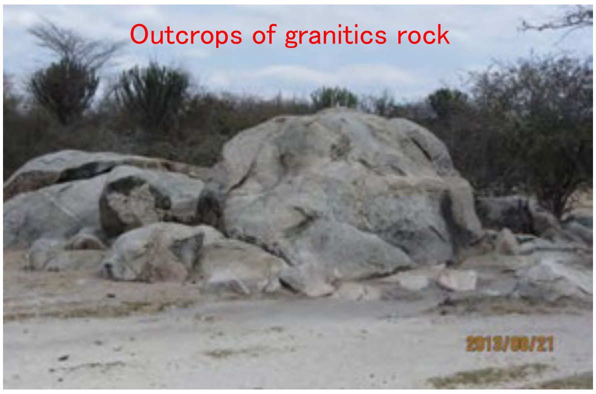
Location No.	Ta01			DATE	21-Aug-13	
Place Name	Takwa			REGION	Dodoma	
Cordination;						
Longitude (E)	35.13322		Latitude (S)	5.15603	Elevation	1244 m
Water sample No.	Ta01					
Temperature	35.9 ºC					
pH	7.8					
Electric conductivity	290 mS/m					
Rock sample No.	Ta01a	granitics rock				
	Ta01b	sediment				

Geological condition;

Granitic rock basement. Being situated on the site where NE-SW and NNW-SSE trending lineaments, seemed to be faults by the presence of their scarps, intersect each other. The former is elder than the latter in the activity age.

Discription;

These fields are located in Takwa Village southeast of Singida Town. Extensive wetland and ponds with thick vegetation are found in the area. The maximum temperature, pH and electrical conductivity of the hot spring were 35.9°C, 7.8 and 290mS/m, respectively. This hot spring is newly reported in this survey.



Location No.	Mp01			DATE	21-Aug-13	
Place Name	Mponde			REGION	Dodoma	
Cordination;						
Longitude (E)	35.10281		Latitude (S)	5.28361	Elevation	- m
Water sample No.	Mp01					
Temperature	43.3 ºC					
pH	8.3					
Electric conductivity	241 mS/m					
Rock sample No.	-					

Geological condition;
Granitic rock basement. Being situated on the site where NE-SW and NNW-SSE trending lineaments, seemed to be faults by the presence of their scarps, intersect each other. The former is elder than the latter in the activity age.

Discription;
These fields are located in Mponde Village southeast of Singida Town. Extensive wetland and ponds with thick vegetation are found in the area. The maximum temperature, pH and electrical conductivity of the hot spring were 43.3°C, 8.3 and 241mS/m, respectively. This hot spring is newly reported in this survey.

Location No.	Mp02			DATE	21-Aug-13	
Place Name	Mponde			REGION	Dodoma	
Cordination;						
Longitude (E)	35.10293		Latitude (S)	5.28284	Elevation	1214 m
Water sample No.	-					
Temperature	45.4 ºC					
pH	8.6					
Electric conductivity	- mS/m					
Rock sample No.	-					

Geological condition;

Granitic rock basement. Being situated on the site where NE-SW and NNW-SSE trending lineaments, seemed to be faults by the presence of their scarps, intersect each other. The former is elder than the latter in the activity age.

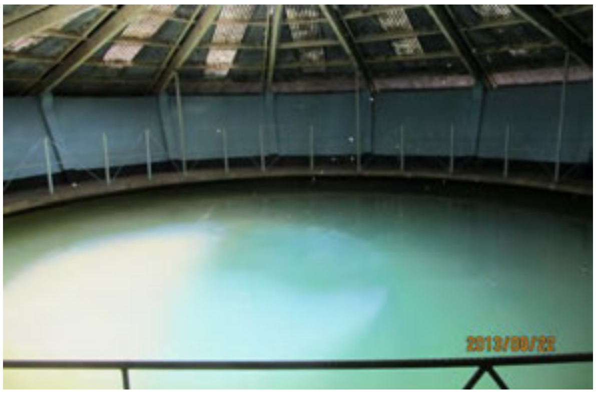
Discription;

These fields are located in Mponde Village southeast of Singida Town. Extensive wetland and ponds with thick vegetation are found in the area. The maximum temperature and pH of the hot spring were 45.4°C, 8.6, respectively. This hot spring is newly reported in this survey.

Location No.	Ko01			DATE	22-Aug-13	
Place Name	Kondoa			REGION	Dodoma	
Cordination;						
Longitude (E)	35.78966		Latitude (S)	4.90346	Elevation	1385 m
Water sample No.	Ko01					
Temperature	30.3 ºC					
pH	7.3					
Electric conductivity	228 mS/m					
Rock sample No.	-					

Geological condition;
Gneiss of Usagaran system. Being situated on the site where NNE-SSW trending fault is developed very well.

Discription;
This field is situated in Kondoa Town. The site of the hot spring is protected by a roofed structure and supplies 3 million L/day to Kondoa Town. The maximum temperature, pH and electrical conductivity of the hot spring were 30.3C, pH 7.3 and 228 mS/m, respectively. Gneissic rock from the Usagaran System is distributed in the field, where a NNE-SSW trending fault is well-developed.



Location No.	So01			DATE	25-Aug-13	
Place Name	Songwe			REGION	Mbeya	
Cordination;						
Longitude (E)	33.18213		Latitude (S)	8.87427	Elevation	1121 m
Water sample No.	So01					
Temperature	74.8 ºC					
pH	7.0					
Electric conductivity	730 mS/m					
Rock sample No.	So01a	travertine				
	So01b	travertine				

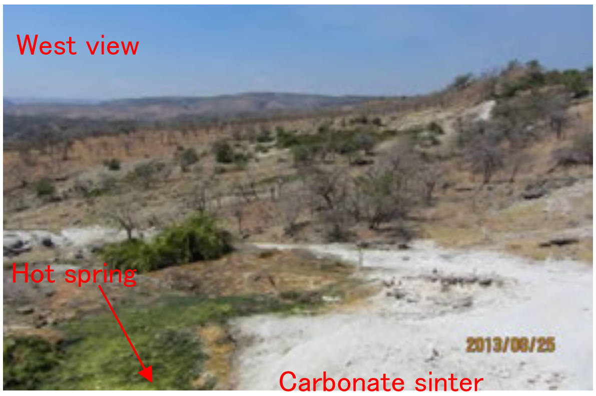
Geological condition;

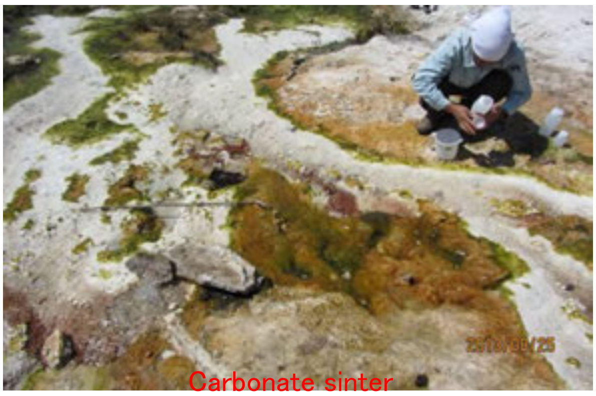
Quaternary travertine and volcanic zone. The basement of travertine is Cretaceous sandstone and mudstone.Being situated on the site where NW-SE trending faults are developed very well. Hot spring and its white sinter are derived from a similar trend of fissures.

Discription;

This site is located at the south side of the Songwe River approximately 30 km west of Mbeya city. The large amount of travertine (carbonate sinter) are widely distributed over the area. The hot spring is gushing out from hill composed of travertine.

Huge amount of white travertine characterizes this area. The sinter is more than 10 m thick in maximum at quarry site observation, and it shows certain layer like a limestone. However, microstructure of the layer shows the colloform texture that is developed under the precipitation process at the surface like a sinter activity.





Location No.	Il01			DATE	25-Aug-13	
Place Name	Ilatile			REGION	Mbeya	
Cordination;						
Longitude (E)	33.21126		Latitude (S)	8.89121	Elevation	1072 m
Water sample No.	-					
Temperature	54.1 ºC					
pH	6.6					
Electric conductivity	- mS/m					
Rock sample No.	-					

Geological condition;
Quaternary travertine and volcanic zone. The basement of travertine is Cretaceous sandstone and mudstone. Being situated on the site where NW-SE trending faults are developed very well. Hot spring and its white sinter are derived from a similar trend of fissures.

Discription;
This site is located at the south side of the Songwe River approximately 30km west of Mbeya city. The large amount of travertine (carbonate sinter) are widely distributed over the area. The hot spring is gushing out from hillside which is consistent of travertine.

Location No.	Ra01			DATE	25-Aug-13	
Place Name	Rambo			REGION	Mbeya	
Cordination;						
Longitude (E)	33.20984		Latitude (S)	8.88503	Elevation	899 m
Water sample No.	Ra01					
Temperature	79.2 ºC					
pH	7.0					
Electric conductivity	728 mS/m					
Rock sample No.	-					

Geological condition;
Quaternary travertine and volcanic zone. The basement of travertine is Cretaceous sandstone and mudstone. Being situated on the site where NW-SE trending faults are developed very well. Hot spring and its white sinter are derived from a similar trend of fissures.

Discription;
These fields are located on the left bank of Songwe River, approximately 30 km west of Mbeya City. A large amount of travertine (carbonate sinter) is widely distributed in the fileds. The hot springs gush out from a hill composed of travertine. The maximum temperature, pH and electrical conductivity of the hot springs were 79.2ºC, pH 7.0 and 728 mS/m, respectively.

Location No.	Ki01			DATE	26-Aug-13
Place Name	Kilambo			REGION	Mbeya
Cordination;					
Longitude (E)	33.81793	Latitude (S)	9.36253	Elevation	984 m
Water sample No.	Ki01				
Temperature	61.5 ºC				
pH	6.9				
Electric conductivity	1,013 mS/m				
Rock sample No.	Ki01a	travertine			
	Ki01b	sediment			

Geological condition;
Quaternary volcanic zone. Being situated on the site where NW-SE trending faults are developed very well. Hot springs are derived from a similar trend of fissures.

Discription;
This field is located on the left bank of the river, approximately 30km southeast of Rungwe Volcano. Travertine accumulates where the hot springs gush out from the hillside and riverbed. The maximum temperature, pH and electric conductivity of the hot springs were 61.5°C, pH 6.9 and 1,013mS/m. Quaternary basic volcanic rocks are widely distributed in the field, where NW-SE trending faults are well-developed. Hot springs well up from fissures with a similar trend.

Location No.	Ki02		DATE	26-Aug-13	
Place Name	Kilambo		REGION	Mbeya	
Cordination;					
Longitude (E)	33.81777	Latitude (S)	9.36403	Elevation	1031 m
Water sample No.	Ki02				
Temperature	57.4 ºC				
pH	6.6				
Electric conductivity	1,030 mS/m				
Rock sample No.	Ki02	basic volcanic rock			

Geological condition;

Quaternary volcanic zone. Being situated on the site where NW-SE trending faults are developed very well. Hot springs are derived from a similar trend of fissures.

Discription;

This field is located on the left bank of the river, approximately 30 km southeast of Rungwe Volcano. Travertine accumulates where the hot springs gush out from the hillside and riverbed. The maximum temperature, pH and electric conductivity of the hot springs were 57.4°C, pH 6.6 and 1,030 mS/m. Quaternary basic volcanic rocks are widely distributed in the field, where NW-SE trending faults are well-developed. Hot springs well up from fissures with a similar trend.

Location No.	Ma01		DATE	26-Aug-13	
Place Name	Mampulo		REGION	Mbeya	
Cordination;					
Longitude (E)	33.79546	Latitude (S)	9.54955	Elevation	954 m
Water sample No.	Ma01				
Temperature	56.3 ºC				
pH	7.1				
Electric conductivity	1,016 mS/m				
Rock sample No.	Ma01	Conglomerate			

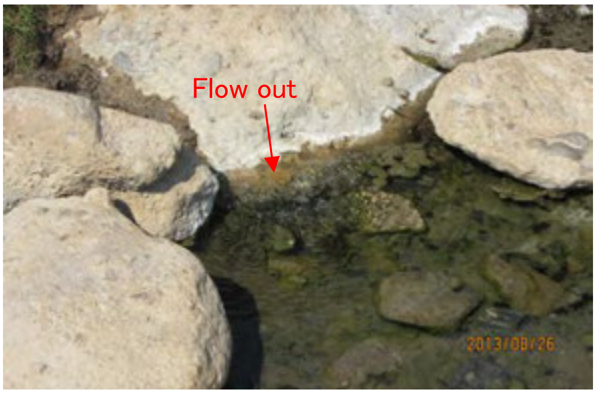
Geological condition;
Conglomerat and pebbly sandstone.
Being situated on the site where NW-SE trending faults are developed very well.

Discription;
This field is located in Mampulo Village, where the hot springs well up from fractures in the conglomerate. The maximum temperature, pH and electrical conductivity of the hot springs are 56.3°C, pH 7.1 and 1,016 mS/m, respectively. Conglomerate and pebbly sandstone, in which NW-SE trending faults are well-developed, are dominant in the field.
The hot springs are derived from NE-SW trending fissures, which form a dome-like structure with a higher resistance rather than surrounding areas.

Location No.	Ma02			DATE	26-Aug-13	
Place Name	Mampulo			REGION	Mbeya	
Cordination;						
Longitude (E)	33.79627		Latitude (S)	9.55239	Elevation	m
Water sample No.	Ma02					
Temperature	52.7 ºC					
pH	6.9					
Electric conductivity	1,022 mS/m					
Rock sample No.	-					

Geological condition;
Quaternary basal conglomerate.
Geological condition: Being situated on the site where NW-SE trending faults are developed very well.

Discription;
This field is located in Mampulo Village, where the hot springs well up from fractures in the conglomerate. The maximum temperature, pH and electrical conductivity of the hot springs are 52.7°C, pH 6.9 and 1,022 mS/m, respectively. Conglomerate and pebbly sandstone, in which NW-SE trending faults are well-developed, are dominant in the field.
The hot springs are derived from NE-SW trending fissures, which form a dome-like structure with a higher resistance rather than surrounding areas.



Location No.	Ka01			DATE	26-Aug-13	
Place Name	Kasimulu			REGION	Mbeya	
Cordination;						
Longitude (E)	33.76252		Latitude (S)	9.58319	Elevation	1025 m
Water sample No.	Ka01					
Temperature	52.6 ºC					
pH	6.8					
Electric conductivity	1,025 mS/m					
Rock sample No.	Ka01a	sandstone				
	Ka01b	silicified rock				

Geological condition;
grey sandstone.Being situated on the site where NW-SE trending faults are developed.

Discription;
This field is located in Kasimulu Village close to the border between Tanzania and Malawi. The hot spring is gushing out from sandstone at the foot of a hill. The maximum temperature, pH and electrical conductivity of hot spring are 52.6°C, pH 6.8 and 1,025 mS/m, respectively. Grey sandstone is distributed in the field, where NW-SE trending faults are developed. NW-SE trending fracture is strongly silicified, and slickenside are observed on the surface.

Location No.	Ks01			DATE	28-Aug-13	
Place Name	Kisaki			REGION	Morogoro	
Cordination;						
Longitude (E)	37.57241		Latitude (S)	7.51107	Elevation	525 m
Water sample No.	Ks01					
Temperature	72.3 ºC					
pH	7.0					
Electric conductivity	721 mS/m					
Rock sample No.	Ks01a	travertine				
	Ks01b	travertine				
	Ks01c	sediment				

Geological condition;

Quaternary unconsolidated materials (Gneiss basement underlying). Being situated on the site where NW-SE trending faults are developed.

Discription;

This field is located in Kisaki Village close to Kisaki Railway Station. The hot springs well up from unconsolidated sediments. The maximum temperature, pH and electrical conductivity of the hot spring were 72.3°C, pH 7.0 and 721 mS/m, respectively. Unconsolidated Quaternary deposits (underlain by gneiss basement) cover the field, where NW-SE trending faults are developed.

There are two hot springs aligned along the faults in the Uluguru Mountain and Rufiji area

Location No.	Ut01			DATE	30-Aug-13	
Place Name	Utete			REGION	Coast	
Cordination;						
Longitude (E)	38.76907		Latitude (S)	8.00640	Elevation	5 m
Water sample No.	Ut01					
Temperature	54.4 ºC					
pH	7.0					
Electric conductivity	436 mS/m					
Rock sample No.	Ut01a	sandstone				
	Ut01b	travertine				

Geological condition;
Tertiary light grey sandstone. Being situated on the site where NW-SE trending lineament is poorly developed.

Discription;
This field is located in Utete Town, approximately 2km south of the Rufiji River. The hot spring gushes out from light grey sandstone. The maximum temperature, pH and electrical conductivity of the hot spring are 54.4°C, pH 7.0 and 436 mS/m, respectively. Tertiary light grey sandstone is widely distributed in the field, and NW-SE trending lineaments in the sandstone are poorly developed. Reddish brown ferruginous irregular veins have developed in the sandstone. There is no Quaternary volcanism in the vicinity.

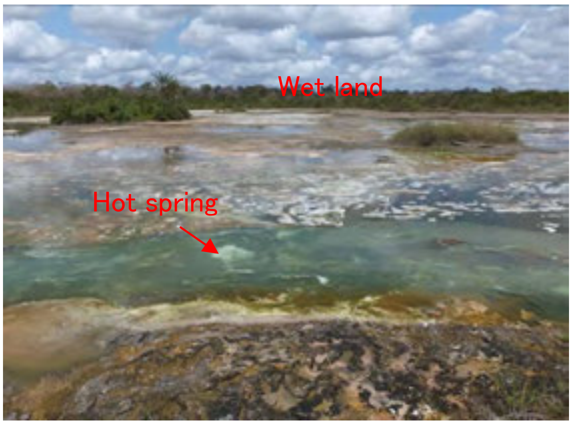
Location No.	Ny01			DATE	31-Aug-13	
Place Name	Nyongoni			REGION	Coast	
Cordination;						
Longitude (E)	38.85676		Latitude (S)	7.82700	Elevation	70 m
Water sample No.	Ny01					
Temperature	67.2 ℃					
pH	6.7					
Electric conductivity	2,230 mS/m					
Rock sample No.	Ny01	travertine				

Geological condition;

Quaternary unconsolidated materials. Being situated on the site where intersection between NE-SW and NW-SE trending lineaments sits.

Discription;

This field is located in Nyongoni Village, northeast of the Luhoi River of tributary of the Rufiji River. The hot springs well up from unconsolidated sediments with travertine. The field is characterized by wetland and ponds. The maximum temperature, pH and electrical conductivity of the hot springs were 67.2°C, pH 6.7 and 2,230 mS/m, respectively. Quaternary unconsolidated sediments cover the field widely, where NE-SW and NW-SE trending lineaments intersect.
The area characterized by hot springs covers a surface area of 300 m by 200 m. There is no Quaternary volcanism in the vicinity.

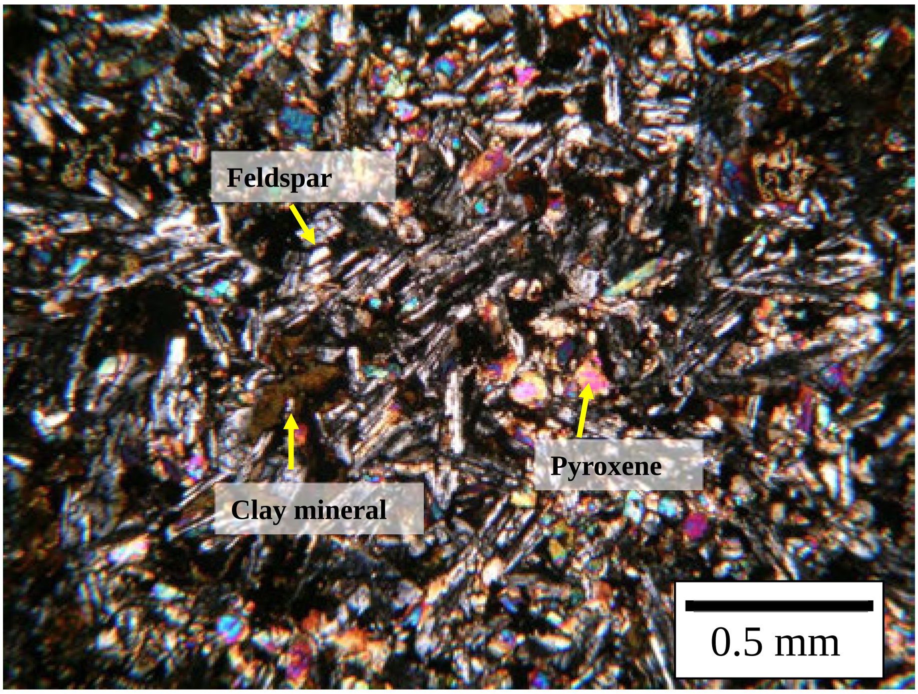


2. Petrography Analysis sheet for rock samples

Petrography sheet No.1	
Field	**Lake Natron (Na01)**

Plane-polarized light

Crossed-polarized light



Description

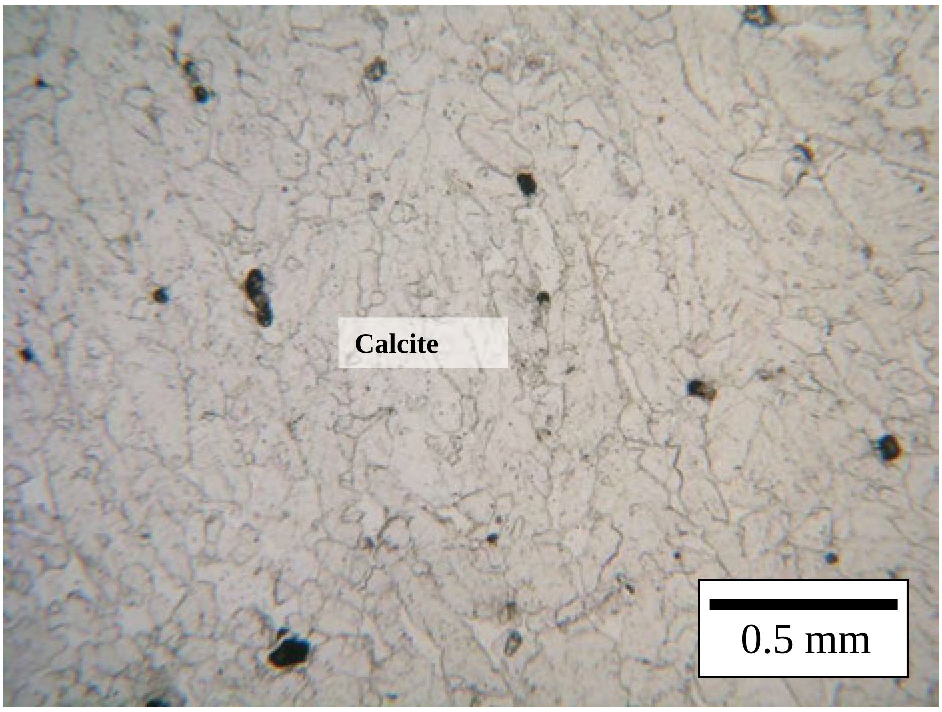
Rock name: Basalt

- The rock is aphyric basalt.
- The ground mass shows intergranular texture and mainly consist of feldspar laths and pyroxenes. The feldspar laths are 0.2-0.3mm in diameter. The pyroxene is under 0.1mm in diameter.
- Altered brown clay minerals are observed.

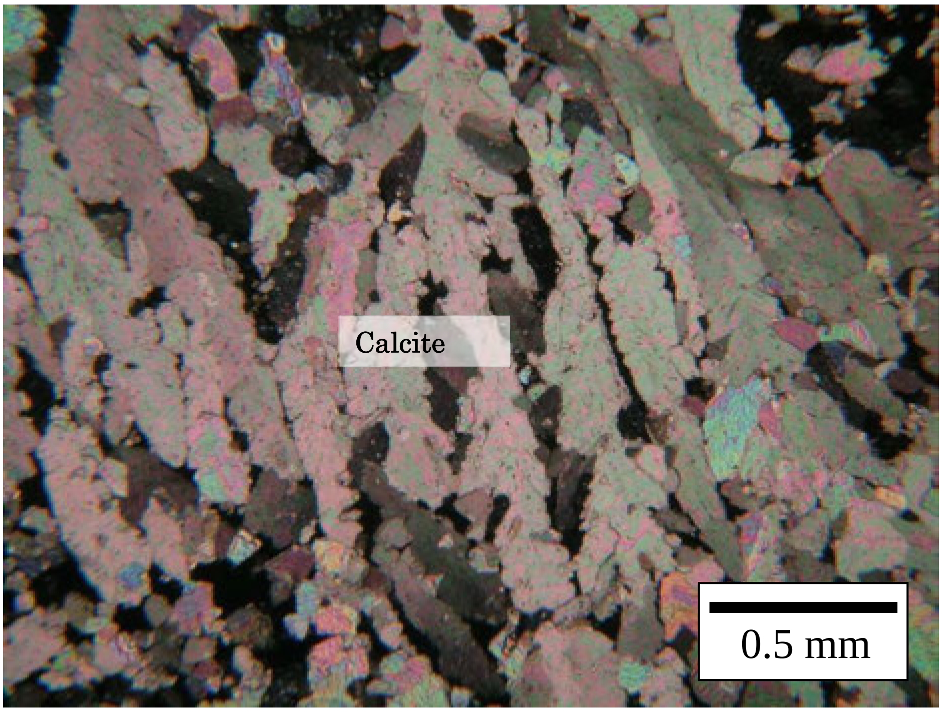
Petrography sheet No.2

Field	Songwe (So01b)

Plane-polarized light



Crossed-polarized light



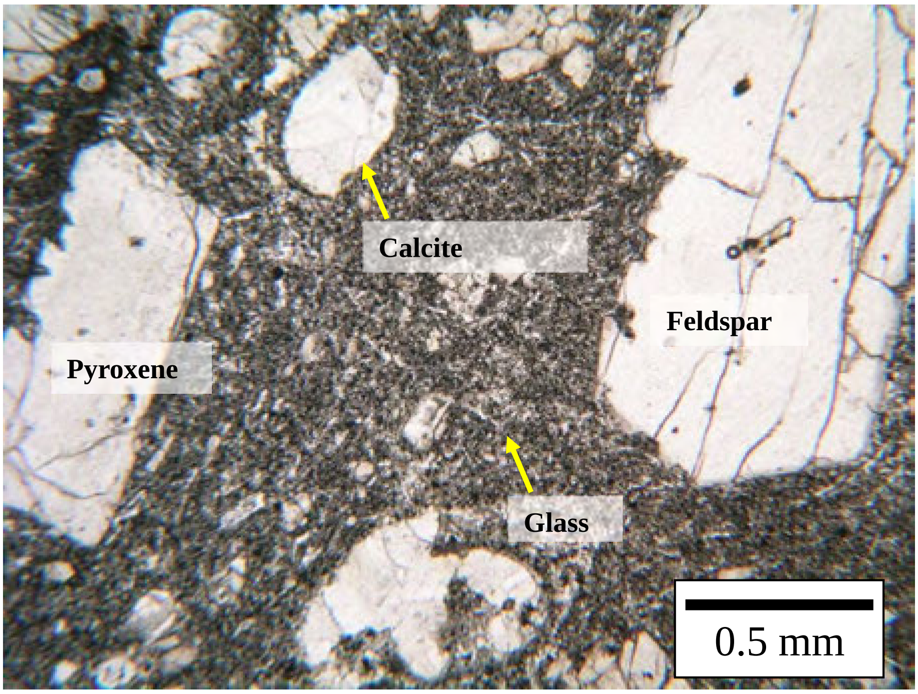
Description

Rock name; Travertine

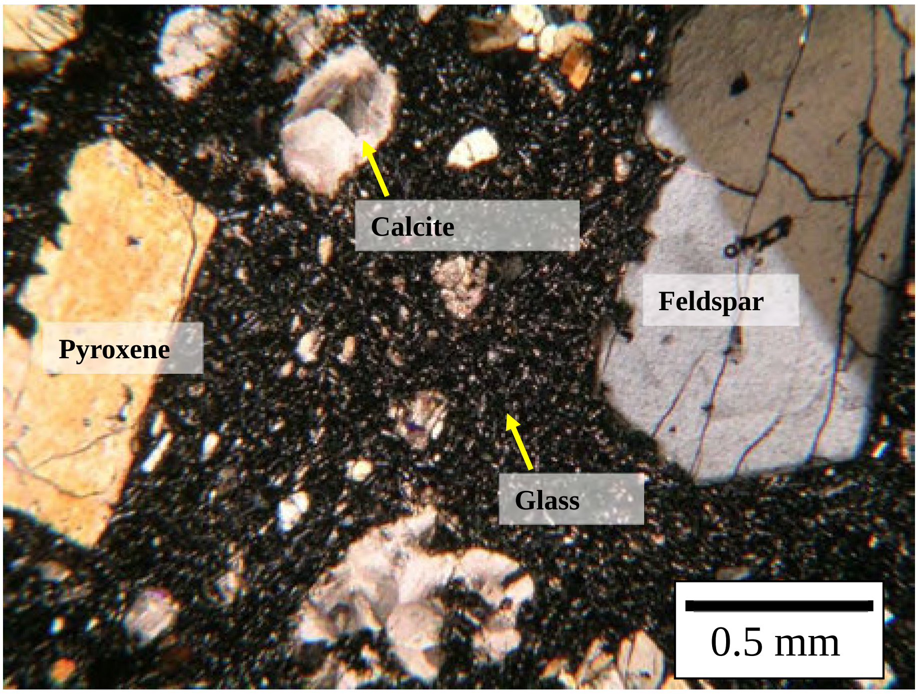
- The rock consists of almost all calcites and shows dendritic texture.

Petrography sheet No.3	
Field	**Kilambo (Ki02)**

Plane-polarized light



Crossed-polarized light



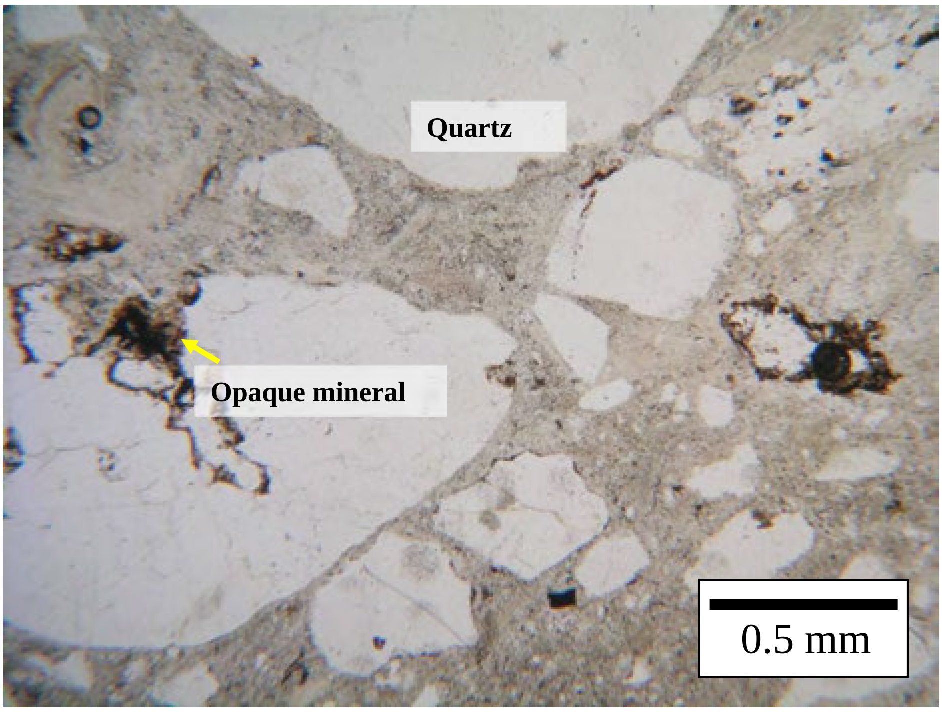
Description

Rock name: basalt

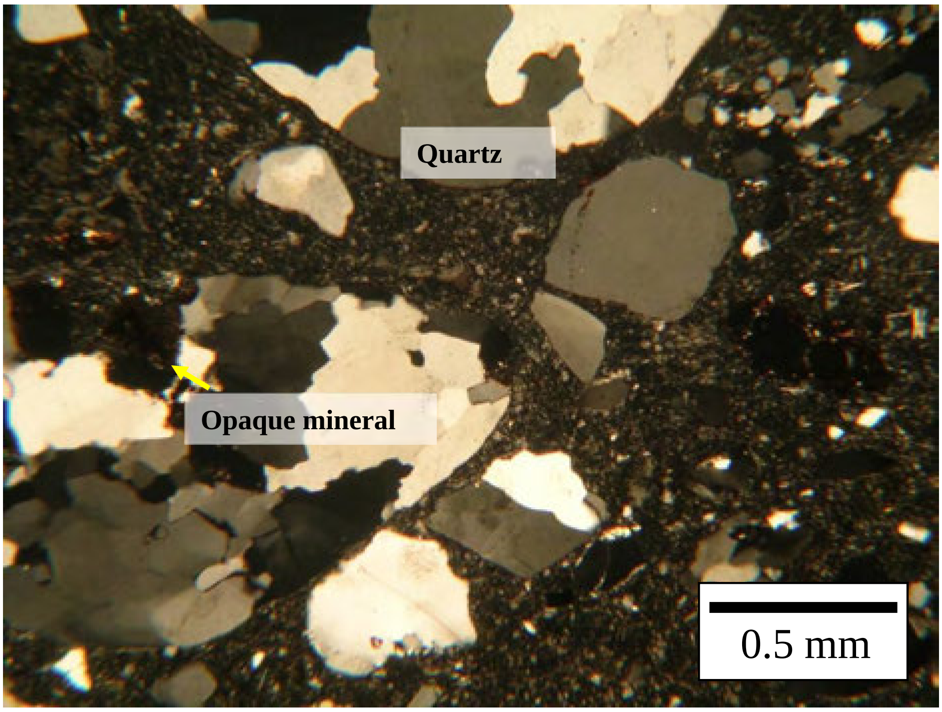
- The rock is plagioclase-pyroxene basalt. The maximum diameter of pyroxene is 5mm. The ground mass shows intersertal texture of volcanic glass, fine plagioclase laths and pyroxene.
- The vesicles (amygdaloidal texture) are filled by intergrowth calcite.

Petrography sheet No.4	
Field	**Mampulo (Ma01)**

Plane-polarized light



Crossed-polarized light



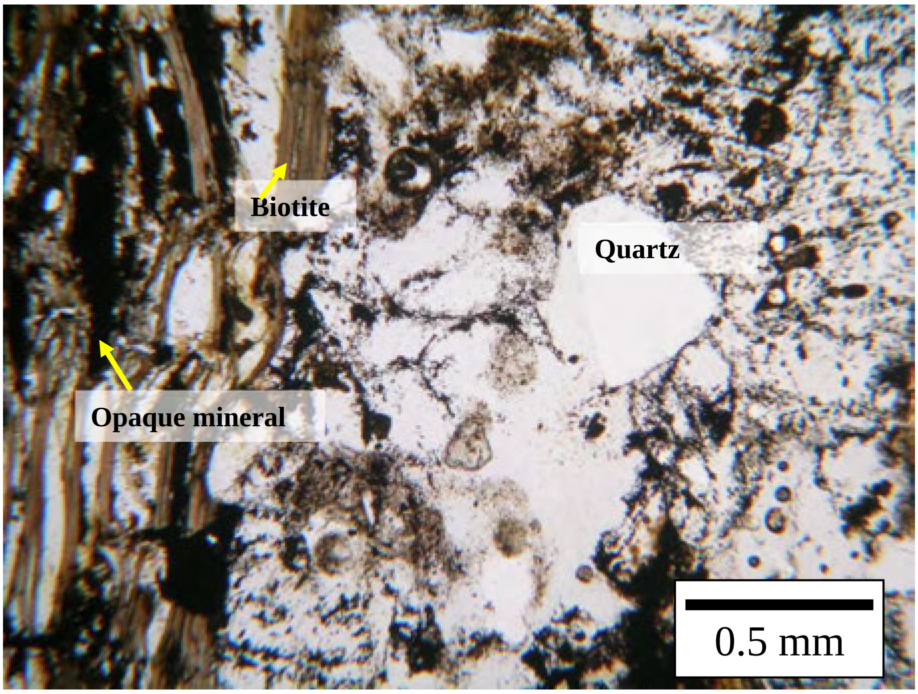
Description

Rock name: Conglomerate

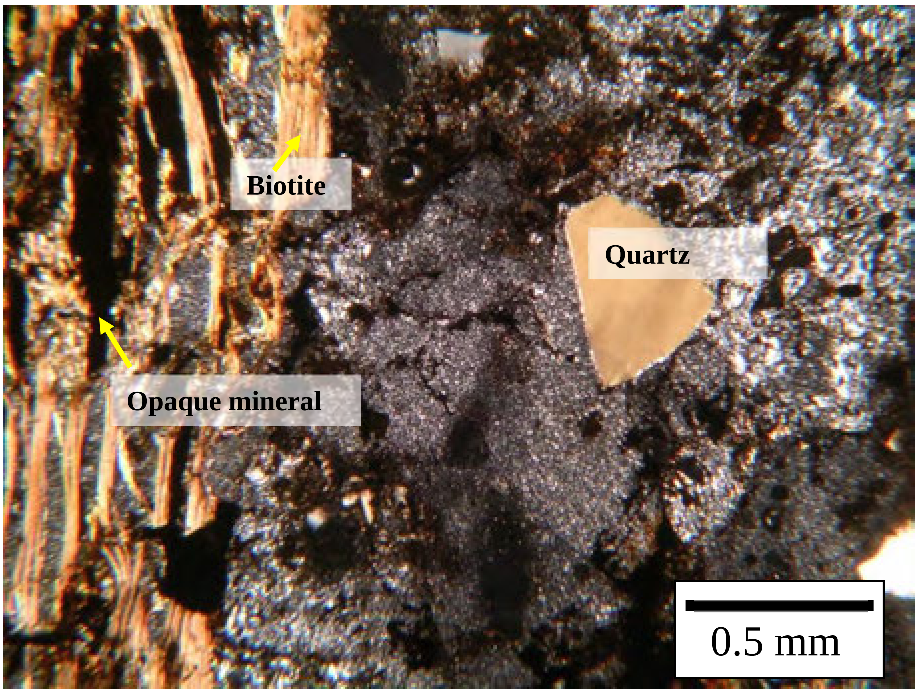
- The rock consists of quartz granule with matrix of fine quartz and opaque minerals. The quartz granules show sub-round form and undulatory extinction. The grain size of quartz is mainly 2mm in diameter, less 1 mm up to more 5mm.
- The matrix shows partially reddish brown color.

Petrography sheet No.5	
Field	**Kasimulu (Ka01a)**

Plane-polarized light



Crossed-polarized light



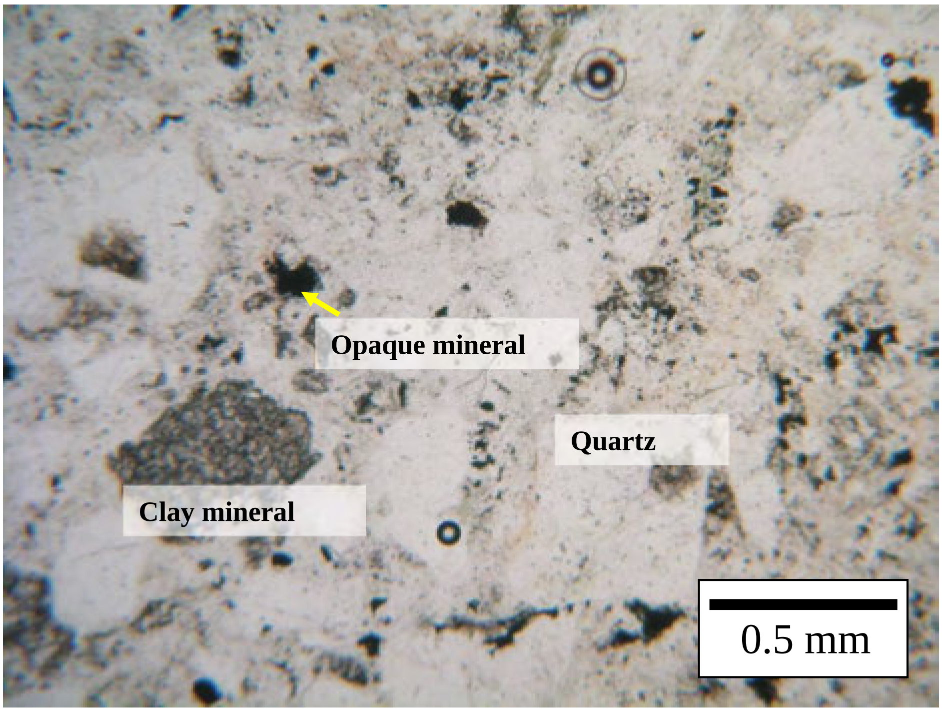
Description

Rock name: sandstone

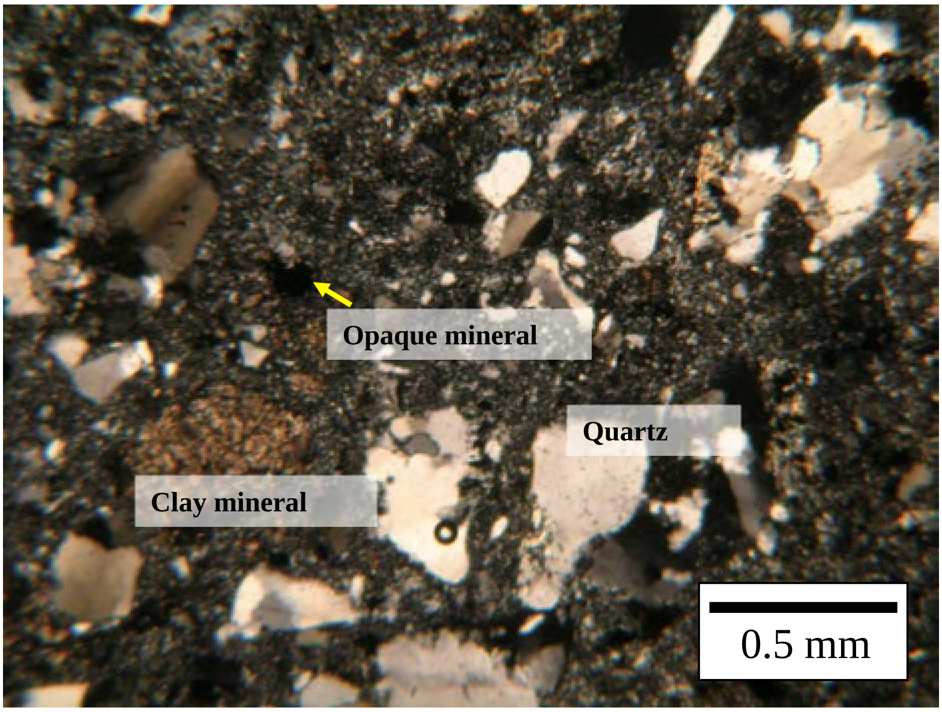
- The rock consists of mainly quartz fragments and fine grain matrix. The quartz fragments have sub-rounded to angular forms. The biotite vein with opaque mineral is observed.
- The matrix consists of fine quartz and observes brown opaque minerals and clay minerals.

Petrography sheet No.6	
Field	**Kasimulu (Ka01b)**

Plane-polarized light



Crossed-polarized light



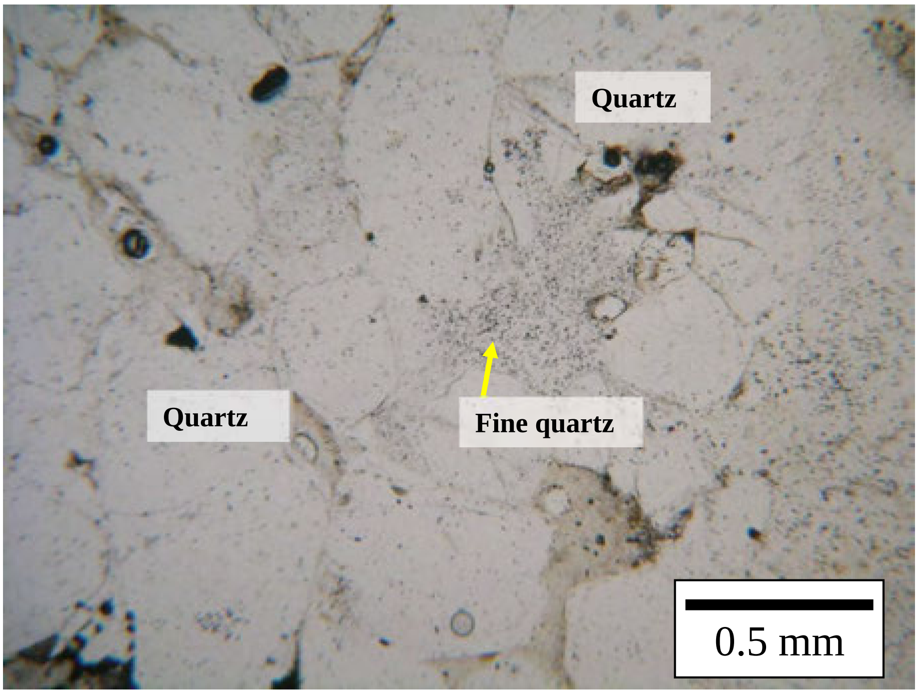
Description

Rock name: Sandstone

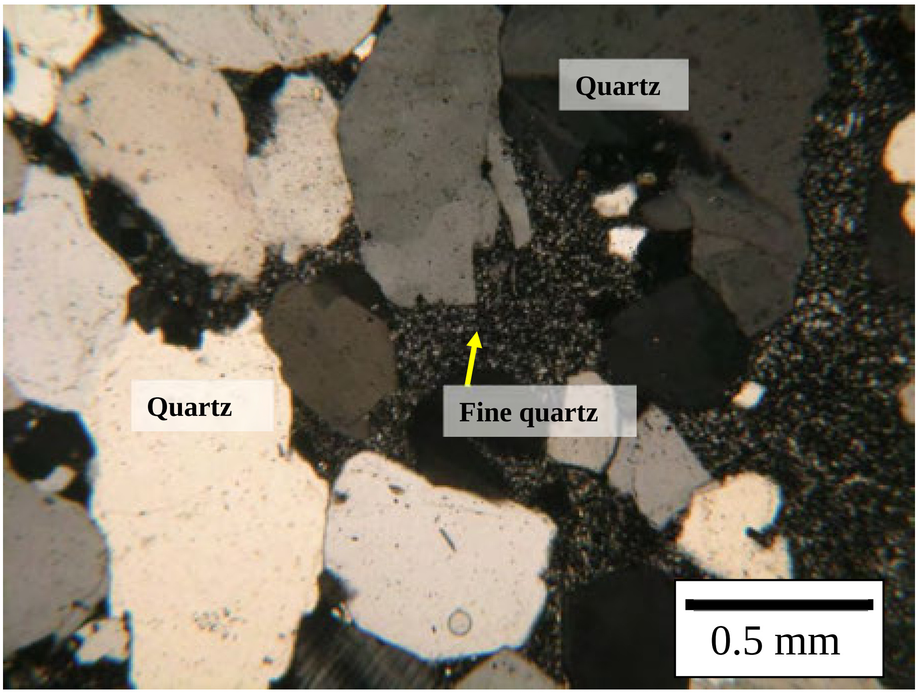
- The grains consist of mainly quartz, irregular form and undulatory extinction. Little opaque minerals in the fine matrix, show aggregate of irregular shape.
- Clay mineral and brown opaque mineral are observed.

Petrography sheet No.7	
Field	**Utete (Ut01a)**

Plane-polarized light



Crossed-polarized light



Description

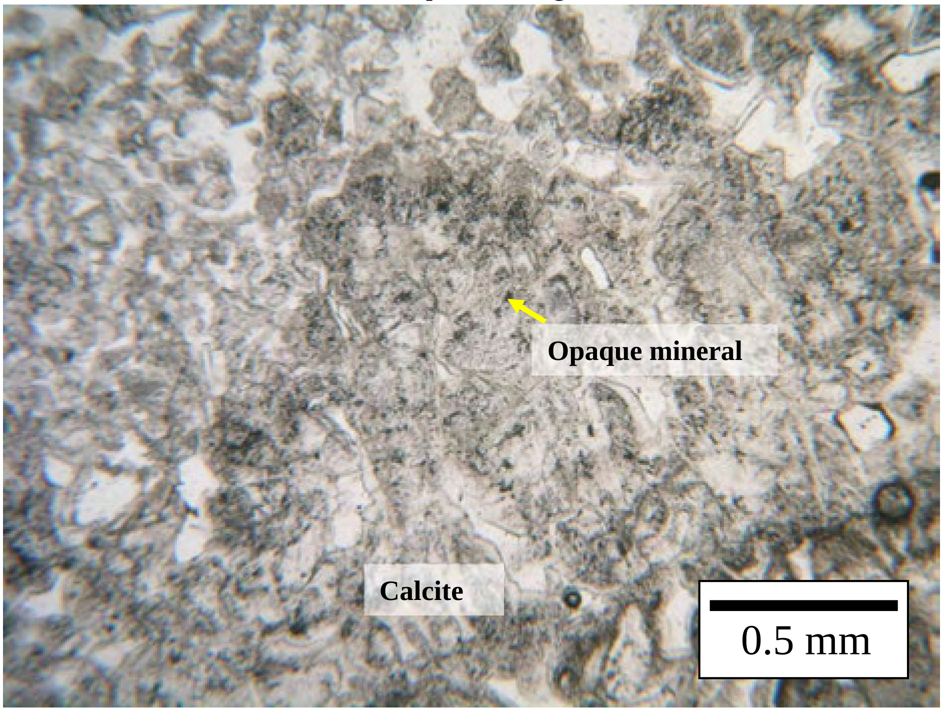
Rock name: silicified rock

- The rock consists of almost quartz, which forming aggregate of subhedral quartz of 1mm in diameter.
- The grain boundaries of quartz show partially corroded form.
- Fine quartz, a small amount of fine opaque and clay minerals are observed in the matrix.

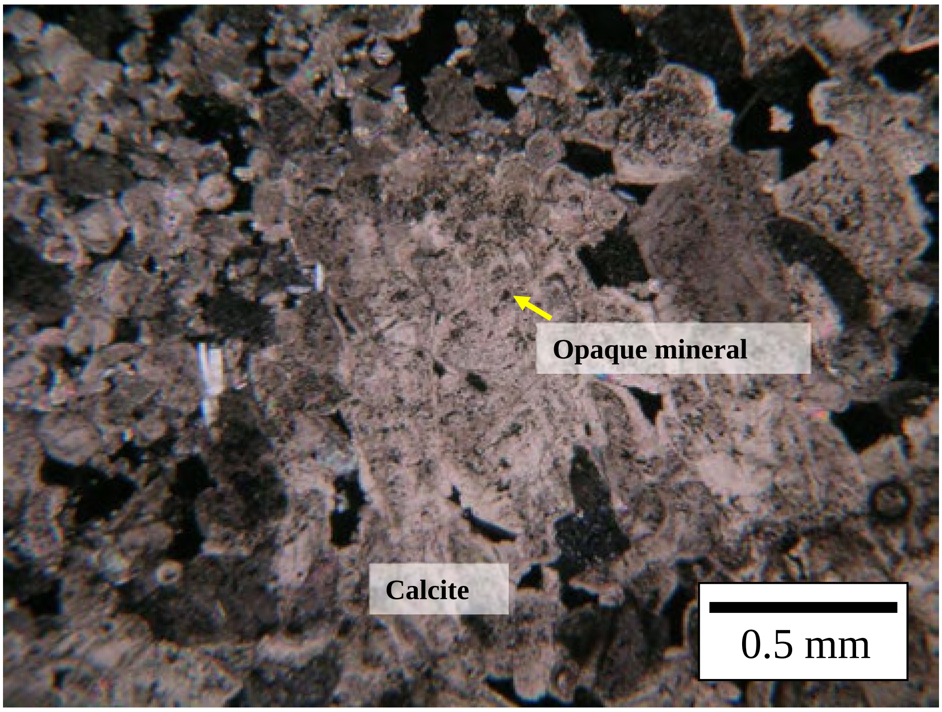
Petrography sheet No.8

Field	**Nyongoni (Ny01)**

Plane-polarized light



Crossed-polarized light

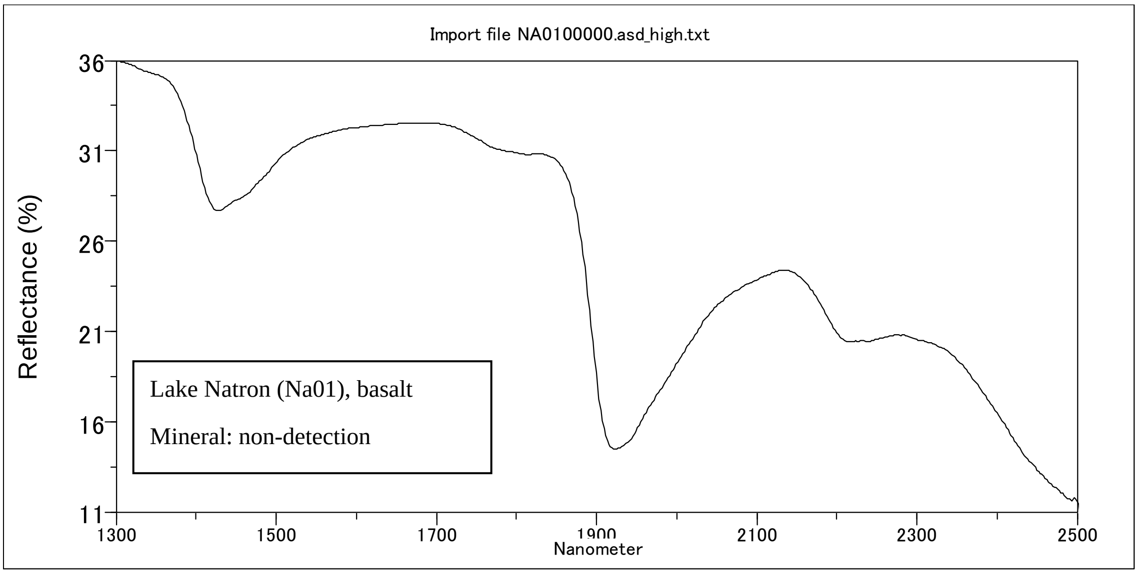


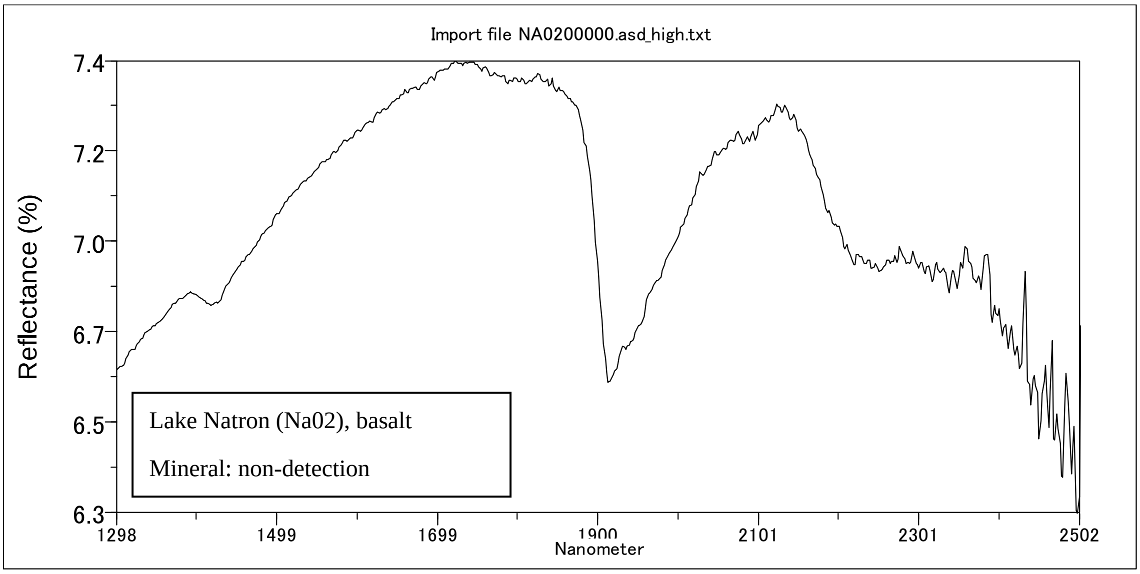
Description

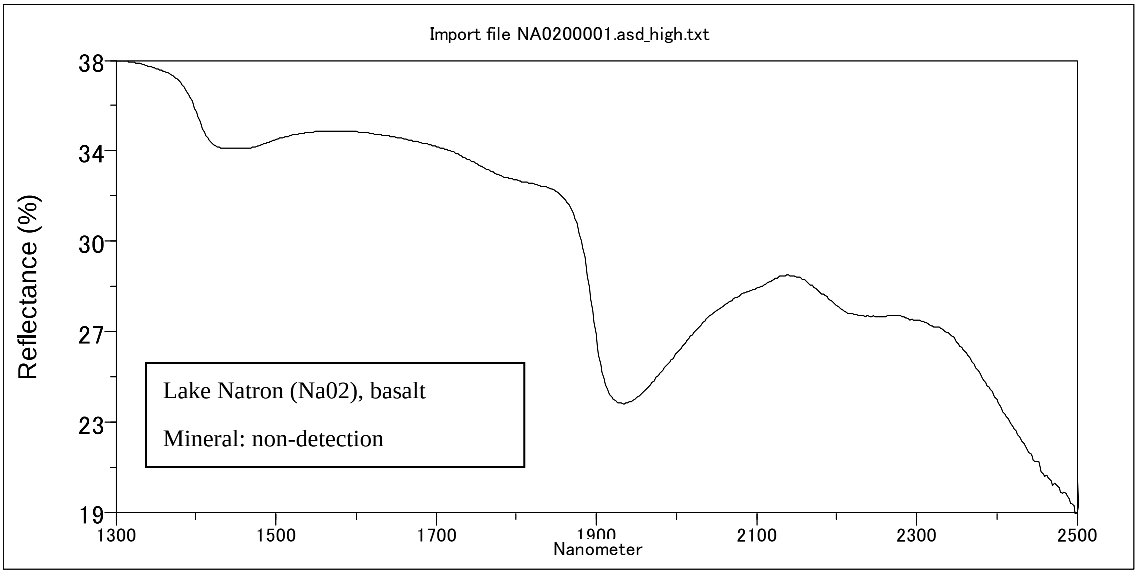
Rock name: Travertine

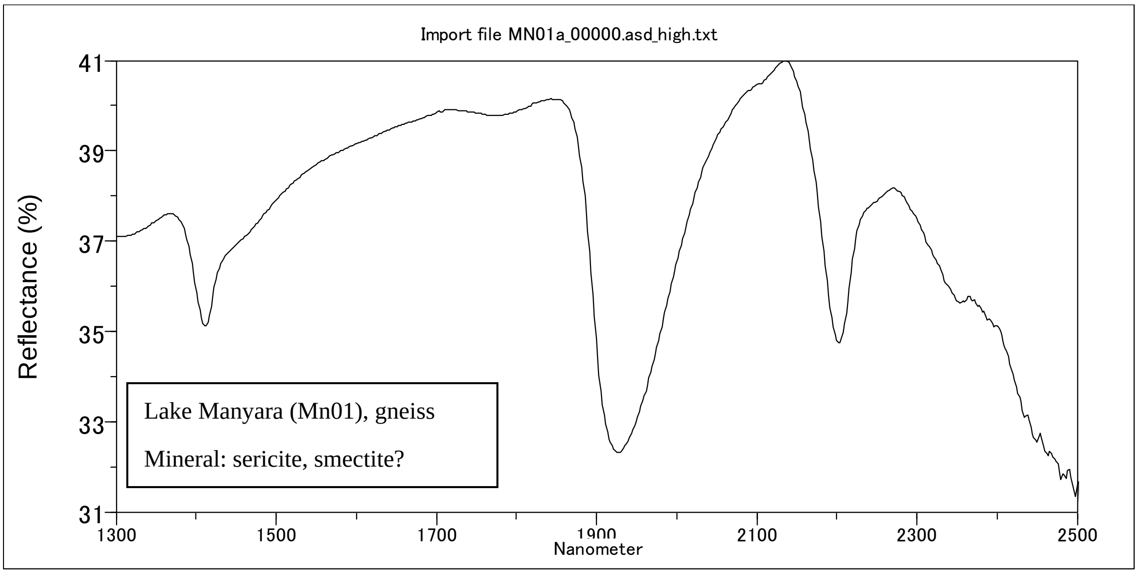
- The rock consists of calcite, which fine opaque minerals are within the calcite.
- The rock shows granular or dendritic texture. The porous texture which inferred to form in precipitation process is observed.

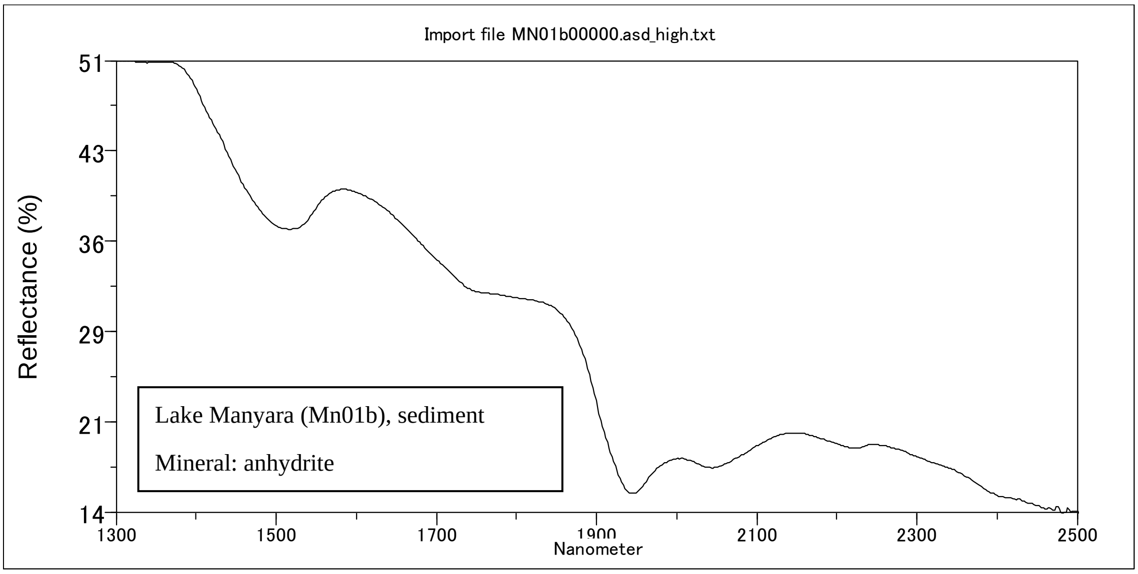
3. Spectral measurement result

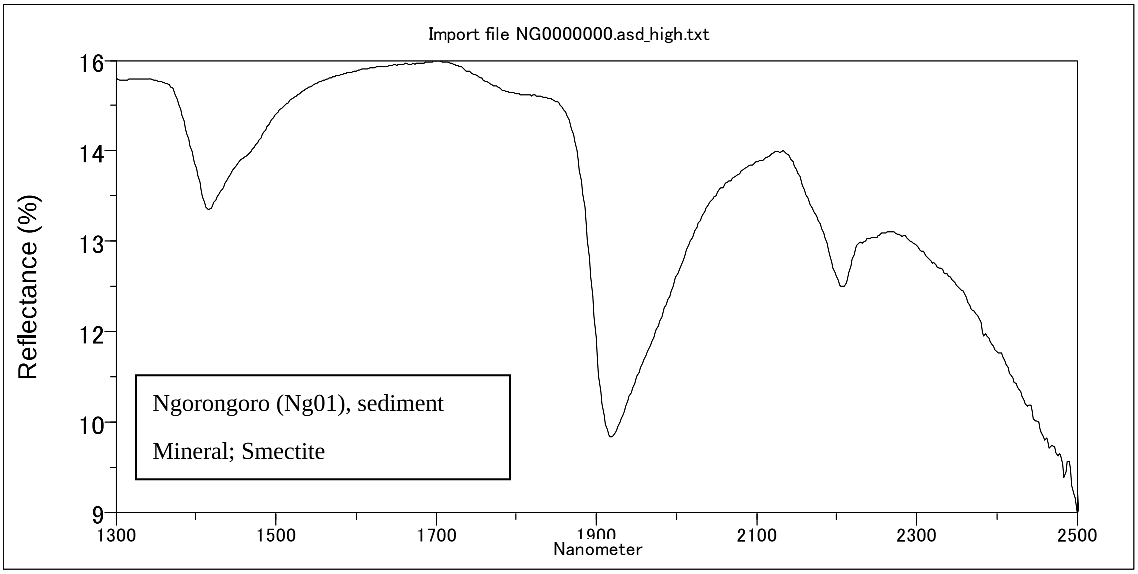


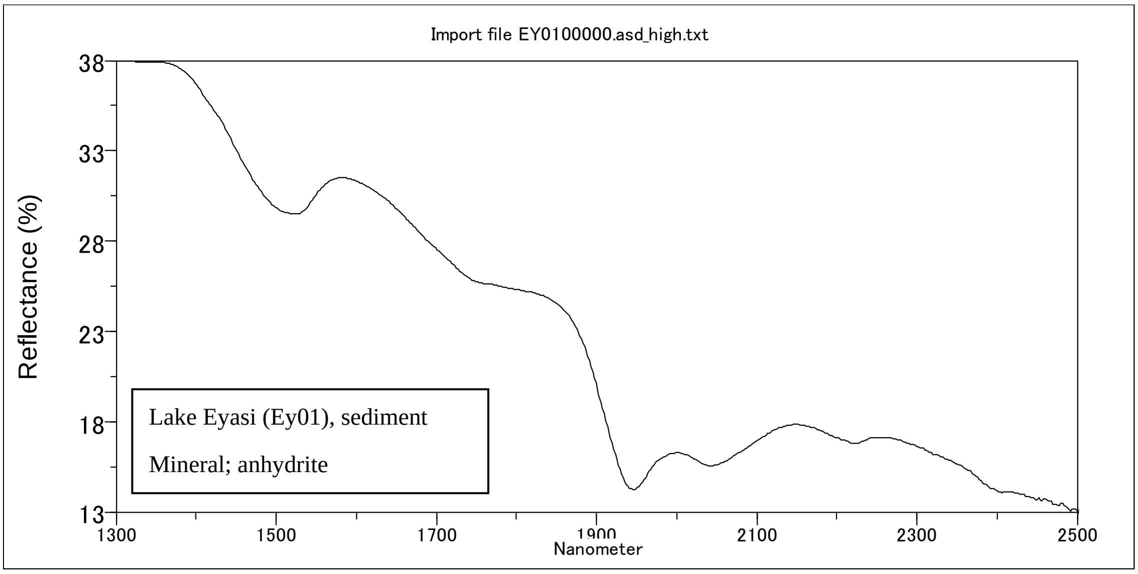


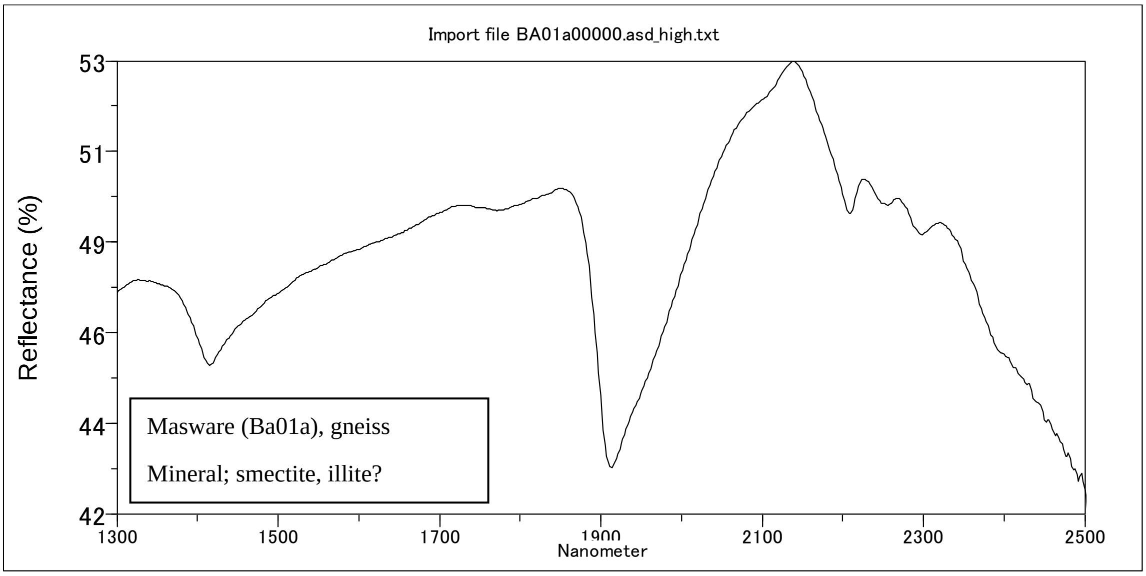


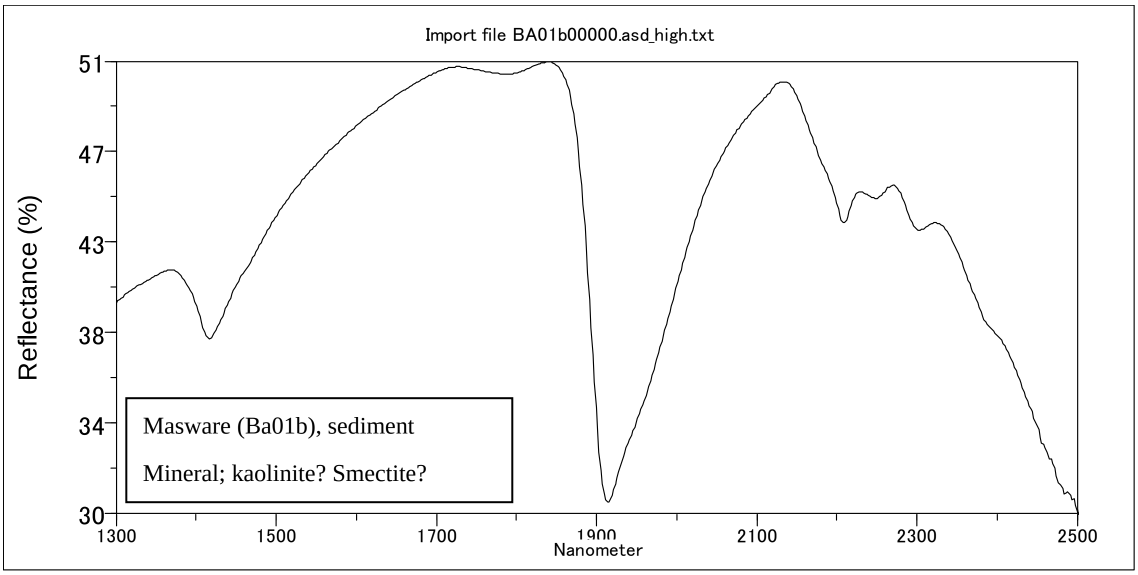

Import file MN01a_00000.asd_high.txt
Reflectance (%)
Nanometer
Lake Manyara (Mn01), gneiss
Mineral: sericite, smectite?

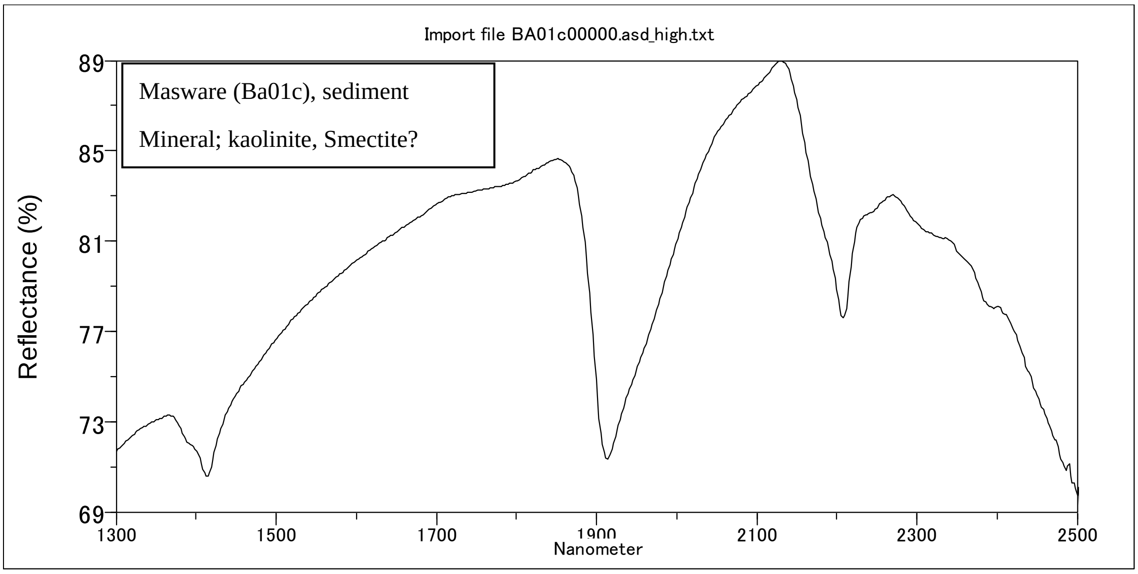

Import file MN01b00000.asd_high.txt
Reflectance (%)
Nanometer
Lake Manyara (Mn01b), sediment
Mineral: anhydrite

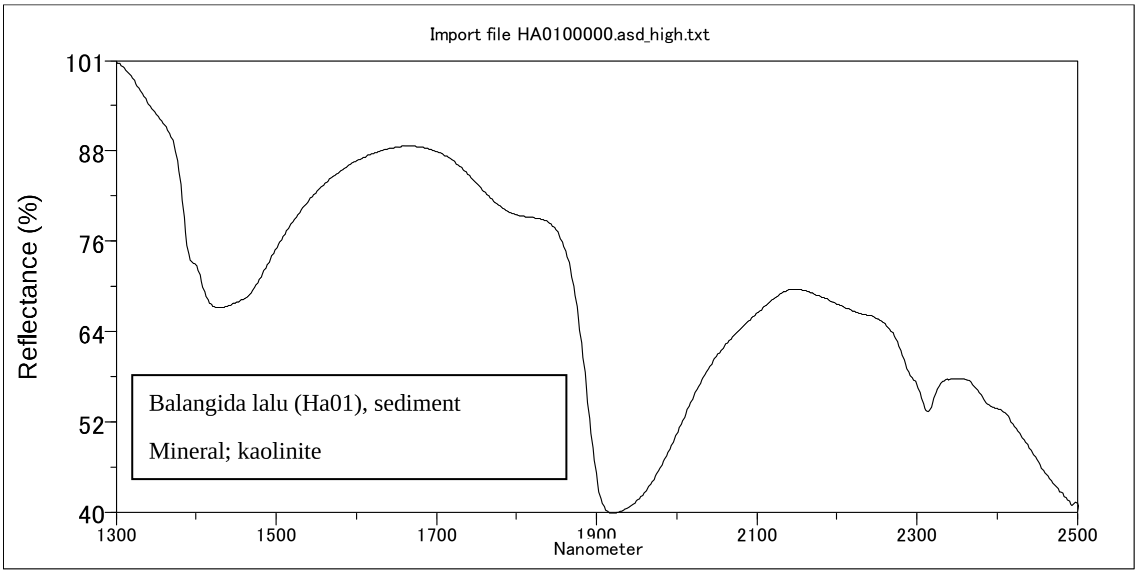

Import file NG0000000.asd_high.txt
Reflectance (%)
Nanometer
Ngorongoro (Ng01), sediment
Mineral; Smectite

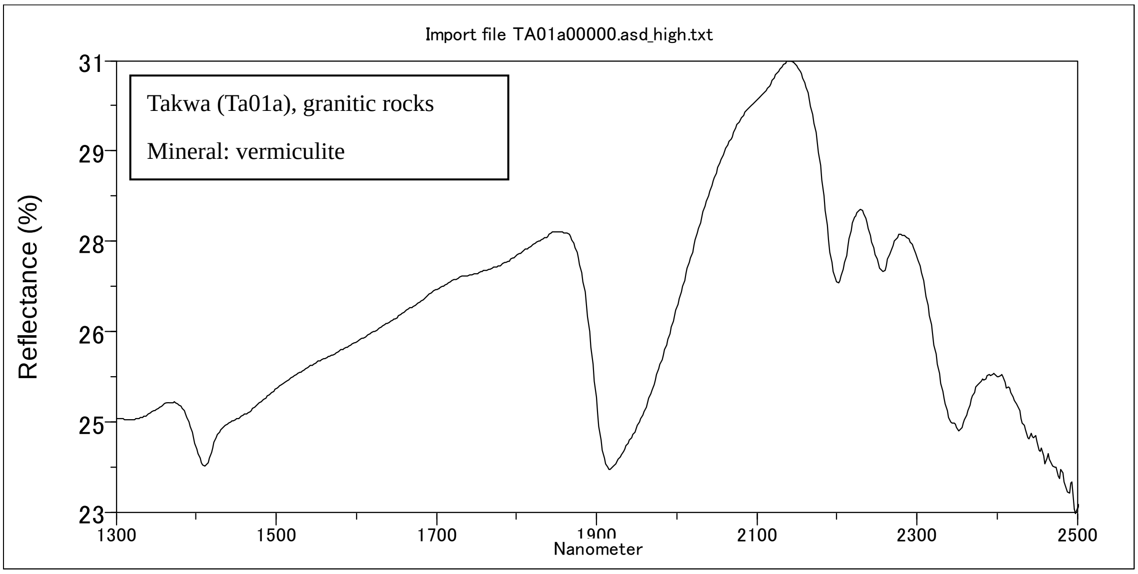

Import file EY0100000.asd_high.txt
Reflectance (%)
38
33
28
23
18
13
1300
1500
1700
1900
2100
2300
2500
Nanometer
Lake Eyasi (Ey01), sediment
Mineral; anhydrite

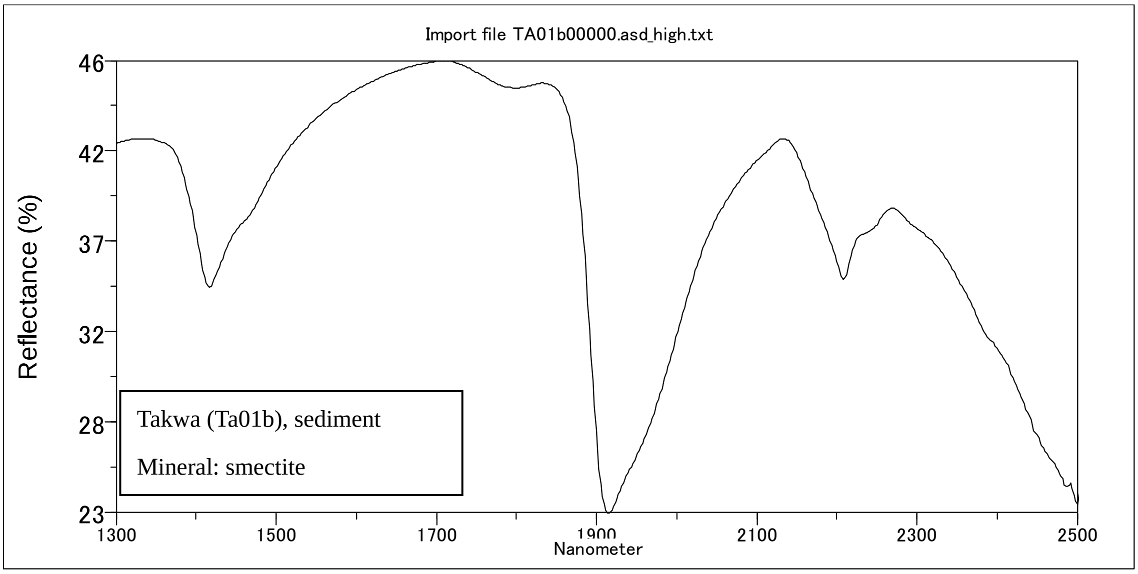

Import file BA01a00000.asd_high.txt
Reflectance (%)
53
51
49
46
44
42
1300
1500
1700
1900
2100
2300
2500
Nanometer
Masware (Ba01a), gneiss
Mineral; smectite, illite?

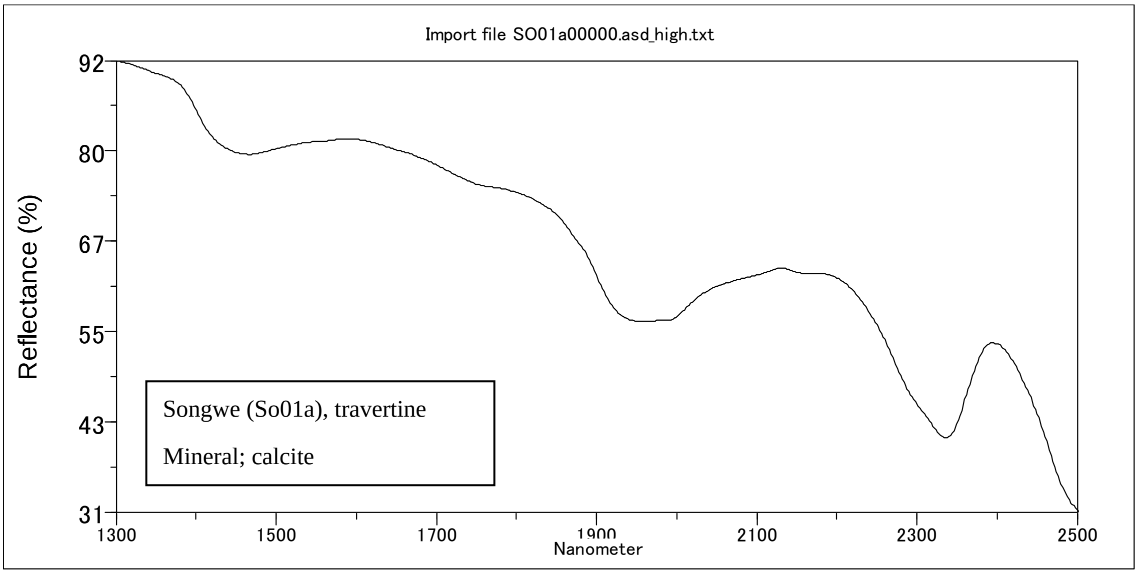

Import file BA01b00000.asd_high.txt
Reflectance (%)
51
47
43
38
34
30
1300
1500
1700
1900
2100
2300
2500
Nanometer
Masware (Ba01b), sediment
Mineral; kaolinite? Smectite?

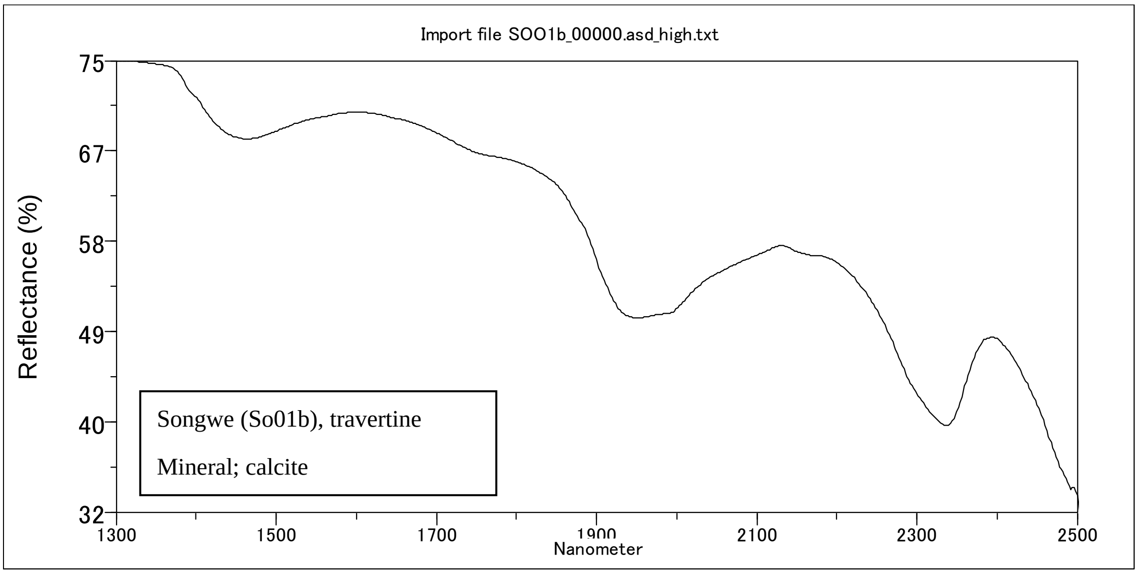

Import file BA01c00000.asd_high.txt
Masware (Ba01c), sediment
Mineral; kaolinite, Smectite?
Reflectance (%)
Nanometer
89
85
81
77
73
69
1300
1500
1700
1900
2100
2300
2500

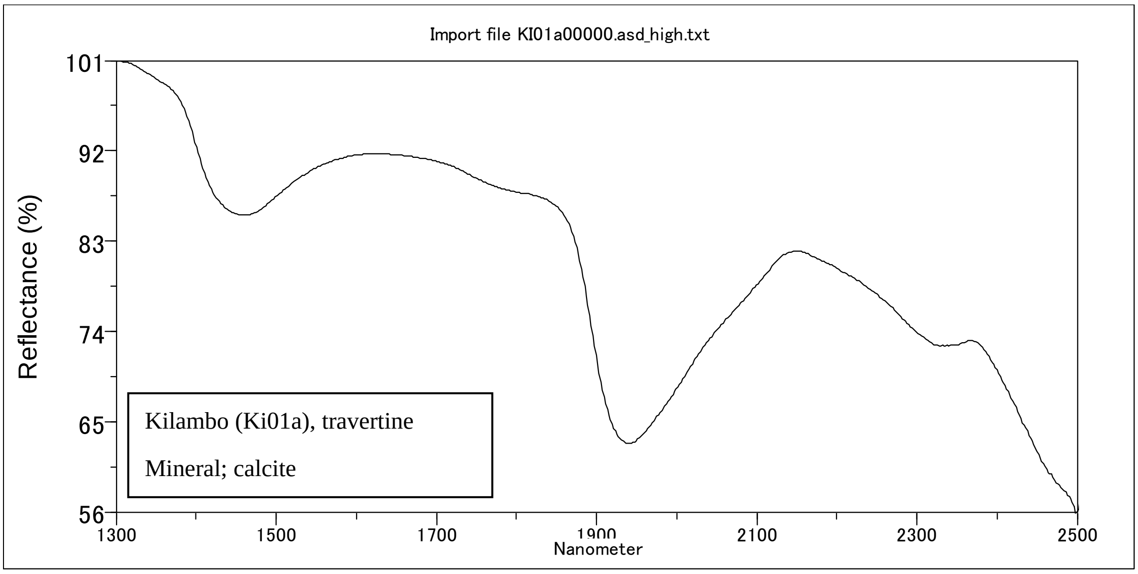

Import file HA0100000.asd_high.txt
Balangida lalu (Ha01), sediment
Mineral; kaolinite
Reflectance (%)
Nanometer
101
88
76
64
52
40
1300
1500
1700
1900
2100
2300
2500

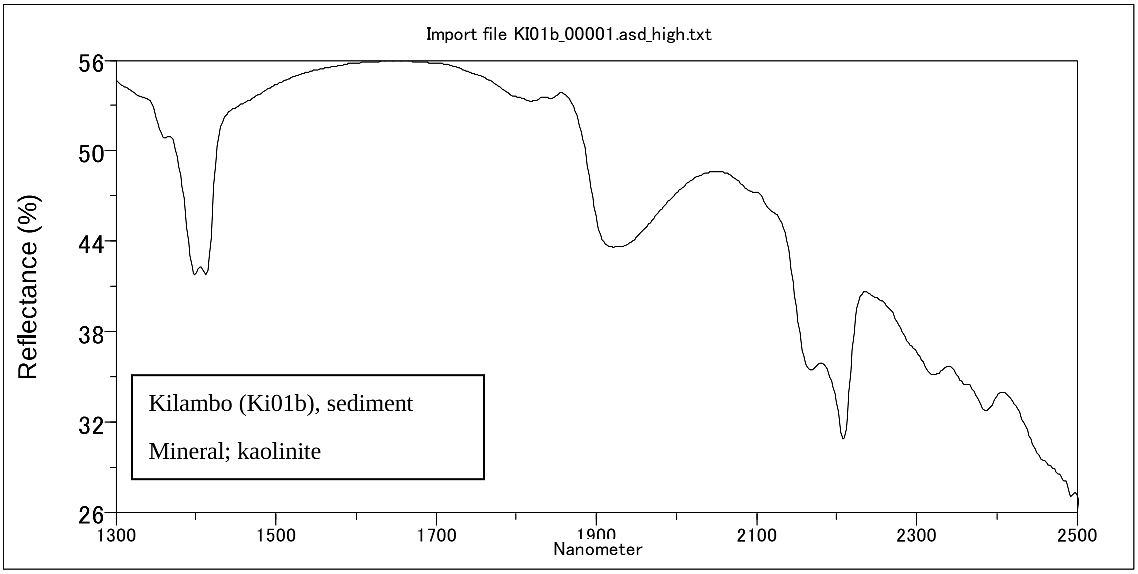

Import file TA01a00000.asd_high.txt
Takwa (Ta01a), granitic rocks
Mineral: vermiculite
Reflectance (%)
Nanometer
31
29
28
26
25
23
1300
1500
1700
1900
2100
2300
2500

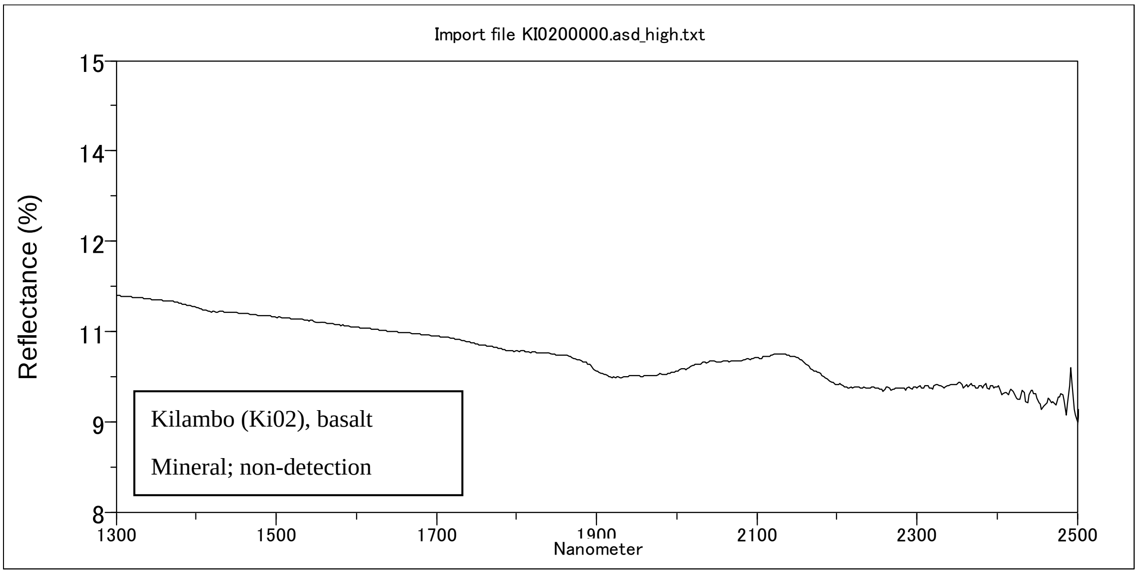

Import file TA01b00000.asd_high.txt
Reflectance (%)
46
42
37
32
28
23
1300
1500
1700
1900
2100
2300
2500
Nanometer
Takwa (Ta01b), sediment
Mineral: smectite

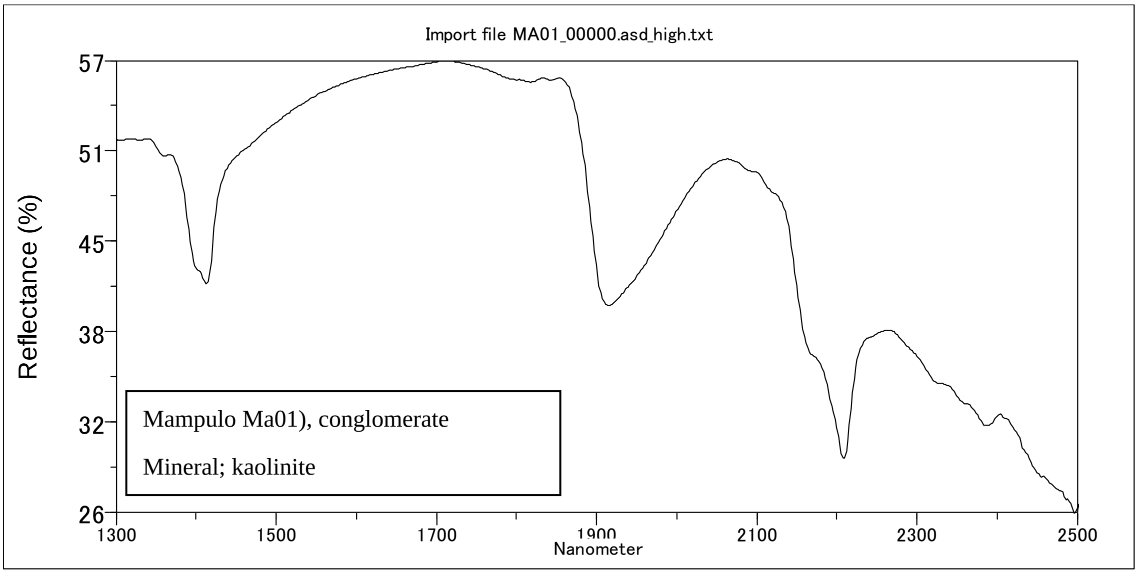

Import file SO01a00000.asd_high.txt
Reflectance (%)
92
80
67
55
43
31
1300
1500
1700
1900
2100
2300
2500
Nanometer
Songwe (So01a), travertine
Mineral; calcite

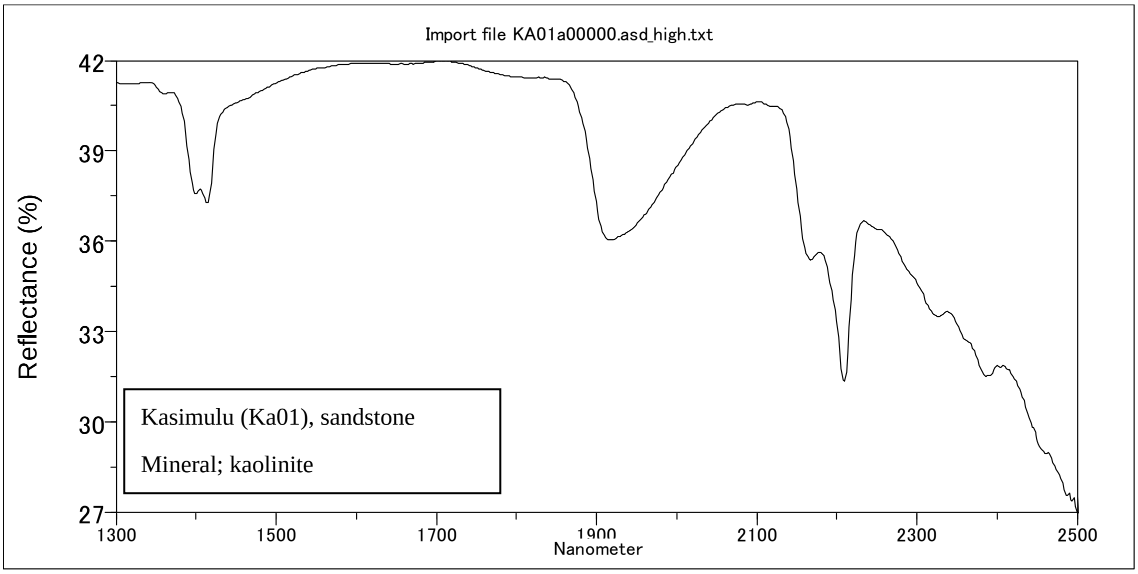

Import file SOO1b_00000.asd_high.txt
Reflectance (%)
75
67
58
49
40
32
1300
1500
1700
1900
2100
2300
2500
Nanometer
Songwe (So01b), travertine
Mineral; calcite

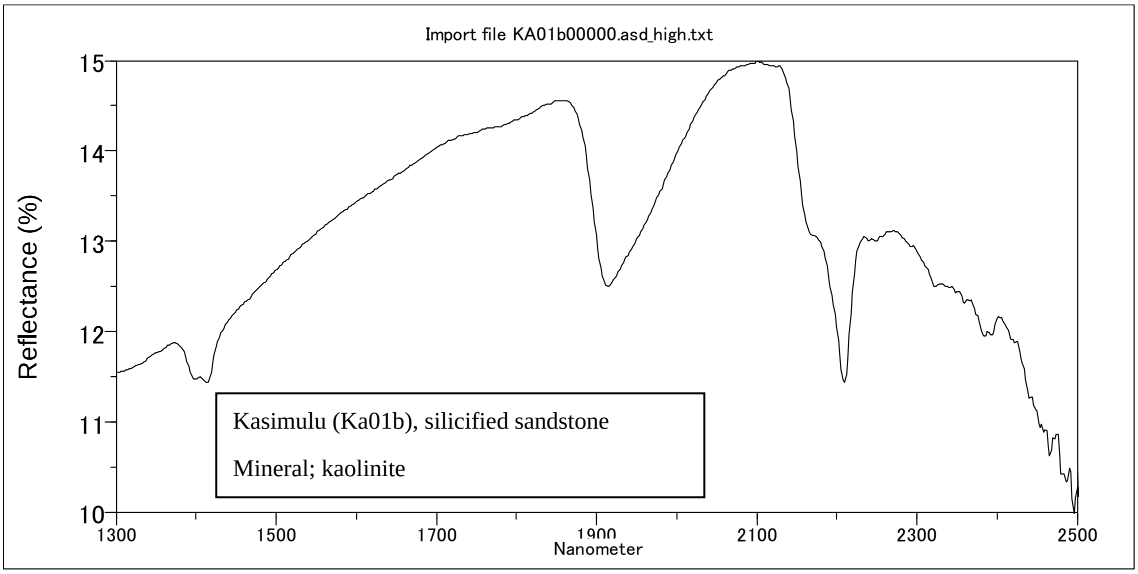

Import file KI01a00000.asd_high.txt
101
92
83
74
65
56
Reflectance (%)
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kilambo (Ki01a), travertine
Mineral; calcite

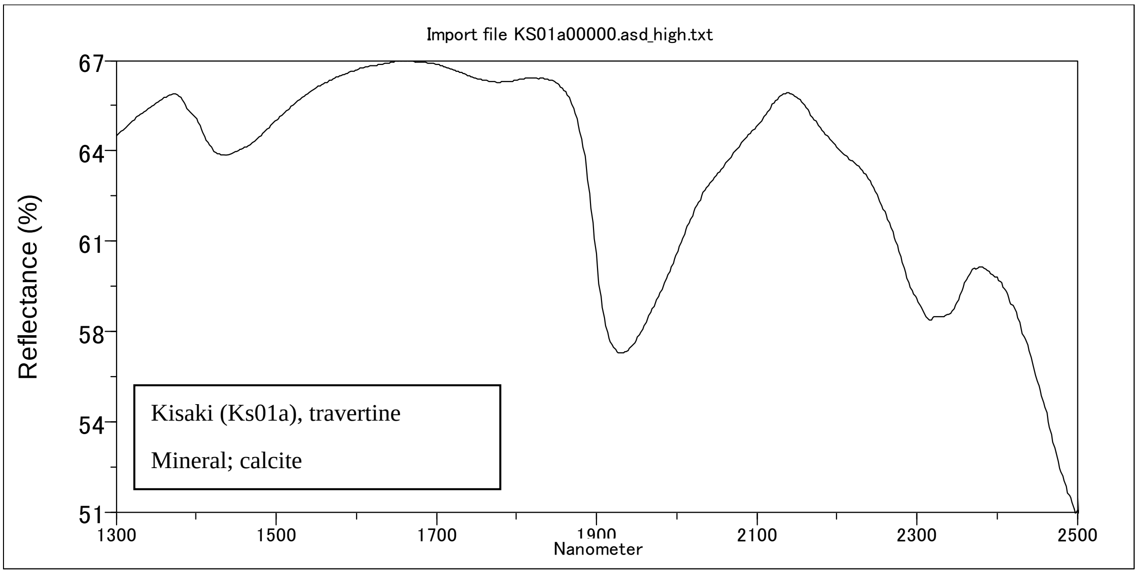

Import file KI01b_00001.asd_high.txt
56
50
44
38
32
26
Reflectance (%)
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kilambo (Ki01b), sediment
Mineral; kaolinite

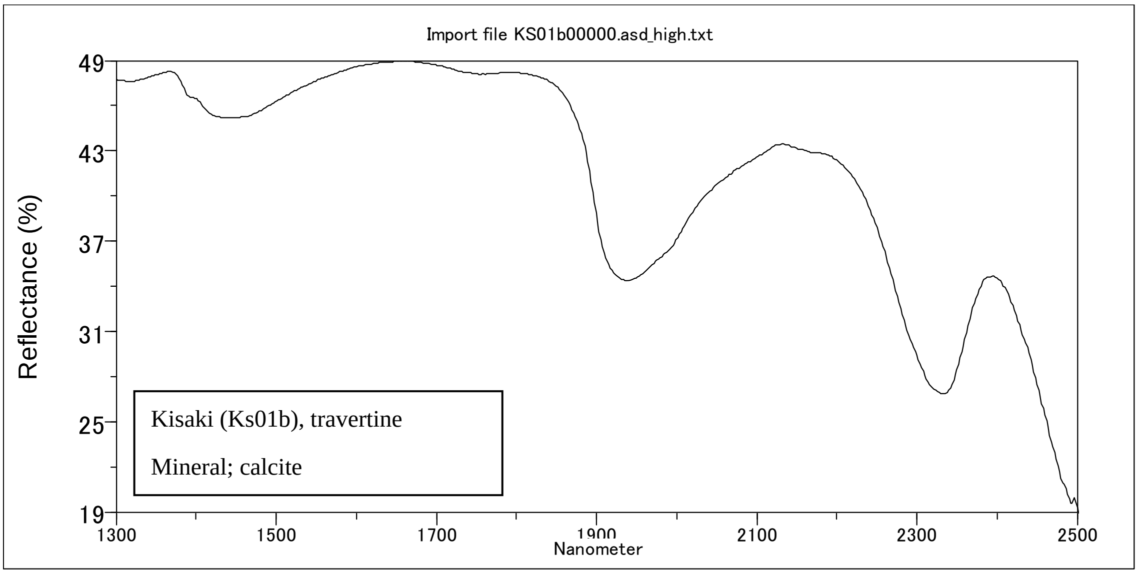

Import file KI0200000.asd_high.txt
15
14
12
11
9
8
Reflectance (%)
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kilambo (Ki02), basalt
Mineral; non-detection

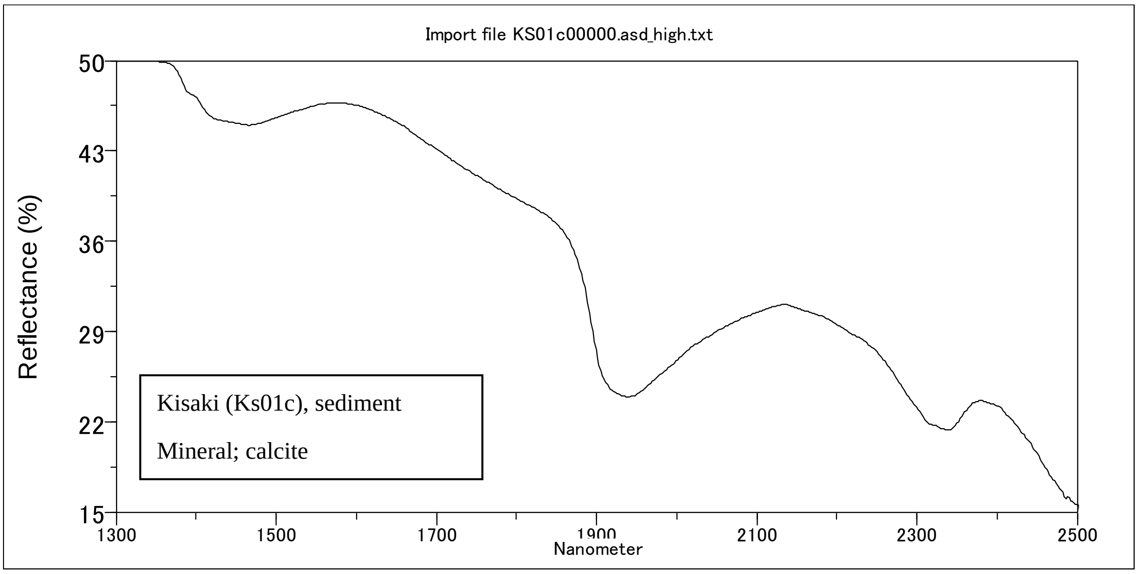

Import file MA01_00000.asd_high.txt
Reflectance (%)
57
51
45
38
32
26
1300
1500
1700
1900
2100
2300
2500
Nanometer
Mampulo Ma01), conglomerate
Mineral; kaolinite

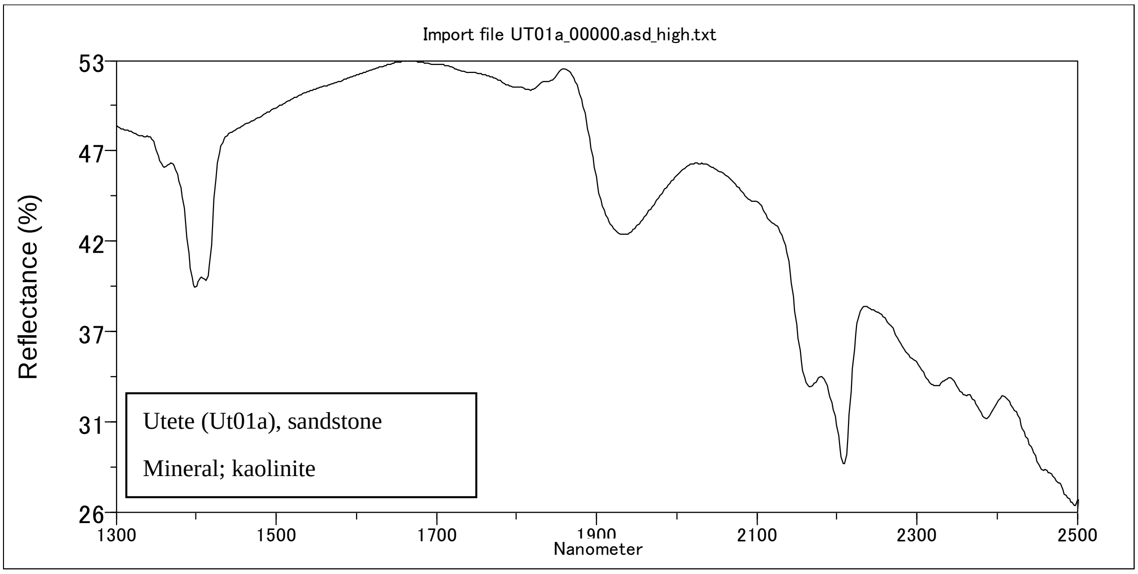

Import file KA01a00000.asd_high.txt
Reflectance (%)
42
39
36
33
30
27
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kasimulu (Ka01), sandstone
Mineral; kaolinite

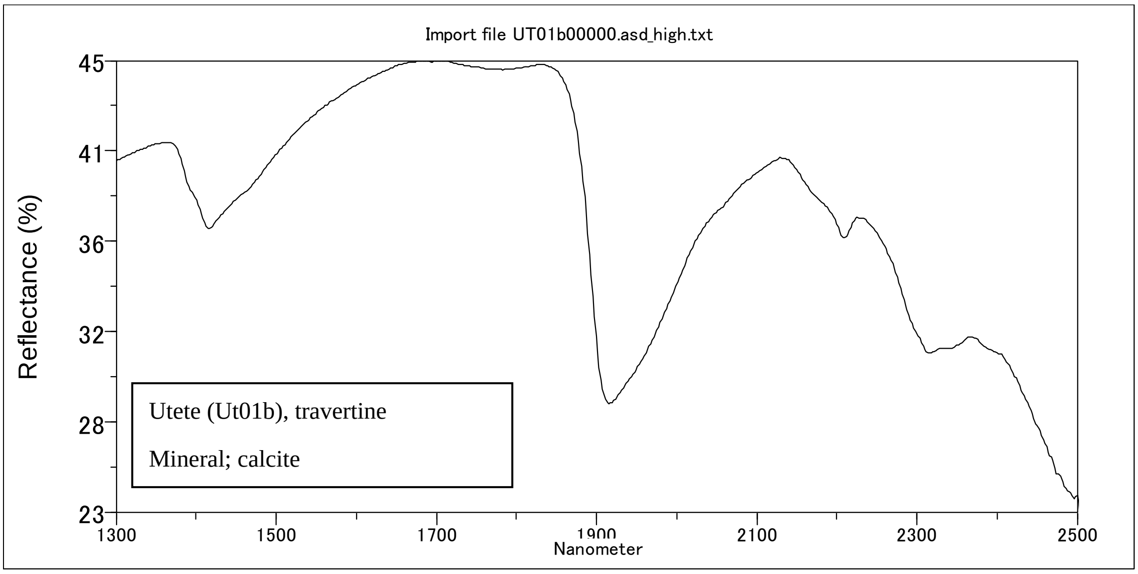

Import file KA01b00000.asd_high.txt
Reflectance (%)
15
14
13
12
11
10
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kasimulu (Ka01b), silicified sandstone
Mineral; kaolinite

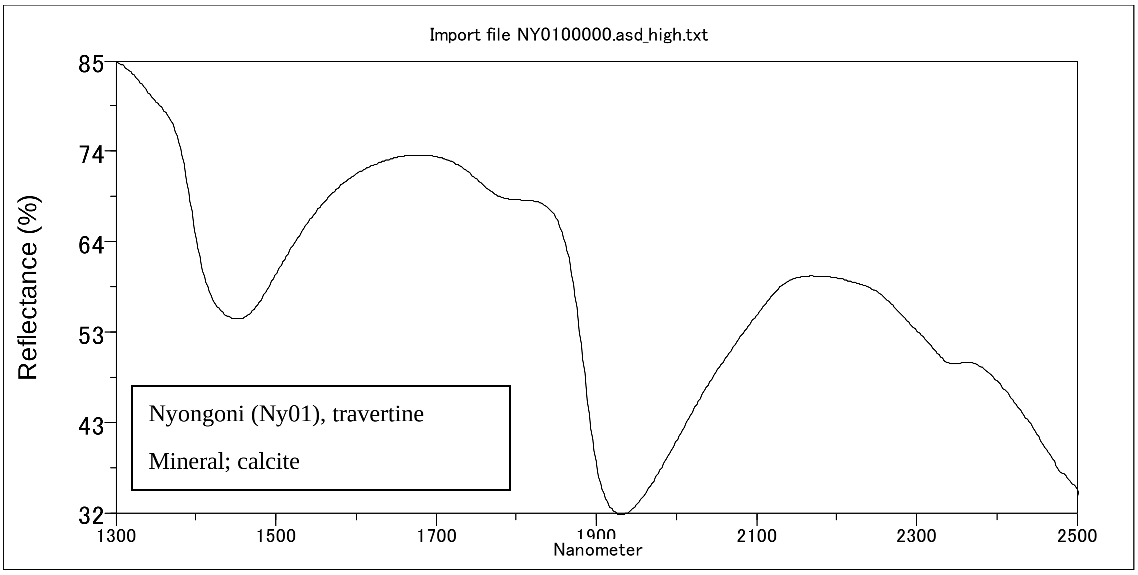

Import file KS01a00000.asd_high.txt
Reflectance (%)
67
64
61
58
54
51
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kisaki (Ks01a), travertine
Mineral; calcite


Import file KS01b00000.asd_high.txt
Reflectance (%)
49
43
37
31
25
19
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kisaki (Ks01b), travertine
Mineral; calcite


Import file KS01c00000.asd_high.txt
Reflectance (%)
50
43
36
29
22
15
1300
1500
1700
1900
2100
2300
2500
Nanometer
Kisaki (Ks01c), sediment
Mineral; calcite


Import file UT01a_00000.asd_high.txt
Reflectance (%)
53
47
42
37
31
26
1300
1500
1700
1900
2100
2300
2500
Nanometer
Utete (Ut01a), sandstone
Mineral; kaolinite


Import file UT01b00000.asd_high.txt
Reflectance (%)
45
41
36
32
28
23
1300
1500
1700
1900
2100
2300
2500
Nanometer
Utete (Ut01b), travertine
Mineral; calcite


Import file NY0100000.asd_high.txt
Reflectance (%)
85
74
64
53
43
32
1300
1500
1700
1900
2100
2300
2500
Nanometer
Nyongoni (Ny01), travertine
Mineral; calcite

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

Spring Area	Temp. °C	pH F/[1)] pH L	HCO_3 mg/l	Cl mg/l	SO_4 mg/l	F mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Si mg/l	SiO_2 mg/l	Ref.
Coastal Basin and Nothern Rift System													
Tanga													
Kidugaro	37	6.6/7.0	620	1,100	63	0.8	192	21	700	49	14	29	G
Lake Natron													
East	38-50	8.9	3,780	940	145	24	2	1	2,280	56	n.a.	30	D
Central	35	9.3/9.4	25,000	2,040	1,730	350	2	0.5	10,800	617	50	106	G
West	32	10/10	3,800	1,070	136	22	0.8	0.1	2,080	34	11	23	G
Ngorogoro	32	7.6	268	12	2	1.4	4.5	11	61	12	n.a.	110	D
Lake Manyara	69	9.9	>1,100	235	30	n.a.	2	2	580	n.a.	n.a.	98	A
Lake Eyasi	42	9.3	3,390	4,810	680	59	1	1	5,440	50	n.a.	44	D
Musoma													
Maji Moto	60	9.4	1,832	1,140	445	20	1	1	1,980	33	n.a.	98	D
West Lake													
Mtagate	53	8.1	44	14	18	1	13	1	20	3	n.a.	50	C
Central Cration Precambrium Terrain-Rufiji Basin													
Dodoma - Singida - Kondoa	31-47	7.2-8.9 7.5-8.9	121-590	48-770	37-360	0.8-9.5	2.3-110	0.1-27	93-915	2-49	n.a.	29-56	D
	Max-Min values from 8 analyses representing 7 different springs												
Rufiji Valley													
Maji y Weta	70	8.5	750	160	300	n.a.	40	32	815	n.a.	n.a.	65	C
Utete	55	7.5	756	147	280	4.3	16	5.8	510	20	n.a.	40	D
Luhoi	50-75	na	na	na	na	na	22.4	na	2,472	176	15.3	n.a.	F
Southern Rift System													
Lake Rukwa													
Ivuna	60	8	200	2,040	225	7	78	17	1,320	76	n.a.	100	E
Songwe River													
Rambo	86	6,6/7,5	1920	215	170	9	23	8	840	93	n.a.	68	D
Main	72	6,7/7,4	2000	197	168	7.6	39	16	773	100	35	75	G
Marlo	53	6,7/7,2	2000	225	175	8.8	44	9	823	90	32	69	G
Nyasa Basin													
Kilambo	59	6,7/7,2	3840	350	405	2.7	30	12	1810	64	n.a.	120	D
Kasimulu	61	6,7/7,1	3070	220	360	2	63	19	1330	74	n.a.	130	D
Kalambo	58	6,8/7,0	2610	410	230	3.2	73	34	1170	75	n.a.	120	D
Mampulo	63	7.2	1425	135	230	na	36	18	910	na	n.a.	125	B

Note: 1) F= field analyzed、 L= laboratory analyzed References: A. Harris 1951 – B. Harkin 1960 – C. Walker 1969 – D. SWECO 1978 – E. Makundi and Kifua 1985 – F. First Energy Company Ltd 1999 – G. SWECO 2004 (DECON-SWECO, 2005)

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

Spring area Name	Temp °C	Silica °C	Chalcedony °C	Na-K °C	Na-K-Ca °C	F mg/l	CO_2[4] mg/l	Ref.
Coastal Basin and Northern Rift System								
Tanga								
Kidugaro	37	78-83[1]	47	146-152[2]	167	0.8	<0.1	C
L. Natron								
East	38-50	80	48	n.a.	172	24	0	A
Central 1	35	136-140	114	127-134	257	350	<0.1	C
Central 2	28	81-85	48	114-122	210	27	<0.1	C
West	32	69-74	37	40-51	159	22	<0.1	C
Ngorogoro	32	143	116	279	215	1.4	12	A
(Caldera)								
L Manyara	69	107	109	n.a.	n.a.	n.a.	n.a.	B
L Eyasi	42	55	66	n.a.	144	59	0	A
Musoma								
Maji Moto	60	123	109	n.a.	156	20	0	A
Central Cration Precambrium Terrain-Rufiji Basin								
Dodoma - Singida - Kondoa	31-47	78-107	n.a.	n.a.	58-116	1-10	1-21	A
	Max-Min values from 8 analyzes representing 7 different springs							
Rufiji Valley								
Maji y Weta	70	91	86	136	177	7.2	74	A
Utete[3]	55	90-92	61	n.a.	154-157	4.3	69	A
Luhoi	50-75	n.a.	n.a.	140	210	n.a.	n.a.	D
Southern Rift System								
Songwe River								
Rambo 1	86	117	88	196	216	9	110	A
Rambo 2	83	111	88	189	213	9.1	222	A
Rambo 3	73	128	88	216	217	7.3	181	A
Main	72	120-121	93	216-217	219	7.6	<1	C
Marlo	53	117-118	89	195-198	209	8.8	94	C
Nyasa Basin								
Kilambo 1[3]	64	148-161	122	113-119	176-177	1.9	245	A
Kilambo 2[3]	59	148-161	122	88-103	164-176	2.7	439	A
Kasimulu 1	61	152	127	124	176	2	441	A
Kasimulu 2	58	140	127	126	180	1.8	208	A
Kalambo[3]	58	148-161	122	144	189	3.2	73	A

1) Higher ref C values represent adiabatic and lower values conductive conditions.
2) Higher ref C values according to White and Ellis and lower according to Fournier and Truesdell.
3) Analyses on duplicate samples.
4) CO_2 are all calculated values.

References: A. SWECO 1978 - B. Hochstein et al. 2000 - C. SWECO 2004 - D. First Energy Company Ltd 1999

(modified from DECON-SWECO, 2005)

6. List of geothermometers of hot spring

Geothermometer	Equation	Unit	Reference
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	$\frac{1647}{\log(Na/K) + \beta \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15$ $For \sqrt{Ca}/Na < 1 \text{ or } \frac{1647}{\log(Na/K) + 4/3 \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15 > 100$ $\beta = 1/3$, $for\ the\ others\ \beta = 4/3$	Na, K, Ca: mol/L	Fournier and Truesdell (1973)
Tna-K-Ca-Mg	$\frac{1647}{\log(Na/K) + \beta \times \log(\sqrt{Ca+Mg}/Na) + 2.24} - 273.15$ $For \sqrt{Ca}/Na < 1 \text{ or } \frac{1647}{\log(Na/K) + 4/3 \times \log(\sqrt{Ca}/Na) + 2.24} - 273.15 > 100,$ $\beta = 1/3$, $for\ the\ others,\ \beta = 4/3$	Na, K, Ca, Mg: mol/L	Fournier and Truesdell (1973)

TΔMg

$R = \frac{Mg}{Mg + Ca + K} \square 100$

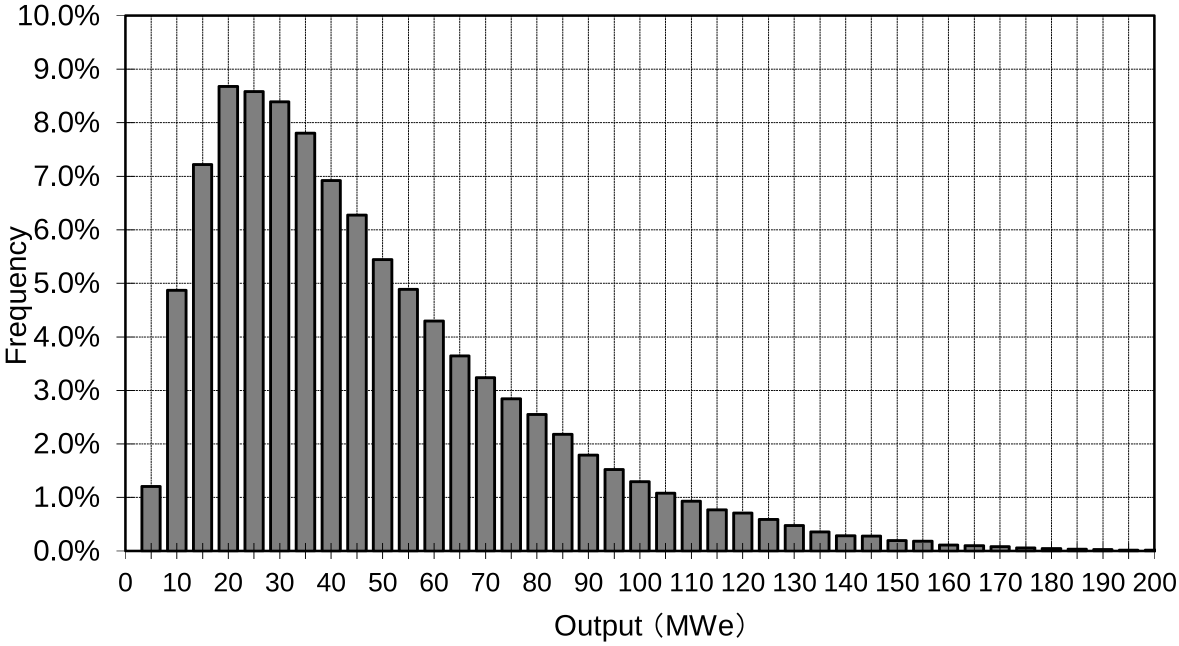
K, Ca, Mg: meq/L

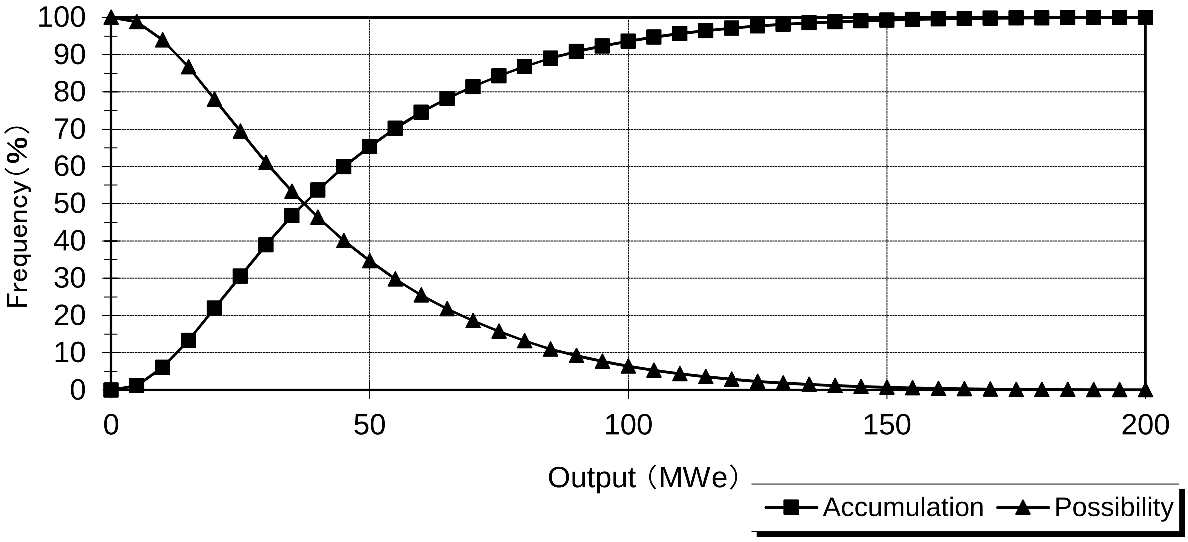
1) Mg correction is needed to the Na-K-Ca geothermometer.
2) The Mg correction is applicable only for waters which have TNa-K-Ca<70℃
3) If R>50, the geothermometer calculation is not applicable.
4) For 5≦R≦50, $\Delta tMg = 10.66 - 4.7415 \times R + 325.85 \times (\log R)^2 - 1.032 \times 10^5 \times (\log R)^2/T - 1.968 \times 10^7 \times (\log R)^2/T^2 + 1.605 \times 10^7 \times (\log R)^3/T^2$
   T=TNa-K-Ca (K)
5) For 0.5<R<5, $\Delta tMg = -1.03 + 59.971 \times \log R + 145.05 \times (\log R)^2 - 36711 \times$
6) In calculation 4), 5), for ΔtMg<0, or R<0.5, this geothermometer is not applicable.
7) TΔMg="TNa-K-Ca"-ΔtMg

Fournier and Potter (1979)

Geothermometer	Equation	Unit	Reference
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

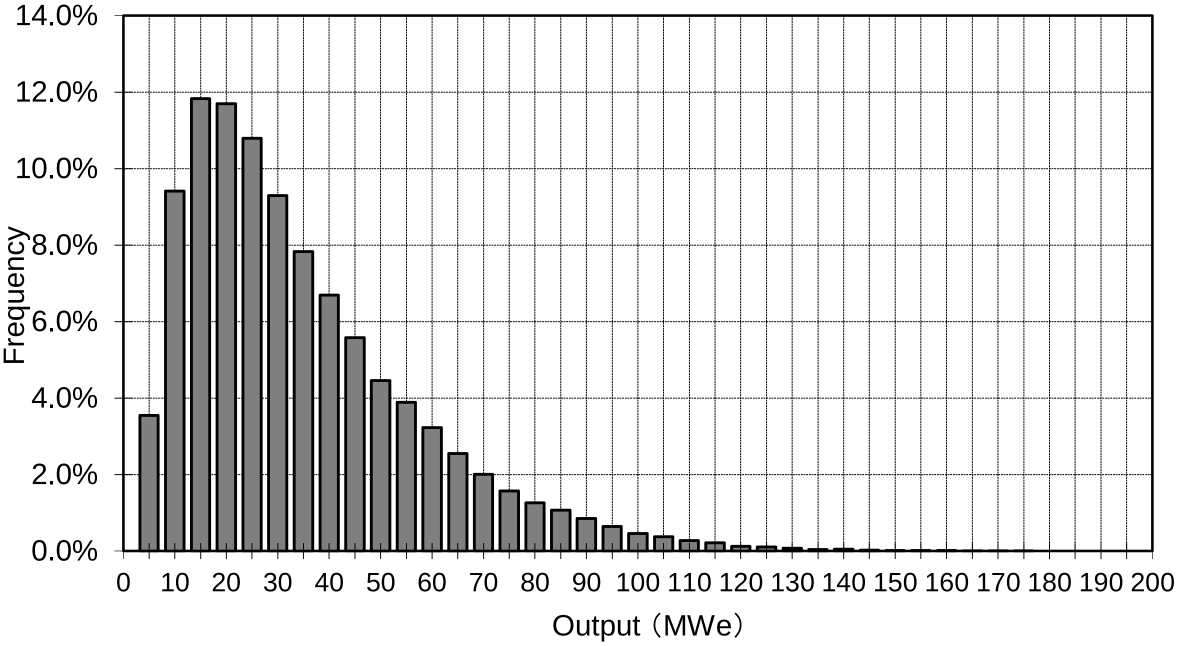


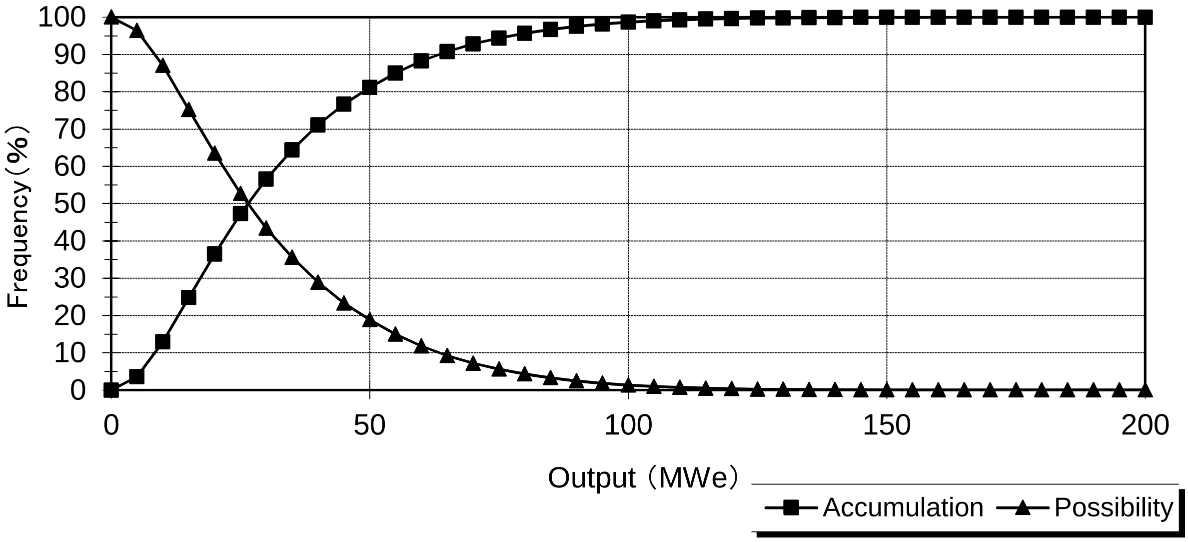


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	6.00	-	24.00
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 Lake Natron

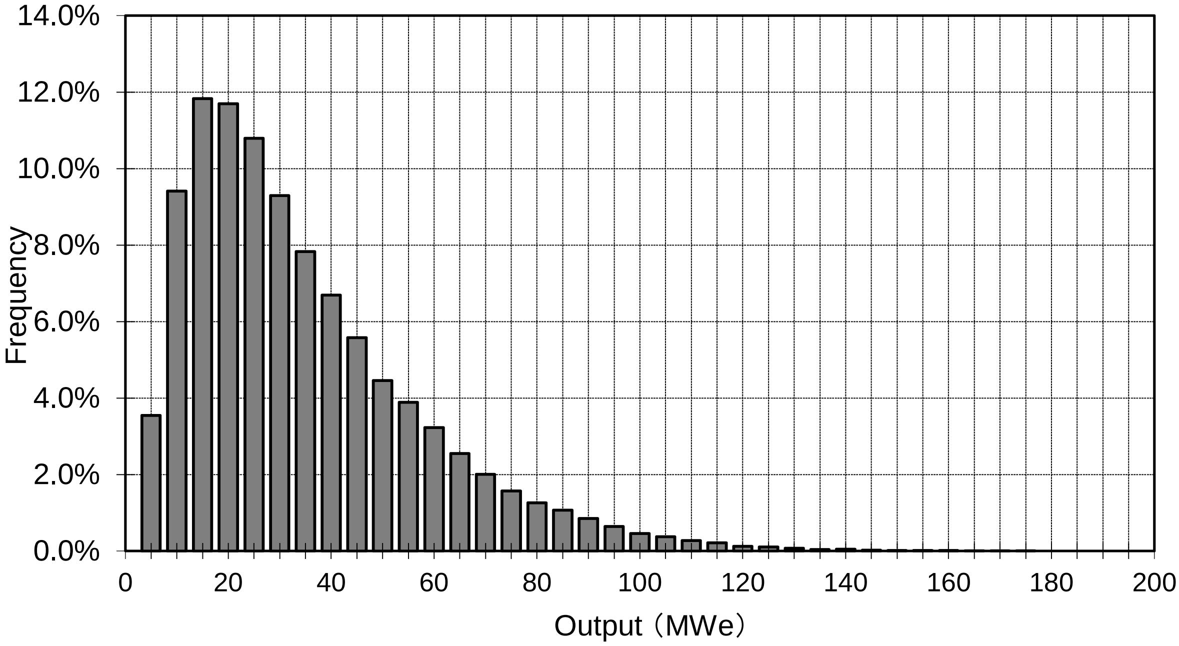


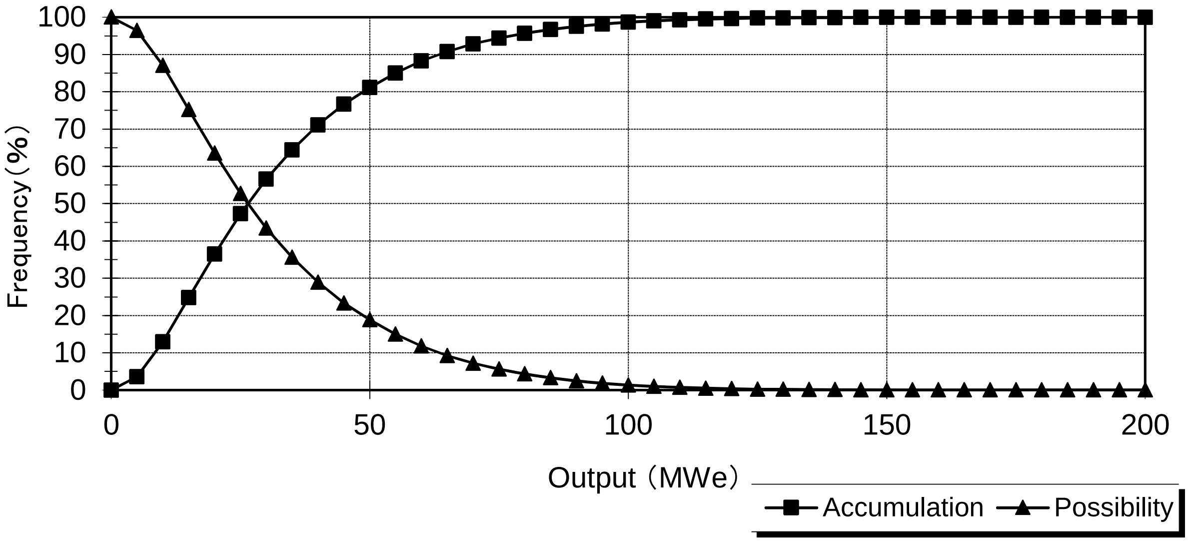


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	6.00	-	24.00
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)	140	160	180
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 Lake Manyara

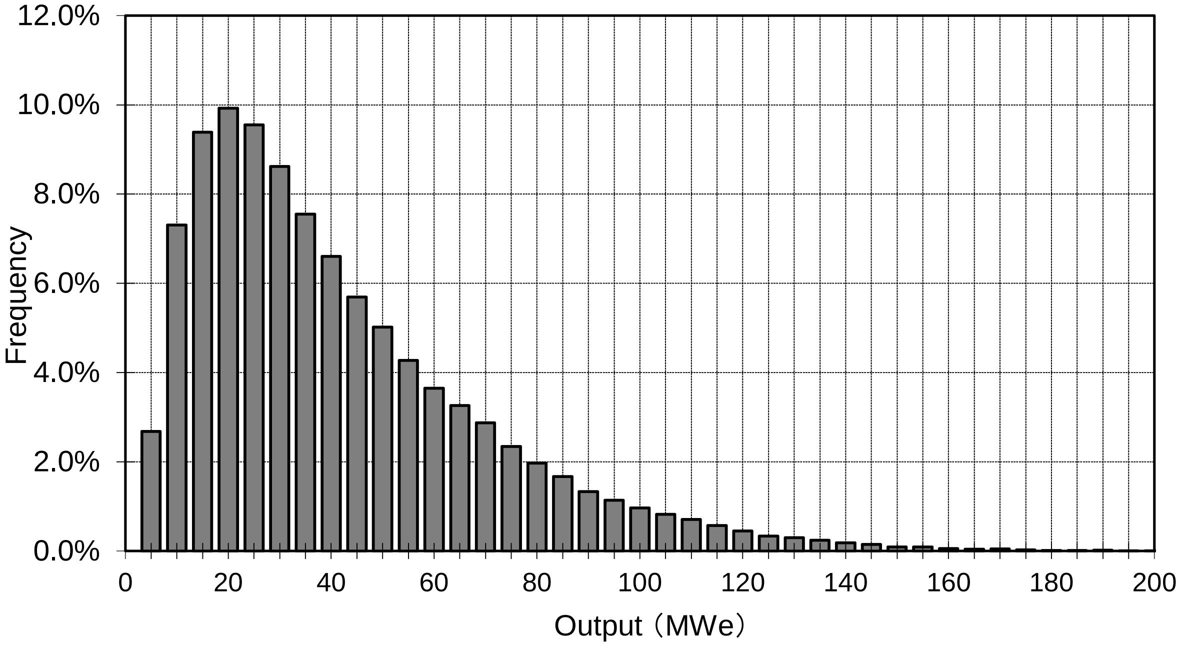


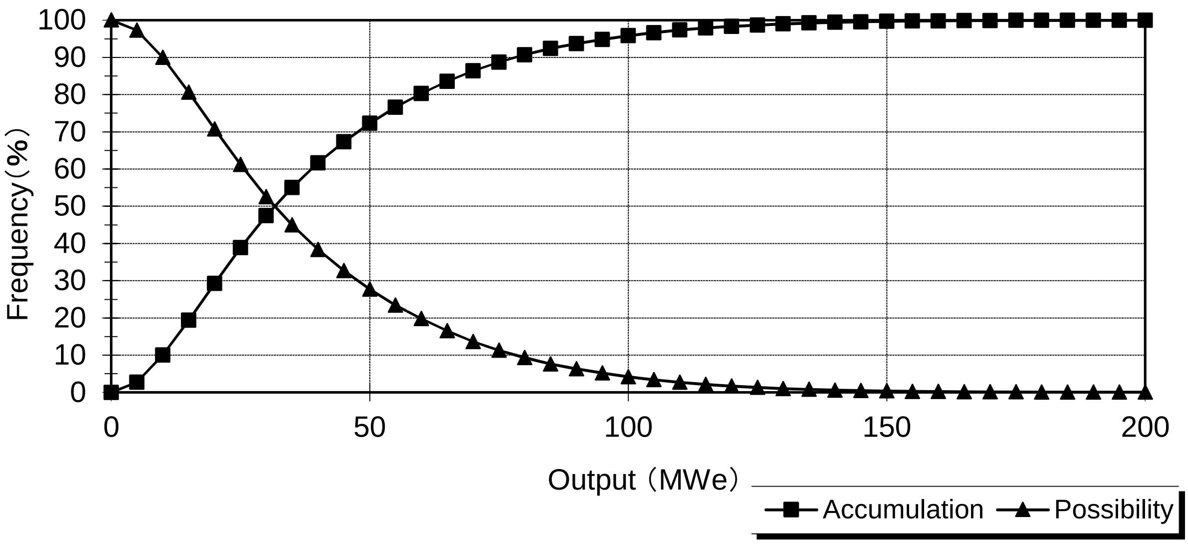


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	6.00	-	24.00
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)	140	160	180
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 Lake Eyasi

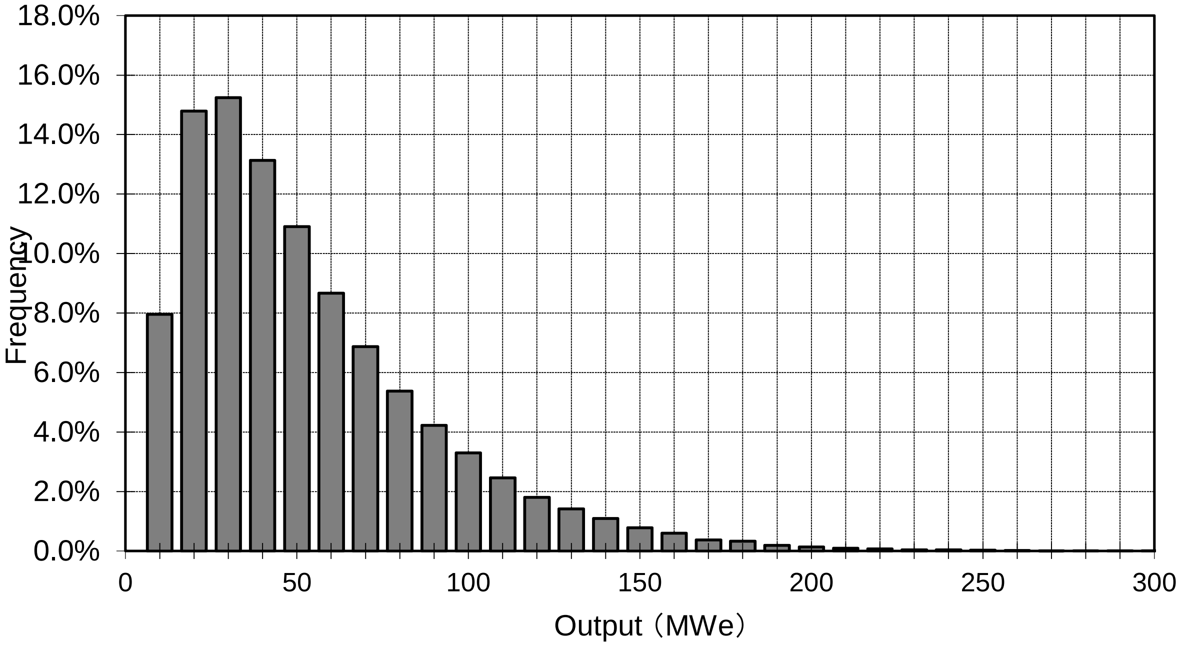


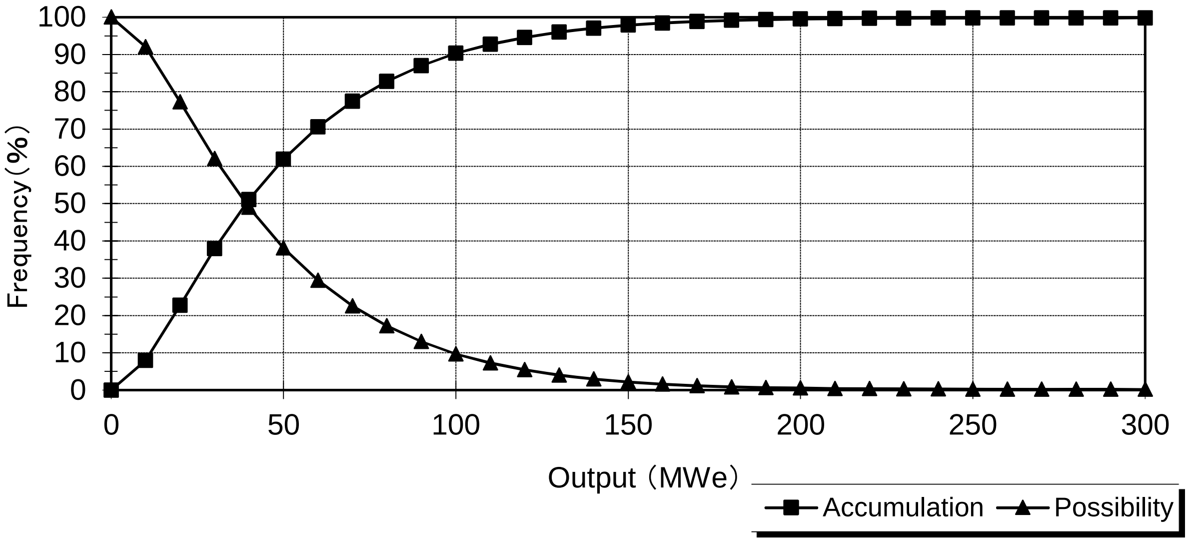


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	6.00	-	30.00
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)	140	160	180
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 Babati

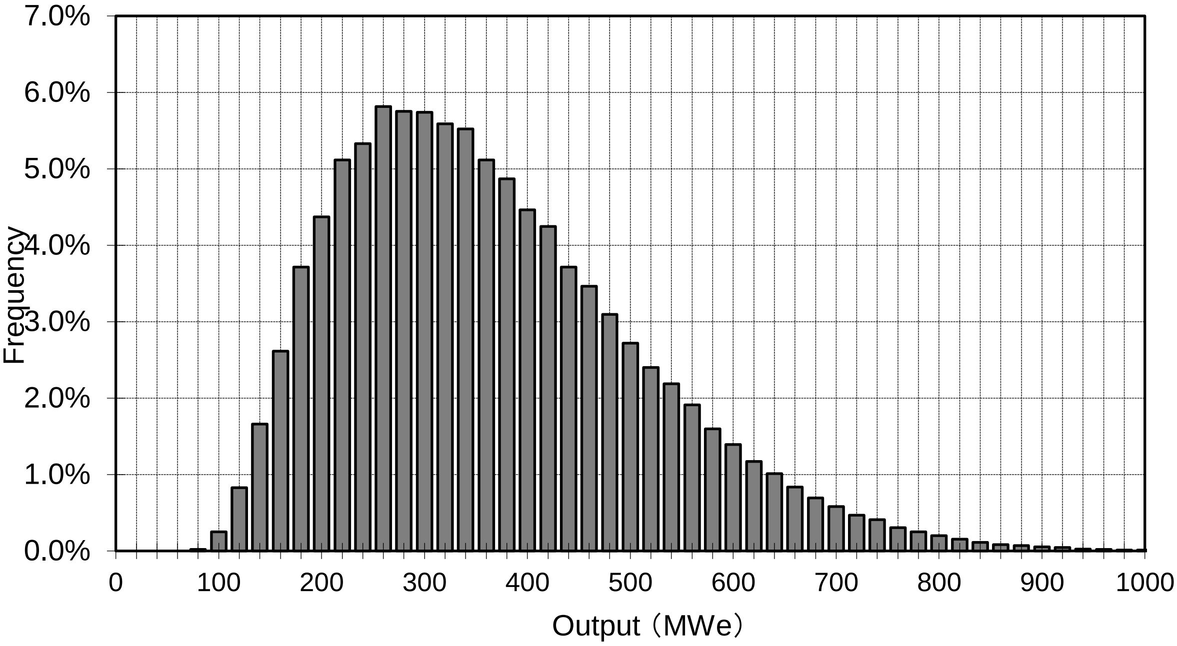


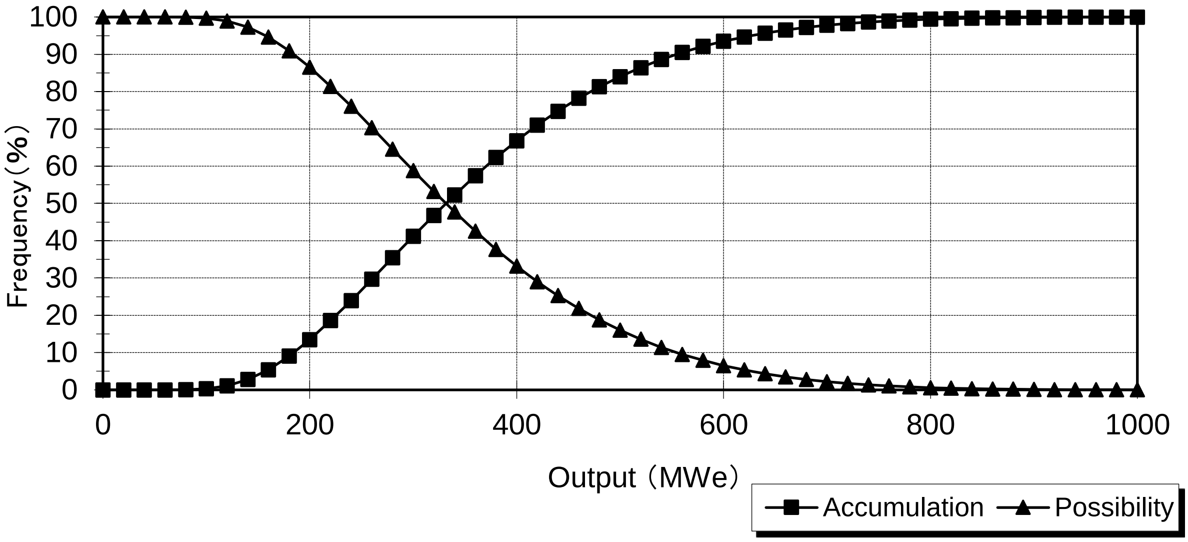


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	18.00	-	72.00
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2600	2800	3000
Porosity (-)	0.01	0.03	0.05
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	100	120	140
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 Msule

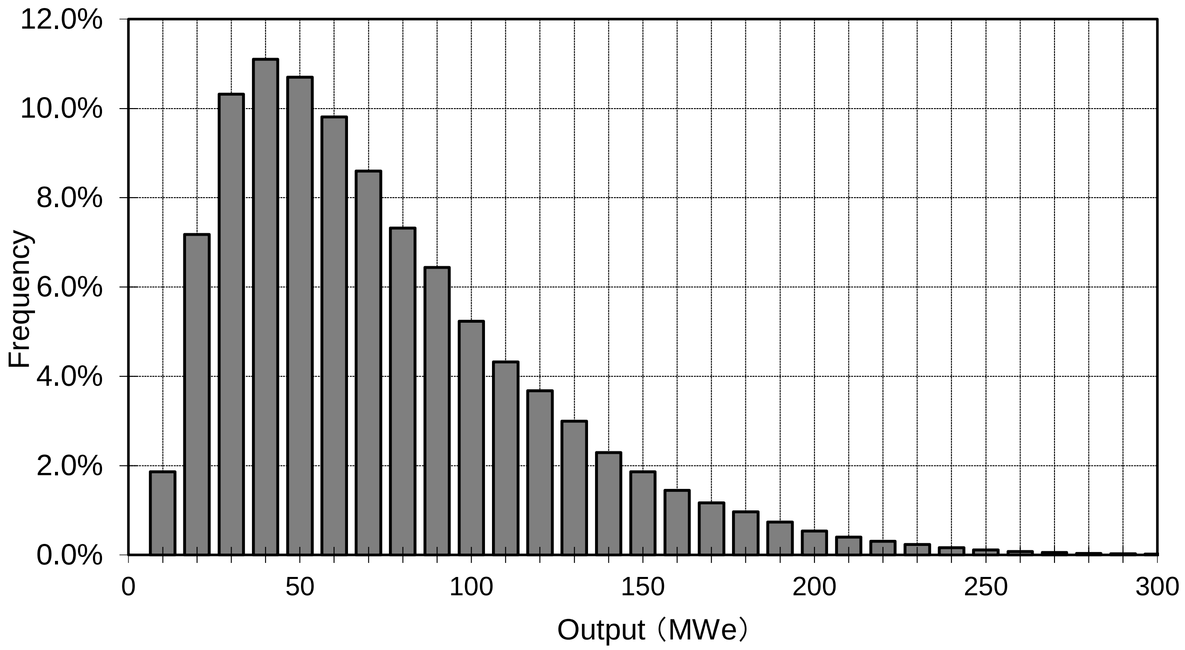


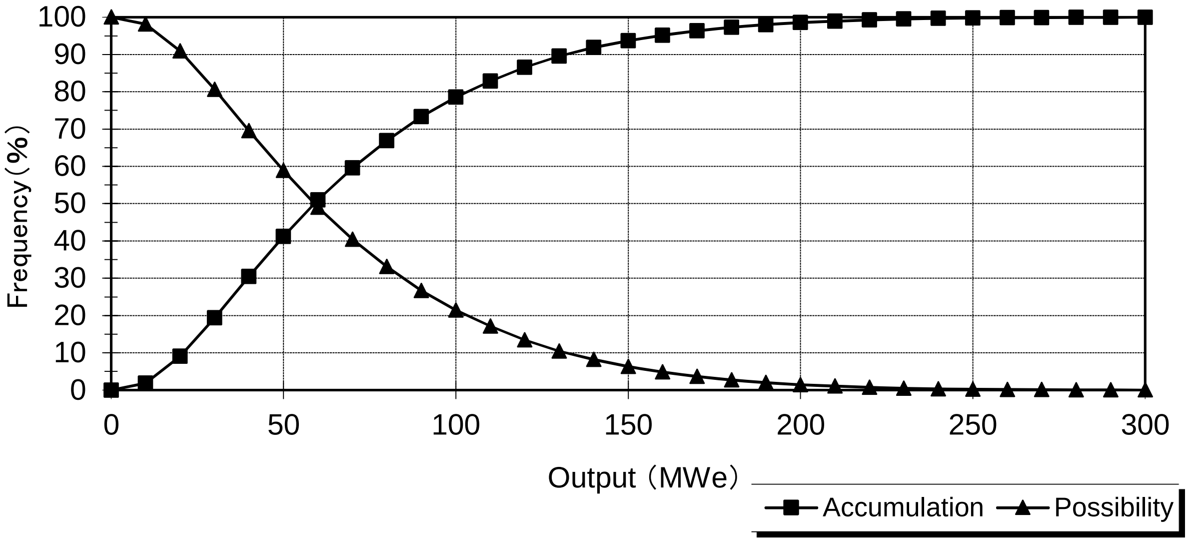


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	27.00	-	75.00
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)	210	230	250
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 Songwe

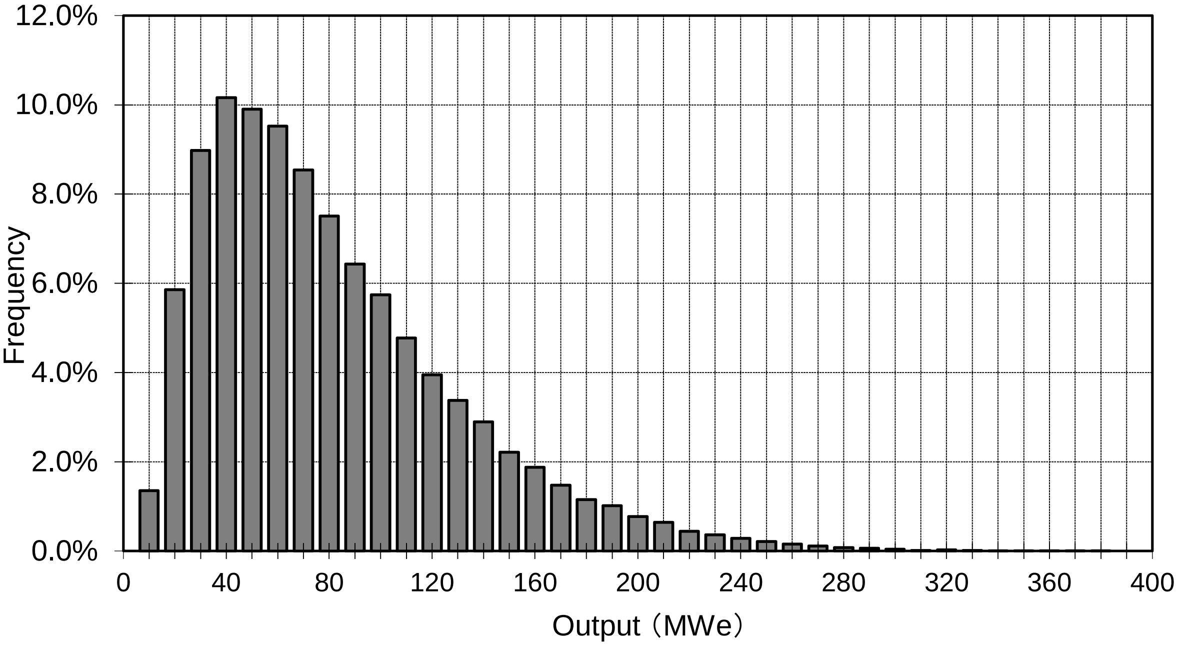


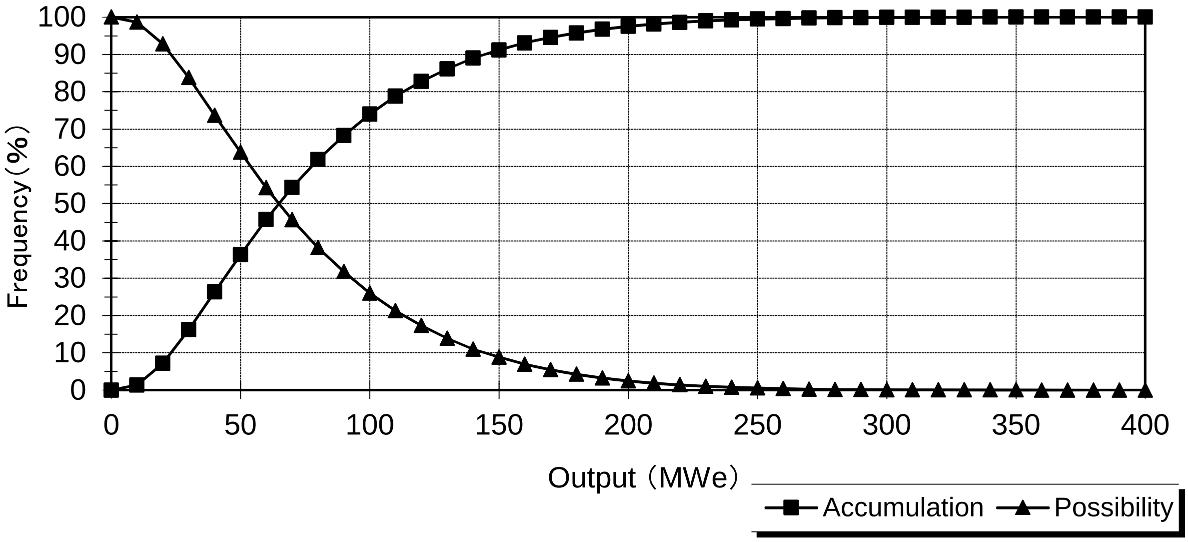


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	12.00	-	35.00
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 Kilambo

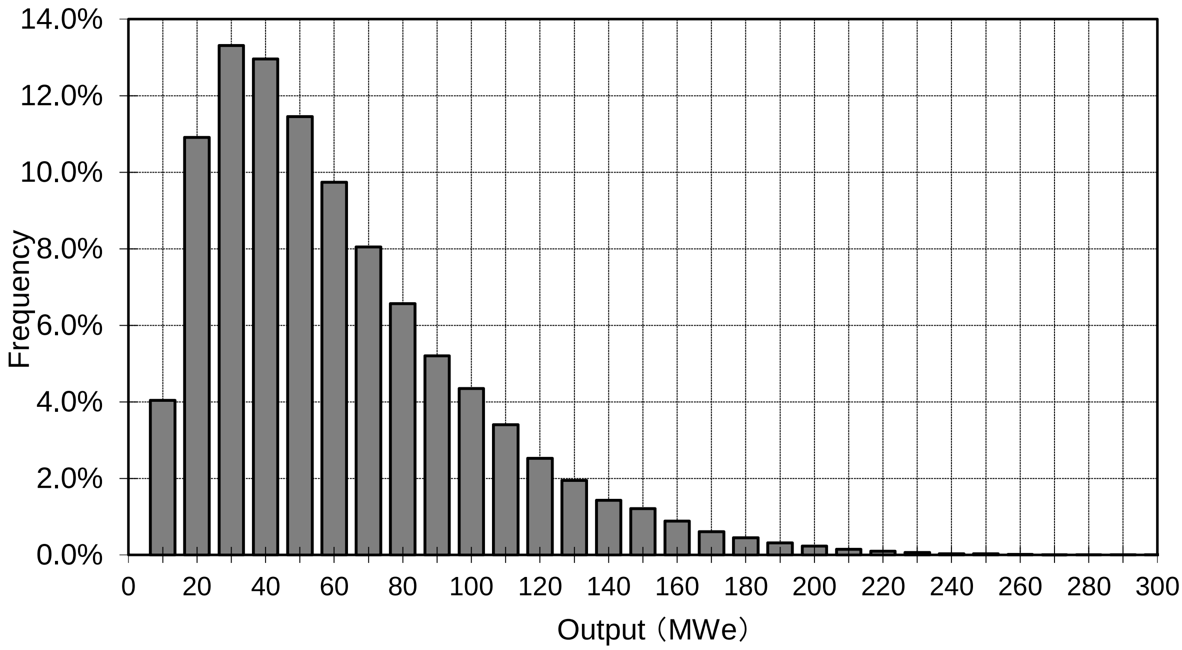


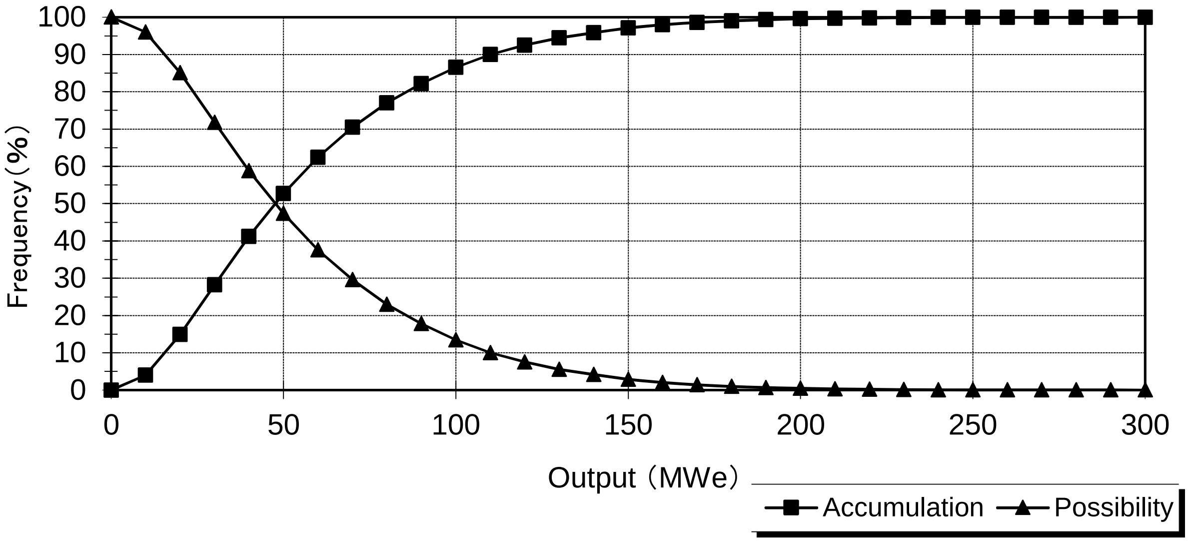


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	12.00	-	35.00
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)	180	200	220
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 Mampulo

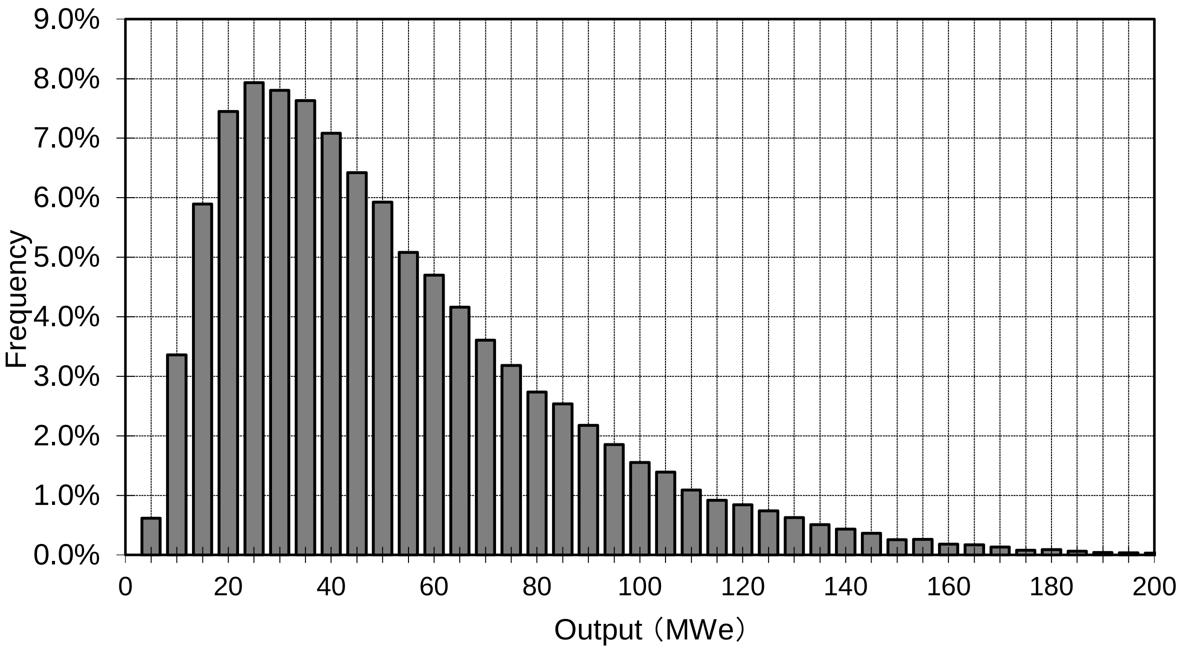


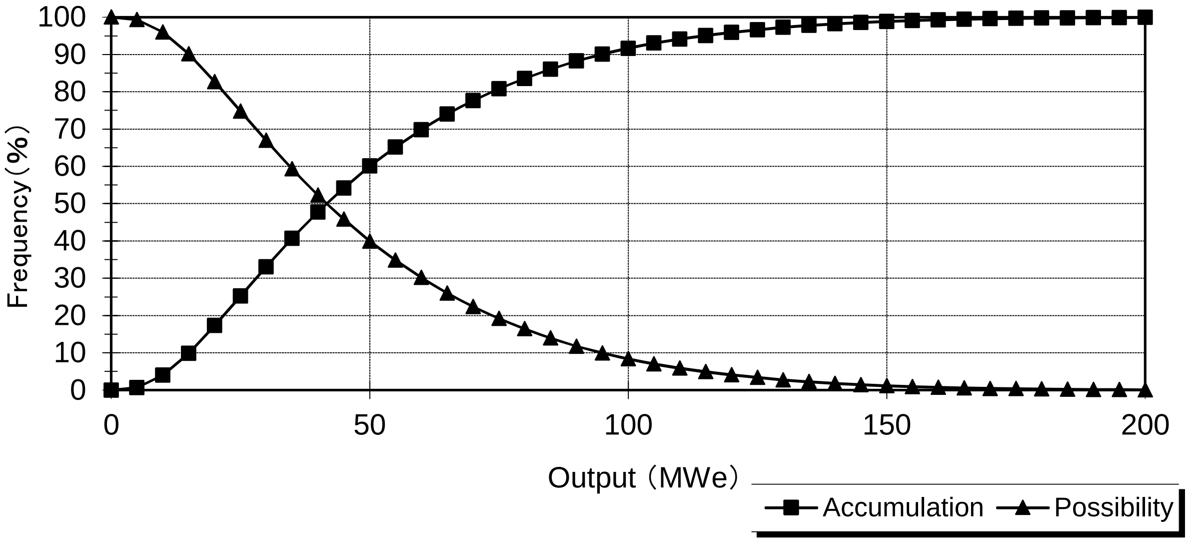


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	9.00	-	30.00
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 Kisaki

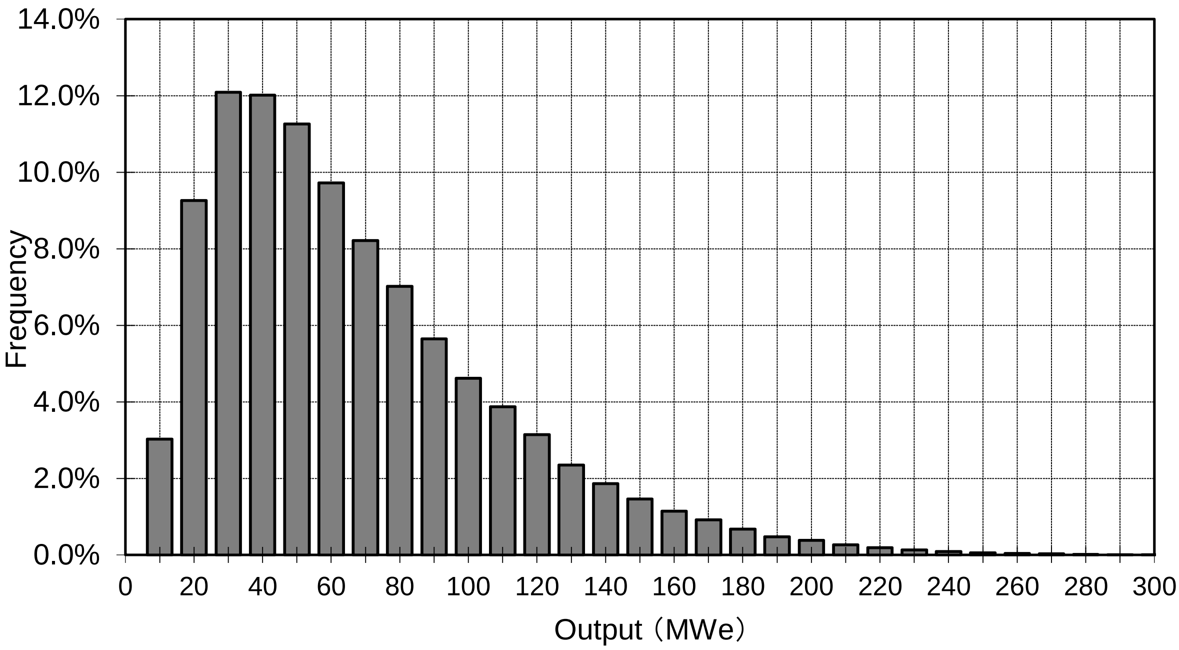


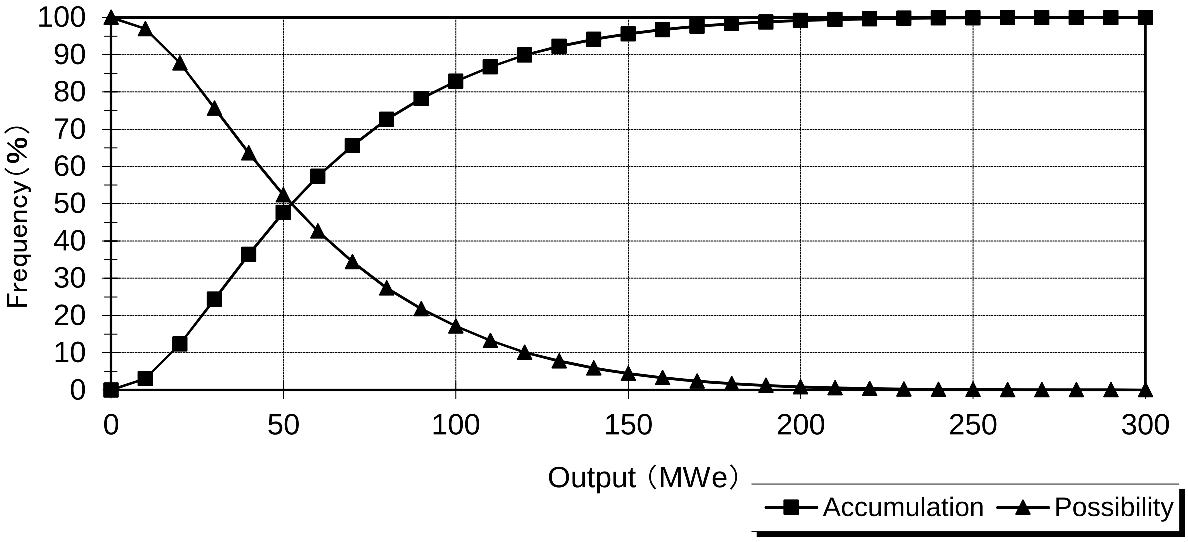


Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	9.00	-	30.00
Reservoir Thickness (m)	1800	2000	2200
Rock Density (kg/m^3)	2600	-	3000
Porosity (-)	0.01	-	0.05
Recovery factor (-)	0.025	-	0.125
Rock Specific Heat (kJ/kg^oC)	0.70	-	1.00
Reservoir Average Temperature (^oC)	150	170	190
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 Utete





Input

Parameter	min.	most likely	max.
Reservoir Area (km^2)	9.00	-	30.00
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)	180	200	220
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 Nyongoni