

# Overview of the "Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia" by the Geological Survey of Japan

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**Abstract:** A five-year Indonesia-Japan bilateral research cooperation program, named "Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia" (ESSEI Project), started in April 1997 and will end in March 2002. This paper gives an overview of the project by the Geological Survey of Japan as an introduction to this special volume. Background information of the project such as the objective, research cooperation regime, research schedule and shared tasks are reviewed. Annual activity and outline results of the Geological Survey of Japan are described.

## 1. Introduction

A five-year Indonesia-Japan bilateral research cooperation program, named "Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia" (ESSEI), started in April 1997 and will end in March 2002. The objective of this project is to develop a geothermal exploration system that is suitable for tropical remote islands in Indonesia and consequently, contribute to the Rural Electrification Program of the Indonesian government. The ESSEI project officially started when the Memorandum of Understanding (MOU) was signed by the three organizations in Jakarta on March 26, 1998. The implementing organizations are the Volcanological Survey of Indonesia (VSI), New Energy and Industrial Technology Development Organization (NEDO), and Geological Survey of Japan (GSJ). Japanese participating organizations have financially been supported by the budget of the Official Development Assistance (ODA) of the Ministry of International Trade and Industry (MITI).

Re-organizations were recently made in Indonesia and Japan during this project. The Geothermal Division of VSI moved into another organization, the Directorate of Mineral Resources Inventory since September 2001 while the major part of VSI was re-organized into the Directorate of the Volcanology and Geological Hazard Mitigation. GSJ was re-

organized into five research units under the National Institute of Advanced Industrial Science and Technology ("new" AIST). Nevertheless, GSJ is maintained as the name of a functional committee among these five units so that the name GSJ is used in this volume.

This paper gives an overview of the project by the GSJ as an introduction to this special volume. Background information of the project such as the objective, research cooperation regime, research schedule and shared tasks are reviewed. Annual activity and outline results of the Geological Survey of Japan are described.

## 2. Outline of the project

### 2.1 Objective and participating organizations

The objective of this project is to develop a geothermal exploration system that is suitable for tropical remote islands in Indonesia and consequently, contribute to the Rural Electrification Program of the Indonesian government.

Figure 1 shows a cooperation regime of this project as of March 1998. Many organizations have been involved in this project regarding the administration, funding, technical investigations and logistics. This project has been administrated by the Directorate General of Geology and Mineral Re-

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Keywords: international cooperation, geothermal research project, geothermal exploration, overview of project, Asia, eastern Indonesia, Flores Island, Bajawa, Mataloko, rural electrification

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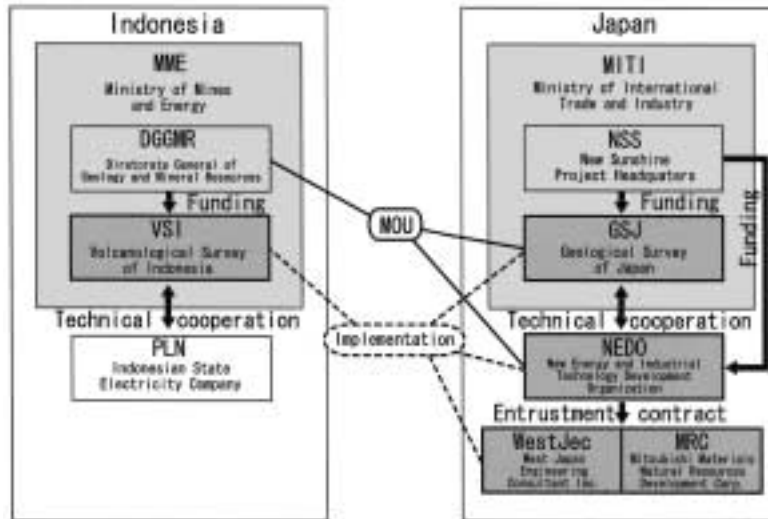


Fig. 1 Cooperation regime of the Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia as of March 1998.

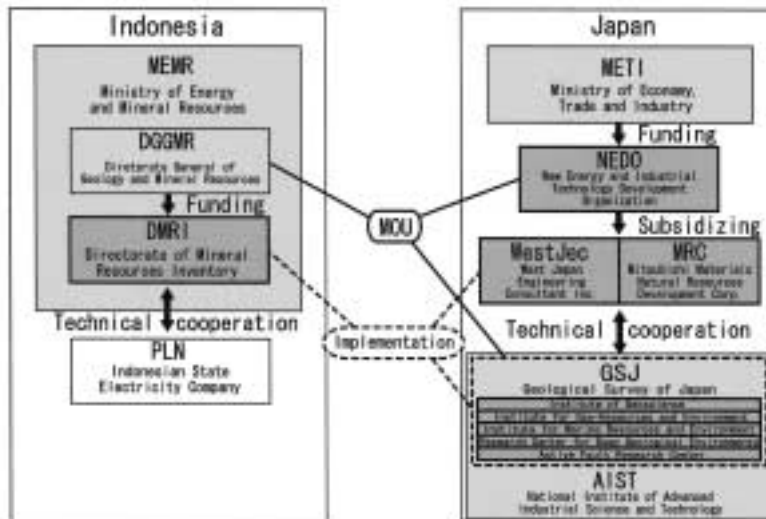


Fig. 2 Cooperation regime of the Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia as of October 2001.

sources (DGGMR) in Indonesia and the New Sunshine Project Promotion Headquarters (NSS) in Japan. The MOU was signed by three organizations, DGGMR, NEDO and GSJ. Technical investigations have been mainly performed by three organizations: VSI, NEDO and GSJ. The VSI and GSJ have conducted the investigations by their own researchers, while NEDO has made an entrustment contract with West Japan Engineering Company Inc. (WestJec) and Mitsubishi Materials Natural Resources Development Corp. (MRC) for the investigations. The Indonesian State Electricity Company (PLN) is the main implementing organization for the Rural Electrification Program and played the role of an adviser to this project as a developer of small-scale geothermal power plants.

However, as already mentioned, re-organizations were recently made in Indonesia and Japan in 2001 as summarized in Fig. 2. In Japan, MITI was re-organized into the Ministry of Economy, Trade and Industry (METI) and its AIST was dissolved in January 2001. Fifteen institutes under the former AIST was re-organized into the National Institute of Advanced Industrial Science and Technology (new AIST) in April 2001 where the former GSJ was re-organized into five research units as shown in Fig. 2. GSJ is no longer an official organization but is still maintained as a functional committee for collaboration of the five research units. In Indonesia, the Ministry of Mines and Energy was re-organized into the Ministry of Energy and Mineral Resources in August 2001. However, before the date, DGGMR

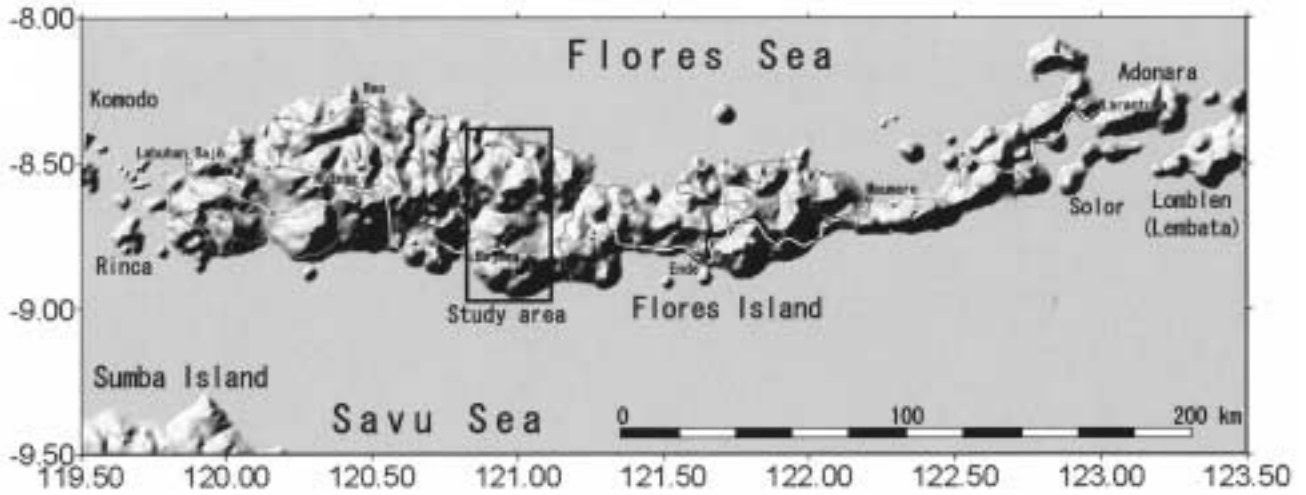


Fig. 3 Shaded-relief digital topographic map of Flores Island and the study area of the Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia. The source DEM data are GTOPO30 released from the USGS EROS Data Center and were shaded by Masao Komazawa.



Fig. 4 Shaded-relief digital topographic map of the study area of the Research Cooperation Project on the Exploration of Small-scale Geothermal Resources in the Eastern Part of Indonesia, central Flores, Indonesia. Keiji Tanaka, Hirofumi Muraoka and Masao Komazawa have digitized it from the topographic maps on a scale 1: 25,000 in this project.

was conceptually reorganizing since February 2001 and implemented in September 2001. Consequently, VSI was re-organized into the Directorate of the Volcanology and Geological Hazard Mitigation (still abbreviated as VSI) and its Geothermal Division moved into the Directorate of Mineral Resources Inventory (DMRI).

### 2.2 Study area

Figure 3 shows the study area of this project selected from the 1997 reconnaissance survey. Based on the objective of this project, the study area should be selected from the remote islands in eastern part of Indonesia. In addition, the study area should have geothermal potential as well as social demand for geothermal electricity developments in the near future from the viewpoint of the Rural Electrification Program in Indonesia.

The selected area includes three steaming grounds as shown in Fig. 4: Mataloko, Nage and Bobo areas and an area with a huge amount of hot spring discharge: Mengeruda. Discharges of 1000 tons per hour of hot water with a temperature of 48.5 °C and 1600 tons per hour of hot water with a temperature of 41.3 °C were roughly estimated at the

lower streams in the Nage and Mengeruda areas, respectively, promising high geothermal potential for the study area. The study area also includes Bajawa City, capital of the Ngada District, with a population of 13,000. Including its suburbs, there are about 50,000 residents, but only 2 MW of electricity are supplied to a limited part of the city from small diesel and hydraulic power plants. Electricity demands are much larger than the present supply, particularly in its suburbs, that have no access to electricity.

### 2.3 Term and roles of participating organizations

Shared tasks among three implementing organizations were defined by two aspects: survey areas and items. Figure 4 shows the project survey areas are on two different scales and categorized as: 1) the GSJ survey area called the regional assessment area, which covers geothermal prospects, heat source volcanoes and exposure of basement units for volcanoes, and 2) the NEDO survey area called the initial exploration area, which includes major geothermal prospects. As the survey work proceeds, a detailed exploration area where potential geothermal reser-

Fiscal year	1997	1998	1999	2000	2001
Selection of the survey area		■			
Satellite remote sensing	■	■	■	■	
Geological survey	■	■	■	■	■
Geochemical survey	■	■	■	■	■
Gravity survey	■	■	■	■	■
Electrical-electromagnetic survey	■	■	■	■	■
Heat hole survey		■	■	■	
Exploration drilling survey			■	■	■
Geothermal modeling			■	■	■
Regional geothermal assessment			■	■	■
Construction of GEMS and analysis		■	■	■	■
Technical training		■	■	■	■

Fig. 5 Work schedule of research items for the project.

Table 1 Task-sharing plan of research items for the project.

Fiscal year	VSI	PLN	GSJ	NEDO
Selection of the survey area	A	A	C	C
Satellite remote sensing	C		A	B
Geological survey	A	C	A	A
Geochemical survey	A		A	A
Gravity survey	A		C	A
Electrical-electromagnetic survey	B		B	A
Heat hole survey	A			C
Exploration drilling survey	C			A
Geothermal modeling	C		A	A
Regional geothermal assessment	C		A	
Construction of GEMS and analysis	C			A
Technical training	A	A	A	A

A is responsible for the task  
 B substantially contributes to carrying out the task  
 C contributes to carrying out the task

Name	Administrative role	Technical role	External role	FY1997	FY1998	FY1999	FY2000	FY2001
Kisaburo Kodama*	Director General		Signer for MOU	*****	*****	*****	*****	*****
Tatsuro Noda*	Director							*****
Masakatsu Sasada	Advisor	Geological survey	Committee Member**					
Minoru Urai		Remote sensing						
Hirofumi Muraoka	Group Leader	Geological survey	Committee Member**					
Isao Takashima		TL age dating						
Takayuki Sawaki		Fluid inclusions analyses						
Masahiro Taniguchi*		Laboratory assist for invitees		*****	*****	*****	*****	*****
Msaaki Takahashi		Geochemistry						
Masao Komazawa		Gravity survey						
Toshihiro Uchida	Sub-Group Leader	Resistivity survey						
Kasumi Yasukawa		Self-potential survey						
Tsuneo Kiauchi		Computer-aided analysis						
Yasukuni Okubo		Computer-aided analysis						

\*Non-member

\*\*Committee for NEDO ESSEI Project by WestJec

Fig. 6 Members of the GSJ ESSEI project and their roles.

voirs are present is extracted from the initial exploration area. The GSJ is responsible for the regional assessment area, and NEDO is responsible for the initial exploration area. The VSI is responsible for both areas as an organization of the host country. The regional assessment area of GSJ is designed as a transection of the central Flores Island from the north shore to south shore between 120° 52' 30" E and 121° 07' 30" E as shown in Fig. 4. It is convenient to make a cross sectional model.

Figure 5 shows a draft work schedule on the research items of this project. Main events are drilling surveys such as the heat hole survey by VSI in FY 1999 and exploration drilling survey by NEDO in FY 2000. Table 1 shows a task-sharing plan among the three implementing organizations. Many items are jointly carried out by the three organizations for cooperation purposes. Items that are mainly conducted by a specific organization are: the heat hole survey by VSI, satellite remote sensing and regional assessment by GSJ and exploration drilling and construction of the Geothermal Expert Modeling System (GEMS) by NEDO.

To construct a geothermal exploration system suitable for tropical remote islands in Indonesia, geothermal modeling of the area is most important. The NEDO mainly focuses on the subsurface modeling by the exploration drilling survey. On the other hand, GSJ mainly focuses on the regional modeling by the survey over the regional assessment area. Another role of GSJ is logistics to NEDO from a viewpoint of scientific research background.

#### 2.4 Roles of members of the Geological Survey of Japan

Figure 6 summarizes the durations and roles of the members that participated in the ESSEI Project for the GSJ. This research group was initiated

with six members and we tried to make an individual role of each member since the initial stage of this project. However, as the requirements of this project expanded, an additional five members participated.

### 3. Reviews of annual activity

Figure 7 summarizes the survey periods of the field works by the GSJ group. Since the study area is situated in a remote area, it takes a few days to the area but the days for transportation are excluded in Fig. 7. Annual activities by the GSJ group are briefly reviewed in this section.

#### 3.1 Summary of FY1997 investigations

Although the project officially started when the MOU was signed by the three organizations in Jakarta on March 26, 1998, preliminary research efforts already started at the beginning of the fiscal year in both Indonesia and Japan.

In July, three GSJ researchers carried out reconnaissance surveys in cooperation with researchers of VSI at the five prospective geothermal areas for this project: Wai Sano, Wai Pesi and Mataloko in Flores, Watukuba in Lembata and Bukapiting in Alor. The survey results were reported in the Chishitsu (Geological) News (Muraoka *et al.*, 1998; Urai *et al.*, 1998; Takahashi *et al.*, 1998). The five prospective geothermal areas have been preliminarily evaluated based on five criteria: accessibility, demand for development, types of geothermal heat sources, extent of surface manifestations and estimated geothermal potential. The Mataloko geothermal field near Bajawa, central Flores, was the only prospective area that satisfied all five criteria among the five areas so it was recommended. The Mataloko geothermal field was officially selected as the study area of this project by the end of this

FY1997 survey																																
Name of Researcher	Theme	July 1997																														
		7	8	9	10	11	12	13	14	15																						
Minoru Urai	Reconnaissance																															
Hirofumi Muraoka	Reconnaissance																															
Masaaki Takahashi	Reconnaissance																															
FY1998 survey																																
Name of Researcher	Theme	July 1998																														
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29													
Hirofumi Muraoka	Geological mapping																															
Isao Takashima*	TL age measurements																															
Masaaki Takahashi	Fluid geochemistry																															
Toshihiro Uchida	Resistivity survey																															
Kasumi Yasukawa	SP-survey																															
FY1999 survey																																
Name of Researcher	Theme	August 1999										September 1999																				
		28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	
Minoru Urai	GPS measurements																															
Hirofumi Muraoka	Geological mapping																															
Isao Takashima*	TL age measurements																															
Masaaki Takahashi	Fluid geochemistry																															
Masao Komazawa	Gravity survey																															
Toshihiro Uchida	Resistivity survey																															
Kasumi Yasukawa	SP-survey																															
Tsuneo Kikuchi	Data integration																															
FY2000 survey																																
Name of Researcher	Theme	July 2000						August 2000																								
		25	26	27	28	29	30	31	1	2	3	4	5	6																		
Minoru Urai	Remote sensing																															
Hirofumi Muraoka	Geological mapping																															
Masakatsu Sasada	Geological mapping																															
Isao Takashima*	TL age measurements																															
Masao Komazawa	Gravity survey																															
Yasukuni Okubo	Data integration																															
FY2000 monitoring																																
Name of Researcher	Theme	January 2001																														
		20	21	22	23	24	25	26	27	28																						
Hirofumi Muraoka	Flow test monitoring																															
Masaaki Takahashi	Flow test sampling																															
Kasumi Yasukawa	SP-monitoring																															
FY2001 survey and monitoring																																
Name of Researcher	Theme	July 2001													August 2001																	
		9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5			
Minoru Urai	GPS measurements																															
Hirofumi Muraoka	Geological mapping																															
Masao Komazawa	Gravity survey																															
Toshihiro Uchida	Resistivity survey																															
Kasumi Yasukawa	SP-monitoring																															

\* Prof. Isao Takashima, Akita University, was temporarily invited to the GSJ party.

Fig. 7 Net survey periods of the field surveys by the GSJ group.

fiscal year.

3.2 Summary of FY1998 investigations

Full-scale budget came to be available from the FY 1998 at GSJ, allowing intensive investigations on remote sensing, geology, geochemistry, geophysics and reservoir engineering. Field works have mainly focused on geology, geochemistry and self-potential (SP) surveys in this year. Geological survey covered the southern half of the study area and fundamental stratigraphy was established. Sampling for thermoluminescence (TL) age measurements was also done in the Mataloko and Nage areas. Sampling of hot spring water for fluid geochemistry was done at major hot spring discharge areas in the southern half of the study area. The SP survey was completed in the Mataloko

geothermal field. Analytical works in laboratories were finished immediately after the field surveys, and most of the results have been described in the 1998 Interim Report for the rapid information exchange among the participating organizations (Muraoka and Uchida, 1999; Urai *et al.*, 1999; Muraoka *et al.*, 1999; Takashima *et al.*, 1999; Takahashi *et al.*, 1999; Uchida and Andan, 1999; Yasukawa *et al.*, 1999).

An other important activity was an invitation program. GSJ invited two VSI researchers, Mr. Fredy Nanlohy and Mr. Dedi Kusnadi, from October 24 to November 12, 1998. Mr. Asnawir Nasution was invited by NEDO. The two researchers and he visited the Sumikawa geothermal power plant, TL age measurement laboratory of Akita University and the drilling site of well N9-AY-4 in the NEDO

Geothermal Development Promotion Survey during November 2-5.

### 3.3 Summary of FY 1999 investigations

The GSJ group's field survey consisted of eight researchers: one remote sensing researcher, two geologists, one geochemist, three geophysicists and one reservoir engineer (Fig. 7). Research items on the field surveys are almost the same as FY1998. However, gravity and MT surveys were initiated this year. A few days were spent in Bandung for the discussion, particularly on the optimum site for the VSI heat hole survey. Figure 7 shows the periods of the field surveys for individual researchers. Preliminary results of the field works were summarized in each paper of the 1999 Interim Report (Muraoka and Uchida, 2000; Urai *et al.*, 2000; Muraoka *et al.*, 2000; Takashima *et al.*, 2000; Takahashi *et al.*, 2000; Komazawa *et al.*, 2000; Uchida *et al.*, 2000; Yasukawa *et al.*, 2000).

The researcher of remote sensing made GPS measurements in the surroundings of the Mataloko geothermal field for the dual purposes of ground control points for image processing and detection of ground deformation. These results can be evaluated after the next GPS measurements two years later. Therefore, Urai *et al.* (2000) described the results of image processing. Muraoka *et al.* (2000) described the results of geological works including tectonics, field observation and K-Ar age measurement. Takashima *et al.* (2000) described the results of TL age measurement that was able to evaluate the age of alteration zones. Takahashi *et al.* (2000) reported the results of analyses of water samples taken from many hot springs in the survey area including the northern half of the study area. Komazawa *et al.* (2000) reported the result of gravity measurements in the Bajawa geothermal field and its surroundings. Uchida *et al.* (2000) reported the results of the MT survey. This provided resistivity profiling, contributing to the subsurface evaluation. Yasukawa *et al.* (2000) reported the results of self-potential measurement in the Nage area that was able to extract up-flow zones of hydrothermal convection.

After the GSJ field surveys, VSI started to drill a heat hole named MTL-1 in the Mataloko geothermal field. This well succeeded to produce dry steam in October.

GSJ invited two VSI researchers, Mr. Kastiman Sitorus and Mr. Ashari, to Japan from January 17 to March 4, 2000. During January 31 to February 5, they visited the Hachijojima geothermal power plant that would have provided a model for the Rural Electrification Program in remote island areas. During February 7 to February 12, they also visited the Hachobaru and Takigami geothermal power plants and Aso caldera. A meeting with the

three implementing organizations was held at GSJ on January 20. The discussion focused on the optimum site for the exploration drilling survey by NEDO. Another meeting was held in Bandung in March 2000, and the optimum site for the NEDO exploration drilling survey was finally determined.

### 3.4 Summary of FY 2000 investigations

A main event of this project is an exploration drilling survey by NEDO. Therefore, the first priority of the work was placed on the NEDO exploration drilling. For this purpose, the GSJ field works were divided into two terms: one was short-term surveys for the integration of the survey results for the drilling survey in July and the other was monitoring surveys during a flow test for the NEDO exploration well after the drilling completion in January 2001.

The VSI has hosted IAVCEI (the International Association of Volcanology and Chemistry of the Earth's Interior) General Assembly 2000 on Bali Island during July 18-22, 2000. Several GSJ researchers for the field surveys attended this symposium for the dissemination of the ESSEI Project results on the way to the field. Six researchers carried out relatively short-term field works: ground truth for infrared sensor of the ASTER satellite, geological survey, sampling for TL age measurements and data integration. Only gravity survey has been carried out in a relatively long term.

A ceremony and demonstration of a flow test on well MT-2 were held at January 20, 2001 in front of several guests from the Indonesian Parliament, other governmental organizations and several hundred local residents. It was quite successful and about 15 tons/hr of dry steam at an atmospheric pressure was discharged from a depth of 162.35 m. Geochemical and SP monitoring were conducted during the flow test of the NEDO well MT-2 to obtain time-sequential data. An eruption of Inie Lika volcano started on January 11, 2001 after 95 years of quiescence. Therefore, during the monitoring surveys, GSJ researchers also observed the eruption centers of Inie Lika volcano.

The GSJ invited two VSI researchers, Mr. Asnawir Nasution and Mr. Herry Sundhoro, to Japan from January 30 to March 8, 2001. During February 3-9, they visited the TL age measurement laboratory of Akita University. During February 19-24, they also visited the Hachobaru and Takigami geothermal power plants and Aso caldera. The GSJ hosted the ITIT International Symposium "Geothermal Development in Asia" in Tokyo during February 28 to March 1. Two GSJ invitees and Dr. Sjafra Dwipa and Mr. Janes Simanjuntak invited by NEDO presented the results of the ESSEI Project at this symposium.

### 3.5 Summary and schedule of FY 2001 investigations

After a short-term flow test of well MT-2 in January 2001, VSI slightly deepened the well to a depth of 182.35 m and conducted a three-month flow test of well MT-2 from April 15 to July 15, 2001. As a result, a stable discharge of 25 tons/hr of dry steam at atmospheric pressure was confirmed. The GSJ group carried out final field works from July to August that consisted of GPS measurements, geological survey, gravity survey, MT survey and SP monitoring of well MT-2 (Fig. 7).

This year is a final stage of this project that is still ongoing. The GSJ will concentrate most of its efforts in publishing and disseminating the final results of this project. The efforts are divided into three lines of works: to publish a special volume, publish a CD-ROM and hold a final seminar. This special volume resulted from the first effort of this year. Obtaining enthusiastic contributions from DMRI, VSI, WestJec and MRC, a scheme of the special volume seems to have succeeded. A CD-ROM will be published immediately after this special volume. An Open Seminar for the ESSEI Project is scheduled on February 20, 2002 at Bandung, Indonesia and Fourth Asian Geothermal Symposium from February 21 to 22, 2002, sponsored by NEDO.

## 4. Outline of the results

A list of all the contributions to ESSEI Project by the GSJ is attached in Appendix 1. Individual results of the ESSEI Project are described in each paper of this special volume in detail. We here summarize only the important points of each survey method conducted by the GSJ party.

### 4.1 Remote sensing

When we have started a reconnaissance survey in July 1997, available base maps were only JERS-1 SAR (synthetic aperture radar) imagery. Although the climate of eastern Indonesia is slightly dry compared to western Indonesia, it takes quite a long time to acquire satellite imagery of the optical sensors with less cloud cover. Actually, we could not have acquired a less cloudy imagery of JERS-1 OPS (optical sensor) in the study area until now. Therefore, microwave band imagery like JERS-1 SAR that can penetrate the cloud cover is quite useful and has been a valuable base map throughout the entire period of this project (Urai *et al.*, 2002). Most field surveys have spent much time on GPS measurements, but unfortunately the data quality seem still unclear probably due to a mechanical trouble of the equipment on the second time measurements in 2001.

In a later stage of this project, Japan/USA

ASTER satellite data became available and its infrared sensor ASTER TIR enables us to directly extract large-scale high-temperature geothermal areas on the night-time imagery. The Nage geothermal field is beautifully displayed on the imagery (Urai *et al.*, 2002). Satellite remote sensing is one of key methods in the geothermal exploration for less accessible remote area.

### 4.2 Geological survey

Geological surveys have been conducted by three methods: geological mapping survey, thermoluminescence age dating and fluid inclusion study. The geological mapping survey has completed a geological map of the entire study area in Fig. 4 (Muraoka *et al.*, 2002a). Although field surveys for one or two weeks a year from FY1998 to FY2001 were not necessarily enough time to complete the regional map, blank areas for the field surveys were considerably assisted by the interpretation of satellite imagery (Urai *et al.*, 2002). One of the representative results was the recognition that the Bajawa Cinder Cone Complex consists of more than 60 cinder cones and plays a key role as a heat source in the study area (Muraoka *et al.*, 2002a). Geochemical analyses on 46 volcanic rock samples were carried out. The study shows that the Bajawa Cinder Cone Complex is andesitic, calc-alkaline and quite homogeneous (Muraoka *et al.*, 2002b). We were fortunate that a phreato-magmatic eruption of the Inie Lika volcano occurred on January 11-16, 2002. Immediately after the eruption, we had an opportunity to visit there and obtained valuable information (Muraoka *et al.*, 2002c).

Most of the prospective heat source volcanoes in the study area are too young to be dated by the K-Ar age dating method. Therefore, an expert of TL age dating was invited from Akita University to be a member of the GSJ group. The TL age dating method provided us valuable age data: 72-160 ka for the Bajawa Cinder Cone Complex and 12-54 ka for the major alteration haloes in the study area (Takashima *et al.*, 2002).

An expert of fluid inclusion analysis was also invited for the analysis of cuttings from the MT-1 and MT-2 wells even in the final year of this project. The MT-1 and MT-2 wells are too shallow to find abundant fluid inclusions. Nevertheless, the fluid inclusion study clarifies that the trapped fluids were derived from vapor condensate at 220-235 °C. The temperature is considerably higher than the boiling point curve and about 100 m of erosion might have occurred after the fluid trapping (Sawaki and Muraoka, 2002).

### 4.3 Geochemical survey

Geochemical survey is one of the practical and



necessary methods to evaluate geothermal resources in a given area. Major components and oxygen, hydrogen and sulfur isotopic components were analyzed on many thermal and cold waters in the study areas (Takahashi *et al.*, 2002a, 2002b). Geochemically, most thermal waters are classified into the acid sulfate type, and Nage thermal waters are classified into acid sulfate-chloride type. The former type is derived by a mixing of low temperature volcanic gases and meteoric waters, and the latter may be originated from high temperature volcanic gases. However, the oxygen and hydrogen relations show that most of the thermal waters are derived from local meteoric waters, and Mataloko thermal waters have no connection with local meteoric waters.

Samples treated in the geochemical survey include a variety of thermal waters not only from the study area but also from almost the entire Flores Island such as Wai Sano in western Flores and Oka Larantuka in eastern Flores.

#### 4.4 Gravity survey

The gravity survey was initiated from the fiscal year 1999. Nevertheless, about 800 points have been measured including those done by the NEDO group (Komazawa *et al.*, 2002). This was partly owing to the introduction of the advanced GPS (Global positioning system) interference technique. Now a gravity survey can be done in unmapped areas using a handheld GPS receiver. Many geological features were observed by gravity survey, but the most prominent detection was a NNW-SSE trending elongated high gravity anomaly in the study area (Komazawa *et al.*, 2002). This exactly coincides with the Bajawa rift zone or the Bajawa Cinder Cone Complex where the vertically extending dike complex is estimated at a wide depth range (Muraoka *et al.*, 2002b). The gravity survey coupled with the GPS technique has no obstacle even in less accessible remote areas.

#### 4.5 Resistivity survey

The resistivity survey is the only method that can predict the depth of anomalies related to geothermal reservoirs among the methods in this project. A DC (Direct current) method was done by VSI (Uchida *et al.*, 2002a). The CSAMT (Controlled-source audiofrequency magnetotelluric) method was carried out by the NEDO group and MT (Magnetotelluric) method was conducted by GSJ. Field measurements of MT of the Mataloko-Nage area are basically done in FY 1999. Two-dimensional and three-dimensional inversions of the data were performed (Uchida *et al.*, 2002b). The three-dimensional inversion may be a first attempt in the geothermal field. Both results are mutually consistent and give a beautiful picture of the subsurface

geothermal geology. Most shallow zones are characterized by a low anomaly suggesting alteration caps and deeper zones by a high anomaly. Mataloko and Nage steaming grounds are situated at an apex where the top of the high anomaly is closest to the surface, whereas the cinder cone alignments are situated at a low anomaly extended to the measurement depth limit.

#### 4.6 Self-potential survey

Facilities required for a self-potential (SP) survey are relatively convenient and operations on the field are not complicated. Nevertheless, this method can detect upflow zones of a hot aquifer, and we can easily obtain the results in almost real time in the field. These characteristics are particularly useful for geothermal exploration in less accessible remote areas.

The SP mapping surveys were efficiently done in the Mataloko and Nage geothermal fields, and the results have been obtained in almost real time. After the data correction and modeling were completed, the SP method provided much information to select the optimum localities for drilling (Yasukawa *et al.*, 2002a).

Moreover, it is typical that when SP monitoring was conducted during the operation of flow tests of well MT-2, the SP responses were detected corresponding to the start of production and shutting in the well. This means that when we prepare a large network of SP stations, the SP monitoring can be used for the assessment of the reservoir extent (Yasukawa *et al.*, 2002b). The efficiency and cost performance of the SP survey method was fully demonstrated in the ESSEI Project.

#### 4.7 Computer-aided analysis

This category was planned to assist the construction of GEMS by NEDO. However, there was hardly any need for this assistance so that researchers responsible for this theme assisted the publication of CD-ROM as a data integration of the GSJ project. The CD-ROM is now under construction based on the contents of this special volume.

### 5. Conclusions

- (1) The ESSEI Project was very fruitful for the GSJ group because we were blessed with enthusiastic Indonesian and Japanese counterparts and we obtained much valuable data. We hope that these data will be useful for our Indonesian colleagues.
- (2) The success of NEDO well MT-2 demonstrated that our exploration results were effective enough for the selection of the well site.
- (3) The purpose of ESSEI Project is to develop a geothermal exploration system that is suitable

for tropical remote islands in Indonesia. A recommended exploration system is the combination of remote sensing, geological survey, geochemical survey, gravity survey, resistivity survey and self-potential survey. They are necessary and reciprocal to each other.

- (4) Even if commercial-based activity is common for geothermal development field, international research cooperation brings a synergy effect and is still useful for each counterpart, particularly in a noble purpose like rural electrification by clean energy.

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#### Appendix 1: A list of contributions to ESSEI Project by the Geological Survey of Japan

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## 地質調査総合センターによる「遠隔離島小規模地熱の探査に関する研究協力」の総括

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### 要 旨

5年計画のインドネシアー日本二国間研究協力プロジェクト「遠隔離島小規模地熱の探査に関する研究協力」は1997年4月にスタートし、2002年3月に終了する予定である。本報は本特集号への導入部として、地質調査総合センターにより実施されたこのプロジェクトの総括を行う。本報では先ず、このプロジェクトの背景として、目標、研究協力体制、研究スケジュール、研究分担等について、レビューする。次いで、地質調査総合センターの年次活動と成果の概要について述べる。