The Republic of Djibouti

DATA COLLECTION SURVEY ON GEOTHERMAL DEVELOPMENT IN THE REPUBLIC OF DJIBOUTI

FINAL REPORT

DECEMBER, 2014

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND DEVELOPMENT

IL
JR
14-131

The Republic of Djibouti

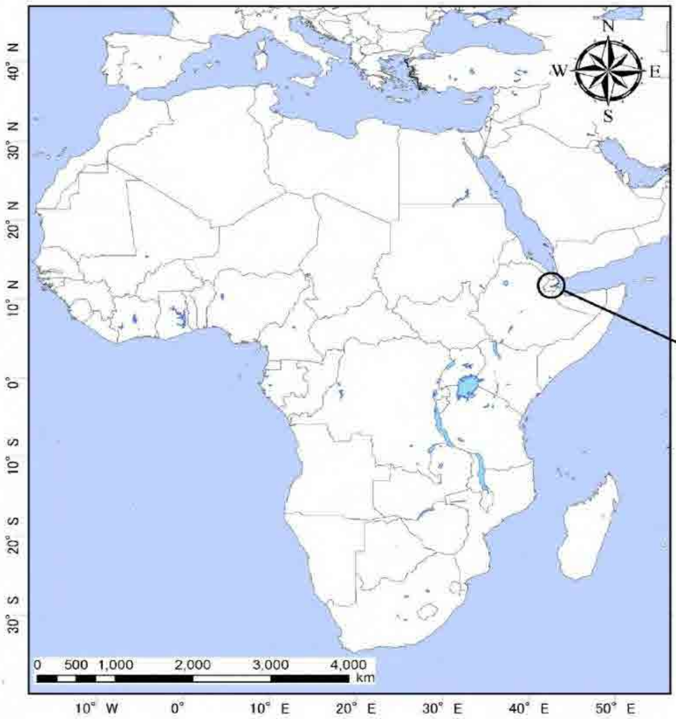
DATA COLLECTION SURVEY
ON GEOTHERMAL DEVELOPMENT
IN THE REPUBLIC OF DJIBOUTI

FINAL REPORT

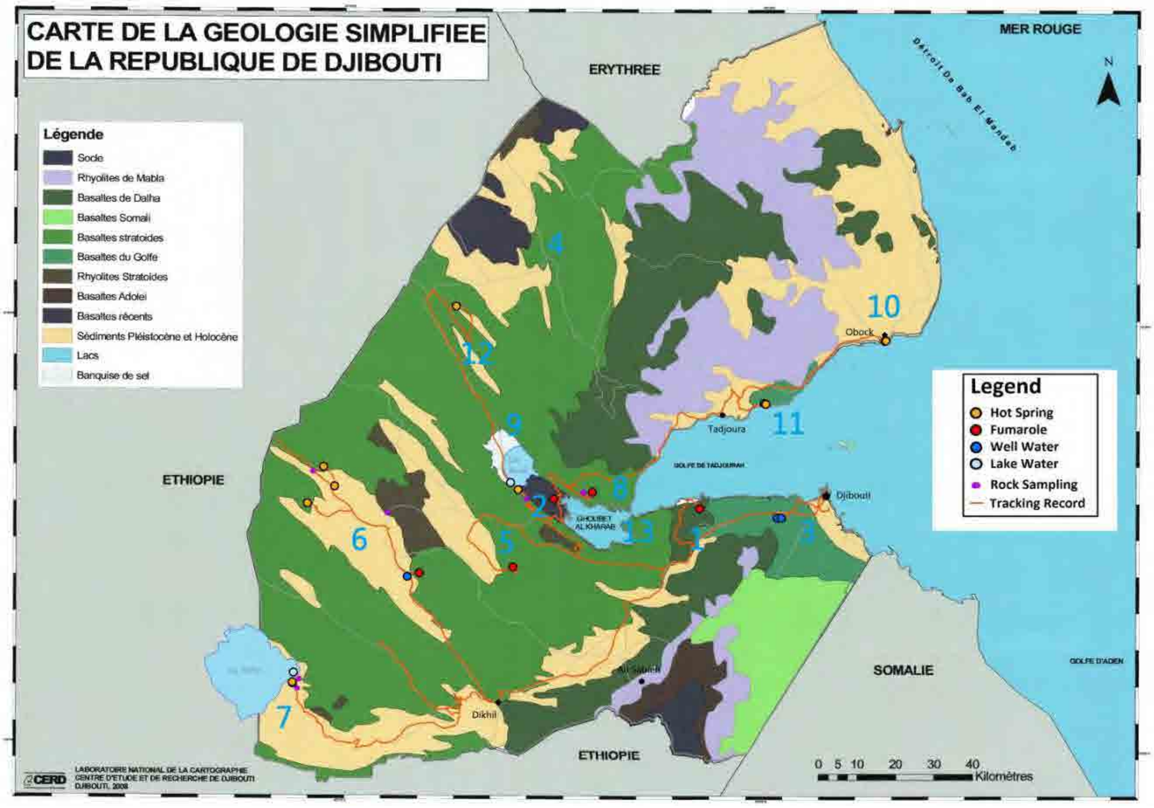
DECEMBER, 2014

JAPAN INTERNATIONAL COOPERATION AGENCY
(JICA)

NIPPON KOEI CO., LTD.
JMC GEOTHERMAL ENGINEERING CO., LTD
SUMIKO RESOURCE EXPLORATION AND
DEVELOPMENT



No.	Site	No.	Site
1	Arta	8	Nord Goubet
2	Asal Rift	9	Nord Lac Asal
3	Djibouti	10	Obock
4	Dorra	11	Rouweli
5	Gaggade	12	Sakalol
6	Hanle	13	Sud Goubet
7	Lac Abhe		



Location Map

Abbreviations

ADDS	Djibouti Social Development Agency
ADME	Djiboutian Agency Control of Energy
AFD	Agence Française de Développement (French Development Agency)
AFDB-ADF	African Development Bank
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUC	African Union Commission
BOP	Blowout Preventer
CERD	Centre for the Study and Research of Djibouti
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DoE	Department of Environment in Ministry of Home, Urbanism, Environment and Land Planning
E/S	Engineering Service
EC	Electrical Conductivity
EdD	Electricité de Djibouti
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ESMAP	Energy Sector Management Assistance Program
EUEIPDF	EU Energy Initiative Partnership Dialogue Facility
F/S	Feasibility Study
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIS	Geographical Information System
GPS	Global Positioning System
GRMF	Geothermal Risk Mitigation Fund
ICEIDA	Iceland International Development Agency
IPP	Independent Power Producer
ISERST	Institute of Higher Studies and Research Science and Engineering
ISOR	Iceland Geosurvey
JICA	Japan International Cooperation Agency
Ma	Million Age
MENR	Ministry of Energy Responsible for Natural Resources
MER	Main Ethiopian Rift
MESR	Ministry of Higher Education and Research

MT	Magnetotelluric Method
NDF	Nordic Development Fund
NUB	Nubian Plate
ODDEG	Djiboutian Office for Development of Geothermal Energy
OFID	OPEC Fund for International Development
ONEAD	National Office for Water and Sanitation in Djibouti
OPEC	Organization of the Petroleum Exporting Countries
ORC	Organic Rankin Cycle
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PPA	Power Purchase Agreement
ppm	parts per million
SAGS	Steamfield Above Ground System
SEFA	Sustainable Energy Fund for Africa implemented by AfDB
SWIR	Short Wave Infrared Radiometer
TAS	Total Alkali-versus-Silica
TDEM	Time-Domain Electro Magnetic Method
TIR	Thermal Infrared Radiometer
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNU-GTP	United Nations University – Geothermal Training Programme
VES	Vertical Electric Sounding
VNIR	Visible and Near-infrared Radiometer
WB	World Bank
WHO	World Health Organization
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

DATA COLLECTION SURVEY
ON GEOTHERMAL DEVELOPMENT IN THE REPUBLIC OF DJIBOUTI
FINAL REPORT

Executive Summary

1. Background of the Survey

Electricity in Djibouti had been produced by diesel engine power generation system of 137 MW installed capacity that requires oil to be all imported, because there is not indigenous energy identified by today for power generation in the country. In November 2011, the country started importing electricity generated at hydropower stations in its neighboring country Ethiopia, which has contributed drastically to reduction of energy costs, but in turn, increased its power generation dependency to Ethiopia by 80% in 2013. The Government of Djibouti considers this situation should not contribute to its energy security policy, and thus places high priority on geothermal energy development in the country as one of the national development targets.

2. Purpose of the Survey

The Survey was executed to collect data necessary for analysis of geothermal development in the Republic of Djibouti. The Survey was carried out through the collection of existing documented information, analysis of satellite images, geological and geochemical field survey, and laboratory analysis. With the information collected, prospective geothermal sites were evaluated for consideration of cooperation from Japan on geothermal development in Djibouti.

3. Present Conditions of Electricity in Djibouti

3.1. Demand and Supply

Electricity demand in Djibouti has steadily been increasing from about 50 GWh in the 1970s to 355 GWh in 2013. Electricité de Djibouti (EdD) with its diesel engine power generation facility, together with hydropower-generated electricity imported from Ethiopia since 2011, has been supplying the electricity in the country. While the installed capacity and available capacity of the diesel-powered facility are 135 WM and 101 MW respectively, Djibouti is able to import a maximum of 700 GWh a year according to a contract with Ethiopia, the energy corresponding to 80 MW of installed capacity. This makes its energy self-sufficiency rate extremely low at 19%.

3.2. National Development Plan, Electric Development Plan

In June 2014 the Government of Djibouti announced "Vision Djibouti 2035", that targets its vision to be realised by 2035. One challenging target stated in Vision Djibouti 2035 is for Djibouti to transform its power generation energy from 100% fossil fuel in 2010 to 100% renewable energy by 2020.

Among the targets and actions stipulated in the national five-year development plan (2011–2015) is the 'confirmation of geothermal energy available' as a target, and 'development of geothermal energy' as an action.

The electric development plan of EdD aims to have its installed capacity at 236 MW in 2020 when 100% of energy demand shall be supplied with renewable energy. Geothermal energy shall cover 50 MW of the 236 MW in 2019.

4. Organization for Geothermal Development

4.1. Djiboutian Office for Development of Geothermal Energy (ODDEG)

The Government of Djibouti has established ODDEG under the Presidential Office in 2014 to specialise in geothermal development. The relevant decree defines that <u>all resources available for geothermal energy development in Djibouti shall be concentrated to ODDEG</u>. While the staff, facilities and/or tools and equipment are limited at present, various activities are being performed, such as purchasing of a drilling rig, constructing of the new office building, assigning of researchers and reservoir engineers from the Centre for the Study and Research of Djibouti (CERD) for geophysical survey, in order to enhance ODDEG's capacity.

4.2. Study and Research Center of Djibouti (CERD)

CERD, formerly the Institute of Higher Studies and Research Science and Engineering (ISERST), was established in 1979 as a scientific and engineering research center. Professionals of geology, hydrogeology, geochemistry, among other scientific fields, are working for the center. Facilities for these specialties are available, but deemed insufficient. CERD has conducted pre-feasibility survey of three geothermal sites (Nord Goubet, Lac Abhe, and Obock) using its own research resources. Professionals for geophysical survey were transferred to ODDEG in July 2014 in accordance with the decree, whereas professionals of geochemistry and geology still belong to CERD including equipment and facilities for analysis, which shall be used for geothermal survey works in the future. The role of CERD in geothermal development is yet to be clarified.

4.3. Evaluation on Present Capacity of ODDEG and CERD

【1】 Geology：

ODDEG is in a close relationship with the Ministry of Energy and Natural Resources, that have mining geologists. There are also geologists in CERD. However, CERD is not sufficiently equipped with tools and/or equipment for geological survey and analysis.

【2】 Geochemistry：

ODDEG officers assigned as geochemists conducted the Survey together with the JICA Survey Team. There are seven researchers and staff in charge of geochemical survey and analysis in CERD, and most of the necessary equipment are available though some of analyzing tools and equipment for geothermal survey still need to be acquired.

【3】 Geophysical Survey：

Two sets of magnetotelluric method (MT) survey equipment are available at CERD as of June 2014 and are expected to be transferred to ODDEG. The equipment is usually used for academic purposes and are not so familiar to experts in the industry. CERD conducted magnetotelluric method (MT) survey for three geothermal sites. As the reports are confidential, the JICA Survey Team is not in a position to make comments on this, but the interpretation of the MT survey may has to be refined because a 2D inversion analysis software is not available.

5. International Assistance

5.1. World Bank and Other Financial Institutes

The Government of Djibouti is in the process of receiving financing from the World Bank (WB) and other six financial institutions for test well drilling in Asal-Fiale. In Asal-Fiale, test wells had been drilled in the 1980s that produced geothermal fluid of high salinity at over 100,000 ppm. More recently, another geophysical survey was conducted from October 2007 to March 2008. The results suggest the existence of low salinity zones, WB and other institutions expressed interest for assistance to the test drillings.

5.2. ICEIDA:

The Icelandic International Development Agency (ICEIDA) started their assistance programme in Arta and Gaggade.

5.3. UNU-GTP:

The Geothermal Training Programme of the United Nations University (UNU-GTP) has been training geothermal engineers from Djibouti since 1989.

5.4. GRMF:

Djibouti submitted applications to the Geothermal Risk Mitigation Fund (GRMF) to request financial assistance to drill test wells in Nord Goubet and to conduct surface exploration in Hanle.

6. Result of Site Survey

6.1. Geological Setting-East African Rift Zone

The Survey area is located in the northern area of the East African Rift Zone. The regional geology of Djibouti is generally characterised by intermittently active volcanic activities from the Oligocene to the Quaternary periods.

6.2. Satellite Imagery Analysis

Satellite imagery analysis was conducted using Japanese satellite products ASTER and PALSAR. The target sites are classified into the following two groups according to the results:

【1】 Areas where acid-neutral alteration zones are identified. These zones are generally associated with fault systems or basaltic composition of alkaline rock series.

Arta, Asal, Gaggage-Taassa, Hanle-Garabbayis, Lac Abhe, Nord Goubet, Nord Lac Asal, Rouweli, and Sud Goubet

【2】 Areas where alteration zones are not observed in the satellite images.

Djibouti-Awrofoul, Dorra, Obock, and Sakalol-AsbouDara

6.3. Geological Survey and Analysis

During the site survey, the JICA Survey Team visually confirmed the location and characteristics of fumaroles, rock outcrops, alteration clays, and fracture zones as necessary. They also collected rock samples and clay samples for analysis.

【1】 Microscopic Observation and X-Ray Fluorescence (XRF) Analysis

From the results of observation of rock sample thin sections by polarisation microscope, low-grade alterations were identified for all rock samples.

According to the bulk chemical composition analysis by XRF, most rock samples are classified in the basalt group, that is generally confirmed as the geological background of the alkaline rock series in Djibouti. Most of the primary rock forming minerals are present forming such ferromagnesian minerals as olivine, pyroxene, plagioclase, k-feldspar and/or magnetite/ilmenite. Ferromagnesian minerals are associated mostly with basaltic rocks and k-feldspar is associated with the intermediate rocks such as dark trachyte and trachybasalt.

【2】 XRD Clay Mineral Analysis

As a result of XRD analysis, alteration minerals such as nacrite, smectite, smectite-mixture, chlorite, and sericite indicate various grades of alteration. In particular, nacrite is a good indication of high-grade alteration, whereas smectite–chlorite is an indication of fairly high-grade alteration. The formulation temperature of clay minerals are estimated as (a) 100 ºC–150 ºC, (b)150 ºC–200 ºC, and (c) 200 ºC–250 ºC, as shown in Table 1 below.

Among the sites surveyed, geothermal activities in Gaggade-Taassa, Hanle-Garabbayis, and Nord Goubet-Anaale are considered to be still active because of geothermal manifestations identified in the field.

Table 1 Summary of XRD Analysis

Site Name	Rock Name	Clay Mineral				Zeolite group			others			Notes	Clay mineral Formaion Temperature (℃)
		Sme	Mix.	Chl /Ser	Kao /Nac	Sti	Nat	Lau	Gyp	Cal	Qz		
N. Goubet	Calcite									○		Cal. only	-
N. Goubet	calcite									○		Cal. only	-
Arta	Gypsum	○		○					○	+	+	Smc-Chl, Gyp (vein)	150-200
Arta	Rhyolite?	○	○							○	+	Smc-Mix, Chl	100-150
Arta	White clay				○						○	Nac.	200-250
Arta	White clay		○		○						○	Nac. & mix.	200-250
Arta	Gypsum								○			Gyp. only	-
Asal (2km east)	White clay, layered			○						○		Chl-Cal	150-200
Lac Asal	White clay								○			Gyp. only	-
N. Goubet_Anaale	Andesitic	○									+	Smc-Qz	100-150
N. Goubet_Anaale	White vein, calcite	○								○	+	Smc-Cal	100-150
Hanle-Garabbayis	Basalt	○	○	○		○	○	○				Smc-Chl + Gyp	150-200
Hanle-Yoboki (hill)	Rhyolite	○	○	○							○	Smc-Mix-Chl-Qz	150-200
Hanle-Yoboki (hill)	Rhyolite									+	○	Qz-Cal	-
Gaggade-Taassa	Reddish clay				○						○	Nac.	200-250
Gaggade-Taassa	Rhyolite	○								+	+	Smc-Cal-Qz	100-150
Smc: Smectite, Chl: Chlorite, Ser: Sericite, Sti: Stilbite, Lau: Laumontite, Gyp: Gypsum, Qz: Quartz, Cal: Calcite, Mix: Mixed layer minerals												(Source: JICA Study Team)	

6.4. Geochemical Survey and Analysis

Geochemical characteristics of hot springs and gases are evaluated by analysis of water and gas chemistry and isotopes.

【1】 Geochemical Analysis

Water samples collected in this Survey are meteoric water and there is no obvious indication of mantle-originated fluid. Most of the water samples are of Na-Cl type.

【2】 Evaluation of Reservoir Temperature

High temperature areas identified by Na-K geochemical thermometer, high temperature areas revealed by CO_2/Ar and CH_4/CO_2 analysis, and areas with evidence of mantle gas are shown in Table 2 below.

Table 2 Summary of Geochemical Analysis

	Na-K Thermometer >190 °C	Gas Thermometer	Mantle Gas
Hanle-Garabbayis	-	☑ 159 °C～266 °C	☑
Arta	-	*(Weak Fumamoles)*	
Nord Goubet	-	☑ 228 °C～323 °C	☑
Gaggade Taassa	-	-	☑
Obock	☑	-	-
Djibouti Awrofoul (No.2)	☑	-	-
Asal – Fiale	-	-	☑
(-: No samples or analysis)			

Source：JICA Survey Team

6.5. Geothermal Potential Sites Identified by Survey Results

According to the results of satellite image, geology and geochemistry analyses, the following sites have been identified as potential geothermal sites:

- Arta
- Gaggade-Taassa
- Hanle-Garabbayis
- Nord Goubet- Anaale
- Obock
- Djibouti-Awrofoul-No.2

7. Social Environmental Survey

7.1. Objective

In order to assess socio-environmental conditions of the target sites, the Team collected information regarding relevant lows/regulations, protected/designated natural areas and the procedure of environmental impact assessment.

7.2. Results

There are nine environmental protection areas in Djibouti. Zoning in the protection areas has not yet been established; the possibility for development not prescribed; or clear boundaries of the environmental protection areas not yet been decided, except the Djalélo and Addaoua Bourale mountain areas.

Among the geothermal prospects surveyed in the Survey, the area near Lac Abhe is possibly included in a protection area. Consultation with the Department of Environment is required in case of developing the area.

8. Proposal for Development of the Priority Sites

The following factors have been considered for the prioritisation of geothermal development sites:

- Geothermal resources
- Access conditions
- Working space and drilling water
- Socio-environmental conditions
- Related information
  ① Distance to the existing/plane transmission line or nearest trunk roads

The proposed priority sites are shown in Table 3 below.

The most prioritised site is Hanle-Garabbayis, and the second most prioritised sites are Arta and Nord Goubet. Gaggade-Taassa is ranked at third because of poor accessibility.

Obock is ranked at a lower priority because of the limited geothermal manifestation and its long distance from the national grid. However, in order to secure the base load demand in the remote area, investigations for small-scale geothermal development would be recommended.

For other sites in Djibouti Awrofoul, water of high geochemical temperature and low conductivity waters were identified. It would be worth conducting MT surveys for future development.

Table 3 Proposed Priority Sites for Cooperation

Site name	Geothermal Resources		Workability			Socio -Environment		Reference	Priority rec'nded	
	Resources	CL (mg/L)	Accessi-bility	Landform	Well Drilling Water	Natural conditions	In-habitant	Distance to transmission line		Survey for the next stage
Garabbayis	☑ A-1	±1,000	C Fair	B Plain -ragged hill	☑ A Ground water in Hanle Plain	☑ A Barren	A none	45 km to Dikhil	**1**	MT survey with geological and geochemical survey
Arta	☑ A-3	☑ D ±15,000	B Good	B Plain - ragged hill	C Sea	☑ A Out of a registered protection area	B a few	6 km to N.1	**2**	MT survey with geological and geochemical survey
Nord Goubet	☑ A-2	☑ D ±15,000	C-D Poor-fair	C Plain - ragged hill	C Sea	☑ A Barren, Desolate	B a few	50 km to P.K. 51	**2**	Review of Pre-Feasibility Study of CERD
Gaggade	☑ A-1	±5,000	☑ D Poor	☑ D Ragged hill	☑ A Ground water in Hanle Plain	☑ A Barren	A none	40 km to P.K 51	**3**	MT survey
Obock *	B	5,000 - 40,000	A Excellent	A plain, costal	C Sea	B Coastal	near town	Isolated	**4***	Review of Pre-Feasibility Study of CERD
Djibouti	C	±5,000	A Excellent	A Plain	C Sea	-	-	-	**5**	MT survey
Lac Abhe	-	±5000	C Fair	A Plain	C Lac Abhe	☑ D Registered	B a few	75 km to Dikhil	**-**	Review of Pre-Feasibility Study of CERD

☑: Conditions that special considerations are given for prioritization

Obock *: Survey of a next stage, separately from survey for a flash type may be recommended if a binary type is considered.

Source：JICA Survey Team

9. Proposed Directions of Cooperation for the Geothermal Development

9.1. Long-Term Cooperation for Geothermal Development

The main tasks of ODDEG are drilling works and related testing and analysis such as well logging, production tests, and interference tests. The general direction of long-term cooperation with ODDEG is summarised in Table 4 below.

Table 4 General Direction of Long-term Cooperation for Geothermal Development

Milestone	Tasks	Cooperation Items
Pre-Survey	Data collection, Inventory Nation wise Survey Selection of Promising Area EIA and Necessary Permits Planning of Exploration	• Additional technical cooperation (T/C) after this survey
Exploration	Surface (Geological, Geochemical survey)	• Technical cooperation (T/C) • Facility procurement (Laboratory analysis equipment for geological and geochemistry analysis)
	Sounding (MT/TEM)	• T/C for site survey • T/C for 2D inversion analysis with soft ware procurement
	Gradient and Slim Holes	• Financial cooperation for drilling • T/C for well drilling • T/C for observation and data analysis of well geology and well geochemistry • T/C for well logging test and data analysis • Procurement of well logging tools • T/C for well testing and data analysis
	Seismic Data Acquisition	• (Not necessary)
	Pre-feasibility Study	• T/C for data analysis and reporting
Test Drilling	Slim holes Full-size wells Well Testing and stimulation Interference test	• Financial cooperation for drilling • T/C for well drilling • T/C for observation and data analysis of well geology and well geochemistry • T/C for well logging test and data analysis • T/C for well testing and data analysis
	First Reservoir Simulation	• Procurement of computer software for analysis • T/C for simulation analysis
Project Review and Planning	Evaluation and decision making Feasibility study and Final EIA	• T/C for F/S preparation • T/C for EIA preparation
	Drilling Plan	• T/C for plan making for well drilling
	Design of Facilities, Tender Process	• Loan Project (E/S : detailed design, Tender process)
	Financial Closure/PPA/IPP	• T/C for policy making
Field Development (ODDEG)	Production wells Reinjection Wells Cooling water wells Well stimulation Reservoir simulation	• Technical cooperation Project • T/C for well drilling • T/C for well testing and data analysis • T/C for well logging and data analysis
Construction (Contractor)	Steam/hot water pipelines Power plant and Cooling Substation and transmission	• Loan Project (E/S : Supervision) • Loan Project (Construction of Power plant and SAGS)
Start up and commissioning		• Loan Project (Defect liability period)
O&M		• Follow-up by a Technical Cooperation Project

T/C: Technical Cooperation, E/S: Engineering Service in a loan project, O&M: Operation and Maintenance

Source：JICA Survey Team

9.2. Cooperation Approaches before Test Well Drilling

【1】 Approach-1 Cooperation for Flash-type Development

The JICA Survey Team confirmed that the four priority geothermal sites (i.e., Hanle-Garabbayis, Nord Goubet, Arta, and Gaggade-Taassa) have the most potential in terms of geothermal resources. It is considered that these four sites have almost equal potential although the grade of geothermal manifestations are slightly different. It is therefore a prudent approach that at least the three sites, namely, Hanle-Garabbayis, Nord Goubet, and Arta, where accessibility are relatively good shall be further compared after conducting geophysical MT survey with additional geological and geochemical survey in order to determine the most promising site for the costly test well drilling. Among these three sites, CERD had already conducted a MT survey in Nord Goubet; thus the other two sites (Hanle-Garabbayis and Atra) shall be the target for the MT survey to be conducted in the next step. However, if the MT survey in Hanle-Garabbayis should show very good results, the test well may be drilled in Hanle-Garabbayis. As for Gaggade-Taassa, where accessibility is not so preferable, the JICA Survey Team expects ODDEG to conduct the MT survey when necessary in the future.

【2】 Approach-2 Geothermal Energy Development in Obock

There is a possibility that a flash type power system may be developed in Obock according to geochemical thermometer data of 197 ºC. However, no other geothermal manifestations were identified in Obock, thus the JICA Survey Team ranked it at lower priority. The approach on Obock's geothermal resources should depend on the purpose of geothermal development in Obock.

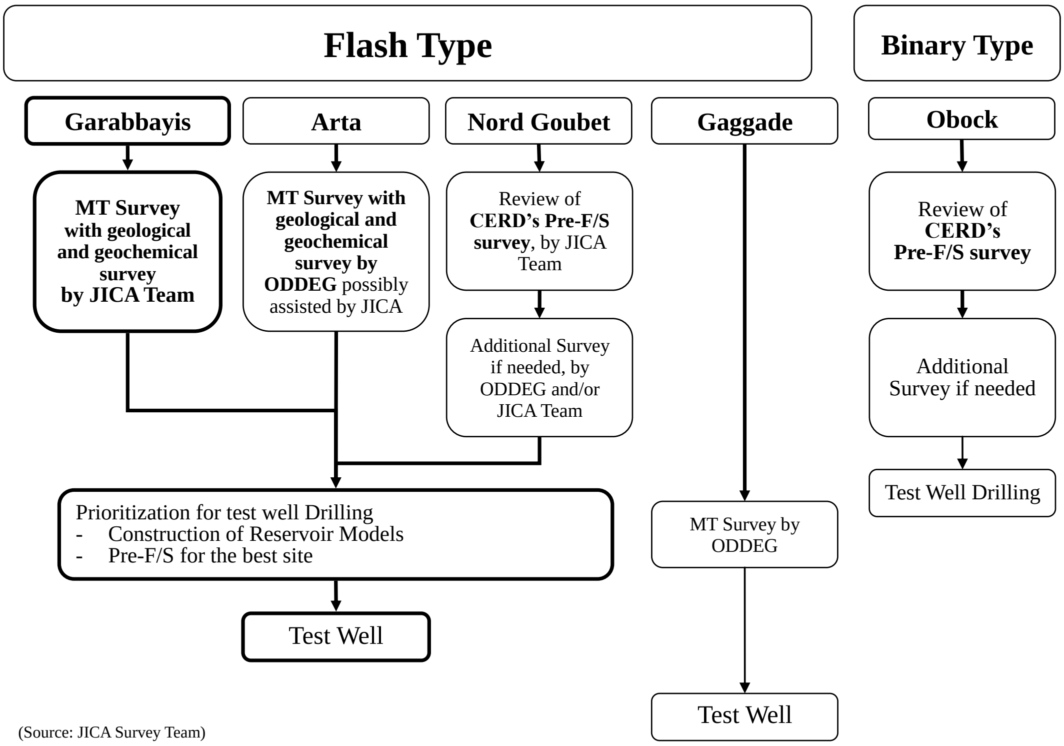
(a) Considerations on development for flash type power system in Obock

CERD had already conducted a pre-feasibility survey including MT survey in Obock. The JICA Survey Team is not in a position to review the report as it is confidential, but they were informed that no remarkable anomalies have been identified in the MT survey result. The MT survey of the ground surface might not be capable enough to identify any anomaly that may be present near or under the sea, because the hot springs are usually under the sea level and become visible only during the lowest tide of a day. For geothermal development of a flash type power generation system, more precise survey results are necessary, and for this reason an MT survey from the sea surface or other technique may be required. However, since experience of conducting such survey is limited, applicability both from technical and cost performance point of view will have to be examined. Furthermore, if the flash type power system should be connected to the national grid, the distance will also have to be considered. It is 150 km from Asal.

From the above, the JICA Survey Team considered that Obock should not be at a high priority for development of a flash type geothermal power generation system.

(b) Development of a binary type geothermal power generation system in Obock

On the other hand, the JICA Survey Team identified that the base load electricity demand would be about 500 kW in Obock. If this base demand should be covered, a small-scale power station constructed within a reasonable amount of investment may be sufficient. In this case, a binary type geothermal power development is worthy of considering, as it may not require large-scale and costly exploration. This approach would then be taken separately from the approach for the development of flash type geothermal development for national grid connection.



(Source: JICA Survey Team)

Figure 1 Approaches of Cooperation up to Test Well Drilling

【3】 Cooperation for Flash type geothermal Power Generation

(a) Exploration in the first priority site - Hanle-Garabbayis

The JICA Survey Team has selected Hanle-Garabbayis site as the first priority site based on potential resource assessment, access conditions, and others. The JICA Survey Team proposed the following surveys to determine the drilling target:

- Detailed Geological and Geochemical Survey

  The published geological map shows that there are some other fumarole points near and around the site the JICA Survey Team visited. In the next stage of exploration, a broader area than the one covered by this Survey should be surveyed, and rock samples, alteration clay samples and/or fumarole samples should be collected wherever necessary to determine the distribution of hydrothermal alteration minerals. The proposed direction of cooperation for geological and geochemical survey was described in Sections 3.3.2(5) and (6).

- Geophysical Survey (MT/TEM Survey)

  Geophysical survey is to be conducted for the purpose of investigating geological structure and reservoir structure. The type of geophysical equipment of ODDEG is usually used for academic purposes. Most of private consulting companies do not use this type of equipment and therefore they may not be operated effectively. For this reason, the JICA

Survey Team proposed that the geophysical survey in Hanle-Garabbayis should be ,conducted by a Japanese team with equipment to be brought in from Japan. should JICA consider technical cooperation.

(b) Geophysical Survey in Arta and Nord Goubet

As mentioned above, the other three sites (Arta, Nord Goubet and Gaggade) would be similarly prospective to Hanle-Garabbayis, therefore it would be a prudent approach that at least the three sites (i.e., Hanle-Garabbayis, Arta, and Nord Goubet) should be compared by the results of the MT survey, to finally determine the most promising site for test well drilling.

Cooperation from Japan thus shall include the Arta site where no MT survey has been conducted so far. If cooperation resources for a full size assistance should be limited within the coming fiscal year, financial assistance may be helpful for ODDEG to start the survey earlier.

On the other hand, CERD already conducted a pre-feasibility survey in Nord Goubet. For this site, a review of the CERD study that is kept confidential at this moment be conducted. If deemed necessary, additional survey should be recommended in the form of either technical assistance or financial assistance, as necessary.

As for Gaggade-Taassa where relatively strong geothermal manifestations are observed, the JICA Survey Team expects the ODDEG to conduct the survey using its own resources in the future when necessary.

(c) Cooperation for the three sites (Hanle-Garabbayis, Arta and Nord Goubet)

- MT data analysis with a 2D inversion software

  At present, a 2D inversion software is not available in ODDEG or CERD. Cooperation shall be made to analyse MT data collected from the three sites using a 2D inversion software that should be procured for technical cooperation with Japanese experts.

  In addition, recommendations for cooperation direction of geophysical exploration were made as discussed in Sections 3.3.1 (4) and (5).

- Geothermal Reservoir Modeling

  Based on the abovementioned survey, a preliminary geothermal reservoir model shall be created for the three sites. With the creation of the model, the following works shall be conducted:

  ✧ Preliminary assessment of geothermal resources; and

  ✧ Proposal for well siting and well drilling method including the methodology of well testing and well logging

- Pre-Feasibility

  Based on the preliminary assessment of geothermal resources, a pre-feasibility study shall be conducted for the best recommended site.

- Best season for site survey

The average monthly temperature in Djibouti from May to September exceeds 30 °C, and reaches over 35 °C in July. Therefore, field surveys are usually conducted during the period from October to April in the following year when the average monthly temperature is below 30 °C. Therefore, field surveys in Djibouti is recommended to be conducted particularly in December to February, when the average monthly temperature is below 25 °C.

【4】 Cooperation for Development of a Binary Geothermal Generation System in Obock

As mentioned above, the JICA Survey Team considered that large-scale geothermal development would not be required in Obock. Instead, small-scale geothermal power development that could satisfy a base load demand of 500–600 kW shall be considered. The JICA Survey Team recommends the following approaches:

(a) Review of the CERD pre-feasibility report

The report, which is currently kept confidential, shall be reviewed first.

(b) Proposal for exploration planning

The JICA Survey Team proposed the following approaches:

- MT survey of the sea surface may be necessary with a combination of additional MT survey of the ground surface, if judged so after the review of the CERD report. Cost effectiveness shall be considered because such survey from the sea may be costly as compared with the effectiveness of power generation for Obock.
- Drilling of slim hole is recommended from the coast in order to explore temperature gradient, and availability/volume of hot water. The slim hole shall be directional toward the sea. It is confirmed that the Ministry of Agriculture possesses a drilling rig capable of drilling down to ca. 500 m. Countermeasures against hot water or blowout preventer (BOP) shall be necessary.

(c) Issues

There will be issues arising from the expected high salinity even if sufficiently high temperature and abundant discharge should be confirmed, because the hot water samples showed similar salinity as seawater, and that isotope analysis indicated that the hot water may be of seawater origin.

- Scale problem in hot water circulation system
- Scale problem in cooling water (seawater is assumed) system

【5】 Djibouti-Awrofoul No. 2 (Well for Drinking Water Supply)

The well is located near PK20 relatively close to Djibouti City and adjacent of the existing substation. The hot water from the well indicated about 73.6 °C, and alkaline geochemical thermometer indicated 191 °C. Also, the electric conductivity is as low as 1,400～1,080 μS/cm. Although the other geothermal manifestations were not confirmed at this site, it may be worthwhile to conduct MT/TEM survey in order to investigate the possibility for geothermal development.

DADA COLLECTION SURVEY
ON GEOTHERMAL DEVELOPMENT IN DJIBOUTI
FINAL REPORT

Location Map

Abbreviations

Executive Summary

Table of Contents

Figures and Tables

Attachments

CHAPTER 1 Introduction

1.1 Background

The Republic of Djibouti, with the present population of approximately 900,000, has long been recognised as an important strategic place for marine transportation. More than 80% of its gross domestic product (GDP) comes from transportation services and tourism because most of its territory is dominated by barren desert, where no significant natural resources have yet been discovered, except geothermal energy. Under this circumstance, Djibouti was dependent on diesel power generation with an installed capacity of 137 MW (as of 2010), that imposed the country relatively high electricity unit prices. This situation has largely been improved by importing electricity from a neighbouring country Ethiopia. The imported electricity has now amounted to approximately 80% of Djibouti's demand. Because more than 90% of electricity from Ethiopia is generated from hydropower stations, the sufficient amount of electricity supply to Djibouti is not guaranteed, particularly during the dry seasons when almost no rains are experienced in the areas of East Africa. This situation has recently become serious, possibly due to the prevailing global climate changes. On the other hand, the electricity demand of Djibouti is expected to increase to 200 MW in 2030 [1]. Therefore, Djibouti has set out a target to develop its indigenous energy for stable supply of electricity.

Geothermal energy in Djibouti's territory was estimated to produce 230–860 MW and has thus been highlighted for development, that aims to install capacity of more than 50 MW. Although geothermal exploration in Djibouti has been conducted since 1970 in prospects such as the Asal Rift, extremely high saline concentration of 120,000 ppm or more [2] in brines that may cause large-scale depositions of plant systems, has hindered investments into geothermal power generation.

Under this circumstance, the President of Djibouti when he visited Japan in May 2013 requested the Prime Minister of Japan for possible assistance from Japan for the geothermal energy development. In response to this request, the Japan International Cooperation Agency (JICA) has decided to conduct the Data Collection Survey on Geothermal Development in Djibouti (hereinafter referred to as the "Survey"), which is aimed at collecting, analysing, and reviewing basic technical information for consideration of possible future cooperation because the development of geothermal brine with high saline concentration in Djibouti is so challenging that it needs a prudent approach.

1.2 Purpose and Scope

1.2.1 Purposes

The purposes of the Survey are to conduct the following data collection and analysis activities with respect to the geothermal prospects in Djibouti and to consider possible future cooperation from Japan on geothermal energy development in Djibouti:

- To collect existing information and its review,
- To conduct remote sensing analysis,
- To conduct field survey that consists of geological and geochemical survey, and
- To analyse the data collected during the Survey.

1.2.2 Survey Areas

The Survey areas is in the Republic of Djibouti. The map is shown at the beginning of this report.

1.2.3 Scope

The terms of reference of the Survey are as follows:

① Survey in the 13 geothermal prospects,

- Collection and review of existing information (survey reports, thesis, articles, etc.),
- Remote sensing analysis,
- Geological and geochemical survey including laboratory analysis,
- Proposing priority from qualitative points of view, such as geothermal potential, economic aspect, environmental aspect, and others as necessary,

② Collection of information from a technical point of view regarding human and facility resources for geothermal energy development, such as geological, geochemical, and geophysical survey,

③ Review of organisational framework for implementation of geothermal energy development, segregation of duties, availability of human resources, and budgetary allocation for geothermal development (Ministry of Energy Responsible for Natural Resources (MERN), ÉMERN), of Energy Respo(EdD), Djiboutian Office for Development of Geothermal Energy (ODDEG), Centre for the Study and Research of Djibouti (CERD)),

④ Collection of information on donor’s activities for geothermal development,

⑤ Collection of information on geothermal brine of high saline concentration and inhibition of it for geothermal energy development, such as the information on the Salton Sea geothermal area in the United States and the Asal Rift in Djibouti where comprehensive surveys have been reportedly conducted,

⑥ Suggestions and/or recommendations for possible future technical assistance and on inhibiting scale deposits, drilling wells, etc.

1.2.4 Joint Survey with ODDEG and CERD – Acknowledgements

The JICA Survey Team would like to express its sincere gratitude to ODDEG for their support as the counterpart in customs clearance, site survey, and other arrangements for logistics, and providing a project office as well. The officers of ODDEG accompanied the JICA Survey Team during the field survey.

The JICA Survey Team would like also to express its appreciation to CERD for assigning their officers to the field survey and their contribution to the analysis of geochemistry for mutual check of examination results.

The JICA Survey Team is very grateful to EdD and the Ministry of Agriculture, and many other organisations in Djibouti for their valuable cooperation to the Survey.

CHAPTER 2 National Electric Development Plan in Djibouti

2.1 Electricity Generation in Djibouti

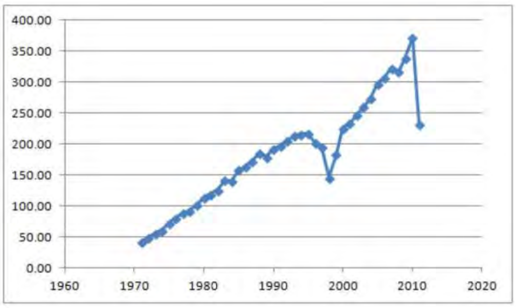
2.1.1 Status

The annual electricity generation in Djibouti shown in Figure 2-1 (1) has continuously increased from 1970 and exceeded 350 GWh in 2010, except for one decreasing period from 1995 to 1998. After 2011, when Djibouti started importing electricity from Ethiopia, the energy production decreased to about 230 GWh.

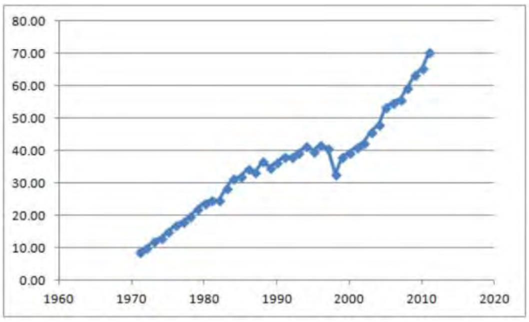
Djibouti's dependence on imported electricity from Ethiopia is rising. In 2013, the amount of electricity generated in Djibouti was 67.5 GWh, that corresponds to 19% of the total electricity supply of 354.9 GWh in Djibouti.

Simultaneously, the annual electricity demand has been increasing. It became 70 MW in 2011 when the electricity supply started to be imported from Ethiopia. In July 2013, it reached 76.9 MW as shown in Figure 2-1 (2).

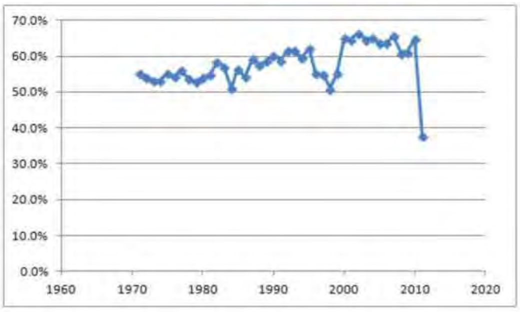
On the other hand, the load factor before 2010 remained at slightly over 60%. It indicated that the new facilities were sequentially invested in during this period. After imported electricity from Ethiopia started in 2011, the load factor decreased to below 40% as shown in Figure 2-1 (3).



(1) Change of Annual Electricity Generation (GWh)



(2) Change of Annual Maximum Electricity Demand (MW)



(3) Change of Load Factor (%)

Source: EUEIPDF, 2013

Figure 2-1 Change of Electric Demand in Djibouti

2.1.2 Power Plants in Djibouti

Presently, there are two power plants connected to the national grid in Djibouti. Both are diesel power generation facilities located in Djibouti city.

Table 2-1 shows their capacities. Boulaos thermal power plant has 15 diesel generators and Marabou has 6 diesel generators. The total installed capacity is over 135 MW, however operational capacity is 101MW due to decrepit of facilities.

Table 2-1 Diesel Generation Facilities of EdD (Connected to Grid)

BOULAOS-1 Power Plant (MW)									
No.	G1	G12	G13	G14	G15	G16	G17	G18	Total
Rated Capacity	6.6	7	6	6	6	6	7	7	52
Practical Capacity	3.1	5.5	4.2	4.2	4.2	4.2	5.5	5.5	36
BOULAOS-2 Power Plant (MW)									
No.	G21	G22	G23	G24	G25				Total
Rated Capacity	13.7	15	7	5.5	15				56
Practical Capacity	8.5	13.4	6.7	3.5	12				44
BOULAOS-3 Power Plant (MW)									
No.	G31	G32							Total
Rated Capacity	4.5	4.5							9
Practical Capacity	4	4							8
MARABOUT-2 Power Plant (MW)									
No.	M1	M2	M3	M4	M5	M6			Total
Rated Capacity	3	3	3	3	3	3			18
Practical Capacity	2	2	2	2	2	2			12
Total									
Rated Capacity									135
Practical Capacity									101

Source: EdD

There are also independent power plants in Tadjoura and Obock across the Gulf of Tadjoura. The installed capacities and production rates are shown in Table 2-2.

Table 2-2 Diesel Generation Facilities of EdD (Independent)

Tadjoura							
No.	Unit-1	Unit-2	Unit-3	Unit-4	Unit-5	Unit-6	Total
Rated Capacity (MW)	0.44	0.44	0.44	0.44	0.44	0.44	2.64
Production Rate (%)	90.8	64.08	52.44	53.28	38.01	60.50	
Obock							
No.	Unit-1	Unit-2	Unit-3	Unit-4	Unit-5		Total
Rated Capacity (MW)	0.28	0.28	0.28	0.44	0.44		1.72
Production Rate(%)	0	94	86	64	59		

Source: EUEIPDF, 2013

2.1.3 Interconnection from Ethiopia and Self-Sufficient Supply

Djibouti started importing electricity through the interconnection of Ethiopia since November 2011. A summary of the power purchase contract are shown inTable 2-3.

The electricity tariff of Ethiopia ranges from 0.06 to 0.07 USD/kW. It is much lower prices than the current tariff of 0.3 USD/kW set by diesel generation in Djibouti. Therefore, this forces them to be dependent on the electricity supply from Ethiopia. The electricity self-sufficiency ratio of Djibouti, as shown in Table 2-4, is very small, that is 33.2% in 2011, 6.2% in 2012, and 19.0% in 2013. Thus, it becomes a major issue on energy security.

Note that the information in Table 2-3 indicating that the contract does not include the period from November to June when the average temperature is low and less electricity demand is expected in Djibouti.

Table 2-3 Summary of Power Purchase Contract from Ethiopia

Season		Peak time (18:30 - 21:30)	Usual time (21:30 - 00:00 - 18:30)
Rainy Season	Jul. 1 – Nov. 7	0.07 USD/kW	0.06 USD/kW
Dry Seaton	Nov.8 – (Dec.)- Jun.30	-	0.07 USD/kW
Max. and Min. of Power Supply			
Maximum Power Supply		700 GWh/yr	(Ave. 80 MW)
Minimum Power Supply		180 GWh/yr	(Ave. 20 MW)

Source: EUEIPDF, 2013

Table 2-4 Energy Self-Sufficiency Rate of Djibouti

	2011	2012	2013
(a) Total Supply (GWh)	232.0	387.0	354.9
(b) Self-Sufficient Supply	77.0	24.0	67.5
Self- Sufficient Rate (%)	33.2	6.2	19.0

Source: EdD

2.2 National Development Plan of Djibouti

2.2.1 Vision Djibouti 2035

The Djiboutian government formulated "Vision Djibouti 2035" [4], and it was presented to parties concerned in Djibouti City in June 2014. Vision Djibouti 2035 was based on the following five pillars that instigates the transformation of the country, engaging it to a new path of progress and development:

1. Peace and national unity
2. Good governance
3. Diversified and competitive economy, with the private sector as an engine
4. Consolidation of human capital
5. Regional integration

In Vision Djibouti 2035, it is said that electricity development is indispensable for economic growth with competitiveness. It is planned to increase power-supplying capacity from 96 MW to 355 MW during the period of 2014 to 2032. It will therefore be necessary to increase its ability to supply electric power drastically from 2014 to 2032. Furthermore, the Djiboutian government has set the following ambitious goal:

> Djibouti will change power generation from 100% thermal in 2010 to 100% renewable energy by 2020.

In order to achieve this goal, the Djiboutian government promotes the interconnection with Ethiopia to import hydropower generated electricity, and focuses on the exploitation of geothermal, solar, and wind energies.

The Vision states that Djibouti has ten geothermal prospects. Among those, three main areas were already identified as the sites having enough potential for geothermal power generation.

2.2.2 National Development Five - Year Plan

Djibouti became independent in 1977. However, the Djiboutian Civil War broke out in November 1991 and it caused confusions in the northern part of the land, including Tajoura and Obock. Some anti-government forces signed a peace accord with the government in December 1994, but small-scale conflicts continued in local regions, which eventually led to the signing of its own peace agreement in 2001, ten years after the civil war started. In addition, Djibouti and Eritrea had an international conflict in 2008. The dispute had obstructed economic growth of Djibouti.

Under this circumstance, the Djiboutian government decided to promote administrative reform with support from International Monetary Fund (IMF) and the World Bank (WB) in 1996. Priority issues were placed on 1) finance, 2) social security, 3) public enterprises, 4) education, and 5) insurance. The five-year plans were formulated for the periods of 2002- 2006, 2008-2012, and 2011-2015.

The following four issues are expressed as the keys for development in the third five-year plan for the 2011-2015 period:

Key 1: Growth, competitiveness, and employment

Key 2: Access to basic social services

Key 3: Reduction of poverty and vulnerability

Key 4: Public governance

Electricity development was included in Key 1 and the following three objectives are pursued to be accomplished from 2010 to 2015"

Objective 1: Improve the electric network connection rate from 52% to 70%, and lower the bill from USD 0.3 to USD 0.27.

Objective 2: Decrease technical loss from 15% to 13%, and nontechnical loss from 10.5% to 1%.

Objective 3: Confirm geothermal development potential.

In order to achieve these objectives, the next four items are advocated:

Action 1: Commence interconnection with Ethiopia.

Action 2: Develop geothermal energy.

Action 3: Extension and rehabilitation of transmission.

Action 4: Improvement of service quality and reduction of loss.

Thus, geothermal energy development is one of the prioritised issues of the electricity sector in Djibouti.

2.2.3 Development Plan of Djibouti Electricity (EdD)

The master plan for electricity development in Djibouti was formulated in 2009 with the support of WB [1]. In this master plan, geothermal power was addressed just as a reference because it was considered that there would be uncertainties until realisation. The geothermal development plan shown here is to develop a total of 60 MW, which consists of installation of 20 MW per year in 2016, 2019, and 2022.

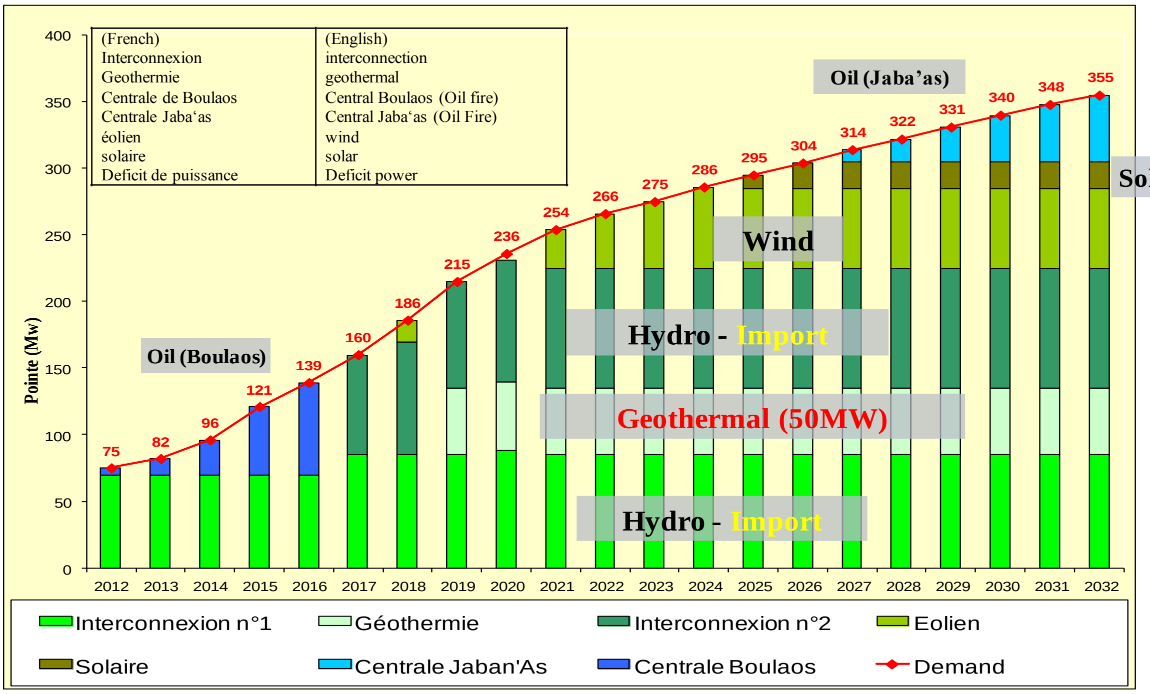
On the other hand, Vision Djibouti 2035, established by the Djiboutian government in 2014, has the goal where renewable energy covers all domestic electricity demand by 2020. Based on this national policy, EdD formulated its electricity supply plan as shown in Figure 2-2 [6].

- Electricity supply in 2032 will be 355 MW.
- As an immediate measure, the electricity demand will be satisfied through the existing Boulaos Diesel Power Plant and imported electricity from Ethiopia until 2016.
- By 2017, all electricity will be supplied from renewable energy sources by increasing imported

electricity with the second interconnected transmission.

- In 2019, a 50 MW geothermal power plant will start operation.
- Wind and solar power plants will be installed in 2021.
- Insufficient electricity after 2027 will be served through diesel generation, which is planned to be constructed in Jaba'as.

As for geothermal energy, the generation capacity is assumed of the planned power plant in Lake Asal.



Source : EdD [6]

Figure 2-2 Electricity Supply Plan of Djibouti

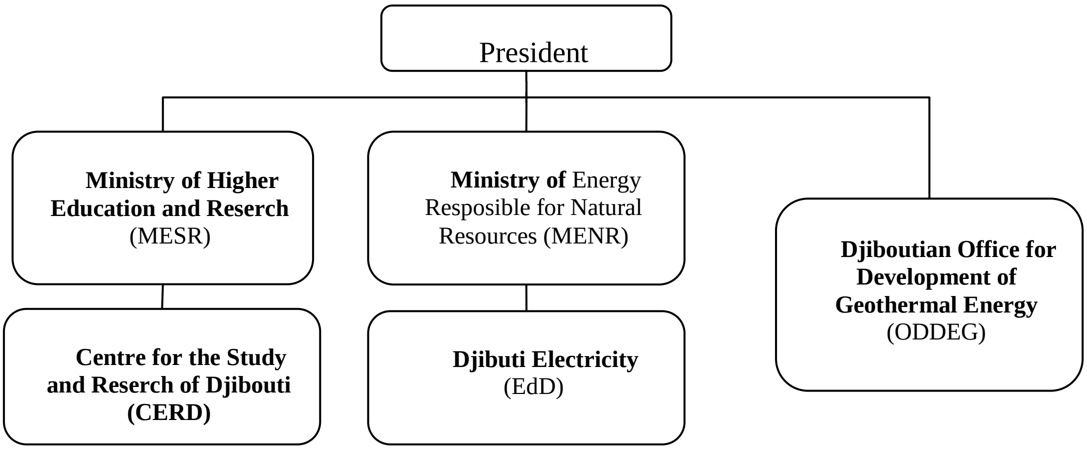
The points to be noted in this plan are as follows:

- This depends on the electricity supplied by Ethiopia, which should amount to 60% of all domestic demand.
- This depends on the wind and solar power generation, which should amount to about 20% of the electricity supply, although the output is unstable because they rely on the weather.
- For geothermal energy, only Asal and Fiale are listed but no other prospects are included.

CHAPTER 3 Geothermal Development Organization in Djibouti

The organisations related to energy policies in Djibouti are the following:

1. Ministry of Energy Responsible for Natural Resources (MENR)
2. Ministry of Higher Education and Research (MESR)
3. Djiboutian Office for Development of Geothermal Energy (ODDEG)



Source: JICA Survey Team

Figure 3-1 Energy Sector in Djibouti

3.1 MENR and EdD

MENR is the organisation that drafts and enforces energy policies of Djibouti and supervise the affiliated energy connection entities. Électricité de Djibouti (EdD) is affiliated with MENR. The organisational chart of MENR is shown in Figure 3-2.

[Électricité de Djibouti (EdD)]

EdD is a public entity established in 1960 and is the only organisation in charge of power generation, transmission, and supply in Djibouti. Although it is under the supervision of MENR, EdD is designated as a public corporation with independent administration and profit. However, changes in the electric tariff need the cabinet approval.

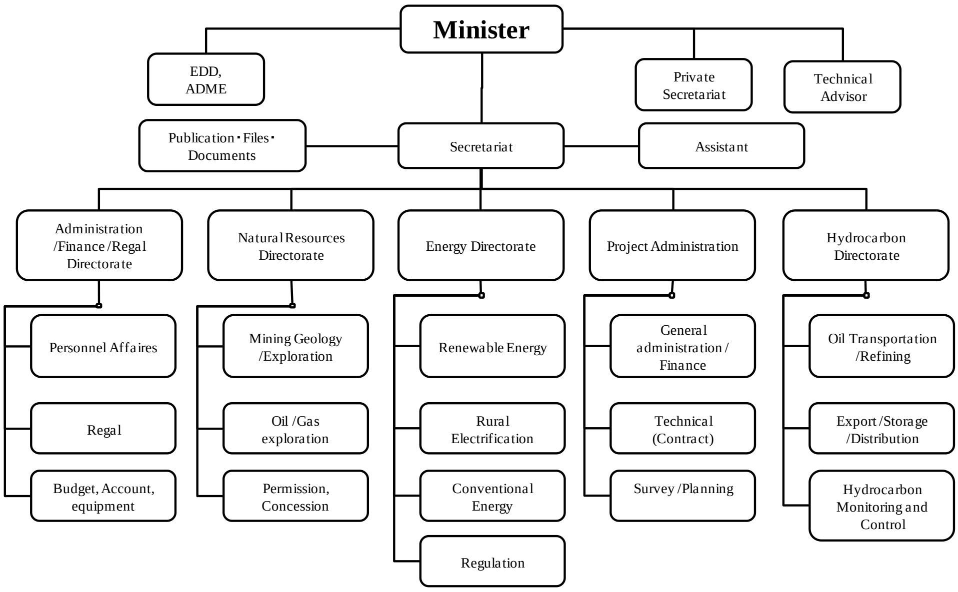
EdD supplies electricity nationwide (Djibouti, Arta, Tadjoura, Obock, Dikhil, and Ali Sabieh). For remote areas not yet connected with the transmission grid, the Djibouti Social Development Agency (ADDS) is in charge of power supply.

The main facilities that EdD owns are as follows:

- Diesel power plants in Marabout and Boulaos,
- PK2 transformer substation and Ali-Sabieh Transformer Substation,
- Independent power stations in Obock and Tadjoura, and
- 63 kV power transmission line which is laid from 9.3 km to 72 km between PK12 - Ali Sabieh and PK12 – Palmeraie,

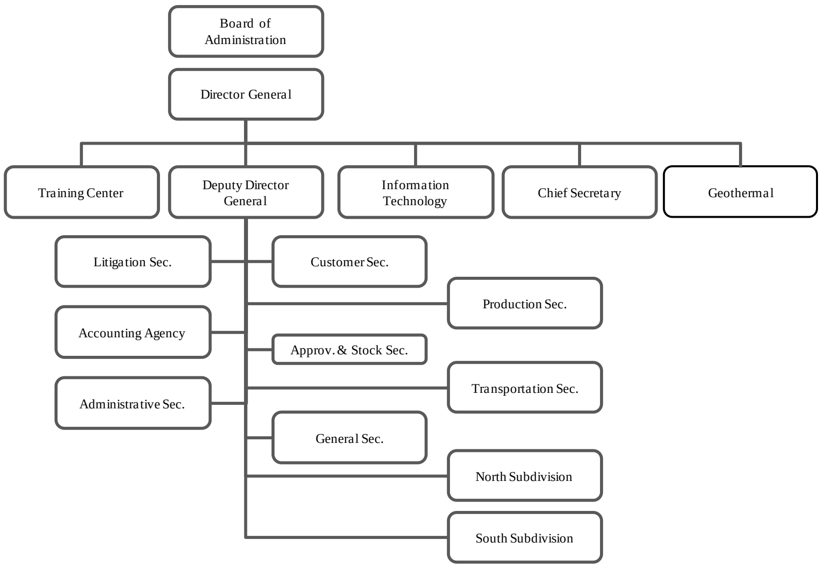
- International power transmission line (230 KV) between Ethiopia (Dire Dawa) and Djibouti (PK12): 203 km section within Djibouti out of 283 km in total.

The organisational chart of EdD is shown below.



Souece: MENR

Figure 3-2 Organization Chart of MENR



Souece: EdD

Figure 3-3 Organization Chart of EdD

3.2 ODDEG

3.2.1 Objective of Establishment

ODDEG is a new organisation established immediately under the Executive Office of the President in 2014.

ODDEG is regulated by a cabinet order as the organisation responsible for geothermal energy development including all human and physical resources related to geothermal energy in Djibouti. According to the reported statement of the minister of MENR, ODDEG is modelled after the Geothermal Development Company (GDC) in Kenya.

The roles of ODDEG are determined in Presidential Decree No. 2014-33/PRE (February 18, 2014), as follows:

- Article 2: The Board belongs to the Presidency of the Republic
- Article 3: The main tasks of ODDEG are as follows:
    - Identification of the various types of geothermal resources in the country (high and low energy);
    - The completion of exploration, reconnaissance work, and studies;
    - The completion of pre-feasibility and feasibility studies for industrial development of these resources, and diversification of their uses; and
    - The identification with the appropriate partners, public, and private operators that are likely to ensure the development of the production of geothermal energy, and possibly associated products.
- Article 4: The actions of ODDEG are as follows:
    - Ensure greater energy independence and make a geothermal resource base in the energy mix of the country;
    - The direction and facilitating technological research, education, and training;
    - The development, demonstration, and dissemination of applicable techniques;
    - The execution of all construction or operation works relating to the subject matter;
    - The collection of data and information, and advice to public and private individuals;
    - Participation in the elaboration and the implementation of international agreements and bilateral cooperation in relation to its prerogatives; and
    - Collaborate with the relevant authorities, including EdD, for each of its projects.

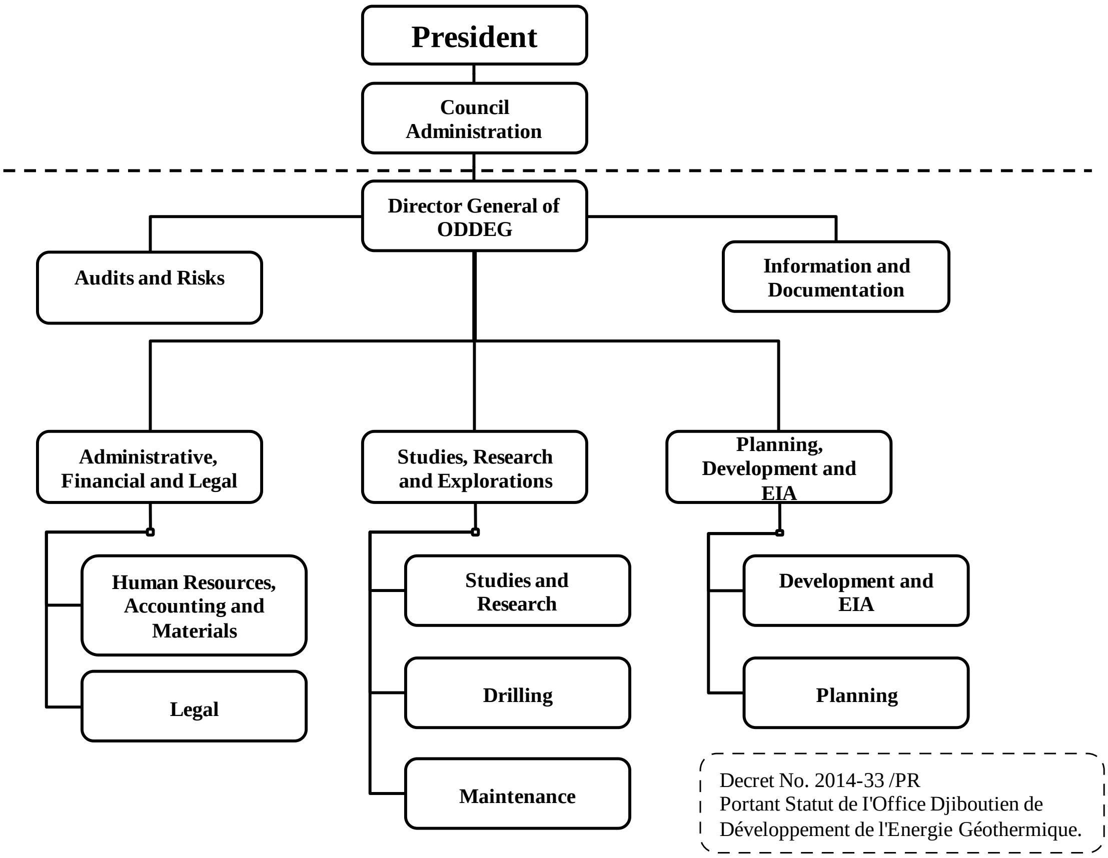
The duties of ODDEG defined by the presidential decree are from investigations, through steam production to steam supply. According to information from the Director General of ODDEG, the Asal and Fiale geothermal fields are planned to be drilled through financial support from WB, and the concessions will be provided to independent power producers (IPP).

3.2.2 Organizational Framework

The organisational chart of ODDEG is shown in Figure 3-4.

From the organisational chart, it indicates that ODDEG is organised for implementing the geothermal development process until the drilling stage.

According to information from an ODDEG officer on July 30, 2014, ODDEG is negotiating with a Turkish rig production company (Petrotek).



Source: Decret 2014-33/PR

Figure 3-4 Organization Chart of ODDEG

3.2.3 Member and Facility of ODDEG

The Director General is Mr. Abdou Mohamed Houmed, a then researcher of the Institute of Higher Studies and Research Science and Engineering (Institute Superieur d'Etudes et de Recherches Scientifiques et techniques: ISERST that is now reorganized as CERD), and was then in charge of the geothermal development of EdD. In addition, by the decree issued on July 30, 2014, three geophysicists, one reservoir engineer, and one technician of CERD and three drilling engineers and two power plant designers of MENR were assigned to ODDEG at the end of July 2014.

Table 3-1 Technical Member of ODDEG (as of July 20, 2014)

ODDEG member	Former organization	Number of staff
Director General	ISERST→EdD	1
PhD Geophysicist	CERD	1
PhD Reservoir Engineer	CERD	1
Physicist	CERD	1
Technician	CERD	1
Geophysics Engineer	CERD	1
Drilling Engineer	MENR	3
Planning	MENR	1
Development	MENR	1
Total		11

Source：JICA Survey Team

The office of ODDEG is formerly situated in the building of EdD in Marabout. The new office is currently under construction within the former agricultural facilities in PK20 of the Djibouti City suburbs. Meanwhile, the headquarter of ODDEG has been shifted to the downtown near the Parliament (Immeuble La plaine). The equipment for geothermal exploration owned by CERD are now under process of being transferred to ODDEG.

Table 3-2 shows the list of geochemical survey equipment that were provided to ODDEG for this Survey.

Table 3-2 Geochemical Survey Equipment of ODDEG

Equipment	Quantity	Remarks
pH meter	2	portable
Conductivity meter	2	portable
Thermometer	2	portable

Source：JICA Survey Team

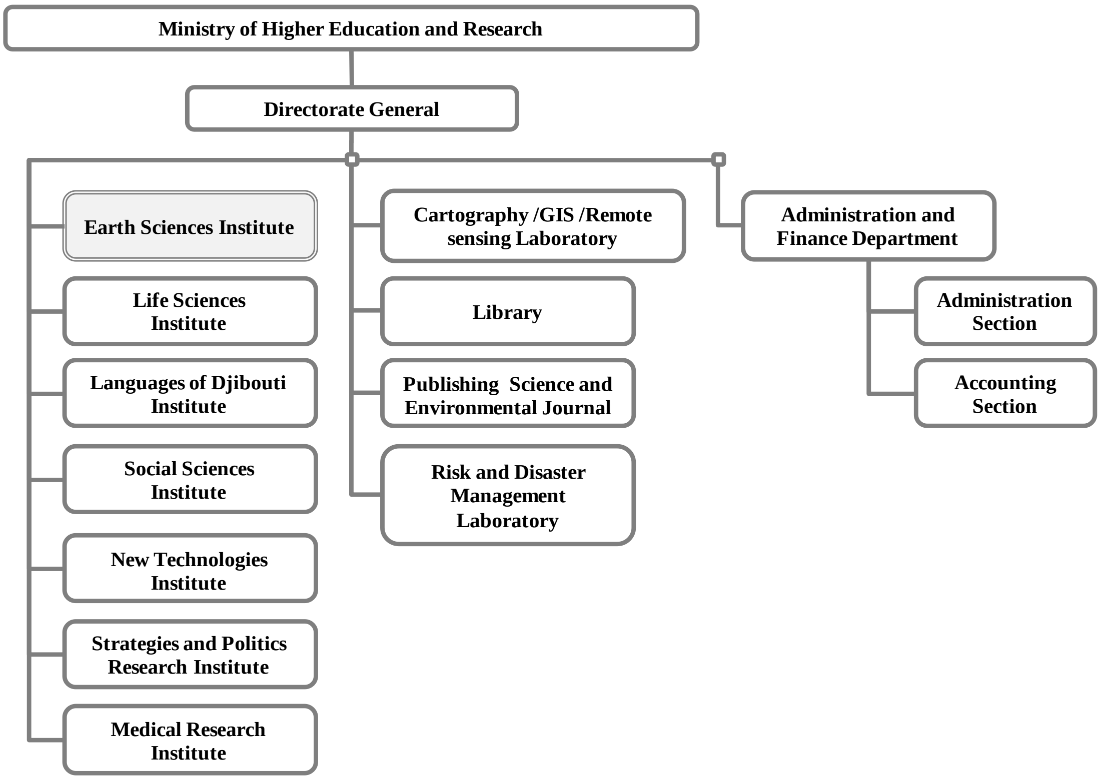
3.3 MESR and CERD

The Ministry of Higher Education and Research (MESR) is in charge of drafting and enforcing policies on higher education in Djibouti. The University of Djibouti, medical schools, and CERD are under MESR.

[CERD]

CERD, that was formerly ISERST, was established on January 1, 1979 for the purpose of investigating natural resources. It was reorganised and became CERD in 2001, then consisting of seven research institutes and some supporting sections.

Figure 3-5 shows the organisational structure of CERD.



Source: CERD

Figure 3-5 Organization Chart of CERD

[Earth Science Institute of CERD]

Members of the Earth Science Institute are listed in Table 3-3. Five officers from this list were already transferred to ODDEG by decree on July 30, 2014, as shown in Table 3-4.

The Earth Science Institute of CERD has ten areas of specialisation. The total number of specialists is 30; seven in geochemistry, five in hydrogeology, four in seismology, and others.

The Earth Science Institute of CERD used to be in charge of geothermal exploration before ODDEG was formed, and it has conducted pre-feasibility studies in Obock, Nord Goubet, and Lac Abhe.

Table 3-3 Member of CERD's Earth Science Institute (as of June 2014)

	PhD	Master	Bachelor	others	Subtotal
Geology	4		1		5
Geothermal	1				1
Metallogeny	1				1
Geophysics	1	2			3
Cartography		3			3
Risk Management		1			1
Hydrogeology	1	2		3	6
Geochemical	1	5		2	8
Seismology		1		3	4
Drilling				2	2
Total	7	12	1	10	30

Source: CERD

Table 3-4 Members of ODDEG Transferred from CERD (as of July 30, 2014)

Member of ODDEG	Former Organization	Number of staff
PhD Geophysicist	CERD	1
PhD Reservoir Engineer	CERD	1
Physicist	CERD	1
Technician	CERD	1
Geophysics Engineer	CERD	1

Source: Decreto 2014-193/PRE

3.3.1 Current status of the Geophysics Department of CERD

(1) Geophysicists

Table 3-5 lists the three geophysicists of CERD. They all have academic degrees from foreign universities, such as in France and Algeria.

Table 3-5 Geophysicists of CERD

Name	Position	Specialty	Remarks
Dr. Hassan Mohamed Magareh	Senior Geophysicist	MT, Electric	PhD at the Université de Bretagne, France
Nasardin Ahmed	Geophysicist	TDEM, Gravity	Studied Seismic method in Algeria and got BD.
Fahman Hassan Abdllah	Geophysicist	DGPS	MD of Physics from French University

Source: CERD

(2) CERD's Equipment for Geophysical Survey

(a) Magnetotelluric（MT）Survey Equipment

CERD has two ADU-07e systems produced by Metronix, Germany. One was purchased by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2010, and the other by CERD in 2012.

Table 3-6 lists CERD's MT survey equipment. Almost all of the equipment are kept in CERD's storage or the geophysics office located in Djibouti City, while the rest are stored in the Seismic Observatory located in Arta.

[Points to be Focused]

In Japan, the Metoronix ADU-07e system is usually used by researchers of Japanese universities and research institutes. Japanese private consulting companies are not familiar with Metronix, that has developed exploration equipment mainly for academic use. Because it contains some parts that can be diverted to military use, an export license is necessary to transport the equipment to foreign countries according to Metoronix. On the other hand, the Phoenix MTU-5A system, that is usually used by Japanese consulting companies, is more practical and easy to handle. MT data can be measured automatically with that system. Therefore, there would be issues for Djiboutian geophysicists, who are familiar with the Metoronix system, when they work together with Japanese geophysicists.

(b) Time-Domain ElectroMagnetic (TDEM) Survey Equipment

CERD has one Terra TEM system, which was produced by Monex Geoscope Pty Ltd, Australia. It was provided by UNESCO in 2010 and kept in CERD's storage or the geophysics office located in Djibouti City, as shown in Attachment-3. Table 3-7 shows the list of CERD's TDEM survey equipment.

Table 3-6 MT Survey Equipment

	Equipment	Model / Specification	Amount
1	MT Receiver	Metronix ADU-07e; SN:107,150	2
2	Magnetic Induction Coil	Metronix MFS-06e; SN:62; 64; 105; 107; 115; 150	6
3	Coil Cable	Metronix	6
4	Non-polarisable Electrode	Metronix EFP-06	18
5	Electric Cables for Potential Measurement	Metronix	16
6	Car Battery for Receiver	-	4~6
7	Battery Charger	-	2
8	Generator	-	2
9	Equipment for Survey (Compass, Level, Tape, etc.)	-	1 set
10	Dibble (Scoop, Pick, etc.)	-	1 set
11	GPS Receiver	GARMIN	2
12	Laptop PC to handle MT Receiver	TOSHIBA, DELL	3
13	LAN Cable	50 m	2
14	Laptop PC for Data Processing	-	some

Source：CERD

Table 3-7 TDEM Survey Equipment

	Equipment	Model / Specification	Amount
1	TDEM Receiver	Monex GeoScope ; Terra TEM:S/N 121076	1
2	Electric Cables for Loops	100 m x 100 m loop	2 sets
3	Battery for TDEM Receiver	Monex GeoScope; Battery Box	1
4	Battery Charger	Monex GeoScope; Battery Charger	1
5	Interface Cable	Monex GeoScope; Interface Cable	1

Source：CERD

(c) Gravity Survey Equipment

CERD has one CG-5 gravimeter, that is produced by Scintrex Ltd., Canada. It was procured by CERD in 2013. They also have one differential global positioning system (DGPS) receiver (the model is unknown) produced by Trimble Navigation Ltd., United States. The DPGS survey will apply to the gravity survey. However, there have been no survey results as of May 2014. The gravimeter and DGPS receiver are stored in CERD's geophysics office located in Djibouti City (see Attachment-3).

(d) Data Processing and Analysis Programs

CERD has performed data processing and analysis of each geophysical survey by themselves. Table 3-8 shows a list of computer programs that CERD has been using for data processing and analysis. Some are commercial and running on Windows OS while others are academic written in Fortran language, and running on Unix OS.

Table 3-8 Programs for Geophysical Data Processing and Analysis

	Method	Purpose	Name	Producer	License
1	MT	Data Processing	Mapros	Metronix	1
2	MT	Data Processing	Birrp	Dr. A. Shaves	Free
3	MT	1D Inversion	IPI2win_MT	Moscow State University	Free
4	MT	1D Inversion	(Fortran Program)	-	-
5	TEM	Data Processing	SiTEM	Aarhus Geophysics	1 (dongle)
6	TEM	1D Inversion	Semdi	Aarhus Geophysics	1 (dongle)
7	Gravity	Data Processing	CGX Tool	Scintrex	1
8	Gravity	Data Processing	(Fortran Program)	-	-
9	Other	Graphics	GMT	Hawaii University	Free

Source：CERD

(3) Previous Geophysical Surveys

After 2010, CERD has independently conducted geophysical surveys in three potential geothermal sites (Nord Goubet, Obock, and Lac Abhe), where CERD have already conducted pre-feasibility studies on. The TDEM survey uses high frequency EM waves for surveying the resistivity structure of shallower parts of underground, whereas the MT survey uses low frequency EM waves for surveying the resistivity structure of deeper parts of underground. The gravity survey is to survey the density structure of underground. Table 3.2.4 shows a list of CERD's previous geophysical surveys only for geothermal exploration.

Table 3-9 Previous Geophysical Surveys by CERD (Geothermal Exploration Only)

	Area	Method	Year	Amount	Remarks
1	Nord Goubet	TDEM	2010	32	
2	Nord Goubet	MT	2010	30	
3	Lac Abhe	TDEM	2011	35	
4	Lac Abhe	MT	2011	34	
5	Lac Abhe	Gravity	2012	85	Gravitometer was rented from the Université de Bretagne
6	Obock	TDEM	2013	46	
7	Obock	MT	2013	46	
8	Obock	Gravity	2013	122	

Source : CERD

The surveys were conducted by CERD's geophysicists listed in Table 3-5 above together with local day workers. For the survey of Nord Goubet where accessibility was very poor, they made a camp. They brought the equipment by hand to the poins where there was no access by cars. The approximate time periods of the surveys were: 30 days for Nord Goubet, 45 days for Lake Abhe, and 30 days for Obock.

The geophysicists of CERD conducted planning of field surveys, data acquisition (field surveys), data analysis, and data interpretation consistently. In addition, they discussed on the geophysical survey results with the geologists of CERD. Their work is not similar to that of Euro-American geophysicists, that are highly divided and specialised, but more similar to that of Japanese geophysicists.

[MT Survey]

In the MT survey, measurement times for 2,048 Hz, 256 Hz, and 32 Hz sampling were set at 2 minutes, 40 minutes, and 20 hours, respectively. The total measured time was 22 hours. In the field, two sets of equipment were used. CERD does not use the remote reference station, and only applies cross-reference technique.

[TDEM Survey]

Before or after the MT survey, the TDEM data from four stations were measured per day. The measurement term was 30 minutes. Generally, the TDEM data are used to correct the static shift of MT data. The static shift is a phenomenon wherein the apparent resistivity curves shift because of the local resistivity anomaly near the survey point. However, CERD does not use TDEM data for the static shift correction and just uses it for estimating the shallow resistivity structure.

[Gravity Survey]

The gravity survey has been conducted together with the TDEM and MT surveys. However, CERD does not have the proper data processing program, and digital terrain models are dependent on foreign organisations. Therefore, CERD does not have the ability to do the proper terrain corrections. In addition, CERD has not surveyed the gravity stations with reasonable accuracy since they have not used the proper survey equipment such as DGPS. For these reasons, the data quality of CERD's gravity survey seems to be insufficient.

[Management of Geophysics Data in CERD]

Geophysical datasets acquired by CERD in Djiboutian geothermal areas since 2010 have been personally managed by each CERD geophysicist. Regarding the geophysical datasets not acquired by CERD, such as that of Lac Asal by REI, CERD mentioned that they could access only the report and not the datasets. Since CERD also does not have nationwide basic geophysical information, such as gravity maps and magnetic maps, CERD usually obtains global geophysical information from foreign institutions. Gravity or magnetic data has not been used for geothermal exploration at that time in Djibouti.

(4) Evaluation of Geophysics Department of CERD

[General]

Judging by the interviews results with the Geophysics Department of CERD, the department has ability to achieve a measure of legitimacy. However, because of insufficient number of personnel, all the geophysicists have to join field survey, and during the survey, other geophysical jobs are suspended and eventually the efficiency of the geophysical study became lower.

[Data Analysis]

Since the survey team had no opportunity to access the pre-feasibility reports of CERD in this Survey, CERD's ability of data interpretation and data compiling were inferred only from the interview.

CERD does only 1-D inversion of electromagnetic data and they do not apply the terrain correction for gravity data. Since CERD only has a four-year experiences of geophysics, they do not have sufficient or updated capabilities of numerical analysis and integrated interpretation. In other words, CERD does not handle the acquired geophysical data efficiently for the next exploration steps, which are targeting of the drilling sites and monitoring of the geothermal reservoirs.

(5) Possible Technical Assistance

Survey Equipment: Djibouti still has sufficient geophysical survey equipment. Because there are not a lot of geothermal prospects in Djibouti, the demand of the MT survey does not seem to increase. Therefore, the donation of geophysical survey equipment in addition to those they have now is considered not to be needed.

Field Survey Technique: Djibouti has a short history of geophysics. In order to confirm the field technique, cooperation on conducting field surveys related to geophysics, such as MT, TDEM, and gravity, is desired. However, CERD only has the Metronix system, which is not being used by Japanese consulting companies. Since the procedure of the receiver is different, assistance on field survey technique is limited to the planning of the field survey and the setting of magnetic induction coils and electrodes.

Software and Technique of Data Analysis: CERD does not have the proper software for data processing and data analysis. CERD's ability of data analysis is assumed to be insufficient. The installation of 2-D inversion software and technical transfer of data analysis are considered to be neccessary.

Approach of Assistance: CERD has already conducted MT surveys in three promising geothermal sites, namely, Nord Goubet, Obock, and Lac Abhe, while Iceland Geosurvey (ISOR) has already conducted an MT survey in Lac Asal. Therefore, there are few sites left where an MT survey must be performed preferentially. (In the following section of this report, the JICA Survey Team nominates three sites, namely, Hanle-Garabbayis, Hanle-Gaggade, and Arta for MT survey. Considering these situations, in order to promote geothermal development in Djibouti, the following approach is deemed to be reasonable:

- To access CERD's pre-feasibility study reports, evaluate CERD's abilities to perform MT data acquisition and analysis.
- To conduct a MT survey in Hanle-Garabbayis and Arta[1] with Djibouti's presently available resources together with technical support from Japan. The JICA Team shall conduct the MT survey Hanle-Garabbayis with two Phoenix systems brought from Japan. At the same time, a Djiboutian team shall conduct the MT survey in Arta using the two Metronix systems that CERD has.
- To procure a 2-D MT inversion software to analyse the data of the MT survey. The Djibouti team shall conduct a re-analysis of the MT survey results of the pre-feasibility study reports with the software to be procured.
- The Djibouti team shall continue the MT survey in Hanle-Gaggade and finish the geophysical surveys in the most promising geothermal sites in Djibouti.

3.3.2 Current Status of Geochemical Section in CERD

(1) Human resources

The number and qualified staff in the geochemical section are as follows:

PhD	: 1 (Director of Earth Sciences Institute of CERD)
MD	: 5
Technician	: 2

[1] There are three promising geothermal sites where MT surveys have not yet conducted, namely, Hanle-Garabbayis, Hanle-Gaggade, and Arta. Among those, Hanle-Gaggade are not easily accessible as compared with the other two.

(2) Equipment and Machinery

As of the end of June 2014, CERD possesses the equipment and machinery for geochemical analysis as shown in Table 3-10.

Table 3-10 Equipment and machines for geochemical analysis in CERD

Equipment	Q'ty	note
AAS-Flame	1	The machine measures Na and K
GC-MS	1	The machine measures pesticides
ICP-OES	1	
Muffle Furnace	1	
Balance	2	Readability 0.1mg
Ball mill	1	
Incuvator	2	The machine is used for BOD analysis
Microscope	1	
Oven	2	
Spectrophotometer	3	One of the machine can measure infrared rays
Deionizer	1	
Ultra Water Purifier	1	
HPLC-MS	1	
Ion chromatography	1	
pH,Conductivity meter	1	

Source: CERD

(3) Current Activities of the Geochemical Section

The activities of the section are as follows:

- Number of samples in a year: about 400 water samples/year
- Analysable parameters:
    - Water sample parameters: pH, conductivity, anions (such as SO4, HCO3, and Cl), cations (such as Ca and Na), organic matter (such as COD and BOD), nutrients (such as NH4, NO3, NO2, and PO4), pesticides, and heavy metals
    - Rock samples: heavy metals
- Clients:
    - Most of the groundwater samples are requested by the National Office for Water and Sanitation in Djibouti (*l'Office National de l'Eau et de l'Assainissement de Djibouti*: ONEAD), for free of charge due to a national importance
    - The number of sewage samples, industrial wastewater samples, and rock samples are occasionally requested.

(4) Evaluating Current Capacity in the Geochemical Field

(a) General

There are two geochemical laboratories in CERD. The equipment in the laboratory are operated and maintained appropriately. For instance, lists of reagents are properly prepared and maintained. Responsible personnel are assigned to operate and maintain the equipment.

The technical capacity of the personnel of CERD in terms of conducting field surveys, such as sample collection and pre-treatment, has been confirmed to an acceptable level in general.

(b) Equipment for analysis

Based on the observation of the present conditions of the CERD-owned equipment for analysis shown in Table 3-10 above, CERD is considered to be capable of measuring the main components in water sampl, such as Cl, SO_4, HCO_3, Na, K, Ca, Mg, and SiO_2. On the other hand, it seems to be difficult to measure components in fumarolic gas.

Dr. Awale pointed out that the budget for consumables is not enough, and the suppliers of equipment parts are limited.

(5) Other Request —Rock Analysis Equipment

CERD wants to introduce and update their rock analysis equipment, as follows:

- Polarising microscopes (update)
- Stereoscopic microscope (update)
- XRD (new)
- XRF (new)
- Fluid inclusion analyser (new)

(6) Technical Support

Field survey tool: A set of basic tools for the field survey on spring water were procured for ODDEG by this project. Although tools for fumarolic gas sampling are not available in CERD or ODDEG, the JICA Team considers them not be necessary for a practical reason because there will be a limited number of fumarolic gas points in Djibouti.

Analytical equipment: Presently, CERD mainly conducts geochemical analysis, but expressed interests in acquiring equipment of gas analysis and enhancing equipment of rock analysis.

Gas analysis equipment: The main objectives of fumarolic gas analysis for geothermal development is to provide with information on possible conditions of reservoir and/or heat source such as approximate temperature, origin of heat and/or others. Once prospects are selected partly based on the information of such fumarolic gas, further survey on fumarolic gas in the selected sites may not usually occur for geothermal development; rather than it more direct methods will be selected. As a conclusion, the JICA Team considers that procurement of gas analysis equipment may not be necessary.

Rock analysis equipment: Once test drilling starts, rock sample analysis will be required to assess underground conditions. This is also necessary in operation stage for production well drillings. The

JICA Team recommends, therefore, that procurement and technical transfer related to rock sample analysis be provided to Djibouti.

Water quality analysis: As was identified in the comparison analysis between the results of CERD and the Team, the analytical precision of CERD has reached a practical level with almost enough equipment for water quality analysis. However, considering the current difficult conditions of maintenance in the laboratory, the provision of consumables in accordance with the project is required.

The items to be provided in the upcoming project are listed as follows:

- Unit to prepare slice of rock (update)
- Polarising microscopes (update)
- Stereoscopic microscope (update)
- XRD (new)
- XRF (new)
- Fluid inclusion analyser (new)
- Hollow cathode lumps for AAS (consumable)
- Gas and reagent (consumable)
- Glassware (consumable)

Technique of field survey: Through this Survey, the JICA Team confirmed that CERD has enough skill for field survey of water quality. On the other hand, ODDEG, which is responsible for geothermal development in the country, has just started and has not enough technical capability. Technical transfer to ODDEG is expected.

Chemical analysis and data analysis: The JICA Survey Team confirmed that CERD is capable of chemical analysis for determining water quality. As for rock analysis, however, mainly due to the insufficient equipment in CERD, the JICA Survey Team could not assess capacity to conduct chemical data analysis. Along with the introduction of equipment for rock analysis, technology transfer is considered to be necessary.

ODDEG does not have a laboratory and only has a few experiences on chemical data analysis. They are requested to increase their capacity on data analysis, and technical transfer for such is expected.

Approach of the technical support: As described before, the Government of Djibouti established ODDEG on January 20, 2014 as the responsible organization of all tasks related to geothermal energy development. Ten officers were officially assigned to ODDEG by a decree dated on July 30, 2014. Five of those officers, most of which are professionals of geophysical exploration, are transferees from CERD. Also, related equipment are expected to be transferred from CERD to ODDEG. However, most of exploration resources for conducting geological and geochemical survey (professionals, tool, and equipment) are still with CERD. At this moment, no clear work demarcation of assignments appears to be defined for ODDEG and CERD. It is therefore necessary to assess the work assignments when further cooperation should be provided to Djibouti for geothermal energy development. Temporarily, the following approaches may be recommended:

- The role imposed on ODDEG is considered to be comprehensive interpretation and analysis of the survey results. Therefore, knowledge on geochemistry and field survey, technology of data analysis, and reservoir management need to be transferred.

- CERD is responsible for overall analytical techniques. Therefore, CERD needs to be provided with equipment for geochemical analysis. It is necessary for technology transfer, such as on rock analysis method and data interpretation.

CHAPTER 4 International Assistance for Geothermal Development

The description will be made based on the information that Djiboutian Office for Development of Geothermal Energy (ODDEG) provided with to the JICA Survey Team regarding the international assistance for geothermal development in Djibouti. A summary of the international assistance is shown in Table 4-1.

4.1 United Nations University-Geothermal Training Programme (UNU-GTP)

The Geothermal Training Programme of the United Nations University (UNU-GTP) is a postgraduate training programme, aiming at assisting developing countries in capacity building of geothermal exploration and development. The programme consists of six months annual training for practicing professionals from developing and transitional countries with significant geothermal potential. Priority is given to countries where geothermal development is under way, in order to maximise technology transfer. The programme has operated in Iceland since 1979. It is a cooperation between the United Nations University and the Government of Iceland and is hosted by the National Energy Authority (Orkustofnun) (http://www.unugtp.is/en).

A total of 31 persons benefited from the training programme offered by UNU-GTP from 1989 to 2013; six persons a year in average. Five persons will be sent to UNU-GTP in 2014 according to ODDEG.

4.2 Icelandic International Development Agency (ICEIDA)

The Icelandic International Development Agency (ICEIDA) and the Nordic Development Fund (NDF) launched in 2012 a project to support geothermal exploration in East Africa. ICEIDA is the lead agency in the Geothermal Exploration Project with joint co-financing of NDF. The project is the initial phase of the Geothermal Compact Partnership, initiated jointly by the Ministry for Foreign Affairs of Iceland and the World Bank (WB). The WB's Energy Sector Management Assistance Program (ESMAP) serves as the focal point of the bank for the Compact.

In January 2012, Iceland signed a Compact with WB Group on Sustainable Geothermal Energy for Africa. The compact promotes the United Nation's initiative entitled “Sustainable Energy for All” and is directed specifically at geothermal energy as a sustainable resource. The initiative is aimed at enabling the countries along the African Rift Valley, to acquire a reliable mapping of geothermal areas and to develop plans for resource testing through drilling. This would enable these countries to further develop, implement, and strategise their realisation of geothermal energy as a clean energy source, with the possibility of providing 150 million people with access to clean energy. With the compact, Iceland is now WB's single largest partner in the field of geothermal development.

For geothermal development in Djibouti, ICEIDA is scheduled to implement a capacity building programme for drilling supervision, geothermal evaluation, project management and so on from 2014 to 2016. In this programme, the existing exploration studies in Arta and Gaggade are to be reviewed.

4.3 International Assistance to Asal-Fiale Geothermal Development

Djibouti intends to implement a test well drilling project in Asal-Fiale Geothermal Field with financial assistance of seven financial sources such as WB (Table 4-1). Negotiation for financing is in progress with the financing agencies. A project managing director, an engineering consultant, and a drilling contractor will be procured for the test well drilling project. It was explained that the drilling contractor to be selected will have to procure not only drilling rigs but all the consumables for the project.

4.4 Others (GRMF, US-Aid)

ODDEG filed an application to the Geothermal Risk Mitigation Facility (GRMF) requesting for financial assistance to drill test wells in Nord Goubet and the surface exploration in Hanle. The application was not accepted due to clerical matters.

It was reported that the US Agency for International Development (USAID) expressed its intention to extend its assistance to Djibouti for geothermal development at the Geothermal Donor Collaboration Meeting in Reykjavik hosted by the African Union Commission (AUC) and ICEIDA, held on May 26, 2014. It was informed, however, that any specific activities were yet to be realised so far, according to ODDEG.

Table 4-1 International Assistance for Geothermal Development

Organisation	Programs	
UNU-GTP	1. Past record (1989 - 2013):	
	Short course	20 persons
	Six month trainings	9 persons
	Masters degree course	1 person
	PhD	1 person
	2. This year (2014)	
	Short course	3 persons
	Six month trainings	2 persons
	Masters degree course	-
ICEIDA	1. Technical training for drilling supervision (2014 - 2016)	
	2. Knowledge improvement of geothermal exploration and review of studies in **Arta** and **Gaggade**	
	3. Improvement of management capacity for geothermal development	
GRMF	1. The application was submitted to GRMF for confirmation drilling in **Hanle** and the **Nord Goubet**, but not accepted due to clerical reasons.	
WB, AfDB-ADF, SEFA, GEF, OFID, AFD, ESMAP	1. Test drilling at Asal-Fiale site - Project managing director - Engineering consultant for technical supervision - Drilling contractor	

1. WB: World Bank
AfDB: African Development Bank
2. ADF: African Development Fund (AfDB)
3. SEFA: Sustainable Energy Fund for Africa implemented by AfDB
4. GEF: Global Environment Facility
5. AFD: Agence Francaise de Developpement
GGDP: Global Geothermal Development Plan through ESMAP
6. ESMAP: Energy Sector Management Assistance Program
7. OFID: OPEC Fund for International Development

SEFA: A joint initiative of the Danish government and the Energy, Environment and Climate Change Department (ONEC) of AfDB

ADF: the concessional window of the AfDB Group.

Source: JICA Survey Team

CHAPTER 5 Site Survey and Laboratory Analysis

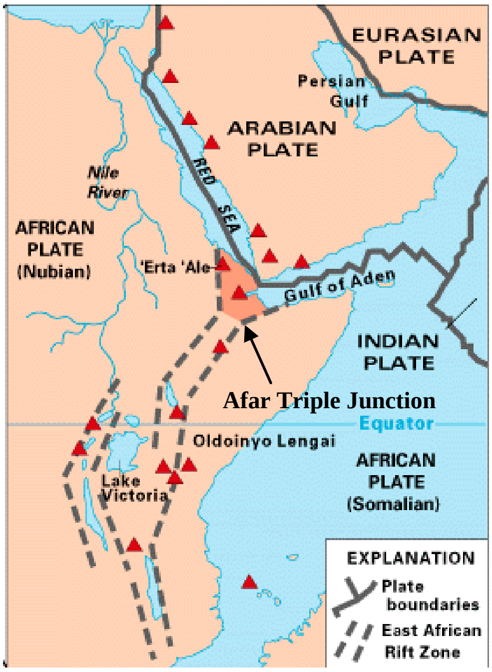
5.1 Geological Settings

5.1.1 East African Rift Zone

The survey area is located in the so-called Afar Triple Junction of the East African Rift Zone.

Figure 5-1 shows some of the historically active volcanoes (red triangles) and the Afar Triangle (shaded, center), wherein three plates are pulling away from one another: the Arabian Plate, and two parts of the African Plate (the Nubial and Somalian) splitting along the East African Rift Zone (according to the United States Geological Survey (USGS) website).

The East African Rift Zone is characterised by active faults and volcanic activities. Earth-scientific researches interpret that the earth crust under the rift is thinner due to the uplifting of magma. For this reason, the East African Rift Zone has been considered a prospective zone for geothermal energy development [8].



Source: USGS Web-site
http://pubs.usgs.gov/gip/dynamic/East_Africa.html

Figure 5-1 East African Rift Zone

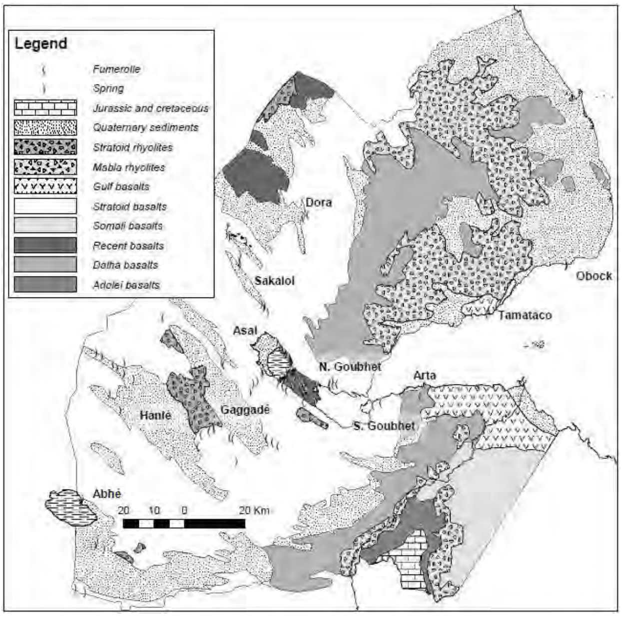
5.1.2 General Regional Geology

(1) Regional Geology

The volcanic series overlie the basement rocks (Jurassic limestone and Cretaceous sedimentary rocks) in relation to the Red Sea, Gulf of Aden, and East African Rift Zone triple junction system (Figure 5-2). Adolei basalts characterise the first rupture movement within the Arab-Nubian block, which occurred during the late Miocene period. The Mabla rhyolite outcrop then formed in 15 Ma. After an interval during which the Mabla rhyolites were eroded, the Dalha basalts were laid down from 3.4 Ma to 9 Ma. The Somali basalts outcrop was formed practically contemporaneously in the eastern part of the region. Between 3.4 and 1.4 Ma, the stratoid basalts and gulf basalts poured out. Recent volcanic formations are mainly located in the Asal Rift and the Manda Inakir Rift. In addition, sedimentary rocks are interbedded in basalts of various periods [9].

The regional geology of Djibouti is generally characterised by intermittently activated volcanic activities from Paleogene to Quaternary.

The JICA Survey Team summarised the schematic geological stratigraphy, as shown in Figure 5-3, that correlates the geology of Djibouti and Ethiopia. The figure illustrates that the volcanic activities in the tow area were similar by the middle of the Miocene period. Thereafter, individual volcanic activities took place differently.



Source: Mohamed Jalludin. (2010) [10]

Figure 5-2 Geological Map of Djibouti

Period/Epoch		Age (Ma)	Ethiopian Rift Valley (WoldeGabriel et al, 1990)	Djibouti (Mohammed, 2010)
Quaternary	Holocene	0.0117	Wonji Group	Recent basalts
	Pleistocene	2.58		Stratoid basalts/ Gulf basalts
Neogene	Pliocene	5.33	Chilalo Trachytes Butajira Ignimbrites	
	Miocene	23.03	Guraghe Basalts Shebele Trachytes	Dalha basalts/ Somali basalts Mabla Rhyolite
Paleogene	Oligocene	33.9	Kella Basalts	Adolei Basalts

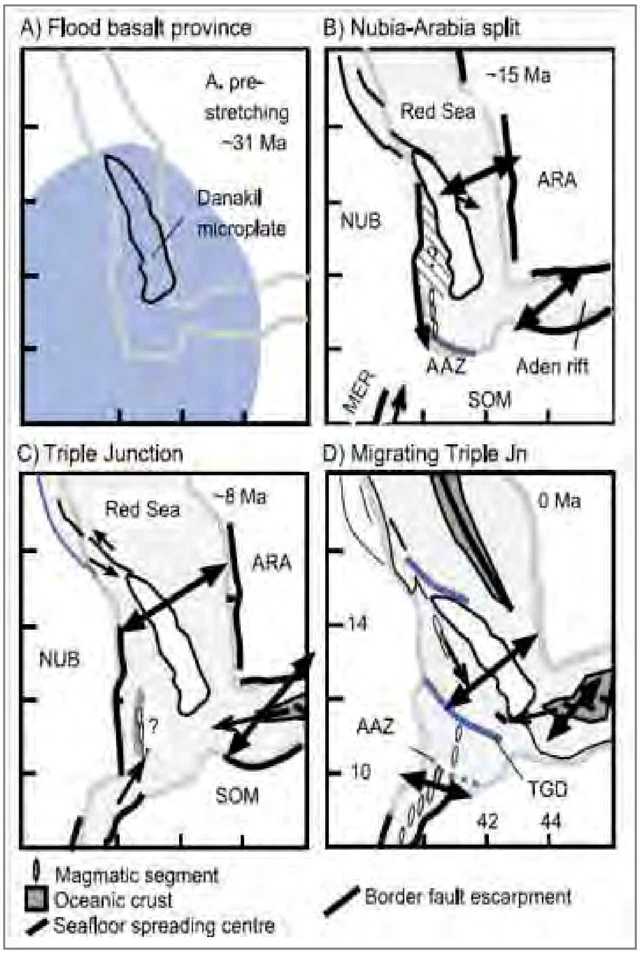
Source: Compiled by JICA Survey Team

Figure 5-3 Schematic Geological Stratigraphy

(2) Regional Tectonics

The development of regional geological structures are as follows (Wolfenden et al., 2004 [11]):

1) Oligocene (±30 Ma): Large amounts of Adolei basalts erupted when the Red Sea and Gulf of Aden rifted (refer to Figure 5-4. A)
2) Mid-Miocene (±15 Ma): The Red Sea basin developed while the Nubian Plate and Danakil microplate began to separate from each other (refer to Figure 5-4. B). At the same time, localised volcanic activities emerged along the Main Ethiopia Rift (MER).
3) Late Miocene (11 Ma-8 Ma): The Main Ethiopia Rift (MER) began to rift, the Afar Triple Junction formed, and the Nubian Plate and Danakil microplate further rifted resulting in the formation of the Afar lowland (refer to Figure 5-4. C).
4) Pliocene – Recent (4 Ma-0 Ma): The Main Ethiopian Rift continues to rift apart while the Red Sea and Aden Sea started to rift again, which resulted in the formation of the present geological setting (refer to Figure 5-4. D).



AAZ: Arcuate Accommodation Zone,
ARA: Arabian Plate,
NUB: Nubian Plate,
MER: Main Ethiopia Rift,
SOM: Somalian Plate,
TGD: Tendaho-Goba'ad Discontinuity

Source: Wolfenden et al.,2004 [11]
http://www.ees.rochester.edu/ebinger/Publications_files/Wolfenden_EPSL.pdf

Figure 5-4 Geological Tectonic Development

5.2 Satellite Imagery Analysis

5.2.1 Objectives

Prior to the field survey, alteration zoning, mineral and lithological mapping, topographic interpretation, and geological structure analysis were carried out using satellite images for the purpose of obtaining data on the 13 potential geothermal sites in the Republic of Djibouti. A field survey was conducted based on the results of this satellite data analysis together with information of existing reports.

5.2.2 Methodology

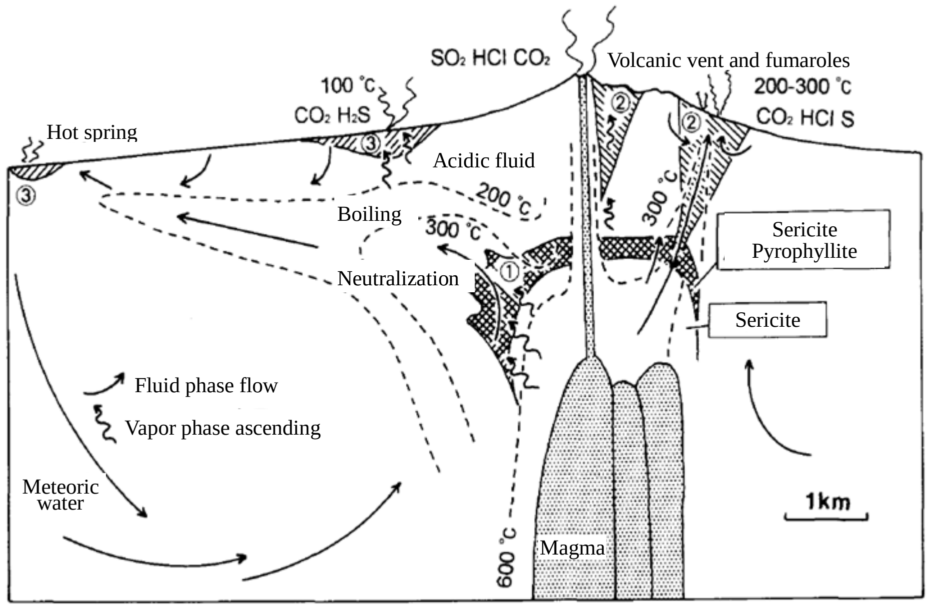
For remote sensing data, ASTER L3A and PALSAR L1.5, that are Japanese satellite products, were used. ASTER has an optical sensor, that has visible and near infrared (VNIR) bands, short wavelength infrared (SWIR) bands, and thermal infrared (TIR) bands for its multi-band sensor (14 bands) and a high resolution (15-30 m). Meanwhile, PALSAR has an active microwave sensor, that is not affected by weather conditions and operable both daytime and nighttime, L-band of multi-polarisation and high resolution (15-30 m).

In ASTER data analysis, apparent distributions of various alteration zones are detected by the band composite image and the band ratio image, which are created by using SWIR bands. Rock facies and mineral mapping and geological structure analysis are also conducted. In PALSAR data analysis, a mosaic image of geothermal development sites is created and geological lineament and so on is extracted. ENVI (Ver. 5.0), a software by ITT-USA, was mainly used for processing and analysis of the abovementioned satellite data.

For the analysis process of ASTER images, non-applicative areas caused by factors of vegetation, water bodies, clouds and their shadows have been masked in the initial step. Then, the band composite images displaying band 4 as red color, band 6 as green color, and band 8 as blue color are created. After calculating band ratio inter bands, the band ratio images displaying band 4/band 6 as red color, band 5/band 6 as green color, and band 5/band 8 as blue color are created. By analysing these images, extraction of the apparent distribution of various alteration zones, rock facies and mineral mapping and geological structure analysis are conducted. In the band composite image (RGB=B4, B6, B8), advanced argillic alteration including alunite and kaolinite mainly shows pinkish color, phyllic alteration including sericite mainly shows yellowish color, and propylitic alteration including chlorite and epidote mainly shows greenish color. In the band ratio image (RGB=B4/B6, B5/B6, B5/B8), advanced argillic alteration shows reddish color and propylitic alteration shows purplish red to deep bluish color.

As mentioned above, the use of ASTER data makes it easy to identify various hydrothermal alteration zones. But those zones include some suspected distributions, e.g., reworked fluvial-alluvial fan sediments of altered material, sabkha evaporates (salts and lacustrine calcareous sediments), which have to be excluded by anticipation of geological-geomorphological interpretation using ASTER band composite image (RGB=B3, B2, B1) and ASTER DEM shaded-graduated coloring relief.

Figure 5-5 illustrates the distribution of advanced argillic alteration zone in/around an active volcano. The hatched areas indicate the broad alteration area around the magma chamber capped zone (①), spotted distribution of the volcanic vent and fumaroles (②) and hot springs (③) as mound-sinter cone. The zonal distribution of alteration center with weak alteration halo seems to be typical.



Source: modified from Watanabe, Y. 1998 [12]

Figure 5-5 Illustration of Distribution of Advanced Argillic Zone In/Around Volcano ①②③

PALSAR data obtained by synthetic aperture radar are useful to grasp topographic relief and ground surface conditions. In PALSAR data analysis, orthomorphic projected images of level 1.5 products of HH single polarised wave are collected, and the mosaic images are created. From these images, geological lineament, fault escarpment, volcanic crater, caldera, lava dome, and flows etc. are interpreted.

In the PALSAR image, the rocky mountain range shows the sharp-edged texture by topographic accentuation. The survey area belongs in the "Afar triangle region", which is a part of the East African Rift Valley. Physiologically it is interpreted in their rocky active surface remarkable volcanic rifts (e.g., Asal Rift) associated with various NW-SE trend graben and horst structures and numerous fissure-fracture systems. Reworked sediment areas are expressed with gradual tone due to sediment diameter (roughness level) and texture, which presents coarse gravel area with bright tone and fine muddy area with dark tone.

As described above, the geology including volcanic topography and distribution of alteration zone are interpreted through ASTER data analysis. Surficial property and fissure-fracture systems are also interpreted through PALSAR data analysis as well, focusing on the volcanic geologic structure alteration mapping of the 13 potential geothermal sites.

5.2.3 Results

In the analysis of ASTER data, the band composite images (RGB=B4, B6, B8) and the band ratio images (RGB=B4/B6, B5/B6, B5/B8) for identifying alteration zones, the graduated coloring relief images by DEM data and band composite images (RGB=B3, B2, B1) for geological interpretation were created. The mosaic images of single polarised wave (HH) for structural and surficial property interpretation were created by PALSAR data.

The integrated analysis on GIS mapping where the results of LANDSAT natural color images were compiled as well as the mentioned results of ASTER and PALSAR data analysis were conducted referring to the published articles and reports. Consequently, the outcrop distributions of hydrothermally-altered rocks were extracted and related volcanic geological structures and reworked sedimentary area were interpreted following the volcanic-geologic structure-alteration map.

The geological unit and formation age data were collected from Mohamed Jalludin (2009) [9], and Mousa, N., et al (2010) [13], and the hot spring and fumaroles position data were from Mohamed Jalludin (2011) [14].

In addition, the reworked sedimentary area (alluvial, salty, and calcareous sediments), recently active volcanoes (cinder cones and stratovolcanoes), alteration related fissure-fracture systems, and rhyolite distributions (intrusive and pyroclastic) are shown, for better understanding, in the volcanic-geologic structure-alteration maps as well as alteration zoning (acidic and intermediate alteration).

The respective satellite data analysis results of the 13 potential geothermal sites are as follows:

(1) Arta Site

Dalha basalt (9-4 Ma) is dominant, geographically from the Arta plateau to the Gulf of Aden (El: 0 to 720 m), and small rhyolitic intrusion-pyroclastic and its extensional two NNE trend fault systems are observed in the western half. It is a relatively well-dissected lava plateau with successive fluvial sediments in their valleys. Acidic alteration spots accompanied with past active fumaroles and their broad halos are clearly identified in the rhyolitic intrusion area. One described active fumarole is situated at the eastern margin of the mentioned hydrothermal alteration zone.

(2) Asal Rift Site

Recent basalt (<1 Ma) lava occupy between Lake Asal and the Bay of Goubet (Asal Rift, El: -150 m to 200 m) with Ardoukoba Volcano, several cinder cones and lava plain. Various aligned cinder-vent cones and maar, surrounded with pyroclastics and Sabkha sediment fillings, are distributed along the rift-built WNW parallel fractures. Weak acidic or intermediate alteration zones are recognised on the northeastern margin, while acidic alteration zones (in part connected with described fumaroles or hot springs) and their weak halos accompanied with stratoid rhyolite intrusions are observed on the southwestern margin concerning rift-built fractures. Small-scale described fumaroles, however, could not be identified in salty sediments.

The tectonic features of Asal rift are characterized as normal fault along two principal trends i.e. NW-SE and NNW-SSE. The third tectonic trend E-W is observed in some part of the rift zone. The NNW-SSE and E-W tectonic features are older than the current NW-SE tectonic feature of the rift and are associated with an older geological formation such as stratoid basalts that outcrop at the margins of the active part of the rift.

(3) Djibouti Site

Coastal lowland and hills surrounding the capital area (El: 0 to 60 m) are composed of the Qued Ambouli estuary, fluvial-alluvial fan-delta sediments (with probable salty sediments and coral reef) aged Pliocene-Quaternary overlaid on the gulf basalt basement (3-1 Ma). Any fracture in the site because of sediment covers is not recognised. Thus, any alteration zone or fumarole hot spring is not observed.

(4) Dorra Site

Stratoid basalt (3.5-1 Ma) completely segmented by NS trend fracture swarm is distributed in the eastern slope of Doda basin (El: 340 to 720 m). Polygonal small depressions caused by tensional fractures are filled with fluvial-lacustrine or calcareous sediments (Sabkha). Any alteration zone or fumarole is not recognised, although one fumarole on the western margin was described.

(5) Gagade Site

Southeastern gentle slope of Gagade basin and its bottom (El: 100 to 580 m) are composed of stratoid basalt (3.5-1 Ma) and basin filled Pliocene-Quaternary sediments (fluvial-lacustrine). NW trend fractures are predominant and cross-cutting NE and NNW trend fractures are also observed. In the northeastern area of the site, aligned acidic alteration spots and halo connected with active fumaroles are observed along the NW fracture system. Several weak acidic alteration zones are also distributed in various slope foot and valley floors.

(6) Hanle-Gartabbaeyis-1 Site

Stratoid basalt (3.5-1 Ma) dominated site correspond to horst structures between Hanle basin and Gagade basin (graben) and eastward of Yoboki Town (El: 160 to 970 m), and large stratoid rhyolite composite volcano (Babba Alou) intrusive pyroclastics (<1 Ma) are suited in the northern half overlaid with recent basalt cinder cones (<1 Ma) sporadically. NW and WNW trend fissure-fracture systems paralleled with the mentioned horst and graben structures are dominant, but minor transversal NNE fracture systems are also developed. Fracture related polygonal small depressions and both basins are filled with sediment mixture of fluvial-alluvial fan-calcareous and salty sediments (Sabkha). In the rhyolitic intrusive-effusive facies centered at Baba Alou Volcano, develop several large-scale acidic alteration zones. Various small acidic alteration spots and their halos in/around active fumaroles on the stratoid basalt are recognised in the southern half, particularly accompanied with recent cinder cones in the contact zone with rhyolitic intrusion.

(7) Lac Abbe Site

Stratoid basalt (3.5-1 Ma) and recent cinder cones dominated site, where correspond to eastern coast of Lake Abbe and Goba’ad basin connected with the northeastern horst (El: 240 to 560 m), several rhyolitic intrusions-pyroclastics are distributed along the southeastern margin. Lacustrine, calcareous and salty sediments fill every small polygonal depressions and the basin (Sabkha) up to salty Lake Abbe. Major WNW fracture systems are parallel to graben and horst structures, while minor transversal NNE trend fractures are also recognised. Recent cinder cone distributions seem to be controlled by intersection positioning of both fracture systems. Scattered acidic alteration spots or small mound (sinter cones) are common in recent pyroclastic cone foothill, and rhyolite related alteration is scarce in this site. It is very particular that mound-shape acidic alteration zone (travertine, sinter cone) accompanied with active fumarole and hot springs in the coastal area of Lake Abbe.

(8) Nord Goubet Site

Stratoid basalt (3.5-1 Ma) lava plateau and its shore (El: 0 to 530 m) correspond to the northwestern Goubet strait and the southern foot of Mt. Day (1,800 m). NNW and NW trend parallel tensile fractures are concordant to valley topography. Fluvial-alluvial fan sediments cover of the valley floor and plateau perimeter, and calcareous sediments, etc. fill the eastern small depressions (Sabkha). Mound shape altered rocks are observed in the southern small depressions, where scattered small acidic altered spots and active fumaroles with halos are distributed.

(9) Nord Lac Asal Site

Stratoid basalt (3.5-1 Ma) plateau intruded by stratoid rhyolite (<1 Ma) correspond to the northern face of Lake Assal (El: -150 to 950 m) and the southwestern foot of Mt. Day (1,800 m). The complexity of NW and NNE trend parallel fracture systems characterise the site topography, where southeastern mountain slopes form the landslide block and both side valley incision traced by huge sedimentary pockets (fluvial and alluvial fan). Several small polygonal depressions are filled with calcareous and salty sediments (Sabkha). Rhyolite-related weak acidic alteration zone occurs around intrusion contacts. Lake Assal's coastal area is described as a spring field; however, it is just identified as salty sediments (only western end outcrop is probable alteration mound).

(10) Obock Site

Pliocene-Quaternary sediments (lacustrine-fluvial and aeolian) cover the the Qued Sadai estuary (El: 0 to 90 m), and uppermost facies is calcareous lacustrine and fluvial sediments. Rhyolitic pyroclastics outcrop in the western hinterland (pyroclastic fan) and distributed as site basement. Any alteration zone is not observed. Low temperature spring appears in the stream end of alluvial fan.

(11) Rouweli Site

Gulf basalt (3-1 Ma) plateau covered with volcanic ash and sediments are dominant and overlaid by rhyolitic pyroclastics (fan) in the western margin (El: 0 to 330 m). Small-scale fluvial and alluvial fan sediments appear along the valley. Acidic alteration (fumarole, only one spot) is recognised in the eastern part. Other described fumaroles are not identified by satellite images (probably very small).

(12) Sakalol Site

Stratoid basalt (3.5-1 Ma) plateau highly segmented by NW and NNW trend fractures correspond to the Doda and Alol basin areas, northward of Lake Assal (El: 10 to 320 m). Variable polygonal depressions (grabens) are filled with fluvial-calcareous and salty sediments (Sabkha). Any alteration spot is not observed. The described spring field in the southern margin of Alol basin can be identified as a salty area.

(13) Sud Goubet Site

Stratoid basalt (3.5-1 Ma) plateau and shore correspond to the eastern side of Goubet strait (El: 0 to 550 m). Both WNW and NNE trend fractures are observed. Fluvial and alluvial fan sediments fill the valleys, and calcareous sediments, etc. in polygonal depressions (Sabkha). Rhyolite intrusion related alteration (intermediate, propyritic) along the NNE trend fracture is remarkable and weak acidic alteration spots (acidic-intermediate) distribution are scattered (in part fumarole?).

The abovementioned results are summarised in Table 5-1. In adition, satellite data analysis maps are shown in Attachment-4

Table 5-1 Satellite data analysis results briefing of 13 geothermal potential sites

Gethermal potential sites		Topography	Elevation (difference)	Geology, Volcanic vents	Fractures, Fissures	Alteration zone	Hot spring / Fumarole
1	Arta	Dissected valley	0 m to 270 m (270 m)	Dalha basalt (9-4 Ma) plateau and Stratoid rhyolite (3-1 Ma)	NNE trend	Acidic alteration spot and broad weak altered halo. Associated with rhyolite.	+
2	Asal Rift	Asal rift, lava plain, Asal lake (Salt lake)	-150 m to 200 m (350 m)	Recent basalt (1 Ma-) with Ardoukoba volcano, lava plain and cinder cones	WNW trend, frequent	Acidic-intermediate alteration spots associated with rift side fractures and rhyolite	described but not observable
3	Djibouti	lowland -estuary zone around urban area	0 m to 60 m (60 m)	Fluvial/fan/delta sediments on Gulf basalt (3-1 Ma)	no	no	-
4	Dorra	Eastern slope of Dorra basin	340 m to 720 m (380 m)	Stratoid basalt (3.5-1 Ma)	NNW trend, frequent	no	described but not observable
5	Gaggade	Southeastern margin of Gaggade basin	100 m to 580 m (480 m)	Stratoid basalt (3.5-1 Ma)	NW, NE and WNW trends mixed	acidic alteration spots and weak altered halo. Associated with fractures.	+
6	Hanle-Garabbayis	Dovisional hill(horst) between Hanle and Gaggade basin	160 m to 970 m (810 m)	Stratoid basalt (3.5-1 Ma), Stratoid rhyolite (3-1 Ma, Babba Alou volcano), cinder cones	NW-WNW trend dominant with minor NNE trend	acidic alteration spots and weak altered halo in recent cinder cones. Broad acidic alteration with rhyolite.	+
7	Lac Abhe	Goba'ad basin and hill(horst) of eastern side of Abhe lake	240 m to 560 m (320 m)	Stratoid basalt (3.5-1 Ma), Stratoid rhyolite (3-1 Ma), recent cinder cones	WNW trend dominant with minor NNE trend	acidic-intermediate alteration spots in recent cinder cone. Acidic alteration mound (sinter cone) .	+
8	Nord Goubet	Southern footslope of Day mountains to Goubet strait	0 m to 530 m (530 m)	Stratoid basalt (3.5-1 Ma)	NNW and NW trends mixed	acidic alteration spot-mound (sinter cone) and weak alterated halo.	+
9	Nord lac Asal	Southwestern footslope of Day mountains to Asal lake	-150 m to 950 m (1,100 m)	Stratoid basalt (3.5-1 Ma), Stratoid rhyolite (3-1 Ma)	NW and NNE trends mixed	weak acidic alteration zone associated with rhyolite.	-
10	Obock	Coastal estuary (fan delta) of Qued Sadai	0 m to 90 m (90 m)	Pyroclastics of Mabla rhyolite (15-11 Ma) and superposed fluvial-alluvial fan sediments	no	no	-
11	Rouweli	Basalt plateau of eastern Tajoura	0 m to 330 m (330 m)	Gulf basalt (3-1 Ma), Mabla rhyolite (15-11 Ma, western margin)	EW trend	acidic alteration spots along fractures.	described but not observable
12	Sakalol	Divisional hill(horst) between Doda and Alol basin	10 m to 320 m (310 m)	Stratoid basalt (3.5-1 Ma)	NW and NNW trends mixed	no	-
13	Sud Goubet	Basalt plateau of eastern Goubet strait	0 m to 550 m (550 m)	Stratoid basalt (3.5-1 Ma)	WNW and NNE trends mixed	Broad intermediate alteration zone associated with rhyolite, partly alteration spot with halo.	+

Geology and formation age data from; Mohamed Jalludin (2009) [9], and Mousa, N et al (2010) [13].

Hot spring and fumaroles position data from; Mohamed Jalludin (2011) [14].

5.3 Geological Survey

5.3.1 General

(1) Purpose

The purpose of the geological survey is as follows.

i) Confirmation of geological conditions on site (topography, geology, geological structures, and alterations)
ii) Confirmation of possible alteration zones identified by remote sensing analysis
iii) Sampling of typical rock and clay sample for laboratory analysis

(2) Methodology

The JICA Survey Team visited geothermal sites recommended by the Djiboutian Office for Development of Geothermal Energy (ODDEG) and Centre for the Study and Research of Djibouti (CERD) recommended to visit. For each site, the JICA Survey Team visually confirmed the location and characteristics of fumaroles, rock outcrops, alteration clays, and/or fracture zones as necessary. They also collected rock samples and/or clay samples wherever deemed necessary for laboratory testing. The collected samples were brought back to Japan for analysis in a laboratory.

(3) Site Survey Results

The results of the geological observations are summarised in Table 5-2, in which the observation targets were categorised as “location and accessibility”, “topographic conditions”, “geology”, “geological structure and fracture system”, “geothermal manifestation (fumarole and/or alteration clay”, and “assessment”.

(4) Laboratory Analysis

The following analyses of collected samples were conducted in the laboratory:

- Microscope observations of rock sample thin sections
- X-ray diffraction (XRD) analysis
- X-ray fluorescence (XRF) analysis

Sample list for the laboratory analysis is shown in Table 5-3.

(a) Methodology of Laboratory Analysis

A detailed methodology for each laboratory analysis is shown in Attachment-5.

Table 5-2 Summary of Geological Observation on Site

	Site name	Location, Accessibility	Topography	Geology	Geo-structure, fractures	Geothermal Manifestations	Preliminary Assessment
1	Arta	- Located on the southern coast of Tadjoura Bay; about 2.5 km from the coast to the fumarole point; - ca. 2.5 km from the coastal line to the fumarole point; - ca. 40 min. from Djibouti city to the junction, ca. 45 min. on unpaved road to the fumarole point through military training field.	- Deeply dissected with ragged hills on both side along the access road; - The fumarole point and alteration zone are located on a edge of wadi where widely eroded; - The mountains around are deeply dissected showing older topographic characteristics	- Dalha basalt together with NS oriented Ribta rhyolite that runs through the fumarole point; - Rock outcrops are generally weathered.	- NS oriented fractures; - NS oriented distribution of three fumaroles described on the geological map, - The fumaroles seemingly along the rhyolite outcrops.	- Three fumaroles described on the geological map, one confirmed on site; - NS oriented acidic alteration zone observed on the satellite images, confirmed on site;	- Strong alteration observed though weak fumarole, suggesting strong hydrothermal activities; - Fumarole outcrops seemingly related to rhyolite outcrops; - Thick cap rock structure expected; - Geothermal fluid with high salinity expected if encountered;
2	Assal Rift (Fiale)	- Located on the western coast of Tadjoura bay, ca. 2km westward from Ghoubbet lake toward Asal lake; - ca. 4 km from the paved to the fumarole point; - ca. 2.5 hours from Djibouti city;	- The fumarole located on the extensive lava field called Lava-Lake; - A few volcanic corns observed; - Located on the central part of the rift that runs from Ghoubbet lake through Lac Asal (el. minus 150m) reaching to Sakalol plain (el. 5m) , showing echelon pattern; - Ardouboba volcano close to the site erupted in November 1978.	- Recent basalt; - the lava lake showing very low viscosity of the lava when erupted.	- NNW-SSE oriented rift zone showing echelon patterned fractures; - Running from Goubet lake to Ethiopian territory; - Rifting still on going.	- Many week fumaroles observed around; - No remarkable alteration observed around; - Geothermal fluid with high salinity over 100,000 ppm occurred from the existing deep wells;	- Not many geothermal manifestations observed except week fumarol; - Ardouboba volcano erupted in 1978; - Heat source may still be close to the ground surface; - Possible lower salinity zones identified by MT survey of ISOR (2008); ca. 2km northern side of the previous site.
	Asal Rift (Koril)	- hot spring site on southern coast of Lac Asal; - Many other springs on the eastern coast of Lac Asal described on geological map; - ca. 3 hours from Djibouti City.	- Located on the coast of Lac Asal, with steep slope on the back; - Not enough drilling space.	- Recent basalt inter-bedded by layered tuff	- Same as above; - NW-SE oriented strong structures	- Temperature of hot spring =78℃; - Salinity = 53,500μS/cm); - While colored clay layers around.	- Hot water may be originated from the Goubet lake heated by Ardouboba volcano; - High salinity
3	Djibouti	- A few km from N.1 road	- Located on lava field;	- Tadjoura basalt 3.4-1.2 Ma	no remarkable structures observed	- Hot water temperature= 73℃; - No other geothermal manifestation - Water level G.L- 130m	- No particular comments
4	Dorra	- Not accessible; no site visit conducted	-	-	-	-	-
5	Hanle-Gaggade Taassa	- Located on mountainous area on a SE rim of Gaggade plain 20-25km south of Lac Asal: - ca. 2 hours from Djibouti to Lake Goubet, ca. 20 min. to the junction of unpaved road, ca. 1.5 hours on jaggy road, ca. 1.0 hours on desert, ca. 1.5 hours on food on ragged path	- SW declining tilted slope; - NW or WNW oriented dissected valley; - NW oriented narrow ridge, underlain by rhyolitic veins.	- Afar stratoid basalt (2.0 - 2.7 Ma) covered by Afar stratoid basalt (1.8 - 2.2 Ma); - Vein or dyke of rhyolite	- NW oriented fractured zones; - Geothermal manifestation along this orientations	- Strong alterations and fumaroles confirmed on site; - These seemingly well associated with fractured zones and rhyolite dykes/veins.	- Strong fumarole and strong alteration along NW direction; - Fairly good geothermal resources expected.
6	Hanle-Garabbays	- Located on a north edge of southern part of the great Hanle plain; - ca. 2.5 hours from Djibouti city to Dikhil town, ca. a hour to the junction on N.1 road, ca. 2.5 km to the fumarole point by car, fairly good access conditions.	- On the boundary zone between the Hanle Plain and the northern mountainous slope; - NW oriented boundary zone, parallel to the Hanle Plain, - Fumaroles on steep slope facing south,	- Afar stratoid basalt (2.0-2.7 Ma) covered by Afar stratoid basalt (1.8 - 2.2 Ma); - A large mass of rhyolite in the northern part of Garabbayis, western Yoboki	- NW oriented lineaments, parallel to Hanle plain	- Strong fumaroles observed on site; - Several fumaroles seemingly along the boundary zone of the older and the younger basal lavas on geological map	- Strong fumaroles confirmed on site; - Test wells in 1980s not encountered high temperature; - Fumaroles emerging along fractured zones possibly associated rhyolite; - Water of Hanle in a range of 3000μS/cm; - Detailed MT survey required to identify fracture system
	Hot springs at Dagguirou, Minkileh, Agna in Hanle Plain	- Located at rims of the great Hanle Plain	- Steep slope of basalt lava on the back of each spring	- Dalha basalt (8.6 - 3.6 Ma)	- The same above	- The temperature ranging 40℃～60℃; - No other remarkable manifestations observed	- No particular comments

	Site name	Location, Accessibility	Topography	Geology	Geo-structure, fractures	Geothermal Manifestations	Preliminary Assessment
7	Lac Abhe	- Located on the western border of Ethiopia: - ca. 2.5 hour from Djibouti to Dikhil, ca. 2.5 hour on desert from Dikhil to Lac Abhe	- Lake deposit plain; - Many large scale travertine, several 10 m high - Ragged basalt hill on north to east	- Lake deposit, desert deposit; - Stratoid basalt on north to east	- No remarkable structures observed on the plain - No regularities in the travertine distribution observed	- Boiling hot water (ca. 100 l/min), EC in a range of 6,000μS/cm - weak fumaroles on the top of two travertine	- Strong geothermal manifestations of boiling water and travertine; - Stopover point of flamingo; - Considered to be worth for eco-tourism
8	Nord Goubet	- Located on the northern coast of Goubet lake, west end of Tadjoura Bay; - ca. 30 min from the national road by car, ca 15 min. on foot to a fumarole point, ca. 2.5 hours to a strong fumarole point	- Fumaroles located in a NS oriented, dissected valley with a relatively wide wadi; - Ragged mountainous topo around	- Dalha basalt on the floor part of valley, covered by Stratoid basalt (Tadjoura basalt 3.4 - 1.2 Ma); - Spotted Ribta rhyolite on valley floor	- NS oriented structures	- Nine fumaroles and one hot springs described on geological map; - Out of these three confirmed on site; - Spotted rhyolite body confirmed near the strong fumarole; - Travertine observed on site	- Fumaroles in a wider area, - Strong fumarole observed, - Some fumarole seemingly associated with rhyolite; - High salinity expected in geothermal fluid if any
9	Nord lac Assal	- Located on northern coast of Lac Asal; - Not assessable	-	-	-	- ca. 15 hot spring described on the geological map on the northern coast of Lac Asal.	-
10	Obock	- Located on north coast of Tadjoura Bay; - South of Obock town; - Easily accessible	- Coastal Plain	- Calcareous coarse sandstone of Pleistocene; - No volcanic rock around	- No remarkable geo-structure observed; - EW oriented lineament on the geological map	- The hot spring emerges at lowest tide in a day; - Temperature ca. 70 ℃, ca. 10 l/min; - No other manifestations observed.	- No particular comments
11	Rouweli	- Located on north coast of Tadjoura Bay; - ca. 50 min. from Obock to the junction, ca. 50 min. on jaggy road to the coast, ca. 50 min. on food to the point.	- Almost vertical steep cliff on the back; - Located on a very narrow coast line on the foot of the cliff; - The springs emerges only at lowest tide in a day	Stratoid Basalt (3.4 - 1.2 Ma)	- NW oriented cliff, possibly fault cliff.	- The hot spring emerges at lowest tide in a day; - Temperature 40 - 50 ℃, seeping; - No other remarkable manifestations observed	-Djuged to be week geothermal activity
12	Sakalol	- Located on a boarder of Ethiopia; - ca. 2.5 hours on ragged bumpy road from Lac Goubet to Garabtison inspection point; - ca. 1.0 hour for inspection at Garabtison; - ca. 1.0 hour to Dalho military camp; - ca. 2.0 hour on lava plain and desert by car to site; - ca. 0.5 hour on foot to the point.	- Located on the edge of lava hill and Sakalol plain; - Sakalol plain covered with salt, - NW oriented lava cliff on the back	- Stratoid basalt (3.5 - 1.0 Ma) on the hill side, lake deposit on Sakalol plain covered with salt deposit	NW oriented structure, - Sakalol plain located in the center of the rift extending from Goubet bay	- Hot water temperature 62℃; - No other manifestation observed; - Some other hot springs at edges of Sakalol Plain described on the geological map	-Judged to be week geothermal activity
13	Sud Goubet	- Located on south coast of Tadjoura Bay; - Not accessible	-	-	-	- Two fumaroles described on the geological map	-

References： [9], [13], [15]
Source：JICA Survey Team

Table 5-3 List of Samples for Laboratory Tests

SN.	Sample No.	Location	Thin section	XRD	XRF
1	140518-1	Rouweli	○		○
4	140519-1	Nord Goubet		○	
5	140519-2	Nord Goubet	○		○
9	140519-6	Nord Goubet		○	
10	140520-1	Arta	○		○
11	140520-2	Arta		○	
12	140520-3	Arta		○	
14	140520-5	Arta		○	
15	140520-6	Arta		○	
17	140520-8	Arta		○	
18	140521-1	Asal-Fiale	○		○
20	140521-3	Asal-Fiale		○	
22	140521-5	Asal-Fiale		○	
25	140522-1	Djibouti-Awrofoul			○
26	140523-1	Nord Goubet_Anaale	○	○	○
27	140523-2	Nord Goubet_Anaale		○	
29	140527-1	Lac Abhe	○		○
32	140528-3	Lac Abhe			○
33	140530-1	Hanle Garabbayis	○	○	○
35	140530-3	Hanle Yoboki		○	
36	140530-4	Hanle Yoboki	○	○	○
38	140531-1	Hanle Dagguirou	○		○
40	140601-1	Hanle Agna	○		○
41	140606-1	Gaggade-Taassa	○		○
43	140606-3	Gaggade-Taassa	○		○
44	140606-4	Gaggade-Taassa		○	
45	140606-5	Gaggade-Taassa		○	
46	140608-1	Sakalol-Asbou-Dara	○		○
Total			13	16	15

Source: JICA Survey Team

(b) Results of Observation of Rock Sample Thin Sections by Polarization Microscope

Observation of rock thin sections was conducted on polarised microscope in order to identify rock-forming minerals, textures, alteration minerals and their characteristics. Observation records were attached as an Attachment-7 together with photos. The JICA Survey Team identified alteration minerals such as secondary quartz, calcite, Zeolite and clay minerals in most of the thin sections. In particular, all samples are considered to have undergone low-grade alteration because brown-colored clay minerals were observed in the matrix part.

(c) Bulk Chemical Composition Analysis (XRF analysis)

Bulk chemical composition analysis was conducted by XRF analysis in order to identify major chemical composition of the sample and then further determine the rock type. The results are as follows:

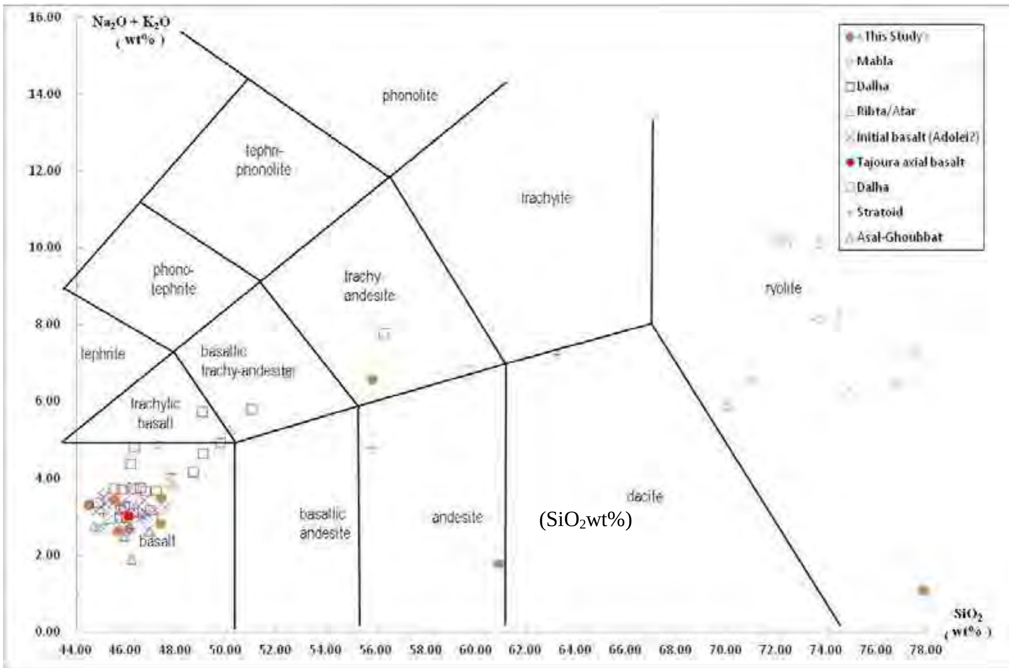
- TAS Diagram （SiO_2-Na_2O+K_2O Diagram）

Analysed results were plotted on a Total Alkali Silica (TAS) diagram together with data from the explanation booklets attached to the geological maps of Djibouti, as shown in Figure 5-6. Most of the data sampled for the Survey are plotted in a domain of ‘basalt’, except one in the ‘trachy-andesites’ domain, and the other two in a range far apart from the others. It is generally confirmed that the geological background of the surveyed point is good in accordance to the general alkaline rock series of Djibouti. The two samples plotted on the range far apart from the others are considered to have undergone severe silicification.

- Zr/TiO_2-Nb/Y Diagram of Winchester and Floyd (1977)

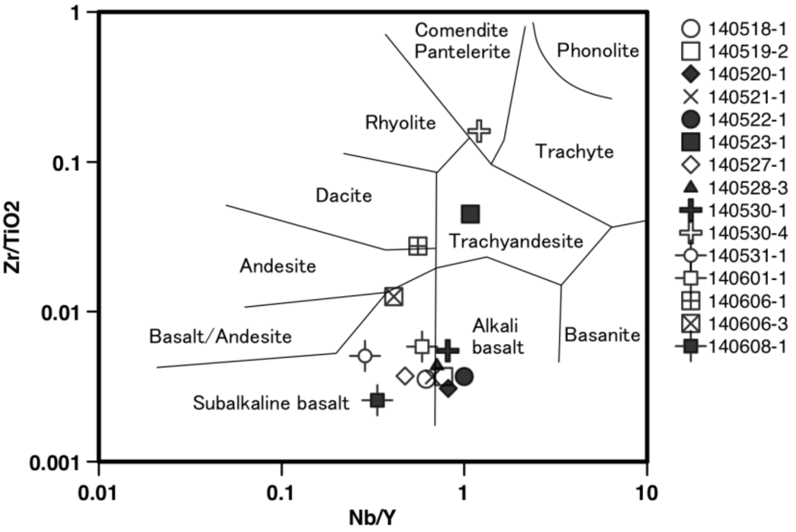
The data of the samples collected by the Survey were also plotted on the Zr/TiO_2 - Nb/Y Diagram of Winchester and Floyd (1977) to cross-check the rock classification because the composition of SiO_2, Na_2O, and K_2O used for the TAS diagram are susceptible to alteration, and therefore the TAS diagram may sometimes not indicate the correct rock types. Figure 5-7 confirms that the rock samples are classified under the alkaline-sub-alkaline series as shown in the TAS diagram.

It may be concluded that most of the rock samples therefore maintain their original chemical compositions though low-grade alteration.



(Data from the survey and from the geological maps of Djibouti) Source: JICA Survey Team

Figure 5-6 TAS Diagram



(Note: Zr: Zircon, Ti: Titanium. Nb: Niobium, Y:Yttrium)

(Data from the Survey only) Source: JICA Survey Team

Figure 5-7 Zr/TiO_2-Nb/Y Diagram of Winchester and Floyd (1977)

(d) XRD Clay Mineral Analysis

XRD analysis was conducted in order to identify clay minerals and/or secondary minerals created, thereby to evaluate grades of alteration of the samples collected. The analysis curves are attached in the Attachment-7 and a summary of the results are shown in Table 5-4.

Table 5-4 Summary of XRD Analysis

Site Name	Rock Name	Clay Mineral				Zeolite group			others			Notes	Clay mineral Formaion Temperature (℃)
		Sme	Mix.	Chl /Ser	Kao /Nac	Sti	Nat	Lau	Gyp	Cal	Qz		
N. Goubet	Calcite									○		Cal. only	-
N. Goubet	calcite									○		Cal. only	-
Arta	Gypsum	○		○					○	+	+	Smc-Chl, Gyp (vein)	150-200
Arta	Rhyolite?	○	○							○	+	Smc-Mix, Chl	100-150
Arta	White clay				○						○	Nac.	200-250
Arta	White clay		○		○						○	Nac. & mix.	200-250
Arta	Gypsum								○			Gyp. only	-
Asal (2km east)	White clay, layered			○						○		Chl-Cal	150-200
Lac Asal	White clay								○			Gyp. only	-
N. Goubet_Anaale	Andesitic	○									+	Smc-Qz	100-150
N. Goubet_Anaale	White vein, calcite	○								○	+	Smc-Cal	100-150
Hanle-Garabbayis	Basalt	○	○	○		○	○	○				Smc-Chl + Gyp	150-200
Hanle-Yoboki (hill)	Rhyolite	○	○	○							○	Smc-Mix-Chl-Qz	150-200
Hanle-Yoboki (hill)	Rhyolite									+	○	Qz-Cal	-
Gaggade-Taassa	Reddish clay				○						○	Nac.	200-250
Gaggade-Taassa	Rhyolite	○								+	+	Smc-Cal-Qz	100-150
Smc: Smectite, Chl: Chlorite, Ser: Sericite, Sti: Stilbite, Lau: Laumontite, Gyp: Gypsum, Qz: Quartz, Cal: Calcite, Mix: Mixed layer minerals												(Source: JICA Study Team)	

There are alteration minerals such as nacrite, smectite, smectite-mixture, chlorite, and sericite that indicate various grades of alteration, as shown in Table 5-4. In particular, nacrite is a good indication of high-grade alteration, whereas smectite–chlorite is also an indication of fairly high-grade alteration. Taking into consideration characteristics of clay minerals, the JICA Survey Team assessed the formulation temperature of clay minerals that may indicate reservoir temperatures, (a) 100 ºC–150 ºC, (b)150 ºC–200 ºC, and (c) 200 ºC–250 ºC, as shown in the table above.

5.3.2 Summary of Geological Information – Preliminary Assessment

Based on the geological information including satellite image analysis, the JICA Survey Team's assessment of the geothermal resources are as follows:

(1) Arta Geothermal site:

The satellite images analysis identified a wide area of weak acidic/pyrophyllitic alteration associated with spotted sever acidic alteration zone. The geological map indicates dotted rhyolitic outcrops. A fumarole though weak was identified on site. The XRD analysis identified nacrite of which formation temperature is considered to be 200 ºC–250 ºC. From these observations, it is considered that these geological observations suggest that there may be prospective geothermal resources for development in Arta.

(2) Nord Goubet-Anaale Geothermal site:

The satellite images analysis identified dotted strong acid alteration zones, the geological map indicates rhyolitic outcrops, strong fumaroles were identified on site, and the XRD analysis identified an alteration mineral combination of smectite, quartz/calcite that suggests mineral formation temperature would be 100 ºC–150 ºC. From these geological observations, the JICA Survey Team considered that there may be prospective geothermal resources for development in Nord Goubet.

(3) Hanle-Garabbayis Geothermal site:

The satellite image analysis identified a large scale of rhyolitic body near Yoboki Town associated with acidic alteration zones. In the Garabbayis area, there were spotted alteration zones and rhyolitic outcrops identified, though small, in the images or on the geological map, strong fumaroles were identified on site. The XRD analysis identified a mixed layer minerals of smectite and chlorite that suggests a mineral formation temperature of 150 ºC–200 ºC. From these geological observation, it is considered that there may be prospective geothermal resources for development in the Hanle-Garabbayis site.

(4) Gaggade-Taassa Geothermal site:

The satellite image analysis identified clear lineaments associated with dotted acidic alteration zones. Also, rhyolitic outcrops are indicated on the geological map. The JICA Survey Team identified strong fumaroles, and rhyolitic veins on site. The XRD analysis identified nacrite, which suggests mineral formation temperature of 200 ºC–250 ºC. From these geological observations, it is considered that there may be prospective geothermal resources for development in the Gaggade-Taassa site.

(5) Other sites:

(a) Lac Abhe site:

There were large-scale travertine distributing a wide area on the western coast of Lac Abhe, and hot springs with boiling temperatures. No other remarkable geothermal manifestations were observed possibly due to the coverage of lake deposits that may mask other geothermal manifestations.

(b) Sud Goubet Site and Nord Lac Asal site:

Due to inaccessibility to these sites, detailed information were made available through the satellite image analysis of the alteration zone.

(c) Other hot-springs of Hanle-Minkileh, Hanle-Dagguirou, and Hanle-Agna

Geological information including satellite images of these sites did not suggest any remarkable geothermal manifestations.

5.4 Geochemical Survey

5.4.1 Survey Objectives

The objectives of the geochemical survey are to clarify the geochemical characteristics of the survey areas and to evaluate the geothermal reservoirs by analysing and interpreting the results of fumarole gas samples and hot spring samples taken from the geothermal fields.

5.4.2 Survey Contents

(1) Survey areas

In order to verify the recharge sources, water samples from wells (for drinking) and lakes have been collected in this Survey. The sampling locations and number of the samples are shown in Table 5-5.

Table 5-5 Sampling Information in the Survey

No.	Sampling location	Fumarolic gas	Hot spring	Well	Lake
1.	Arta	1	0	0	0
2.	Asal	1	1	0	1
3.	Djibouti	0	0	2	0
4.	Dorra	Failed to sample due to road damage			
5.	Gaggade	1	0	0	0
6.	Hanle	1	3	1	0
7.	Lac Abhe	0	2	0	1
8.	Nord Goubet	1	1	0	0
9.	Nord Lac Asal	Failed to sample due to no access way			
10.	Obock	0	2	0	0
11.	Rouweli	0	1	1	0
12.	Sakalol	0	1	0	0
13.	Sud Goubet	Failed to sample due to no access way			
Number of samples		5	11	4	2

Source JICA Survey Team

(2) Survey Research Items

(a) Research items on site

The following items were measured on site: geographic coordinates, elevation, air temperature, hot spring or fumarolic gas temperature, discharge flow (hot spring), and emission intensity (fumarolic gas).

(b) Analysis items to determine chemical composition

Chemical components analysed in the Survey are tabulated in Table 5-6.

Table 5-6 Chemical Analysis Items

Fumarolic gas samples	H_2O, NCG, H_2S, CO_2, R gas, H_2, N_2, CH_4, O_2, He, Ar, $^3He/^4He$, $^4He/^{20}Ne$, $\delta^{13}C(CO_2)$
Hot spring, well and lake water samples	pH, Electric Conductivity, Li, Na, K, Ca, Mg, Cl, SO_4, T-CO_2, H_2S, T-SiO_2, B, T-Fe, Al, As, T-Hg, δD, $\delta^{18}O$

Source JICA Survey Team

(3) Methodology

The procedure for collecting fumarolic gas is provided in the Attachment-5. The water samples (hot spring water, well water, and lake water) were taken using a handled beaker, and then sealed into the sample container. The pre-treatment and analysis method for each item is shown in Table 5-7.

Table 5-7 List of Chemical Analysis Methods

Analysis Items	Pre-Treatment Method	Analysis Method	Detection Method or Accuracy	Analysis Standard
Water Samples				
pH	No pre-treatment	Glass electrode	0.1	JTS K 0102-12.1
EC	No pre-treatment	Depends	±5%	JTS K 0102-13
Na	No pre-treatment	Flame photometry	0.02 mg/L	JTS K 0102-48.1
K	No pre-treatment	Flame photometry	0.01 mg/L	JTS K 0102-49.1
Ca	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-50.3
Mg	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-51.3
Li	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	---
Cl	No pre-treatment	Ion chromatography	0.01 mg/L	JTS K 0102-35.3
SO_4	No pre-treatment	Ion chromatography	0.1 mg/L	JTS K 0102-41.3
T- CO_2	Add 2mL of KOH (20wt%) to 100mLof sample	Infrared analysis	5 mg/L	JTS K 0101-25.2
H_2S	Add 10mL of compound liquid of cadmium acetate (5wt%) and sodium acetate(3mol/L) per 500mLof sample	Iodimetric method	0.5 mg/L	JTS K 0102-39.2
B	No pre-treatment	ICP-AES	0.01 mg/L	JTS K 0102-47.3
SiO_2	Add 5mL of HCl (6mol/L) per 500mLof sample	Gravimetric method	0.01 mg/L	JTS K 0101-44.3.2
T-Fe	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-57.4
Al	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-58.4
T-Hg	Add 5mL of HCl (6mol/L) per 500mLof sample	AAS	0.005 mg/L	JTS K 0102-66.1.2
δD	No pre-treatment	Mass spectrometry	±1‰ SMOW	JIkken Kagaku Koza
$\delta^{18}O$	No pre-treatment	Mass spectrometry	±0.1‰ SMOW	JIkken Kagaku Koza
Fumarolic Gas Samples				
H_2O	---	Volumetric method	---	---
H_2S	Absorb into KOH aqueous solution (5mol/L), then fix as CdS by adding 10mL cadmium acetate (5wt%)	Iodimetric method	0.5 mg/L	JIS K 0102-39.2
CO_2	Absorb into KOH aqueous solution (5mol/L)	Infrared method	5 mg/L	JIS K 0101-25.2
H_2	---	Gas chromatography	---	JIS K 2301
N_2	---	Gas chromatography	---	JIS K 2301
CH_4	---	Gas chromatography	---	JIS K 2301
He	---	Gas chromatography	---	JIS K 2301
Ar	---	Gas chromatography	---	JIS K 2301
O_2	---	Gas chromatography	---	JIS K 2301
$^3He/^4He$	---	Mass spectrometry	Depends	New-JIkken Kagaku Koza
$^4He/^{20}Ne$	---	Mass spectrometry	±10%	New-JIkken Kagaku Koza
$\delta^{13}C$	Absorb into KOH aqueous solution (5mol/L)	Mass spectrometry	±0.2‰ PDB	JIkken Kagaku Koza

Source JICA Survey Team

5.4.3 Results

The results of chemical analysis of water samples (hot spring water, well water, and lake water) and fumarolic gas samples are presented in the Attachment-7. Based on the analysis results, geochemical temperature of each location has also been calculated and shown in the Attachment-7.

Among the hot springs surveyed, the highest temperatures were in the Lac Abhe area i.e. SP-1 (99.2 °C) and SP-2 (96.2 °C); similarly the hot spring temperature of Korili (Asal area, 77.5 °C), Awrofoul No. 6 (Djibouti area, 73.6 °C), and Obock-2 (Obock area, 70.7 °C) are also be classified as high temperatures. On the other hand, though the hot water of Anaale (Nord Goubet area, 98.0 °C) showed very high temperature with a small discharge flow but associated with extraordinarily strong fumarolic gas emission, the hot water is considered to be the results of steam condensation because the electric conductivity is very low (39 mS/m) compared to the ones of other spring water surveyed by the Team.

As for salinity, the water samples taken from Lac Asal showed extremely high chloride (Cl) concentration (Cl: 197,000 mg/L), and water samples from Lac Abhe also showed high Cl concentration (28,800 mg/L) (see Table Attachment-7). The hot spring samples with relatively high Cl concentrations were from Korili (Asal area), Obock-2 (Obock area), and Obock-1 (Obock area); the concentrations of those are 22,200 mg/L, 20,300 mg/L, and 16,800 mg/L, respectively. The range of the Cl concentrations of these hot spring samples was similar to the level of seawater (19,353 mg/L; The Geochemical Society of Japan, 2005). On the other hand, the Cl concentrations of the other hot springs samples were not higher than 2,720 mg/L, even the sample from Lac Abhe SP-1, that showed the highest temperatures, had a Cl concentration of 1,680 mg/L.

The stable and intense gas emissions in Anaale (Nord Goubet area) and Garabbayis (Hanle area) made the gas sample collection very successful. On the contrary, due to tenuous and inactive fumarolic gas emissions in Arta (Arta area) and Fiale (Asal area), the collected gas samples were found to be mixed with the atmospheric air, that resulted in failure of satisfactory gas sample analysis. Similarly, though the gas emission was strong and active in Taassa (Gaggade area), the samples taken there have been revealed to be mixed with atmospheric air to a great extent possibly due to the intense fracturing that might allow the atmospheric air to be mixed with the fumarolic gas.

5.4.4 Discussions

(1) Geochemical Characteristics of Hot Spring and Well Water Samples

In order to interpret the geochemical characteristics of the hot spring and well water samples collected by this Survey, the following interpretation diagrams were produced:

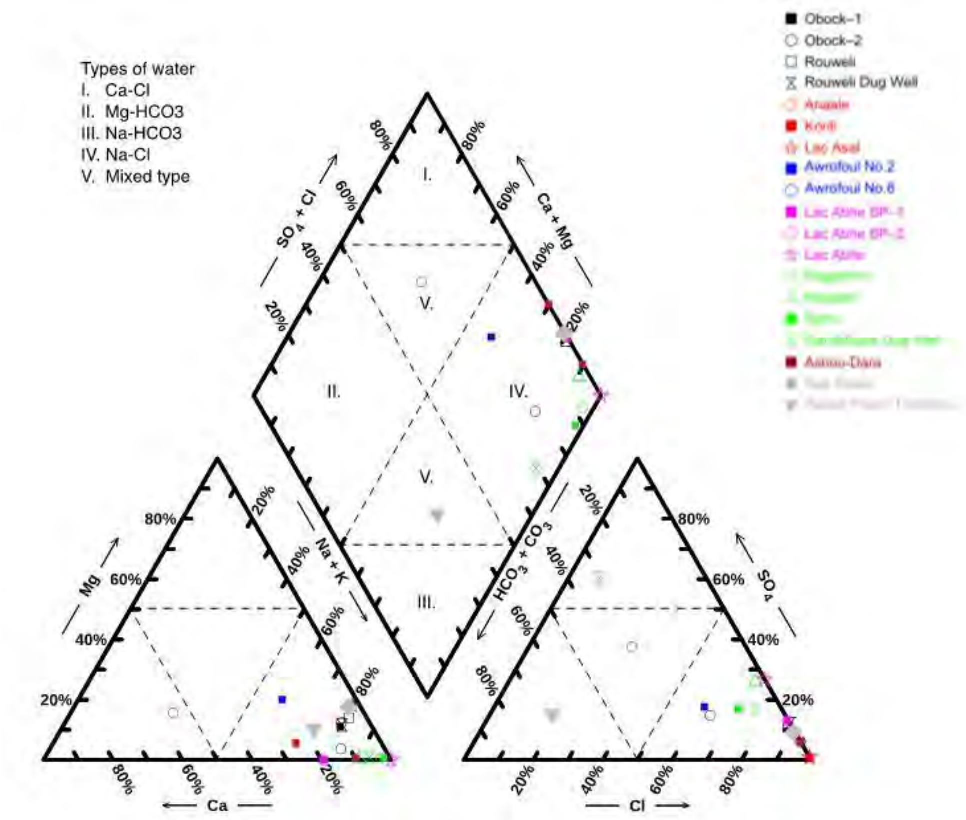
- Trilinear diagram
- Hexa-diagram
- Plots of δD versus $\delta^{18}O$
- Plots of B versus Cl
- Na-K-Mg ternary diagram (Geoindicator diagram; Giggenbach, 1988 [16])

(a) Tri-linear diagram and hexa-diagram

The trilinear diagram and hexa-diagram are shown in Figure 5-8 and Figure 5-9, respectively.

Through Figure 5-8 and Figure 5-9, all the water samples collected in this Survey are characterised as the Na-Cl type, except the Anaale (Nord Goubet area). For the samples taken from the Garabbayis Dug Well, the proportion of SO_4 and HCO_3 was higher than that of Cl; this may be interpreted that .

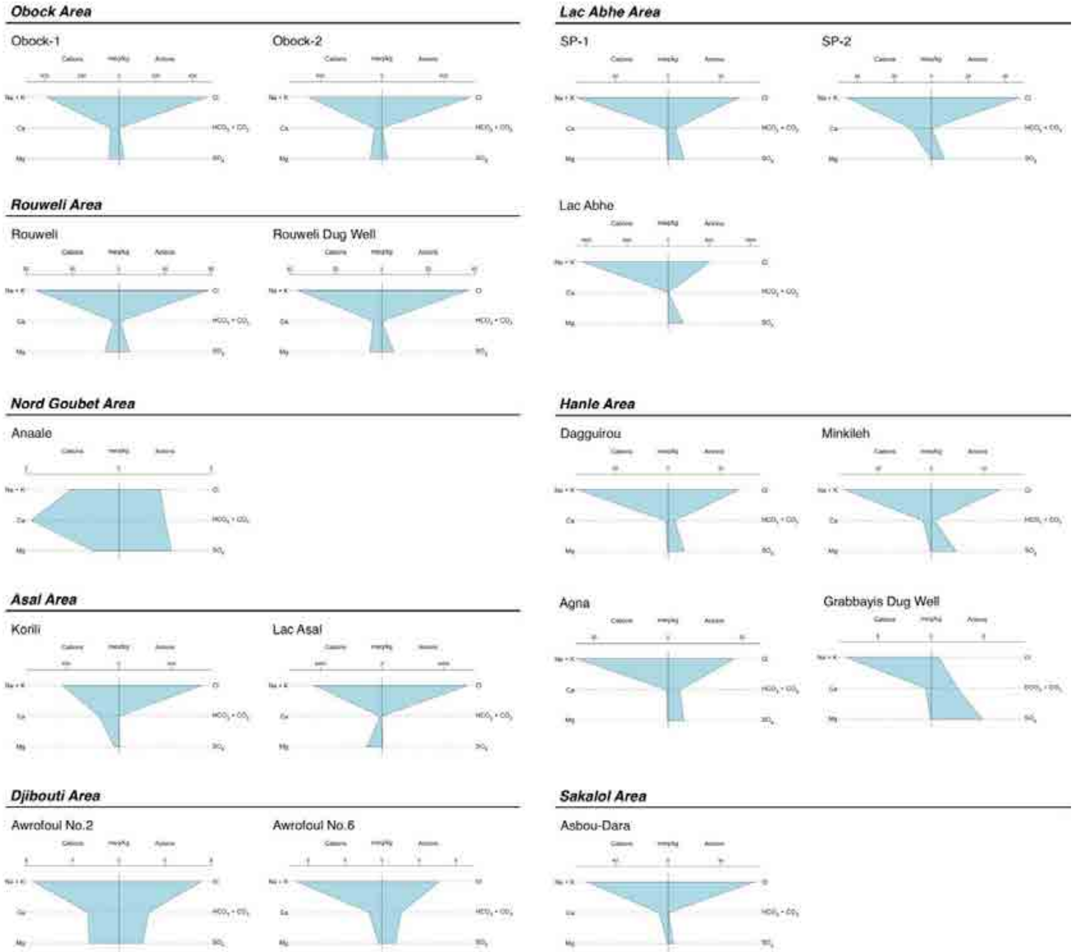
the Garabbayis Dug Well is mixed with gas or condensation water originated from the fumarolic activities that are identified at some 5km distance in the NE, although a relatively high pH value (8.5) and a low water temperature (33.7 °C) were observed. As to Anaale, although it is not classified as a dominant type (area V in the trilinear diagram), the sample is considered not to reflect the geothermal fluid information here because Anaale probably is mainly sourced from steam condensation water, as mentioned in Section 5.4.3.



Source: JICA Survey Team

Figure 5-8 Trilinear Diagram

The comparison of values of seawater and water from the Awash River are plotted in Figure 5-8. The latter is a subterranean stream flowing from Ethiopia to Djibouti.



Source: JICA Survey Team

Figure 5-9 Hexa-Diagram

Figure 5-10 shows the location of hexa-diagrams. This figure shows the difference of Na-Cl concentration of water samples. In the figure, water at Obock and Korili are colored orange and water at Lac Asal and Lac Abhe are colored red, signifying very high salinity as compared with other sites. The red-colored samples have extremely high concentration, which is six times the scale.

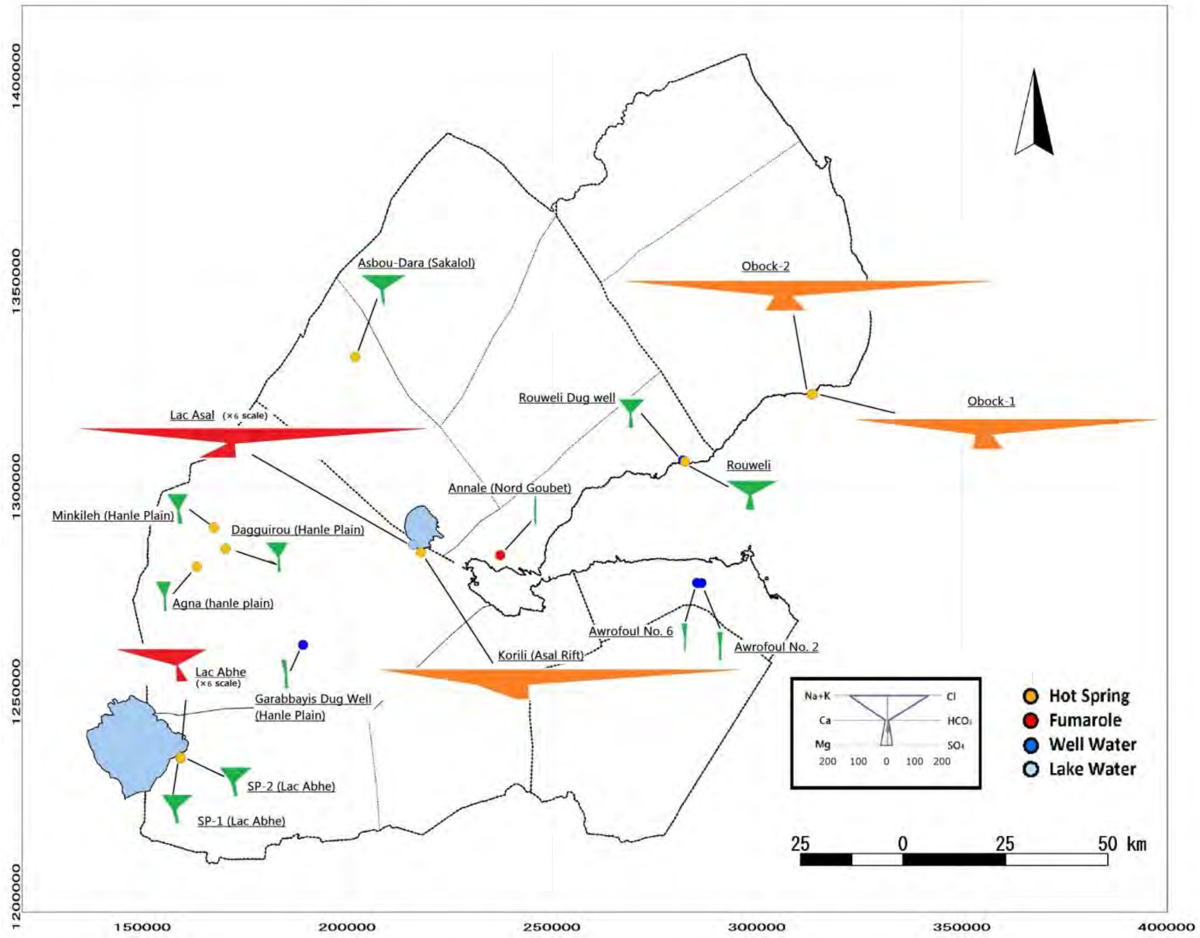


Figure 5-10 Location of Hexa-Diagram

Source: JICA Survey Team

(b) Correlation diagram of δD-δ^{18}O (Delta Diagram)

Correlation diagram of δD-δ^{18}O is shown in Figure 5-11. All water samples are plotted below the World Meteoric Water Line (WMWL) and parallel to it in this diagram. The diagram indicates that the origin of water samples are meteoric water because there is no evidence of shifting towards mantle-originated fluid composition (Hoefs, 1996 [17]).

Water samples in this study area are classified into the following five groups according to recharge mechanisms:

- Group 1

Feature: Water samples with the smallest isotopic ratios

Location: Agna (Hanle Plain), Lac Abhe SP-1, Lac Abhe SP-2, Asbou-Dara (Sakalol area)

Consideration: Water samples collected from the western and southern areas of Djibouti have the smallest isotopic ratios in this study. It is estimated that the origin of these water are precipitation on higher land (‘altitude effect’), or precipitation under cooler climate (‘temperature effect’). This means that water from the present Awash River might not be a resource of Group 1.

- Group 2

Feature: Isotopic ratios between Group 1 and Group 4

Location: Korili (Lake Assal), Dagguirou (Hanle plain), Minkileh (Hanle plain)

Consideration: Plotted between Group 1 and Group 4 on the delta diagram. It is estimated that the origin of these water samples are recharged at lower land or warmer climate than Group 1.

- Group 3

Feature: Similar isotopic ratios to groundwater in Djibouti city

Location: Awrofoul No. 2, Awrofoul No. 6, Rouweli, and Rouweli Dug Well

Consideration: Isotopic ratios of water samples from Rouweli and Djibouti, the area facing to the Gulf of Tadjoura are similar to groundwater from Djibouti City (Houssein, 2010 [18]). Recharge water might be regional precipitation and locally mixed with seawater.

- Group 4

Feature: Similar isotopic ratios to present seawater

Location: Obock-1, Obock-2

Consideration: Isotopic ratio of this group shows similar that of present seawater (*). The concentration of Cl is also similar to seawater. This may indicate seawater recharge into the reservoir of this group.

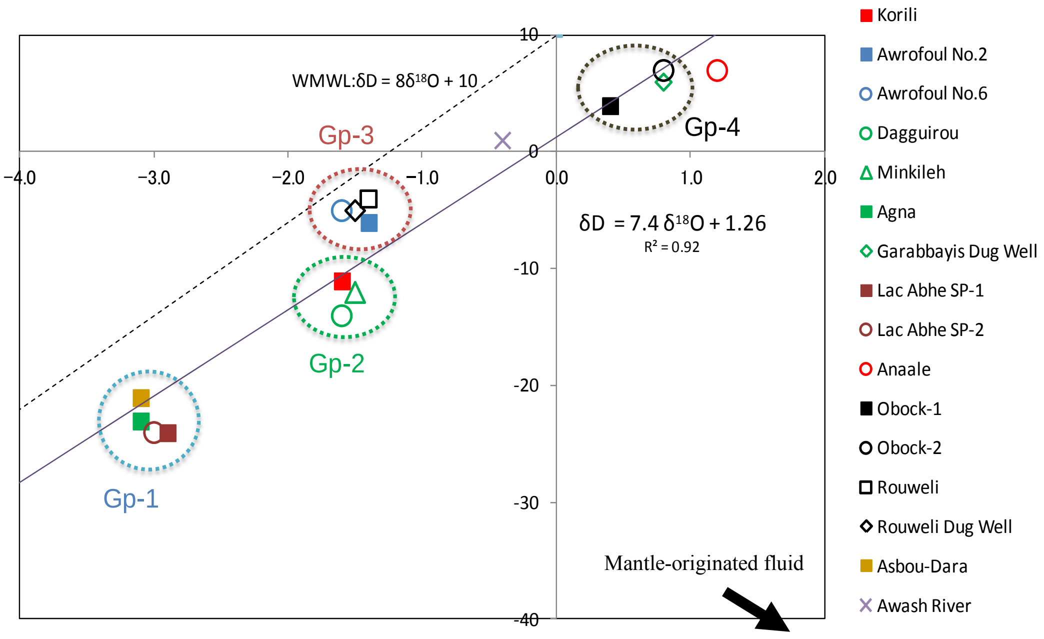
*Note: The isotopic ratios of the seawater in Djibouti (δD=6‰, $\delta^{18}O$ =1.5‰ (Houssein Bouh, 2010) [18]) is heavier than Standard Mean Ocean Water (SMOW).

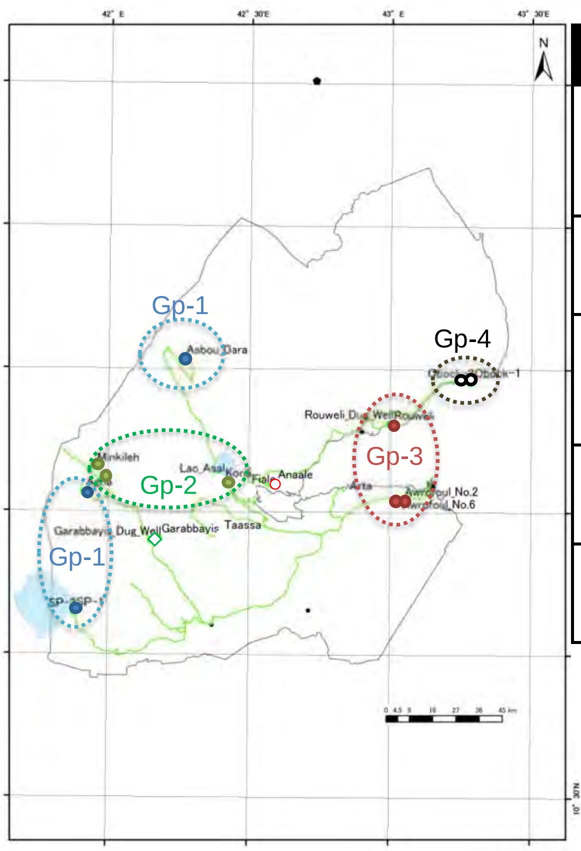
- Group 5

Feature: Others

Location: Garabbayis Dug Well (Hanle plain), and Anaale (Nord Goubet area)

Consideration: These water samples are plotted near Group 4 on the delta diagram. However, Cl concentration of this group is low. It is estimated that the isotopic ratios became heavier due to evaporation.





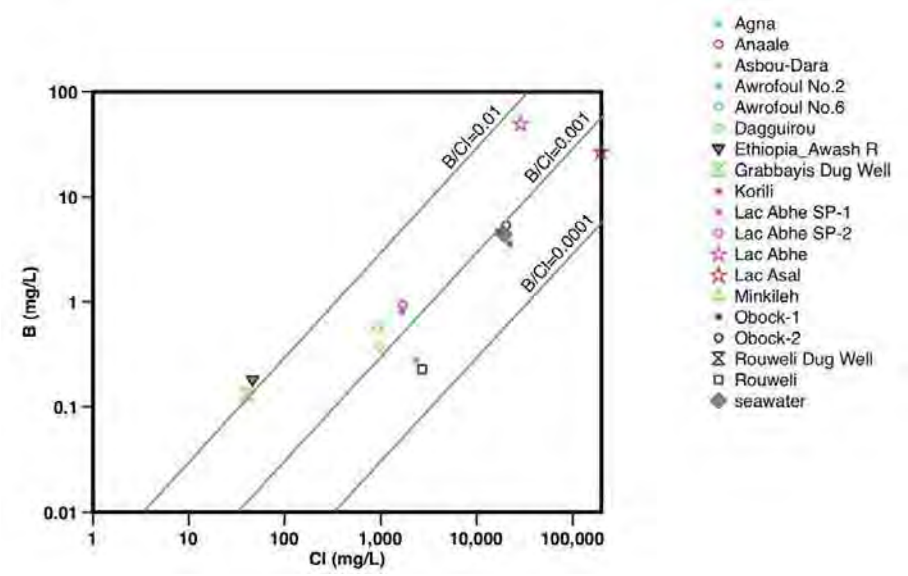
Group	Type	Location
1	Smallest isotope ratios	Agna, Lac Abhe SP-1, Lac Abhe SP-2, Asbou-Dara
2	Located between Gp.1 and Gp.4	Korili, Dagguirou Minkileh
3	Similar isotope ratios to groundwater in Djibouti city	Awrofoul No.2, Awrofoul No.6, Rouweli, Rouweli Dug Well
4	Similar isotope ratios to sea water	Obock-1, Obock-2
5	Others	Garabbayis Dug Well, Anaale

Source: JICA Survey Team

Figure 5-11 Correlation of δ D- δ ^{18}O and Location Map

(c) Plot of B versus Cl

The plot of B versus Cl is shown in Figure 5-12. The plot of B versus Cl is used for consideration of the water quality forming mechanism in connection to interaction with reservoir rock. The plot shows that all the samples (except the samples from the Garabbayis Dug Well) exhibit the B/Cl molar ratios similar to that of seawater (about 0.001), which indicates that those may be originated from meteoric water. On the other hand, the B/Cl molar ratio of the Garabbayis Dug Well is on the line of B/CL= 0.01 indicating a higher B proportion than others of the survey areas. This result may be explained that the Garabbayis Dug Well is partly recharged by B-enriched condensation water that has repeatedly experienced boiling/enrichment processes. This result is well in accordance with the interpretation results illustrated by trilinear diagram and hexa-diagram.



Source JICA Survey Team

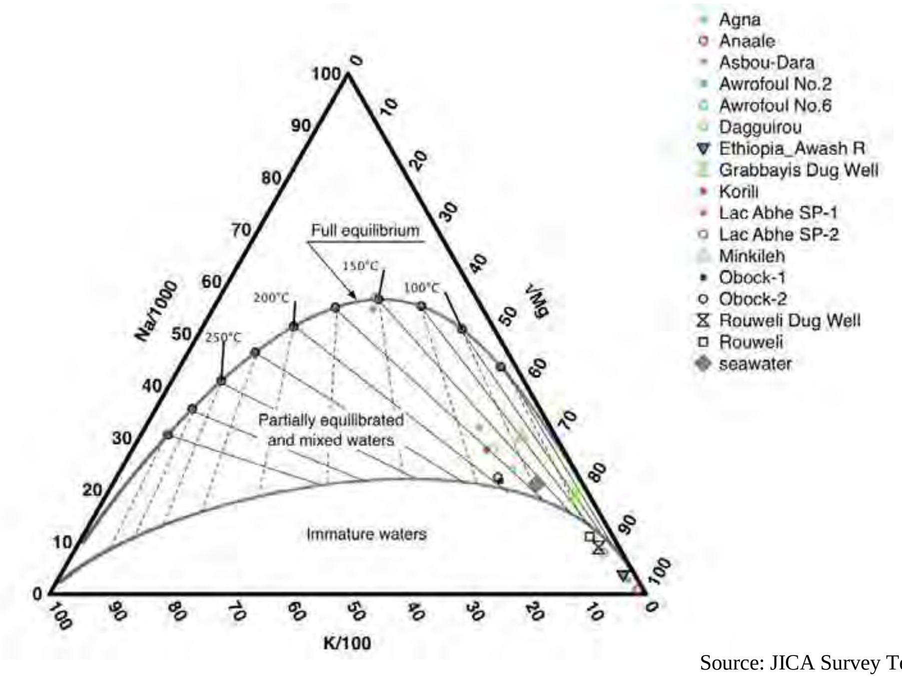
Figure 5-12 Plot of B Versus Cl

(d) Na-K-Mg ternary diagram（Geoindicator diagram）

Na-K-Mg ternary diagram (Geoindicator: Giggenbach, 1988 [16]) is shown in Figure 5-13. Using the two different types of geochemical thermometers (Na-K thermometer and K-Mg thermometer) that have different reaction speeds, the diagram shows water quality equilibrium (or non-equilibrium) status of water samples that have undergone water-rock reaction process in the underground reservoir. The principle for the interpretation is that: since the Na-K reaction takes place slowly, the Na-K equilibrium status in underground water is maintained for a longer time during its process of appearing to the ground surface; whereas the K-Mg reaction takes place speedily (susceptible to solution with the mother rocks), the K-Mg equilibrium status in underground water will not be maintained and become non-equilibrium status if the process of appearing to the ground surface need a longer time.

The results shows that the Lac Abhe SP-1 and SP-2 are plotted on the full equilibrium line that indicates both Na-K and K-Mg reactions are in the full equilibrium conditions. This result indicates that the Lac Abhe SP-1 and SP-2 maintains the K-Mg equilibrium status even at the ground surface, which may further be interpreted that the Lac Abhe SP-1 and SP-2 may be originated from a shallower reservoir from which water has come up to the surface without taking a longer time. Since the Na-K and Chalcedony geochemical temperatures here are 151～158 °C and 115～124 °C, respectively, the Lac Abhe SP-1 and SP-2 are considered to be originated from the aquifer with temperature of 115～158 °C. The estimations (110～157 °C) by Houssein (2010)[18] as the result of his comprehensive geochemical survey substantially aligned with the results of this study.

On the other hand, the all other samples were plotted as "immature water" or "partially-equilibrated and mixed water". Among these samples, Obock-1 (197 °C), Obock-2 (195 °C) in the Obock area, and Awrofoul No. 2 (191 °C) in the Djibouti area represented relatively high Na-K geochemical temperatures. As the reaction rate of Na-K is slow, the Na-K geothermometer may correctly reflected the temperature information in deeper depth. It is therefore highly possible that reservoirs of high temperature (about 200 °C) may exist underground in these three locations.



Source: JICA Survey Team

Figure 5-13　Na-K-Mg Ternary Diagram

(2)　Geochemical Characteristics of Fumarolic Gas

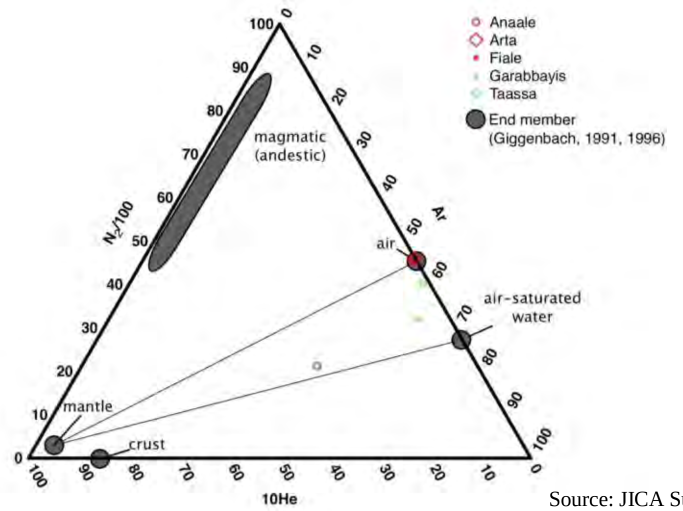
The following diagrams were created to clarify the geochemical characteristics of fumarolic gas collected in this Survey:

- He-Ar-N_2 ternary diagram
- The plot of $^3He/^4He$ versus $^4He/^{20}Ne$
- $\delta^{13}C$

(a)　He-Ar-N2 ternary diagram

Figure 5-14 presents the results of the He-Ar-N_2 ternary diagram of gas samples, the diagram may explain the origin of the gas. It shows that Anaale (Nord Goubet area) is plotted on the line that represents mix of air-saturated water and mantle-origin gas; similarly, Garabbayis (Hanle area) also shows a slight shifting to mantle-origin gas. These may suggest that the fumarolic gas samples taken in Anaale and Garabbayis be mixed with mantle-origin gases, which may indicate that the sampling points may not very far from the heat source. The heat source temperatures in these two locations were estimated at 323 °C and 266 °C by use of CH_4/CO_2.

The fumarolic gas samples taken in Arta (Arta area), Fiale (Asal area), and Taassa (Gaggade area) are plotted on or nearby the atmosphere air plot in Figure 5-14. This suggests that mantle-origin gas may not significantly contribute to fumarolic gases as recharge sources in these locations.

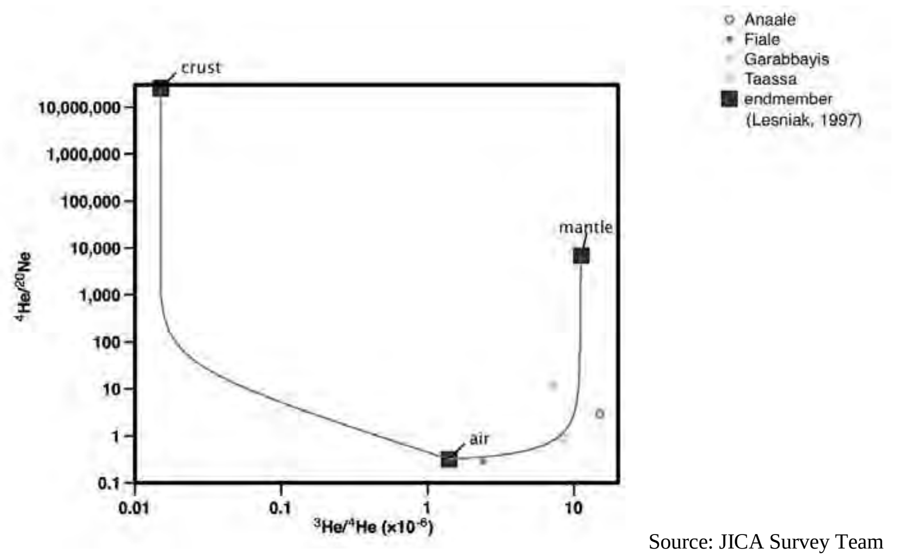


Source: JICA Survey Team

Figure 5-14 He-Ar-N2 Ternary Diagram for Fumarolic Gas Samples

(b) $^3He/^4He$ vs. $^4He/^{20}Ne$ diagram

The $^3He/^4He$ vs. $^4He/^{20}Ne$ diagram (Figure 5-15) shows that the Anaale and Garabbayis are plotted on an areas between the air and mantle, indicating that those are mixed with mantle origin gases as indicated by the results of He-Ar-N_2 diagram mentioned above. In addition to this result, both Taassa and Fiale are also plotted on an area between the air and mantle in this diagram. This result may indicate that mantle-origin helium gases contributes to the Taassa and Fiale as the heat source of fumarolic gases. In addition, there were six geothermal wells drilled in the Asal area, where the highest temperature was recorded at 359 °C in the Well A5, depth of 2,105 m, and geothermal fluid with temperatures ranging from 265 to 280 °C was observed at the Well of A3 and A6 (D'Amore et al., 1998 [19]).



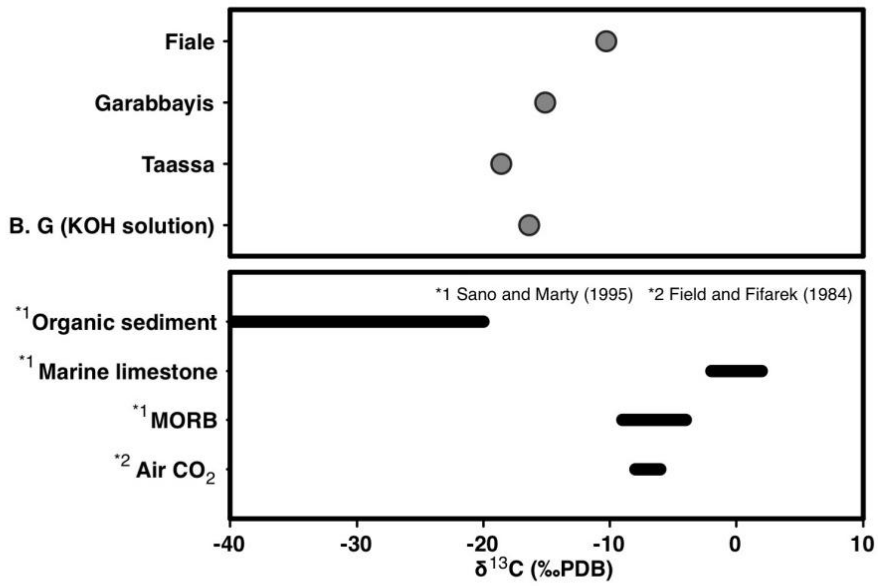
Source: JICA Survey Team

Figure 5-15 Relationship Between $^3He/^4He$ and $^4He/^{20}Ne$ of Fumarolic Gases

(c) Plot of $\delta^{13}C(CO_2)$

The origin of CO_2 gas is examined based on the plot of δ13C (CO_2) (Figure 5-16).

The values of water samples from Fiale (Asal area), Garabbayis (Hanle area), and Taassa (Gaggade area) are -10.3‰, -15.1‰, and -18.6‰, respectively. These values are lower than magmatic values (-8‰～-4‰), or values of marine limestone. However, they are significantly greater than values typically associated with organic sediments (usually less than -20‰). The values of Fiale (Asal area) and Garabbayis (Hanle area) are greater than the background value, and this indicates that these samples are affected by CO_2 in air.



.

Source: JICA Survey Team

Figure 5-16 Plot of $\delta^{13}C$ (CO_2)

5.4.5 Summary of Geochemical Survey

An outline of the geochemical survey is given in Table 5-8. The results of the geochemical survey are summarised below.

- The water samples collected in this Survey were recharged by precipitation or seawater, and the contribution from mantle-origin fluid has not been confirmed. The geochemical type of water samples is classified as Na-Cl type, except for the sample from Garabbayis Dug Well (Hanle area) where the proportion of HCO_3 and SO_4 was relatively high. This was probably caused by mixing with steam condensation water.
- High-temperature areas with Na-K geochemical temperature over 190 °C are as follows:

  - Obock-1, Obock-2 (Obock area), and

  - Awrofoul No. 2 (Djibouti area, outside the target area of the Survey)
- The CO_2/Ar geochemical temperature and CH_4/CO_2 geochemical temperature of high-temperature areas are as follows:

  - Garabbayis (Hanle): 159°C - 266°C, and

  - Anaale (Nord Goubet): 228°C - 323°C
- Areas where fumarolic gas containing mantle-origin gas was collected are as follows:

  - Taassa (Gaggade),

  - Garabbayis (Hanle),

  - Anaale (Nord Goubet), and

  - Fiale (Asal area)

From the above results, the prospects for geothermal development can be narrowed down to the following areas:

1. Promising areas

   (a) Garabbayis (Hanle),

   (b) Anaale (Nord Goubet),

   (c) Taassa (Gaggade), and

   (d) Fiale (Asal area)

2. Area that can be develop

   (a) Obock

The Na–K geochemical temperature was high in Awrofoul No. 2, one of the source wells for water supply in the Djibouti area. The well is located near an electric power substation, and near Djibouti City. Awrofoul is worthy of being investigated for the possibility of geothermal development.

Table 5-8 Summary of Geochemical Survey

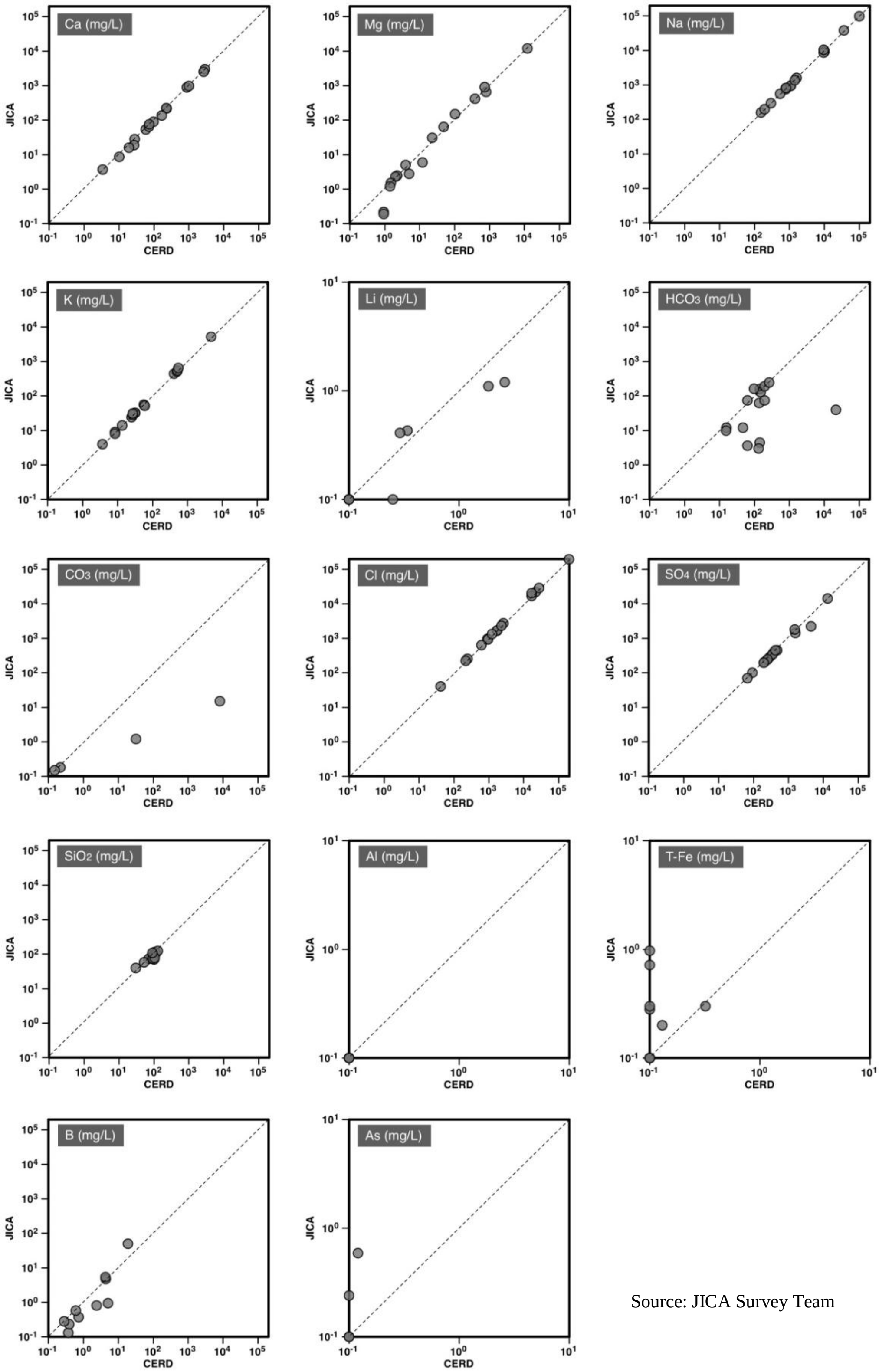
No.	Site Name	Gas	Geochemical Analysis: Hotspring	Well Water	Lake Water	Geochemical Thermometer: Quartz	Chalcedony	Na-K	Na-K-Ca	K-Mg	Evaluation
1	Arta	(Very weak, Air mixed)	-	-	-	-	-	-	-	-	Week Fumarole, largely mixed with air
	Asal_Fiale	Mixed with gas of mantle origin		-	-	-	-	--	-	--	Reference Site (★Prospective)
2	Asal_Koril	-	Na-Cl_type, Meteoric_2	-	-	111	96	177	167	116	Low - moderate Temperature
	Asal_Lake	-	-	-	Na-Cl_type, Meteoric_1	-	-	-	-	-	(Reference Site)
3	Djiboubi_Awrofoul-No.2	-	-	Na-Cl_type, Meteoric_3	-	118	103	191	143	52	★worthy to survey
	Djibouti_Awrofoul-No.6	-	-	Na-Cl_type, Meteoric_3	-	133	119	169	136	69	★Prospective
4	Dorra	Not accessible									(Not Accessible)
5	Gaggade_Taassa	Mixed with gas of mantle origin	-	-	-	-	-	-	-	-	★Prospective
	Hanle-Garabbayis	Mixed with gas of mantle originT(CH4/CO2)=266	-	-	-	-	-	-	-	-	★Prospective
	Hanle-Dagguirou		Na-Cl_type, Meteoric_2			109	94	170	162	113	Low - moderate Temperature
6	Hanle_Minkileh		Na-Cl_type, Meteoric_2			118	103	126	116	91	Low Temperature
	Hanle-Agna					107	92	173	165	107	Low - moderate Temperature
	Hanle_Garabayyis (Dug well)	-	-	(Mixed with gas or condensed water)	-	78	61	111	101	67	(Reference Site)
	Lac Abhe_SP-1	-	Na-Cl_type, Meteoric_1	-	-	130	115	158	136	154	Moderate Temperature
7	Lac Abhe_SP-2	-	Na-Cl_type, Meteoric_1	-	-	138	124	151	130	152	Moderate Temperature
	Lac Abhe_lake	-	-	-	Na-Cl_type, Meteoric_1	-	-	-	-	-	(Reference)
8	Nord Goubet_Anaale	Mixed with gas of mantle originT(CH4/CO2)=323	-	-	-	-	-	-	-	-	★Prospective
	Nord Goubet_Anaale	-	(condensed, Meteoric_4)	-	-	90	74	242	147	41	(Reference)
9	Nord Lac Asal	Not accessible									(Reference)
10	Obock_Sp-1	-	Na-Cl_type, Meteoric_4 & Seawater	-	-	105	90	197	192	115	★worthy to survey
	Obock_Sp-2	-	Na-Cl_type, Meteoric_4 & Seawater	-	-	108	93	195	193	116	★worthy to survey
11	Rouweli_spring	-	Na-Cl_type Meteoric_3 & Seawater	-	-	95	79	160	152	75	Low - moderate Temperature
	Rouweli_DugWell	-	-	Na-Cl_type, Meteoric_3	-	111	96	165	147	71	(Reference)
12	Sakalol_Asbou-Dara	-	Na-Cl_type, Meteoric_1	-	-	130	115	164	150	116	Moderate Temperature
13	Sud Goubet	Not accessible									(Reference)

Source JICA Survey Team

5.5 Comparison of the Results Geochemical Analysis with CERD

Two staffs from CERD also participated in this field survey in May and June 2014, who took the same samples together with the JICA Team, and analyzed these samples in the CERD geochemical laboratory. The comparison between CERD results and JICA results analyzed in Japan is shown in Attachment-7. The co-relationship for each analyzed item is shown in Figure 5-17.

Figure 5-17 shows that there is a quiet good agreement between CERD results and JICA results in major components. The JICA Team considers that CERD has the ability of analysis technique. However, the results of minor components such as Li, Fe, and As showed some differences with JICA's.



Source: JICA Survey Team

Figure 5-17 Corelationship Between CERD and JICA Results for Each Analysed Item

CHAPTER 6 Evaluation of Geothermal Resources

The JICA Survey Team summarised the results of satellite imageries analysis, geological and geochemical survey, and laboratory analysis with reference to existing information and references in Table 6-1. Based on the results, the JICA Survey Team evaluated the geothermal resources in the target sites as follows:

6.1 Arta

The satellite images showed wide alteration areas with spotted severe alteration, the geological map indicated several fumarole points and rhyolite rocks. The JICA Survey Team observed at the site one weak fumarole, severe acidic alteration zones, and altered rhyolite outcrops as geothermal manifestations. While the fumarole sample analysis showed no significant results due to the weakness of the fumarole resulting in mixture with ambient air while reaching to the ground surface, geothermal alteration clays identified by XRD showed high formation temperature as 250 °C. The JICA Survey Team therefore considered that the Arta site may have prospective geothermal resources for development. In addition, geothermal fluid may have high salinity because Arta is close to Tadjoura Bay.

6.2 Gaggade Taassa

The satellite images showed spotted severe alterations together with remarkable lineament, and the geological map indicated fumarole and rhyolite dykes. The JICA Survey Team also confirmed strong fumarole, rhyolite dyke, and severely altered acidic clay. The laboratory analysis showed that the collected gas was mixed with mantle-originated gas and that the geothermal alteration clays identified by XRD showed high formation temperature at 200 ºC–250 ºC. From the above, the JICA Survey Team considered that Gaggade Taassa also may have prospective geothermal resources for development.

6.3 Hanle-Garabbayis

The satellite images and geological map showed a large rhyolite rock mass near Yoboki about 10 km NW from Hanle-Garabbayis site. On the rhyolite rock mass, acidic alteration zones were identified and spotted alteration in Garabbayis site. Several fumarole points were indicated near or around the boundary of the rhyolite rock mass. At the site, the JICA Survey Team confirmed strong fumarole activities. The laboratory analysis results showed that the gas collected was a mixture with mantle-originated gas and that the geothermal alteration clays identified by XRD indicated a formation temperature at 150 ºC–200 ºC. With this information, the JICA Survey Team considered that Hanle-Garabbayis may have prospective geothermal resources for development.

In 1985, three shallow wells (450 m) were drilled. The maximum temperature was recorded at 87 ºC only. In 1989, two deep wells (1,623 m and 2,038 m) were drilled which resulted in the maximum temperatures of 72 ºC at 1,420 m and 124 ºC at 2,020 m. Permeable zones are encountered in the rhyolitic complex at the contact with the basalts and in the scoriaceous layers. The crust is significantly thick without any shallow thermal anomalies related to intrusions or magma chamber. The fumaroles of Garabbayis would therefore represent exceptional situation, which are the major fault system connected to some very deep thermal anomalies [9] . The JICA Survey Team considered the lessons learned would suggest that identification of the major fault zones or the fractured rhyolite should be key points for geothermal exploration in the next stage.

6.4 Lac Abhe

The JICA Survey Team confirmed the large scale of travertine distributed in a wider area on the western coast of Lac Abhe. The JICA Survey Team also confirmed boiling hot springs at the site. These may be good indications that there have been strong geothermal activities in this area although it was covered largely with lake deposits that may mask other manifestations such as hydrothermal alteration. However, the laboratory analysis of hot water samples collected indicated maximum geochemical temperature of 150 ºC only. This result is in accordance with the results reached by Bouh Houssein (2010) [18]. From these geochemical analyses, the JICA Survey Team considered that Lac Abhe may not have prospective geothermal resources for a flash type power system.

In addition, the pre-feasibility study report prepared by CERD for Lac Abhe shall first be reviewed to decide the priority for exploration.

6.5 Nord Goubet

The satellite images showed spotted severe alterations, and the geological map indicated spotted rhyolitic rocks and ten fumarole points. At the site, the JICA Survey Team confirmed several fumaroles, altered geothermal clays, and rhyolitic rock masses. The geothermometer （CH_4/CO_2） derived from the collected gas indicated a maximum temperature of 320 ºC. The JICA Survey Team therefore considered that Nord Goubet may have prospective geothermal resources. In addition, geothermal fluid may have high salinity because this site is close to Tadjoura Bay.

6.6 Obock

Obock site is covered with calcareous sedimentary rock of Pleistocene age, and therefore, no remarkable geothermal manifestations can be identified by the satellite images and geological map, except the hot springs that emerge on the coastline when the lowest tide in a day. Geochemical thermometer analysis indicates 197 ºC that may suggest prospective geothermal resources. However, the geothermal fluid may have high salinity because the isotope analysis suggests that the hot springs probably originate from the sea water. Similar to Lac Abhe, CERD conducted a pre-feasibility survey in Obock for geothermal development. This report shall be referred to if the site is selected for the next stage of exploration.

6.7 Djibouti Awrofoul

There are no remarkable geothermal manifestations identified in this site by the satellite images, geological map, and site survey. However, a water sample collected from the water well indicated a geochemical temperature of 191 ºC, and lower electrical conductivity of 156 mS/m. There is a possibility that the site may have prospective geothermal resources.

6.8 Other sites

6.8.1 Asal-Koril hot spring

The satellite images indicated spotted acidic alterations on the southern coast of Lake Asal. Several hot springs along the eastern coast of Lac Asal were described on the geological map. Geochemical temperature shows 177 ºC, and no other remarkable geothermal manifestations were observed. The JICA Survey Team considered that the geothermal resource in Asal-Koril site may not be suitable for a flash type power generation system while it may be used for a binary type power generation system. In addition, the electric conductivity of the hot spring shows as high as the one of the seawater.

6.8.2 Hotsprngs at Hanle-Dagguiro, Hanle-Minkileh, Hanle-Agna

Hot springs are indicated along the rim of the Hanle Plain on the geological map. The geochemical temperature indicated a maximum value of 170 ºC. No other remarkable geothermal manifestations were confirmed. The JICA Survey Team considered that the geothermal resources associated with the hot springs along the rim of the Hanle Plain may not be suitable for a flash type power generation system while it may be used for a binary type power generation system.

6.8.3 Rouweli hot spring

No remarkable geothermal manifestations were observed on the satellite images and on the geological map. The geochemical temperature of the water sample collected indicated about 160 ºC. The JICA Survey Team therefore considered that the geothermal resources associated with the hot springs at Rouweli site may not be suitable for a flash type power generation system while it may be used for a binary type power generation system.

6.8.4 Sakalol Asbou-Dara hot spring

Similar to hot spring sites along the rim of the Hanle Plain, the geochemical temperature indicated about 164 ºC. No other remarkable geothermal manifestations were confirmed. The JICA Survey Team considered that the geothermal resources associated with the hot springs in Sakalol may not be suitable for a flash type power generation system while it may be used for a binary type power generation system.

Table 6-1 Evaluations of Geothermal Resources

No.	Survey Site	Regional Geology（Satelite image, Geological Map, Site Survey）			Geothermal Alteration			Fumarolic Gas	Geochemical thermometer		Electrical Conductivity of Water (μS/cm)	Evaluation	
		Regional Alteration	Geological Characteristic	Fractures	Mineral Zone	Intensity	Temperature of formation(℃)		Quartz	Alkali			
1	Arta	Spotted acidic alteration + wide area alteration halo	Associated with Rhyolite	NNE	Kaolinite-phyrophylite	severest	max. 200-250	(Very weak, Air mixed)	-	-	>30,000	★Good	A-3
2	Asal_Fiale	Spotted acidic alteration + wide area alteration halo	Recent basaltic lava	WNW, abundant	-	-	-	Mixed with gas of mantle origin	-	--	>30,000	(★Good)	(Not for evaluation)
	Asal_Koril				-	-	-	-	96-111	116-177	>30,000	poor	-
3	Djiboubi_Awrofoul_No.2	not observed	Basalt	not notable	-	-	-	-	103-118	52-191	±1,000	(★Worthy to survey)	(Not for evaluation)
4	Dorra	not observed	Basalt	NNW and NNE	Not accessible							（評価対象外）	
5	Gaggade_Taassa	Spotted acidic alteration + wide area alteration halo	Associated with Rhyolite	NW, NE, WNW	Kaolinite-phyrophylite	severest	Max. 200-250	Mixed with gas of mantle origin	-	-	±5,000	★good	A-1
6.1	Hanle-Garabbayis	Spotted acidic alteration + wide area alteration halo	Neighboring larger scale Rhyolite	NW, WNW	Smectite-Chlorite Mix	severe	150-200	Mixed with gas of mantle originT(CH_4/CO_2)=266℃	-	-	±5,000	★good	A-1
6.2	Hanle-Dagguirou	-	Basalt	NW, WNW	-	-	-	-	94-109	113-170	±5,000	Poor	-
6.3	Hanle_Minkileh	-	Basalt	NW, WNW	-	-	-	-	103-118	91-126	±5,000	Poor	-
6.4	Hanle-Agna	-	Basalt	NW, WNW	-	-	-	-	92-107	107-173	±5,000	Poor	-
7	Lac Abhe	Spotted acidic alteration + neutral alteration	Basalt and lake deposit	WNW、NNE	-	-	-	-	115-138	136-158	±5,000	Poor	-
8	Nord Goubet	Spotted - mound-like acidic alteration + wide area alteration halo	Dotted rhyolite and andesite	NNW, NNE	Smectite	fair	100-150	Mixed with gas of mantle originT(CH_4/CO_2)=323℃	-	-	>30,000	★good	A-2
9	Nord Lac Asal	Weak acidic alteration	Basalt	NNW, NNE	Not accessible							(Not accessible, not for evaluation)	
10	Obock	not observed	Calcareous deposit	not observed	-	-	-	-	90-108	115-197	>30,000	(★Worthy to survey)	A-4
11	Rouweli	Spotted acidic alteration	Basalt	EW	-	-	-	-	79-95	75-160	±5,000	poor	-
12	Sakalol_Asbou-Dara	not observed	Basalt	NW, NNW	-	-	-	-	115-130	116-164	±5,000	poor	-
13	Sud Goubet	Wide area neutral alteration + spotted acidic alteration + wide area alteration halo	Basalt	WNW, NNE	Not accessible							(Not accessible, not for evaluation)	

Source: JICA Survey Team

CHAPTER 7 Environmental Survey

7.1 Objective

In order to assess socio-environmental conditions of the target sites, the Team collected information regarding relevant lows/regulations, protected/designated natural areas and the procedure of environmental impact assessment (EIA).

7.2 Methodology

Laws and decrees related to environmental protection and the EIA process were confirmed. The JICA Survey Team interviewed the Ministry of Housing, Urbanism, Environment and Land Management, Department of Environment (hereafter referred to as DoE).

7.3 Result of the Survey

7.3.1 Natural Protection Area

Regulations related to environmental protection area are shown in Table 7-1.

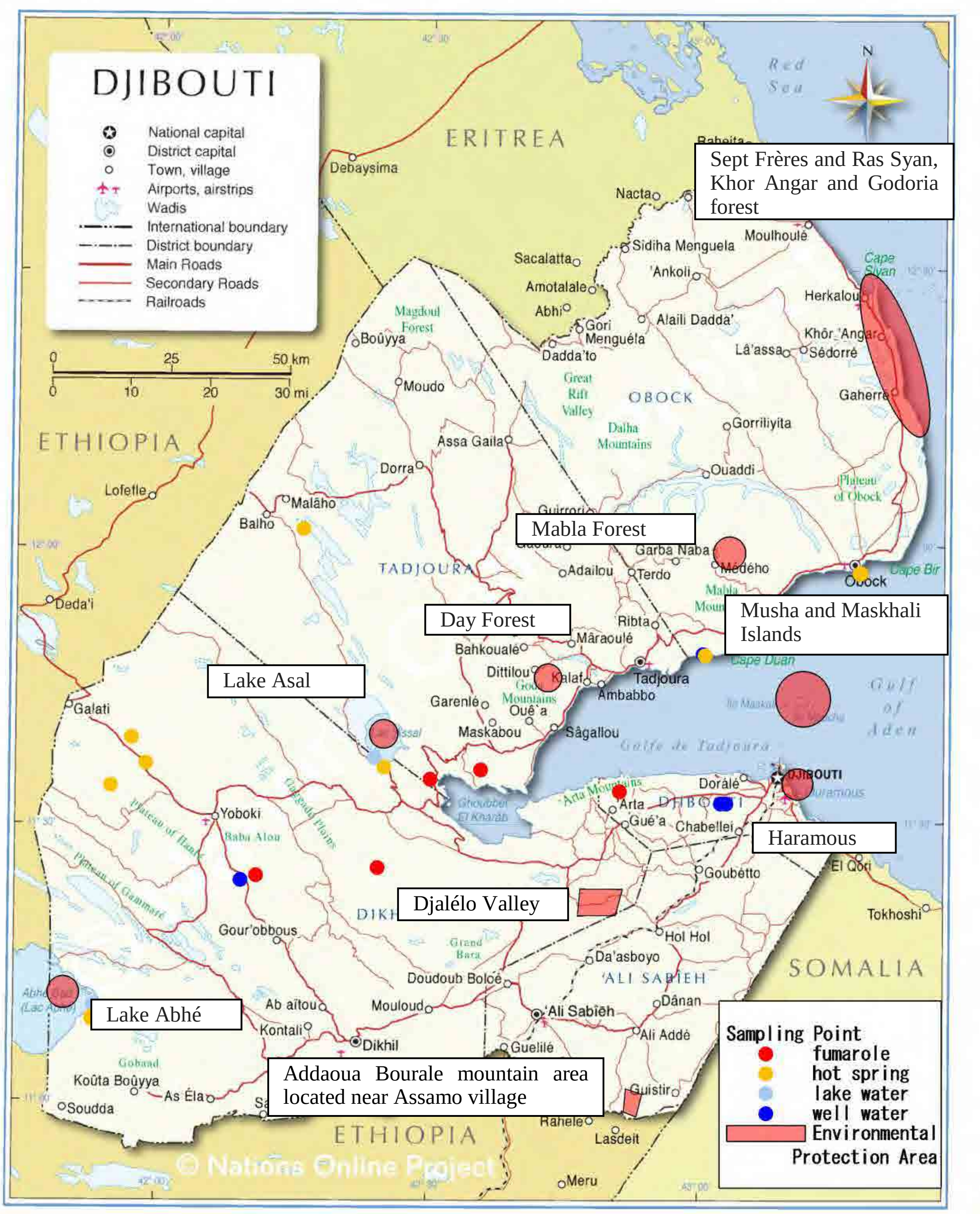
Seven protected areas were designated in 2004 and two more were in 2011. The district boundaries of the protected areas have been established in only two places that have been added in 2011, the boundaries of the other seven places have not clearly been decided. DoE is planning to introduce a zoning system in the protected areas. Redevelopment of the areas is not necessarily prohibited. When the promoter has a plan to develop some of the protected areas, he/she should inquire first DoE regarding the possibility for development for DoE to judge on such possibility.

Table 7-1 Regulation Related to Environmental Protection Area

Law and Decree	Outline	note
Low45/AN/04/5emeL : Establishment of protection area	Four land protection areas and three coastal protection area are designated.	Districal boundaries are not mentioned. Among the seven protection area, geothermal prospects near Lake Asal and Lake Abhe can be involved in the protection area.
Decree 2011-0236/PR/MHUE on two land protection area	The decree added two protection areas. Location data of the boundaries are mentioned in the decree.	The geothermal prospects are not involved in the two added areas.
Ratification of the Ramsar Convention	Ratification of the Ramsar Convention	Djibouti has one wetland selected by the Ramsar Convention. However, geothermal prospects are not located near the wetland.

Source：JICA Survey Team

Locations of the environmental protection areas and sampling points in the survey are illustrated in Figure 7-1. As shown in the figure, geothermal prospects of Lake Asal and Lake Abhe may possibly be included in or close to the environmental protection areas. Therefore, preliminary consultation with DOE is required in case of developing the geothermal prospects.



*Boundary of protection area except Valley Djalelo、 Addaoua Bourale mountain area located near Assamo Village not clearly settled.

Source：JICA Survey Team

Figure 7-1 Location of Protection Areas and Geothermal Prospects

7.3.2 Environmental Impact Assessment (EIA)

Regulation related to EIA are listed in Table 7-2.

According to the Decree 2011-029/PR/MHUEAT on revision of the EIA process, depending on the scale and type of development, EIA has been divided into two categories i.e., detailed EIA and summary EIA. Geothermal development and test drill can be classified into detailed EIA.

Table 7-2 Regulation Related to EIA

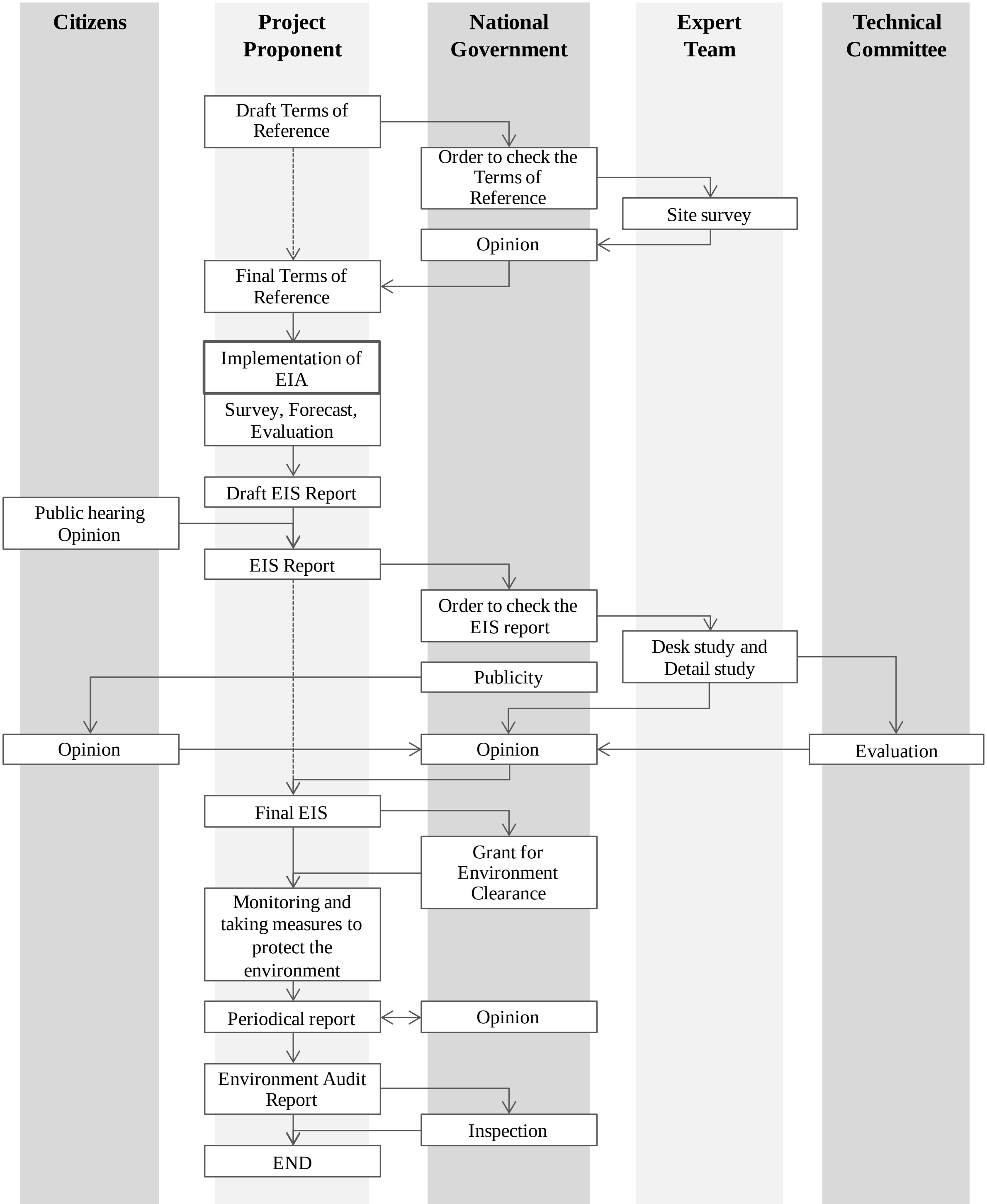
Regulation	Outline	Notes
Decree 2001-0011/PR/MHUEAT on definition of EIA procedure (old EIA procedure)	This decree mentioned the first EIA procedure in Djibouti.	As of 2014, this decree is not applied.
Decree 2011-029/PR/MHUEAT on revision of EIA procedure (current EIA procedure)	In the decree, category of EIA, EIA procedure, fee are described in detail.	Geothermal development and test drill need detail EIA process.

Source：JICA survey team

The EIA procedure in Djibouti is shown in Figure 7-2. Based on the interview, it took three months to accept the EIA report of the geothermal survey in Asal. Therefore, similar period seems to be necessary for the EIA report to be accepted by DoE when the new geothermal project is conducted.

Information related to the EIA process in Djibouti is described below. From an interview survey with the Department of Environment, the JICA Survey Team obtained the following information:

- The environmental standard is not finalized in Djibouti. World environmental standards such as World Health Organisation (WHO) standard, or environmental standards of other developed countries are to be adapted when the JICA Survey Team conducts the EIA study.
- There is no consulting companies that have the ability to conduct the EIA survey in Djibouti. There are a few experts who have expertise in the EIA survey under the supervision of an EIA consultant from another donor.



source：JICA survey team prepared the figure based on the decree

Figure 7-2 EIA Procedure in Djibouti（Decree 2011-029/PR/MHUEAT）

(1) Development in the Environmental Protection Area

As mentioned above, as of the end of June 2014, there are nine environmental protection areas in Djibouti. Zoning in the protection area is not decided yet and the possibility of development is not finalized. Furthermore, the environmental protection areas do not have clear boundary, except the Djalélo and Addaoua Bourale mountain area.

Among the geothermal prospect areas surveyed in the survey, a prospect near Lac Abhe may possibly be included in the protection area. Preliminary consultation to the Department of Environment is required in case of developing the prospect.

(2) Environmental Impact Assessment

The decree on EIA was revised in 2011 by another decree. Thus, the process of EIA became clearer than before. EIA is necessary not only for the construction of geothermal power plants but also for exploratory drilling. Therefore, the period of conducting EIA has to be considered when preparing the timetable of geothermal development.

(3) Resettlement

The JICA Survey Team found that even there is no infrastructure existing in the area such as water supply, roads, and electricity, nomads grazing goats lived in the plains near a spring. According to the decree, the development and mitigation plan has to be discussed with the inhabitants in advance.

CHAPTER 8 Proposal of the Priority Sites for Cooperation

8.1 Factors to be Considered for the Prioritization

The JICA Survey Team considered the following factors for prioritisation:

8.1.1 Geothermal Resource Evaluation

The JICA Survey Team considered only seven sites that were selected as priority sites based on geological and geochemical conditions as discussed in Chapter 6, for prioritisation.

8.1.2 Access Conditions

Table 5-1 includes the information on access conditions based on the actual survey record. Access conditions from the trunk roads were considered.

8.1.3 Working Space and Drilling Water

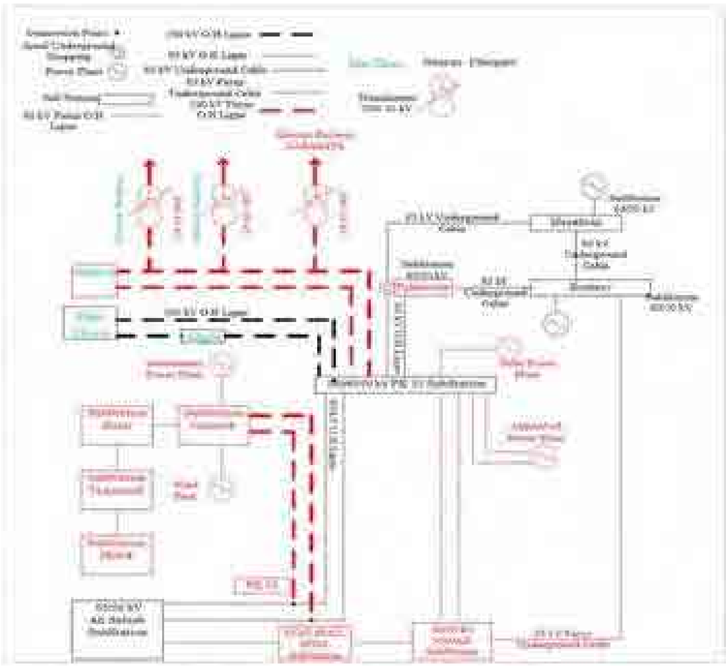
The JICA Survey Team considered the topographic conditions for consideration of working space. Availability of drilling water was also taken into consideration.

8.1.4 Socio-Environmental Conditions

The JICA Survey Team considered the environmental conditions discussed in Chapter 7.

8.1.5 Distance to the Existing/Plane Transmission Line or Nearest Trunk Roads

Djibouti Electricity (EdD) prepared the electrical development plan. The JICA Survey Team principally considered this EdD plan or the distance to the nearest trunk road as necessary.



Source: EdD

Figure 8-1 EdD Electrical Development Plan

8.2 Proposed Priority for Cooperation

The JICA Survey Team's proposal on the priority for cooperation is as follows:

8.2.1 Selection of the First Priority for Cooperation- Hanle-Garabbayis

Among the seven sites nominated, the JICA Survey Team considered the four sites, namely, Nord Goubet, Hanle-Garabbayis, Gaggade-Taassa, and Arta, as prospective sites from geothermal potential point of view. Among these four sites, Hanle-Garabbayis and Gaggade-Taassa demonstrate relatively strong geothermal manifestation. However, Gaggade-Taassa is not easily accessible and in a rugged topographic conditions. Therefore, the JICA Survey Team proposed that Hanle-Garabbayis should be the first priority for development cooperation.

In Hanle-Garabbayis, test wells were drilled resulting in a confirmation of not so high temperatures. The lesson learned suggests the steam observed is considered to emerge through fracture systems. The JICA Survey Team at this moment considered that the target for the test well drilling should be at fracture zone together with rhyolitic rock that may be part of the fractured zones.

In addition, access conditions are favorable to the site where steam is emerging on the surface.

8.2.2 Arta and Nord Goubet

The JICA Survey Team considered that both sites of Arta and Nord Goubet will have similar geothermal potential based on the survey conducted. Arta is located in the southern Tadjoura Bay and Nord Goubet in the northern Tadjoura Bay, and both sites are topographically of similar characteristics. Arta is close to PK12 where the new substation is located; whereas Nord Goubet is about 10 km to Asal Fiale where test wells will be drilled with financial arrangement from the World Bank and other donors, and therefore there may be a possibility that Nord Goubet be connected to the transmission line to be constructed for Asal Fiale. In addition, the military training zone in Djibouti is located on the way from the Trunk Road No.1 to Arta site, which may be a beneficial point because the access road will be regularly maintained.

8.2.3 Gaggade-Taassa

Although Gaggade-Taassa exhibits fairly good geothermal manifestation, the JICA Survey Team placed it in the fourth priority because the access conditions to the site is poor and construction of a working space for well drilling and plant construction may not be easy and entails a lot of cost.

8.2.4 Obock

The JICA Survey Team noted that construction of a geothermal power station in Obock is desirable because the present electrical power is generated by costly diesel engine generation systems. The geochemical survey indicated that there may be a possibility of reservoir temperature of 200 °C, and therefore a flash type geothermal power plant may be possible. However, the JICA Survey Team also considered it important that the present base-load demand will not be more than 500 kW and installation of new transmission lines from Goubet is on the planning stage. Under such circumstance, necessity of high capacity power plant in Obock shall be examined from economical point of view; for an example, to construct a high capacity power plant will require considerably expensive test wells. At this moment, the JICA Survey Team would recommend that the pre-feasibility study conducted by CERD should first be reviewed. It would be a prudent approach that exploration should be conducted with locally available survey resources and that a binary system (ORC) be considered for the base-load demand in Obock.

8.2.5 Lac Abhe

Although Lac Abhe exhibits a fairly good geothermal manifestation, the geothermometer indicated only 150 °C. A researcher of CERD obtained similar result in 2010 [18]. In addition, Lac Abhe is possibly located in a protection zone and is considered to be a tourism resource. The JICA Survey Team therefore placed lower priority to Lac Abhe for cooperation priority of geothermal development.

8.2.6 Others—Djibouti-Awrofoul

Geochemical thermometer of Djibouti–Awrofoul indicated about 190 °C, and the electrical conductivity of the hot water is in a range of 150 mS/m. The JICA Survey Team therefore considered it worthwhile to conduct the Magneto-Telluric Method (MT) survey at the ODDEG's survey stage in the near future although other geothermal manifestations were not observed.

Table 8-1 Proposed Priority for Cooperation

Site name	Geothermal Resources		Workability			Socio -Environment		Reference	Priority rec'nded	
	Resources	CL (mg/L)	Accessi-bility	Landform	Well Drilling Water	Natural conditions	In-habitant	Distance to transmission line		Survey for the next stage
Garabbayis	☑ A-1	±1,000	C Fair	B Plain -ragged hill	☑ A Ground water in Hanle Plain	☑ A Barren	A none	45 km to Dikhil	**1**	MT survey with geological and geochemical survey
Arta	☑ A-3	☑ D ±15,000	B Good	B Plain - ragged hill	C Sea	☑ A Out of a registered protection area	B a few	6 km to N.1	**2**	MT survey with geological and geochemical survey
Nord Goubet	☑ A-2	☑ D ±15,000	C-D Poor-fair	C Plain - ragged hill	C Sea	☑ A Barren, Desolate	B a few	50 km to P.K. 51	**2**	Review of Pre-Feasibility Study of CERD
Gaggade	☑ A-1	±5,000	☑ D Poor	☑ D Ragged hill	☑ A Ground water in Hanle Plain	☑ A Barren	A none	40 km to P.K 51	**3**	MT survey
Obock *	B	5,000 - 40,000	A Excellent	A plain, costal	C Sea	B Coastal	near town	Isolated	**4***	Review of Pre-Feasibility Study of CERD
Djibouti	C	±5,000	A Excellent	A Plain	C Sea	-	-	-	**5**	MT survey
Lac Abhe	-	±5000	C Fair	A Plain	C Lac Abhe	☑ D Registered	B a few	75 km to Dikhil	**-**	Review of Pre-Feasibility Study of CERD

☑: Conditions that special considerations are given for prioritization

Obock *: Survey of a next stage, separately from survey for a flash type may be recommended if a binary type is considered.

Source: JICA Survey Team

CHAPTER 9 Strategy for High Salinity Geothermal Fluids

9.1 Strategy for High Salinity Geothermal Fluids Affecting Plant Equipment

Salinity of the geothermal fluids produced from the test wells drilled in the Asal Geothermal Field in Djibouti is over 100,000 ppm. In such a case, scale deposition and corrosion in the wellbore and pipeline will pose serious problems.

The scaling and corrosion tests using the production fluid of Asal-3 were conducted in the Asal Geothermal Field from 1989 to 1990 (Virkir-Orkint, 1990) [2]. This section reviews the result of the test and summarises the case study of Salton Sea Geothermal Field that produces extremely high salinity brines.

9.1.1 Summary of the Scaling and Corrosion Test in the Asal Geothermal Field

Table 9-1 shows the typical brine composition that was used in the scaling and corrosion test at the Asal Geothermal Field. The chemical composition of brine produced in the Salton Sea Geothermal Field (Featerstone et. al., 1995 [20]) is also shown in the table.

Table 9-1 Brine Chemical Composition in the Asal and Salton Sea Geothermal Fields

Contents		Djibouti Asal-3	United States Salton Sea
pH		5.57	-
TDS	(mg/kg)	-	214,000
SiO_2	(mg/kg)	511	-
Cl	(mg/kg)	105,500	119,000
Li	(mg/kg)	19.6	160
Na	(mg/kg)	39,300	51,200
K	(mg/kg)	6,540	12,000
Ca	(mg/kg)	23,360	20,600
Mg	(mg/kg)	35.8	50
Fe	(mg/kg)	36.5	540
Zn	(mg/kg)	52	300
Pb	(mg/kg)	3.5	70
Cu	(mg/kg)	0.30	2
Ba	(mg/kg)	115	210
Mn	(mg/kg)	-	770
Sr	(mg/kg)	323	360

Source: the Survey Team referred to [2] [20]

The summary of the scaling and corrosion test using the production fluid of Asal-3 is as follows:

- Asal-3 was set to produce during a 93-day trial. In that period, the scaling and corrosion tests using production fluid of Asal-3 were conducted.
- The total discharge of Asal-3 decreased to 25-28% during the production test. This

decreasing value includes initial decline of the well and scaling in the wellbore[2].

- The coupons (76×13×3-4 mm) made by carbon steel and stainless steel were placed in the test plant for 48 days at the longest, and scale deposition rates on these were measured.
- The scale deposition rate of the coupons set in the two-phase line was 1.8-2.3 μm/h when the wellhead pressure was 17.7-20 barg. On the other hand, the deposition rate when the wellhead pressure was 12.4-14.4 barg was 10.5-10.7μm/h. The former and latter deposits were mainly galena (PbS) and iron silicate, respectively.
- The amorphous silica was deposited in the silencer installed at the end of the test plant.
- Galena and iron silicate scale depositions were prevented by the use of inhibitors (aliphatic and aromatic polymer and carbocyclic polymer). But the other soft and flocky deposits were formed.
- In the corrosion test, various coupons made by carbon steel, stainless steel, and alloy were set in the steam and condensate flow line; and the corrosion extent of the coupons was evaluated. In the result, the carbon steel coupon set in the condensate has only corroded.

The deposition of sulfide and silica minerals was confirmed in the test. However, this has not been evaluated whether the amount of these minerals affected the steam production. The effect of the inhibitors is opaque. Moreover, the materials for well casing and pipeline resistant to the high saline fluid have not been found because corrosion test using brine was not conducted.

9.1.2 Methods of Preventing Scale Deposition and Corrosion in the Salton Sea Geothermal Field

Table 9-1 shows that the brine produced in the Salton Sea Geothermal Field has extremely high salinity as well as Asal-3. The technology of preventing scale deposition and corrosion in the field are mentioned below.

(1) Technology of preventing a scale deposition

The following two technologies of preventing a scale deposition are effective in the Salton Sea Geothermal Power Plant (Featerstone et. al., 1995) [20].

- Crystallizer Reactor Clarifier
- pH Modification

Crystallizer Reactor Clarifier is the technology of removing suspended particles formed by injection of seed material into brine before injection. That has made to prevent the deposition of iron rich amorphous silica effectively in the Salton Sea Geothermal Power Plant. However, large cost for discarding the removal scale from the brine is necessary.

While pH modification is the method for preventing a deposition of siliceous scale by reducing pH of the geothermal brine, it is a general method for controlling the scale deposition at the pipeline. It has been applied in some geothermal power plants in Japan. The dosing rate of sulfuric acid used for pH modification commonly has to be controlled closely because of preventing a siliceous scale

[2] It is also noted that there are some effect of the drill string (10 drill pipes) remaining in the well, for one of the main causes of the well decline. (FARAH OMAR, Argeo C5 2014 paper “Problems encountered while drilling and completion stages of Asal rift wells”).

deposition and corrosion of the pipeline. Mixing equipment manufactured by alloy material (hastelloy for example) is installed typically at the dosing point.

(2) Corrosion protection

Steel materials used in the Salton Sea Geothermal Power Plant with high salinity geothermal fluid (Featerstone et al., 1995) [20] are as follows. These materials are resistant against erosion affected by high salinity fluids.

- Well casing: Alloy
- Two-phase pipeline and separator: Alloy (Hastelloy and Incoloy)
- Injection pipeline: Cement lining

Carbon steel is commonly used for well casings and pipelines in many geothermal power plants with low salinity geothermal fluid. However, corrosion-resistant steels (high-grade) will be necessary when high salinity geothermal fluid is produced. The cost of well drillings and pipeline settings with corrosion-resistant steels will be considerably expensive.

9.2 Estimation of the Cost for Treatment of High Salinity Fluids

9.2.1 Objective of Estimation

This estimation aims to assess the costs for construction and maintenance of several geothermal power plants producing high salinity fluid. The results are useful for investigating the possibility of promotion for geothermal development in Djibouti.

9.2.2 Method of Estimation

The costs for the construction and maintenance of several geothermal power plants producing high salinity fluid (four types of high salinity fluids, i.e., Standard, Mid, High, and Extremely High) were estimated. A category of salinity based on chloride concentration is shown in Table 9-2. The geothermal power plants in Japan and discharge areas of hot springs in Djibouti are shown in Table 9-2.

Table 9-2 Values of Chloride Concentration Categorised Four Kinds of Salinity

Category of Salinity	Cl concentration (mg/L)	Relevant GPP in Japan	Hot Springs in Djibouti [Cl concentration (mg/L)]
Standard	500～1,000	Kakkonda (Unit 1), Sumikawa, Takigami	Hanle [636 - 953]
Mid Salinity	1,000～5,000	Kakkonda (Unit 2), Onikobe, Ohtake	Lac Abhe [1,680 – 1,690], Rouweli [2,720], Sakalol [2,320]
High Salinity	5,000～40,000	Mori, Yamagawa	Asal [22,200], Obock [16,800–20,600]
Extremely High Salinity	40,000～160,000	N/A (Salton-Sea in US)	N/A (Lac Asal [197,000])

Source: JICA Survey Team

The estimation is based on some examples of construction and maintenance of geothermal power plants in Japan. The extensive civil engineering works are not included in the estimation.

9.2.3 ***Results of Estimation***

Estimations of construction and maintenance cost for the 25 MW and 50 MW geothermal power plants are shown in Table 9-3 and Table 9-4, respectively. In each output power, construction cost for the geothermal power plant producing “extremely high salinity” fluid is three times higher than the case of producing “standard - high salinity” fluid. The reason is that the geothermal power plant needs noncorrosive high-grade metal for well casing and the Crystallizer Reactor Clarifier Technology for preventing scale deposition at injection wells. Based on this study, areas with “extremely high salinity” should be dropped from the geothermal development promotion.

All salinity of hot springs sampled in this survey area were ranked in “standard - high salinity” (only Asal Lake has “extremely high salinity”). Cl concentrations of the hot springs in Hanle area having prospective geothermal resource correspond to “standard”. It is assumed that salinity of the reservoir fluid is “high” which is ten times of Cl concentration from the hot springs if salinity of geothermal fluid is high in deep zone.

The Hanle area containing some hot springs with “standard” salinity fluid is desired as high priority of geothermal development. There is a promising geothermal resource in Hanle area. Technical experience and management skills originated from some geothermal development area with “high salinity” in Japan (Mori and Yamagawa) will assist to solve any technical problems in Hanle area.

The cost for well drillings and plant construction will be affected on the further study. These estimations should be used as reference, the cost for development of prospective geothermal area drawn out from this survey needs to be reviewed circumstantially.

Table 9-3 Estimation of Construction and Maintenance Cost for 25 MW GPP

Category	Standard	Mid Salinity	High Salinity	Extremely High Salinity	Assumption
Construction (unit: USD in million)					
Drilling Cost for Production Wells	39	40	48	227	・Drilling 6 production wells to 2,000 m. ・Drilling condition and productivity are unity.
Drilling Cost for Injection Wells	8	8	8	10	・Drilling 3 injection wells to 1,000 m. ・Drilling condition and injectivity are unity.
Pipeline Construction Cost	20	33	37	149	・Separator included. ・pH controlling equipment is included.
Scale Preventer Construction Cost	N/A	N/A	N/A	2	・Crystallizer Reactor Clarifier is installed.
GPP Construction Cost	100	100	100	100	
Summation	**167**	**181**	**193**	**488**	
O&M (unit:USD in million)					Estimation Period: 20 years
Cost for scale preventer	3	3	3	3	・Purchase of sulfuric acid.
	-	-	-	2	・Maintenance of CRC.
Workover cost for Production Wells	10	10	10	10	・1 well workover / 5 years.
Workover cost for Injction Wells	5	5	5	5	・1 well workover / 3years.
Periodic Inspection Cost for Pipeline	30	30	30	30	・Performing biyearly.
Periodic Inspection Cost for GPP	39	39	39	39	・Performing biyearly.
Employment Cost	30	30	30	35	
Summation	**117**	**117**	**117**	**124**	

Source：JICA Survey Team

Table 9-4 Estimation of Construction and Maintenance Cost for 50 MW GPP

Category	Standard	Mid Salinity	High Salinity	Extremely High Salinity	Assumption
Construction (unit: USD in million)					
Drilling Cost for Production Wells	78	80	97	454	・Drilling 12 production wells to 2,000 m. ・Drilling condition and productivity are unity.
Drilling Cost for Injection Wells	16	16	16	21	・Drilling 6 injection wells to 1,000 m. ・Drilling condition and injectivity are unity.
Pipeline Construction Cost	38	60	64	285	・Separator included. ・pH controlling equipment is included.
Scale Preventer Construction Cost	N/A	N/A	N/A	4	・Crystallizer Reactor Clarifier is installed.
GPP Construction Cost	150	150	150	150	
Summation	**282**	**306**	**327**	**914**	
O&M (unit: USD in million)					Estimation Period: 20 years
Cost for scale preventer	6	6	6	6	・Purchase of sulfuric acid.
	-	-	-	4	・Maintenance of CRC.
Workover cost for Production Wells	17	17	17	17	・1 well workover / 3 years.
Workover cost for Injction Wells	8	8	8	8	・1 well workover / 2 years.
Periodic Inspection Cost for Pipeline	30	30	30	30	・Performing biyearly.
Periodic Inspection Cost for GPP	49	49	49	49	・Performing biyearly.
Employment Cost	30	30	30	35	
Summation	**140**	**140**	**140**	**149**	

Source : JICA Survey Team

CHAPTER 10 Geothermal Development Profile (GIS data base)

For the creation of geothermal development profiles of the target areas in this Survey, the JICA Survey Team made a GIS database of the existing information collected and new information surveyed during the survey period. ArcGIS is the software used for this database creation and an updated software has been provided to the Djiboutian Office for Development of Geothermal Energy (ODDEG). The following information was compiled for the database creation:

○ Site survey information

- Sampling points of samples of hot-water, gas, lake water, well water, rock, and alteration clay;
- Track record of the survey; and
- Delineation of protection zones.

○ Information from in-door analysis and laboratory analysis

- Satellite Imagery analysis for identification of hydro-thermal alteration, volcano shape, secondary deposit (alluvial, salt deposit, calcareous deposit), displacement/lineament, rhyolitic rock (intrusion and/or pyroclastic); and
- Geochemical analysis, geological analysis.

○Existing information collected

- Figures and plates

  Geological maps, annual average rainfall distribution map, annual potential evaporation map, groundwater flow distribution map, brackish groundwater distribution map, watershed map, soil classification map, population density map, cultivation land map, vegetation map.
- Positional information with attribute data

  Geothermal wells with information of depths, temperatures and others; Geothermal manifestations (fumaroles, hot springs).

○Basic information

- International borders, district boarders, provincial boarders, coast lines, location of major cities and towns, roads, topographic map (90 m mesh), 10m contour, lakes and wadi locations.

Profiling sheets were prepared in the format shown in Figure 10-1 based on the GIS database and the results of the priority selections for the seven priority sites selected in Chapter 6. Profiling sheets for each sites are shown in Attachment-8.

Geothermal Prospect Profile Sheet

as of Octber 2014

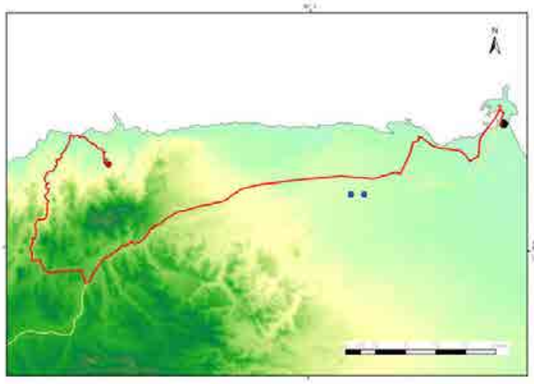
No. 1	Arta	Region	Arta	Sampling location	N	E

Topography

- Deeply dissected with ragged hills on both side along the access road
- The fumarole point and alteration zone are located on a edge of wadi where widely eroded;
- The mountains around are deeply dissected showing older

Development Priority	**2**
Geothermal Potential	**A-3**
ODDEG Priority	**4**

Access map



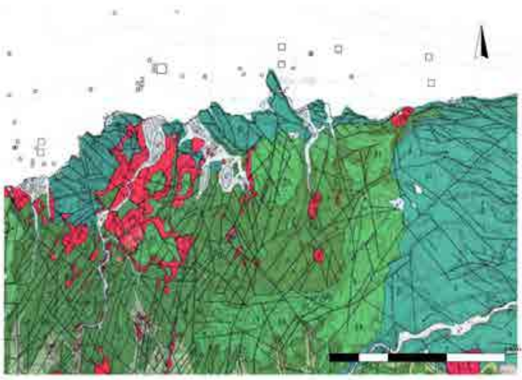
Accessibility

- Located on the southern coast of Tadjoura Bay; about 2.5 km from the coast to the fumarole point
- ca. 2.5 km from the coastal line to the fumarole point
- ca. 40 min. from Djibouti city to the junction, ca. 45 min. on unpaved road to the fumarole point through military training field

Geology

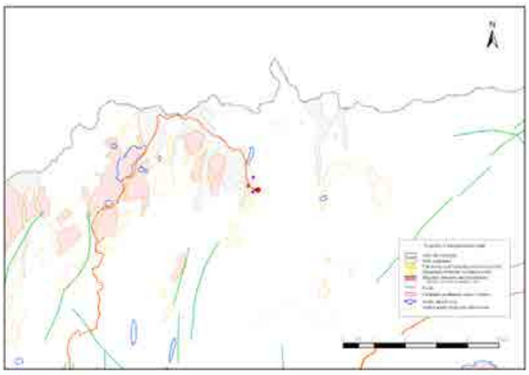
Reservoir Area km2 Thickness m

Geological map



- Dalha basalt together with NS oriented Ribta rhyolite that runs through the fumarole point
- Rock outcrops are generally weathered
- NS oriented fractures
- NS oriented distribution of three fumaroles described on the geological map
- The fumaroles seemingly along the rhyolite outcrops

Satellite Imagery Analysis Result



Acidic alteration spot and broad weak altered halo. Associated with rhyolite.

Evaluations of Geothermal Resources

Temp. of formation	200-150	degree C.
Fumarolic Gas Origin	-	degree C.
Geochemical Temperature	-	degree C.
Salinity	>30,000	μ S/cm

Transmission Condition

Required T/L	6	km
Connection	N.1	substation (city)

Socio-Environmental Aspect

Natutral Condition	Barren
Inhabitant	a few

Source: JICA Survey Team

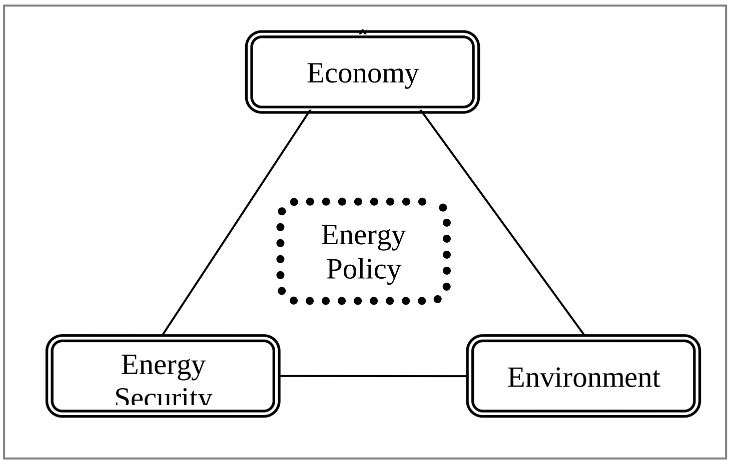
Figure 10-1 Profiling Format

CHAPTER 11 Proposed Directions of Cooperation for the Geothermal Development

11.1 Electrical Development Policy and Geothermal Development in Djibouti

Three "Es" are considered important for the national energy development policy, i.e., energy security, economic growth, and environmental protection.

The Government of Djibouti in "Vision Djibouti 2035" published in 2014 declares that Djibouti will utilise 100% renewable energy for electric power generation by 2020, whereas the electricity is generated by 100% oil-fired power generation facilities. At the same time, the government stated in the Third Five-year National Development Plan that it aims at 70% electrification and the development of geothermal energy which is available in the territory of Djibouti, in accordance with the three pillars represented by three Es.



Source：JICA Survey Team

Figure 11-1 Three Es for Electric Development Policy

While pursuing its targets, Djibouti is now importing over 80% of its electricity through a 230 kV transmission line from the neighboring Ethiopia and the second transmission line of 230 kV will be constructed by 2017 between two countries. Thereby, the Government of Djibouti will attain the 100% target of electrical energy supplied by renewable energy by 2020. However, the planned installed capacity of 236 MW will include a capacity of 186 MW (about 79%) from Ethiopia and only 50 MW of geothermal energy will be made available within the territory of Djibouti. The geothermal energy is assumed to be from the Asal-Fiale area only and the other sources are not considered because of its uncertainty for development. The "energy security" is one of the essential factors for electric development and the development of locally available geothermal energy in the territory of Djibouti will be of paramount importance.

On the other hand, the electric development plan includes wind power generation from 2021 increasing to about 50 MW by 2024. The wind power generation needs back-up power generation from oil-fired or hydropower plant due to its unstable power generation characteristics. The plan indicates that Djibouti will depend on electric energy from Ethiopia for most of its base load capacity and all other loads (peak, middle peak, and back-up load for wind and solar power).

Therefore, for the very reason of “energy security”, geothermal development is considered essential. It should be noted that effective and economical geothermal development is important in order to balance “energy security” and that unit prices of electricity purchased from Ethiopia is at US ¢ 6 to 7/kw.

➔ To immediately promote the development of locally available geothermal energy.

➔ To balance the development costs with the prices of hydropower energy imported from Ethiopia.

11.2 Segregation of Duties of ODDEG in Relation to Geothermal Development Process

The general process of geothermal development is as follows [21].

1. Planning and Pre-survey,
2. Exploration from the ground surface,
3. Test drilling,
4. Project review and planning,
5. Field development – production well, reinjection well and reservoir evaluations,
6. Construction of power plant and steamfield above ground system (SAGS),
7. Start up and commissioning, and
8. Operation and maintenance.

While the presidential decree describes that ODDEG will be in charge of the stages of development from planning and pre-survey to steam development/supply, ODDEG intends to conduct works up to the stage of confirmation of geothermal energy. Thereafter, ODDEG will transfer the concession to the independent power producer (IPP) in the field of Asal-Fiale where the drilling of test well will be conducted with financial assistance from WB and other international partners. On the other hand, as ODDEG is now on the process of purchasing a drilling rig, it may be in charge of the drilling of production and injection wells, and possibly drilling of renewal wells for the future Asal-Fiale geothermal plants.

From the above, the cooperation for geothermal development should be directed mainly to “drilling works” associated with various works from stages (3) to (5) above, which includes stage (2) whenever necessary. It features, when the development stage proceeds adequately, assistance for capacity enforcement for IPP formation and contract may be required.

11.3 Present Capacity Available in Djibouti in Relation to Geothermal Development Process

Table 11-1 shows the present capacity of Djibouti (ODDEG and CERD) in accordance with a general process of geothermal development process.

The said table shows that ODDEG is now able to undertake the geophysical survey by the staff that recently shifted from the Centre for the Study and Research of Djibouti (CERD) at the end of

July 2014. The survey equipment that are in the hands of CERD are in the process of being transferred to ODDEG. The capacities for geological and geochemical survey that are necessary in the earlier stages of exploration are not sufficient or not even available in ODDEG. Technical input from CERD will be necessary for the geological and geochemical survey and even CERD needs enhancement of their capacity to conduct these surveys.

On the other hand, CERD has conducted the geophysical and geochemical surveys in three sites, namely, Obock, Nord Goubet, and Lac Abhe, and prepared the “pre-feasibility reports”. However, the JICA Survey Team is not in a position to review those reports because they are not open to public. They consider that the interpretation of the magneto-telluric method (MT) survey may not be sufficient because CERD does not possess a 2D inversion analysis software.

CERD monitors the micro-seismic activities of Asal-Fiale area at the monitoring station in Arta Town. This monitoring system does not cover other geothermal sites.

ODDEG is now negotiating the purchase of a drilling rig with a Turkish supplier/manufacturer. The JICA Survey Team observed that drilling works would be a main task of ODDEG. For this reason, ODDEG urgently gives training to its staff with assistance from the United Nations University–Geothermal Training Programme (UNU-GTP) and/or Iceland International Development Agency (ICEIDA).

A geothermal reservoir simulation will have to be conducted with the data obtained by test well drillings in order to estimate geothermal resources. This simulation analysis requires advanced computer software and technique. ODDEG and/or CERD will have to acquire this technique and software.

Table 11-1 Capacity Assessment of ODDEG/CERD in Accordance with the Geothermal Development Process [21]

Milestone	Tasks	ODDEG		CERD	
		Staff	Tools	Staff	Tools
1. Pre-Survey	Data collection, Inventory Nation wise Survey Selection of Promising Area EIA and Necessary Permits Planning of Exploration	Almost completed with JICA's assistance			
2. Exploration	Surface (Geological)	**(MoM)**	**N/A**	**Yes**	**N/S**
	Geochemical	**N/S**	**N/A**	**Yes**	**N/S**
	Sounding (MT/TEM)	**Yes**	**Yes**	**N/A**	**N/A**
	Gradient and Slim Holes	**U/T**	**N/A**	**N/A**	**N/A**
	Seismic Data Acquisition	**N/A**	**N/A**	**Yes**	**Yes**
	Pre-feasibility Study	**N/S**	**-**	**Yes**	**-**
3. Test Drilling	Slim holes Full-size wells Well Testing and stimulation Interference Test	**U/T**	**U/P**	**N/A**	**N/A**
	First Reservoir Simulation	**Yes**	**N/A**		
4. Project Review and Planning	Evaluation and Decision-making Feasibility Study and Final EIA Drilling Plan Design of Facilities Financial Closure/PPA/IPP	**U/T**	-	**N/S**	-
5. Field Development	Production Wells Reinjection Wells Cooling Water Wells Well Stimulation	**U/T**	**U/P**	**N/A**	**N/A**
	Reservoir Simulation	**N/A**	**N/A**		
6. Construction	Steam/Hot Water Pipelines Power Plant and Cooling Substation and Transmission	*(IPP)*	*(IPP)*	*(IPP)*	*(IPP)*
7. Start up and Commissioning		*(IPP)*	*(IPP)*	*(IPP)*	*(IPP)*
8. Operation and Maintenance		*(IPP)*	*(IPP)*	*(IPP)*	*(IPP)*
MoM: Ministry of Mining; Yes: Available; U/T: Under Training ; U/P: Under Procurement, N/A: Not Available; N/S: Not Sufficient; *(IPP):* Independent Power Provider					

Source：JICA Survey Team

11.4 Survey Records in Priority Geothermal Sites and Major Tasks of ODDEG

Similar to Table 11-1, Table 11-2 shows the survey records conducted in priority geothermal sites in the past, in accordance with the general process of geothermal development. This Survey conducted preliminary and general geological and geochemical surveys for all the accessible sites; consequently, the JICA Survey Team proposed the priority sites for development. While detailed geological and/or geochemical survey will be necessary in the priority sites, the major tasks in these sites will be the geophysical survey in order to investigate underground conditions.

As described earlier, CERD has already conducted the MT survey in three sites, i.e., Obock, Nord Goubet, and Lac Ahbe. The other priority sites (Arta, Hanle-Garabbayis, and Gaggade-Taassa) should be the target of MT survey. Even after the MT survey in an area of priority site, the survey area may have to be extended in the future for further exploration for well siting. Therefore, ODDEG/CERD should continuously possess those capacities, not only geological and geochemical survey but also geophysical survey.

On the other hand, the main task of ODDEG will be drilling works together with related testing and analysis such as well logging, production test, and interference test. Further, well drilling works will require not only drilling skills but knowledge and skills on various civil works. On top of these skills, reservoir resource evaluation technique is also necessary for sustainable development.

Therefore, the cooperation to ODDEG should be directed to such business model where the main tasks will be well construction together with related exploration techniques including reservoir resource evaluations.

Table 11-2 Survey Record in Priority Sites for Geothermal Development

Milestone/Tasks \ Geothermal Site	Arta	Hanle -Gaggade	Hanle -Garabbayis	Nord Goubet	Obock	Lac Abhe	Asal Fiale
1. Pre-Survey	Flash				Binary	Tourism	WB
Data collection, Inventory Nationwide Survey Selection of Promising Area EIA and Necessary Permits Planning of Exploration	☑	☑	☑	☑	☑	☑	☑
2. Exploration							
Surface (Geological)	☑	☑	☑	☑	☑	☑	☑
Geochemical	☑	☑	☑	☑	☑	☑	☑
Sounding (MT/TEM or VES)	VES	-	VES	MT	MT	MT	MT
Gradient and Slim Holes	-	-	☑	-	-	-	☑
Seismic Data Acquisition	-	-	-	-	-	-	☑
Pre-feasibility Study	-	-	-	☑	☑	☑	-
3. Test Drilling							
Slim Holes Full-size Wells Well Testing and Stimulation Interference Test	-	-	-	-	-	-	-
First Reservoir Simulation	-	-	-	-	-	-	-
4. Project Review and Planning							
Evaluation and Decision-making Feasibility Study and Final EIA Drilling Plan Design of Facilities Financial Closure/PPA/IPP	-	-	-	-	-	-	-
5. Field Development							
Production Wells Reinjection Wells Cooling Water Wells Well Stimulation	-	-	-	-	-	-	-
Reservoir Simulation	-	-	-	-	-	-	-
6. Construction							
Steam/hot Water Pipelines Power Plant and Cooling Substation and Transmission	-	-	-	-	-	-	-
7. Start up and Commissioning					-	-	
8. Operation and Maintenance					-	-	

Note: ☑:done, VES: Vertical Electric Resistivity Survey, MT: MT survey; Additional survey may be needed wherever necessary., - : not yet, WB: World Bank

Source: JICA Survey Team

11.5 Proposed Direction of Cooperation to Geothermal Development

11.5.1 General Directions for Long-term Cooperation

Based on the observations described above, Table 11-3 shows the general directions for long-term cooperation for geothermal development.

Table 11-3 General Directions for Long-Term Cooperation for Geothermal Development

Milestone	Tasks	Cooperation Items
Pre-survey	Data Collection, Inventory Nationwide Survey Selection of Promising Area EIA and Necessary Permits Planning of Exploration	· Additional technical cooperation (T/C) after this survey
Exploration	Surface (Geological and Geochemical Survey)	· Technical cooperation (T/C) · Facility procurement (Laboratory analysis equipment for geological and geochemistry analysis)
	Sounding (MT/TEM)	· T/C for site survey · T/C for 2D inversion analysis with software procurement
	Gradient and Slim Holes	· Financial cooperation for drilling · T/C for well drilling · T/C for observation and data analysis of well geology and well geochemistry · T/C for well logging test and data analysis · Procurement of well logging tools · T/C for well testing and data analysis
	Seismic Data Acquisition	· (Not necessary)
	Pre-feasibility Study	· T/C for data analysis and reporting
Test Drilling	Slim Holes Full-size Wells Well Testing and Stimulation Interference Test	· Financial cooperation for drilling · T/C for well drilling · T/C for observation and data analysis of well geology and well geochemistry · T/C for well logging test and data analysis · T/C for well testing and data analysis
	First Reservoir Simulation	· Procurement of computer software for analysis · T/C for simulation analysis
Project Review and Planning	Evaluation and Decision-making Feasibility Study and Final EIA	· T/C for F/S preparation · T/C for EIA preparation
	Drilling Plan	· T/C for plan formulation for well drilling
	Design of Facilities, Tender Process	· Loan project (E/S : Detailed design, tender process)
	Financial Closure/PPA/IPP	· T/C for policy making
Field Development (ODDEG)	Production Wells Reinjection Wells Cooling Water Wells Well Stimulation Reservoir Simulation	· Technical cooperation project · T/C for well drilling · T/C for well testing and data analysis · T/C for well logging and data analysis
Construction (Contractor)	Steam/hot Water Pipelines Power Plant and Cooling Substation and Transmission	· Loan project (E/S : Supervision) · Loan project (Construction of power plant and SAGS)
Start-up and Commissioning		· Loan project (Defect liability period)
O&M		· Follow-up by a technical cooperation project

T/C: Technical cooperation, E/S: Engineering service in a loan project, O&M: Operation and maintenance

Source: JICA Survey Team

An overall time schedule from the initial stage to the operation and maintenance stage of a 50 MW class geothermal power station is shown in Table 11-4, with an assumption that ODDEG will undertake all the production and re-injection well drilling as reference. The time schedule may be lengthened considerably if financial arrangement for test well drilling and/or for field development should not be made available on time.

Table 11-4 Overall Time Schedule for the Construction of a Geothermal Power Station (50 MW Class)

		1st	2nd	3rd	4th	5th	6th	7th	lifetime
1. Pre-Survey									
ODDEG	a. Data collection, Inventory								
ODDEG	b. Nationwise Survey								
ODDEG	c. Selection of Promsing Area								
ODDEG	d. EIA and Nessessary Permits								
ODDEG	e. Planning of Exploration								
2. Exploration									
ODDEG	a. Surface (Geological, Geochemical survey)								
ODDEG	b. Sounding (MT/TEM)								
ODDEG	c. Gradient and Slim Holes								
ODDEG	d. Seismic Data Acquisition								
ODDEG	e. Pre-feasibility Study								
3. Test Drilling									
ODDEG	a. Slim holes								
ODDEG	b. Fullsize wells								
ODDEG	c. Well Testing and stimulation								
ODDEG	d. Interference test								
ODDEG	e. First Reservior Simulation								
4. Project Review and Planing									
ODDEG	a. Evaluation and decision making								
ODDEG	b. Feasibility study and Final EIA								
ODDEG	c. Drilling Plan								
ODDEG	d. Design of Facilities								
ODDEG	f. Financial Clousure/PPA/IPP								
5. Field Development									
ODDEG	a. Production wells								
ODDEG	b. Reinjection Wells								
ODDEG	c. Cooling water wells								
ODDEG	d. Well stimulation								
ODDEG	e. Reservoir simulation								
6. Construction									
Contractor	a. Steam/hot water pipelines								
Contractor	b. Power plant and Cooling								
Contractor	c. Substation and transmission								
7.Start up and commissioning									
8.Operation and Maintenance									
		1st	2nd	3rd	4th	5th	6th	7th	lifetime

Source: ESMAP

11.5.2 Proposed Direction for an Immediate Cooperation

(1) Approach-1 Cooperation for Flash-type Development

The JICA Survey Team confirmed that the four priority geothermal sites (Hanle-Garabbayis, Nord Goubet, Arta, and Gaggade-Taassa) are the most prospective sites from the geothermal resources point of view. The JICA Survey Team considered that the four sites would be almost equally prospective although the grade of geothermal manifestations are slightly different. It is therefore a prudent approach that at least the three sites (Hanle-Garabbayis, Nord Goubet, and Arta), where accessibility are relatively good, shall be further compared after conducting the geophysical MT survey in order to determine the most promising site for costly test well drilling. Among the three sites, CERD had already conducted the MT survey in Nord Goubet; thus, the other two sites (Hanle-Garabbayis and Nord Goubet) shall be the target for the MT survey that will be conducted in the next phase. However, if the MT survey in Hanle-Garabbayis should show very good results, then the test well may be drilled in Hanle-Garabbayis. As for Gaggade Taassa, where accessibility is not so preferable, the JICA Survey Team expects that ODDEG would conduct the MT survey in the future, when necessary.

(2) Approach-2 Geothermal Energy Development in Obock

There is a possibility that a flash type power system may be developed in Obock according to the geochemical thermometer data of 197 ºC. However, no other geothermal manifestations were identified; thus, the JICA Survey Team ranked Obock at lower priority. The approach for Obock geothermal resources should depend on the purpose of the geothermal development in Obock.

(a) Considerations on the development of a flash type power system in Obock

CERD had already conducted a pre-feasibility survey including the MT survey. The JICA Survey Team is not in a position to review the report that is kept confidential, but the team was informed that no remarkable anomalies were identified by the MT survey. The MT survey from ground surface might not be capable enough to identify any anomaly that may be present near or under the sea, because the hot springs are usually under the sea level and become visible only on lowest tide during the day. For geothermal development of a flash type power generation system, more precise survey results shall be necessary, and for this reason the MT survey from the sea surface or other techniques may be required. However, experience on such surveys is limited and applicability on both technical and cost performance point of view will have to be examined. Further, should the flash type power system be connected to the national grid, the distance will also have to be considered, which is 150 km from Asal.

From the above, the JICA Survey Team considers that Obock should not be on high priority in the development of a flash type geothermal power generation system.

(b) Development of a binary-type geothermal power generation system in Obock

On the other hand, the JICA Survey Team identified that the base load demand for electricity would be 500 kW in Obock. If this base demand should be covered by geothermal power, the JICA Survey Team considered that a small-scale power station that would be constructed within a reasonable range of investment may be sufficient. In this case, a binary type geothermal power development will be worthy to consider, which may not require a large scale and costly exploration. This approach would be taken separately from the approach of flash type geothermal development.

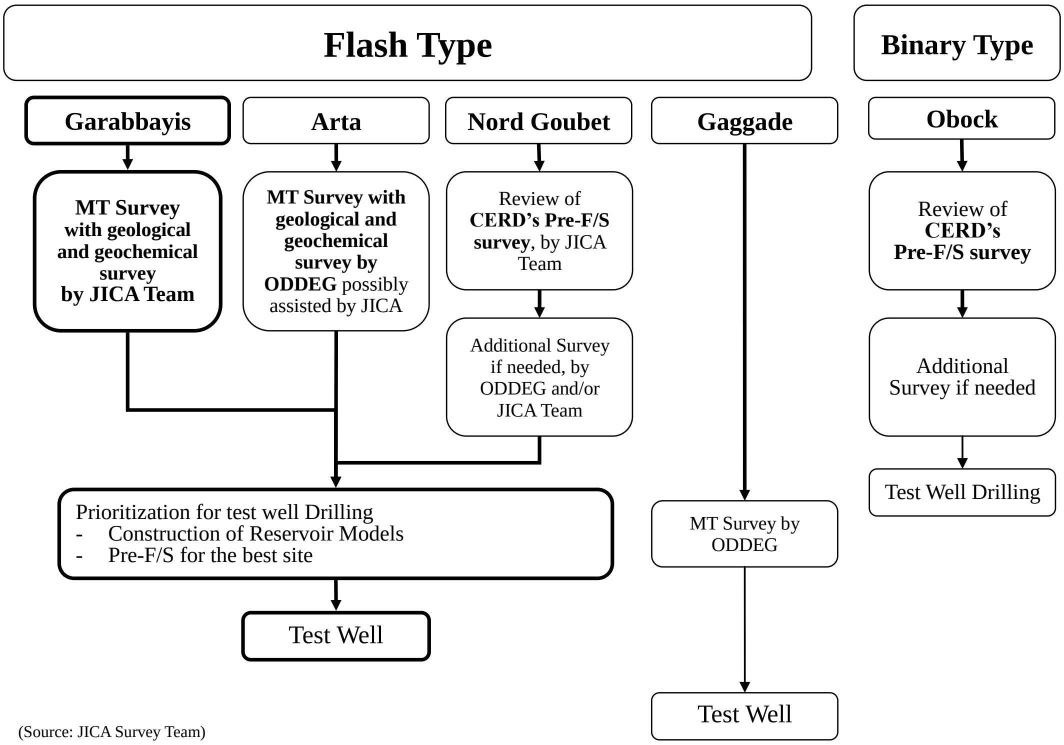


Figure 11-2 Approaches of Cooperation up to Test Well Drilling

(3) Cooperation for Flash Type Geothermal Power Generation

(a) Exploration in the first priority site - Hanle-Garabbayis

The JICA Survey Team has selected Hanle-Garabbayis site as the first priority site from the viewpoints of potential resource assessment, access condition, and others. The JICA Survey Team proposes the following survey to determine the drilling target:

- <u>Detailed Geological and Geochemical Survey</u>

The published geological map shows that there are some other fumarole points near and around the site that the JICA Survey Team visited. In the next stage of exploration, a broader area other than the one in this Survey should also be surveyed and rock samples, alteration clay samples, and/or fumarole samples should be collected wherever necessary to determine the distribution of hydrothermal alteration minerals. The proposed directions of cooperation for geological and geochemical survey were described in Section 3.3.2 (5) and (6).

- <u>Geophysical Survey (MT/TEM Survey)</u>

Geophysical survey will be conducted to investigate the geological structure and reservoir structure. The geophysical equipment of ODDEG is a model that is used in the academic fields. Most of the private consulting companies do not use this type of equipment and therefore, they may not be able to operate them effectively. For this reason, the JICA Survey Team proposes that a geophysical survey in Hanle-Garabbayis should be conducted by a Japanese team with equipment to be brought in from Japan, should a technical cooperation be considered by the Japan International Cooperation Agency (JICA).

(b) Geophysical survey in Arta and Nord Goubet

As mentioned above, the other three sites would be similarly explored as the Hanle-Garabbayis site; therefore, it would be a prudent approach that at least the three sites (i.e., Hanle-Garabbayis, Arta, and Nord Goubet) shall be compared with the results of the MT survey to finally determine the most promising site for test well drilling.

Therefore, the cooperation from Japan shall include Arta site, where no MT survey was conducted so far. If cooperation resources for full size assistance should be limited within the coming fiscal year, financial assistance may only be helpful for ODDEG to start the survey soon.

On the other hand, CERD already conducted a pre-feasibility survey in Nord Goubet. For this site, a review of the CERD study that is kept confidential at this moment should be conducted. If deemed necessary, an additional survey should be recommended in a form of either technical assistance or financial assistance as necessary.

As for Gaggade-Taassa, where relatively strong geothermal manifestations were observed, the JICA Survey Team expects that ODDEG will conduct the survey with its resources in the future, when necessary.

(c) Cooperation for the three sites (Hanle-Garabbayis, Arta, and Nord Goubet)

- <u>MT data analysis with a 2D inversion software</u>

At present, a 2D inversion software is not available in ODDEG or CERD. Cooperation shall be made to analyse the MT data from the three sites with a 2D inversion software which will be procured for technical cooperation by the Japanese experts.

In addition, recommendations for cooperation directions for geophysical exploration were discussed in Section 3.3.1 (4) and (5).

- <u>Geothermal Reservoir Modeling</u>

Based on the above survey, a preliminary geothermal reservoir model shall be constructed for the three sites. With the model to be constructed, the following works will be conducted:

- ✧ Preliminary assessment of geothermal resources; and
- ✧ Proposal for well siting and well drilling methods including the methodology of well testing and well logging.

- <u>Pre-Feasibility</u>

Based on the preliminary assessment of geothermal resources, a pre-feasibility study shall be conducted for the best recommended site.

- <u>Best season for site survey</u>

The average monthly temperatures from May to September in Djibouti exceed 30 °C and reach up to 35 °C in July. Therefore, field survey is usually conducted during the period from October to April in the next year when the average monthly temperatures are below 30 °C. Therefore, conducting the field survey in Djibouti is recommended particularly from December to February, when the average monthly temperatures are below 25 °C.

(4) Cooperation for Development of a Binary Geothermal Generation System in Obock

As mentioned above, the JICA Study Team considers that a large-scale geothermal development would not be required in Obock; instead, a small-scale geothermal power development that could provide the base load demand of 500–600 kW should be considered. The JICA Study Team recommends the following approach:

(a) Review of CERD's pre-feasibility report

The report that is kept confidential should be reviewed first.

(b) Proposal of exploration planning

The JICA Study Team proposes the following approaches:

- The MT survey from the sea surface may be necessary with a combination of an additional MT survey from the ground surface, if judged so after the review of the CERD report. Cost effectiveness shall be considered because such survey from the sea may be costly compared with the effectiveness by power generation for Obock.
- Drilling of a slim hole is recommended from the coast in order to explore temperature gradient, and availability and volume of hot water. The slim hole shall be directional towards the sea. It is confirmed that the Ministry of Agriculture possess a drilling rig capable of drilling down up to ca. 500 m. Countermeasures against hot water or blowout preventer (BOP) will be necessary.

(c) Assumption - ORC

If hot water should become available due to the drilling of rig by the Ministry of Agriculture, ORC maybe assumed for the geothermal electric power generation. In order to have a common understanding, the following information may be useful:

Table 11-5 shows a case study on the relation between hot water temperature and the power capacity that will be generated by ORC [22]. If the temperature of hot water would be 130 °C and discharge would be 720 L/min, then, 200 kW may be available. Similarly, discharge of 480 L/min may be sufficient if the hot water temperature would be 150 °C for the 200 kW power generation that is correspondent to half of the base load of Obock at present.

Table 11-5 Preliminary Information for Power Generation by ORC

Hot water temperature \ Electric power	100 kW	200 kW
130 °C	380 L/min	720 L/min
150 °C	250 L/min	480 L/min
The information above is preliminary only.		

Source：Reference [22]

(d) Issues

There will be issues arising from high salinity expected even if sufficiently high temperature and abundant discharge should be confirmed, because hot water sample shows similar salinity as seawater and that isotope analysis indicates that the hot water may be of seawater origin. The issues include the following:

- Scale problem in hot water circulation system.
- Scale problem in cooling water (sea water is assumed) system.

(5) Djibouti-Awrofoul No. 2 (A Well for Drinking Water Supply)

The well is located near PK20, which is relatively close to Djibouti City and just adjacent the existing substation. The hot water from the well indicated about 73.6 °C, and alkaline geochemical thermometer indicated 191 °C. In addition, electrical conductivity is as low as 1,400～1,080 μS/cm. Although other geothermal manifestations were not confirmed in this site, it may be worthwhile to conduct the MT/TEM survey in order to investigate the possibility of geothermal development.

EOD

CHAPTER 12 Reference

[1] Parsons Brinckerhpff Ltd (UK), “Least Cost Electricuty Master Plan, Djibouti; Final Report,” World Bank, Djibouti, November 2009.

[2] Virkir-Orkint Consulting Group Ltd., “Geothermal Scaling and Corrosion Study Final Report,” Electricite de Djibouti of the Republic of Djibouti, Reykjavik,Iceland, August 1990.

[3] AF-Mercados EMI / Axenne / Alcor, “Elaboration D'UNE STRATEGIE NATIONALE ET D'UN PLAN D'ACTION POUR LE DEVELOPPEMENT DESECTEUR ELECTRIQUE A DJIBOUT Rapport Scenarios (Version Finale),” EUEIPDF, Djibouti, Decembre 2013.

[4] Goverment of Djibouti, “VISION Djibouti 2035,” Republic of Djibouti, Djibuti, 2014.

[5] Goverment of Djibouti, “Initiative Nationale de Developpement Social 2011-2015 Cent Actions Pour Transformer Djibouti,” Goverment of Djibouti, Republic of Djibouti, 2011.

[6] Elecgtricity De Djibouti, “Elecgtricity De Djibouti (Presentation),” EdD(Elecgtricity De Djibouti), Kempinski Palace Hotel, Djibouti, 29 May 2013.

[7] Lxrichter, “Geothermal Crucial in Renewables Ambitions in Djibouti,” *Think Geoenergy,* p. http://thinkgeoenergy.com/archives/18502, May 7, 2014.

[8] D. S. Stamps, E. Calais, E. Hartnady, J.-M. Nocquet, C. J. Ebinger , R. M. Fernande, “A kinematic model for the East African Rift,” Geophysical Research Letters, Vol. 35, 2008.

[9] M. Jalludin, “State of knowledge of the geothermal provinces of the republic of Djibouti,” Short course IV on exploration for geothermal resources, UNU-GTP, GDC and KenGen, 2009.

[10] M. Jalludin, “State of Knowledge of the geothermal provinces of the Republic of Djibouti, presented at short course V on Exploration for Geothermal Resources,” Short Course V on Exploration for Geothermal Resources, UNU-GTP, GDC and KenGe, Lake Bogoria and Lake Naivasha, Kenya, 2010.

[11] E. Wolfenden, C. Ebinger, G. Yirgu, A. Deino , D. Ayalew, “Evolution of the northern Main Ethiopian rift: birth of a triple junction,” Elsevier, 2004.

[12] Y. Watanabe, “Advanced Argillic Alteration,” Earth Science (Chikyu Kagaku), Vol 52, 55-56, 1998.

[13] N. Moussa, Y. Fouquet, B. Le Gall, M. Bohn, J. Etoubleau, N. Grassineau, A. Caminiti, J. Robert , M. Jalludin, “Epithermal Au-Ag-Bi-Te mineralization in the SE Afar Rift, Republic of Djiouti,” ARGeo-C, Third east African rift geothermal conference, Djibouti, 2010.

[14] M. Jalludin, “State of knowledge of the geothermal provinces of the republic of Djibouti,”

Short Course VI on Exploration for Geothermal Resources, UNU-GTP, GDC and KenGen, 2011.

[15] BRGM, I'ORSTOM, “CARTE GEOLOGIQUE DE LA REPUBLIQUE DE DJIBOUTI AU 1/100 000; DORRA, DIKHIL, ALI SABIH, TADJOURA, DIBOUTI,” BRGM, I'ORSTOM, PARIS, 1995, 1987, 1986, 1985, 1983.

[16] W. F. Giggenbach, “Geothermal solute equilibrium, Derivation of the Na-K-Mg Geoindicators,,” Geochimca et Cosmochimica. Acta, 52, 2749-2765, 1988.

[17] J. Hoefs, “NEW Stable Isotope Geochemistry,” Springer, London, 1996.

[18] B. Houssein, “Geochemistry overview of hot spring from the lake Sbbe area: Republic of Djibouti,” ARGEO-C3, Third East Africa Rift Geothermal Conference, Djibouti, 2010.

[19] F. D'Amore, D. Giusi , A. Abdallah, “Geochemistry of the high-salinity geothermal field of Asal, Republic of Djibouti, Africa,” Geothermics, Volume 27, Issue 2, pp.197-210, London, 1998.

[20] John Featherstone, Steven Butler, and Bnos Bonham, “Comparison of crystallizer reactor clarifier and pH MOD process technologies used at the Salton Sea geothermal field,” Geothermal energy organization, IGA standard, WGC, Magma Operating Company, Calipatria, Ca, 1995.

[21] Energy Sectore Management Assistance Program, World Bank, “Geothermal handbook: Planning and Financing Power Generation,” International Bank for Reconstruction and Development, Washington, USA, 2012.

[22] Engineering Advncement Association of Japan, “Study on Small Scale Geothermal Power Generation and Cascade Use of Geothermal Energy (in Japanese),” Japan Oil Gas and Metals Nationla Corporation, Tokyo, Japan, 2013.

Attachment-1

Minutes

Meeting with ODDEG

Date: 2014/5/12　11：00～

Place: ODDEG's Meeting Room

Participants: ODDEG: Mr. Hamoud Souleiman Cheikh,

Mr.Mahdi Robleh,

Mr. Habib

MEMR: Mr.Haga

JICA Survey Team: Takahashi, Yamamoto, Watanabe, Hiura, Fukuda, Yoshida

Overview:

JICA Survey team:

Thanks to support the customs clearance of equipment.

ODDEG:

ODDEG conducted a preliminary survey through April 28 to May 2. Site conditions were as follows.

- Lake Abhe: Geothermal manifestations have been identified in two points. But one site is difficult to access. In addition, because there is a place where people and cars is stuck in sand in the field, you need to hire a local guide.
- Hanle: Fumarole site is about 300m on foot from the car accessible point. In the past there was a gold mine.
- Gaggade: Geothermal Manifestations has been identified in four places. Among them, two places are particularly important. Among two places, one place need to walk about 200m, another place needs to walk about 2 hours (Since very strict, there is a need to carry 5L water for one person). Native sulfur was confirmed in the vicinity.
- Nord Gobet: About 2 hours on foot.
- Sakalol: There were many hot springs. Escort of military personnel will be required to survey. In addition, the distance of the foot is long, necessary to carry 5L water for one person. Government camp is in the Balho town (near Sakalol). But, there is a need to bring a cot because there is no bed in the government camp.
- N.Lake Abhe: We could not be accessed. However, CERD has been reached in the past.
- Obock and Ruweri: Hot spring is in gthe seabed usually. It can be seen only at low tide.

It is expected that ODDEG's 2 person and CERD's 2 person will accompany the survey.

Hotel reservation is almost finished.

Since daytime temperature is 40ºC or more, it is better to finish the survey until 11AM as possible

We will share with JICA Survey Team about the location information of geothermal manifestations. The coordinate system can be unified in WGS84 (38P).

JICA Survey team:

Thanks for providing valuable information and practice of preliminary investigation.

EOD

Meeting with CERD

Date：2014/5/14　10：00～

Place：CERD Meeting Room

Participants：　CERD : Dr Jalludine Mohamed (Director General),

Dr. Mohamed Osman Awaleh (Chief of Geochemical Section),

Dr. Abdi (Staff of the Geochemical Section)

JICA Survey Team: Takahashi, Yamamoto, Watanabe, Hiura, Fukuda, Yoshida

Overview:

JICA Survey Team:

Mr. Takahashi has explaining an outline of the project.

CERD:

From CERD, two geochemical experts accompany the site survey. It is assumed to be a very severe survey. Please be careful health management, safety management.

JICA Survey Team:

In order to consider the cooperation of the future, we want to interview geophysical staff about the ability of CERD's geophysical survey.

CERD:

Yes, understand.

JICA Survey Team:

Deionized water is required to fumarolic gas sampling. We would like you to provide it.

CERD:

Yes, understand. You can buy pure water with pure water manufacturing company named Kubec (Coca Cola factory). If you can carry the pure water to CERD, it is possible to provide it purifies again by ion exchange.

JICA Survey Team:

Understand.

EOD

Meeting with ONEAD (National Office for Water and Sanitation in Djibouti)

Date: 2014/5/24　7：30～

Date: ONEAD's Meeting Room

Participants: ONEAD - Mr.Marc (Technical Sales Manager)

Mr.Nachoial Ahmed (Reseach Manager)

JET - Takahashi, Yamamoto, Watanabe, Hiura, Fukuda, Yoshida

Overview:

JICA Survey Team:

As part of geothermal manifestation survey around the Djibouti city, if possible, we would like to obtain the following information about your wells.

- Well name
- Well location
- Measured depth
- Water usage volume flow rate
- Chemical data
- Screen depth
- Pumping test data
- Data of location (coordination)
- Geological log
- Logging data

ONEAD:

It is difficult to reply immediately. We will reply by e-mail.

JICA Survey Team:

Thank you for cooperation.

EOD

Data Collection Survey on Geothermal Development in Djibouti
Minutes of meeting

Meeting with:

Department of Environment, Ministry of Home, Urbanism, Environment and Land Planning
Mr. Idriss ISMAEL, Dupty Director of the Environment

Date: 2014/6/17　8：00～

Place: Department of Environment Meeting Room

Participants: Mr. Hamoud Souleiman Cheikh (ODDEG), Mr. Idriss ISMAEL (Dupty Director of the Environment), Yamamoto and Fukuda（JET）

Overview:

- Nine protected area has been specified. Among them, seven areas are specified by Law No. 45/AN/04/5ème L. Also, two areas (Ali Sabieh and Arta) have been added by Decree 2011-0236 / PR / MHUE of 2011. At a later date, these law and decree has sent from the Department of Environment.
- Boundaries of the protected area are underdeveloped. However, for each protected area considering the Zoning (National Park, Reserve etc). When the promoter has plans to develop the pretected area, they should ask first Department of Environment about the possibility.
- As of 2014, EIA is carried out in compliance with Decree 2011-029/PR/MHUEAT that has been revised in 2011.
- There are two EIA types (Simple and Detail). Detail EIA is required for geothermal development and well drilling. Also, when you drill a well of about 170m in rural areas, EIA is required.
- Process of EIA is as follows. 1) TOR is submitted to Department of Environment. 2) Department of Environment is reviewing the contents of TOR, and issues a comment and approval within 30 days 3) EIA study is carried out, and Report is submitted to Department of Environment. 4) Department of Environment will review the contents of the report in about three months, and perform the approval procedures of business.
- If the amount of TOR is small, be approved in less than 30 days. Also, if the contents can't understand, consultants convened, and do a description of TOR.
- There is no consulting company that has the ability to conduct the EIA survey in Djibouti. However, there are few experts under the supervision of an EIA consultant from another donor that have expertise in the EIA survey.

- EIA of Asal geothermal development has been conducted by Fisnner (German company). Report sould be able to download via Internet.
- The environmental standard is not settled in Djibouti. World environmental standards such as WHO, or environmental standards of other developed countries has been adapted to the EIA study.
- Resettlement and public reactions for the project to the residents are described in Decree 2011-029/PR/MHUEAT.
- Example of compensation: For transmission lines between Djibouti (PK12) to Ethiopia (Dirudara), it has been considered as the subject of compensation for each house and tree.
- EIA guidelines are currently under development.

Collected Documents (Sent from Department of Environment):

1. COMMUNICATION NATIONALE INITIALE DE LA REPUBLIQUE DE DJIBOUTI; A LA CONVENTION CADRE DES NATIONS UNIES SUR LES CHANGEMENTS CLIMATIQUES
2. Monographie Nationale de la Diversité Biologique de Djibouti
3. Plan d'action d'adaptation aux changements climatiques
4. Plan d'ActionNational pourl'Environnement 2001-2010
5. Plan de Gestion Integree de la Zone Cotiere de Djibouti
6. SECONDE COMMUNICATION NATIONALE DE LA REPUBLIQUE DE DJIBOUTI A LA CONVENTION CADRE DES NATIONS UNIES SUR LES CHANGEMENTS CLIMATIQUES
7. STRATÉGIE ET PROGRAMME D'ACTION NATIONAL POUR LA DIVERSITÉ BIOLOGIQUESECONDE COMMUNICATION NATIONALE DE LA REPUBLIQUE DE DJIBOUTI; A LA CONVENTION CADRE DES NATIONS UNIES SUR LES CHANGEMENTS CLIMATIQUES
8. Loi n°51/AN/09/6ème L portant Code de l'Environnement.
9. Loi n°45/AN/04/5ème L
10. Décret n°2011-0236/PR/MHUE portant création de deux aires protégées terrestres.
11. Profil Cotier de la Republique de Djibouti
12. Décret n°2004-0065/PR/MHUEAT Portant protection de la biodiversite
13. Décret n°2011-0029/PR/MHUEAT

EOD

Attachment-2

List of Collected Documents

No.	Field	Title of Collected Data/ Information	Type	Size	En/Fr/Jn	Original/ Copied	Collected from/ Published by	Donated/Purchased (Price)	note
1	Geothermal	Least Cost Electricity Master Plan, Djibouti	PDF	A4	Eng	Copied	World Bank	Donated	
2	Geothermal	Data Collection Survey on Present Conditions of Geothermal Development in Africa	PDF	A4	Eng	Copied	JICA	Donated	
3	Geothermal	Diboouti Geothermal Scaling and Corrosion Study Final Report	PDF	A4	Eng	Copied	Virkir-Orkint Consulting Group Ltd. /Reykjavik Energy Invest	Donated	
4	Geothermal	Situation analysais study on geothermal development in Africa	PDF	A4	Jp	Copied	JICA	Donated	
5	Geothermal	Geothermal Exploration Project Hanle-Gaggade	PDF	A4	Eng	Copied	Aquater	Donated	
6	Geothermal	Djibouti Geothermal exploration project Draft final report	PDF	A4	Eng	Copied	Aquater	Donated	
7	Geothermal	The Asal geothermal field, Djibouti, Geophysical surface exploration 2007-2008	PDF	A4	Eng	Copied	Reykjavik Energy Invest	Donated	
8	Geothermal	A revised approach to the hanle - Gaggade (Djibouti Republic): the Garabbayis geothermal site	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
9	Geothermal	Proposal for new geothermal models and sites hierarchy in Djibouti Republic	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
10	Geothermal	Geothermical patterns of scale deposition in saline high temperature geothermal systems	PDF	A4	Eng	Copied	H.Armannsson and V.Hardardottir, Reykjavik	Donated	
11	Geothermal	Geochemistry overview of hot spring from the lake Abhr area: republic of Djibouti	PDF	A4	Eng	Copied	Bouh Houssein, CERD	Donated	
12	Geothermal	The Manda-Inakir geothermal prospect area, Djibouti Republic	PDF	A4	Eng	Copied	Abdourahman Omar Haga and others, Ministry of Energy, Water and Natural Resources	Donated	
13	Geothermal	Nord-Ghoubbet geothermal site, Djibouti Republic	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
14	Geothermal	The Obock and Roueli geothermal sites, Djibouti Republic	PDF	A4	Eng	Copied	Abdourahman Omar Haga and others, Ministry of Energy, Water and Natural Resources	Donated	
15	Geothermal	The Asal geothermal field, Djibouti Republic (model update 2012)	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
16	Geothermal	Nord-Ghoubbet geothermal site, Djibouti Republic	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
17	Geothermal	The Obock and Roueli geothermal sites, Djibouti Republic	PDF	A4	Eng	Copied	Abdourahman Omar Haga and others, Ministry of Energy, Water and Natural Resources	Donated	
18	Geothermal	Proposal for new geothermal models and sites hierarchy in Djibouti Republic	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
19	Geothermal	The Asal geothermal field, Djibouti Republic (model update 2012)	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
20	Geothermal	The Manda-Inakir geothermal prospect area, Djibouti Republic	PDF	A4	Eng	Copied	Abdourahman Omar Haga and others, Ministry of Energy, Water and Natural Resources	Donated	
21	Geothermal	State of knowledge of the geothermal provinces of the republic of Djibouti	PDF	A4	Eng	Copied	Mohamed Jalludin, CERD	Donated	
22	Geothermal	The Asal geothermal field, Djibouti Republic (model update 2012)	PDF	A4	Eng	Copied	Abdou Mohamed Houmed and others, Ministry of Energy, Water and Natural Resources	Donated	
23	Geothermal	A Proto-Volcanic Margin along the Asal Rift,. The Makarassou Fault System, Djibouti	PDF	A4	Eng	Copied	Bernard Le Gall, Mohamed A. Daoud and Joel Rolet	Donated	
24	Geothermal	Activities volcaniques et geothermiques en republique de djibouti revelees	PDF	A4	Fr	Copied	Kassim Mohamed Kassim, CERD	Donated	
25	Geothermal	Analysis of geothermal well test data from the Asal Rift area, Republic of Djibouti	PDF	A4	Eng	Copied	Deher Elmi, CERD	Donated	
26	Geothermal	Appraisal of geostatistcal methods to estimate hydraulic properties of a complex basaltic reservoir. The gulf basaltic aquifer, Djibouti, Horn of Africa	PDF	A4	Eng	Copied	Mohamed Jalludin and Mountaz Razack, CERD	Donated	
27	Geothermal	Djibouti Potential Status and Prospectives in Geothermal Resources Development	PDF	A4	Eng	Copied	Farah Ali Ainan	Donated	
28	Geothermal	Electricity and freshwater macro-project in the ARID African landscape of Djibouti	PDF	A4	Eng	Copied	Radu D. Rugescu	Donated	
29	Geothermal	Epithermal Au-Ag-Bi-Te mineralization in the SE AFAR RIFT, Republic of Djibouti	PDF	A4	Eng	Copied	Moussa, N and others	Donated	

30	Geothermal	Geothermal Development in Djibouti Republic: A Country Report	PDF	A4	Eng	Copied	Aboulkader Khaireh and Fouad Aye, Ministry of Energy, Water and Natural Resources	Donated	
31	Geothermal	Geothermal Development in the Assal Area, Djibouti	PDF	A4	Eng	Copied	Gunnar Hjartarson and others, Reykjavik Energy Invest	Donated	
32	Geothermal	Geothermal Energy Development of L.Abbe and CDM for Djibouti	PDF	A4	Eng	Copied	D Chandrasekharam and Varun Chandrasekhar, Indian Institute of technology Nobbay	Donated	
33	Geothermal	Geothermal Exploration Advancement in Djibouti	PDF	A4	Eng	Copied	Mohamed Jalludin, CERD	Donated	
34	Geothermal	Geothermal Exploration by TEM-Soundings in the central Asal rift in Djibouti, East Africa	PDF	A4	Eng	Copied	Knutur Arnason and Otaffur G Flovens, Reykjavik	Donated	
35	Geothermal	Geothermal prospects in the Djibouti republic	PDF	A4	Eng	Copied	Abdou Mohamed Houmed, University of Auckland	Donated	
36	Geothermal	Geothermal Resource Assessment of Asal Field, republic of Djibouti	PDF	A4	Eng	Copied	Daher Elmi Houssein, CERD	Donated	
37	Geothermal	Pilot Project for Energy and Mining Economic Benefication from Assal (Djibouti) Geothermal and Mineral resources	PDF	A4	Eng	Copied	Abdi Farah Chideh, Ministry of Engineer, Ministry of Energy, Water and Natural Resources	Donated	
38	Geothermal	Republic of Djibouti - Country Report	PDF	A4	Eng	Copied	Isleifur Jonsson	Donated	
39	Geothermal	State of knowledge of the geothermal provinces of the republic of Djibouti	PDF	A4	Eng	Copied	Mohamed Jalludin, CERD	Donated	
40	Geothermal	Study of the effect of several wellbore conditions on the output characteristics of wells at the asal field, republic of Djibouti	PDF	A4	Eng	Copied	Battistelli, A. and others, Aquater S.P.A.	Donated	
41	Geothermal	The Asal geothermal field (Republic of Djibouti)	PDF	A4	Eng	Copied	H.Correia and others, B.R.G.M-Energy Division, France	Donated	
42	Geothermal	Use of a new sodium/Lithium (Na/Li) geothermometric relationship for high-temperature (HT) geothermal fluids derived from seawater/basalt interaction processes: Application to the Djibouti case	PDF	A4	Eng	Copied	Bernard Sanjuan, B.R.G.M-Energy Division, France	Donated	
43	Geothermal	Volumetaric resource assessment of Asal geothermal field, Republic of Djibouti	PDF	A4	Eng	Copied	Daher Elmi Houssein, CERD	Donated	
44	Geothermal	Young rift kinematics in the Tadjoura rift, western gulf of Aden, Republic of Djibouti	PDF	A4	Eng	Copied	Mohamed A. Daoud and others	Donated	
45	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Ali Sabih	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
46	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Dadda'to	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
47	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Dikhil	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
48	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Djibouti	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
49	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Dorra	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
50	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Doumera	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
51	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Gamarri	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
52	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Khor Angar	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
53	Geology	Carte Geologique_De La Republique de Djibouti a 1:100000 Tajoura	Paper,PDF		Fr	Original	BRGM	Purchased(3000FDJ)	大判地質図のみPDF化
54		Carte des Bassins Versants Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
55		Carte des Categories des Cultures Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
56	Hydrology	Debit Annuel des Aquifferes (m3/an) Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
57		Qualite des eaux Southeeaines Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
58	Hydrology	Carte des Evaporations Reeles	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
59	Hydrology	Carte des Evapotranspirations Potentielles en RDD	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	

60		Carte de la Geologie Simplifiee de la Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
61		Carte de la Densite des Populations Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
62		Carte de la Vegetation Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
63	Hydrology	Pluie Moyenne Annuelle (mm/an) Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
64		Carte de Reconnaissance des Eaux Souterraines de la Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
65		Carte des Sols Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
66		Carte des Sources et Fumerolles Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
67		Systemes Aquiferes Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
68		Cartes Thematiques de la Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
69		Carte Topographique Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
70		Carte de la Cote Francaise des Somalis au 1/100000 Territoire Francais des Afars et des Issas Assal	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
71		Carte de la Cote Francaise des Somalis au 1/100000 Territoire Francais des Afars et des Issas Abhe bad	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
72		Zones Physiographiques Republique de Djibouti	Paper,PDF		Fr	Original	CERD	Purchased(3000FDJ)	
73	Geothermal	Ressources Geothermiques Etudes Effectuees par Aquater 1980-1982	PDF	A4	Fr	Copied	Aquater	Donated	
74	Geothermal	Updating of field data from Assal 3 and Assal 4 wells	PDF	A4	Eng	Copied	Aquater	Donated	
75	Geothermal	Camp Geothermique D'Asal Djibouti	PDF	A4	Fr	Copied	ISERST	Donated	
76	Geothermal	Etude du potentiel geothermique zone D'Arta	PDF	A4	Fr	Copied	Geothermica Itariana	Donated	
77	Geothermal	Projet Pour L'Evaluation des Ressources Geothermiques (Aquater,1981)	PDF	A4	Fr	Copied	Aquater	Donated	
78	Geothermal	Aide Memoire Preliminaire Banque Mondiale Projet de Development de la Geothermie	PDF	A4	Fr	Copied	ISERST	Donated	
79	Geothermal	Geothermal Scaling Corrosion	PDF	A4	Eng	Copied		Donated	
80	Geothermal	Geothermie	PDF	A4	Fr	Copied		Donated	
81	Geothermal	Rapport A L'attention de la Commission Marche Propose par EDD-ISERST	PDF	A4	Fr	Copied	ISERST	Donated	
82	Geothermal	Rapport D'activites De la Geothermie	PDF	A4	Fr	Copied	ISERST	Donated	
83	Geothermal	Rapport D'evaluation sur L'appel D'offre	PDF	A4	Fr	Copied	ISERST	Donated	
84	Geothermal	Scaling Study Adresses of Companies	PDF	A4	Eng	Copied	EdD	Donated	
85	Geothermal	Etude du Ptentiel Geothermique Zone D'Arta Phase de Prefaisabilite Rapport de Synthese	PDF	A4	Fr	Copied	Geothermica Itariana	Donated	
86	Geothermal	Projet d'evaluation des Ressources geothermiques	PDF	A4	Fr	Copied	Etude d'Impact Environmental et Sociel	Donated	
87	Geothermal	Interpretation of Gradient Wells Data - Hanle Plain	PDF	A4	Eng	Copied	Geothermica Itariana	Donated	
88	Geothermal	Assal 3 Drilling Program	PDF	A4	Eng	Copied	Aquater	Donated	
89	Geothermal	Assal 3 Geological Program	PDF	A4	Eng	Copied	Aquater	Donated	

90	Geothermal	Assal 3 Geological Program (Shyntesis)	PDF	A4	Eng	Copied	Aquater	Donated	
91	Geothermal	Assal 3 Updating of Testing Program	PDF	A4	Eng	Copied	Aquater	Donated	
92	Geothermal	Assal 4 Well Drilling Program	PDF	A4	Eng	Copied	Aquater	Donated	
93	Geothermal	Assal 4 Well Report	PDF	A4	Eng	Copied	Aquater	Donated	
94	Geothermal	Assal 5 Well Drilling Program	PDF	A4	Eng	Copied	Aquater	Donated	
95	Geothermal	Assal 5 Well Geological Program	PDF	A4	Eng	Copied	Aquater	Donated	
96	Geothermal	Assal 5 Well Report	PDF	A4	Eng	Copied	Aquater	Donated	
97	Geothermal	Assal 6 Well Report	PDF	A4	Eng	Copied	Aquater	Donated	
98	Geothermal	Hanle 1 Well Drilling Program	PDF	A4	Eng	Copied	Aquater	Donated	
99	Geothermal	Hanle 1 Well Drilling Program	PDF	A4	Eng	Copied	Aquater	Donated	
100	Geothermal	Hanle 2 Well Report	PDF	A4	Eng	Copied	Aquater	Donated	
101	Geothermal	Borehole geology of well Asal-5, Asal Geothermal field, Djibouti	PDF	A4	Eng	Copied	Ali Elmi Khaireh	Donated	
102	Geothermal	Geothermal deep exploration in Djibouti: Stratigraphy authigenic mineral assemblage and temperature data of the drilled wells. Structural data from the Asal rift.	PDF	A4	Eng	Copied	Giovanni Gianelli, Pietro Passerini, Carlo Troisi, Leonardo Zan	Donated	
103	Geothermal	Drilling and Testing of Geothermal Exploration wells in the Assal Area, Djibouti -Environmental Management Plan-	PDF	A4	Eng	Copied	Reykjavik Energy Invest	Donated	
104	Geothermal	Draft final report (Hanle, Asal)	PDF	A4	Eng	Copied	Aquater	Donated	
105	Geothermal	TENDER for Provision of Geothermal Well Drilling Services at assal Geothermal Field Djibouti	PDF	A4	Eng	Copied	Assal Geothermal Power	Donated	
106	Geothermal	Water rock interaction between basalt and high salinity fluids in the asal refit	PDF	A4	Eng	Copied	Fouillac, A. M., Fouillac, C., Cesbron, F., Legendre, O. (BRGM)	Donated	
107	Geothermal	Analysis of geothermal well test data from the asal rift area, republic of Djibouti	PDF	A4	Eng	Copied	Daher Elmi	Donated	
108	Geothermal	Geothermal Scaling and Corrosion Study Final report	PDF	A4	Eng	Copied	Virkir-Orkint Consulting Group Ltd.	Donated	

Atacchment-3
Photographs

Arta and Asal

Sampling Location (Arta)

Fumarolic Gas Sampling (Arta)

After Survey (Arta)

Distant View of Fumarole Site(Arta)

Funarolic Gas Sampling (Fiale)

Distant View of Sampling Site(Asal Fiale)

Sampling Site (Asal Korili)

Lac Asal

Hanle and Djibouti

Fumarole and Old Well (Hanle - Garabbayis)

Fumarolic Gas Sampling (Hanle - Garabbayis)

Old Well (Hanle – Garabbayis)

Hanle Plain

Distant View of Hot Spring Area (Hanle -

Hot Spring (Hanle Agna)

Awrofoul No.2 Well (Djibouti)

Awrofoul No.6 Well (Djibouti)

Gagade and Lac Abhe

Alteration Area (Gaggade)

Fumarole Area (Gaggade)

Fumarole Point (Gaggade)

Fumarokic Gas Sampling (Gaggade)

Travertine (Lac Abhe)

Hot Spling (Lac Abhe – SP2)

Big Travertine (Lac Abhe)

Sampling of Lake Water (Lac Abhe)

Nord Goubet, Obock and Rouweli

	
Gas Sampling (Nord Goubet - Anaale)	Tower for Extracting Water from Steam (Nord
	
On Survey (Nord Goubet)	Arternation Area Around Fumarole (Nord Goubet -
	
Hot Spring Sampling (Obock)	Sampling Site (Obock)
	
Hot Spring Sampling (Rouweli)	Sampling Site (Rouweli)

Sakalol_etc

	
Salt Plain (Sakalol)	Hot Spring (Sakalol - Asbou-Dara)
	
Distant View of Hot Spring (Sakalol - Asbou-Dara)	After Survey (Sakalol - Asbou-Dara)
	
Delivery of Equipments	ODDEG's New Office (Under Construction)
	
CERD's Office	Survey Team

CERD保有機材

CERD’s MT Receiver ADU-07e


CERD’s MT Survey Equipment Non-polarizable


CERD’s MT Survey Equipment Magnetic Induction Coil


CERD’s TDEM Survey Equipment Terra TEM

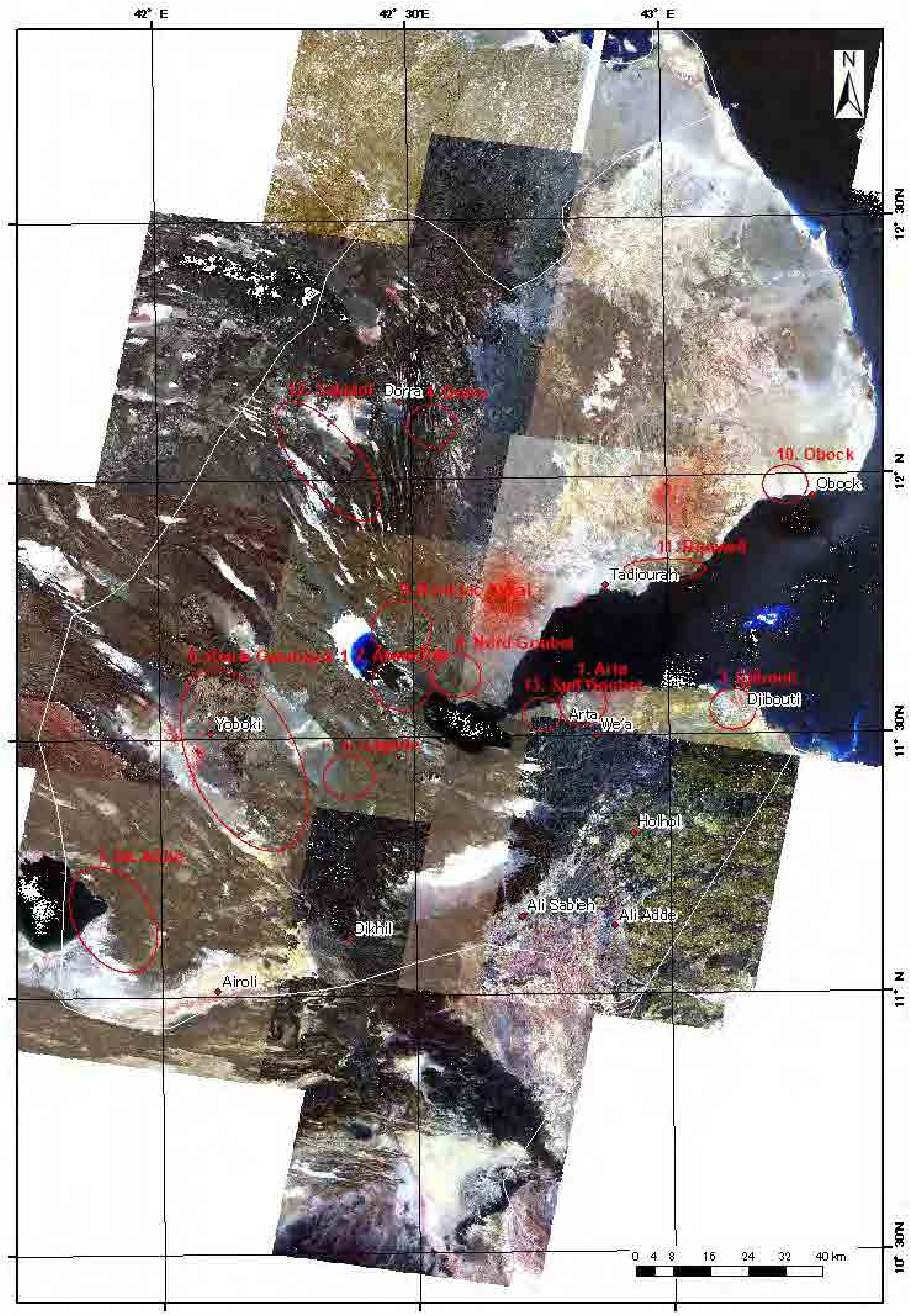
CERD’s Gravity Survey Equipment CG-5 Autograv


CERD’s Equipment Storage (in Djibouti City)


CERD's Geochemical Equipment GC-MS

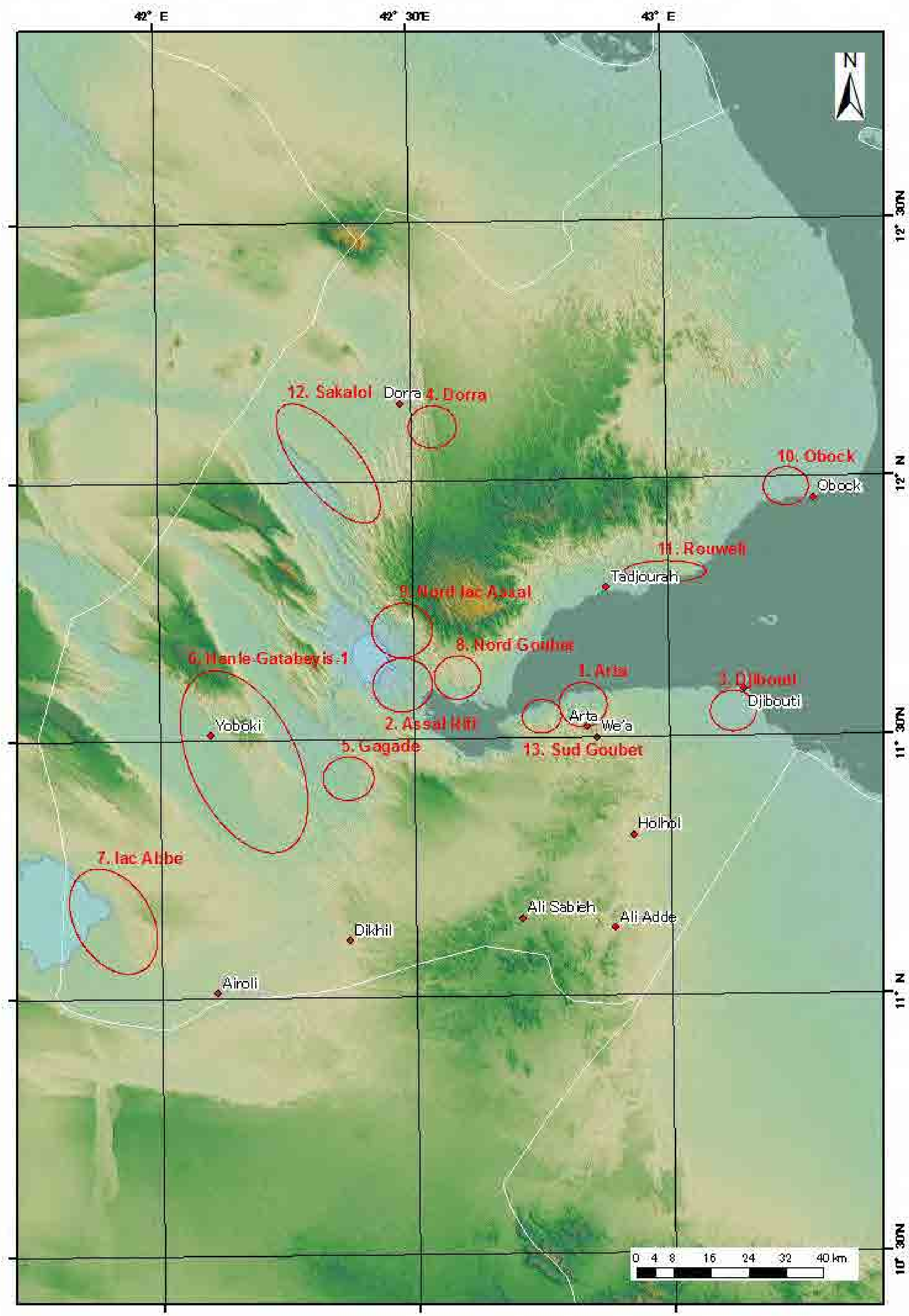

CERD's Geochemical Equipment AAS-Flame

Attachment－4
Satellite Data Analysis Results



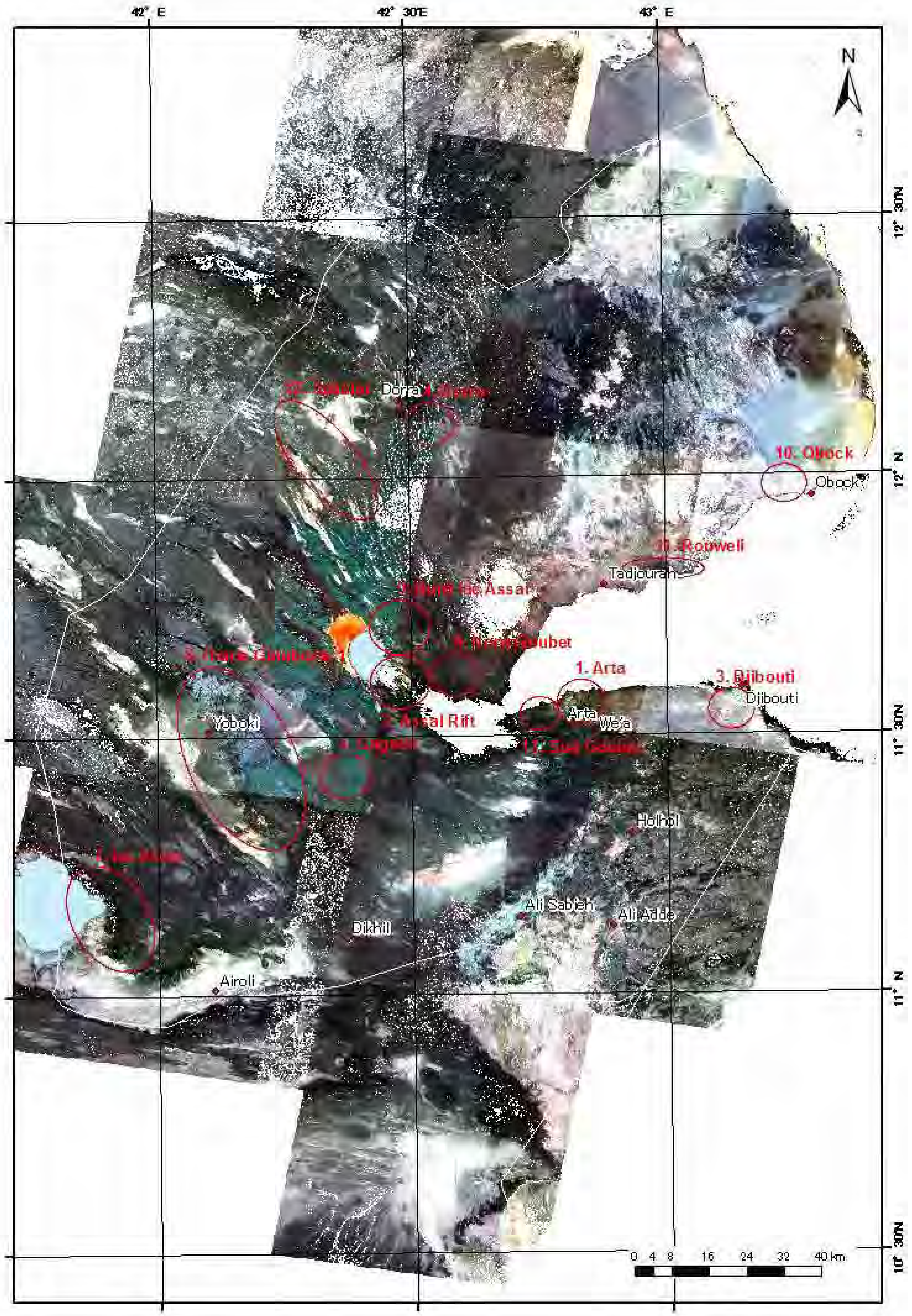
Source : JICA Survey Team

Geothermal potential sites on ASTER band composite image (RGB=B3,B2,B1)



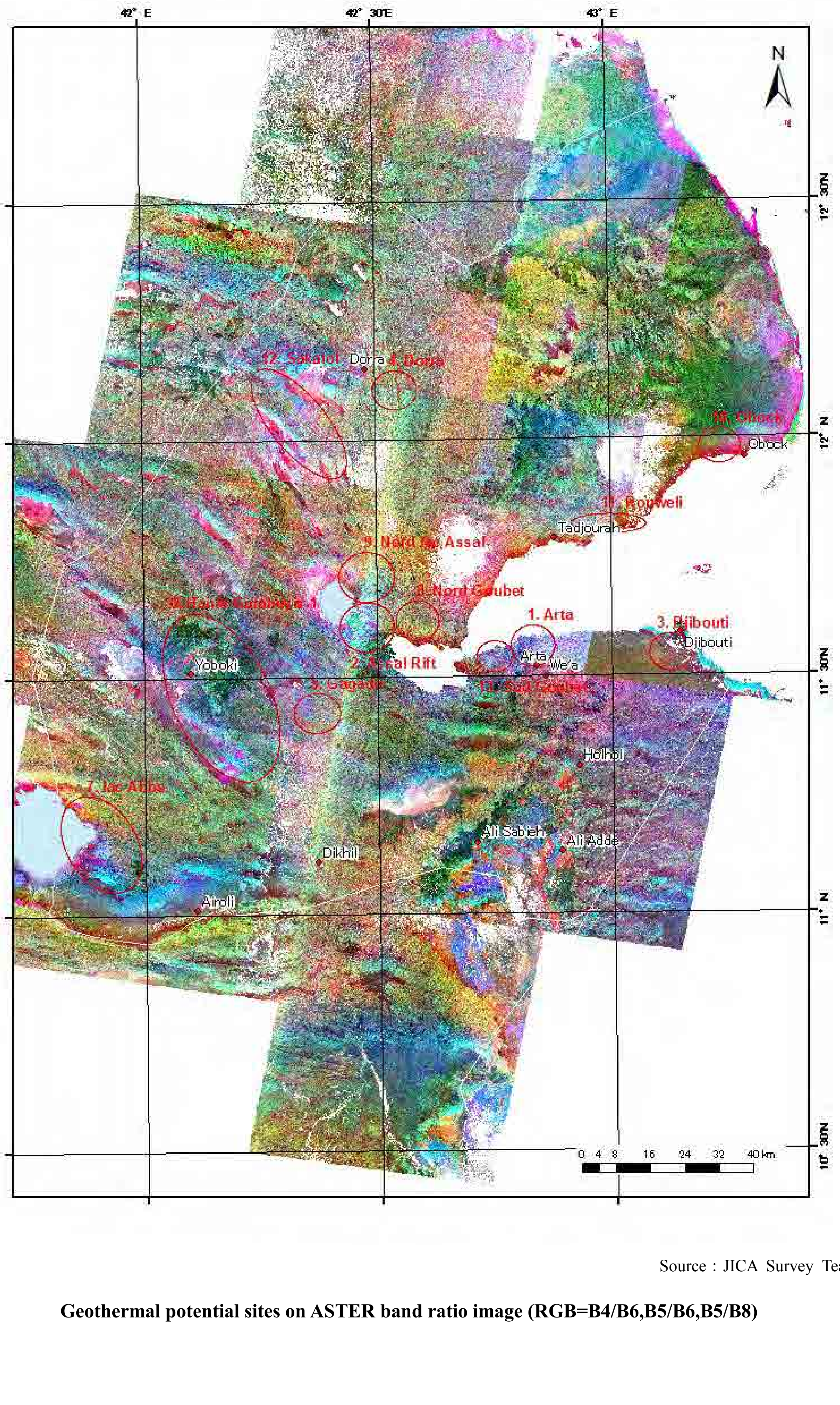
Source : JICA Survey Team

Geothermal potential sites on ASTER DEM image



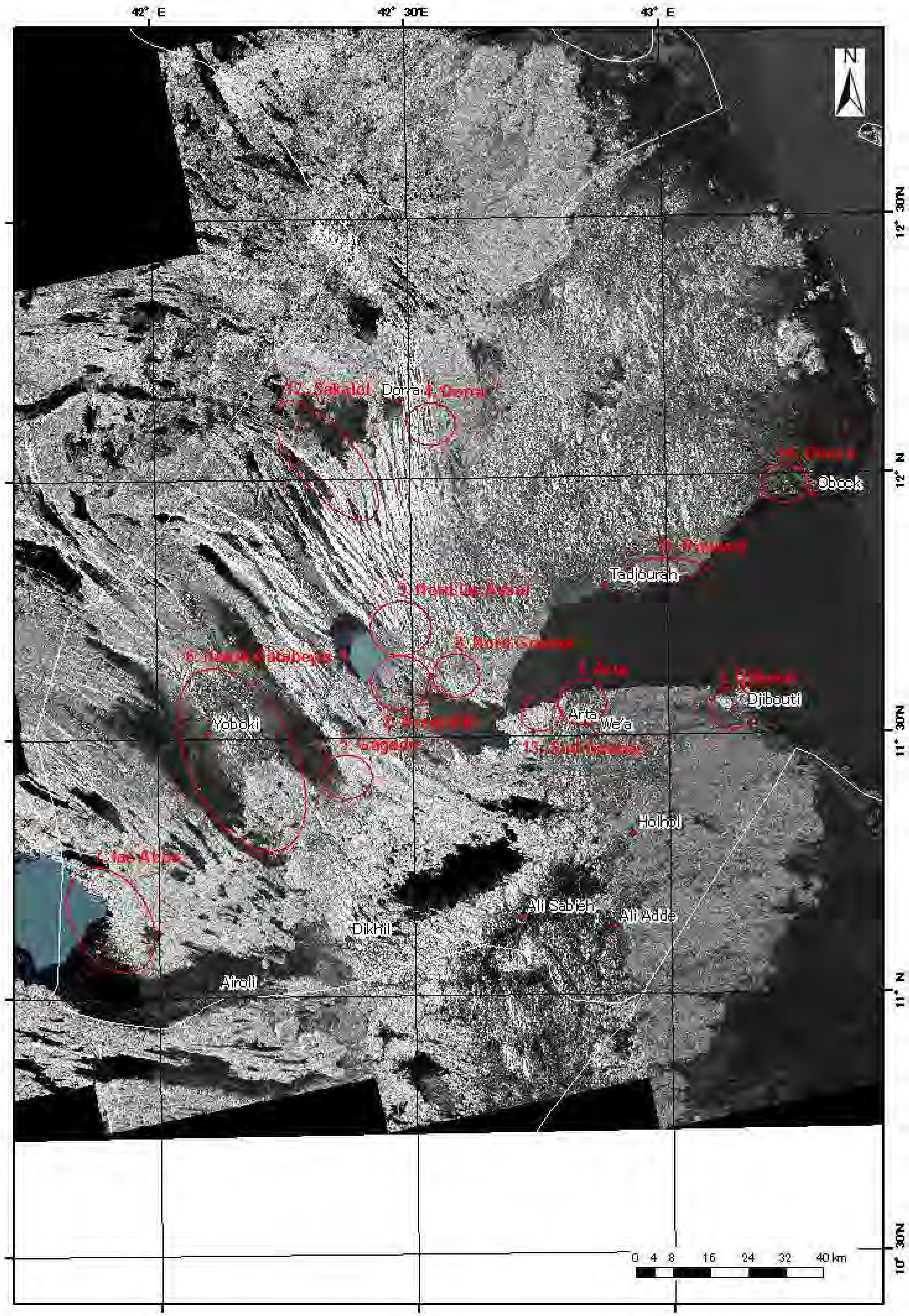
Source : JICA Survey Team

Geothermal potential sites on ASTER band composite image (RGB=B4,B6,B8)



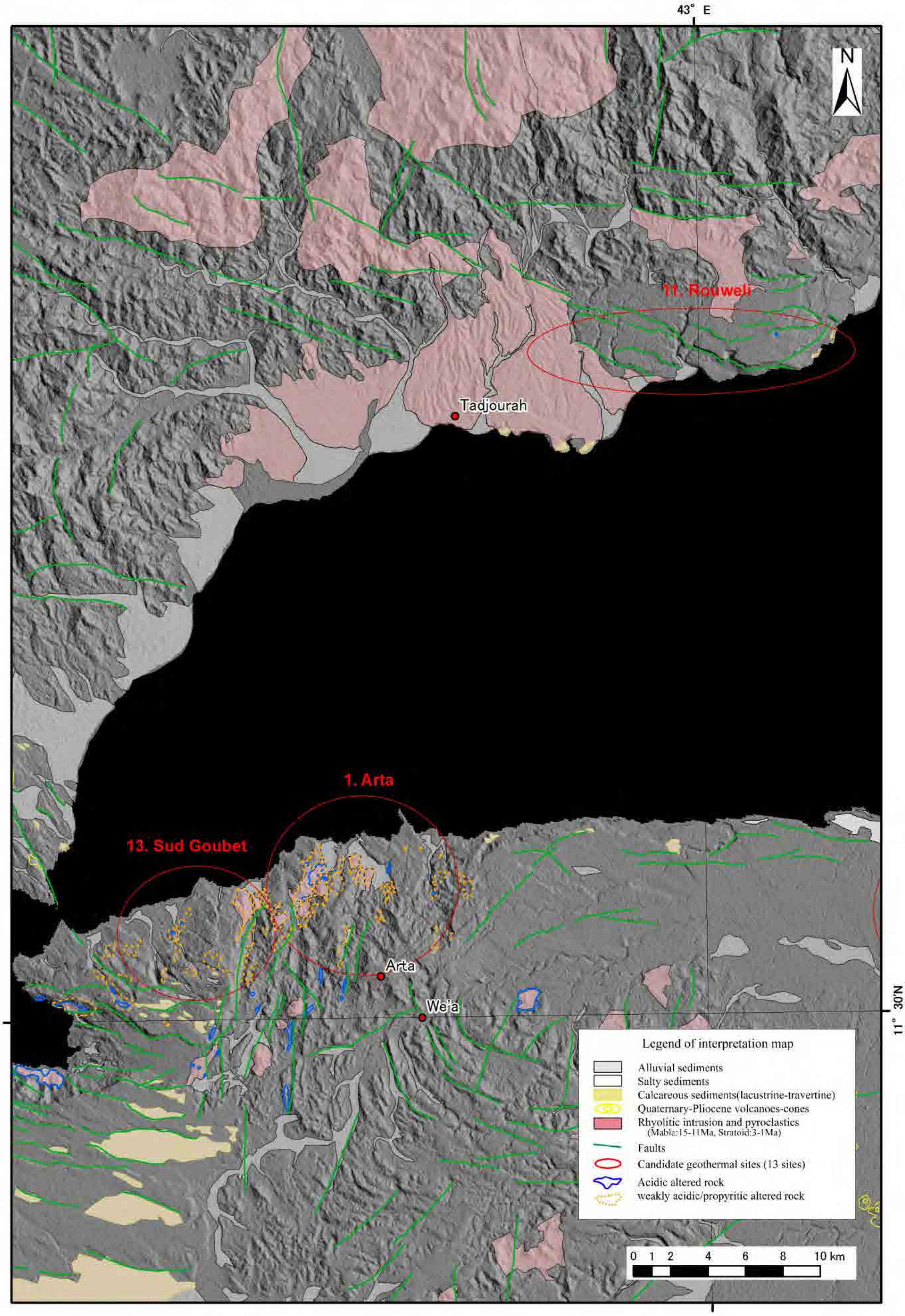
Source : JICA Survey Team

Geothermal potential sites on ASTER band ratio image (RGB=B4/B6,B5/B6,B5/B8)



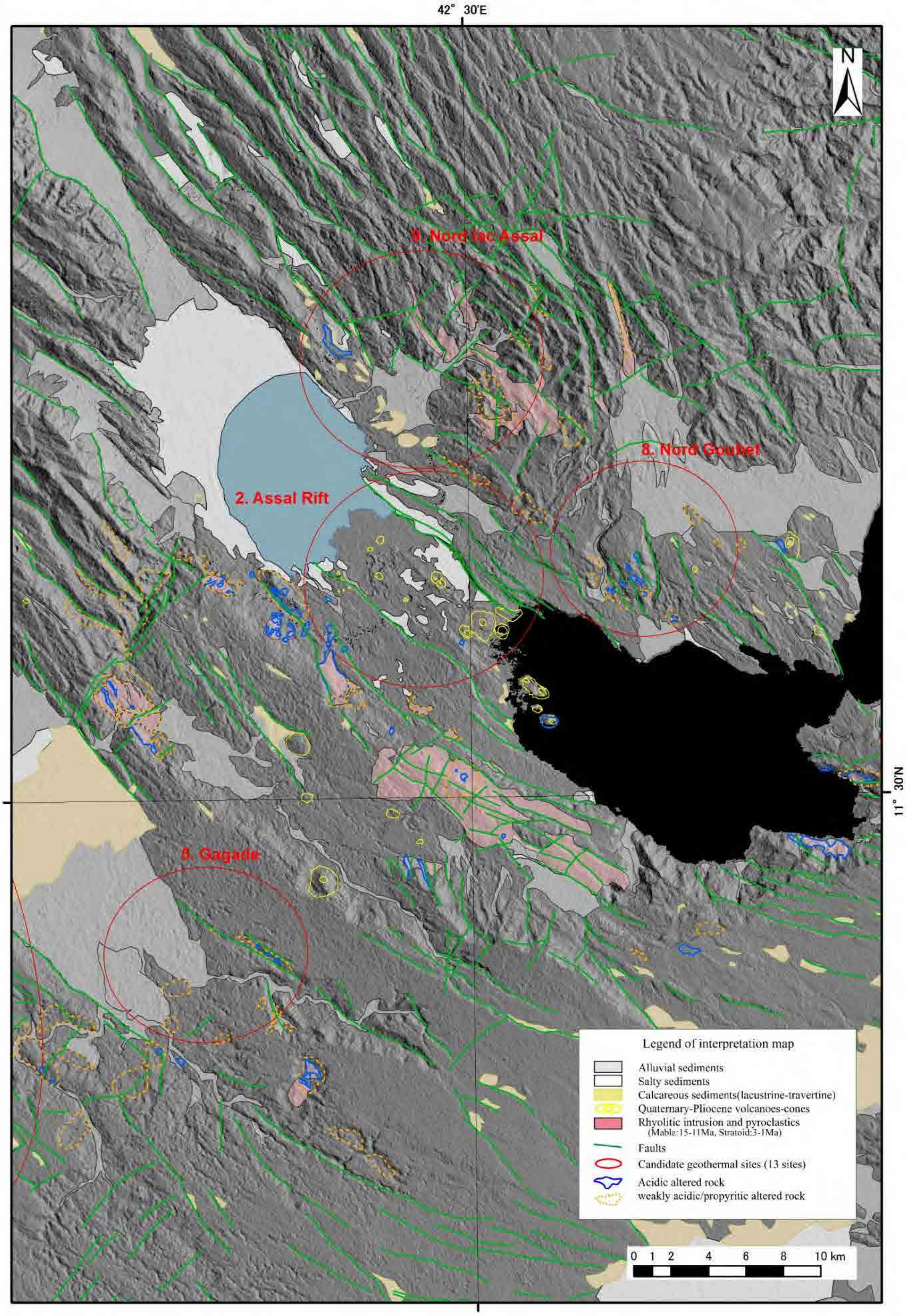
Source : JICA Survey Team

Geothermal potential sites on PALSAR mosaic image of single polarized wave (HH)



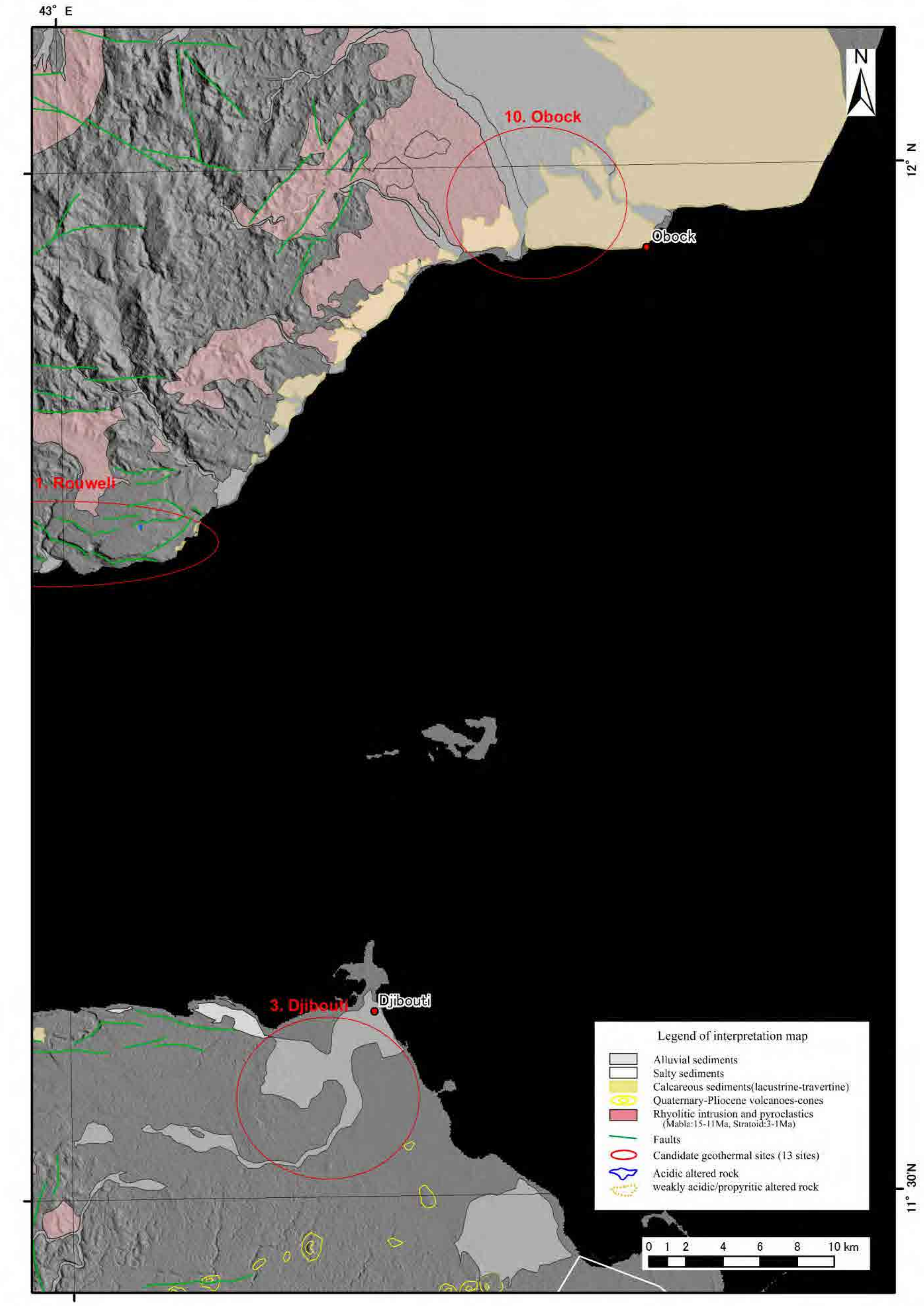
Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Arta, Rouweli, Sud Goubet)



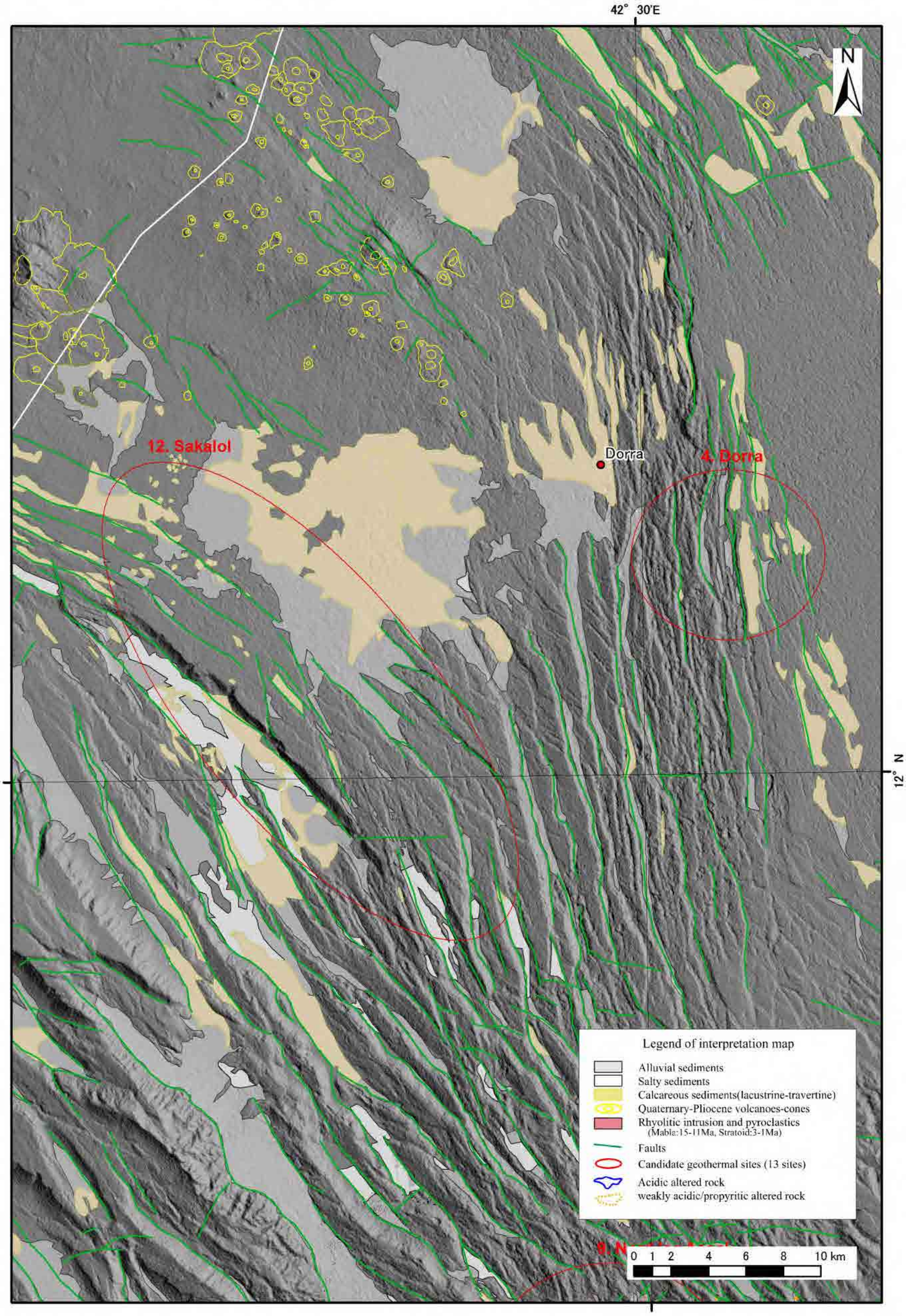
Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Asal Rift, Gaggade, Nord Goubet, Nord Lac Asal)



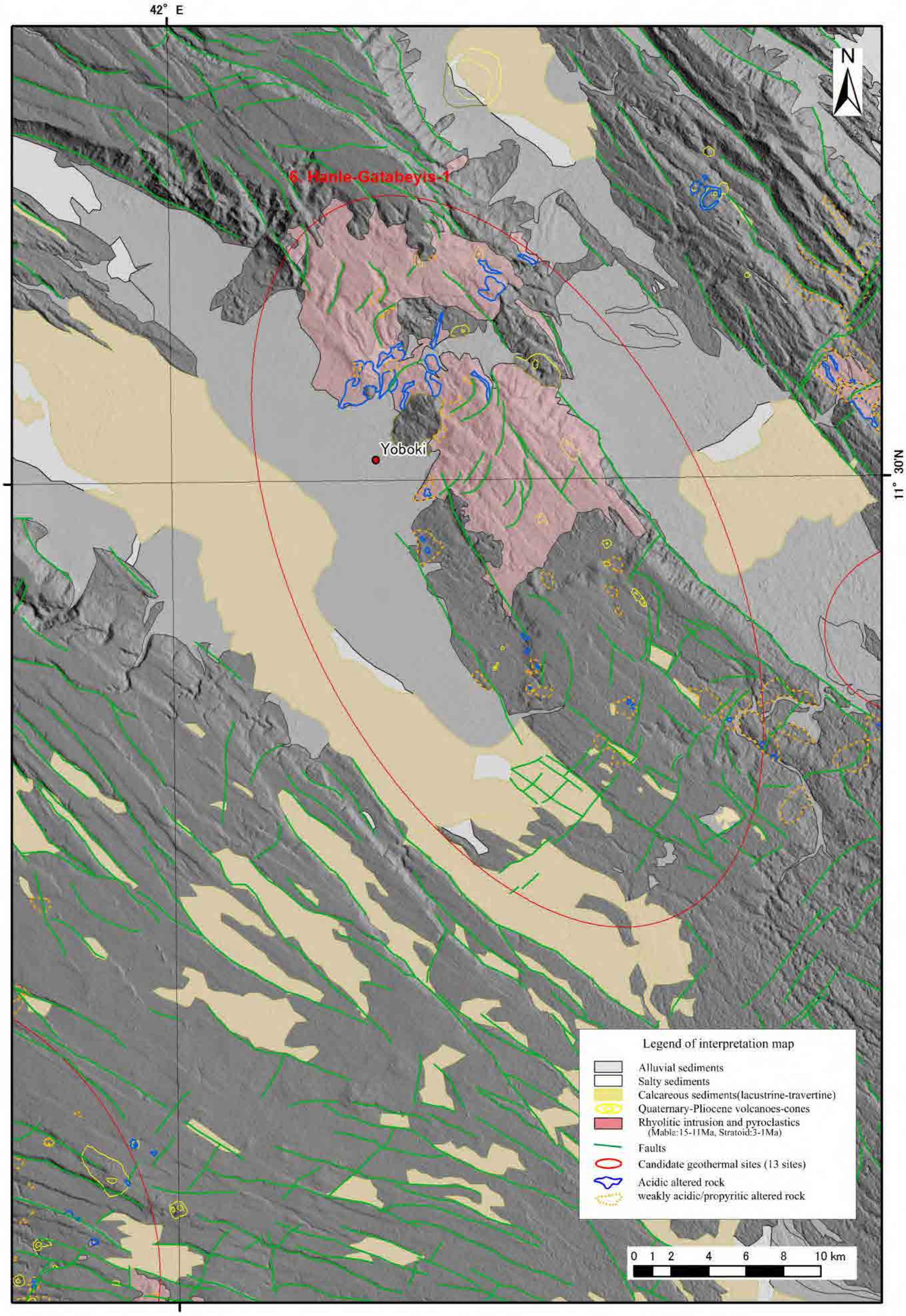
Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Djibouti, Obock)



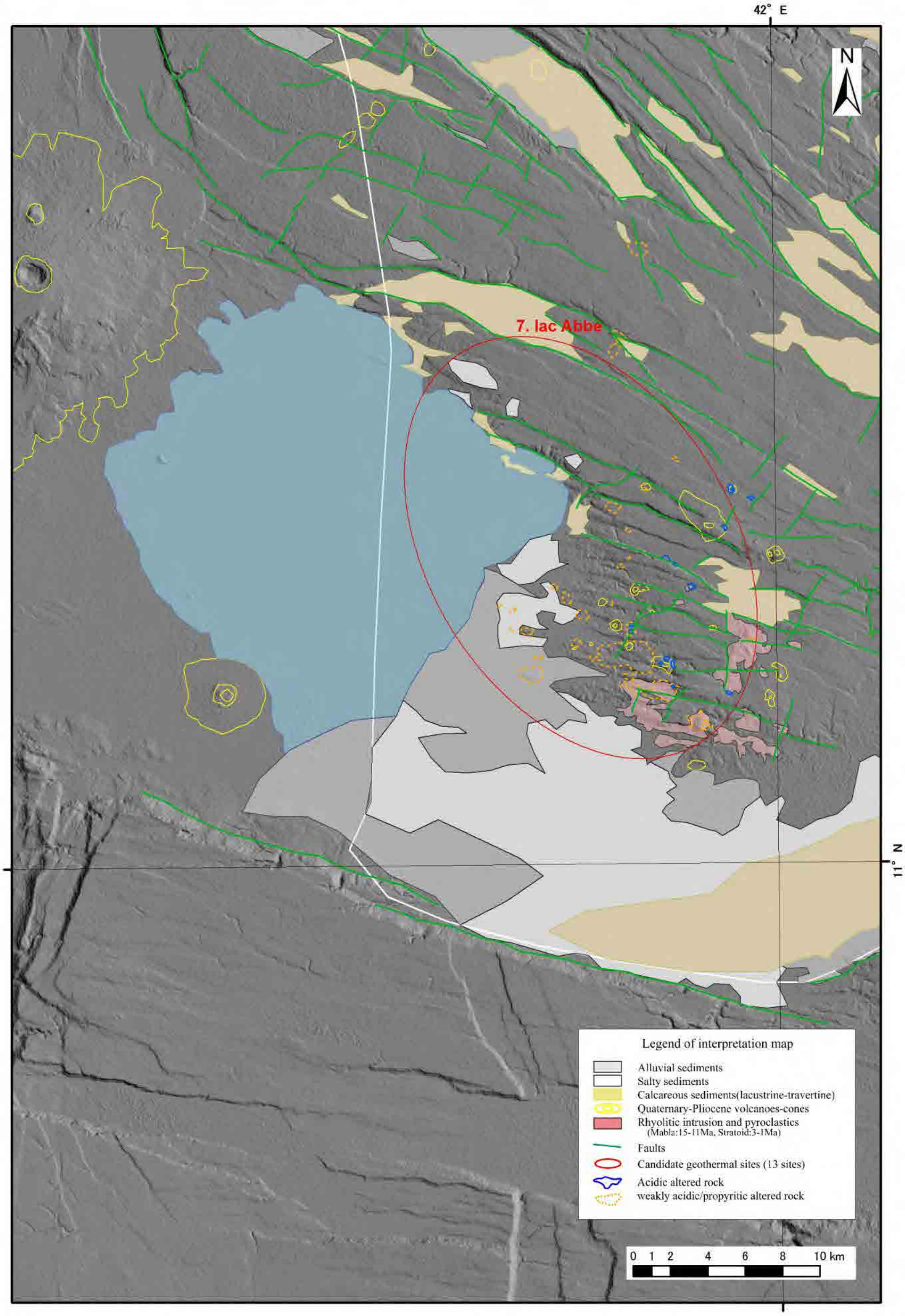
Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Dorra, Sakalol)



Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Hanle Garabbayis)



Source : JICA Survey Team

Volcanic-Geological structure-Alteration Map (Lac Abhe)

Attachment－5
Methodology of Geological and Geochemical Survey

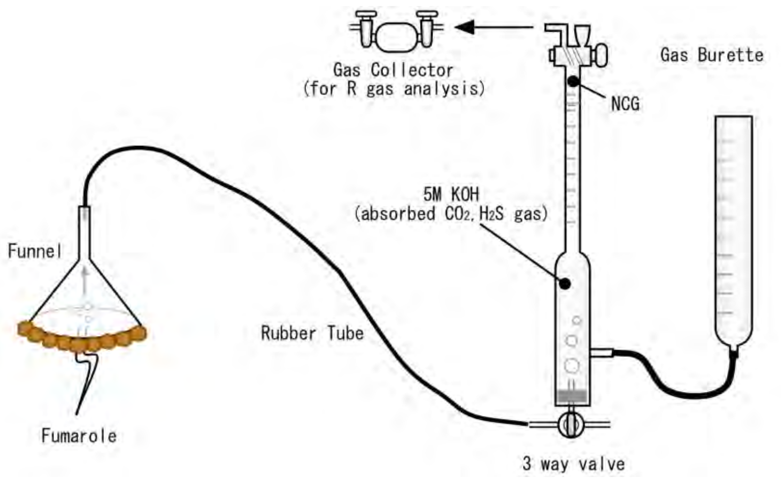
Methodology

(1) Geochemical Survey

(a) Sampling Method

The method of fumarolic gas sampling is shown in Figure a. Fumarolic gas sampling is done by the following method: 1) Cover the area of fumarolic gas ejection by a funnel that is connected to the rubber tube, 2) Derive the fumarolic gas into the gas burette connecting to the rubber tube. The gas burette is filled with potassium hydroxide solution (5 mol/L) in order to absorb CO_2 and H_2S from the fumarolic gas, 3) Collect 8 ml of Residual gas (R gas) that is not absorbed by the potassium hydroxide solution.

After cooling the liquid inside the gas burette until its temperature equals to the outside air temperature, read the amount of R gas and the level of liquid increased amount of potassium hydroxide solution. The R gas is transferred into the Gas Collector. Potassium hydroxide solution in the gas burette is collected for H_2S and CO_2 separately. Cadmium acetate solution is added to sample for H_2S analysis in order to fix H_2S as the cadmium sulfide in the solution.



Source：JICA Survey Team

Figure a Method of Collecting Fumarolic Gas

The sample for He isotope analysis is collected by introducing a fumarolic gas into the gas collector directly, which is sealed by water. Also the $\delta^{13}C$ analytical sample is given by the fumarolic gas which is absorbed from CO_2 gas through a potassium hydroxide solution (5 mol / L).

Samples of hot spring water, well water and lake water are collected by a scoop with beaker and poured into sample containers. For some analytical component, pre-treatment is conducted in order to prevent the component concentration changes before analysis, as shown in Table A.

(b) Analytical Methods

Analysis of the water samples (hot spring, well water and lake water) and fumarolic gas samples collected in this study is performed by the method shown in Table A.

Table A　Chemical analysis method

Analysis Items	Pre-Treatment Method	Analysis Method	Detection Method or Accuracy	Analysis Standard
Water Samples				
pH	No pre-treatment	Glass electrode	0.1	JTS K 0102-12.1
EC	No pre-treatment	Depends	±5%	JTS K 0102-13
Na	No pre-treatment	Flame photometry	0.02 mg/L	JTS K 0102-48.1
K	No pre-treatment	Flame photometry	0.01 mg/L	JTS K 0102-49.1
Ca	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-50.3
Mg	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-51.3
Li	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	---
Cl	No pre-treatment	Ion chromatography	0.01 mg/L	JTS K 0102-35.3
SO_4	No pre-treatment	Ion chromatography	0.1 mg/L	JTS K 0102-41.3
T- CO_2	Add 2mL of KOH (20wt%) to 100mLof sample	Infrared analysis	5 mg/L	JTS K 0101-25.2
H_2S	Add 10mL of compound liquid of cadmium acetate (5wt%) and sodium acetate(3mol/L) per 500mLof sample	Iodometric method	0.5 mg/L	JTS K 0102-39.2
B	No pre-treatment	ICP-AES	0.01 mg/L	JTS K 0102-47.3
SiO_2	Add 5mL of HCl (6mol/L) per 500mLof sample	Gravimetric method	0.01 mg/L	JTS K 0101-44.3.2
T-Fe	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-57.4
Al	Add 5mL of HCl (6mol/L) per 500mLof sample	ICP-AES	0.01 mg/L	JTS K 0102-58.4
T-Hg	Add 5mL of HCl (6mol/L) per 500mLof sample	AAS	0.005 mg/L	JTS K 0102-66.1.2
δD	No pre-treatment	Mass spectrometry	±1‰ SMOW	JIkken Kagaku Koza
$\delta^{18}O$	No pre-treatment	Mass spectrometry	±0.1‰ SMOW	JIkken Kagaku Koza
Fumarolic Gas Samples				
H_2O	---	Capicitance method	---	---
H_2S	Absorb into KOH aqueous solution (5mol/L), then fix as CdS by adding 10mL cadmium acetate (5wt%)	Iodometric method	0.5 mg/L	JIS K 0102-39.2
CO_2	Absorb into KOH aqueous solution (5mol/L)	Infrared method	5 mg/L	JIS K 0101-25.2
H_2	---	Gas chromatography	---	JIS K 2301
N_2	---	Gas chromatography	---	JIS K 2301
CH_4	---	Gas chromatography	---	JIS K 2301
He	---	Gas chromatography	---	JIS K 2301
Ar	---	Gas chromatography	---	JIS K 2301
O_2	---	Gas chromatography	---	JIS K 2301
$^3He/^4He$	---	Mass spectrometry	Depends	New-JIkken Kagaku Koza
$^4He/^{20}Ne$	---	Mass spectrometry	±10%	New-JIkken Kagaku Koza
$\delta^{13}C$	Absorb into KOH aqueous solution (5mol/L)	Mass spectrometry	±0.2‰ PDB	JIkken Kagaku Koza

Source：JICA Survey Team

(2) Geological Survey

(a) Microscope observations of rock sample thin sections

For collected samples, observations of rock thin sections were conducted. Rock thin are made to cut out about 35 ×25 mm of rock sample.

In polarized light microscopy, rock name and organization of the entire rock is described in single and crossed Nicole. Rock thin are described about shape, size, color, and relationship with matrix (less than 30 μm). For minerals, shape, size, color, twin crystal, and relationship with matrix are described. For mineral veins, mineral species and age relationship with alteration minerals and othe mineral veins are described.

Ratio of the amounts of mineral is determined by the rule of thumb by the observation, and classified large amount (more than 30 %), medium amount (10 ~ 30 %), small amount(3 ~ 10 %), and slight amount (less than 3 %). Alteration degree is classified in five steps below; 1 (non alteration ~ worm eaten like), 2 (partial alteration of mafic minerals), 3 (most of mafic minerals altered), 4 (mafic minerals not remain and most of felsic minerals altered), and 5 (altered overall). Microscopic observation results is fill in the microscopic observation described card in each rock sample thin. Typical composition of rocks and minerals are taken a color photography under a single and crossed Nicole.

Eqipment used for observation is as follows.

- Polarizing microscope: ECLIPSE LV100POL made by Nikon
- Photography equipment: IUC-300CN2 USB camera made by Trinity

(b) X-Ray Diffraction (XRD) analysis

(b)－1 Sample Adjustment

To carry out the X-ray diffraction analysis, oriented sample and non-oriented sample is created. Non-oriented specimen is created by the following procedure: 1) Milled to 50-100 mesh in stainless steel mortar. 2) after 1), powdered in agate mortar (extent that it does not feel the finger tip).

For samples that representing the reflection of 14 ~ 15Å in analysis, oriented sample is created by hydraulic elutriation method and ethylene glycol process (hereafter EG) is applied.

Hydraulic elutriation method is performed in the following procedure. 1) Milled to 50-100 mesh in stainless steel mortar. 2) Distributed with distilled water in a beaker. 3) After standing for 8 hours, recovered supernatant liquid 500mL. 4) After collecting the sample, left for 24 hours. 5) Spreading the deposits for analysis glass holder and drying by air.

(b)－2 Equipment and Analytical method

Equipments and Measurement conditions are as follows.

- Measuring device: X-ray diffraction equipment MultiFlex made by Rigaku
- Measurement condition:
    - X-Ray: CuK α_1

- Tube voltage and tube current: 40kV · 20mA
- Goniometer: wide-angle goniometer
- Monochromator: full automatic monochromator
- Counter: scintillation counter
- Slit: 1 °(divergence), 0.3mm (receiving), 1 °(scattering)
- Angle range (2θ): non-oriented sample; 2 θ = 2 ~ 62 °
  Oriented sample (untreated); 2 θ = 2 ~ 32 °
  Oriented sample (EG processing); 2 θ = 2 ~ 22 °
- Scan speed: 2°/ min (undefined orientation analysis)
  1°/min oriented sample (Untreated, EG treatment)
- Scan step: 0.02

(c) X-Ray Fluorescence

(c)-1 Analytical Method

Concentrations of the component containing Major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5) and minor elements (Cr, Ni, Nb, Rb, Sr, Y, Zr) is measured by X-ray fluorescence equipment, after creating a powder sample. Quantification method is performed by using a calibration curve method. In preparing the calibration curve, using eleven igneous rock (JA-1, JA-2, JB-3, JF-1, JG-1a, JG-2, JGb-1, JGb-2, JH-1, JR-1, JR-3) included in the standard rock samples in Japan that have been published by the Geological Survey of Japan.

(c)-2 Equipments and Measurement Conditions

- Measuring device:

  Energy Dispersive X-ray Fluorescence Analyzer EDX-720

  (manufactured by Shimadzu Corporation)

- Measurement condition

  X-ray tube target: Rh

  Tube voltage and tube current: 15kV·100 μ A

  (Si, Al, Mg, Ca, Na, K, P, Rb, Sr, Y, Zr, Nb)

  50kV·100 μ A

  (Ti, Fe, Mn, Cr, Ni)

- Atmosphere during measurement:

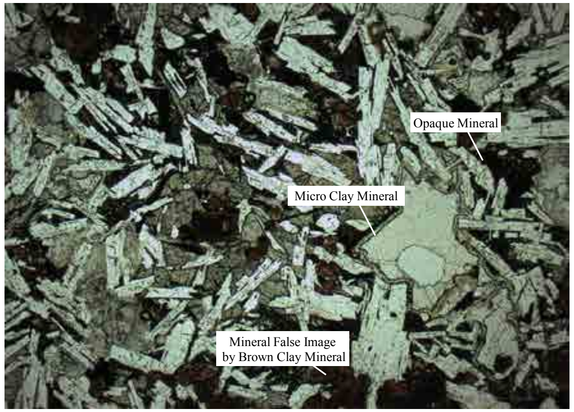
  Vacuum

- Quantification method:

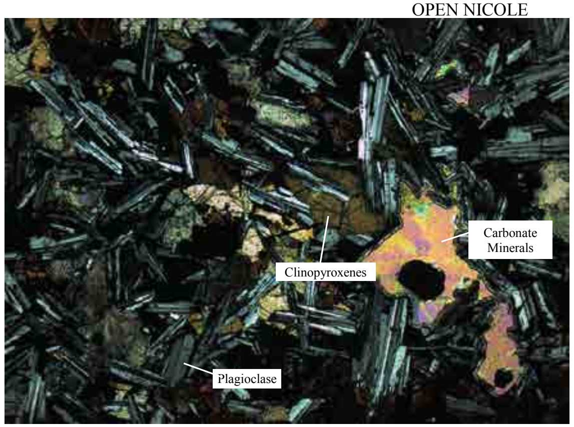
  Calibration Curve Method

Attachment －6
Microphotographs

SN.1



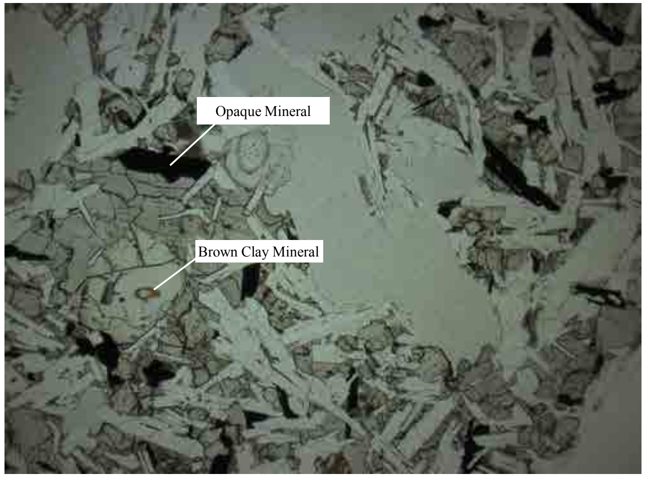
OPEN NICOLE



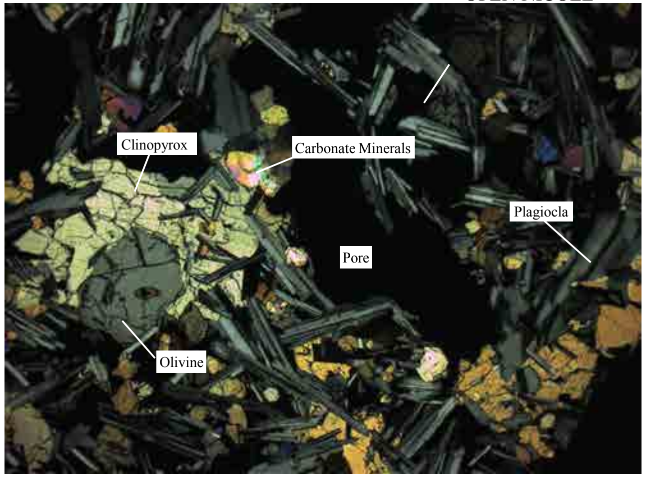
1mm CROSS NICOLE

Sample Nc 140518-1
Rock: Coarse-grained basalt
Alteration Degree: 2
Area: Djibouti Rwelli

SN.5



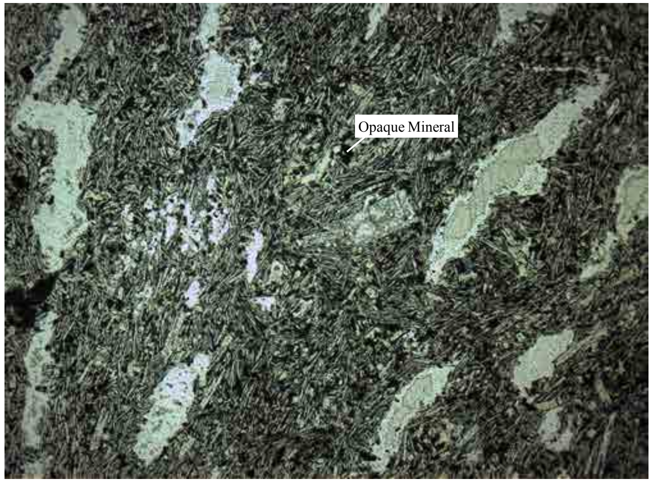
OPEN NICOLE



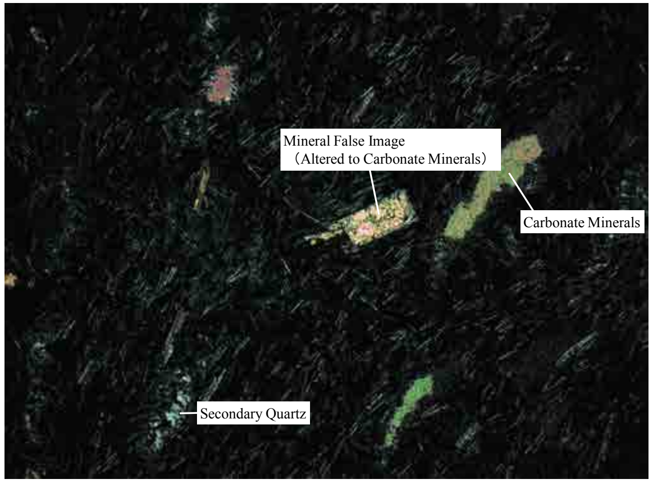
1mm CROSS NICOLE

Sample Nc 140519-2
Rock: Coarse-grained basalt
Alteration Degree: 1
Area: Djibouti N. Goubet

SN.10



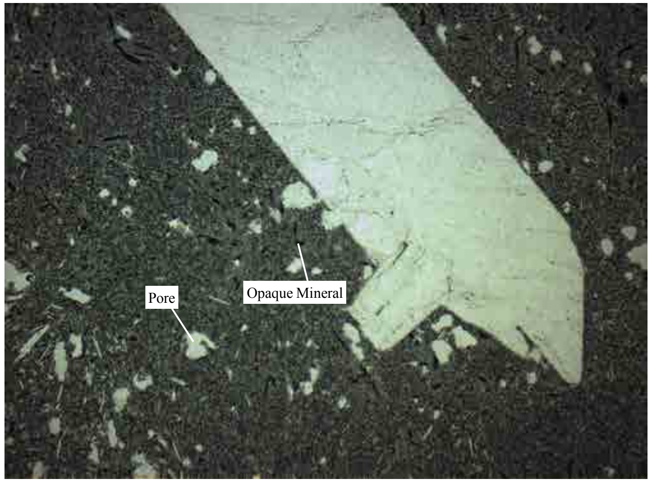
OPEN NICOLE



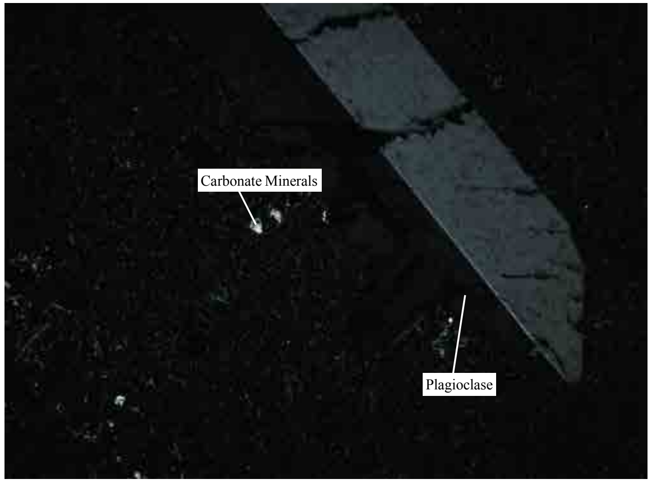
1mm CROSS NICOLE

Sample Nc 140520-1
Rock: Basalt
Alteration Degree: 2
Area: Djibouti Arta

SN.18



OPEN NICOLE

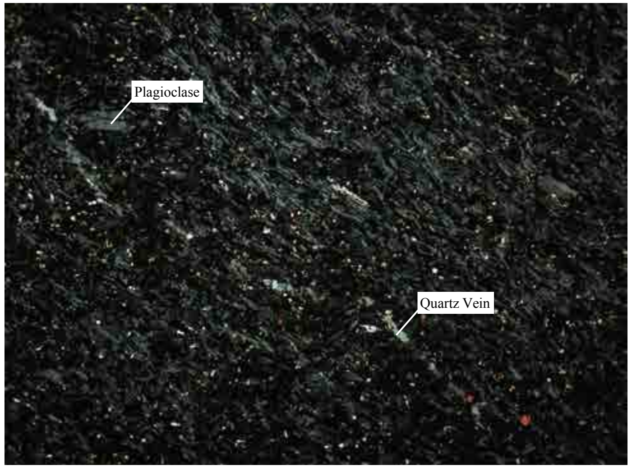


1mm CROSS NICOLE

Sample Nc 140521-1
Rock: Basalt
Alteration Degree: 1
Area: Djibouti Fiale

SN.26

OPEN NICOLE



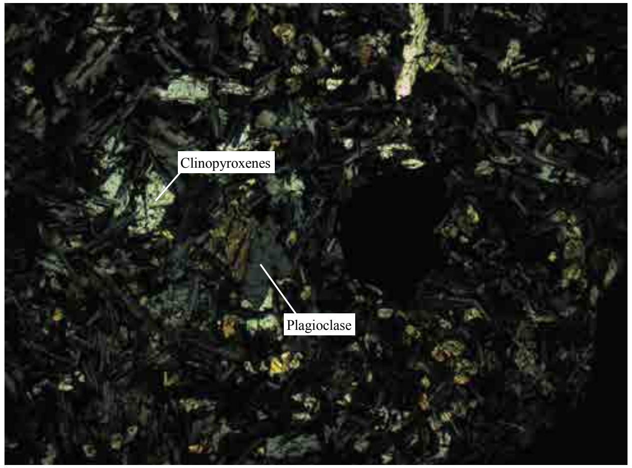
1mm

CROSS NICOLE

Sample Nc 140523-1
Rock: Andesite
Alteration Degree: 1
Area: Djibouti N. Goubet-2

SN.29

OPEN NICOLE



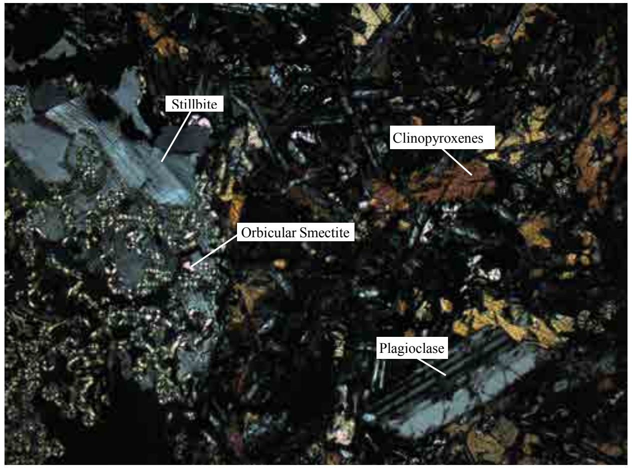
1mm

CROSS NICOLE

Sample Nc 140527-1
Rock: Coarse-grained basalt
Alteration Degree: 2
Area: Djibouti Lac Abhe

SN.33

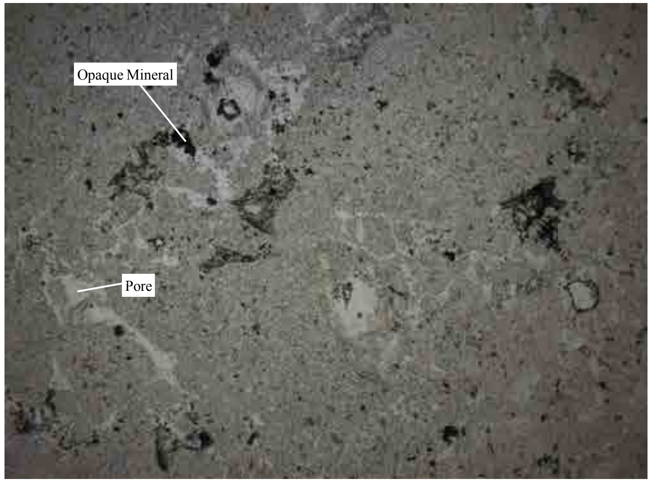
OPEN NICOLE



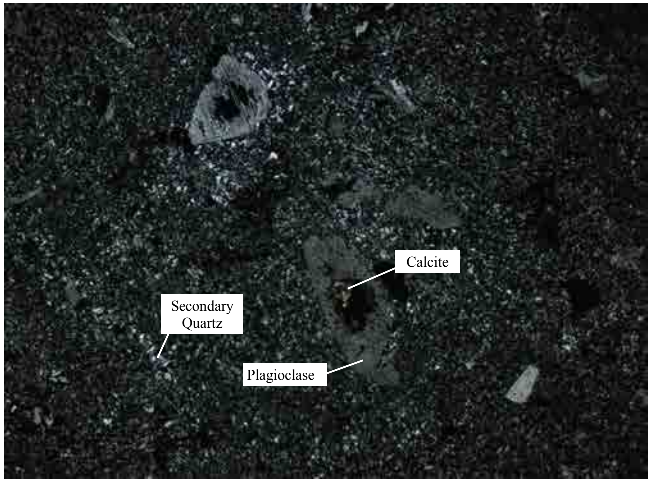
1mm CROSS NICOLE

Sample Nc 140530-1
Rock: Coarse-grained basalt
Alteration Degree: 2
Area: Djibouti Hanle Garabbayis

SN.36



OPEN NICOLE

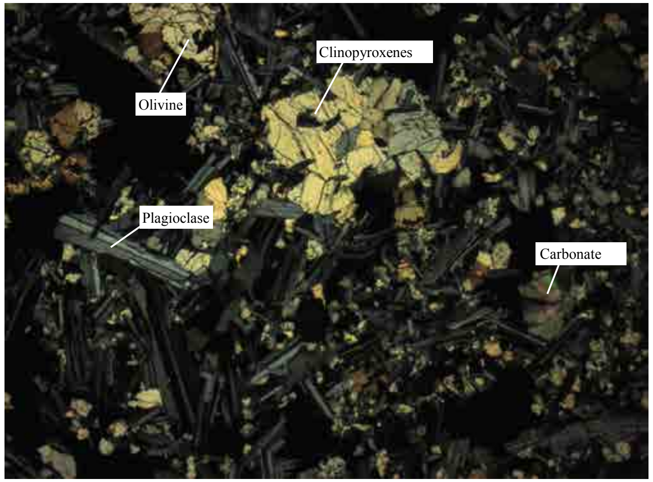


1mm CROSS NICOLE

Sample Nc 140530-4
Rock: Rhyolite
Alteration Degree: 2
Area: ジブチ Hanle Yoboki

SN.38

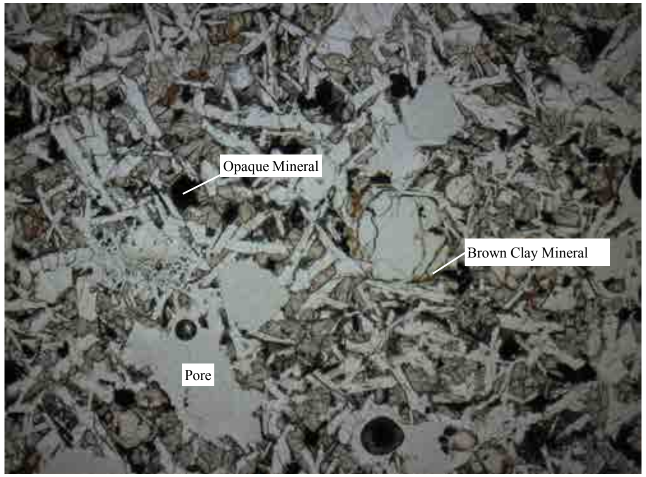
OPEN NICOLE



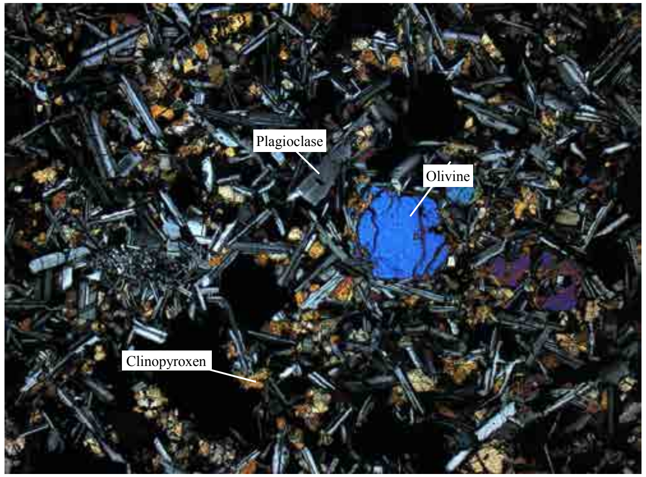
1mm CROSS NICOLE

Sample Nc 140531-1
Rock: Basalt
Alteration 1
Area: Djibouti Hanle Dahotto

SN.40



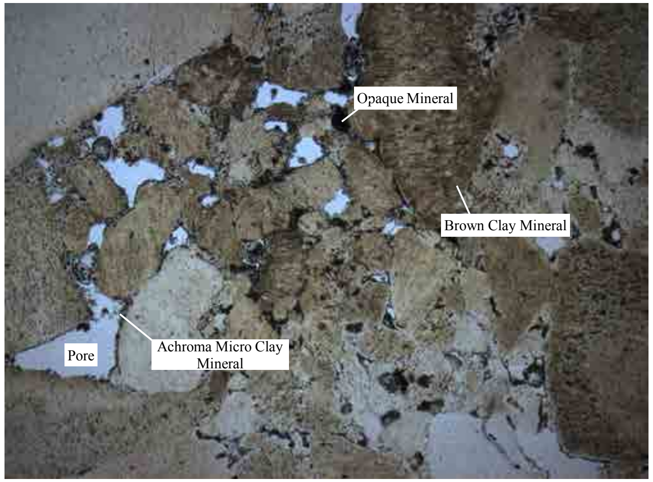
OPEN NICOLE



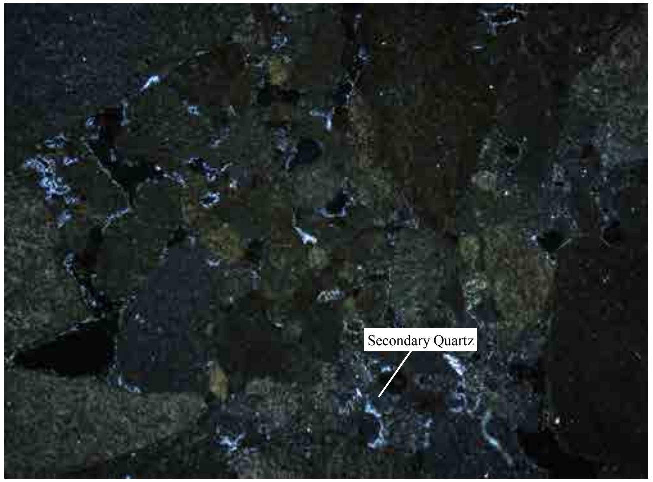
1mm CROSS NICOLE

Sample Nc 140601-1
Rock: Basalt
Alteration 1
Area: Djibouti Hanle Agna

SN.41



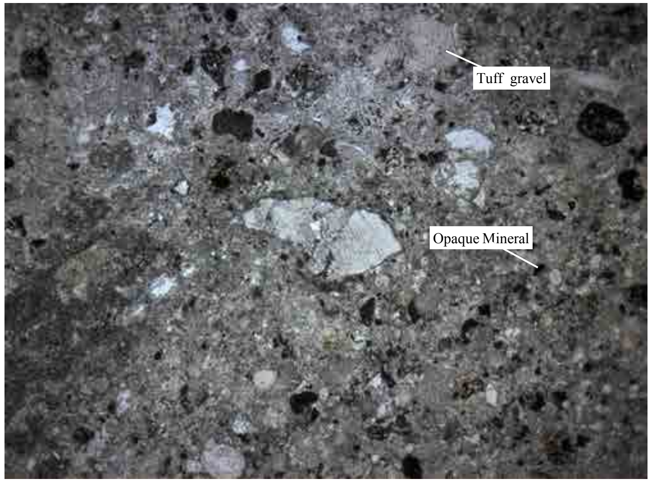
OPEN NICOLE



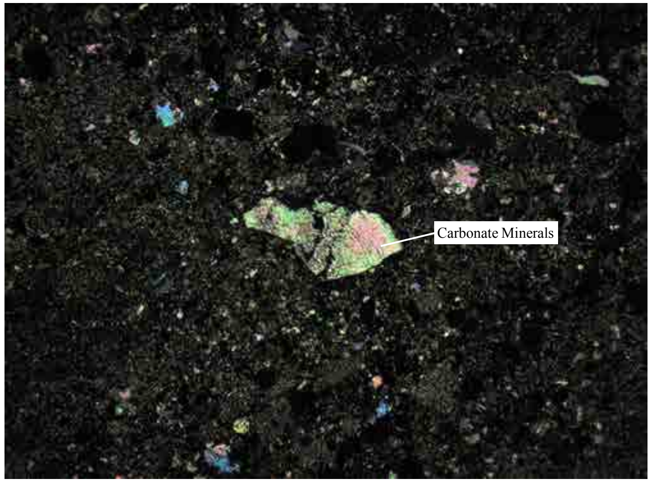
1mm CROSS NICOLE

Sample Nc 140606-1
Rock: Conglomerate
Alteration Degree: 4
Area: Djibouti Gaggade

SN.43



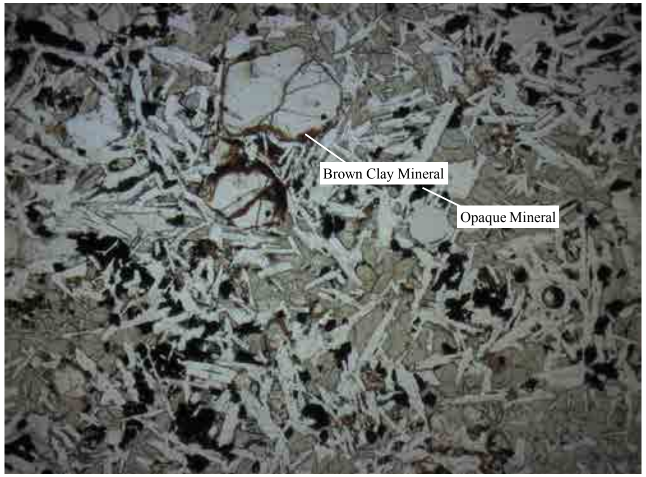
OPEN NICOLE



1mm CROSS NICOLE

Sample Nc 140606-3
Rock: Calcareous Snadstone
Alteration Degree: 4
Area: Djibouti Gaggade

SN.46



OPEN NICOLE

1mm CROSS NICOLE

Sample Nc 140608-1
Rock: Coarse-grained basalt
Alteration Degree: 2
Area: Djibouti Sakalol

Attachment－7

Geological and Geochemical Analysis Results

Results of Observation of Rock Thin Sections by Polarization Microscope (1)

Sample			Sedimentary Rock/Pyroclastic Rock										Organization Texture	Igneous Rock														Alteration Mineral											Alteration Degree
			Crystalline				Matrix				Debris			Phenocryst/ Primary Mineral							Ground mass																		
SN	Sample Number	Rock	Qtz	Pl	Cab	Opq	Qtz	Pl	Ui	Opq	Quantity	Species		Qtz	Pl	Kf	Cpx	Olv	＊	Opq	Qtz	Pl	Fs	Cpx	Olv	Ui	Opq	Qtz	Tm	Stb	Anl	Chl	Sme	Clay	Cal	Cab	#	Opq	
1	140518-1 Rouweli	Dolerite											Ophitic Texture		◎		◎	●	○	◦														◦		◦	○		2
5	140519-2 Nord Goubet	Dolerite											Ophitic Texture		◎		◎	○		◦																●	◦		1
10	140520-1 Arta	Basalt											Porphyritic Texture						●			○				○	○	◦				◦				◦	●		2
18	140521-1 Asal-Fiale	Basalt											Porphyritic Texture		●							○		◎			○									●	●		1
26	140523-1 N.Goubet-Anaale	Andesite											Porphyritic Texture		●				●			◎		○		○	○	●			●		●				○		1
29	140527-1 Lac Abhe	Dolerite											Equigranular Texture (Partially Ophitic Texture)		◎		○	●	○	●														●			●		2
33	140530-1 Garabbayis	Dolerite											Ophitic Texture		◎		◎		◦	○									●	●			◦				◦		2

[Minerals]
Qtz Quartz, Pl Plagioclase, Cab Carbonate Mineral, Opq Opaque Mineral, Ui Unidentified Fine Mineral, Kf K Feldspar, Cpx Augite, Olv Olivine, ＊ Pseudomorph, Fs Feldspar, Lm Laumontite, Tm Thomsonite, Stb Stilbite, Anl Analcite, Chl Chlorite, Sme Smectite, Clay Colorless Fine Clay Mineral, Cal Calcite, # Brown Clay Mineral

[Volume Rate]
More than 30 vol.%, ◎ Large
10～30 vol.%, ○ Medium
3～10 vol.%, ◦ Small
Less than 3 vol.%, ● Slight

[Alteration Degree]
1: Non-Alteration - Worm-Eaten-Like
2: Partial Alteration of Mafic Minerals
3: Alteration of Mafic Minerals
4: Mafic Minerals not remain, most of the Felsic Minerals Altered
5: Altered Overall

Results of Observation of Rock Thin Sections by Polarization Microscope (2)

Sample			Sedimentary Rock/Pyroclastic Rock										Organization Texture	Igneous Rock														Alteration Mineral											Alteration Degree
			Crystalline				Matrix				Debris			Phenocryst/ Primary Mineral							Ground mass																		
SN	Sample Number	Rock	Qtz	Pl	Cab	Opq	Qtz	Pl	Ui	Opq	Quantity	Species		Qtz	Pl	Kf	Cpx	Olv	＊	Opq	Qtz	Pl	Fs	Cpx	Olv	Ui	Opq	Qtz	Tm	Stb	Anl	Chl	Sme	Clay	Cal	Cab	#	Opq	
36	140530-4 Yoboki	Rhyolite											Porphyritic Texture		◦	●					○	○	○				◦	●							●				2
38	140531-1 Hanle-Dagguirou	Basalt											Porphyritic Texture		◦		○	○				◎		◦	◦		◦									●	●		1
40	140601-1 Hanle-Agna	Basalt											Porphyritic Texture		◦		◦	◦				◎		○	◦	●	◦									●	●		1
41	140606-1 Gaggade-Taassa	Conglometate									◎ ◦	Rhyolite Tuff	Phyroclastic Texture															○						◦			◎	◦	4
43	140606-3 Gaggade-Taassa	Calcareous Sandstone		◦	◎	●					◎	Tuff	Phyroclastic Texture															○						◦		○	◦	◦	4
46	140608-1 Sakalol-Asbou Dara	Dolerite											Ophitic Texture		○		◎	◦		○																◦	●		2

［Minerals］
Qtz Quartz, Pl Plagioclase, Cab Carbonate Mineral, Opq Opaque Mineral, Ui Unidentified Fine Mineral, Kf K Feldspar, Cpx Augite, Olv Olivine, ＊ Pseudomorph, Fs Feldspar, Lm Laumontite, Tm Thomsonite, Stb Stilbite, Anl Analcite, Chl Chlorite, Sme Smectite, Clay Colorless Fine Clay Mineral, Cal Calcite, ＃ Brown Clay Mineral

[Volume Rate]
More than 30 vol.%, ◎ Large
10～30 vol.%, ○ Medium
3～10 vol.%, ◦ Small
Less than 3 vol.%, ● Slight

[Alteration Degree]
1: Non-Alteration - Worm-Eaten-Like
2: Partial Alteration of Mafic Minerals
3: Alteration of Mafic Minerals
4: Mafic Minerals not remain, most of the Felsic Minerals Altered
5: Altered Overall

Analysis Results of Hot Spring, Well Water, and Lake Water Samples

Survey Area		Asal		Djibouti		Hanle				Lac Abhe			N. Goubet	Obock		Rouweli		Sakalol
Sampling Location		Korili	Lac Asal	Awrofoul No.2	Awrofoul No.6	Dagguirou	Minkileh	Agna	Garabbayis Dug Well	Lac Abhe SP-1	Lac Abhe SP-2	Lac Abhe	Anaale	Obock-1	Obock-2	Rouweli	Rouweli Dug Well	Asbou-Dara
Types		Spring	Lake	Well water	Well water	Spring	Spring	Spring	Well water	Spring	Spring	Lake	Spring	Spring	Spring	Spring	Well water	Spring
Date		2014/5/21	2014/5/21	2014/5/22	2014/6/16	2014/5/31	2014/5/31	2014/6/1	2014/6/1	2014/5/27	2014/5/27	2014/5/27	2014/5/23	2014/5/18	2014/5/19	2014/5/18	2014/5/18	2014/6/8
Latitude		N 11°36′	N 11°37′	N 11°32′	N 11°32′	N 11°36′	N 11°39′	N 11°34′	N 11°23′	N 11°08′	N 11°08′	N 11°10′	N 11°35′	N 11°57′	N 11°57′	N 11°48′	N 11°48′	N 12°02′
Longitude		E 42°24′	E 42°23′	E 43°02′	E 43°01′	E 41°58′	E 41°57′	E 41°54′	E 42°09′	E 41°52′	E 41°52′	E 41°53′	E 42°35′	E 43°17′	E 43°17′	E 43°00′	E 42°59′	E 42°15′
Elevation	(m)	-140	-149	123	135	131	119	144	218	254	261	247	168	0	0	0	3	19
Air	(°C)	41.1	40.9	36.0	35.2	35.6	30.0	34.8	37.2	33.4	32.1	38.5	35.5	30.6	28.1	30.8	32.3	39.0
Spring/Water Temperature	(°C)	77.5	40.7	56.2	73.6	40.4	57.7	42.7	33.7	99.2	96.2	35.2	98.0	67.0	70.7	40.7	35.0	61.8
Discharge Flow	(L/s)	---	---	---	7.6	16	---	2.9	---	1.7	3.4	---	few	0.1	0.2	few	---	80
pH	-	6.8	6.9	7.9	7.6	8.0	7.9	8.3	8.5	8.3	8.3	9.7	7.7	6.9	6.8	7.4	7.7	7.1
Conductivity	(mS/m)	5050	16500	156	121	391	396	283	145	582	581	8860	39	4150	4820	896	486	750
SiO_2	(mg/L)	78	15	88	114	76	88	73	40	108	124	98	52	70	74	58	78	108
Cl	(mg/L)	22200	197000	253	221	953	924	636	41	1680	1690	28800	32	16800	20300	2720	1320	2320
SO_4	(mg/L)	239	2200	100	70	291	453	207	377	348	345	14300	55	1440	1790	448	246	197
T-CO_2	(mg/L)	3.6	58	118	99	121	56	142	182	8.7	7.5	40	47	4.2	3.0	58	---	10
HCO_3	(mg/L)	3.6	62	158	129	163	74	192	245	12	10	40	61	4.5	3.0	74	---	12
CO_3	(mg/L)	<0.01	0.04	0.95	0.39	1.2	0.45	2.9	5.9	0.18	0.15	15	0.23	<0.01	<0.01	0.14	---	0.01
Li	(mg/L)	1.5	3.9	<0.01	0.04	0.02	0.05	<0.01	<0.01	0.43	0.41	<0.01	<0.01	1.1	1.2	0.05	<0.01	0.08
Na	(mg/L)	9520	98500	158	199	775	751	556	295	956	948	38300	22	8660	10600	1600	820	1390
K	(mg/L)	440	5200	9.0	8.0	32	14	24	4.0	32	28	500	2.5	540	640	56	31	52
Ca	(mg/L)	3000	2540	54	28	19	65	8.6	16	220	221	3.7	38	890	973	90	76	136
Mg	(mg/L)	415	12100	31	5.0	2.8	2.5	2.3	1.5	0.22	0.19	1.2	6.6	664	910	150	64	5.9
Al	(mg/L)	<0.01	<0.01	<0.01	0.04	0.04	0.08	0.03	0.08	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
T-Fe	(mg/L)	0.10	0.17	0.04	0.06	0.30	0.97	0.28	0.20	0.03	0.72	0.01	<0.01	0.08	0.09	0.30	<0.01	0.09
H_2S	(mg/L)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.5	<0.5	<0.5	<0.5
B	(mg/L)	3.6	27	<0.01	<0.01	0.37	0.58	<0.01	0.13	0.81	0.94	50	<0.01	4.7	5.4	0.23	<0.01	0.28
As	(mg/L)	<0.01	<0.01	0.01	0.01	0.01	0.24	0.02	0.01	0.02	0.06	0.59	<0.01	<0.01	0.01	0.01	0.01	<0.01
T-Hg	(mg/L)	<0.0005	---	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	---	<0.0005	<0.0005	---	0.011	<0.0005	<0.0005	<0.0005	---	<0.0005
δD	(‰ SMOW)	-11	11	-6	-5	-14	-12	-23	6	-24	-24	46	7	4	7	-4	-5	-21
$\delta^{18}O$	(‰ SMOW)	-1.6	unmeasurable	-1.4	-1.6	-1.6	-1.5	-3.1	0.8	-2.9	-3.0	unmeasurable	1.2	0.4	0.8	-1.4	-1.5	-3.1
T quartz *1	(°C)	111	---	118	133	109	118	107	78	130	138	---	90	105	108	95	111	130
T chalcedony *2	(°C)	96	---	103	119	94	103	92	61	115	124	---	74	90	93	79	96	115
T Na-K *3	(°C)	177	---	191	169	170	126	173	111	158	151	---	242	197	195	160	165	164
T Na-K-Ca *4	(°C)	167	---	143	136	162	116	165	101	136	130	---	147	192	193	152	147	150
T K-Mg *5	(°C)	116	---	52	69	113	91	107	67	154	152	---	41	115	116	75	71	116

*1 Arnórsson (2000), conductive cooling
*2 Founier (1977)
*3 Giggenbach (1988)
*4 Fournier and Truesdell (1973)
*5 Giggenbach (1988)

Analysis Results of Fumarolic Gas Samples

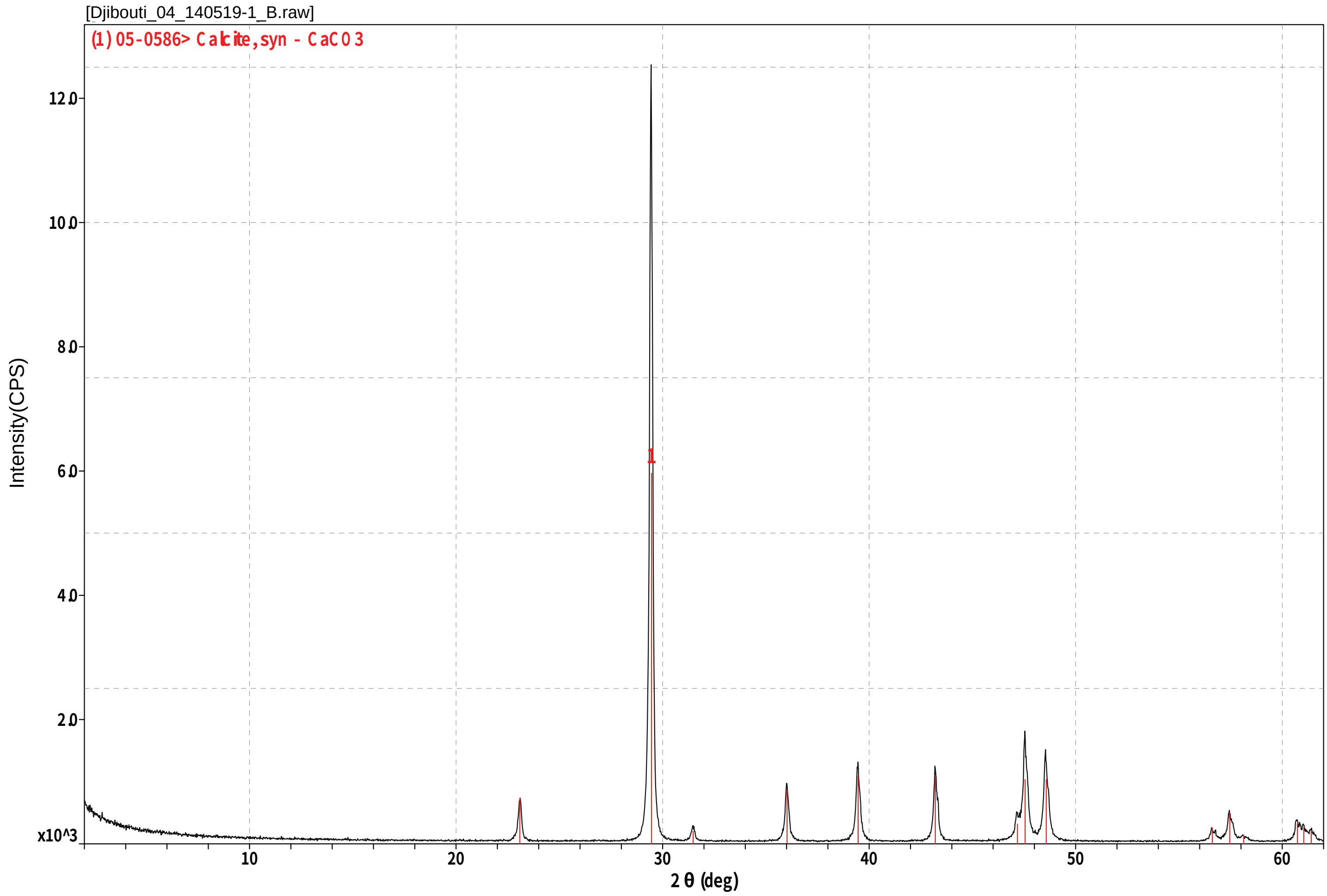
Survey Area			Nord Goubet	Arta	Asal	Hanle	Gaggade
Sampling Location			Anaale	Arta	Fiale	Garabbayis	Taassa
Date			2014/5/23	2014/5/20	2014/5/21	2014/5/30	2014/6/6
Latitude			N 11º35'58.42"	N 11º33'44.50"	N 11º34'55.78"	N 11º24'23.33"	N 11º25'17.98"
Longitude			E 42º35'29.04"	E 42º50'48.70"	E 42º29'56.87"	E 42º10'50.48"	E 42º24'12.42"
Elevation		(m)	168	156	120	319	285
Air Temperature		(°C)	35.5	35.6	34.5	32.3	33.4
Temperature		(°C)	98.0	98.7	87.5	99.8	95.3
H_2O and NCG (total 100%)	H_2O	(vol%)	99.88	0	0	99.98	0
	NCG	(vol%)	0.12	100	100	0.02	100
NCG composition (total 100%)	H_2S	(vol%)	0.0	0	0	0.0	0
	CO_2	(vol%)	94.1	0	0	45.0	0
	R gas	(vol%)	5.9	100	100	55.0	100
R gas composition (total ~100%)	H_2	(vol%)	0.57	0.002	0.008	0.054	0.003
	N_2	(vol%)	91.7	78.3	78.3	93.5	79.3
	CH_4	(vol%)	3.2	<0.01	<0.01	1.0	0.13
	O_2	(vol%)	2.4	20.8	20.7	3.6	19.5
	He	(vol%)	0.14	0.0003	0.0015	0.019	0.0027
	Ar	(vol%)	2.0	0.92	0.93	1.8	1.1
R gas composition (total ~100%, Air correct)	H_2	(vol%)	0.64	---	---	0.066	0.041
	N_2	(vol%)	93.4	---	---	96.7	94.2
	CH_4	(vol%)	3.6	---	---	1.2	1.8
	He	(vol%)	0.16	---	---	0.022	0.03700
	Ar	(vol%)	2.2	---	---	2.0	3.9
$^3He/^4He$		($\times 10^{-6}$)	15.0±0.1	---	2.39±0.03	7.13±0.06	8.46±0.07
$^4He/^{20}He$		-	2.91	---	0.280	11.6	0.883
$\delta^{13}C(CO_2)$		(%PDB)		---			
T CO_2/Ar [*1]		(°C)	228	---	---	159	---
T H_2/Ar [*1]		(°C)	138	---	---	72	36
T CH_4/CO_2 [*1]		(°C)	323	---	---	266	---

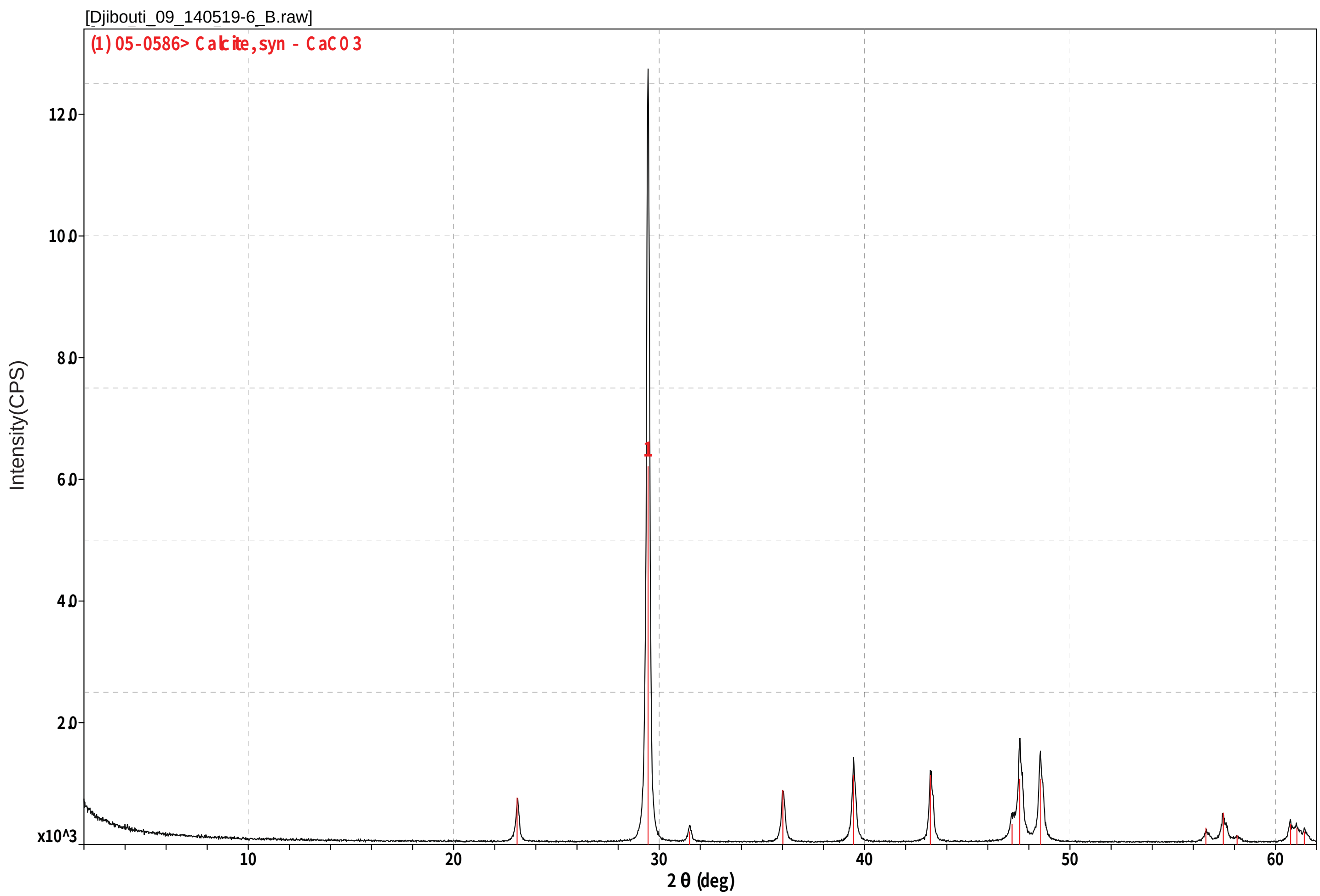
*1 Giggenbach (1991)

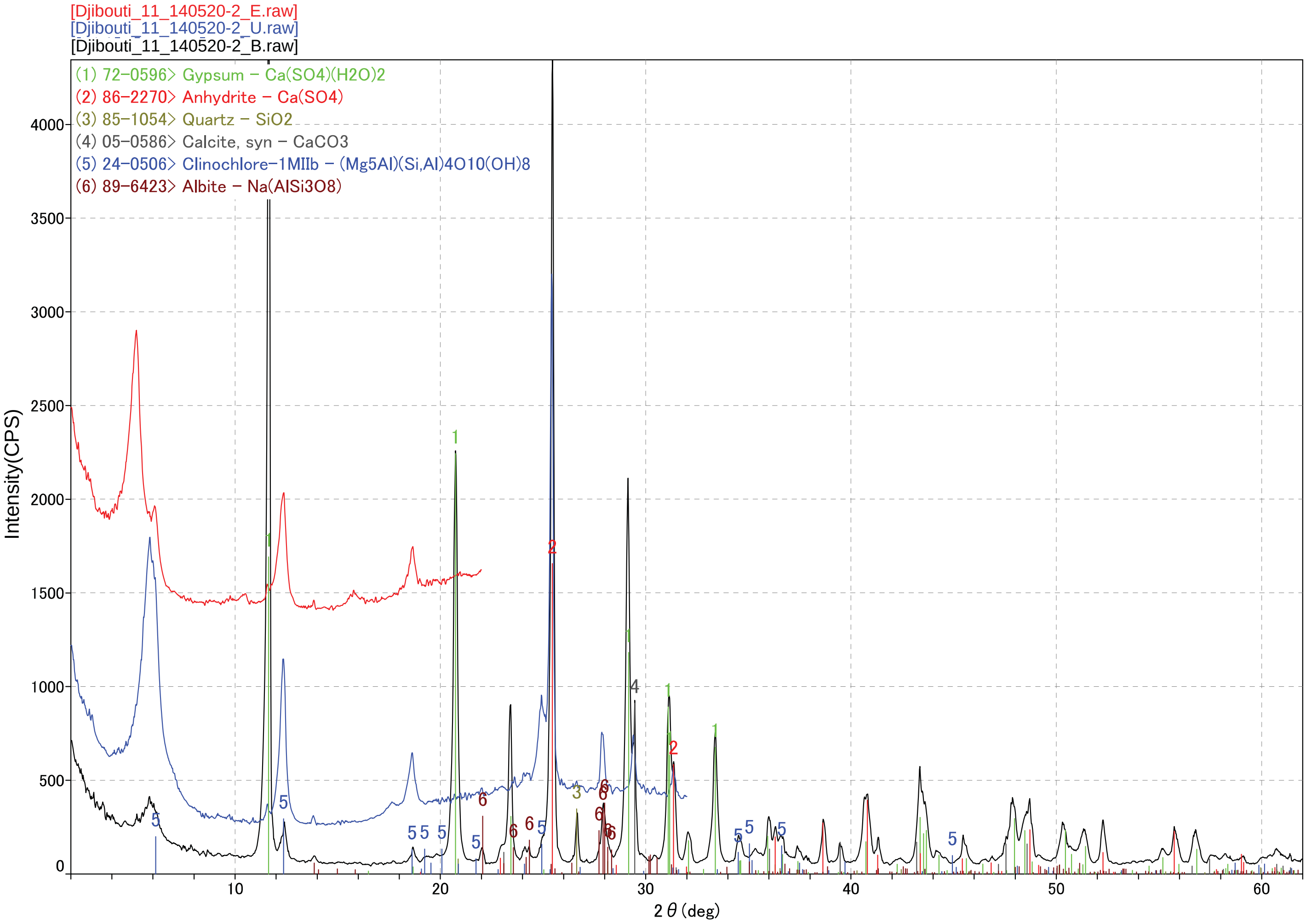
Comparison of the Results Geochemical Analysis with CERD

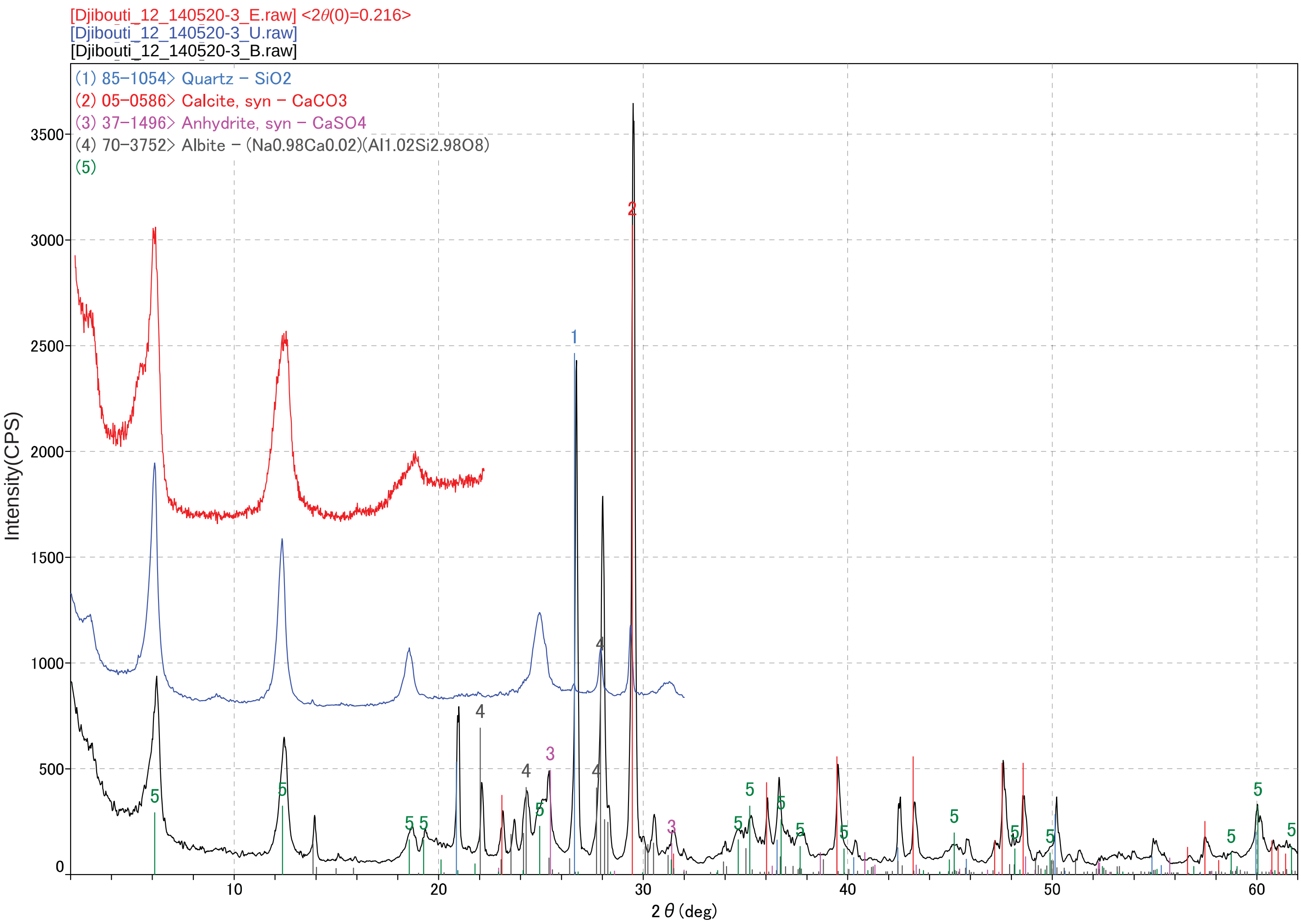
Sampling Site	Ca (mg/L)		Mg (mg/L)		Na (mg/L)		K (mg/L)		Li (mg/L)		HCO_3 (mg/L)		CO_3 (mg/L)		Cl (mg/L)	
	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA
Korili	2848	3000	385	415	10175	9520	415	440	---	1.5	63.5	3.6	0	<0.01	21985	22200
Lac Asal	2645	2540	12177	12100	101155	98500	4770	5200	---	3.9	136	62	0	0.037	198537	197000
Awrofoul No.2	58.09	54	22.73	31	153.14	158	8.39	9.0	0.029	<0.01	140.5	158	0	0.95	245.1	253
Awrofoul No.6	28.2	28	3.94	5.0	196.44	199	8.48	8.0	0.049	0.04	148.85	129	0	0.39	219.62	221
Dagguirou	26.95	19	5	2.8	766.4	775	31.2	32	0.0862	0.02	97.98	163	31.91	1.2	917	953
Minkileh	72.09	65	2.24	2.5	787.65	751	13.6	14	0.0486	0.05	63.5	74	0	0.45	947	924
Agna	10.21	8.6	2	2.3	540	556	24.87	24	0.019	<0.01	195.8	192	0	2.9	612.83	636
Garabbayis Dug Well	19.09	16	1.49	1.5	291.97	295	3.65	4.0	0.028	<0.01	262.13	245	0	5.9	42.02	40.5
Lac Abhe SP-1	232	220	0.94	0.22	1096	956	31.5	32	0.34	0.43	15.67	12	0.22	0.18	1721	1680
Lac Abhe SP-2	225	221	0.93	0.19	1074	948	27	28	0.29	0.41	15.26	10	0.15	0.15	1737	1690
Lac Abhe	3.4	3.7	1.4	1.2	36623	38300	497.05	500	0.0086	<0.01	21622.3	40	8085.8	15	27548	28800
Obock-1	881	890	797	664	9640.4	8660	515	540	1.85	1.1	140.38	4.5	0	<0.01	16711	16800
Obock-2	1000.5	973	727	910	9565	10600	550	640	2.6	1.2	131.8	3.0	0	<0.01	16698	20300
Rouweli	98	90	103	150	1615.15	1600	55.97	56	0.05	0.05	193.3	74	0	0.14	2599.94	2720
Rouweli Dug Well	73.7	76	48.35	64	796	820	26.93	31	0.1	<0.01	188	---	0	---	1225	1320
Asbou-Dara	166.09	136	12.07	5.9	1426.22	1390	59.07	52	0.25	0.08	46.8	12	0	0.01	2296.5	2320

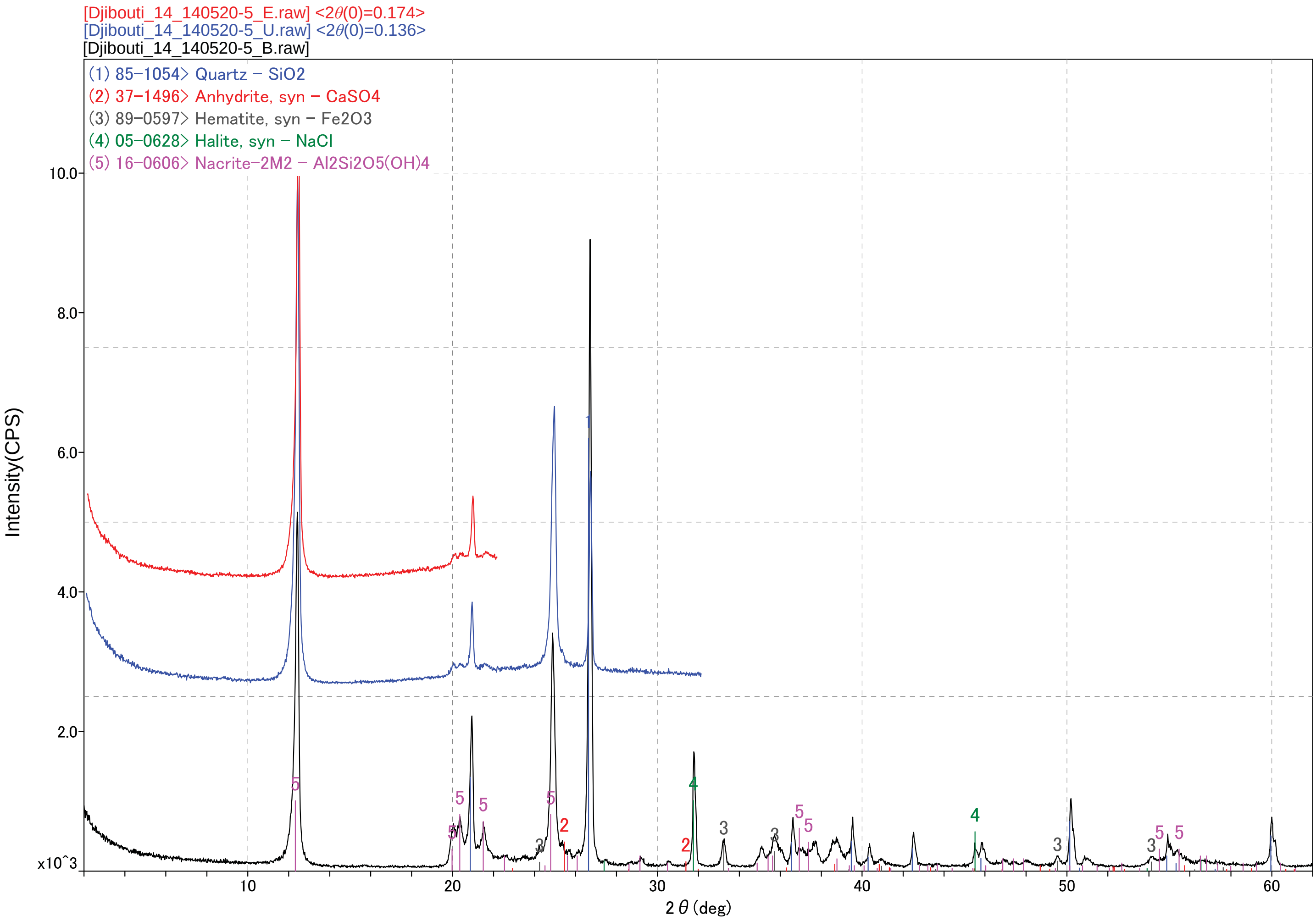
Sampling Site	SO_4 (mg/L)		SiO_2 (mg/L)		Al (mg/L)		T-Fe (mg/L)		B (mg/L)		As (mg/L)		T-Hg (mg/L)	
	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA	CERD	JICA
Korili	248	239	---	78	---	<0.01	---	0.10	---	3.6	---	<0.01	<0.0013	<0.0005
Lac Asal	4399	2200	---	15	---	<0.01	---	0.17	---	27	---	<0.01	<0.0013	---
Awrofoul No.2	92.42	100	90.65	88	0.01	<0.01	0.06	0.04	<0.0003	<0.01	---	0.01	<0.0013	<0.0005
Awrofoul No.6	67.12	70	105.1	114	0.02	0.04	0.07	0.06	<0.0003	<0.01	<0.0012	0.01	<0.0013	<0.0005
Dagguirou	293.63	291	81.9	76	0.1	0.04	0.32	0.3	0.73	0.37	0.009	0.01	<0.0013	<0.0005
Minkileh	471.09	453	95.92	88	0.01	0.08	0.07	0.97	0.61	0.58	0.009	0.24	<0.0013	<0.0005
Agna	205.86	207	70.2	73	0.02	0.03	0.06	0.28	0.34	<0.01	<0.0012	0.02	<0.0013	<0.0005
Garabbayis Dug Well	367.63	377	30	40	0.09	0.08	0.13	0.2	0.37	0.13	0.009	0.01	<0.0013	---
Lac Abhe SP-1	348	348	115.06	108	0.0425	<0.01	0.0064	0.03	2.4	0.81	---	0.02	<0.0013	<0.0005
Lac Abhe SP-2	349	345	129.01	124	0.046	<0.01	0.0071	0.72	5.11	0.94	---	0.06	<0.0013	<0.0005
Lac Abhe	13126.1	14300	---	98	0.06	<0.01	0.07	0.01	18.86	50	0.12	0.59	<0.0013	---
Obock-1	1562	1440	101.65	70	---	<0.01	---	0.08	4.37	4.7	---	<0.01	<0.0013	<0.0005
Obock-2	1503	1790	91.98	74	---	<0.01	---	0.09	4.25	5.4	---	0.01	<0.0013	<0.0005
Rouweli	423	448	52.16	58	0.01	<0.01	0.06	0.30	0.39	0.23	<0.0012	0.01	<0.0013	<0.0005
Rouweli Dug Well	248.5	246	105.38	78	0.03	<0.01	0.08	<0.01	<0.0003	<0.01	---	0.01	<0.0013	---
Asbou-Dara	194.01	197	90.74	108	0.02	<0.01	0.07	0.09	0.28	0.28	<0.0012	<0.01	<0.0013	<0.0005

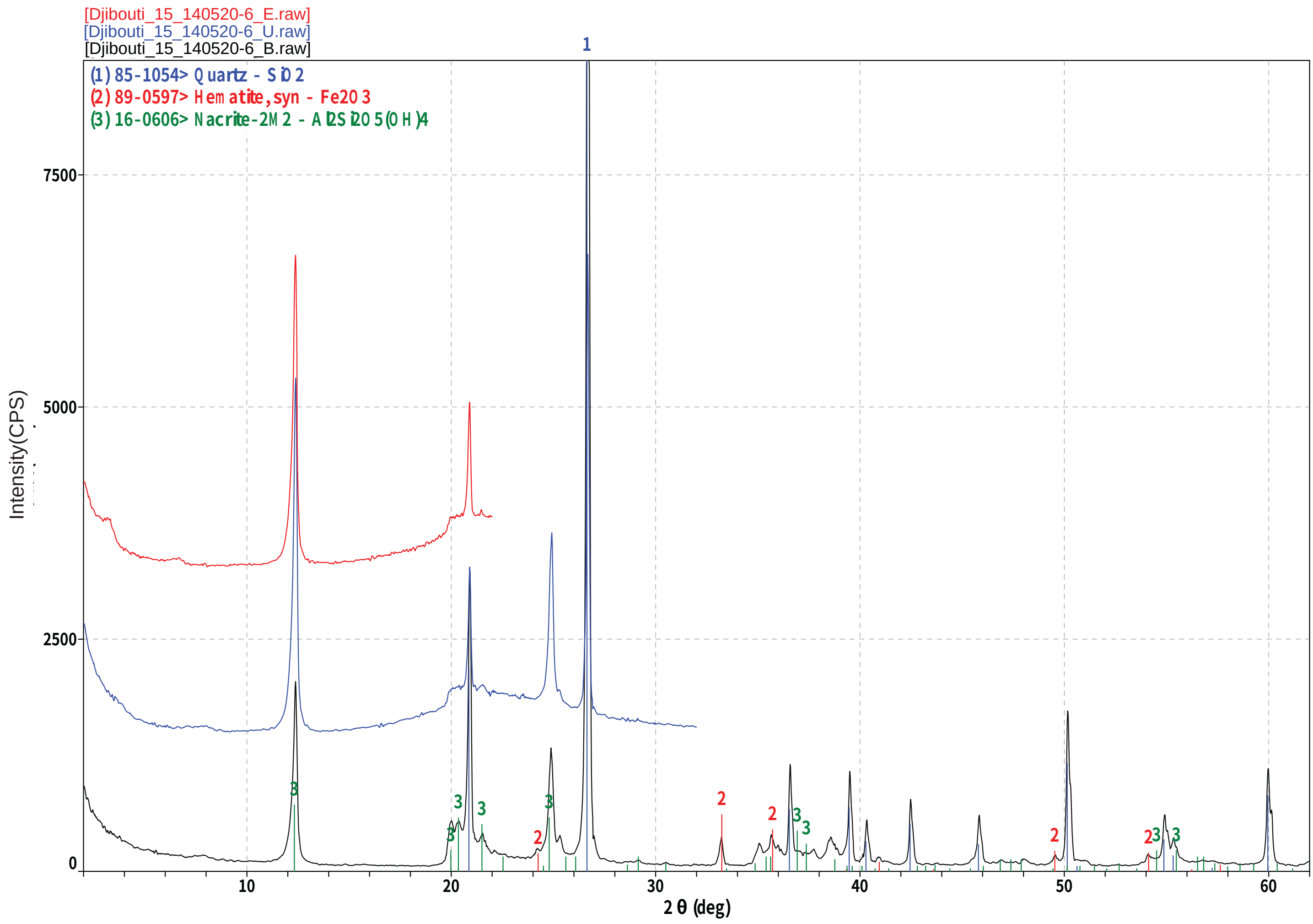

[Djibouti_04_140519-1_B.raw]
(1) 05-0586> Calcite, syn - CaCO3
Intensity(CPS)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
1
10
20
30
40
50
60
2θ (deg)

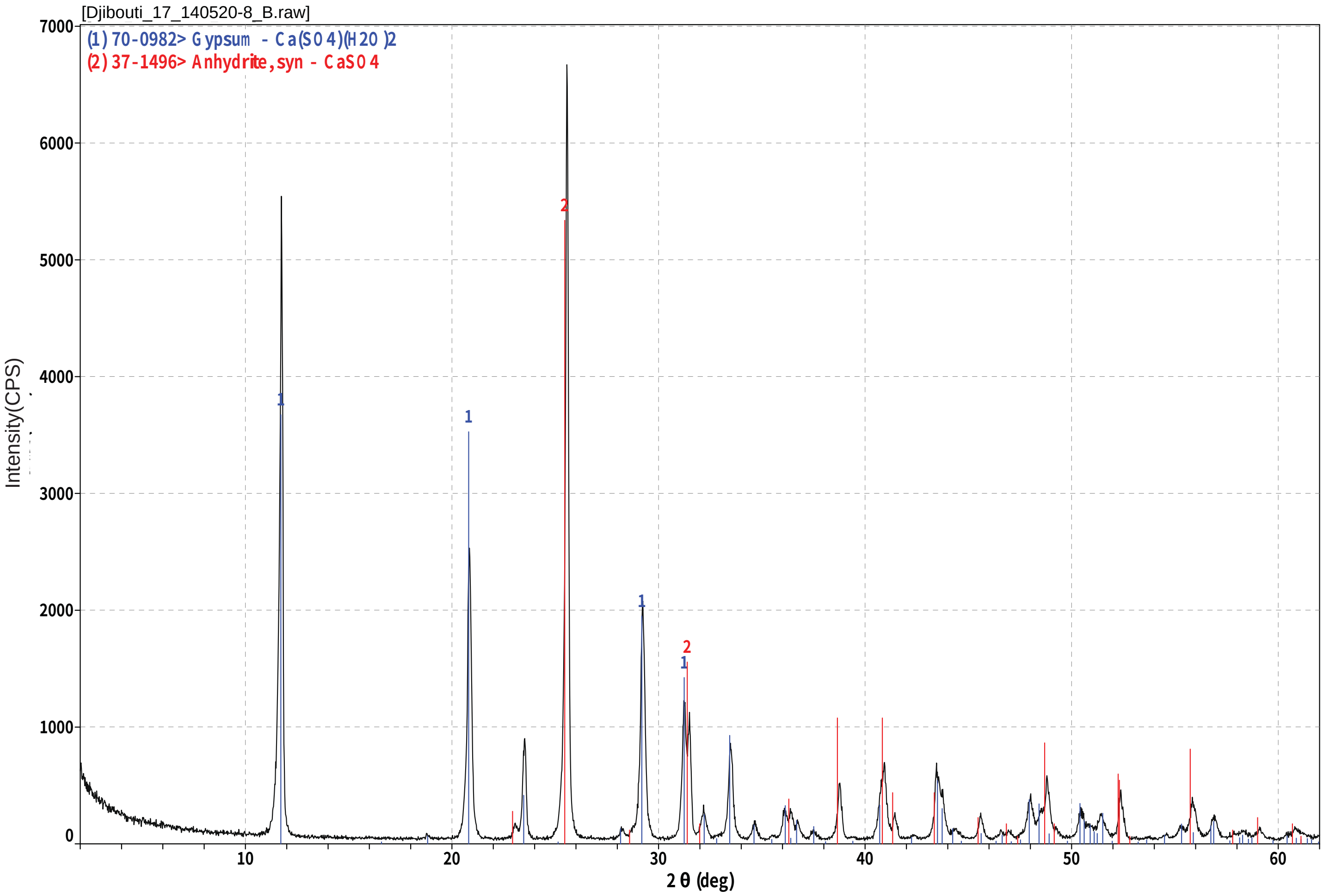

[Djibouti_09_140519-6_B.raw]
(1) 05-0586> Calcite, syn - CaCO3
Intensity(CPS)
12.0
10.0
8.0
6.0
4.0
2.0
x10^3
1
10
20
30
40
50
60
2θ (deg)

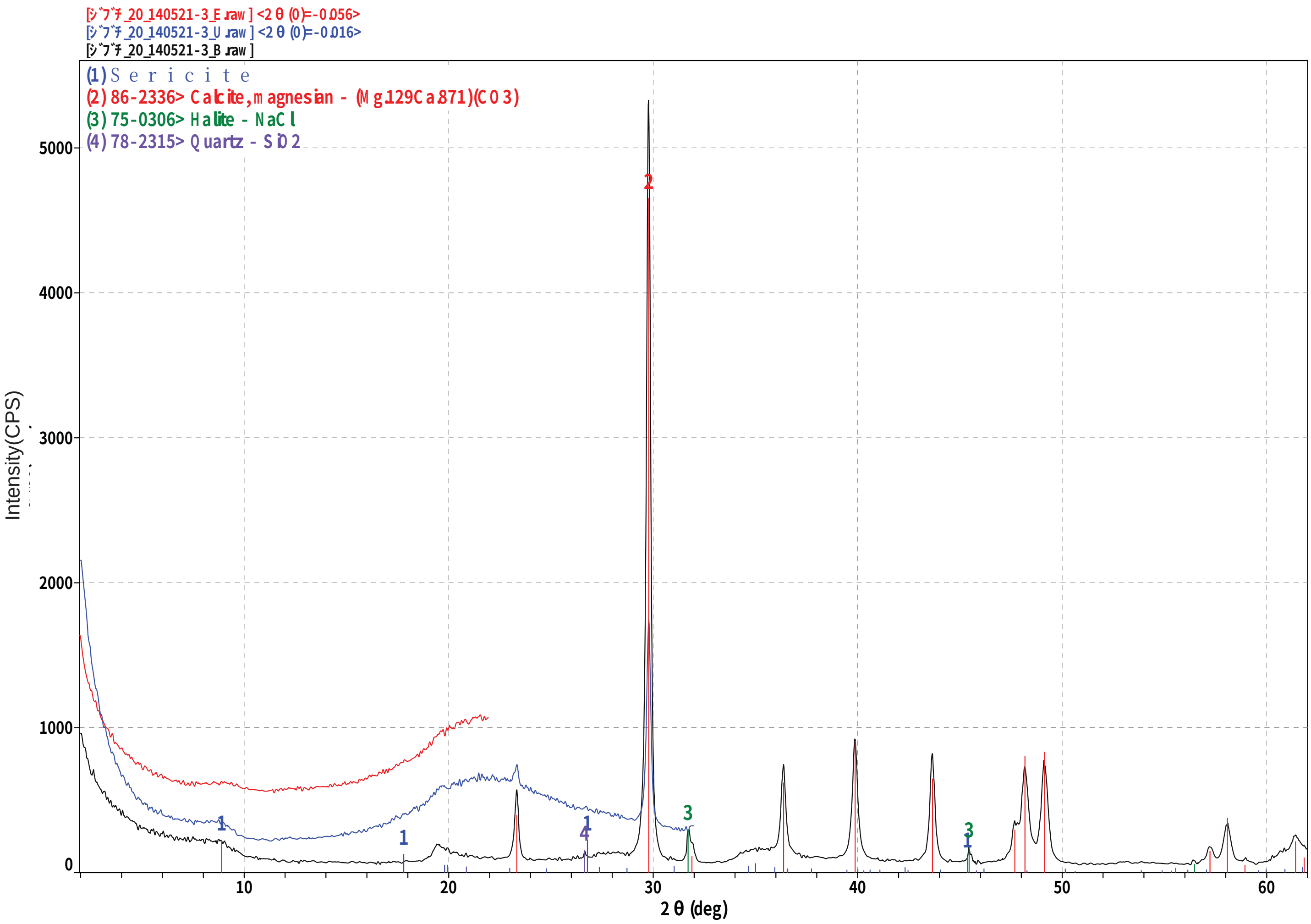

[Djibouti_11_140520-2_E.raw]
[Djibouti_11_140520-2_U.raw]
[Djibouti_11_140520-2_B.raw]
(1) 72-0596> Gypsum - Ca(SO4)(H2O)2
(2) 86-2270> Anhydrite - Ca(SO4)
(3) 85-1054> Quartz - SiO2
(4) 05-0586> Calcite, syn - CaCO3
(5) 24-0506> Clinochlore-1MIIb - (Mg5Al)(Si,Al)4O10(OH)8
(6) 89-6423> Albite - Na(AlSi3O8)
Intensity(CPS)
2θ(deg)

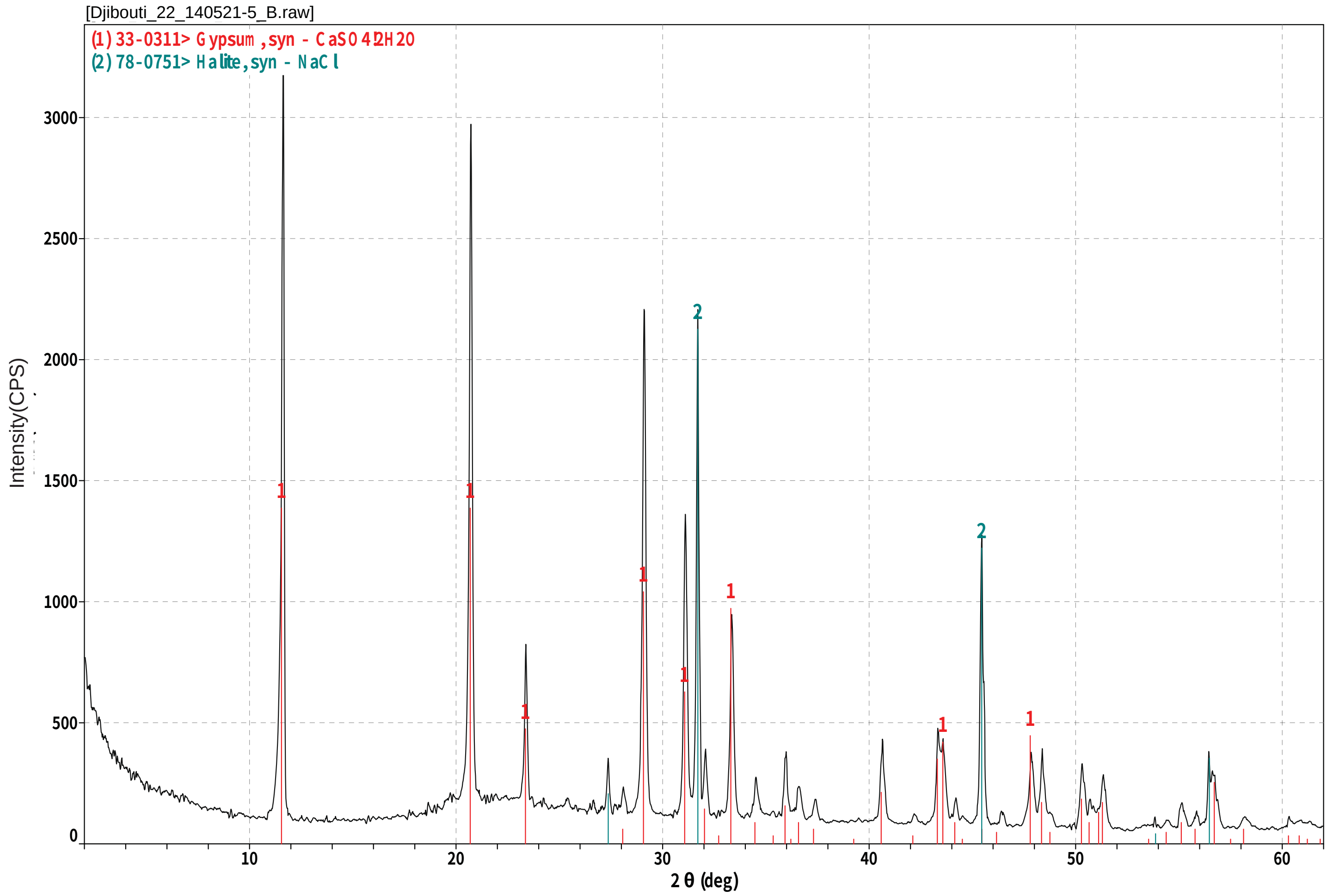

[Djibouti_12_140520-3_E.raw] <2θ(0)=0.216>
[Djibouti_12_140520-3_U.raw]
[Djibouti_12_140520-3_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 05-0586> Calcite, syn - CaCO3
(3) 37-1496> Anhydrite, syn - CaSO4
(4) 70-3752> Albite - (Na0.98Ca0.02)(Al1.02Si2.98O8)
(5)
Intensity(CPS)
2θ(deg)

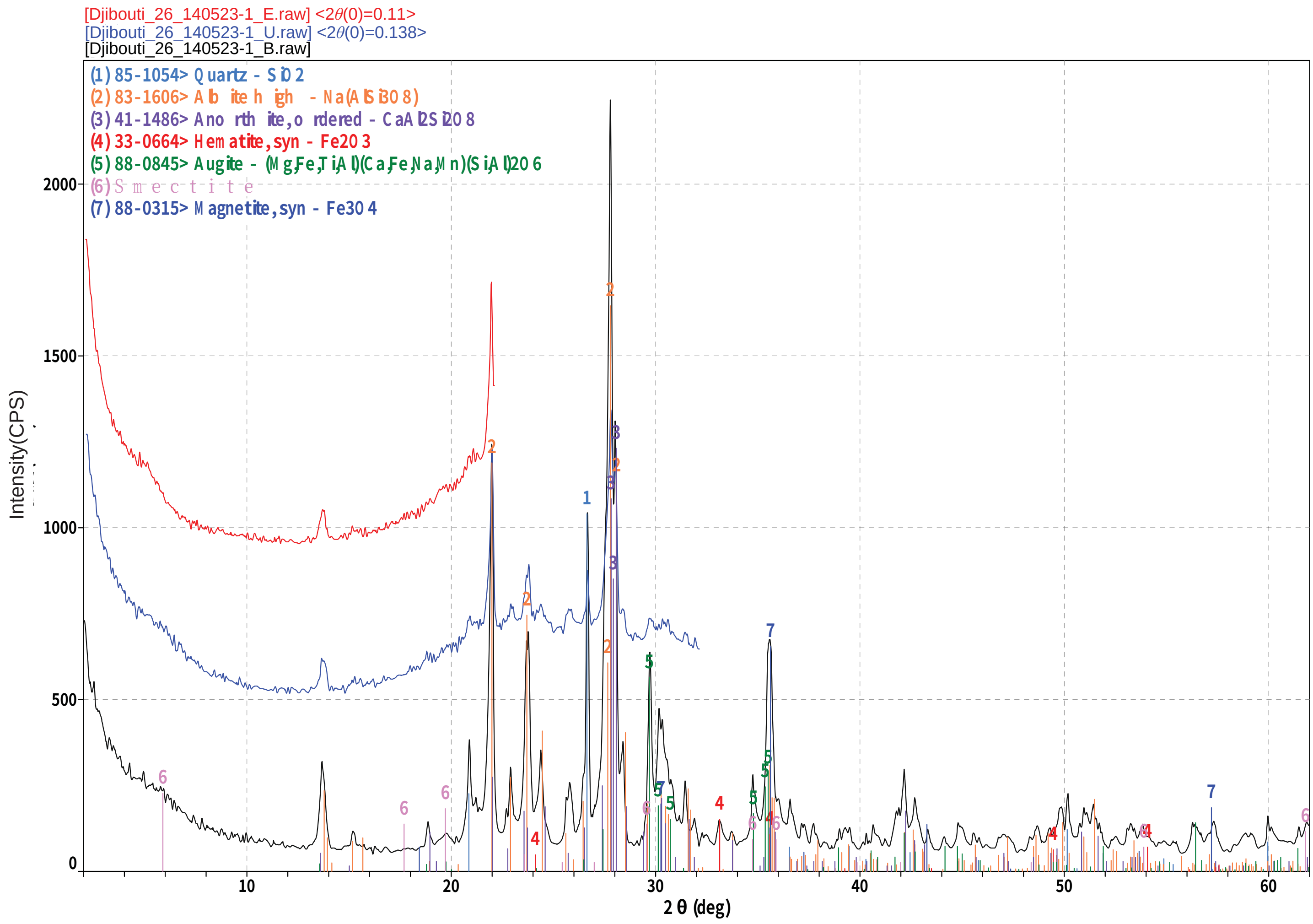

[Djibouti_14_140520-5_E.raw] <2θ(0)=0.174>
[Djibouti_14_140520-5_U.raw] <2θ(0)=0.136>
[Djibouti_14_140520-5_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 37-1496> Anhydrite, syn - CaSO4
(3) 89-0597> Hematite, syn - Fe2O3
(4) 05-0628> Halite, syn - NaCl
(5) 16-0606> Nacrite-2M2 - Al2Si2O5(OH)4
Intensity(CPS)
x10^3
2θ (deg)

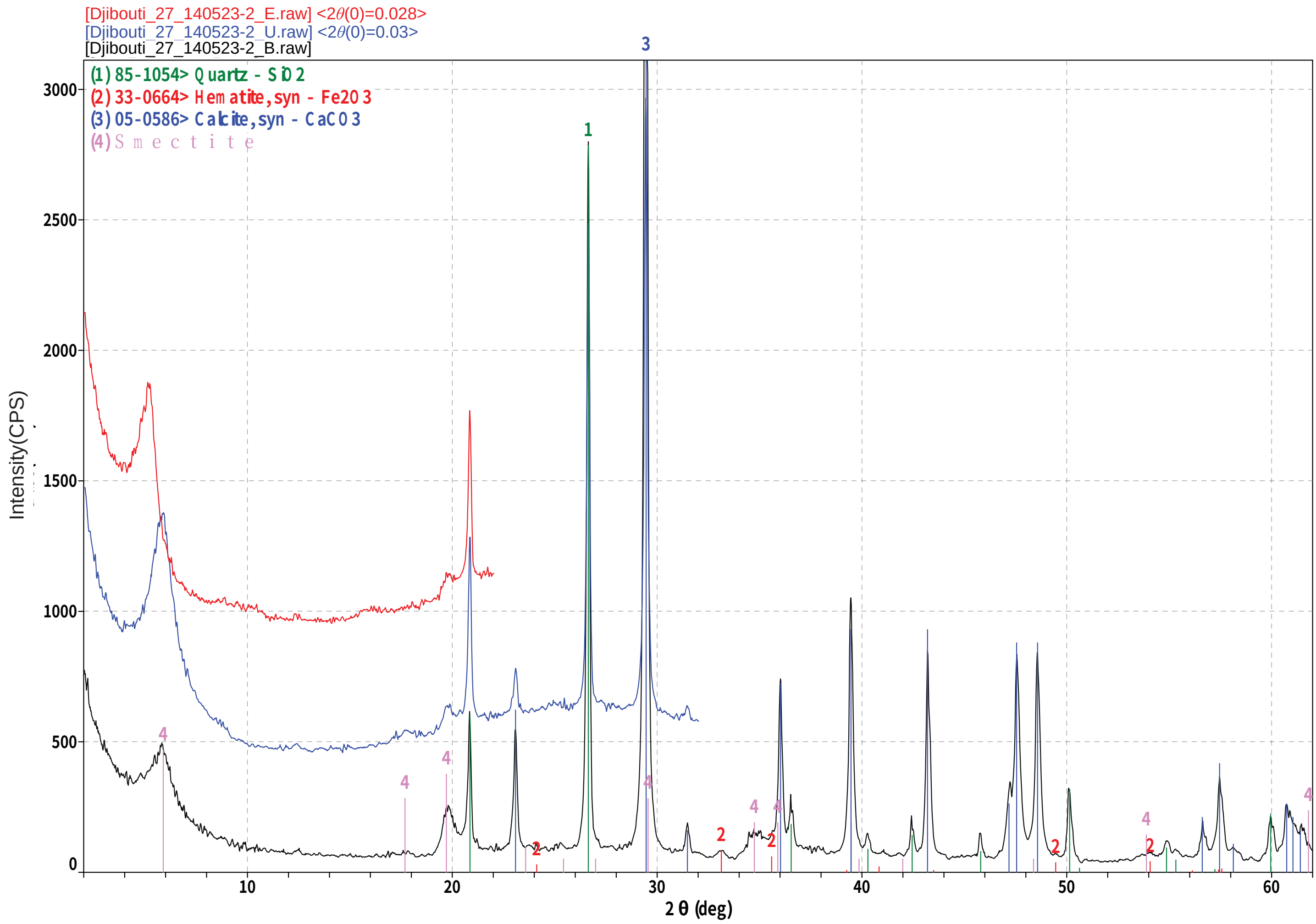

[Djibouti_15_140520-6_E.raw]
[Djibouti_15_140520-6_U.raw]
[Djibouti_15_140520-6_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 89-0597> Hematite, syn - Fe2O3
(3) 16-0606> Nacrite-2M2 - Al2Si2O5(OH)4
Intensity(CPS)
2θ (deg)


[Djibouti_17_140520-8_B.raw]
(1) 70-0982> Gypsum - Ca(SO4)(H2O)2
(2) 37-1496> Anhydrite, syn - CaSO4
Intensity(CPS)
2θ (deg)

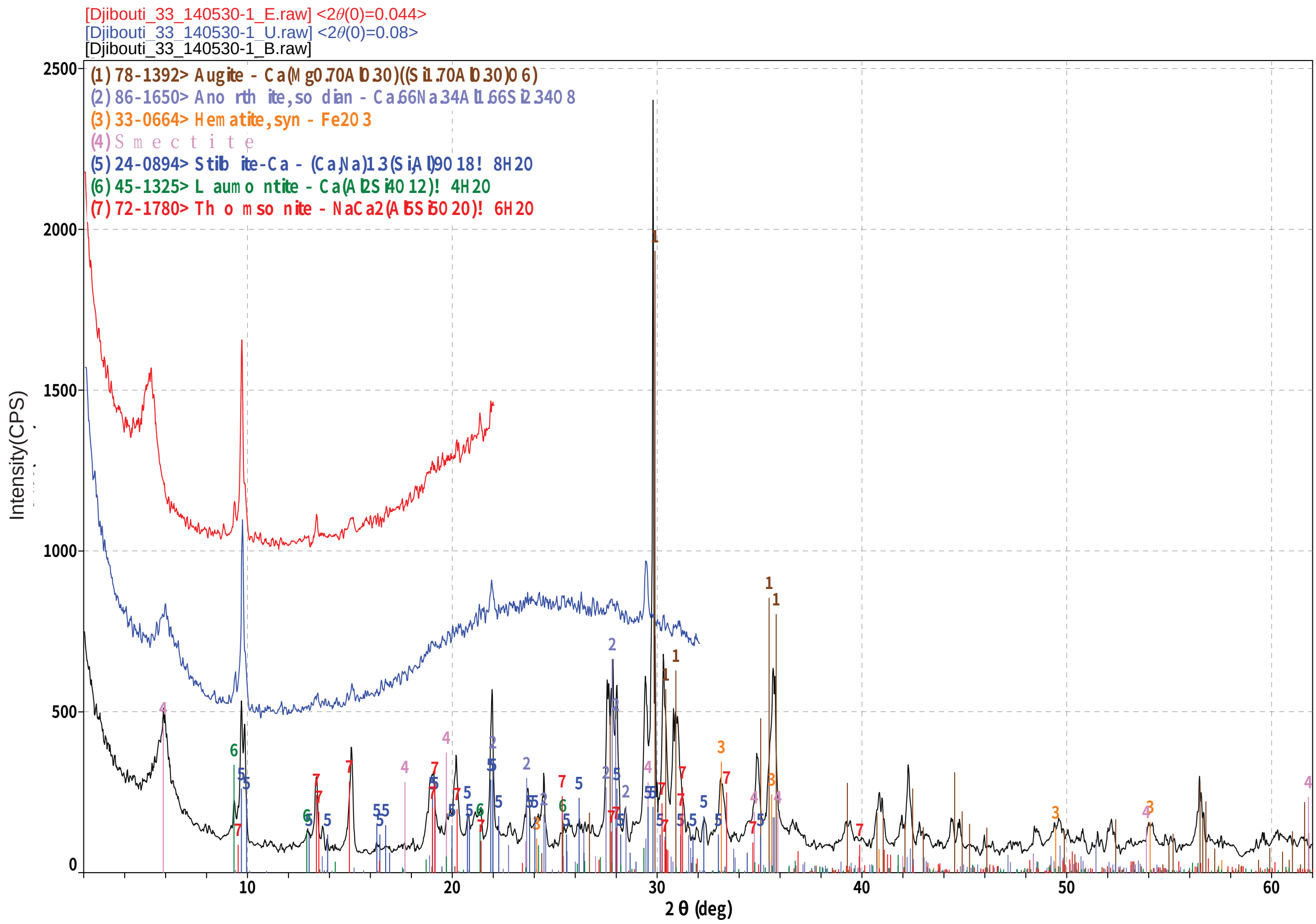

[ジブチ_20_140521-3_E.raw] <2θ(0)=-0.056>
[ジブチ_20_140521-3_U.raw] <2θ(0)=-0.016>
[ジブチ_20_140521-3_B.raw]
(1) Sericite
(2) 86-2336> Calcite, magnesian - (Mg.129Ca.871)(CO3)
(3) 75-0306> Halite - NaCl
(4) 78-2315> Quartz - SiO2
Intensity(CPS)
2θ (deg)


[Djibouti_22_140521-5_B.raw]
(1) 33-0311> Gypsum, syn - CaSO4!2H2O
(2) 78-0751> Halite, syn - NaCl
Intensity(CPS)
2θ (deg)

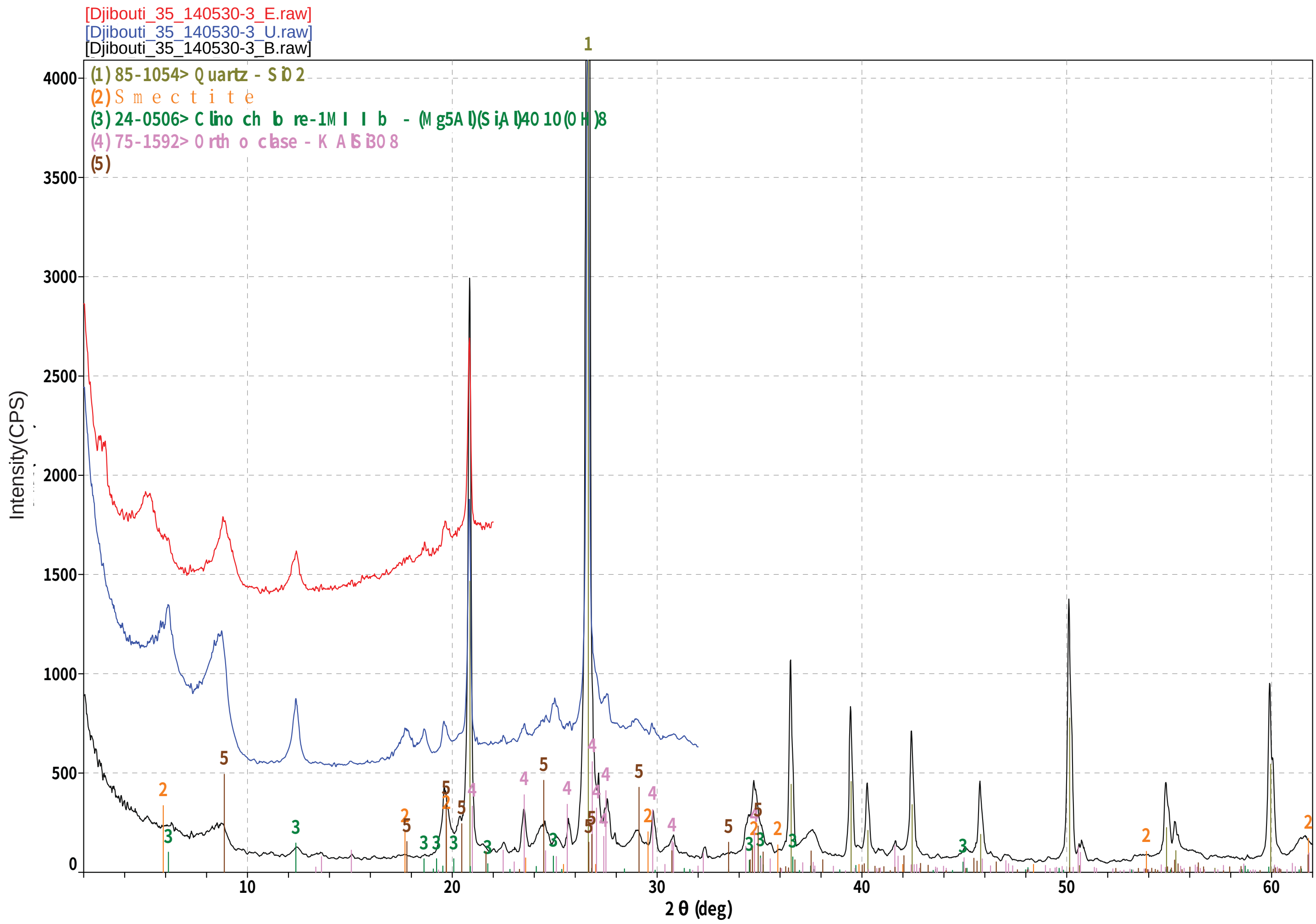

[Djibouti_26_140523-1_E.raw] <2θ(0)=0.11>
[Djibouti_26_140523-1_U.raw] <2θ(0)=0.138>
[Djibouti_26_140523-1_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 83-1606> Albite high - Na(AlSi3O8)
(3) 41-1486> Anorthite, ordered - CaAl2Si2O8
(4) 33-0664> Hematite, syn - Fe2O3
(5) 88-0845> Augite - (Mg,Fe,Ti,Al)(Ca,Fe,Na,Mn)(Si,Al)2O6
(6) Smectite
(7) 88-0315> Magnetite, syn - Fe3O4
Intensity(CPS)
2θ (deg)

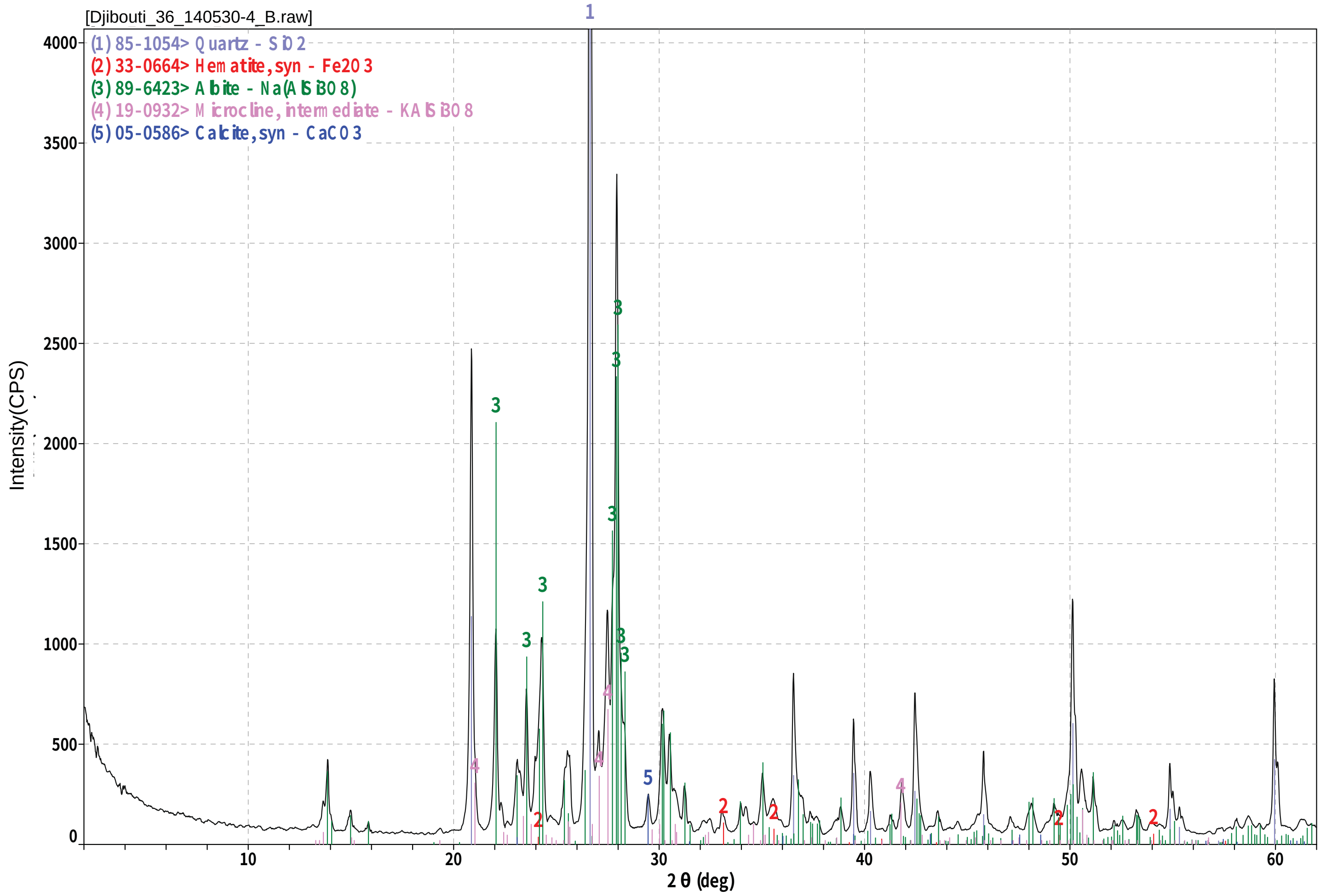


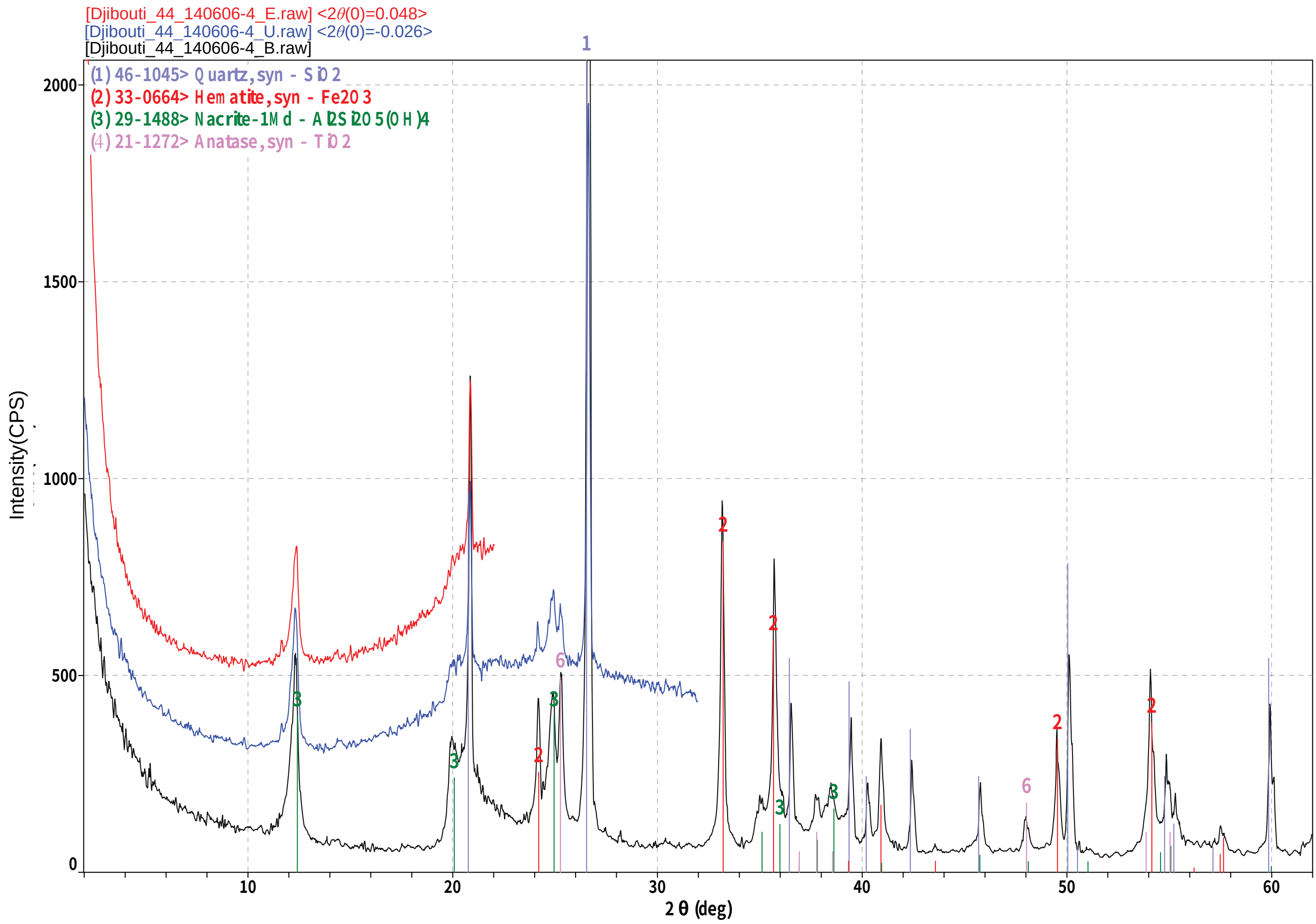
[Djibouti_27_140523-2_E.raw] <2θ(0)=0.028>
[Djibouti_27_140523-2_U.raw] <2θ(0)=0.03>
[Djibouti_27_140523-2_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 33-0664> Hematite, syn - Fe2O3
(3) 05-0586> Calcite, syn - CaCO3
(4) Smectite
Intensity(CPS)
2θ (deg)



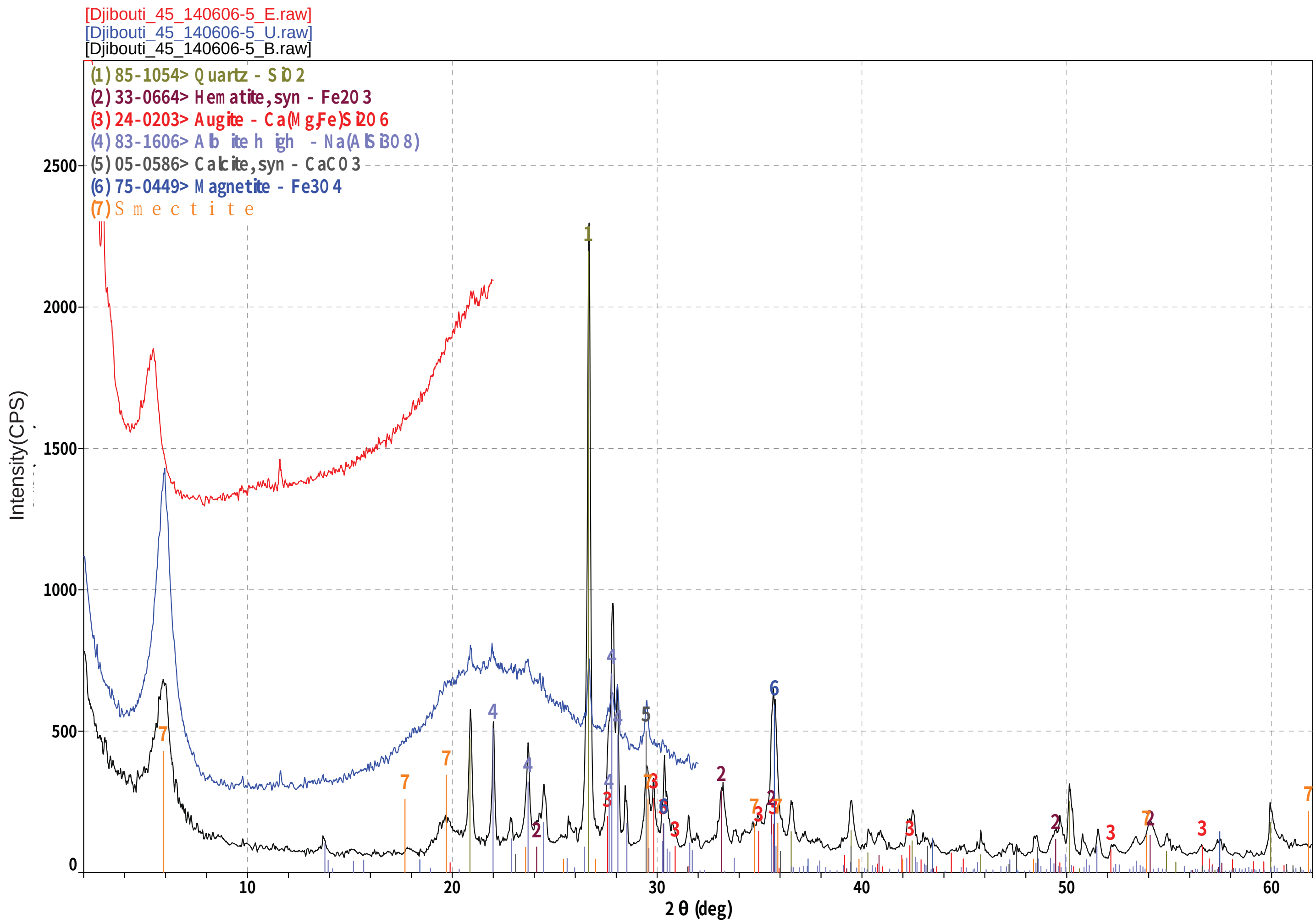
[Djibouti_33_140530-1_E.raw] <2θ(0)=0.044>
[Djibouti_33_140530-1_U.raw] <2θ(0)=0.08>
[Djibouti_33_140530-1_B.raw]
(1) 78-1392> Augite - Ca(Mg0.70Al0.30)((Si1.70Al0.30)O6)
(2) 86-1650> Anorthite, sodian - Ca.66Na.34Al1.66Si2.34O8
(3) 33-0664> Hematite, syn - Fe2O3
(4) Smectite
(5) 24-0894> Stilbite-Ca - (Ca,Na)1.3(Si,Al)9O18! 8H2O
(6) 45-1325> Laumontite - Ca(Al2Si4O12)! 4H2O
(7) 72-1780> Thomsonite - NaCa2(Al5Si5O20)! 6H2O
Intensity(CPS)
2θ (deg)


[Djibouti_35_140530-3_E.raw]
[Djibouti_35_140530-3_U.raw]
[Djibouti_35_140530-3_B.raw]
(1) 85-1054> Quartz - SiO2
(2) Smectite
(3) 24-0506> Clinochlore-1MIIb - (Mg5Al)(SiAl)4O10(OH)8
(4) 75-1592> Orthoclase - KAlSi3O8
(5)
Intensity(CPS)
2θ (deg)


[Djibouti_36_140530-4_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 33-0664> Hematite, syn - Fe2O3
(3) 89-6423> Albite - Na(AlSi3O8)
(4) 19-0932> Microcline, intermediate - KAlSi3O8
(5) 05-0586> Calcite, syn - CaCO3
Intensity(CPS)
2θ (deg)



[Djibouti_44_140606-4_E.raw] <2θ(0)=0.048>
[Djibouti_44_140606-4_U.raw] <2θ(0)=-0.026>
[Djibouti_44_140606-4_B.raw]
(1) 46-1045> Quartz, syn - SiO2
(2) 33-0664> Hematite, syn - Fe2O3
(3) 29-1488> Nacrite-1Md - Al2Si2O5(OH)4
(4) 21-1272> Anatase, syn - TiO2
Intensity(CPS)
2θ (deg)



[Djibouti_45_140606-5_E.raw]
[Djibouti_45_140606-5_U.raw]
[Djibouti_45_140606-5_B.raw]
(1) 85-1054> Quartz - SiO2
(2) 33-0664> Hematite, syn - Fe2O3
(3) 24-0203> Augite - Ca(Mg,Fe)Si2O6
(4) 83-1606> Albite high - Na(AlSi3O8)
(5) 05-0586> Calcite, syn - CaCO3
(6) 75-0449> Magnetite - Fe3O4
(7) Smectite
Intensity(CPS)
2θ (deg)