THE REPUBLIC OF INDONESIA
PT. PERTAMINA (PERSERO)
PT. PLN (PERSERO)

JICA PREPARATORY SURVEY FOR LUMUT BALAI GEOTHERMAL POWER PLANT DEVELOPMENT PROJECT (2)

Final Report

March 2011

JAPAN INTERNATIONAL COOPERATION AGENCY
WEST JAPAN ENGINEERING CONSULTANTS, INC.

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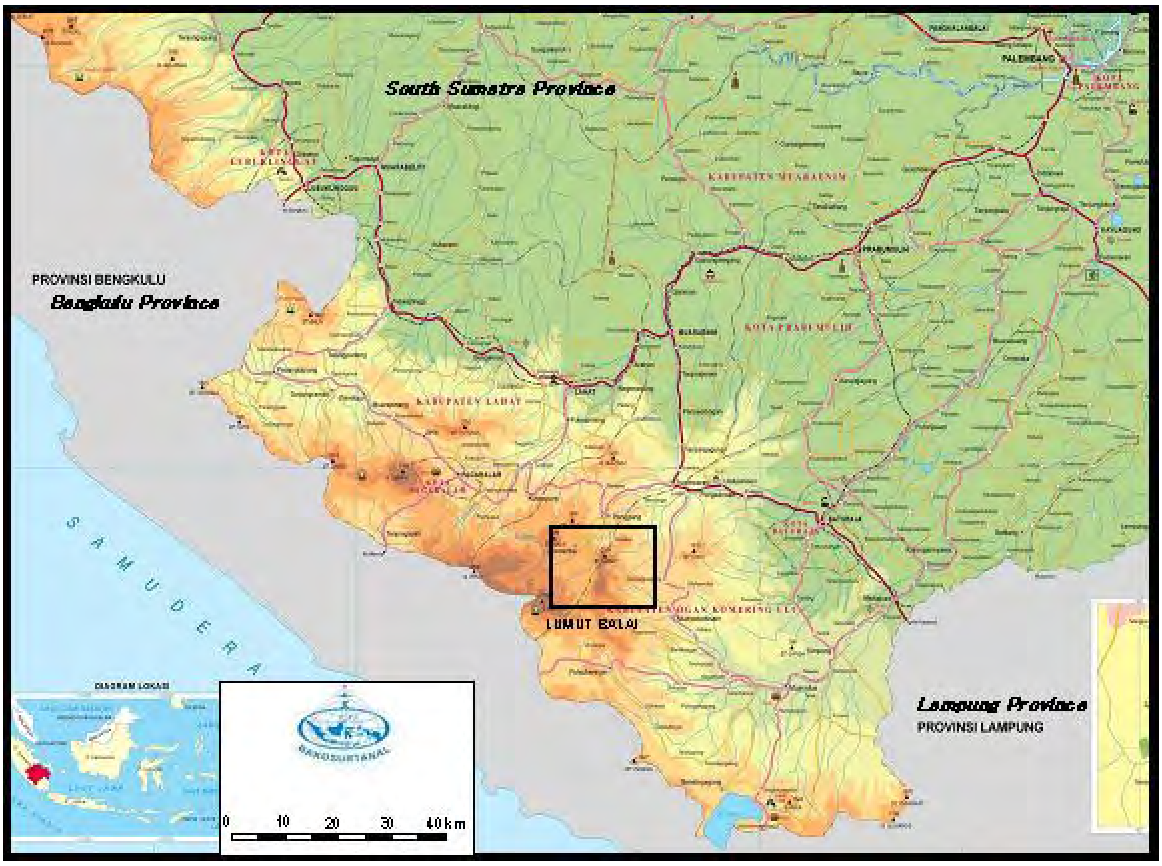

Location of Lumut Balai Geothermal Field

(Ogan Komering Ulu District and Muaraenim District, South Sumatra Province

Abbreviations and Acronyms

Abbreviations and Acronyms	Definition
AMDAL	Environmental impact assessment system in Indonesia (Analisis Mengenai Dampak Lingkungan, in Indonesian)
ANDAL	Environmental impact assessment report (Analisis Dampak Lingkungan Hidap, in Indonesian)
ACSR	Aluminium Conductor Steel Reinforced (cable)
BAPPENAS	National Development Planning Agency (Badan Perncanaan Penbangunan Nasional, in Indonesian)
bara	Bar absolute
CB	Circuit Breaker
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
COD	Commercial Operation Date
CRF	Capital Recovery Factor
EIRR	Economic Internal Rate of Return
EPC	Engineering, Procurement and Construction
FCRS	Fluid Collection and Reinjection System
FEED	Front-End Engineering and Design
FIRR	Financial Internal Rate of Return
FRP	Fiberglass-Reinforced Plastic
F/S	Feasibility Study
GCB	Generator Circuit Breaker
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Green House Gas
GOI	Government of Indonesia
GPP	Geothermal Power Plant
GWh	Gigawatt hour
HL	Protected Forest (Hutan Lindung, in Indonesian)
hPa	hectopascal
HSAW	Conservation Forest (Hutan Suaka Alam dan Wisata, in Indonesian)
Hz	Hertz (cycles per second)
IDC	Interest During Construction
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFD	Integrated Finite-Difference

Abbreviations and Acronyms	Definition
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
kV	Kilovolt
kVA	Kilovolt Ampere
kW	Kilowatt
kWh	Kilowatt hour
L/A	Loan Agreement
L/C	Letter of Credit
L/Com	Letter of Commitment
LEC	Levelized Energy Cost
m asl	meters above sea level
M/C	Metal-Clad switchgear
MCC	Motor Control Center
MEMR	Ministry of Energy and Mineral Resources
MSV	Main Stop Valve
MVA	Mega Volt Ampere
MW	Megawatt
NAD	Nangroe Aceh Darusalam
NCG	Non-condensable Gas
NEP	National Energy Plan
ODA	Official Development Assistance
ONAF	Oil Natural Air Forced (transformer cooling method)
ONAN	Oil Natural Air Natural (transformer cooling method)
ORC	Organic Rankine Cycle
OWS	Operator Workstation
O&M	Operation and Maintenance
P/C	Power Center
PDD	Project Design Document
PERTAMINA(Persero)	State-owned Oil & Gas Company (National Oil Company)
PGE	Pertamina Geothermal Energy
pH	Hydrogen Power (Potentia Hydrogenii, in Latin)
PIN	Project Information Note
PLN(Persero)	State-owned Electricity Company
PLTA	Hydro Power Plant (Pembangkit Listrik Tenaga Air)
PLTD	Diesel Power Plant (Pembangkit Listrik Tenaga Diesel)
PLTG	Gas Turbine Power Plant (Pembangkit Listrik Tenaga Gas)
PLTGU	Combined Cycle Power Plant (Pembangkit Listrik Tenaga Gas & Uap)
PLTMH	Micro Hydropower Plant (Pembangkit Listrik Tenaga Micro-Hydro)

Abbreviations and Acronyms	Definition
PLTP	Geothermal Power Plant (Pembangkit Listrik Tenaga Panas Bumi, in Indonesian)
PLTU	Steam Power Plant (Pembangkit Listrik Tenaga Uap)
PPA	Power Purchase Agreement
P/Q	Pre-Qualification
PT.	A stock company (Perseroan Terbatas, in Indonesian)
P3B	Generation & Transmission Load Center (Pusat Pembangkit dan Penaluran Beban)
RKL	Environmental Management Plan (Rencana Pengelolaan Lingkungan Hidap)
RPL	Environmental Monitoring Plan (Rencana Pemantauan Lingkungan Hidap)
rpm	Revolutions Per Minute
RUPTL	National Electricity Provision Plan (Rencana Usaha Penyediaan Tenaga Listrik)
SCADA	Supervisory Control And Data Acquisition system
Sumbagut	North Sumatra region (Sumatera Bagian Utara)
Sumbagteng	Central Sumatra region (Sumatera Bagian Tengah)
Sumbagsel	South Sumatra region (Sumatera Bagian Selatan)
S2JB	South Sumatra, Jambi and Benkulu (Sumatra Selatan, Jambi dan Benkulu)
TFC	Total Fuel Consumption
TSS	total suspended solids
UKL	Environmental Management Effort (Upaya Pengelolaan Lingkungan, in Indonesian)
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UPL	Environmental Monitoring Effort (Upaya Pemantauan Lingkungan, in Indonesian)
UPB	Load Dispatch Unit (Unit Pengator Beban)
UPS	Uninterruptible Power Supply
UPT	Transmission Control Unit (Unit Pelayanan Transmisi)
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

English equivalents for Indonesian terms used in this report

Indonesian	English
Air (A.)	Water, River
Batang (Bt.)	River (R.)
Bukit (BT.)	Mountain (Mt.)
Danau (D.)	Lake (L.)
Desa	Village
Gunung (G.)	Mountain (Mt.)

Indonesian	English
Kabupaten	District
Kota	City
Kecamatan	Sub district
Provinsi	Province
Sungai (S.)	River (R.)

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EXECUTIVE SUMMARY

The Preparatory Survey is conducted to create feasibility study documents for Lumut Balai Units 3 and 4 as a condition for an ODA loan. The Executing Agency of the project will be PT. Pertamina (Persero) for steam-field development and power plant construction, and PT PLN (Persero) for transmission line and substation construction. PT. Pertamina Geothermal Energy (PT. PGE) is expected to implement the project on behalf of PT. Pertamina. The Preparatory Survey is composed of a review and assessment of the geothermal resource by reservoir simulation, programming of steam field development, conceptual design of power plants and transmission lines, an environmental study and a financial/economic assessment of the project. In addition to these studies, the current condition of production well LHD-23 in the Lahendong geothermal field is investigated as confirmation of the current status of a similar Japanese ODA loan project.

Based on this assessment of the Lumut Balai project, the Survey team formulated an implementation program for construction of the geothermal power station and associated transmission lines and substation. This Survey is to review and update the results of the previous feasibility study for realization of the Project. The survey results are summarized as follows.

1. FIELD DEVELOPMENT PLAN

Conceptual Model

(1) Major Permeable Structure Controlling Geothermal Activity

From geological information, 4 faults (F1, F2, F3 and F4) are deduced to control geothermal activity near the surface. From gravity information, it is deduced that 3 faults (G1, G2 and G3) are distributed under the ground. An additional 3 faults (R1, R2 and R3) are also estimated. Geothermal manifestations and altered ground in the Gemurah Besar-Gemurah Pamalibar sector are distributed along faults F1, F2, F3 and F4, and in the Kelumpang-Sindawan-Bunbun sector are distributed along faults F5 and F6.

(2) Cap Rock of Geothermal Resources

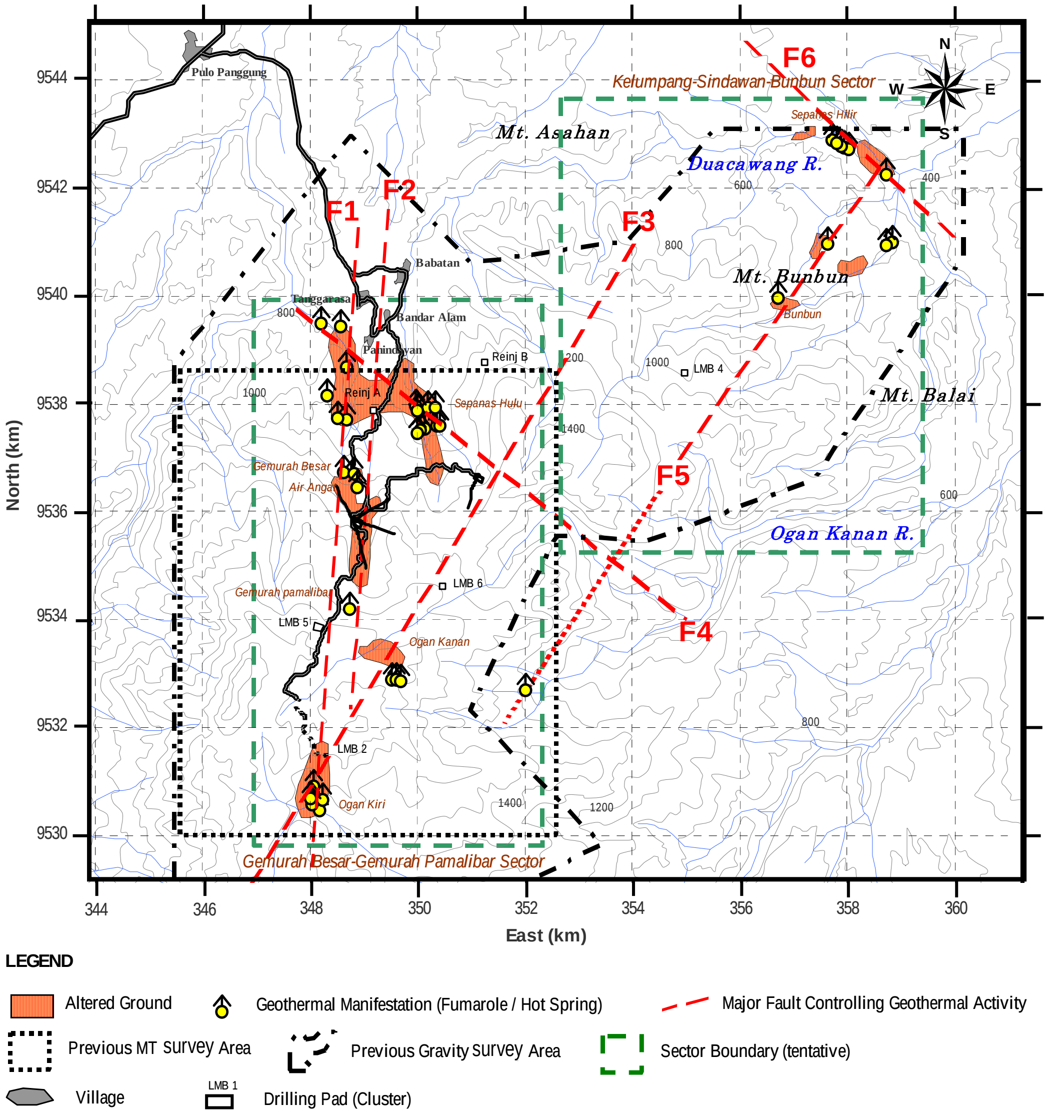
A low resistivity layer is detected by MT survey in this field. The elevation of the bottom of this layer around LMB 1 and LMB 3 is about 500 m to 800 m above sea level. Considering the well geology, this low resistivity layer can be correlated with an argillized layer. Temperature profiles of all drilled wells at the horizons of the argillized layer give a rather linear gradient. Moreover, lost circulation can scarcely be recognized at these horizons. This means that the detected low resistivity layer corresponding with the argillized layer can be regarded as a cap rock (impermeable layer).

(3) Fluid Flow Pattern

In the Gemurah Besar-Gemurah Pamalibar sector (the western part of the Lumut Balai geothermal field), meteoric water is heated at depth and turns into geothermal brine. This brine flows up on the eastern side of the Mt. Lumut summit and flows north along faults F1, F2, F3 and F4. This flowing brine must be neutral in pH. Steam, gas and conductive heat derived from this brine, flowing through an argillized impermeable layer, come into a shallower aquifer and heat it up. Hot water from this heated aquifer is discharged as hot springs. The bottom of well LMB 1-2 is situated around fault F1. The bottoms of wells LMB 1-3, LMB 1-4 and LMB 1-5 are situated around fault F2, and that of well LMB 3-1 is situated around fault F3.

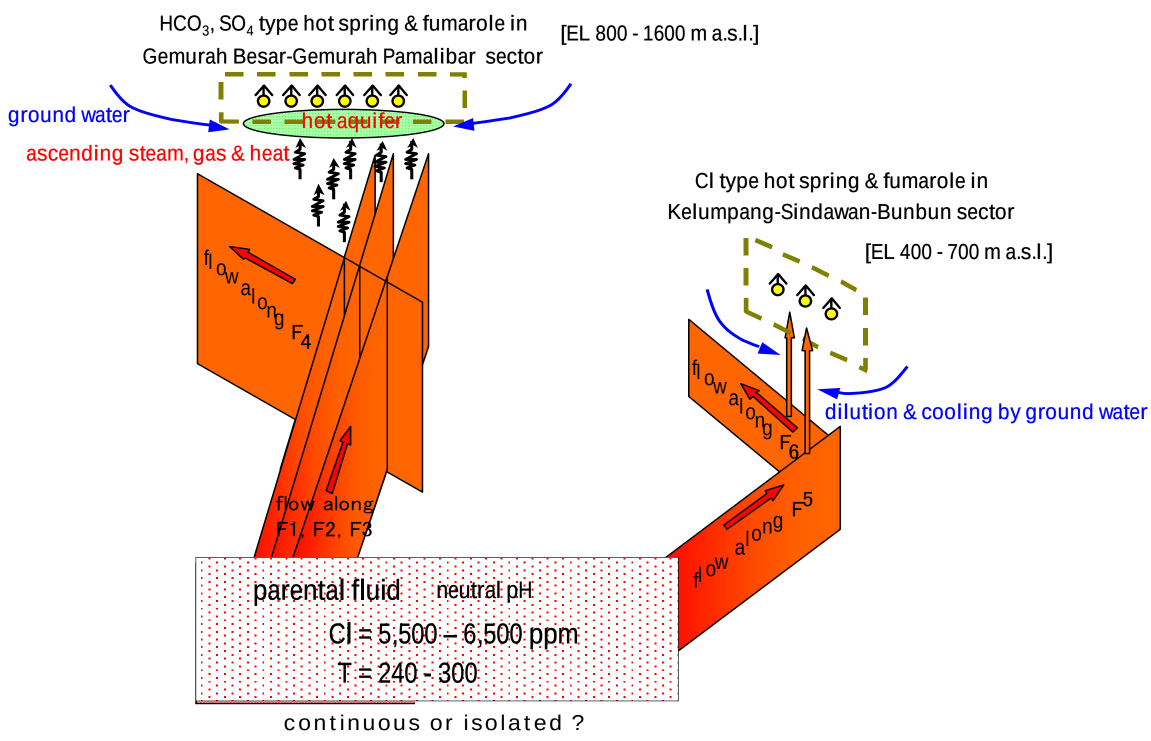
In the Kelumpang-Sindawan-Bunbun sector (the northeastern part of the Lumut Balai geothermal field), geothermal brine flows northeast along fault F5, and this flow branches off where fault F5 crosses fault F6, flowing northwest along fault F6. Geothermal brine also flows up to the ground surface around that crossing point. The source of this geothermal brine flow must also be situated on the eastern side of the Mt. Lumut summit. The parental fluid has a temperature of 240°C to 300°C and Cl concentration of 5500 to 6500 ppm. However, it is still uncertain whether the source is the same as for the fluid flow system in the Gemurah Besar-Gemurah Pamalibar sector or not. They may be the same.

Considering the chemistry of fumarolic gases, the content of NCG in the geothermal steam produced in this field seems to be relatively low, which is good for future geothermal power generation.

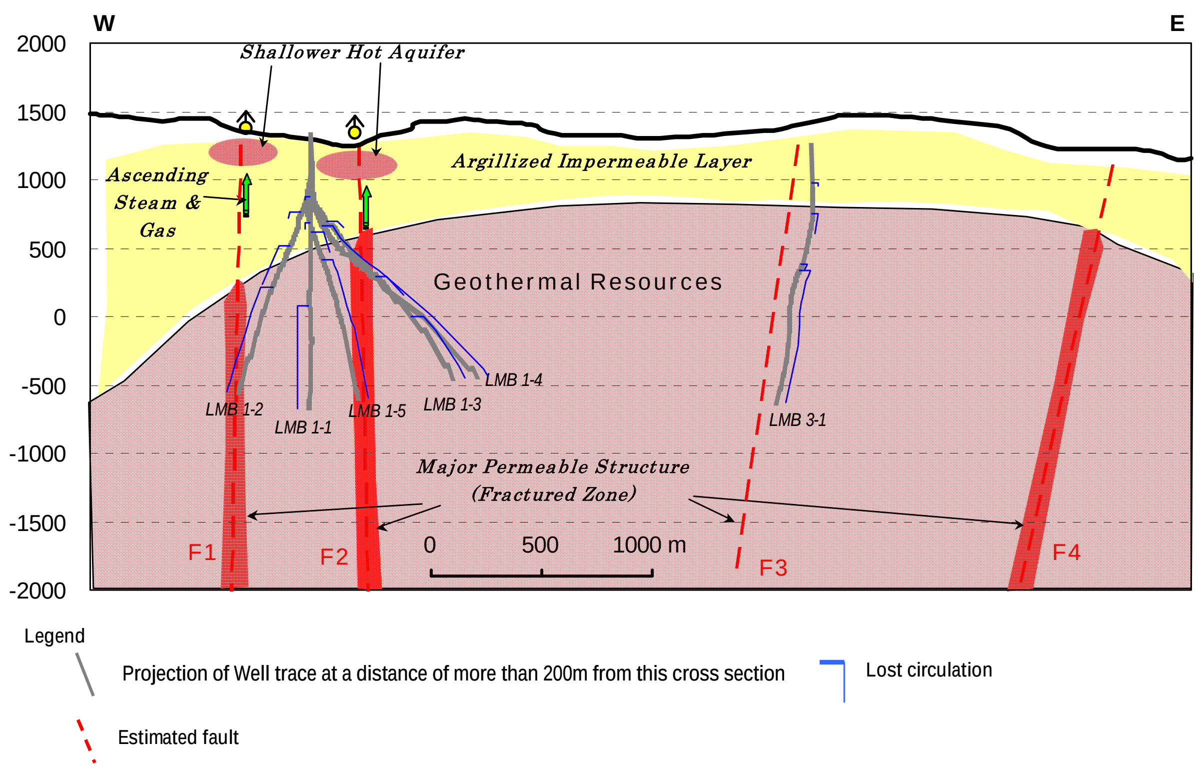


(Based on PGE's data)

Major Structures Controlling Geothermal Activity



Fluid Flow Pattern Model



(Based on PGE's data)

Proposed Conceptual Model

Preliminary Reservoir Simulation Study

Based on the reservoir conceptual model, a reservoir numerical model was constructed for dedicated reservoir simulation study. As a result of the forecasting simulation it is concluded that the reservoirs in Lumut Balai will have enough capacity to sustain the power plant operation of 220 MW (Units 1 to 4) during the plant operation life of 30 years.

(1) Number of start-up wells

The numbers of start-up wells that are required to commence the power plant operation of Units 3 and 4 (110 MW) are 17 for production and 8 for reinjection, the latter consisting of 7 for brine reinjection and one for steam condensate reinjection. Three well pads, LMB 2, 7, and 10, will be used as production well pads to commence the power plant operation of Units 3 and 4. On the assumption that the maximum number of production wells at each well pad is six, the simulated numbers of wells at the well pads LMB 10, 2 and 7 are six, six, and five, respectively. The simulated steam flow rate at each well pad is around 280 to 340 t/h and brine flow rate is around 900 to 1100 t/h.

Simulated No. of well	Unit 1&2 (110 MW)		Unit 3&4 (110 MW)		Total (220 MW)	
	Start-up	Make-up	Start-up	Make-up	Start-up	Make-up
Production well	21	2	17	1	38	3
Reinjection well	8	2	8 (1)	2 (1)	16 (1)	4 (1)
Total	29	4	25	3	54	7

* Make-up wells would be required for the 30-year plant operation. () indicates the number of steam condensate injection well

(3) Optimum turbine inlet pressure

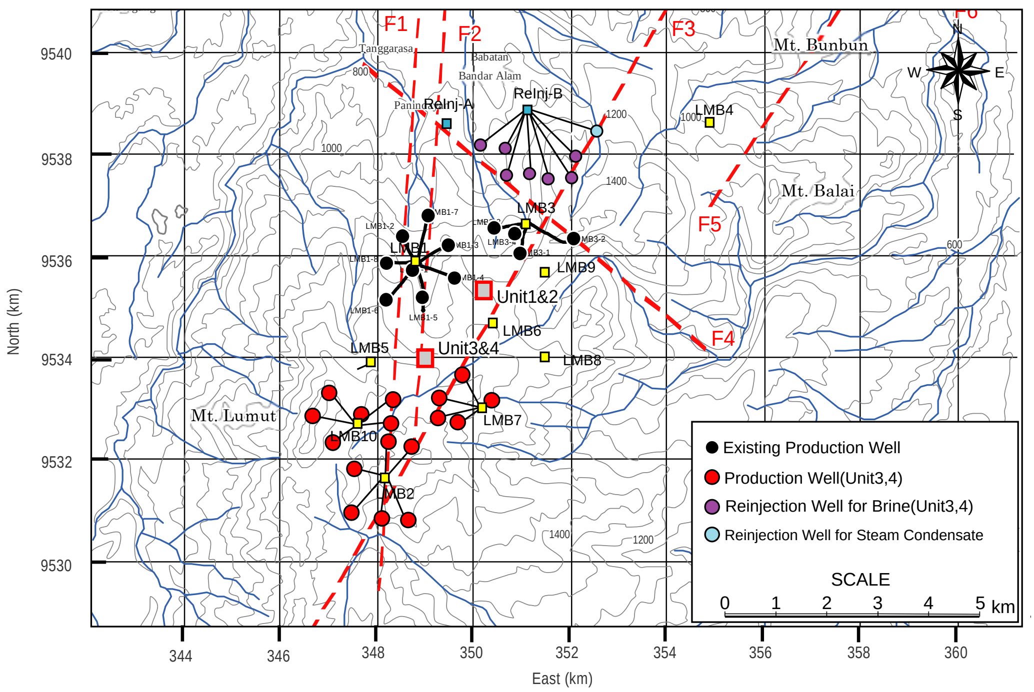
It is recommended that the optimum turbine inlet pressure be 5.5 bara, talking into account appropriate turbine size in terms of manufacturing cost. In the future, detailed turbine design should be discussed after additional data from production wells at well pads LMB 2, 5, and 10 is obtained. If the production wells at these well pads show dominant productivity beyond the current estimation, it will be possible to increase the design turbine inlet pressure. In this case, the manufacturing cost of the turbine will decrease compared to the current cost estimation, because the turbine size will be reduced.

(4) Number of make-up wells

The forecasted results suggest that only one production well and two reinjection wells will be required over the plant life of 30 years. This means that the reservoir will be very stable after producing and reinjecting the geothermal fluids for power generation. However, an annual decline rate of 3% should be assumed in determining the number of necessary make-up wells for the calculation of O&M costs to avoid overly optimistic predictions, considering that the precision of this reservoir numerical model is still low. As a future task, the model should be revised to validate its reliability based on additional data from the wells.

Steam-field Development Plan

The production wells for Units 3 and 4 will be drilled from well pads LMB 10, 2 and LMB 7, targeting the prospective productive faults F1, F2 and F3, where reservoir temperature and permeability are expected to be higher. Seventeen (17) production wells should be prepared to commence the 110 MW power plant operation (55 MW x 2 units). The reinjection wells should be drilled from well pads InjA and InjB, targeting the faults F1, F2 and F4 in the northern area of the field. The simulation results suggest that eight (8) reinjection wells will be required for the disposal of 3060 t/h of brine and 380 t/h of steam condensate (about 20% of the total steam flow rate for all units 1 to 4), assuming the permeability-thickness product (kh) of the reinjection zones to be 10 darcy-m. Seven reinjection wells should be used for brine disposal and one reinjection well for steam condensate. When the reinjection wells are actually drilled in the prospective area in the future, reinjection zones to be developed will be distinguished more clearly.



Prospective Production and Reinjection Zones

The decline in capacity of production and reinjection wells will require make-up production and reinjection wells to be drilled at appropriate times to maintain the rated power output. The results of reservoir simulation forecasted that only 1 make-up production well and 2 make-up reinjection wells would be required over the plant operating life of 30 years. However, it should be noted that the current reservoir numerical model is only a preliminary model because this model was established based on the very limited existing well data from well pads LMB 1 and LMB 3. Therefore, the model should be updated to increase its precision after additional well data is obtained in the future. Therefore, in order to avoid underestimation of the required number of make-up wells in this preliminary study, the ordinary annual decline rates given below should be assumed in determining the number of make-up wells and estimating the attendant costs.

- Power output of production wells: 3% per year
- Injection capacity of reinjection wells for brine disposal: 3% per year
- Injection capacity of reinjection wells for steam condensate disposal: 1% per year

As a result, 12 make-up production wells and 4 make-up reinjection wells for brine disposal will be required over 30 years of plant operation. A new well pad for production wells LMB 8 and LMBX should be prepared within 6 years and 19 years after commencement of plant operation, respectively. To arrive at a conservative estimate, the number of make-up wells was finalized by combining the above number of wells with that forecasted as necessary by the reservoir simulation, as follows.

Timing of Adding Make-up Wells over 30 Years after Commissioning

Year	3	6	8	10	12	15	17	19	21	24	26	28	Total
Production wells	1	1	1	1	1	1	1	1	1	1	1	1	12
Reinjection wells	1	0	0	0	1	0	1	0	1	0	1	0	5
Total	2	1	1	1	2	1	2	1	2	1	2	1	17

Strategy of Well Drilling and Production Tests

The Lumut Balai project area is located in the mountainous district of Bukit Lumut and Bukit Balai and is characterized by a relatively steep topography. In this area two drilling pads (LMB 1 and LMB 3) for Units 1 and 2 have already been constructed. Another well pad, LMB 4, is prepared for investigation in the Kelumpang-Sindawan-Bunbun Sector in the northeastern area of the field, which is more than 4 km from well pad LMB 3. This well pad cannot be used for this project, because it is too distant to utilize as a reinjection well pad. Access roads from the existing road to these drilling pads in the field have been constructed and extended in a southerly direction for the new well pads, LMB 5, LMB 10 and LMB 2, which are under construction. Three new production pads (LMB 7, LMB 8, and LMBX) should be newly constructed for the development wells and make-up wells.

Production tests and interference tests using not only existing wells but also new wells are strongly recommended to confirm well deliverability and reservoir properties, including gas and chemical conditions. This information is of extreme importance for the detailed design of the power facilities and also for reservoir management over the course of power plant operation. If testing is to be done and investment in the required facilities is to be made, then it is desirable to provide permanent production testing equipment and installations at all production well pads so that the steam and water flow rates of production wells can be measured whenever it is necessary.

2. POWER PLANT AND TRANSMISSION LINE

Power Plant

1) FCRS

Taking into account the medium pressure and high brine content of the resource, a two-phase transportation system from the production wells to the power plant would not be appropriate for Lumut Balai Units 3 and 4 because a significant pressure loss is anticipated. Accordingly, a wellpad separation system (constructing separator stations adjacent production well pads) will be adopted. Separated steam will be sent to the power plant, while separated brine will be sent to the reinjection well pads and injected into the ground.

2) Power Plant

Lumut Balai Units 3 and 4 (single flash 2 x 55 MW(net) turbine-generator units) will be constructed in the southern area of Lumut Balai geothermal field. A steam ejector system would be suitable for design NCG content of 1.0% wt. However, three (3) different ejector sizes will be installed to cope with unforeseeable future NCG variation from 0.4% wt up to 1.8% wt.

3) Transportation

Two (2) unloading ports are conceivable for the project, i.e. Panjang seaport and Palembang river port. Panjang seaport is suitable for unloading heavy and bulky plant equipment and materials such as turbines, generators, condensers, etc., but the distance to the project site is a whole 370 km, so Palembang river port may be used for miscellaneous equipment and materials because of the shorter (approximately 260 km) land transportation route to the project site. Another alternative for small and miscellaneous logistic equipment and materials from Jakarta will be transportation by truck using a commuter ferry between Java and Sumatra islands.

4) O&M

PGE will be responsible for operation and maintenance of the Lumut Balai geothermal power plant both upstream and downstream.

PGE will perform routine preventive maintenance, periodical maintenance and predictive maintenance. Improvement work, such as plant rehabilitation/revamping/reconditioning/retrofitting/renovation and relocation, will be arranged and implemented by PGE.

The O&M personnel for Units 1 and 2 will be able to operate Units 3 and 4, providing that these units are controlled remotely from the Unit 1 and 2 power plant. Common use of maintenance equipment and spare parts for Units 1 and 2 would reduce total O&M cost.

Transmission Line and Substation

1) Transmission Line

It is recommended that 2 x DOVE (2 x 556.5 MCM, equivalent to 282 mm^2) be employed for the 275 kV transmission line between Lumut Balai geothermal power plant and Lahat substation in order to deliver the eventual full 4 x approx. 55 MW capacity.

The main specifications of 2 x DOVE are as follows.

- ✓ Operating Voltage : 275 kV
- ✓ Material / Cord Name : ACSR / DOVE
- ✓ Cross Section : 556.6 MCM (282 mm^2)
- ✓ Number of Conductors : 2
- ✓ Number of Circuits : 2
- ✓ Transmission Capacity : Approx480MVA (per circuit)
- ✓ Length : Approx. 63 km (to Lahat substation)

2) 275 kV Substation

- ✓ Existing Lahat 150/20kV Substation must be completely upgraded to 275/150/20kV before work to connect the transmission line from Lumut Balai geothermal power plant is commenced.
- ✓ Two sets of 275 kV complete line bay should be expanded to connect the transmission line from Lumut Balai.

3. IMPLEMENTATION PROGRAM

Implementation Schedule

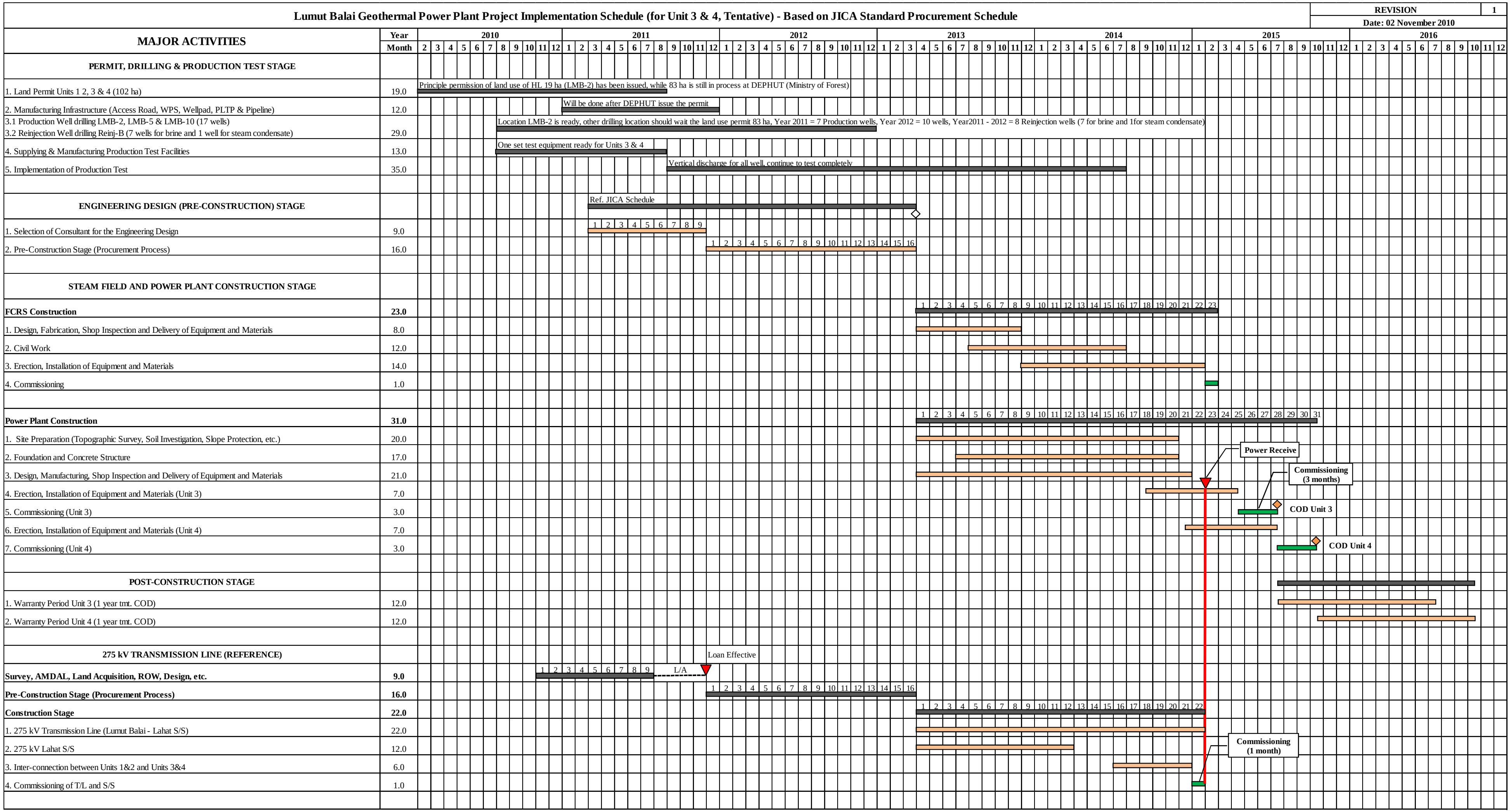
1) Implementation Schedule

Assuming that the L/A will be concluded at the end of February 2011 and that a certain period of time for JICA concurrence requirements for several procurement procedures is incorporated, the tentative implementation schedule is formulated as shown in the following Figure. JICA's standard schedule is shown in the following table.

JICA Standard Schedule

1. Consultant selection *(Note)*	9 months
2. Project procurement	
a. Bidding document preparation	4 months
b. Bidding period	3 months
c. Bid evaluation	5 months
d. JICA concurrence	1 month
e. Contract negotiation	1.5 months
f. JICA concurrence of the contract	0.5 months
g. L/C opening and issue of L/Com	1 month
Subtotal	16 months

(Note): Consultant selection could be 6 months in the case of direct appointment.
(Needs justification for direct negotiation)



Project Schedule

4. ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

Basically, Lumut Balai units 3 and 4 is located in the same area as units 1 and 2. Legal permission for the power plant was checked and cleared last year in the preparatory survey for unit 1 and 2. So this year, we confirmed whether units 3 and 4 are also covered or not. As a result, they are confirmed to be covered.

Geothermal WKP

PERTAMINA obtained Confirmation of the Geothermal Working Area (WKP) in Lumut Balai and permission under the Minister of Mining and Energy Decree No.1268.k/20/M.PE/1993 on 7 February 1993.

Surface Water Utilization

PERTAMINA had been allowed to utilize surface water for geothermal exploration drilling activity by the Muara Enim Regency under Decree No.739/KPTS/Tamben/2007 on 25 July 2007. And this permission was extended for 2 years for PGE by Muara Enim Regency under Decree No. 668/KPTS/TAMBEN/2009 on 12 November 2009 in response to request No. 789/PGE1P2/2009-SO on 21 July 2009 by PGE.

EIA

The EIA Reports were approved by the Governor of Muara Enim Regency decree No.758/KPTS/BLH-I/2008 on 21 August 2008.

Based on the map from Ministry of Forestry published in November 2008, border line between Muara Enim regency and OKU (Ogan Komering Ulu) regency is drawing in the center of the Lumut Balai geothermal field. Border line between regencies should be determined officially by National survey and investigation board but is not confirmed it has already changed or not. AMDAL law (Article 24 of No. 27/1999) defines the valid period and cancellation conditions of approved AMDAL, but change of the border line of approved regency is not written in it. So this AMDAL is still valid.

Land Acquisition

As the project will take place in a protected forest area (Hutan Lindung) of 102 ha, there is no cost for land acquisition, but permission for the utilization of the forest area from the Ministry of Forests is required. 19 ha is already permitted, and PGE is still waiting for permission for the use of the remaining 83 ha. PGE expects to receive permission for that 83 ha in December 2010.

Resettlement

There will be no resettlement activities because the Project will take place within a protected forest area.

EIA Review and Field Survey

The EIA reports are considered to satisfy with the “JBIC Guidelines for Confirmation of Environmental and Social Considerations (April, 2002).

To confirm the actual situation of living and breeding of the species which should be carefully considered among them, site surveys were carried out mainly for the area of well pads, power plants and access roads (existing and planned) of Lumut Balai geothermal development field to observe the animals themselves or traces of them such as hair, waste, tracks and trails, and to study their habitat. In addition, hearings were conducted with participation of the local residents to collect relevant information required. In this survey, the species which are protected by Indonesian law/regulation were listed up. Laws/Regulations used as references are:

- Law No. 5 / 1990 on Conservation of Biological Resources and Ecosystems;
- Government Regulation No. 7 of 1999 concerning the Preservation of Plants and Animals.
- Government Regulation No. 60 of 2007 on the Conservation of Fish Resources

As a result of the site survey, regarding precious fauna and flora, the existence of eight species of mammals, ten species of aves and one species of flora were confirmed. Aves, mammals and flora are thought to be distributed all through the forest area in and around the Lumut Balai geothermal development field. These results should contribute to the environmental impact evaluation for those species and also to recommendations of plans to mitigate the anticipated impacts on these species.

Land clearing in the area of Lumut Balai geothermal development field will have an impact either directly or indirectly on wildlife. The impact will occur in the form of habitat loss or habitat fragmentation. But the habitat and breeding area of each precious species confirmed in this survey is not thought to be limited to the development field, but to be widely distributed in and around the development field. Therefore, the environmental impact on the precious flora and fauna will be small given the application of appropriate mitigation measures. General information about precious flora and fauna in and around the Lumut Balai geothermal power development area were obtained by this short-term field survey. Considering seasonal changes in situation of flora and fauna, it is desired that further impact assessment and considering about mitigation of preservation should be conducted after the survey about vegetation and ecological characteristic of each species as possible as they can.

Transmission Line

✓ EIA

Part of the land for the transmission line is in the protected forest (Hutan Lindung). The voltage of the line is 275kV. Indonesian environmental regulations require an EIA, which will be conducted by PLN.

✓ Land acquisition

Land acquisition will be conducted by PLN. In the protected forest (Hutan Lindung), PLN will obtain permission for utilization from the Ministry of Forestry after the EIA is approved.

✓ Compensation of ROW

Compensation of ROW will be conducted by PLN.

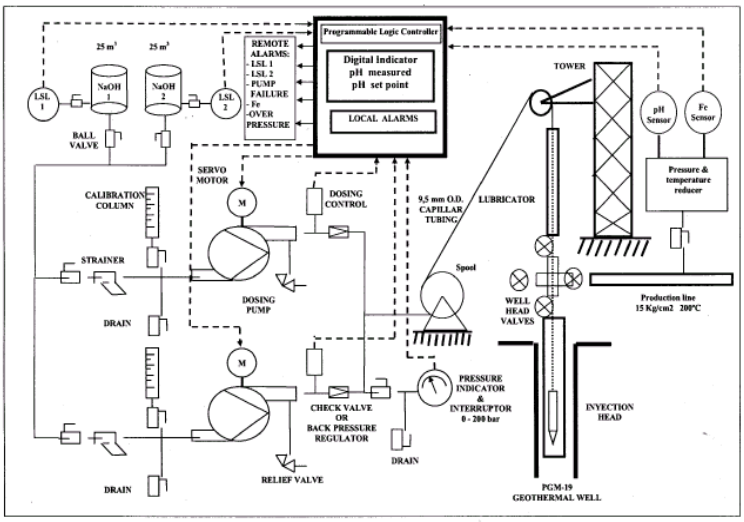
5. CONFIRMATION OF THE CURRENT STATUS OF SIMILAR JAPANESE ODA LOAN PROJECT

✓ In the Lahendong geothermal field, North Sulawesi, well LHD-23 is one of production wells which produce acid fluids, and this fluid is separated into two branch lines. One is made from carbon steel line (CSL) and the other one is a stainless steel line (SSL). A caustic soda of 48% is already dosed into the bleed pipe of LHD-23 to shift the pH value slightly to the alkaline side.

- ✓ Two 48% caustic soda tanks whose capacity is 30m^3 were installed just beside LHD-23 in order to inject caustic soda into it. When the neutralization system is adopted, this equipment is utilized. Alkaline concentration is an important factor because hydrogen cracking occurs at high temperature. Therefore, 48% caustic soda should be reduced to 30% to avoid this cracking. At the site, fresh water from the river is supplied to the caustic soda line to dilute it. 10 mg/L dissolved Oxygen is usually contained in it, and Oxygen in fresh water is also one reason for corrosion problems. So, this gas should be removed by de-gassing equipment.
- ✓ The pH value of the acidic fluids in the reservoir is around 5 due to the un-dissociated condition of sulfuric acid. After flushing, protons are dissociated and leached from the sulfuric acid to lower the pH value. Therefore, the optimum dispersion depth of caustic soda should be below the flashing point. Judging from PTS data, it is recommended that the dispersion depth of caustic soda be in the range from a depth of 1650m to 1700 m at a well-head pressure of 0.84 MPa.
- ✓ Eight month of experiments on the CS line at pH 4.5 showed that the scale deposition rate was 18mm/year near the dosing point. This causes a clogged condition near the dispersion point, and steam production decreases. There are two ways to solve this problem. One is for pH modification to be in the range from 4 to 4.5. In this case, at the beginning stage (the first one or two months), pH is modified to 4.5 to make a thin scale film on the pipe to protect it from corrosion, and next, the pH value is shifted to 4.0 to control the growth rate of scale on the pipe. This is the best way to operate the system. The implementation plan for corrosion and scale testing should be carried out to estimate the actual scale thickness. Rough cost estimates for 5 MW and 15 MW of LHD-23 were calculated, and these are itemized below. The whole system for the neutralization method is also shown below.

Cost estimates for LHD-23 in the case of 5MW and 15MW

Chemical cost		unit	5MW	15MW	Remarks
A	The amount of 48%-NaOH	t/D	2.4	7.2	From field data
B	Purchase price of 48%-NaOH	US$/t	300	300	
C	Dosing day	day/y	340	300	
(1)	Annual cost	US$/y	244,800	648,000	
Surface equipment cost					
D	Dosing pump	US$	15,000	15,000	one unit
E	Monitoring system	US$	70,000	70,000	pH & Fe
F	Pipe	US$	12,000	20,000	
G	Weight Bar	US$	1,500	3,000	
H	Lubricator	US$	2,000	2,000	
I	winch truck	US$	150,000	150,000	8 years for service life
J	Service life	y	8	4	
(2)	Annual cost		31,313	46,250	
Well bore equipment cost					
K	Coiled tubing(1500m)	US$	14,000	14,000	
L	Service life	y	0.5	0.3	
(3)	Annual cost		28,000	46,666	
aaa	Total cost=(1)+(2)+(3)	US$/y	304,113	740,916	



Permanent dosing system for LHD-23

6. CONCLUDING REMARKS

Resource Development

- ✓ The reservoir will be able to sustain the power generation of 110 MW for Units 3 and 4 for 30 years as well as Units 1 and 2.
- ✓ 17 production wells and 8 reinjection wells (7 for brine and 1 for steam condensate) will be required to commission the power plant operation of Units 3 and 4.

- ✓ Well pads LMB5 (6 wells), LMB10 (6 wells) and LMB2 (5 wells) should be used as production well pads for Units 3 and 4.

Environmental and social considerations

- ✓ There are no serious constraints on the construction of a geothermal power plant due to the social/natural environment.
- ✓ As a result of the site survey, the existence of eight species of mammals, ten species of aves and one species of flora were confirmed. Aves, mammals and flora are thought to be distributed all through the forest area in and around the Lumut Balai geothermal development field. These results should contribute to the environmental impact evaluation for those species and also to recommendations of plans to mitigate the anticipated impacts on these species.
- ✓ Land clearing in the area of Lumut Balai geothermal development field will have an impact either directly or indirectly on wildlife. The impact will occur in the form of habitat loss or habitat fragmentation. But the habitat and breeding area of each precious species confirmed in this survey is not thought to be limited to the development field, but to be widely distributed in and around the development field. Therefore, the environmental impact on the precious flora and fauna will be small given the application of appropriate mitigation measures.
- ✓ For the transmission line, PLN is now preparing to deal with environmental and social considerations on the basis of the regulations.

7. RECOMMENDATIONS

Additional Survey and Analysis

- ✓ Detailed MT survey

  In order to secure and raise the success rate of well drilling in the development area for Units 3 and 4, an additional detailed MT survey is recommended that should be conducted with high density measurement points for the purpose of clarifying the drilling targets for wells. For example, the following specifications for a detailed MT survey should be implemented.

  - ➢ Remote reference measurement

    The location for remote reference should be in a place which is sufficiently far from the survey area to avoid electro-magnetic noise.

  - ➢ Space between the measurement points

    The space between measurement points should be decided based on the survey area and survey cost. The recommended spacing is 500 to 1000 m.

  - ➢ Measurement time

    The measurement time should be around 15 hours from 17:00 to 8:00 AM. If the data quality is bad, it is recommended to continue measurement for a few days or change the direction of the measurements.

  - ➢ Measurement frequency

    More than 60 kinds of frequency are recommended within the range between 300 HZ to 0.005 HZ.

- ➢ Measurement factors

  Five factors (Ex, Ey, Hx, Hx, Hy and Hz) are recommended.

- ➢ Measurement points

  Assuming the space between the measurement points is 1000 m, around 40 points for the survey area of around 6 km^2 are recommended.

- ✓ Update of Simulation Study

  In order to optimize field development plan, resource assessment should be updated through further reservoir modeling and simulation study after the drilling of wells for Units 3 and 4.

- ✓ Horizontal discharge tests are strongly recommended to be conducted as soon as possible to confirm deliverability and the chemical features of discharged fluids, including non-condensable gas contents in the steam and contents in the discharged brine of the existing wells.

- ✓ These tests will make clear the quality and quantity of produced steam/brine and provide essential data for detailed plant design. Moreover, the required number of start-up wells and of make-up wells can be examined in detail, using data obtained from these tests.

Power Plant

- ✓ FCRS (Fluids Collection and Reinjection System)

  For detailed planning/design, a topographic survey of pipeline routes should be carried out by PGE.

- ✓ Power Plant

  Several truss and concrete bridges, including a railway overpass, are found on both of the transportation routes, i.e. Panjang seaport to site and Palembang river port to site. Accordingly, it is strongly recommended that the EPC Contractor carry out detailed surveys, including inspection of the heights of the truss bridges and their strength for safe transportation of the equipment and materials, once the EPC Contractor for the power plant has been selected, so that the EPC Contractor can confirm for itself if its equipment and materials can be transported without problem.

- ✓ O&M

  In order to achieve efficient and effective O&M management, Lumut Balai Units 1 and 2 should be the principle power plant of the whole Lumut Balai geothermal field. Under such a scheme, Lumut Balai Units 3 and 4 would be operated remotely from Units 1 and 2. Likewise, heavy equipment for maintenance, common spare parts, manpower, etc. could be centralized at the Unit 1 and 2 power plant.

Transmission Line and Substation

- ✓ Summary

  It is important that PLN should control the construction schedule for the transmission line from Lumut Balai Geothermal power plant to Lahat substation.

- ✓ 275 kV Transmission line

  1) Construction schedule

     The transmission line from Lumut Balai Geothermal power plant to Lahat Substation must be completed before receiving power from Lumut Balai units 1&2. If PLN applies consulting service using JICA loan, the completion of the transmission line will not be in time by the commissioning of Lumut Balai units 1&2. Since PLN has already substantial construction experience of 275kV transmission line over 500km between Lahat S/S and Kiliranjao S/S, consulting service for the 275kV transmission line is not mandatory for PLN.

2) 275 kV Lahat substation

155/20kV Lahat substation will be upgraded to a 275/150/20kV substation. According to RUPTL 2010 - 2019, the construction of Lahat 275kV substation and 275kV upgrading work are scheduled for completion in 2012 by World Bank loan. The transmission line from Lumut Balai geothermal power plant will be connected to the 275kV Lahat substation. It is recommended that the upgrading schedule for Lahat substation should be followed.

3) Interconnection line between Lumut Balai units 1&2 and 3&4

A transmission line connecting Lumut Balai units 1&2 and units 3&4 should be constructed. It is recommended that early negotiations be held with PLN and PGE to agree who will construct the transmission line, and preparation of AMDAL should be commenced for construction of the transmission line.

Environmental and social considerations

✓ General information about precious flora and fauna in and around the Lumut Balai geothermal power development area were obtained by this short-term field survey. Considering seasonal changes in situation of flora and fauna, it is desired that further impact assessment and considering about mitigation of preservation should be conducted after the survey about vegetation and ecological characteristic of each species as possible as they can.

✓ Based on the results of the environmental survey, the following mitigation of impacts on precious flora and fauna should be implemented.
- Preventing the clearing of land beyond what is absolutely necessary.
- Replanting the precious flora that is found in the development field
- Taking care to ensure water quality during construction work (sand basin, treatment for turbid water)
- Creation of habitat with vegetation harmonized with the environment (with plants found in the power plant site as far as possible)
- Road and site preparation that do not create turbid water (during construction and operation)
- Considering all the conditions, preserving animal trails by lifting up part of the pipeline or lowering the ground level, if necessary
- Patrolling to prevent hunting wild animals, and safety patrols around the project site

✓ Study of the environmental impact of the construction of a transmission tie – line between units 1,2 and units 3,4 should be conducted after the transmission line route and responsible company have been decided.

Implementation Plan and Costs

✓ The feasibility of a brine binary system to get additional electricity output may be studied in the future on the basis of the chemical and delivery data for wells which will be accumulated during commercial operation of the power plants.

CHAPTER 1 INTRODUCTION

1.1 Background

(1) The initial capacity of electricity supply in Indonesia was 24,509 MW in 2008, while the peak electricity demand in 2008 was 25,407 MW, according to the National Electricity General Plan 2008-2027 of the Ministry of Energy and Mineral Resources. This deficit of supply capacity is expected to become even severer as the capacity of existing power plants will degrade over time and electricity demand is forecasted to increase at an average rate of 9.1% every year until 2017.

(2) The peak electricity demand for the Sumatra grid in 2008 was 3,316 MW and it is expected to increase at an average rate of 7.9% every year until 2017, reaching 6,602 MW. The installed capacity in 2008 was 3,700 MW, but greater capacity needs to be developed rapidly as the degradation of capacity and growth in demand are expected.

(3) The Government of Indonesia (GOI) is working on developing the electricity supply capacity to meet the growing demand as well as diversifying Indonesia's energy mix by promoting the use of renewable energy sources. To achieve these goals, GOI has announced the second 10,000 MW development program called Crash Program II, which plans to tap into Indonesia's reserves of geothermal power, estimated at 27,000 MW and the world's largest, to provide 3,977 MW of the power developed under this program.

(4) Lumut Balai geothermal power plant 3 and 4 are listed in Crash Program II. JICA recognizes the priority of the proposed project and sees a need to review the overall project scheme, including an assessment of the feasibility of the project.

(5) JICA had discussions on the draft Implementation Program of the JICA Preparatory Survey for Lumut Balai Geothermal Power Plant (2) (hereinafter referred as "the Survey") with Bappenas, PT. Pertamina (Persero), and PT. PLN (Persero), and the parties agreed on July 7th 2010 that the Survey should be conducted on the basis that this was a candidate project for a Japanese ODA Loan. It was also agreed that Bappenas, PT. Pertamina and PT. PLN will undertake to provide required conveniences to the Survey team to assist the implementation of the Survey through close coordination with the authorities of GOI.

1.2 Outline of the Project

(1) Objectives

1) To support the implementation of Crash Program II to enhance Indonesia's effort to rapidly strengthen its electricity supply capacity
2) To reduce the negative impacts of electricity development on the environment through the development of geothermal energy
3) To improve the living conditions and investment climate in Sumatra by strengthening the power supply capacity

(2) Scope of the Pertamina Portion of the Project

The project consists of five (5) major components:

1) Steam production facility construction for Lumut Balai Geothermal Power Plants (3, 4)

2) Geothermal power plant construction for Lumut Balai Geothermal Power Plants (3, 4)
3) Construction of other necessary facilities for Lumut Balai Geothermal Power Plants (3, 4)
4) Consulting services (detailed design, bidding support, construction monitoring, environmental management, etc.)

Implementation Structure

1) Executing Agency

PT. Pertamina (Persero)

2) Implementation Agency

PT. Pertamina Geothermal Energy (PGE) on behalf of Pertamina

(3) Scope of the PLN Portion of the Project

The project consists of the following major components:

1) Transmission and distribution line construction for Lumut Balai Geothermal Power Plants (1, 2, 3, 4)
2) Consulting services (detailed design, bidding support, construction monitoring, environmental management, etc.)

Implementation Structure

1) Executing Agency

PT. PLN (Persero)

1.3 Terms of Reference of the Preparatory Survey

(1) Review and Confirmation of the Project and Electricity Demand in Indonesia (Review of the following matters)

A. Review of the current status of the electricity sector in Indonesia and the Lumut Balai area
B. Review of the overall scope of the Project in the context of electricity demand and supply in Indonesia and the Lumut Balai area
C. Review of Indonesia's development plan for the electricity sector
D. Review of the current status of other donors in terms of their state of support and plans for the electricity sector

(2) Review of the Details of the Geothermal Reserve of the Project

A. Review of the geological, geochemical, geophysical, well and other existing data
B. Review of surface survey data around the expected well-drilling area
C. Review of the estimated amount of geothermal resource potential
D. Review of geothermal reservoir model and conducting of a reservoir simulation study
E. Review of steam-field development plan and recommendation concerning the plan

(3) Review of the Detailed Plans for Power Plant Construction

A. Review of the scope, cost and schedule of drilling for production and re-injection wells
B. Review of the scope, cost and schedule of pipeline construction
C. Review of the scope, cost and schedule of power plant construction

D. Review of the scope, cost and schedule of construction of transmission line and facilities
E. Review of the construction methods

(4) Review of the Implementation and O&M Organization

A. Review of the implementation organization for steam-field development
B. Review of operation organization for the power plant
C. Review of implementation organization for maintenance (including Environmental monitoring)
D. Confirmation of the current status of similar Japanese ODA loan projects

(5) Review of Calculation of the Total Project Cost and O&M Cost, and Preparation of Implementation Program

A. Details and total cost for the steam-field development
B. Details and total cost for the power plant construction
C. Details and total cost for the transmission line and substation construction
D. Details and total cost for the operation and maintenance (O&M)
E. Total project cost and its ODA loan portion (including procurement and implementation plan)
F. Procurement plan (including package) and procedure of permissions
G. Review of the entire schedule of the project
H. Proposal of the project implementation plan

(6) Confirmation of the Project Effects

A. Identification of Operation and Effect Indicators
B. Calculation of qualitative effects
C. Calculation of Financial and Economic Internal Rate of Return (FIRR/EIRR)

(7) Environmental and Social Considerations

A. Confirmation of environmental impacts
B. Confirmation of social impacts
C. Discussion on the alternative plan taking account of environmental and social considerations

(8) Report of the Survey Results to GOI

A. A workshop will be held during the study, in which the Survey team will present feedback from survey items 1 to 7 above, and collect and reflect comments from GOI, Pertamina, and PLN in the Draft Final Report

1.4 Methods of the Preparatory Survey

This survey has three main focuses: resource potential evaluation, environmental constraints, and construction of power plant and transmission line with substation (including environmental assessment). The basic technical approaches for these focuses are as follows.

(1) Geothermal resource evaluation and review of steam-field development plan

The Survey team will formulate a geothermal reservoir conceptual model that explains the structure of the geothermal reservoir and fluid flow in the model, by integrating information relating to reservoir structure, distribution, fluid flow and physical/chemical features. On the basis of such information, the Survey team will conduct reservoir simulation to quantitatively evaluate the resource potentials of the Lumut Balai geothermal fields. For the simulation, the program TOUGH2 developed at the Lawrence Berkeley National Laboratory, USA will be used. In the simulation study, the allocation of wells, the produced steam and brine flow rate, and the number of wells required will be forecasted for the purpose of supporting PGE in drawing up a steam-field development plan, considering the current steam-field development scenario, including well-drilling, steam production and the brine reinjection plan. Although the objective of this survey is to evaluate the feasibility of the development plan for units 3 and 4 (55 MW x 2 units), the reservoir simulation study should cover all of units 1 to 4, because it is necessary to evaluate the balance in the reservoirs for stable steam supply to the new units 3 and 4 in addition to the units 1 and 2. Based on the forecasted results, the Survey team will discuss with PGE the number and allocation of wells, the pipeline plan, and the power plant facilities to elaborate the optimum steam-field development plan. The procedure of reservoir simulation study is indicated in Fig. 1.4-1. In this survey, a reservoir numerical model will be constructed through a natural state simulation that represents the reservoir conditions in a steady state before the start of production and reinjection. The number of wells required for steam production and brine injection to operate units 1 to 4 will be forecasted, using this reservoir numerical model.

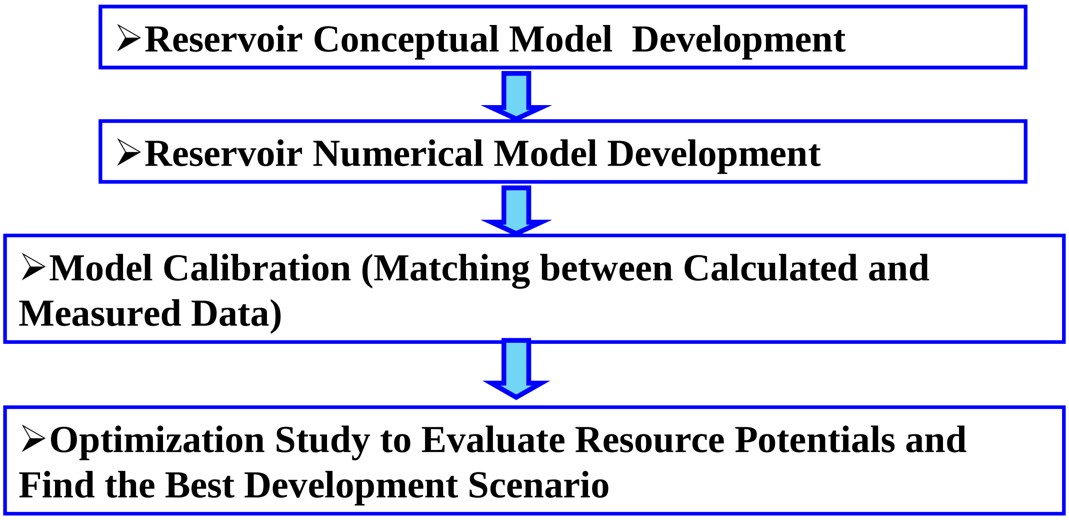


Fig. 1.4-1 Procedure of reservoir simulation study

(2) Power Plant Construction Plan

1) Well Drilling Plan

The Survey team will review the items below with reference to the results of reservoir simulation and production tests, and recommend a revised plan, if necessary.

A. Drilling plan for production and reinjection wells

B. Specifications of production and reinjection wells

C. Measures against scale deposition and corrosion, and well operation plan

2) Fluid Collection and Reinjection System Construction Plan

The Survey team will review the scope, cost and schedule of pipeline construction for steam production and water-reinjection into the ground (Fluid Collection and Reinjection System: FCRS) with particular attention to the following:

A. Geothermal fluid characteristics (wellhead pressure, steam and brine flow, non-condensable gas content, brine chemicals, etc.) should be anticipated by geothermal resource study.

B. Location of prospect plant site, steam and brine transmission system and locations of separator stations should be in accordance with locations of production and reinjection wells including additional wells, topography, geology, soil conditions, scenery, etc.

If necessary, The Survey team will propose an alternative power plant location and conceptual design for FCRS piping.

3) Review of Existing Data and Information related to Design of Geothermal Power Plant, and Preparation of Planning

The Survey team will review the selection of the prospective power plant site for units 3 & 4 and confirm that it takes into account the production and reinjection well drilling plan, prospective plant site, transmission line route, etc. for units 1 & 2. The Survey team will also review the civil engineering aspects of the suitability of the location and construction methods for the given topography and geology.

For the proper design of cooling towers, one of the major components of a geothermal power plant and one that is essential for ensuring a stable supply of electric power, the collection and analysis of meteorological data (especially temperature and relative humidity) is very important. At this writing, site meteorological data for Lumut Balai is not available. Accordingly, the Survey team will make reference to the short-term meteorological data (temperature, relative humidity, wind direction, wind speed, and rainfall) observed during the survey and will also consider the design of the existing Kamojang Unit 4 (altitude: 1,500 m asl) which faces similar conditions of relative humidity. The Survey team will suggest that PGE carry out meteorological observations at the site in parallel with the well-drilling work in advance of power plant construction. The Survey team will collect as much data and information as possible regarding topography, geology, soil conditions, surface faults, landslides, geographic features, slopes, vegetation, natural forest, wild animals, etc., to facilitate the planning of power plant construction.

A. Conceptual design of geothermal power plant mechanical equipment (turbines)

The Survey team will review the optimization of the turbine inlet pressure for the plant cycle selected from among various options, based on anticipated geothermal fluid characteristics and steam pipeline design. Upon confirming the reasonableness of the preliminary heat balance diagram and plant performance, the Survey team will review the conceptual design of the plant mechanical equipment (turbines, condensers, gas extraction equipment, cooling towers, hotwell pumps, etc.). Based on this conceptual design, the Survey team will further consider whether topography, geology and the prevailing wind direction have been considered in plant site selection and plant layout.

B. Conceptual design of geothermal power plant electrical equipment (generators)

Air-cooled module type generators are widely adopted in geothermal power plants because of their high reliability and easy operation and maintenance. Since corrosive H_2S gas is present in geothermal power plants, it is essential to take proper measures against H_2S gas. The generator power factor is an important factor in generator capacity, which depends upon requirements from the Network. The proposed power factor will be reviewed based on collected data.

The station service electric power system should be planned to supply electricity to the many auxiliary pieces of power plant equipment. The system will be reviewed based on existing power plants.

(4) Transmission Line

A. Conceptual design of transmission and substation facilities

Electricity generated at the Lumut Balai geothermal power plant units 3 and 4 will be delivered to the South Sumatra power system via the switchyard of units 1 and 2. Therefore, a suitable transmission line route will be reviewed from the proposed unit 3 and 4 site to the switchyard of units 1 and 2. Subsequently, the adopted conductor for the line will be reviewed based on voltage drop and power loss calculations. Furthermore, the capacity of the 150 kV transmission line from the planned units 1 and 2 to Lahat substation must be confirmed. In addition, the possibility for expansion at Lahat substation must be confirmed for Lumut Balai geothermal power plant construction. If there are any disadvantages in the current planning, suitable solutions will be proposed.

B. Power system analysis of and System stability report on the South Sumatra power system

Existing documents relevant to a power system analysis and system stability report will be collected for review of “Influence on / by the Network of the 220 MW Lumut Balai geothermal power plant”. The review will be limited to the affected area around Lumut Balai geothermal power plant.

(5) Review of Implementation Method

The Survey team will review the implementation method emphasizing the following considerations:

- Project cost
- Economy
- Balance of technology and cost
- Implementation schedule (period for PPA with PLN, various procedures for Japanese ODA loan, selection of consultant, preparation of bid documents, bidding period, designing, construction, tests and commissioning, etc.)

(6) Economic and Financial Evaluation

The Survey team will provide an economic and financial evaluation, assuming the application of a Japanese ODA loan to the Pertamina portion of steam-field development and construction of the power plant and to the PLN portion involving the construction of a transmission line with substation. In particular, if expansion of the substation is necessary in the PLN portion of the project, the Survey team will confirm whether or not PLN intends to apply a Japanese ODA loan to the expansion of the substation in addition to the construction of transmission line. Then, the team will show that this project is more economically viable in fact, with the application of a Japanese ODA loan. Furthermore, it becomes possible to provide various kinds of technical support. In order to enhance the rapid development of geothermal power plant projects in Indonesia, the team will introduce a scheme of the Japanese ODA loans that are available to support the geothermal power plant projects of PGE.

A. Cost Estimates

Based on the cost estimates in the 2009 JICA FS for Lumut Balai units 1 and 2 and AECOM’s FS, the project cost will be finalized through discussions with PGE. All costs and the subsequent economic and financial evaluation are expressed in Japanese yen.

B. Finance Procurement Plan

The project finance plans will be drawn up following the JICA guidelines for Yen Loans; 85% of the total project cost will be financed by a Yen Loan and the remaining 15% will come from PGE’s own assets.

C. Economic and Financial Evaluation

The economic viability of the Project will be studied through comparison with the alternatives, coal-fired power and the combined cycle power considered in AECOM's FS. As for the financial evaluation, the levelized energy cost of the project will first be calculated in consideration of the drilling program estimated through reservoir simulation, and then the FIRR will be calculated on the basis of the unit selling rate of the levelized energy cost. In addition, a repayment schedule and cash flow statement will be prepared.

(7) Environmental and social considerations

Now exploratory wells are already being drilling in the Lumut Balai unit 1 and 2 area adjacent to this study area (Lumut Balai units 3 and 4), and the AMDAL (environmental impact assessment) for 440 MW at Lumut Balai has already been executed. If this AMDAL can be applied to Lumut Balai units 3 and 4, then we will confirm whether it follows JBIC Guidelines for Confirmation of Environmental and Social Considerations (April, 2002) and is sufficient for the power plant construction or not. If it proves to be insufficient, we will support PGE in preparing the additional AMDAL. In addition, it seems that the items to be considered and the standards for judging environmental issues sometimes differ between PGE and JICA. This is because PGE must follow Indonesian rules, whereas, on the other hand, JICA is an ODA organization. When undesirable environmental consequences of power plant construction are anticipated, we will study technically whether they can be evaded or mitigated.

In particular, the Survey team will measure the wind direction and velocity near the power plant site over the short-term (7-10 days), because the nearest weather station is about 200 km away. Airborne hydrogen sulfide, noise and water quality will be measured and their environmental impact considered.

The Survey team will pay special attention to the issues of 1) encroachment into the natural protected forest, 2) environmental impacts on natural forest/production forest/reserve forest, 3) the relevant necessary permissions, 4) land acquisition and resettlement (if needed, and the details of impacts and compensation), and 5) compensation for ROW.

(8) Confirmation of present status of other Yen loan projects

In order to confirm the present status of other Yen loan projects, the Survey team will analyze the chemical characteristics in the acidic brine produced from the dominant production well LHD-23 at the Lahendong geothermal field. Based on the results of this analysis, the Survey team will report on the cause of the acidity and possible mitigating measures.

1.5 Survey Flow and Schedule

The work flow and schedule of this survey are indicated in Fig. 1.5-1 and Fig. 1.5-2, respectively. Members of the site survey team are listed in the table, below.

Name	Specialty	Assignment
TOKITA, Hiroyuki	Survey project manager, Reservoir engineer	Team Leader Resource evaluation (potential estimation),
MAEDA, Shun'ichi	Geologist	Resource evaluation (geology, well geology and geophysics)
KIMOTO, Hisao	Power plant engineer	Design of power plant (general and mechanical)
YAMAMOTO, Takeshi	Power plant engineer	Basic design of power plant (mechanical)
SAKEMURA, Kenji	Power plant, transmission line and substation engineer	Design of electrical system, I&C of power plant and transmission line and substation
KONDO, Shinya	Power plant, transmission line and substation engineer	Basic design of electrical system, I&C of power plant and transmission line and substation
UCHIYAMA, Noriaki	Environmentalist	Social/natural environment research, CDM
FUJII, Kenji	Economist	Financial and economic evaluation
IWANAGA, Tatsuto	Geochemist	Survey of discharge brine, logging and measurement of wells, chemical neutralization

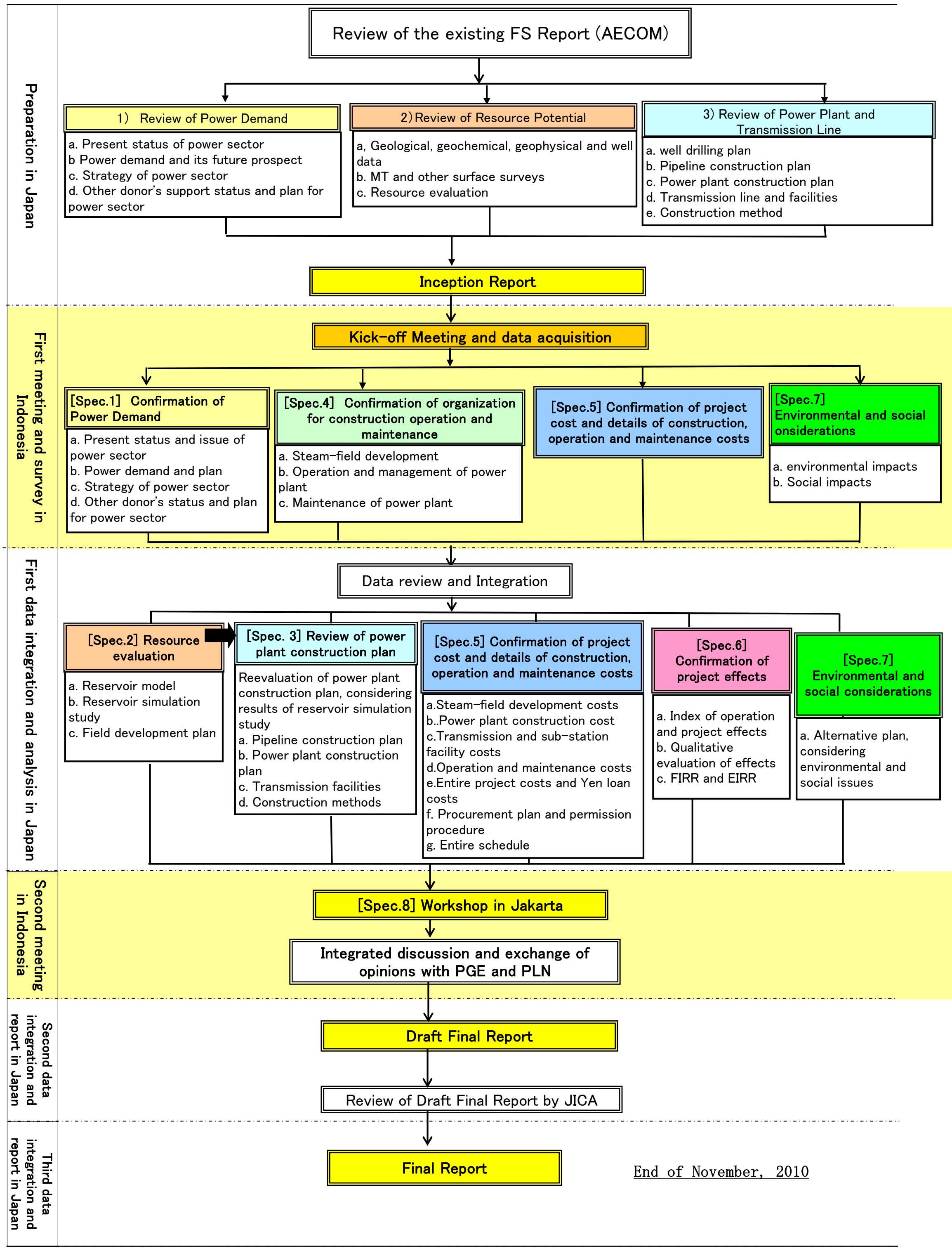


Fig. 1.5-1 Flow of the Preparatory Survey

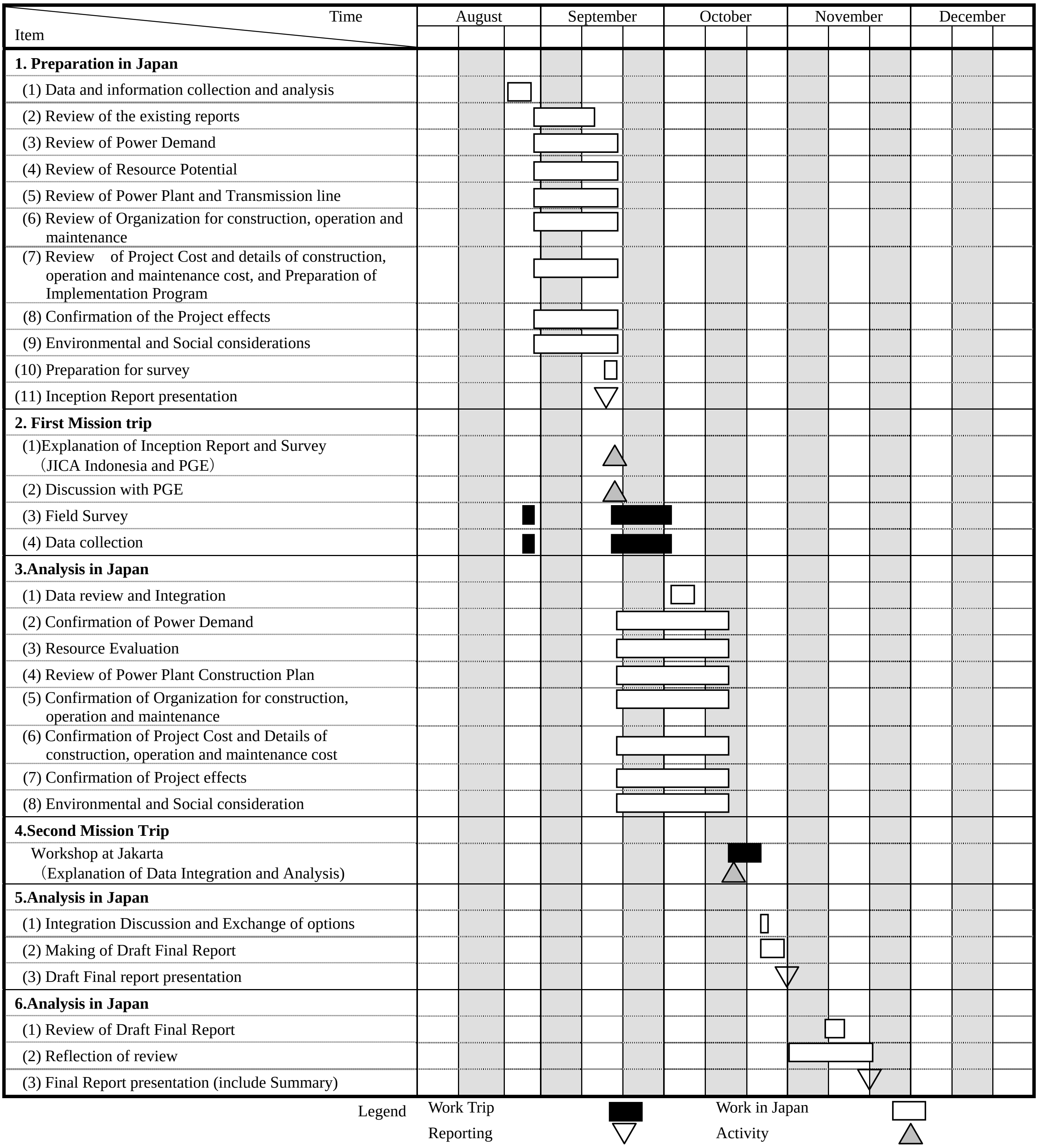


Fig. 1.5-2 Flow of the Preparatory Survey

CHAPTER 2 REVIEW AND CONFIRMATION OF THE NECESSITY OF THE PROJECT AND ELECTRICITY DEMAND IN INDONESIA

2.1 Outline of the Indonesian Sector

Indonesia suffered the largest impact among ASEAN countries in the Asian economic crisis of 1997. The Indonesian economy, however, has shown a great improvement since the crisis, energized by the results of various policy reforms and supported by the inflow of investment from foreign and domestic sources. (Source; Indonesia Overview in World Bank homepage) Thus, the Indonesian economy is expanding steadily, and electric power demand is also increasing rapidly. The peak power demand for the whole country reached 24,069 MW in 2009, showing a 5.1% increase from the previous year. The aggregate amount of energy demand in 2009 was 133.11 TWh, a 4.3% increase from the previous year. The National Electricity Provision Plan 2010 (RUPTL 2010 - 2019) estimated that the peak power demand of the country would increase at an average annual rate of 9.5% and would reach 59,863 MW in 2019. It also estimated that the energy demand would increase at a higher rate than the power demand and will reach 334.4 TWh in 2019. In order to secure a stable energy supply, the development of power plants to meet these demands is one of the urgent issues confronting the Indonesian power sector. Since demand in the Java-Bali system accounts for 78.2% (as of 2009) of total national demand, power plant development in this system is most important. For this purpose, the Indonesian government promulgated a President Decree in 2006 entitled “Crash Program” with the aim of developing 10,000 MW in the Java-Bali system. Construction work implementing this program is in progress today. Furthermore, power development in systems other than the Java-Bali system is also very crucial because power demand will increase rapidly due to the expansion of rural electrification and the rural economy. Thus, a second crash program has been promulgated by the Indonesian government in 2010. This is also a program to develop 10,000 MW of generating capacity, with 53% being developed in systems other than the Java-Bali system. It is to be noted that most of the plants in these other systems will tap renewable energy, most of them taking the form of IPP-managed geothermal power plants.

Another urgent issue that the Indonesian power sector faces is the diversification of energy sources. In the light of high oil prices, it is necessary to reduce dependency on oil as an energy source in order to reduce generation costs and to secure a stable energy supply. For this purpose, the Indonesian government worked out a "National Energy Policy (NEP)" in 2002, and set the target of obtaining 5% or more of primary energy from renewable sources by 2020. To achieve this target, the government is placing great reliance on geothermal energy, which is abundant in the country.

2.2 Current Status of Electric Power Supply and Demand

The power demand of Indonesia (sales of electric power) in 2009 was 133.11 TWh. To meet this demand, 133.11 TWh of electric power was generated by power plants with an aggregate capacity of 30,320 MW. The breakdown of this capacity is 11,700 MW of steam power plants (38.6%), 7,521 MW of gas combined-cycle power plants (24.8%), 3,648 MW of hydro power plants (12.0%), 2,619 MW of diesel power plants (8.6%), 3,116 MW of gas turbine plants (10.3%), and 1,105 MW of geothermal power plants (3.6%). In 2009, there were 41.0 million power purchase contracts, marking a 16% increase over the year 2005. Since many customers are waiting for electric power to become available, the number of contracts would increase at a higher rate than previously, if the power supply were adequate.

The national electric power system of Indonesia can be divided into two categories: interconnected electric power systems and isolated electric power systems. The Java-Bali System has already developed and established an interconnected electric power system through an Ultra-high-voltage (500 kV) power transmission network. The Sumatra system is also interconnected by a 150 kV transmission network running from north to south. However, since the network voltage (150 kV) is relatively low considering the length of transmission lines, the North and South networks have been operating independently. Power supply systems other than the above two Systems have not been integrated yet and are not completely interconnected with each other. These power systems consist of sub-systems and individually isolated smaller sub-systems, and there are still many independent/isolated regions. 22,906 MW (75.7%) of total power plant capacity is concentrated in the Java-Bali system, and only 4,598 MW (15.2%) of total capacity is generated in the Sumatra system. The two systems account for 90.7% of total national capacity.

2.3 Current Status of Geothermal Energy Development in Indonesia

It is said that Indonesia has the world's greatest geothermal energy potential, which is estimated at more than 27,000 MW and is thought to account for more than 40% of total world potential. Therefore, the development of geothermal power has been eagerly awaited in order to supply energy to satisfy the increasing power demand and to advance the diversification of energy sources. Today, geothermal power plants are found in seven fields in Indonesia, i.e. Sibayak in north Sumatra, Salak, Wayang Windu, Kamojang, and Darajat in west Java, Dieng in central Java, and Lahendong in north Sulawesi, as shown in Table. 2.3-1. Although this capacity ranks as the third largest in the world, Indonesia is just beginning to utilize its huge geothermal potential.

Table. 2.3-1 List of Geothermal Power Plants in Indonesia

<table>
<tr><th>Power Plant</th><th>Location</th><th>Unit</th><th>MW</th><th>Turbine Maker</th><th>Operation</th><th>Steam Supply</th><th>Power Generation</th></tr>
<tr><td rowspan="3">Sibayak</td><td rowspan="3">North Sumatra</td><td>#1</td><td>2</td><td>Unknown</td><td>1996</td><td colspan="2">Pertamina</td></tr>
<tr><td>#2</td><td>5</td><td>Unknown</td><td>2007</td><td rowspan="2">Pertamina</td><td rowspan="2">PT. Dizamatra</td></tr>
<tr><td>#3</td><td>5</td><td>Unknown</td><td>2007</td></tr>
<tr><td rowspan="6">Salak</td><td rowspan="6">West Java</td><td>#1</td><td>55</td><td>ANSALDO</td><td>1994</td><td rowspan="3">Chevron Geothermal Indonesia</td><td rowspan="3">PLN</td></tr>
<tr><td>#2</td><td>55</td><td>ANSALDO</td><td>1994</td></tr>
<tr><td>#3</td><td>55</td><td>ANSALDO</td><td>1994</td></tr>
<tr><td>#4</td><td>55</td><td>Fuji</td><td>1997</td><td colspan="2" rowspan="3">Chevron Geothermal Indonesia</td></tr>
<tr><td>#5</td><td>55</td><td>Fuji</td><td>1997</td></tr>
<tr><td>#6</td><td>55</td><td>Fuji</td><td>1997</td></tr>
<tr><td rowspan="2">Wayang-Windu</td><td rowspan="2">West Java</td><td>#1</td><td>110</td><td>Fuji</td><td>2000</td><td colspan="2" rowspan="2">Mandala Nusantara Ltd</td></tr>
<tr><td>#2</td><td>117</td><td>Fuji</td><td>2009</td></tr>
<tr><td rowspan="4">Kamojang</td><td rowspan="4">West Java</td><td>#1</td><td>30</td><td>MHI</td><td>1983</td><td rowspan="3">Pertamina</td><td rowspan="3">PLN</td></tr>
<tr><td>#2</td><td>55</td><td>MHI</td><td>1988</td></tr>
<tr><td>#3</td><td>55</td><td>MHI</td><td>1988</td></tr>
<tr><td>#4</td><td>63</td><td>Fuji</td><td>2008</td><td colspan="2">Pertamina</td></tr>
<tr><td>Darajat</td><td>West Java</td><td>#1</td><td>55</td><td>MHI</td><td>1994</td><td>Chevron Geothermal Indonesia</td><td>PLN</td></tr>
</table>

Power Plant	Location	Unit	MW	Turbine Maker	Operation	Steam Supply	Power Generation
		#2	81.3	MHI	2000	PT. Chevron Geothermal Indonesia	
		#3	110	MHI	2007		
Dieng	Central Java	#1	60	ANSALDO	1999	Geodipa Energi	
Lahendong	North Sulawesi	#1	20	ALSTOM	2001	Pertamina	PLN
		#2	20	Fuji	2007	Pertamina	PLN
		#3	20	Fuji	2009	Pertamina	PLN

The Indonesian economy has shown a strong recovery from the Asian economic crisis, and has been continuously expanding in recent years. Accordingly, domestic energy demand is also expanding. On the other hand, oil supply has decreased due to the depletion of existing oilfields or aging of the production facilities. As a result, Indonesia changed from being an oil-exporting country to being an oil-importing country in 2002.

Under the impetus of this worsening situation, the Indonesian government decided to diversify energy sources and to promote domestic energy sources in order to lower oil dependency. The government worked out a "National Energy Policy" (NEP) in 2002, and set a target of deriving 5% or more of primary energy from renewable sources by 2020. In addition, the government promulgated the "Presidential Decree on the National Energy Policy" (PD No.5/2006) in 2006, raising the NEP from ministerial level policy to the level of presidential policy. On another front, the government enacted a "Geothermal Energy Law" for the first time in 2003 to promote the participation of the private sector in geothermal power generation. Moreover, in 2004 the Ministry of Energy and Mineral Resources (MEMR) worked out the "Road Map Development Plan for Geothermal Energy" (referred to hereafter as the "Road Map") to materialize the national energy plan. This Road Map sets high geothermal development targets of 6,000 MW by 2020 and 9,500 MW by 2025. In 2001, the Indonesian government issued a law that limited the business activities of Pertamina to Oil and Gas. Subsequently, Pertamina was transformed into a limited company owned by the Indonesian government in 2003 (Government Regulation No.31/2003), and Pertamina Geothermal Energy Ltd. was established in 2006 to expedite the geothermal component of the plan. Thus, a basic framework for geothermal energy development has been created and the government has initiated efforts to attain its development targets.

2.4 Electric Power Supply and Demand in the Project Area

2.4.1 Sumatra Overall

Installed capacity in the Sumatra system reached 4,070MW in 2009, as shown in Table. 2.4-1. However, 378MW or 9.3 % of installed capacity was installed more than 20 years ago, 403 MW or 9.9 % of installed capacity consists of diesel power plants which are being phased out starting from 2007 for technical or economic reasons, and 855 MW or 21 % of installed capacity consists of hydropower plants, which depend on seasonal conditions.

Table. 2.4-1 Installed Capacity in Sumatra System (2009)

(Source: PLN data)

Name of PP	Fuel	Install Capacity [MW]	Net Capacity [MW]
Northern Sumatra			
HPP	Hydro	132.0	132
GTPP	HSD	190.7	158.9
STCFPP	MFO	260.0	220
STCFPP	Coal	115.0	115
CCPP	Gas/HSD	817.8	710
Diesel	HSD	85.0	59.1
Micro Hydro	Hydro	7.5	6.7
Geo PP	Geo	10.0	10
Rent Diesel	HSD	117.7	107
Sun Total		**1735.7**	**1518.7**
Southrn - Central Sumatra			
HPP	Hydro	716.1	711.3
GTPP	Gas	356.5	323.2
GTPP	HSD	85.4	7.6
STCFPP	Coal	660.0	599.7
STCFPP	Gas	25.0	22.3
CCPP	Gas	280.0	273.4
Micro Gas	Gas	11.6	11.6
Diesel	HSD	147.0	107.5
Diesel	IDO	25.2	24.2
Diesel	MFO	28.2	26.2
Sub Total		2335.0	2107.0
Total		4070.7	3625.7

Fig. 2.4-1 shows the Transmission network of Sumatra Island. The network is interconnected through 150 kV transmission lines between NAD province (northernmost) and Lampung province (southernmost). As mentioned in section 2.2 above, the north and south networks have been operating independently.

Fig. 2.4-1 Transmission network of Sumatra Island

(Source: RUPTL 2010-2019)

Table. 2.4-2 and Fig. 2.4-2 show the Power balance in the Sumatra System (2010 to 2019) in accordance with RUPTL 2010 – 2019.

Energy production in the Sumatra system is expected to rise an average 10.9% per year between 2010 and 2019, increasing from 21,533 GWh in 2010 to 54,807 GWh in 2019. Load factor is estimated to be from 65.4% to 66.9%. Peak load in 2010 is 3,743 MW and will grow an average of 10.7% per year, reaching 9,355 MW in 2019.

It seems that the generating capacity is quite sufficient to meet demand, as shown in Fig. 2.4-2. However, in the future development plan, there are as-yet unnamed projects in the list whose capacity is approximately 2,125 MW in total. In addition, generating capacity frequently decreases for various reasons such as regular maintenance of units, forced outages of units, low water flow rate of hydropower plants, etc.

Table. 2.4-2 Power Balance in the Sumatra System (2010 to 2019)

（Based on RUPTL 2010-2019）

	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Demand											
Energy production	GWh	21,533	23,470	25,707	28,345	31,829	35,805	40,266	44,886	49,626	54,807
Peak load	MW	**3,743**	**4,099**	**4,487**	**4,958**	**5,553**	**6,219**	**6,965**	**7,731**	**8,505**	**9,355**
Load factor	%	66	65	65	65	65	66	66	66	67	67
Supply											
Existing Installed capacity	**MW**	**4,038**	**3,778**	**3,621**	**3,006**	**3,006**	**3,006**	**2,940**	**2,940**	**2,940**	**2,940**
PLN		3,683	3,387	3,230	2,680	2,680	2,380	2,680	2,680	2,680	2,680
IPP		260	260	260	260	260	260	260	260	260	260
Lease		95	131	131	66	66	66				
PLN projects		**354**	**815**	**1,734**	**2,304**	**2,614**	**2,614**	**3,089**	**3,764**	**4,064**	**4,464**
Ongoing Projects		354	815	1,634	1,534	1,534	1,534	1,534	1,534	1,534	1,534
Planned Projects		0	0	100	770	1,080	1,080	1,555	2,230	2,530	2,930
IPP		**180**	**607**	**837**	**1,324**	**3,060**	**4,080**	**4,495**	**4,850**	**5,580**	**6,510**
Ongoing Projects		**180**	**407**	**407**	**407**	**407**	**407**	**407**	**407**	**407**	**407**
Simpang Belimbing	PLTG		227								
Asahan I	PLTA	180									
Planned Projects		**0**	**200**	**430**	**917**	**2,653**	**3,673**	**4,088**	**4,443**	**5,173**	**6,103**
Sewa PLTG Jambi Merang	PLTG		200	200				-200	-200		
Gunung Megang, ST Cycle	PLTGU			30							
Banjarsari	PLTU				100	100					
Jambi (Infrastruktur)	PLTU									400	400
Sumsel - 2 (Keban Agung)	PLTU				112	112					
Sumsel - 6, Mulut Tambang	PLTU					300	300				
Riau Mulut Tambang (Cirenti)	PLTU							300	300		
Tarahan #1,2	PLTU									200	200
Sumbar - 1	PLTU						200				
Sumsel - 5	PLTU					150	150				
Sumsel - 7	PLTU						150	150			
Sumut - 2	PLTU								225		
Ulubelu #3,4 (FTP2)	PLTP				55	55					
Lumut Balai (FTP2)	PLTP					220					
Seulawah (FTP2)	PLTP					55					
Sarulla I (FTP2)	PLTP				220	110					
Rajabasa (FTP2)	PLTP					220					
Muara Laboh (FTP2)	PLTP						220				
Rantau Dedap (FTP2)	PLTP					220					
Sarulla II (FTP2)	PLTP					110					
Wai Ratai	PLTP										55
Pusuk Bukit	PLTP									55	55
Sorik Merapi (FTP2)	PLTP					55					
Sipaholon	PLTP										55
G. Talang	PLTP									20	
Suoh Sekincau	PLTP									55	55
Danau Ranau	PLTP										110
Wampu	PLTA							45			
Lawe Mamas	PLTA							60	30		
Asahan #4,5	PLTA							60			
Simpang Aur (FTP2)	PLTA					29					
Total Capacity	MW	4,572	5,200	6,192	6,635	8,681	9,701	10,525	11,555	12,585	13,915
Dependable Capacity excluding Unnamed projects	MW	4,572	5,200	6,192	6,635	8,531	9,051	9,625	10,130	10,860	11,790
Unnamed projects	MW	0	0	0	0	150	650	900	1,425	1,725	2,125
Reserve margin	%	22%	27%	38%	34%	56%	56%	51%	49%	48%	49%

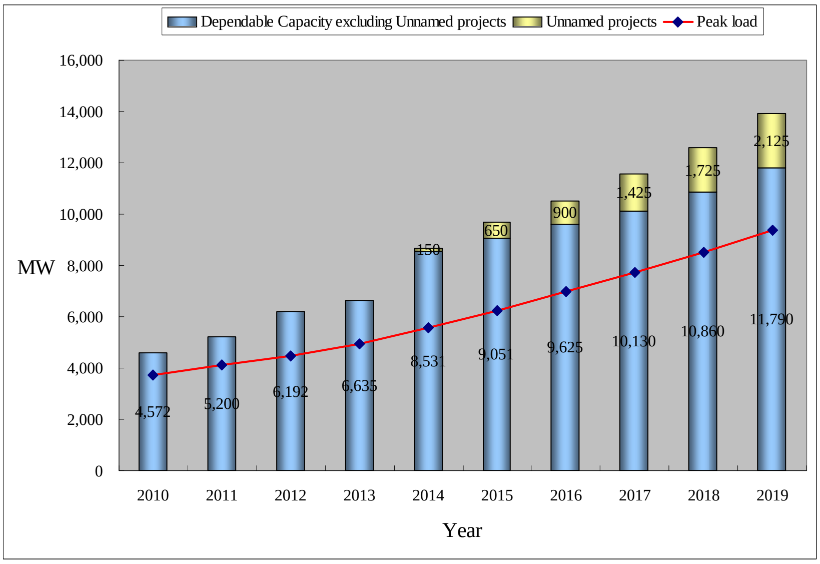


Fig. 2.4-2 Power Balance in the Sumatra System (2010 to 2019)

（Based on RUPTL 2010-2019）

2.4.2 South Sumatra

Lumut Balai geothermal power plant is located in South Sumatra province. The total area of the province is 91,592 km^2 (4.8% of Indonesia's total area), and the total population is approximately 7 million (as of 2007, a 1.8% increase over the previous year) according to 2008 statistical data. The capital is Palembang city, and provincial GDP is 96 million Rupiah (as of 2006, 2.9% of total Indonesian GDP). The percentage of people below the poverty line - 17.73% in 2008 (down 6% over the previous year) - is decreasing steadily, but this figure is still higher than the average (15.42%) for the whole country.

According to RUPTL 2010 – 2019, Lumut Balai geothermal power plant will be connected to Lahat substation which is 50 km north of the power plant.

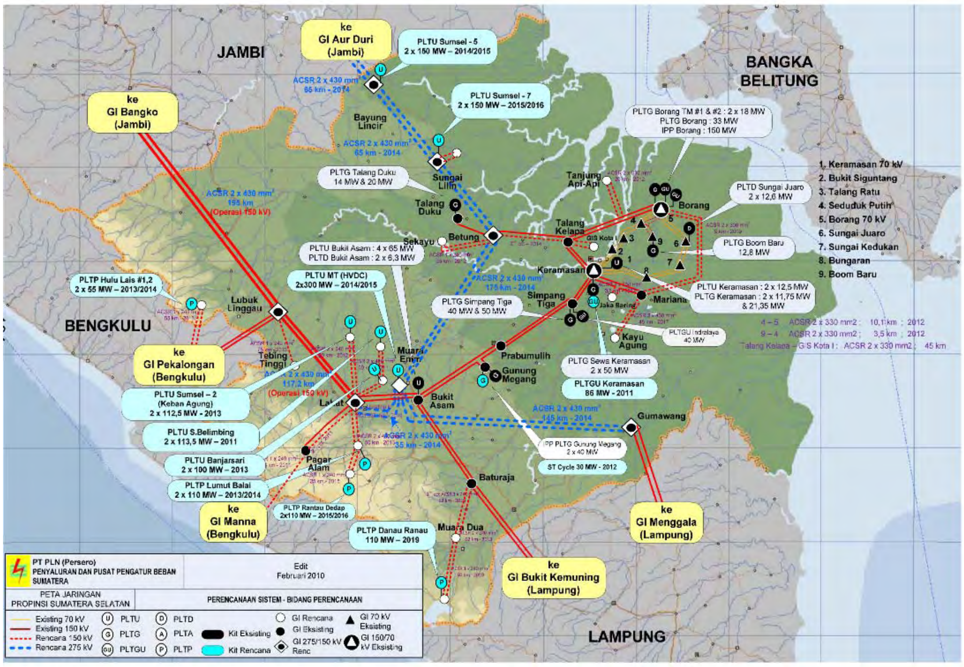


Fig. 2.4-3 Transmission Network of Sumatra Selatan (Source: RUPTL 2010-2019)

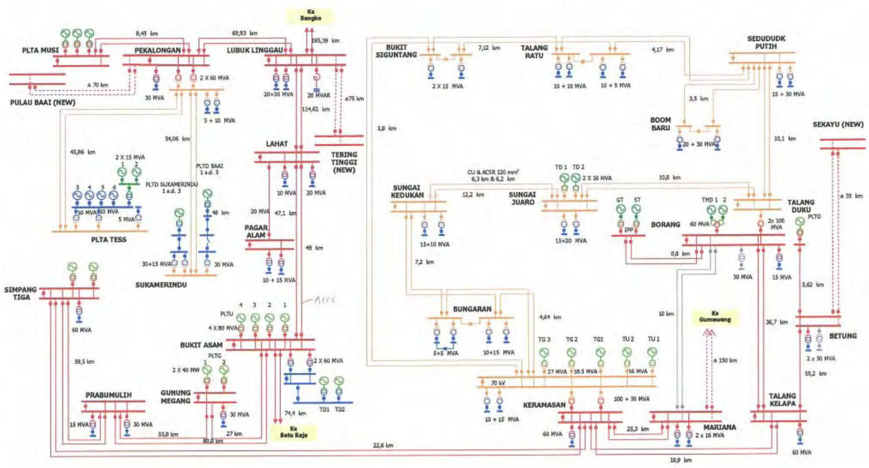


Fig. 2.4-4 Single Line Diagram of Sumatra Selatan Network (Source: PLN data)

The 150 kV transmission lines between the Southern Sumatra system and the Central Sumatra

system were completed in July 2004. The 150 kV southern to Central Sumatra interconnection is already designed for 275 kV between Lahat substation in South Sumatra and Kiliranjao substation in West Sumatra.
According to RUPTL 2010 – 2019, transmission lines between Lahat substation and Kiliranjao will be upgraded to 275kV grid in 2012.

Lahat substation will be upgraded to a 275/150/20 kV substation. Lumut Balai geothermal power plant will be connected to the Lahat 275kV substation. Fig. 2.4-5 shows the present Lahat 150/20kV substation and planned 275/150/20kV substation.

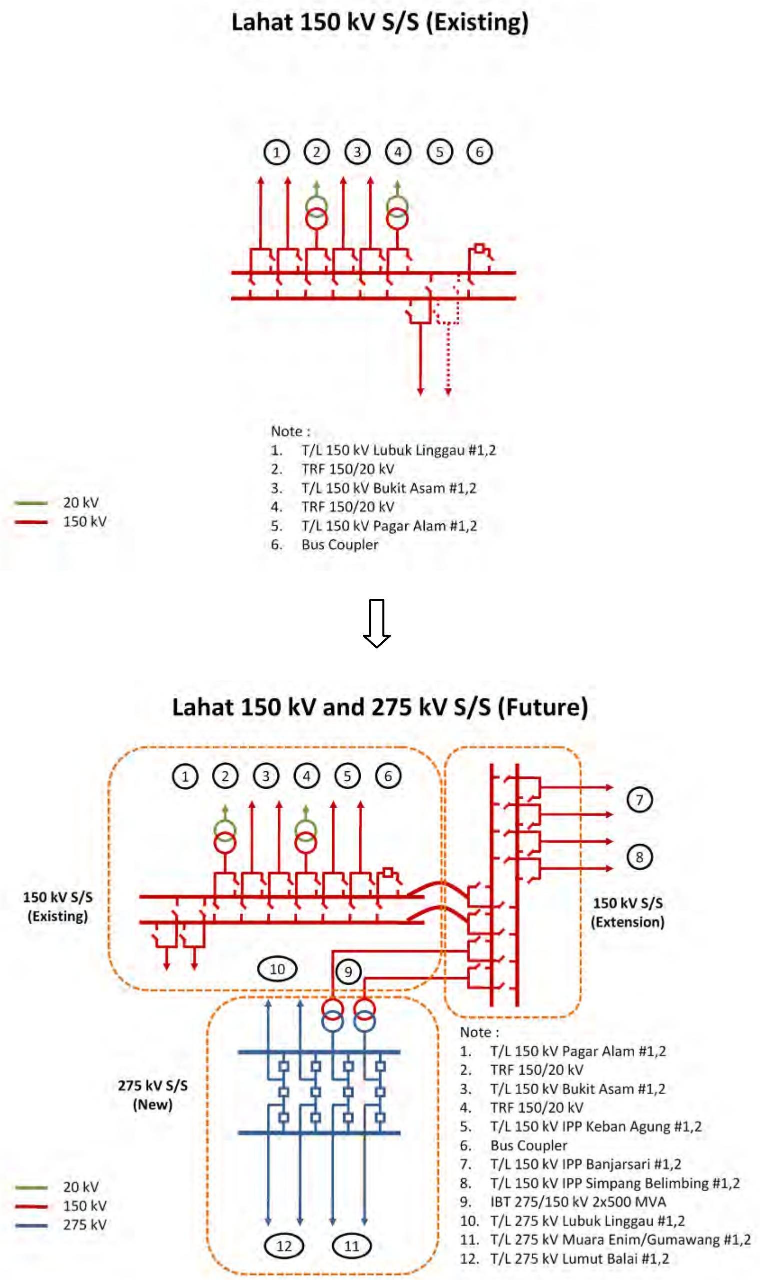


Fig. 2.4-5 Present Lahat 150/20kV substation and planned Lahat 275/150/20kV substation

(Source: PLN data)

In 2015, Lumut Balai geothermal power plant will transfer its total generated output (220MW) to the Lahat 275 kV substation. Most power will flow to Lubuk Linggau 275 kV substation, as shown in Fig. 2.4-6.

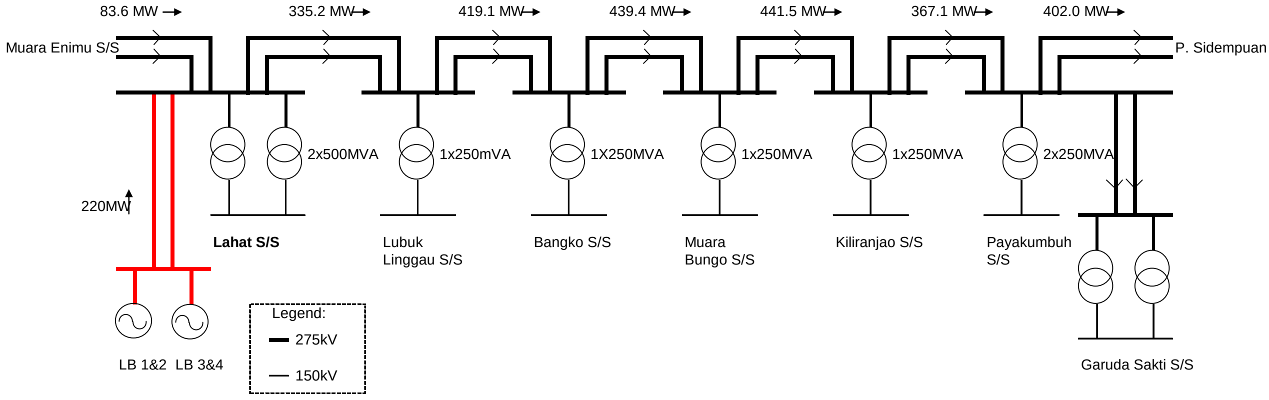


Fig. 2.4-6 Power flow at Lahat substation and 275kV grid in 2015

(Based on RUPTL 2010 – 2019)

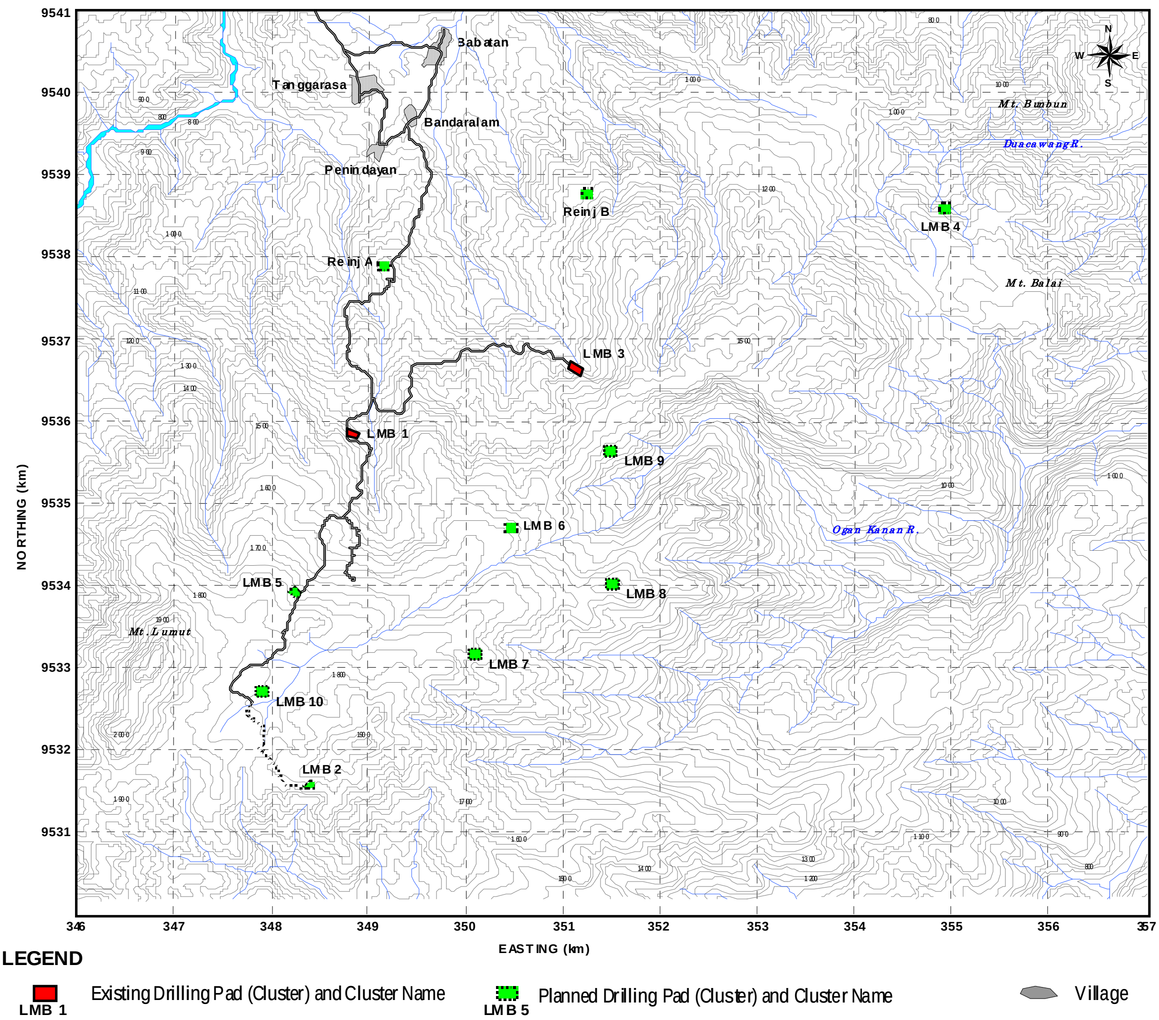
CHAPTER 3 GEOTHERMAL FIELD DEVELOPMENT

3.1 REVIEW OF EXISTING DATA AND INFORMATION ABOUT GEOTHERMAL RESOURCES

3.1.1 Current Status of Drilling Operations in Lumut Balai

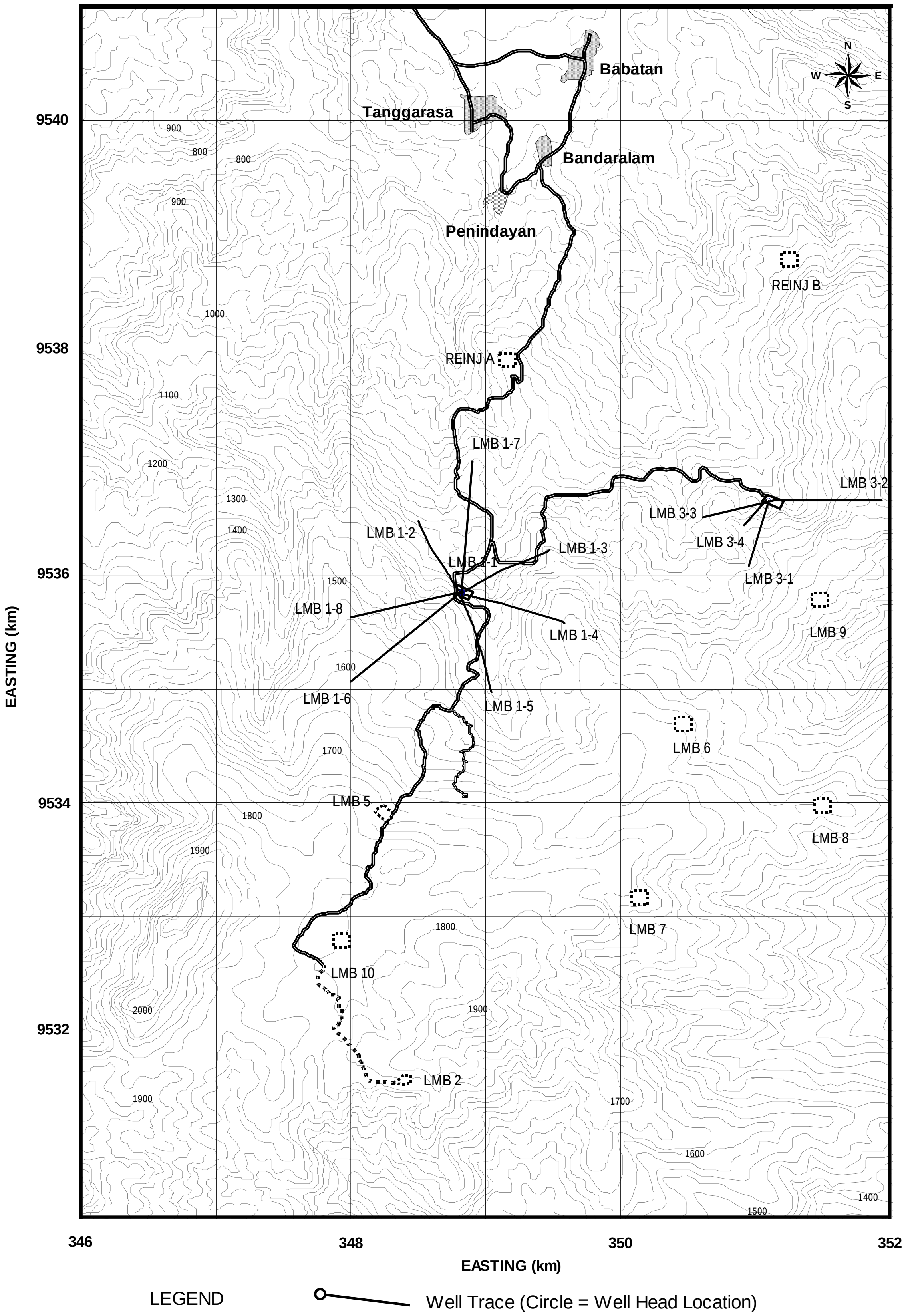
(1) Drilling Pad (Cluster)

Two drilling pads (Cluster LMB 1 and Cluster LMB 3) have already been constructed in Lumut Balai (see Fig. 3.1-1, Fig. 3.1-2 and Table 3.1-1). Also, access roads from the existing road to these drilling pads have already been constructed. Although their construction has not yet commenced, PGE plans to construct 10 drilling pads (LMB 2, LMB 4, LMB 5, LMB 6, LMB 7, LMB 8, LMB 9, LMB 10, Reinj A and Reinj B). An access road from Cluster LMB 1 to Cluster LMB 2 is also under construction. According to PGE, Clusters LMB 2, LMB 7, LMB 8 and LMB 10 are drilling pads for production wells of Unit 3 and Unit 4. Cluster Reinj B is a drilling pad for the future reinjection wells.



(Based on PGE data)

Fig. 3.1-1 Location of Drilling Pads in Lumut Balai Geothermal Field



(Based on PGE data)

Fig. 3.1-2 Location of Drilled Wells

Table 3.1-1 Well Summary

(1) LMB1 Pad (Cluster)

Cluster	LMB 1							
Well	LMB 1-1	LMB 1-2	LMB 1-3	LMB 1-4	LMB 1-5	LMB 1-6	LMB 1-7	LMB 1-8
Spud	9 May 2008	20 Jul 2008	20 Oct 2008	4 Jun 2009	3 Aug 2009	–	–	17 Jan 2010
Complete	10 Jul 2008	4 Oct 2008	6 Dec 2008	15 Jul 2009	10 Sep 2009	–	–	26 Feb 2010
Well-head coordinate X	348830 m	348830 m	348830 m	348830 m	348830 m	348830 m	348830 m	348830 m
Well-head coordinate Y	9535851 m	9535856 m	9535846 m	9535841 m	9535831 m	9535865 m	9535879 m	9535887 m
Well-head coordinate Z	1328 m	1328 m	1328 m	1328 m	1328 m	1328 m	1328 m	1328 m
KOP	—	350 m	310 m	430 m	430 m	351 m	420 m	430 m
Azimuth	339°	330°	60°	110°	165°	220	15	266°
Max drift angle		33°	34°	35°	35°	35°	35°	30°
Drilled depth	1999.9 m	2045 m	1980 m	2000 m	2200 m	2201 m	2167 m	1989 m
Vertical depth	1999 m	1879 m	1778 m	1762 m	1935 m	1829 m	1815 m	1792 m
Throw	26 m	705 m	749 m	800 m	907 m	1064 m	1021 m	705 m
30" CSG	0 – 30 m	0 – 21.75 m	0 – 13 m	0 – 30 m	0 – 30 m	–	–	0 –20.5 m
20" CSG	0 – 148.6 m	0 – 297.7 m	0 – 268 m	0 – 394.21 m	0 – 390 m	–	–	0 – 402 m
13$^{3}/_{8}$" CSG	0 – 434.8 m	0 – 750.6 m	0 – 709 m	0 – 834.32 m	0 – 919 m	0 – 1008 m	0 – 999 m	0 – 986 m
10$^{3}/_{4}$" BL				781.1 – 834.32m	857.3 – 919 m	939 –1609 m	966 – 1700 m	
10$^{3}/_{4}$" SL			709 – 1771 m	834.32 – 1491 m	919 – 1596 m			971.5 – 1687.7m
9$^{5}/_{8}$" CSG	0 – 958 m							
9$^{5}/_{8}$" BL		707.7 – 750.6 m						
9$^{5}/_{8}$" SL		750.6 – 1783 m	1771 – 1980 m			1562 – 2201 m	1676 – 2167 m	
8$^{5}/_{8}$" BL				1391.4 – 1491 m	1391.4 – 1596 m			1677 – 1989 m
8$^{5}/_{8}$" SL				1491 – 1962 m	1596 – 2170 m			
7" BL	906.5 - 958 m							
7" SL	958 – 1986 m	1770 – 2045 m						
26" BH	30 – 150 m	21.75 – 301 m	13 – 272 m		30 – 392 m	–	–	19 – 402 m
17$^{1}/_{2}$" BH	150 – 435.9 m	301 – 752.25 m	272 – 783 m		392 – 920 m	–	–	402 – 988 m
12$^{1}/_{4}$" BH	435.9 – 965.3 m	752.25 – 1789 m	783 – 1177 m		920 – 1599 m	–	–	988 – 1687.7 m
9$^{7}/_{8}$" BH			1177 – 1980 m	- 2000 m	1599 – 2200 m	–	–	1687.7 –1989 m
8$^{5}/_{8}$" BH	965.3 – 1999.9 m							
8$^{1}/_{2}$" BH		1789 – 2045 m						
Remarks	Vertical well	Directional well	Directional well	Directional well	Directional well	Directional well	Directional well	Directional well
	Vertical discharge tests were conducted (expected power output ranges from 5 MW to 15 MW per well).							

CSG = Casing BL = Blind Liner SL = Slotted Liner BH = Borehole

(2) LMB3 Pad (Cluster)

Cluster		LMB 3			
Well		LMB 3-1	LMB 3-2	LMB 3-3	LMB 3-4
Spud		26 Jun 2009	–	7 May 2010	24 Jun 2010
Complete		10 Aug 2009	–	7 Jan 2010	10 Aug 2010
Well-head coordinate	X	348830 m	348830 m	351062 m	348830 m
	Y	9535851 m	9535851 m	9536651 m	9535851 m
	Z	1328 m	1328 m	1235 m	1328 m
KOP		340 m	352 m	424 m	340 m
Azimuth		195°		262°	222°
Max drift angle		25°		35°	15°
Drilled depth		2005 m	2319 m	1800 m	1800 m
Vertical depth		1879 m	1986 m	1585 m	1757 m
Throw		597 m	1028 m	686 m	300 m
30” CSG		0 – 16 m	–	0 – 30 m	0 – 31 m
20” CSG		0 – 300.5 m	–	0 – 395 m	0 – 444.75 m
$13^{3}/_{8}$” CSG		0 – 909.6 m	0 – 797 m	0 – 833 m	0 – 750 m
$10^{3}/_{4}$” BL		878 – 909.6 m			729 – 741 m
$10^{3}/_{4}$” SL		909.6 – 1622 m	776 – 1671 m	809 – 1600 m	741 – 1400 m
$9^{5}/_{8}$” CSG					
$9^{5}/_{8}$” BL					
$9^{5}/_{8}$” SL			1647 – 2319 m		
$8^{5}/_{8}$” BL		1600 –1662 m			
$8^{5}/_{8}$” SL		1662 – 2004 m		1575 – 1800 m	1384 – 1800 m
7” BL					
7” SL					
26” BH		16 – 302 m	–	30 – 395 m	0 – 446 m
$17^{1}/_{2}$” BH		302 – 924 m	–	302 – 833 m	446 – 750.5 m
$12^{1}/_{4}$” BH		924 – 1623 m	–	924 – 1600 m	750.5 – 1400 m
$9^{7}/_{8}$” BH		1623 – 2005 m	–	1600 – 1800 m	1400 – 1800 m
$8^{5}/_{8}$” BH					
$8^{1}/_{2}$” BH		0 – 16 m			
Remarks		Directional well	Directional well	Directional well	Directional well
		Vertical discharge tests were conducted (expected power output ranges from 5 MW to 15 MW per well).			

CSG = Casing BL = Blind Liner SL = Slotted Liner BH = Borehole

[As of October 2010]

(Based on PGE data)

3.1.2 Exploration Data and Information

(1) Geology

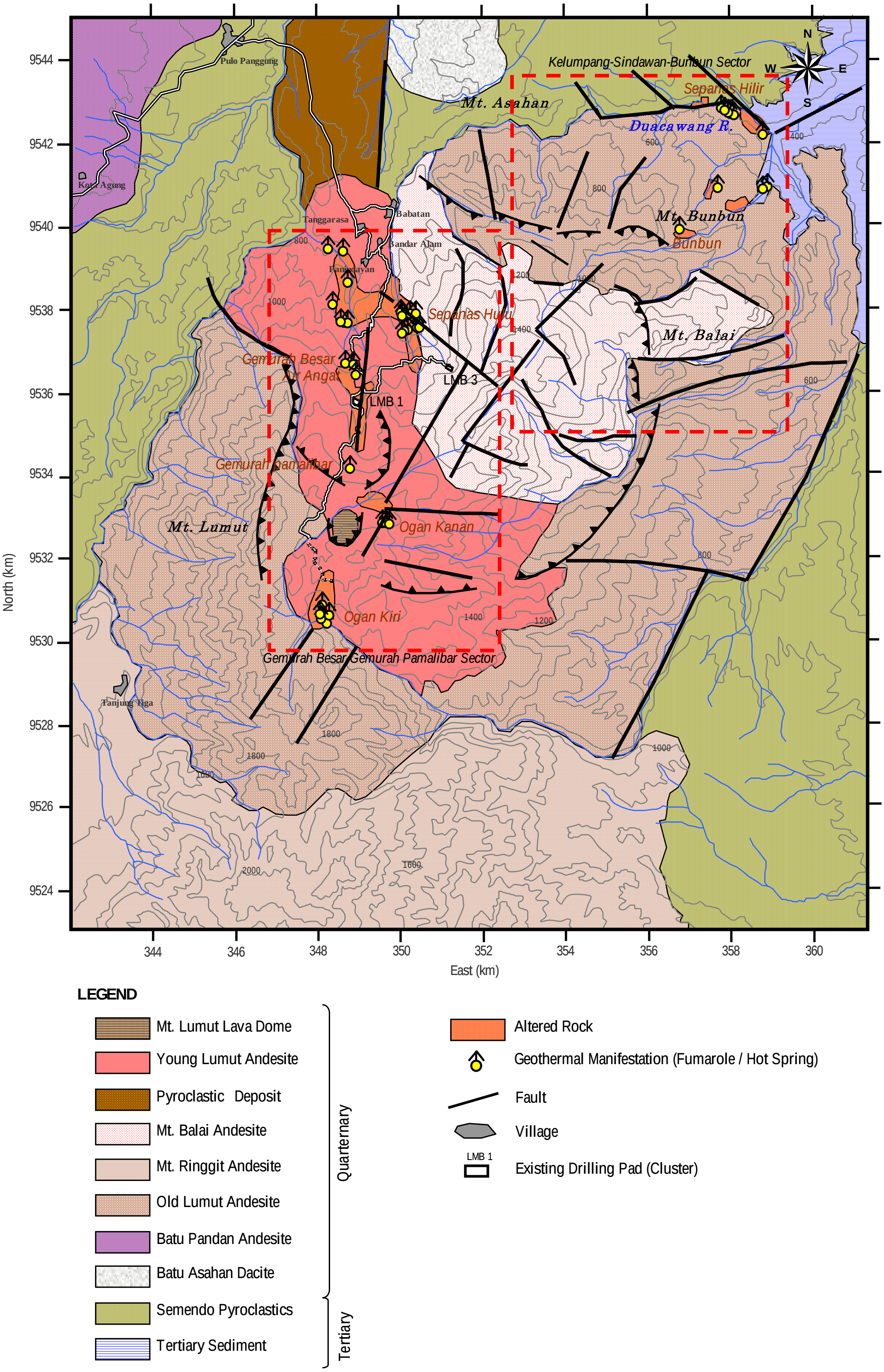
Surface Geology

Quaternary volcanic rocks cover the Lumut Balai geothermal field (see Fig. 3.1-3). However, sedimentary rocks of the Pliocene crop out in the northeast part of this field, and this formation consists of sandstone, siltstone and claystone. Quaternary volcanic rocks are classified as follows: Semendo pyroclastic rocks, Batu Asahan dacite, Batu Pandan andesite, Old Lumut andesite, Mt. Ringgit andesite, Mt. Balai andesite, pyroclastic deposits, young Lumut andesite, and Mt. Lumut lava dome.

The Semendo pyroclastic rocks give an age of 1.8 Ma. This formation crops out in the southeast and the northwest part of the field. The Batu Asahan dacite gives an age of 1.5 Ma and crops out in the north part of the field. The Batu Pandan andesite crops out in the northwest part of the field. The Old Lumut andesite gives an age of 1.2 Ma and crops out in the central part of the field. The Bt. Ringgit andesite gives an age of 1.15 Ma and crops out in the southwest part. The Mt. Balai andesite crops out in the central part and gives an age of 1.1 Ma. The pyroclastic deposits crop out in the north part and give an age of 1.0 Ma. The Young Lumut Balai andesite gives an age of 0.9 Ma. The Mt. Lumut lava dome gives an age of 0.6 Ma and its outcrop is narrow. Phenoclyst minerals in these rocks are composed of pyroxene and hornblende. However, pyroxene is found in all andesites, while hornblende is found only in the older andesites. In generally, the pyroxene phenocryst is more dominant than the hotter magma. The youngest dome lying in the southern part has the most basic composition in all this area, and the magma's temperature was highest in these rocks. According to existing geological data, a volcanic depression is estimated to lie between Mt. Lumut and Mt. Balai.

Altered Ground and Geothermal Manifestation

Altered ground and geothermal manifestations (hot springs and fumaroles) in the western part of this field are arranged in a line trending north to south on the whole (from around Penindayan village to the geothermal manifestations called "Ogan Kiri", through Cluster LMB 1) (see Fig. 3.1-3). However, an arrangement trending northwest to southeast is also recognized in their distribution. On the other hand, those distributions in the northeastern part of this field, around Mt. Bunbun, trend northeast to southwest, from the geothermal manifestations called "Sepanas Hilir" to the geothermal manifestations called "Bunbun". An arrangement trending northwest to southeast, along the Duacawang River, is also recognized. As mentioned in the following section, "(2) Fluid Chemistry", there is a remarkable difference in the chemical composition of the hot spring waters in the western part of the area (hereinafter described as "Gemurah Besar-Gemurah Pamalibar Sector" for convenience) and those in the northeastern part (hereinafter described as "Kelumpang-Sindawan-Bunbun Sector" for convenience). The former are sulfate-type and bicarbonate-type waters, whereas the latter are chloride-type waters. In the southeastern part of this field, altered ground or geothermal manifestations are not recognized.



(Based on PGE data)

Fig. 3.1-3 Geological Map of Lumut Balai Field

Subsurface (Well) Geology

As mentioned before, 6 wells had been drilled (5 wells at Cluster LMB 1 and 1 well at Cluster LMB 3), as of October 2009. Information about the geological conditions under the ground is obtained from these drilled wells, though information from the deeper portions is not complete because of total circulation loss (cannot sample cuttings), as shown in Fig. 3.1-4. Formations identified by well drilling are volcanic rocks composed of basaltic andesite, andesite breccia and tuff breccia. The basement rock in this field is Tertiary sediment, but no well reaches to this formation.

Cluster LMB 1 is situated in an area where young Lumut andesite crops out. On the other hand, Cluster LMB 3 is situated in an area where Mt. Balai andesite crops out. Therefore, the formation near the surface at Cluster LMB 1 can be correlated to the Lumut andesite and the formation near the surface at Cluster LMB 3 can be correlated to the Mt. Balai andesite. Considering the stratigraphy of this field, the Mt. Balai andesite must be distributed under the young Lumut andesite around Cluster LMB 1. However, it is difficult to identify this from the obtained data.

Around Cluster LMB 1, basaltic andesite is dominant near the surface (at a level of 1100 m above sea level) and pyroclastic rocks (andesite breccia and tuff breccia) are dominant under this level. On the other hand, pyroclastic rocks (andesite breccia and tuff breccia) are dominant through the drilled depths.

From all of drilled wells, argillization is recognized at a shallower horizon and its bottom is situated at the following elevations.

LMB 1-1 = at a level of 574 m above sea level

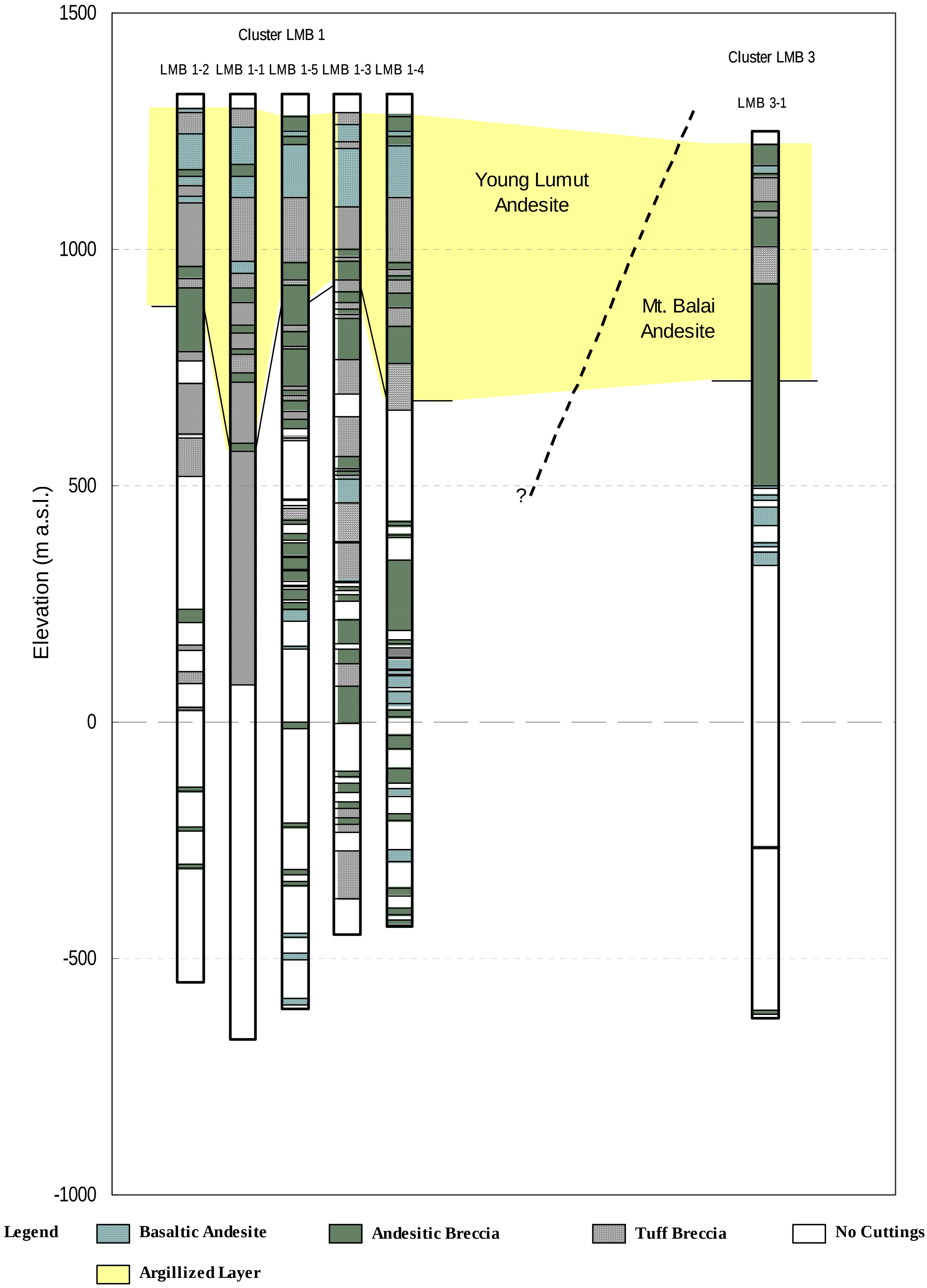
LMB 1-2 = at a level of 880 m above sea level

LMB 1-3 = at a level of 923 m above sea level

LMB 1-4 = at a level of 679 m above sea level

LMB 1-5 = at a level of 888 m above sea level

LMB 3-1 = at a level of 723 m above sea level



(Based on PGE data)

Fig. 3.1-4 Well Geology

(2) Geological Structure

Information about Geology

As shown in Fig. 3.1-5, many faults are estimated in this field. Most of them trend northwest to southeast and northeast to southwest. Some of them have circular features. Considering the distribution of altered ground and geothermal manifestations, the following 4 faults can be regarded as controlling geothermal activity near the surface, as altered ground and geothermal manifestations are distributed along these faults.

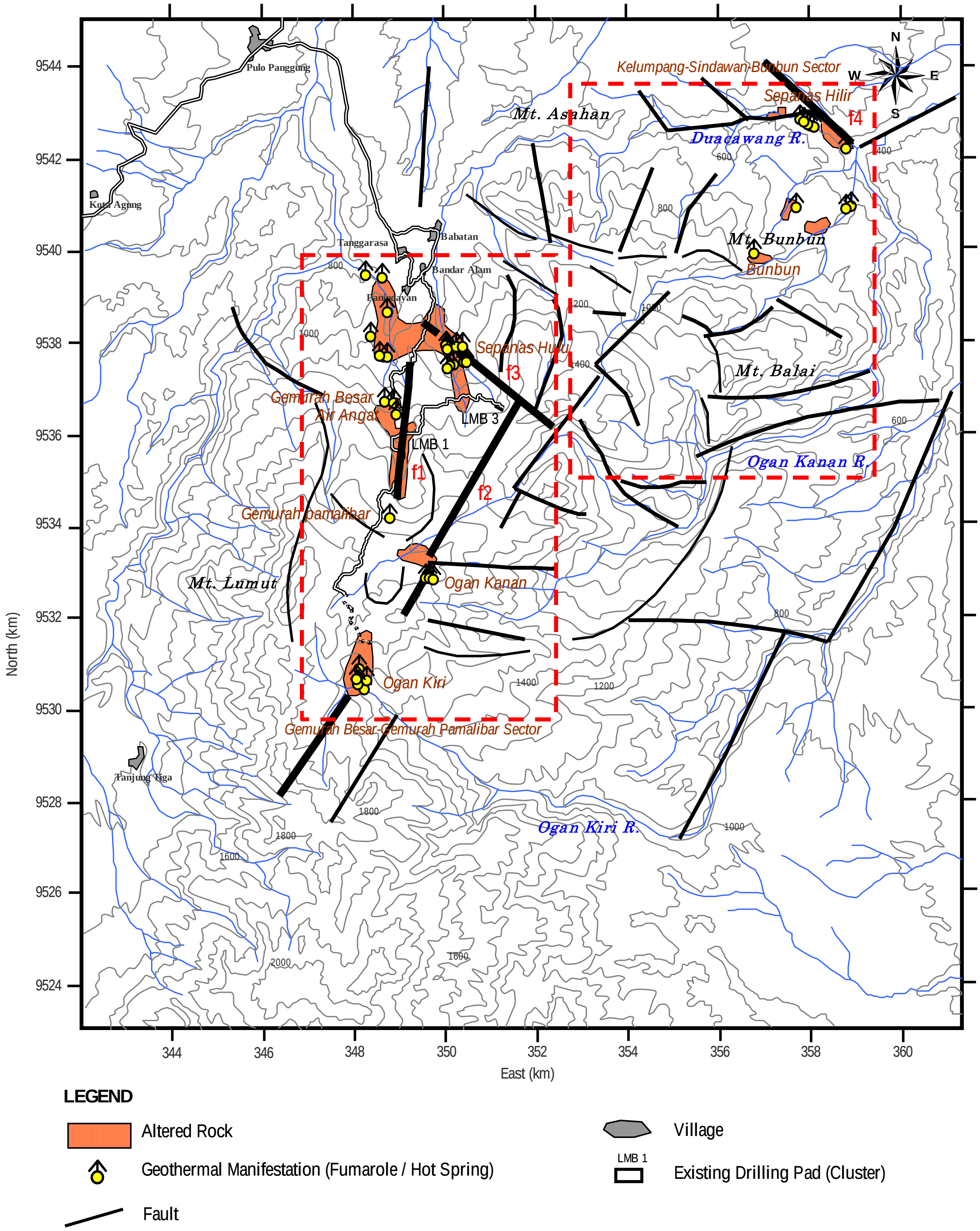
Fault f1: situated near Cluster LMB 1 and trending north to south; altered ground around Cluster LMB 1 extends along this fault.

Fault f2: situated near Cluster LMB 3 and trending northeast to southwest; geothermal manifestations Ogan Kiri and Ogan Kanan occur along this fault.

Fault f3: situated near Cluster LMB 3 and trending northwest to southeast; geothermal manifestations occur along this fault and its northwestern extension.

Fault f4: situated near geothermal manifestation Sepanas Hilir and trending northwest to southeast; geothermal manifestations occur along this fault.

No fault corresponding to the arrangement of geothermal manifestations from Bunbun to Sepanas Hilir, on the northern side of Mt. Balai, is estimated. However, a corresponding structure is detected from gravity data, as mentioned in the following section describing “gravity information”. Therefore, these geothermal manifestations are also related to a fault.



(Based on PGE data)

Fig. 3.1-5 Distribution of altered Ground, Geothermal Manifestations and Faults

Information about Gravity

The Bouguer anomaly map and the first order residual map of gravity Bouguer are shown in Fig. 3.1-6 and Fig. 3.1-7, respectively. In the Bouguer anomaly map, a broadly distributed relatively low Bouguer anomaly zone of less than –24 mgal is recognized in the southwestern portion of this field and a relatively low Bouguer anomaly zone showing greater than –8 mgal can be seen in the northeastern portion of the field. Thus, the southwestern portion of the field is likely to be a subsidence zone of the basement rock and the relatively low Bouguer anomaly zone situated in the northeastern portion is possibly indicative of an up-lifted zone of the basement rock.

In addition, three prominent linearly aligned steep gradient zones of the Bouguer anomaly values (G1, G2 and G3) are detected in the Bouguer anomaly map (see Fig. 3.1-6), and the features of these steep gradient zones can also be seen in the residual Bouguer gravity map (see Fig. 3.1-7). This feature of linearly aligned steep gradients (usually called gravity lineaments) often reflects a fault, and thus the gravity lineaments G1, G2 and G3 can be associated with faults and/or fracture zones that might control the underground movement of geothermal fluids in this field. In addition, the features of the gravity lineaments G1, G2 and G3 described above are detectable even in the density structure map at 0.6-1.7 km based on the 2D inversion process (see Fig. 3.1-8), which has been drawn up by PT. Pertamina Geothermal Energy.

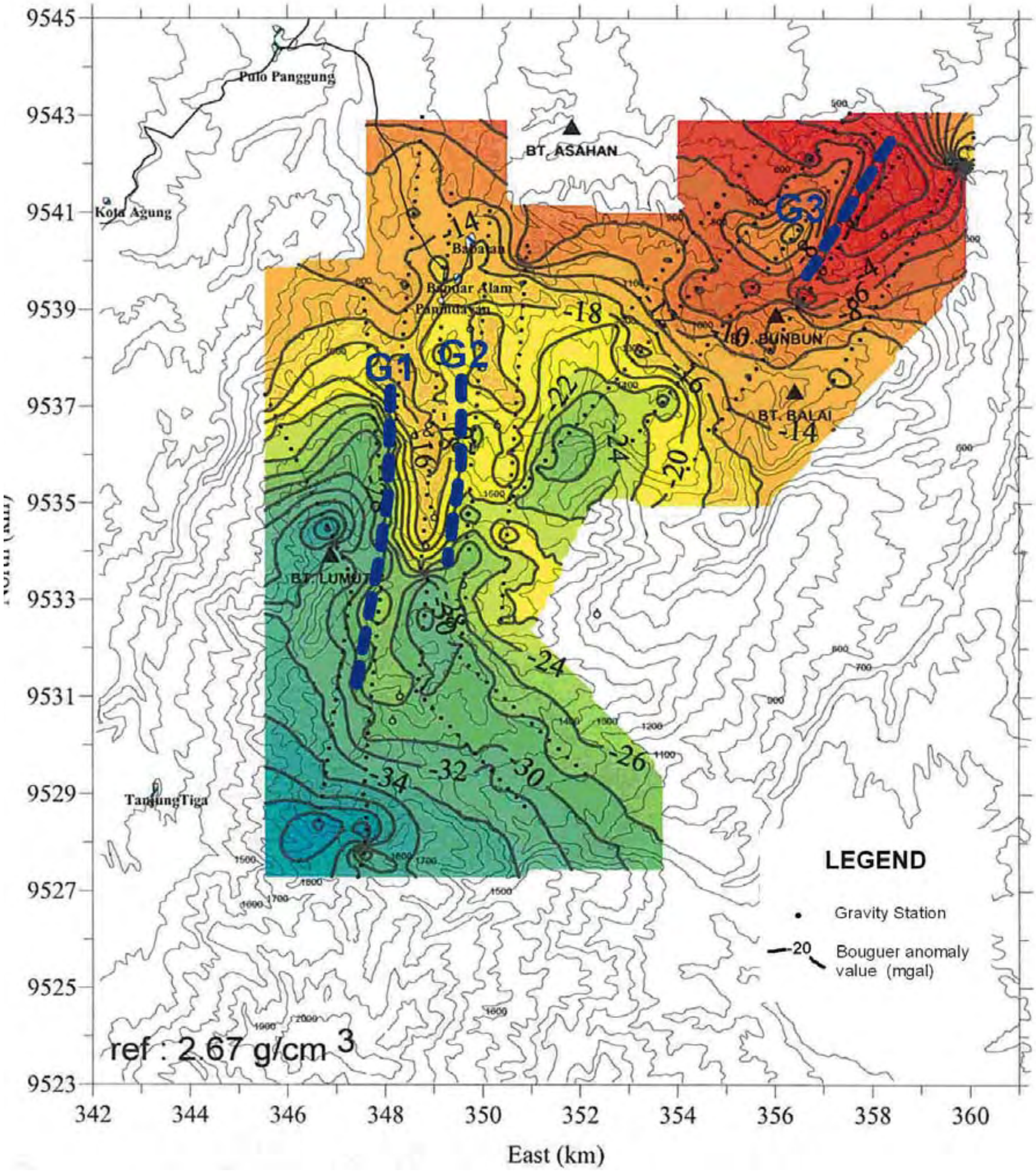


Fig. 3.1-6 Bouguer Anomaly Map

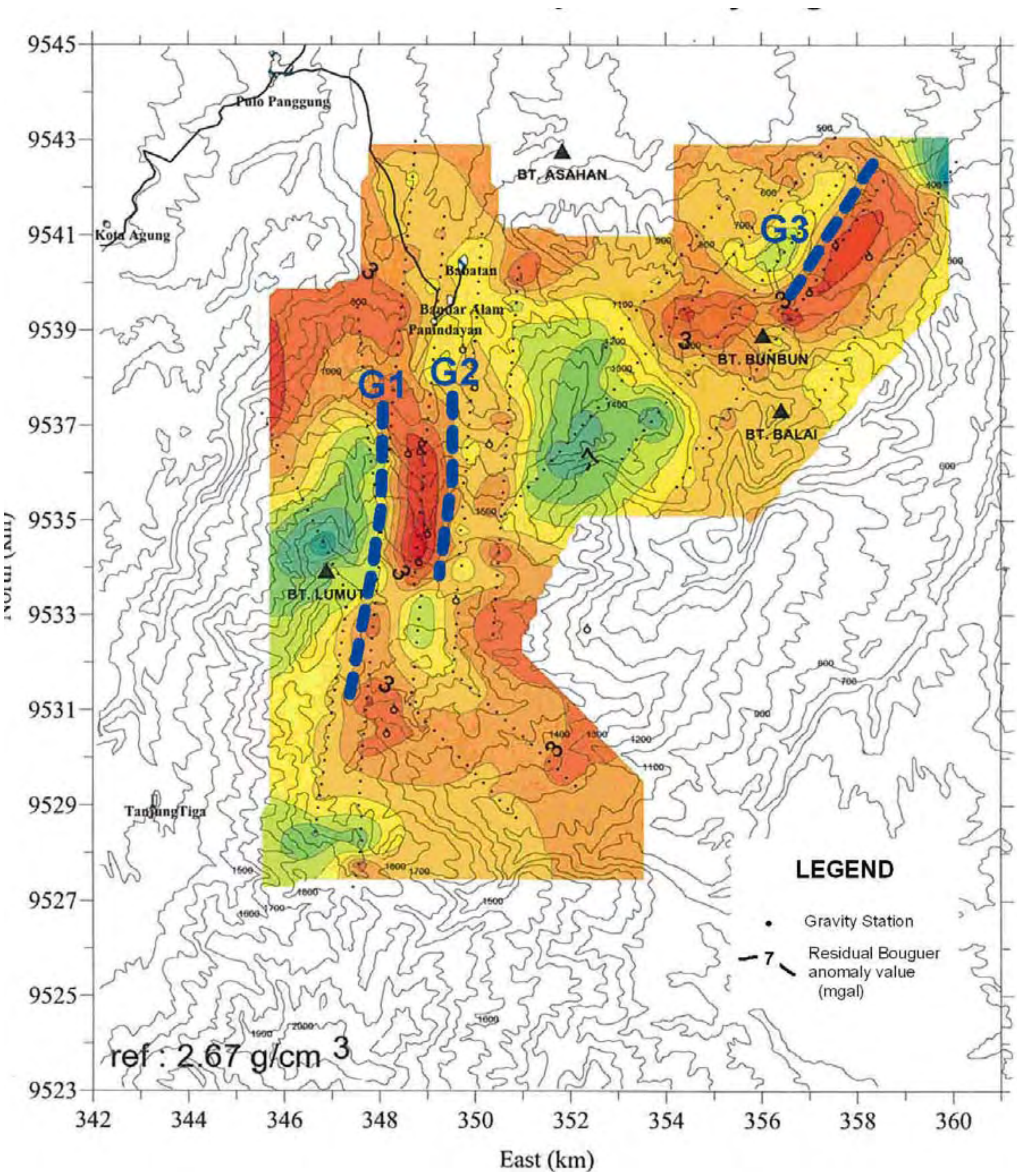


Fig. 3.1-7 First Order Residual Bouguer Gravity Map

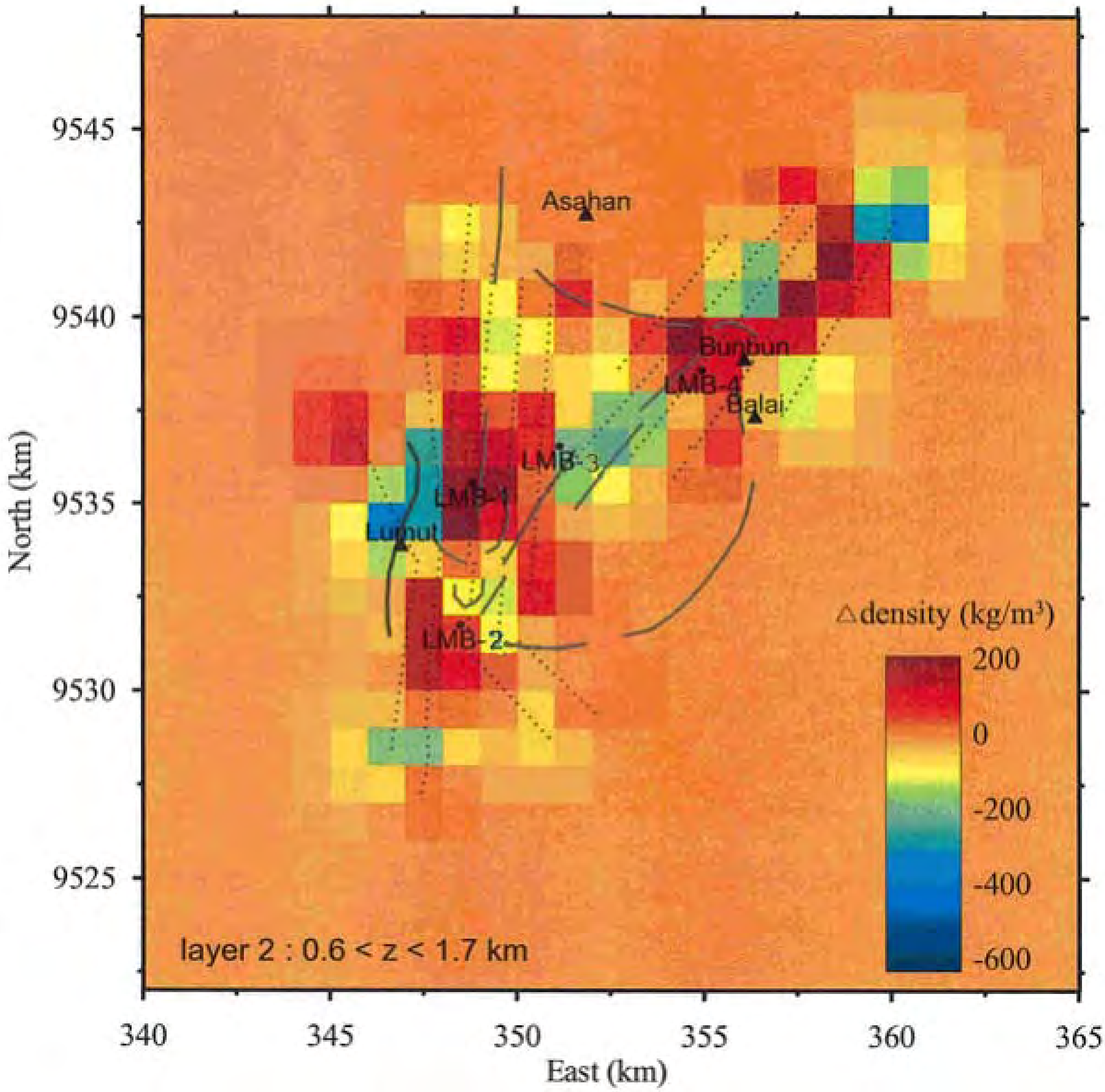


Fig. 3.1-8 Density Structure Map at 0.6 – 1.7 km based on 2D Inversion Process

Information about Resistivity

For the Magnetotelluric (MT) data review, apparent resistivity maps at frequencies of 0.1 second, 1 second and 10 seconds and resistivity section maps derived from 2D and resistivity inversion results have been provided by PT. Pertamina Geothermal Energy. The apparent resistivity maps at frequencies of 0.1, 1 and 10 seconds are shown in Fig. 3.1-9, Fig. 3.1-10 and Fig. 3.1-11, and the resistivity sections and maps are depicted in Fig. 3.1-12 and Fig. 3.1-13.

Electromagnetic frequencies are related to penetration depths in Magnetotelluric theory. Namely, the apparent resistivity at high frequencies reflects the resistivity structure in the shallow zone and that at low frequencies reflects the resistivity structure in the deep zone. However, the penetration depths of electromagnetic signals at every station differ from each other, and the apparent resistivity value is a sort of accumulated resistivity from ground surface to the penetration depth. Thus, an interpretation based on the apparent resistivity maps at different frequencies is sometimes misleading concerning the actual subsurface resistivity structure. Here, to avoid being misled, only general trends will be attempted from the apparent resistivity maps.

A broadly distributed low apparent resistivity zone is detected in the northern, central, western and southwestern portions of the survey area in the apparent resistivity map at a frequency of 1 second (see Fig. 3.1-10). Since many hydrothermal manifestations (hot springs and fumaroles) are situated inside of this low apparent resistivity zone, the low apparent resistivity zone is likely to correlate with an argillized zone composed of clay minerals such as smectite and interstratified clay minerals containing smectite layers. The low apparent resistivity zone is similar to those indicating the cap rock of the geothermal reservoir detected in many geothermal fields, and thus the low apparent resistivity zone is considered to be an impermeable zone functioning as a cap rock of the geothermal reservoir in this field.

In addition, three resistivity discontinuities, R1, R2 and R3, can be detected in the apparent resistivity maps at frequencies of 1 and 10 seconds (see Fig. 3.1-10 and Fig. 3.1-11). Resistivity discontinuities are structures exhibiting a big lateral change in resistivity, and if such structures are distributed continuously along a line, a fault and/or fractured zone will be expected along the resistivity discontinuities. The resistivity discontinuities (R1, R2 and R3) are roughly located around the eastern and south edge portions of the broadly distributed low apparent resistivity zone (which is likely to reflect hydrothermally altered argillized rock) at a frequency of 1 second (see Fig. 3.1-10), and thus these resistivity discontinuities are probably indicative of faults and/or fracture zones controlling high-temperature geothermal fluids in the Lumut Balai field. Based on the resistivity sections (see Fig. 3.1-10 and Fig. 3.1-11), an up-lifted high resistivity zone (which is probably indicative of higher temperature alteration products such as illite, chlorite, epidote etc) is recognized around these resistivity discontinuities (R1, R2 and R3). Therefore the area along the resistivity discontinuities R1, R2 and R3 and the area between these resistivity discontinuities may be promising zones for targets of future production wells.

Moreover, a relatively high apparent resistivity zone is detected around stations LB-12 and LB-14 in the apparent resistivity map at 10 seconds (see Fig. 3.1-11). This relatively high apparent resistivity zone seems to indicate an up-lifted high resistivity zone at depth. Since this relatively high apparent resistivity zone is possibly reflecting high-temperature alteration products (illite and/or chlorite), this zone around stations LB-12 and LB-14 may reflect a higher temperature zone at depth compared with the surrounding area’s. Considering that resistivity discontinuity R1, probably reflecting fracture zones controlling geothermal fluids, is located between stations LB-12 and LB-13, it is thought that the zone along resistivity discontinuity R1 and between stations LB-12 and LB-13 may be situated close to an up-flow zone of high-temperature geothermal fluids.

The eastern portion of the survey area shows relatively high apparent resistivity values compared with the central, northern and southwestern portions in all the apparent resistivity maps at frequencies between 0.1 second and 10 seconds. Thus this area is considered to be an area where hydrothermal activity is relatively weak compared with the central, northern and southwestern portions of the survey area, suggesting that this area is probably less promising for geothermal development.

There are hot springs characterized by high Cl components around Mt. Bunbun. In addition, the gravity lineament G3 is detected around these hot springs. Therefore, a Magnetotelluric survey around Mt. Bunbun is highly recommended to estimate the geothermal potential there. In addition, it is recommendable to apply a three-dimensional resistivity inversion technique to Magnetotelluric data acquired in the Lumut Balai field to estimate a more detailed sub-surface resistivity structure and further clarify the geothermal structure in the Lumut Balai geothermal field.

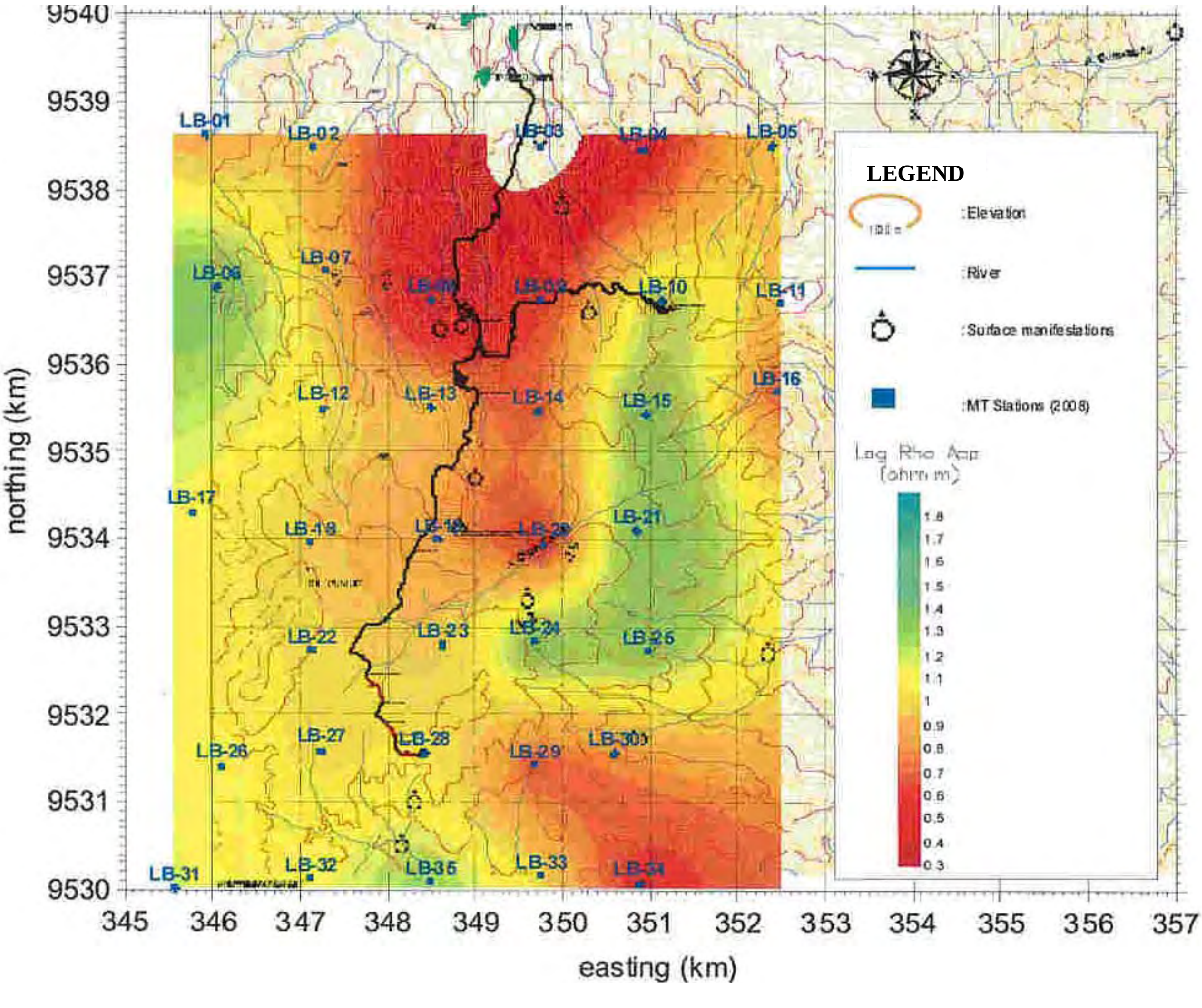


Fig. 3.1-9 MT Apparent Resistivity Map (frequency = 0.1 second)

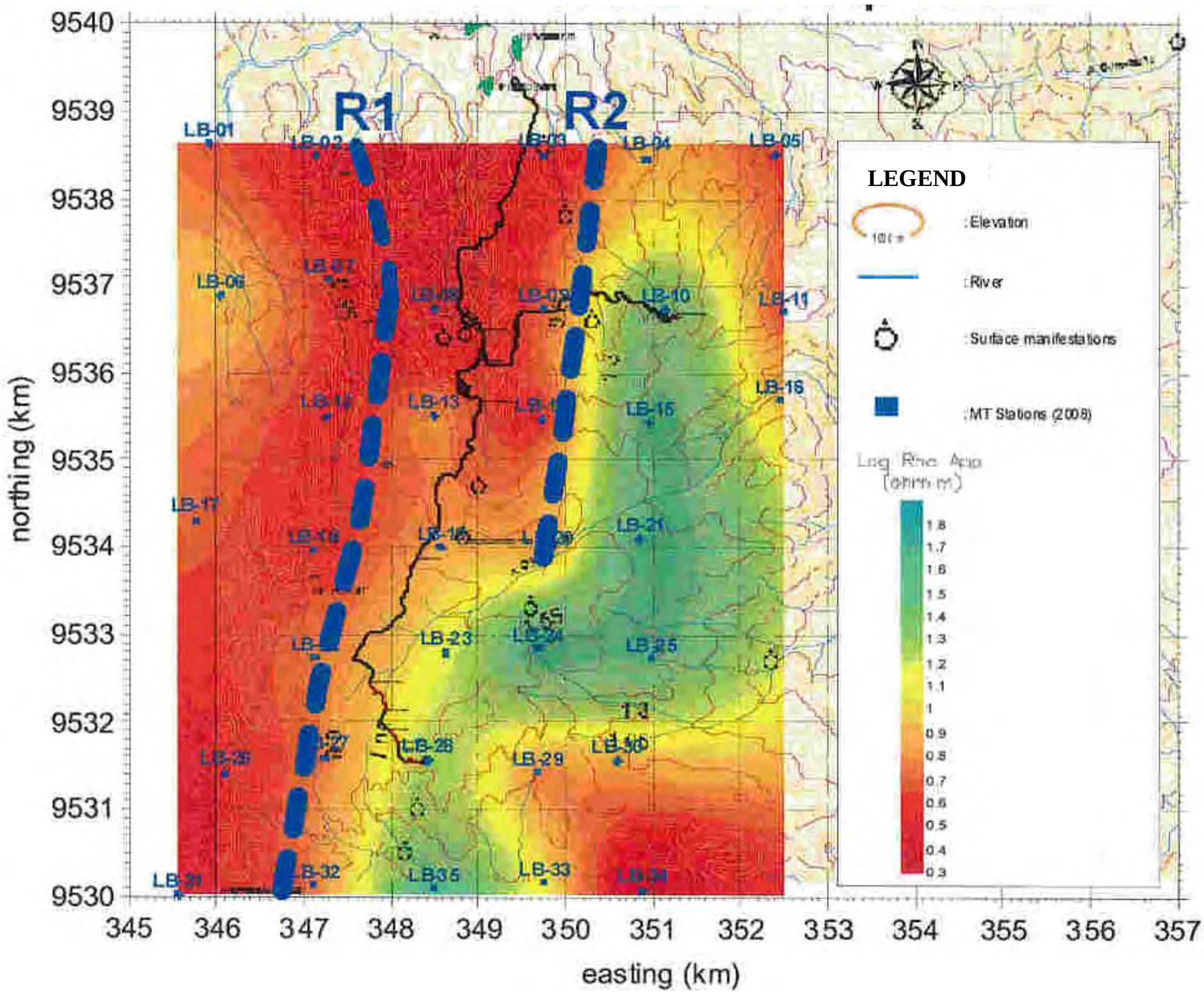


Fig. 3.1-10 MT Apparent Resistivity Map (frequency = 1 second)

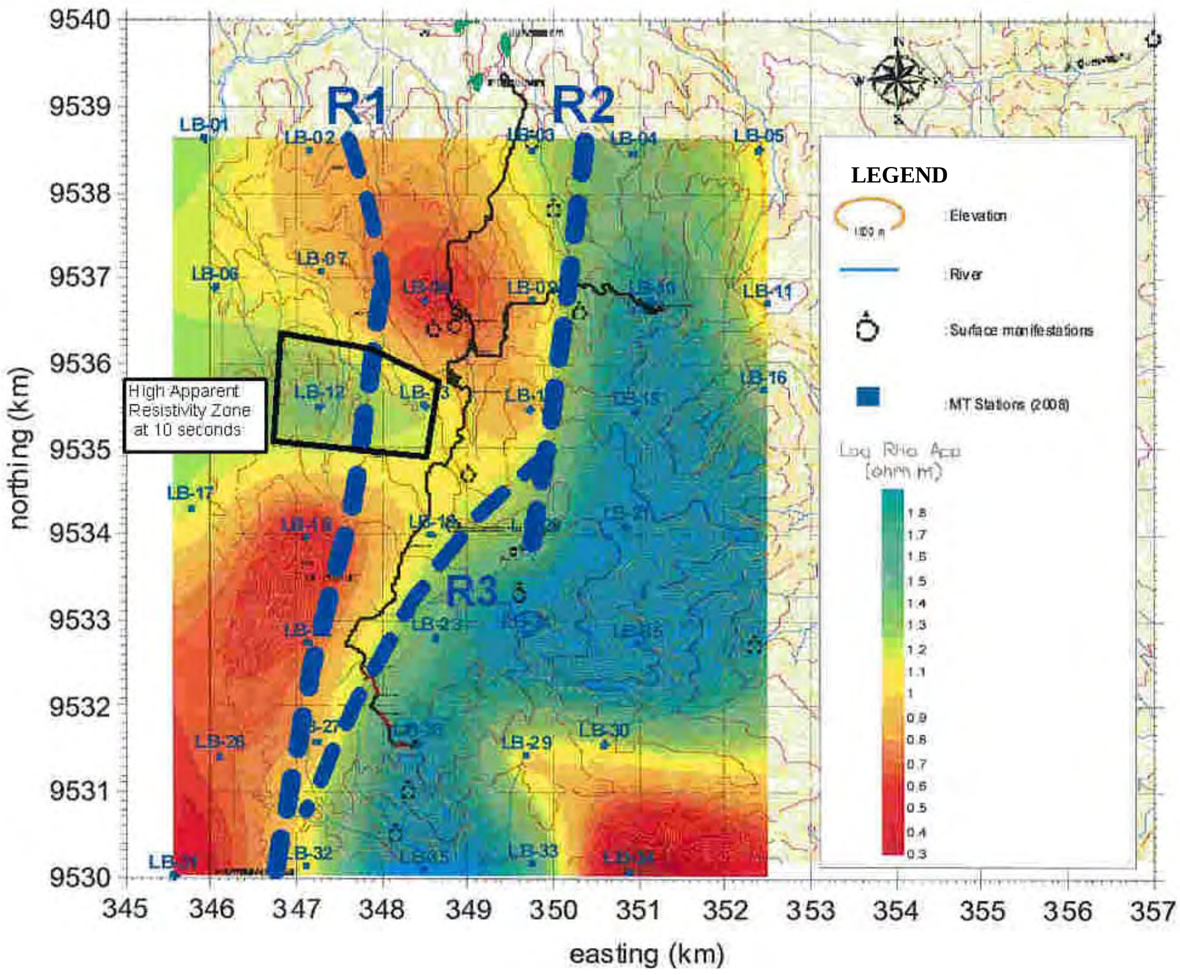


Fig. 3.1-11 MT Apparent Resistivity Map (frequency = 10 seconds)

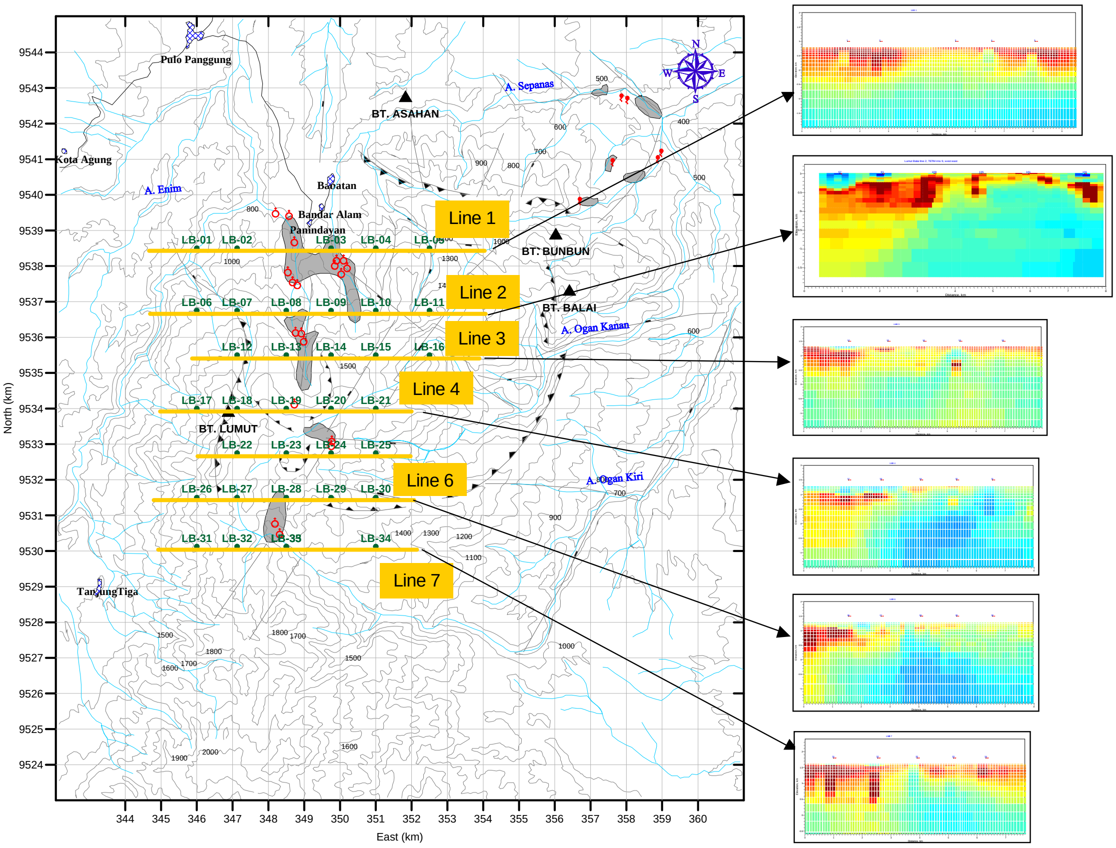


Fig. 3.1-12 Resistivity Sections Derived from 2D Resistivity Inversion Results

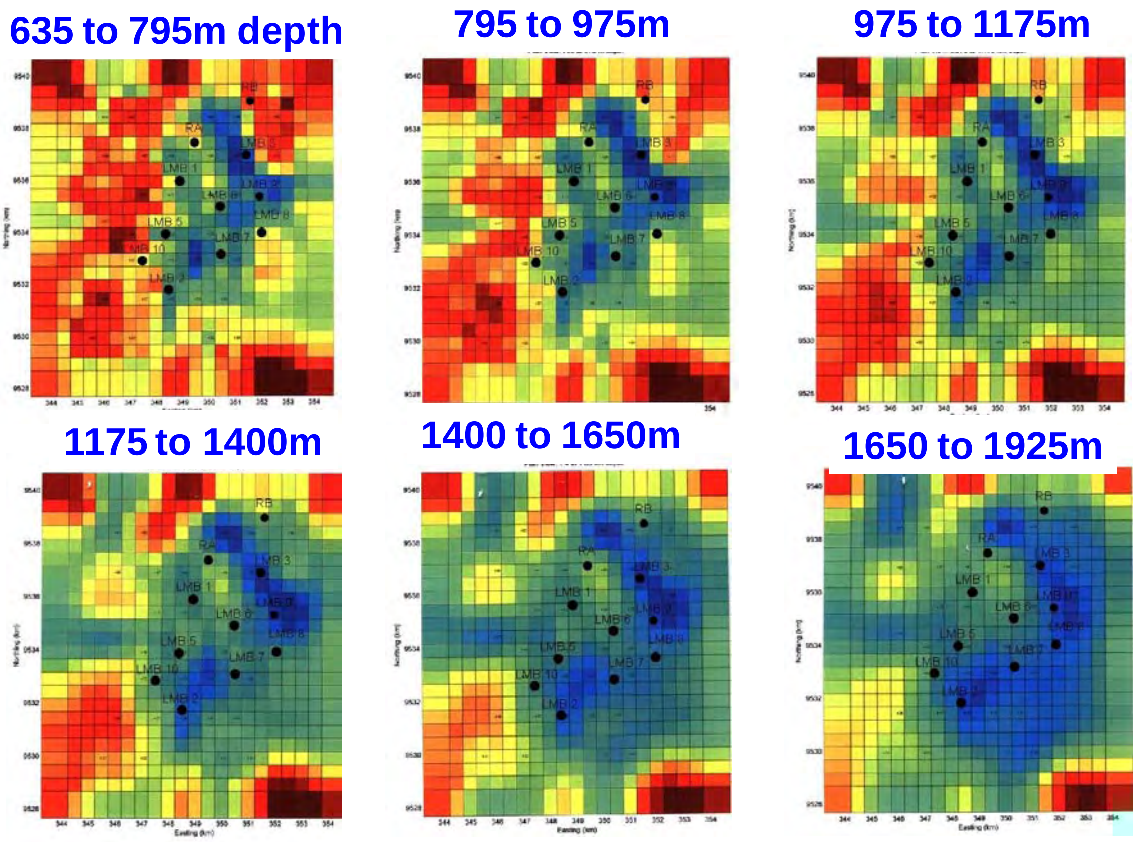


Fig. 3.1-13 Resistivity Maps Derived from 3D Resistivity Inversion Results

Information about FMS

For the FMS (Formation Micro Scanner) data review, information concerning drilling-induced fractures, conductive fractures, resistive fractures, and faults derived from rose diagram of LMB-1 well has been provided by PT. Pertamina Geothermal Energy. The induced fractures are shown in Fig. 3.1-14. The conductive and resistive fracture and faults are depicted in Fig. 3.1-15.

According to the induced fracture frequency in the rose diagram, the maximum stress in Lumut Balai Geothermal Field is assumed to trend NNE to SSW. This trend is consistent with subduction trend of Sumatra Island (see Fig. 3.1-14). The conductive open fracture and faults show a dominant NNE-SSW and/or NE-SW strike. This strike trend is in agreement with the maximum stress direction suggested by the induced fractures (see Fig. 3.1-15).

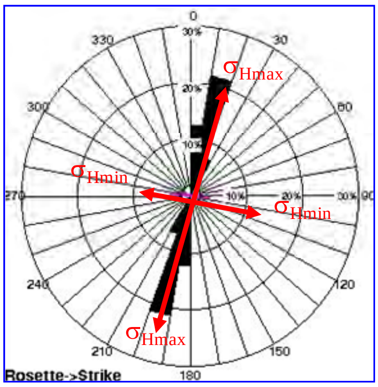
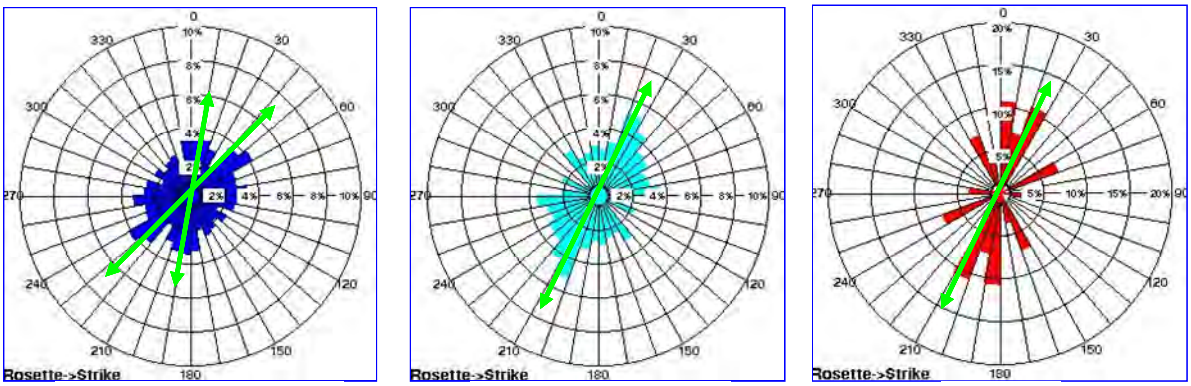


Fig. 3.1-14 Induced fracture rose diagram



Conductive Fracture Resistive Fracture Faults

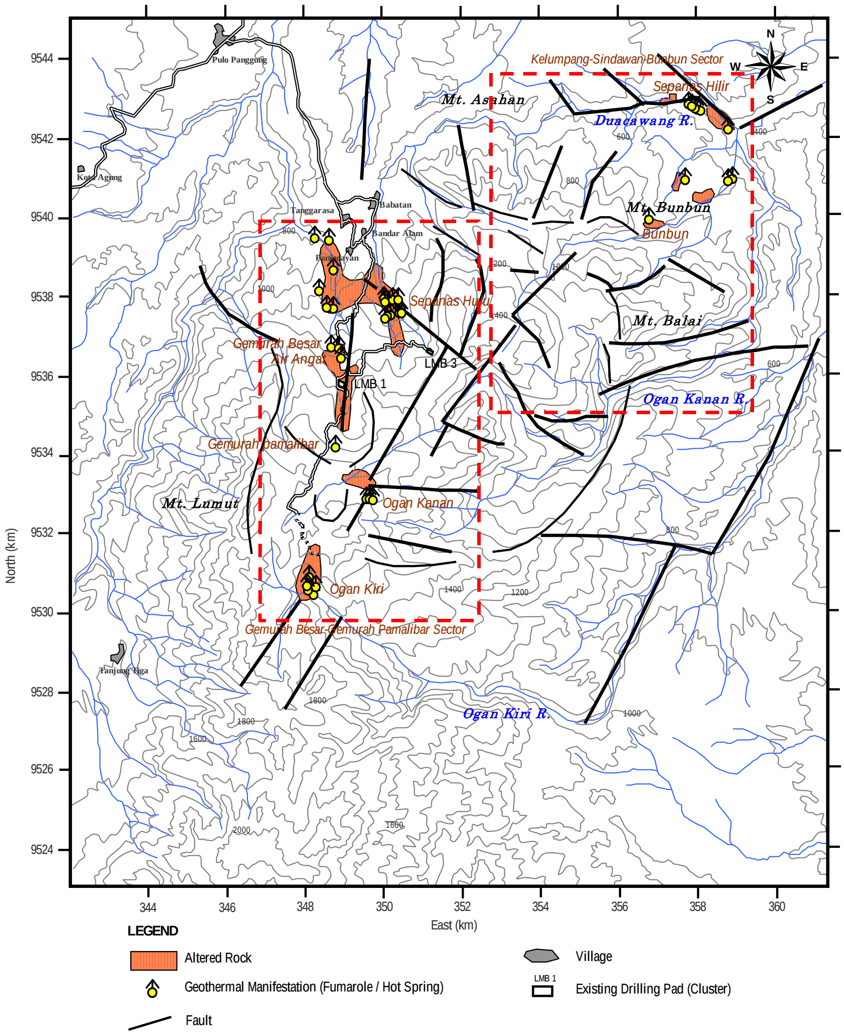
Fig. 3.1-15 Fractures and faults of LMB-1

(2) Fluid Chemistry

LMB1-5 Fluid Data and its Quality

The only fluid chemical data for LMB 1-5 comes from the single short-term well discharge test in May 2010.

The equivalent balance of the sum total of anions and cations of LMB 1-5 data was calculated to check the quality of the data. The Cation concentration is quite a bit smaller than that of anions. So the quality of the data is not so good. Additional fluid chemical data from production testing is required. Surface hot spring and fumarole data are also considered for geochemical analysis (see Table 3.1-, Table 3.1-3 and Fig. 3.1-16).



(Based on PGE data)

Fig. 3.1-16 Location of Thermal Springs in Lumut Balai

Table 3.1-2 Water Chemistry of Springs in Lumut Balai Field

(tahun 1994-PERTAMINA dan 2002-PNOC)

Code	Lokasi	Temp. °C	Debit lpm	Elevasi. m	Type	pH at °C	TDS	Li	Na	K	Ca	Mg	SiO2	Cl	HCO3	SO4	HBO3	Temp. Geotherm., °C Na/K	Na-K-Ca	SiO2
	Cloride springs																			
LMB-174	G. B. Kelumpang	96	100	370	MAP	7.9	8210	7.16	2477	293.5	309.4	2.1	319	4756	47	3	29.6	232	216	214
LMB-179	G. Sindawan	99	100	385	MAP	8	7655	6.53	2307	328.1	252.3	2.5	323	4344	42	4	24.67	249	229	215
BUN-01	Bun-bun				MAP	7.9		10.5	2612	268	319	2.03	171	4852	17.2	19.8	39.4	219	208	170
BUN-03	Bun-bun				MAP	7.02		8.54	2063	265	227	2.63	142	3775	23	18.7	32.3	239	221	158
	Bicarbonate springs																			
LMP-2	G. Aek Undangan	84	2	960	MAP	7.55	252	0.02	19.9	5.6	29.1	2.6	138	2	130	31	0.12			
LMB-183	G. Aek Abang	21	5	840	MAD	6.69	124	0.01	3.8	1.9	0.5	0.1	102	1	15	2	0.06			
LMB-184	G. Aek Abang	65	15	890	MAP	7.05	492	0.04	53.1	18.1	43.9	9.8	313	4	332	7	0.06			
LMD-2	Aek Abang Hulu	24	10	225	MAD	6.05	44	0.01	0.5	0.5	1.1	0.5	30	1	8	1	0.06			
LMD-3	Aek Abang Hulu	23	1	400	MAD	6.64	52	0.01	1.2	0.5	1.3	0.6	39	1	10	1	0.06			
	Acid sulfat springs																			
LMB-42	Ogan kanan	75	50	1585	MAP	2.77	195	0.04	2	0.3	8.7	1.5	46	1	0	126	0.05			
LMB-54	G. Bayur	-				2.54	828	0.03	16.5	7.4	26.8	11.3	159	2	0	541	0.99			
LMP-1	G. Aek Undangan	98	5	425	MAP	2.91	180	0.01	0.1	1.5	14.1	1.8	69	1	0	81	0.06			
LMP-3	G. Aek Undangan	43	30	975	MAP	3.45	244	0.01	5.8	2.5	12.2	3.4	84	2	0	110	0.05			
LMB-26	G. Pamalibar	90	15	1525	MAP	2.68	232	0.01	1.9	1.4	8.5	2.3	63	1	0	151	0.05			
ASP-01	Panindayan				MAP	2.62		0.03	13	8.12	27.2	8.38	158	0.88	na	489	0.54			
	Sulfat-Bicarbonat springs																			
ASP-02	Panindayan				MAP	7.46		0.03	23.4	8.12	29.2	0.28	161	0.6	23.8	106	0.75			

Catatan : Yang dicetak tebal mempunyai ion balance <5% dan pH netral dan digunakan untuk interpretasi.
G. Aek Undangan, Aek Abang dan Panindayan mencerminkan air permukaan yang terpanasi (pengkayaan HCO3 dan SO4)
G. B. Kelumpang, G. Sindawan dan Bun-bun mencerminkan fluida reservoir yang mengalami pencampuran dengan air permukaan (dominan Cl pada elevasi rendah)
Geothermometer yang dapat digunakan hanya geothermometer Na/K yang relatif lebih baik untuk kondisi mixing (T. Geothermometer berkisar 230 s/d 250°C)

Table 3.1-3 Gas Chemistry of Fumaroles in Lumut Balai Field

(1)

Hasil Analisa Kimia Gas

No. Conto	Lokasi	Tipe	Elevasi (m)	T (°C)	Gas (% mol)	CO_2	CO	H_2S	CH_4	H_2	N_2	NH_3	CO_2/H_2S
	Gemurah Besar-Pamalibar												
LMG-1	G. Pamalibar	FUM	1525	89.5	0.0033	91.08	nil	4.67	0.71	1.05	1.1	0.21	20
LMG-4	G. Aek Udangan 1	FUM	1035	98.5	0.0017	74.82	nil	5.39	0.34	nil	12.1	0.2	14
LMG-6	G. Aek Udangan 2	FUM	1070	96.3	0.0022	84.81	nil	3.87	0.11	nil	7.36	0.063	22
RF-02***	G. Aek Udangan	FUM	1000	97	0.19	91.60	0.00282	4.18	0.997	1.61	0.57	1	22
LMG-7	G. Besar Panindayan 1	FUM	1025	98	0.0033	90.25	nil	4.33	0.53	2.25	1.67	0.21	21
LMG-8	G. Besar Panindayan 2	FUM	1025	98	0.0054	89.69	nil	4.48	0.57	1.11	1.37	0.12	20
LMG-9	G. Besar Panindayan 3	FUM	1025	96.8	0.003	87.86	nil	3.85	0.52	1.6	1.84	0.57	23
LMG-10	G. Ogan Kanan 3	FUM	1625	96	0.0013	64.50	nil	5.59	0.12	nil	3.3	0.48	12
LMG-14	G. Sipanas	FUM	900	96	0.0048	83.55	nil	3.64	0.27	nil	4.92	0.45	23
LMG-15	G. Aek Udangan 3	FUM	1230	103	0.0023	81.56	nil	5.17	0.5	nil	6.17	0.12	16
RF-03***	Air Angat	FUM	1280	97	0.13	88.30	0.00036	7.16	0.997	1.95	1.17	1.12	12
LMG-2	G. Ogan Kanan 1	FUM	1585	97	0.0029	89.69	nil	4.73	0.35	2.2	1.53	0.065	19
LMG-3	G. Bayur	FUM	1490	98.5	0.0037	94.37	nil	2.84	0.49	0.53	0.68	0.100	33
LMG-5	G. Ogan Kanan 2	FUM	1600	99	0.0021	90.41	nil	3.8	0.35	2.29	2.29	0.33	24
RF-05***	G.A. Ogan Kanan	FUM	1075	97	0.51	95	0.00013	2.9	0.37	1.42	0.0086	0.335	33
RF-07***	G. Tanjung Tiga	FUM	1480	130	0.78	94.4	0.000089	3.34	0.73	0.68	0.566	0.293	28
	Bukit Bunbun												
LMG-11	G. Sindawan	MAP	410	96	0.0022	nil	0.36	0.011	nil	3.88	0.07	63	
LMG-12	G. Besar Kelumpang 1	MAP	410	97	0.00085	nil	1.9	0.013	nil	8.42	0.3	41	
LMG-13	G. Besar Kelumpang 2	MAP	410	97	0.0017	nil	0.24	0.0076	nil	2.13	1.37	83	

(2)

Code	Lokasi	Temp. °C	Elevasi m	BPT °C	Type	gas/H2O %mol	CO2 (% mol gas kering)	CO	H2S	CH4	H2	N2	NH3	Ar	CO2/H2S	CO2/N2	CO2/CH4	Temp. Geo., °C CO2-H2S	H2-Ar	DAP	H2
LMG-2	G. Ogan kanan-1	97	1585	96.4	FUM	0.0029	89.69	nil	4.73	0.35	2.2	1.53	0.065		19	59	256	235		301	284
LMG-3	G. Bayur	98.5	1490	96.8	FUM	0.0037	94.37	nil	2.84	0.49	0.53	0.68	0.1		33	139	193	243		253	271
LMG-5	G. Ogan kanan-2	99	1600	96.4	FUM	0.0021	90.41	nil	3.8	0.35	2.29	2.29	0.33		24	39	258	238		299	285
RF-05 *)	G. A Ogan Kanan	97	1075	98.1	FUM	0.51	95	0.0001	2.9	0.371	1.42	0.0086	0.335		33	11047	256	243		280	280
RF-07 *)	G. Tanjung Tiga	130 ?	1480	96.8	FUM	0.78	94.4	9E-05	3.34	0.734	0.677	0.566	0.293		28	167	129	240		258	274
LMG-1	G. Pamalibar	98.5	1525	96.6	FUM	0.0033	91.08	nil	4.67	0.71	1.05	1.1	0.21		20	83	128	235		274	278
LMG-4	G. Aek Undangan-1	98.5	1035	98.2	FUM	0.0017	74.82	nil	5.39	0.34	0	12.1	0.2		14	6	220	231			
LMG-6	G. Aek Undangan-2	96.3	1070	98.1	FUM	0.0022	84.81	nil	3.87	0.11	0	7.36	0.063		22	12	771	237			
RF-2 *)	G. Aek Undangan	97	1000	98.3	FUM	0.19	91.6	0.0028	4.18	0.997	1.61	0.57	1		22	161	92	237		281	282
LMG-7	G. B. Panindayan-1	98	1025	98.2	FUM	0.0033	90.25	nil	4.33	0.53	2.25	1.67	0.21		21	54	170	236		296	285
LMG-8	G. B. Panindayan-2	98	1025	98.2	FUM	0.0054	89.69	nil	4.48	0.57	1.11	1.37	0.12		20	65	157	236		277	278
LMG-9	G. B. Panindayan-3	96.8	1025	98.2	FUM	0.003	87.86	nil	3.85	0.52	1.6	1.84	0.57		23	48	169	237		286	281
LMG-10	G. Ogan Kanan-3	96	1625	96.3	FUM	0.0013	64.5	nil	5.59	0.12	0	3.3	0.48		12	20	538	228			
LMG-14	G. Sipanas	96	900	98.5	FUM	0.0048	83.55	nil	3.64	0.27	0	4.92	0.45		23	17	309	238			
LMG-15	G. Aek Undangan-3	103	1230	97.6	FUM	0.0023	81.56	nil	5.17	0.5	0	6.17	0.12		16	13	163	232			
RF-03 *)	Aek Angat	97	1280	97.5	FUM	0.13	88.3	0.0004	7.16	0.997	1.95	1.17	1.12		12	75	89	229		294	283
LMG-11	G. Sindawan	96	370	99.7	AP	0.0022	22.7	nil	0.36	0.011	0	3.88	0.17		63	6	2064	252			
LMG-12	G.B. Kelumpang-1	97	385	99.6	AP	0.0008	77.86	nil	1.9	0.013	0	8.42	0.3		41	9	5989	246			
LMG-13	G.B. Kelumpang-2	97	385	99.6	AP	0.0017	19.9	nil	0.24	0.007	0	2.13	1.37		83	9	2843	256			
						% Udara															
LB-4D	G. B Panindayan	94.4	1025	98.2	FUM	0.09	90.9		3.47	0.4	1.57	3.58	0.001	0.07	26	25	227	239	270	286	281
LB-5	G. Aek Abang	96.1	1000	98.3	FUM	0.37	96.2		2.94	0.227	0.0941	0.37	0.0193	0.0026	33	260	424	243	284	220	256
LB-6	G. Aek Abang	99.4	1000	98.3	FUM	3.11	97.8		0.502	0.319	0.132	0.723	0.358	0.0037	195	135	307	269	284	206	259
	Pembanding					gas/H2O %mol															
Kamojang	Fumarole	98				0.59	97.4		2.248	0.0038	0.282	0.08			43	1218	25632	247		274	266
	Well	243	res			< 1	92.384		5.3424	0.0188	0.5416	0.4932	0.0046		17	187	4908	234		290	272
Masigit	Fumarole	98				2.87	96.4		2.943	0.0044	0.498	0.06			33	1607	21909	243		291	271
Ulubelu	Fumarole	98.9				0.28	96.1		2.81	0.0644	0.139	0.859			34	112	1492	243		237	259
	well	200	res			< 1	95		1.428	0.226	0.979	2.225		0.55	67	43	420	253	193	266	277
N-I Langit	Fumarole	94					97.1		2.85			0.01			34	9710		243			
	well	260	res			3.25	97.5	1E-05	1.51	0.0112	0.0205	0.12	0.87	0.0019	65	813	8705	252	248	202	242

Catatan : Geothermometer gas CO2-H2S (Giggenbach & Sheppard, 1980), Geothermeter H2-Ar (Giggenbach, 1984), GeothermometerDAP (D'Amore & Panici) dan Geothermometer H2 (Amorrson & Gunlaugsson, 1985).
Rasio CO2/H2S Lumut Balai mirip dan hampir sama dengan Kamojang. Ulubelu dan Namora I Langit(berkisar antara 12 s/d 33)
Rasio H2/H2S Lumut Balai 3 atau 4 kali lebih besar dibanding dengan Kamojang. Ulubelu dan Namora I Langit, sehingga temperatur reservoirnya juga kemungkinan lebih tinggi.
Geothermometer yang dapat digunakan geothermometer CO2-H2S (T. res 230 s/d 270°C) sedangkan Geothermometer H2/Ar (T. res 270 s/d 280 °C)
Rasio N2/Ar (51 s/d 195) mengindikasikan geothermal source (38 s/d 800) dan Rasio He/Ar (0.0005 s/d 0.02) mengindikasikan gas berasal dari geothermal source (sekitar 0.1) sampai meteoric source (<0.001).
RF-2 = LMG-6, RF-3 = LMG-15 dan RF-7 = LMG-3

Existence and Extent of Geothermal Resource

Surface geothermal manifestations in this field consist of numerous fumaroles, steaming ground, mud pools and hot springs. Spring water chemistry shows that they can be classified into neutral-pH chloride type, neutral-pH bicarbonate type, acid sulfate type and neutral-pH sulfate-bicarbonate type (see Table 3.1-3 and Fig. 3.1-17).

The existence of neutral-pH hot springs of chloride type is worthy of attention. In general, precious information about the geothermal reservoir at depth can be deduced from the data concerning these chloride-type hot springs. Neutral-pH chloride type waters occur in the northeastern part (Kelumpang-Sindawan-Bunbun Sector) at low elevations with discharge temperatures close to the boiling point (96-99^{o}C). The chloride ion concentrations in these hot spring waters are relatively high (3,780 to 4,850 ppm) compared with those of other fields, but the bicarbonate, sulfate and magnesium contents are very low. These chemical characteristics suggest that these hot spring waters originate from deep water-dominated reservoirs. It is necessary to confirm if the reservoir water of chloride type attains equilibrium chemically to apply geochemical techniques to clarify the geological, physical and chemical conditions of the reservoir water. Except for chloride-type water originating from seawater or magmatic water, chloride water in geothermal fields is believed to result from water-rock interaction over a long period under conditions of high temperature. Confirming this geochemically is usually done by analyzing the D and ^{18}O of the water in addition to chemical interpretation of the water-rock interaction, but the necessary isotope data for chloride-type water could not be obtained this time. In spite of the absence of isotope data, since the Cl/B ratio of the chloride-type hot spring water indicates a reservoir extending in volcanic rocks, indications which have actually been confirmed by geological study and well-drilling, this chloride-type water is believed to attain equilibrium chemically with the reservoir rocks. Geochemical techniques are usefully applied to the geothermal resource study of chloride-type hot springs in this field.

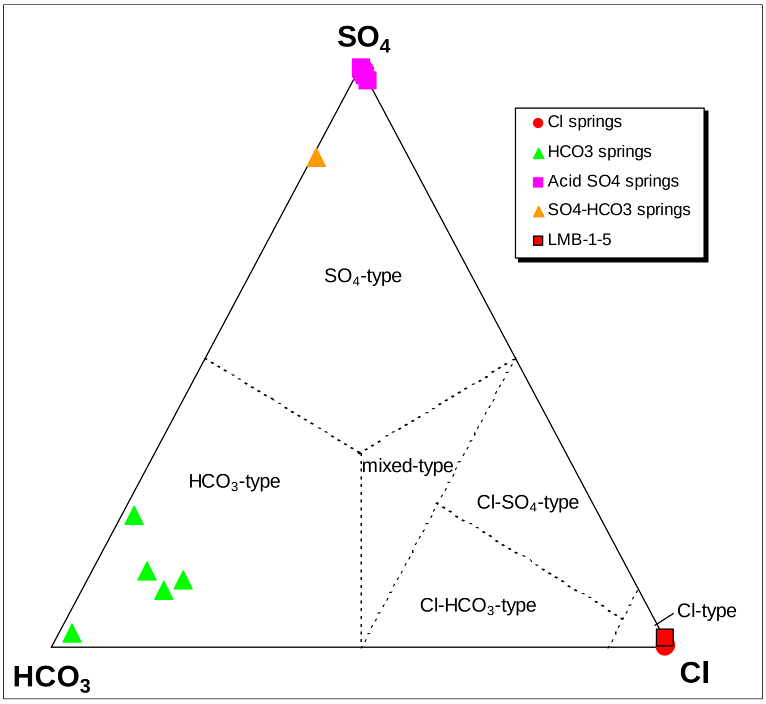


Fig. 3.1-17 Major Anion Classification of Spring Water in Lumut Balai Field

Acid sulfate-type waters occur at high elevations around the summit of Mt. Lumut (Gemurah Besar-Gemurah Pamalibar Sector). They are low in Cl (<2 ppm) and fairly but not extremely high in SO_4 (81-541 ppm), suggesting that no magmatic fluids (i.e. HCl and SO_2) contribute to them. High SO_4 concentration and subsequent low pH in waters are likely to be caused by oxidation of hydrogen sulfide at the near-surface level.

Chloride-type hot spring indicates definitely that geothermal reservoirs of high temperature exist in this field. Since chloride-type springs are concentrated in the Kelumpang-Sindawan-Bunbun sector, the relationship between these hot springs and hot springs of bicarbonate type and sulphate type in the Gemurah Besar-Gemurah Pamalibar sector were not clarified. However, bicarbonate-type water and sulphate-type water are generally formed by the heating of deeper chloride-type water.

Chloride-type springs occur within approximately 10 km from the probable center of the Lumut Balai geothermal system around Mt. Lumut, as described later. If chloride-type waters derive from the reservoir in the Gemurah Besar- Gemurah Pamalibar sector, the hydrothermal system may be very extensive in this field. The existence of geological structures such as high permeability zones along faults between chloride-type hot springs and bicarbonate/sulphate hot springs should be detected in the geological study and geophysical study. Since the extent of chloride-type reservoirs could not be revealed in geochemical study, compiling the results with those of other surveys and well tests is required to clarify the reservoir structure in this field. LMB 1-5 are classified as Cl-type. The reservoir Cl concentration of LMB 1-5 is high at 6,170mg/L.

Behavior of Geothermal Fluid under the Ground

Most of the fumaroles occur at high elevations around the summit of Mt. Lumut (in the Gemurah Besar- Gemurah Pamalibar sector), and the acid sulfate springs as well. A few of the fumaroles have a discharge temperature above the boiling point, reaching up to 130°C(?). Gas contents in the steam are below 3.11 mole%, and the dominant gases are CO_2 (mostly around 90 mole %) and H_2S (2.9-7.2 mole %). These gas chemistries imply that fumarolic steam and gases most likely originate from the boiling of primary reservoir water. Judging from the distribution of the CO_2/H_2S ratio in fumarolic gases shown in Fig. 3.1-18, the upflow area of the hydrothermal system is located northeast of Mt. Lumut (in the area of the lowest CO_2/H_2S ratio).

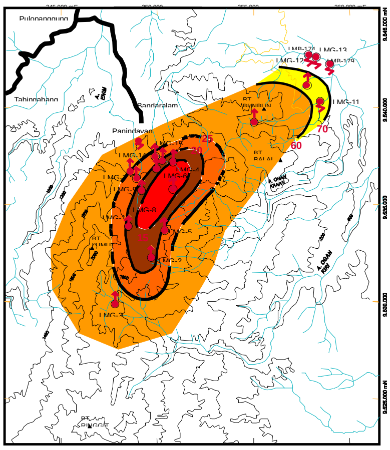


Fig. 3.1-18 Locality and CO_2/H_2S Ratio of Fumaroles in Lumut Balai Field

As chloride-type waters may originate in deep reservoir water, their cation geothermometry can sometimes provide a temperature for the primary reservoir fluid. $T_{Na\text{-}K}$ (Giggenbach et al., 1983) for the chloride-type waters as plotted in a Na-K-Mg ternary diagram (see Fig. 3.1-19) gives a deep reservoir temperature of around 240-260°C. Several gas geothermometers indicate a deep reservoir temperature of around 250-300°C (see Fig. 3.1-20). According to these geothermal temperatures, the geothermal reservoir in this field may have a temperature of 240°C to 300°C at depth. A diagram plotting the H_2/Ar ratio against the CO_2/Ar ratio (see Fig. 3.1-21) suggests that the deep reservoir is liquid water-dominated. The Silica geothermometer of LMB 1-5 is calculated as 247°C. The Alkali geothermometer cannot be applied to LMB 1-5, because of the cation data quality.

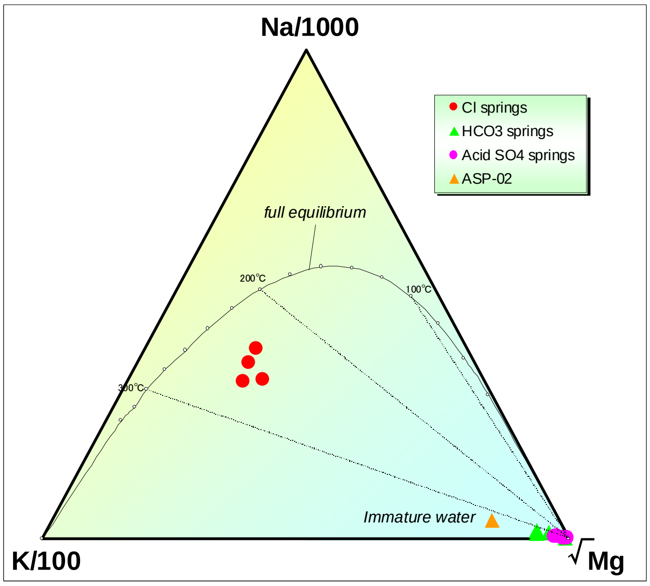


Fig. 3.1-19 Na-K-Mg Ternary Plot of Spring Water in Lumut Balai Field

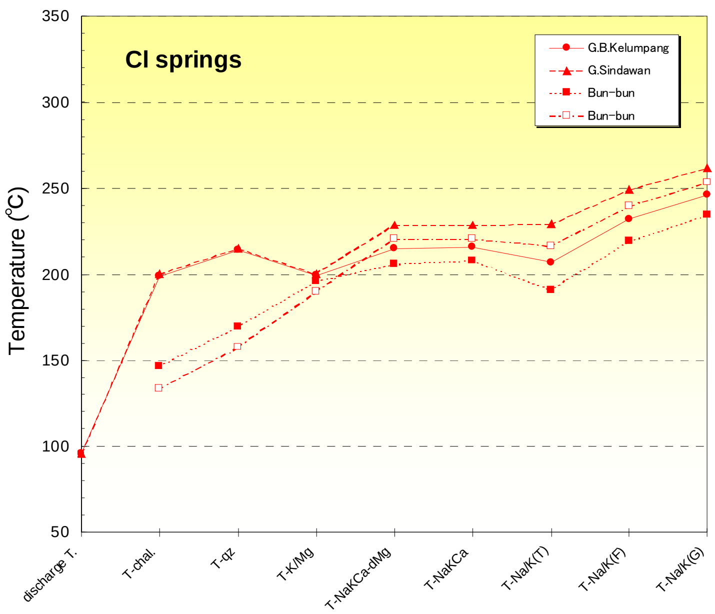


Fig. 3.1-20 Comparison of Geochemical Temperatures for Spring Water in Lumut Balai Field

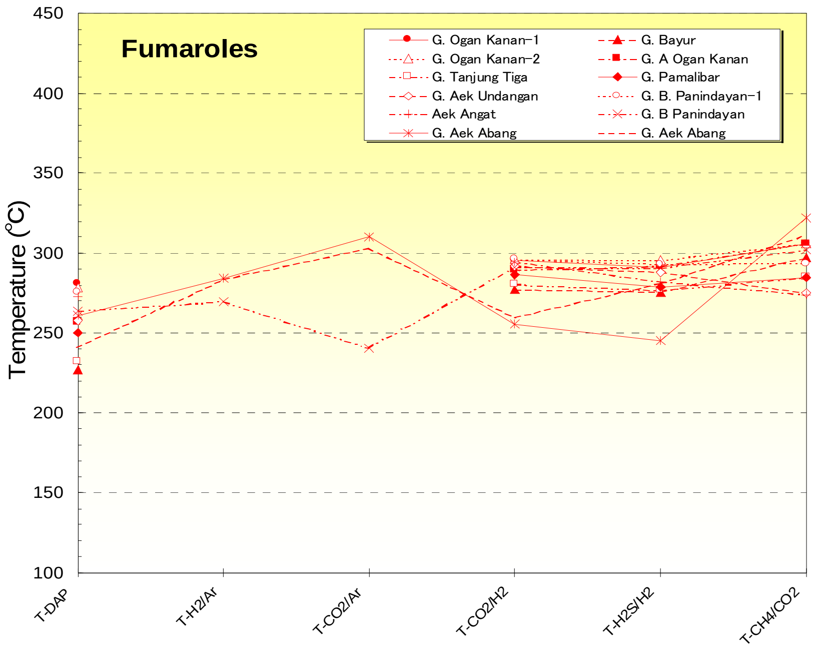


Fig. 3.1-21 Comparison of Geochemical Temperatures for Fumarolic Gases in Lumut Balai Field

An enthalpy-chloride mixing model is shown in Fig. 3.1-22. This model indicates the mixing relationship between spring waters and possible reservoir fluid. Chloride spring waters can be explained by steam loss from the possible parental fluid. This mixing relationship and the results of geothermometry suggest that the parental fluid has a chloride concentration of ca. 5,500-6,500 ppm with a temperature of 240-300°C. However, chloride springs occur fairly far from the current development area, so the connection between chloride springs and the deep reservoir in the development area is still unclear. Further study utilizing chemical data on well-discharge fluids after the production tests in the development area is strongly recommended for resource evaluation.

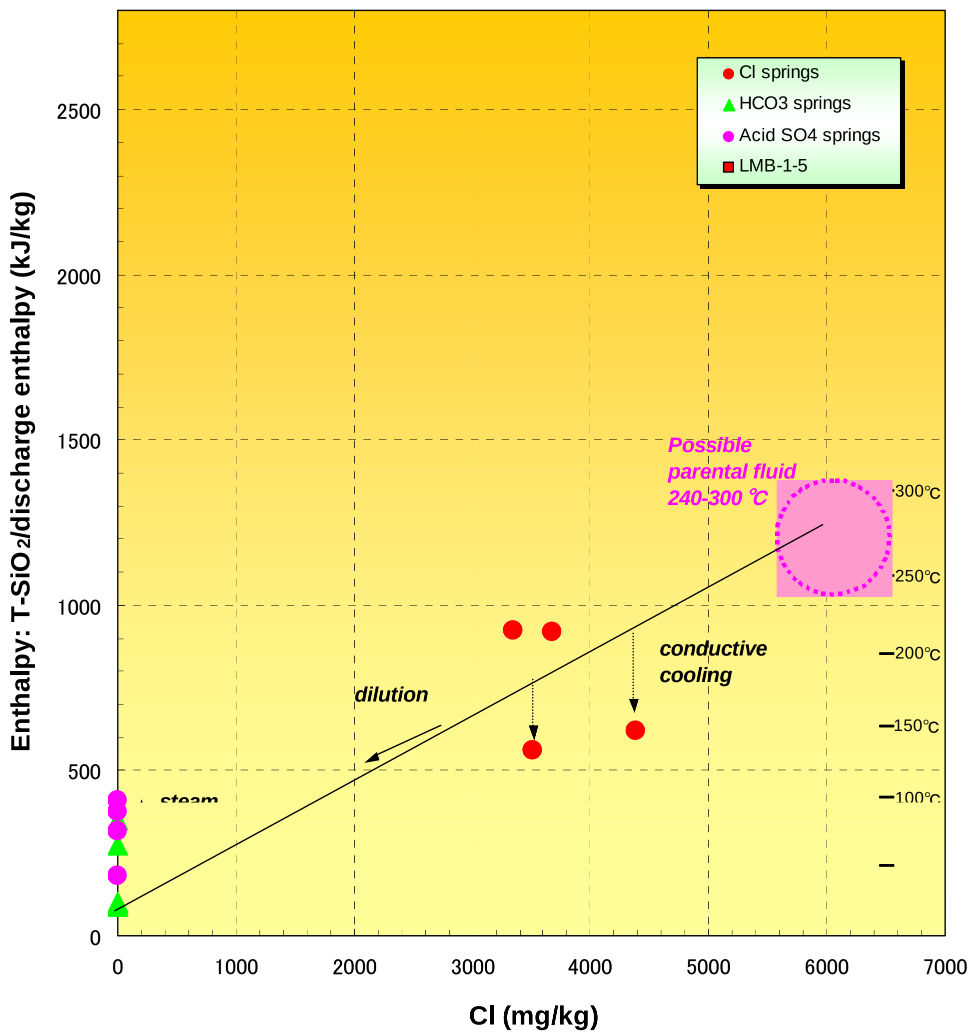


Fig. 3.1-22 Enthalpy-Chloride Mixing Model for Spring Waters in Lumut Balai Field

Concerning Noncondensable Gas in Geothermal Well Discharge Steam

Hydrogen sulfide (H_2S) and carbon dioxide (CO_2) are the major gases discharged from the steam of geothermal wells in general. Chemical data concerning noncondensable gases (H_2S and CO_2) are used in the design of power facilities and in assessing environmental impacts. The short-term well discharge test for LMB 1-5 indicates NCG=0.19vol%, 0.40wt%, CO2=67.1vol%, H_2S.

According to the existing data from the fumaroles, the content of NCG in geothermal steam in this field seems to be relatively low (see

Table 3.1-4). However, in designing the power facilities, it is advisable to adopt gas extraction facilities which can deal with a relatively high content of NCG, because there is a possibility that NCG content from production wells tapping shallow reservoirs or deep reservoirs in sedimentary rocks will be high in the initial stage of plant operation. Noncondensable Gas tends to concentrate in the shallow part of the reservoir and to be generated from the decomposition of organic matter in sedimentary rocks. The content of NCG in steam from production wells decreases gradually with time. It is recommended that gas extraction facilities be introduced into the Lumut Balai power plants, in consideration of the various characteristics of the NCG in the geothermal steam.

Table 3.1-4 Gas Content and Composition of Noncondensable Gases in Fumarolic Gas

Location	NCG (wt%)	NCG(vol%)	CO2(v%)	H2S(v%)	CH4(v%)	H2(v%)	N2/other(v%)
G. Aek Udangan	0.45	0.19	91.6	4.18	0.997	1.61	1.61
Air Angat	0.30	0.13	88.3	7.16	0.997	1.95	1.59
G.A.Ogam Kanan	1.21	0.51	95	2.9	0.37	1.42	0.31
Average	0.65	0.28	91.63	4.75	0.79	1.66	1.17

Concerning Silica Scale Deposition from Geothermal Water

Silica, which causes geothermal well clogging as silica scale, is usually contained in geothermal water (brine) originating from reservoirs of high temperature. Various measures have been applied to geothermal power plants to prevent silica scale deposition in reinjection pipelines and wells. As effective methods, high-temperature injection or pH modification (acidification) of wastewater (brine) from geothermal facilities have been adopted in many geothermal power plants. Equipment and a continuous supply of chemicals are necessary for pH modification, and this method slightly raises the cost of the construction and operation of the power plant. The alternate method of high-temperature injection has been adopted in many geothermal power plants as a measure against silica scale deposition in the reinjection system.

Given the LMB 1-5 silica concentration in the brine, silica scale is expected to deposit below a brine temperature of 146^{o}C (Fig. 3.1-23).

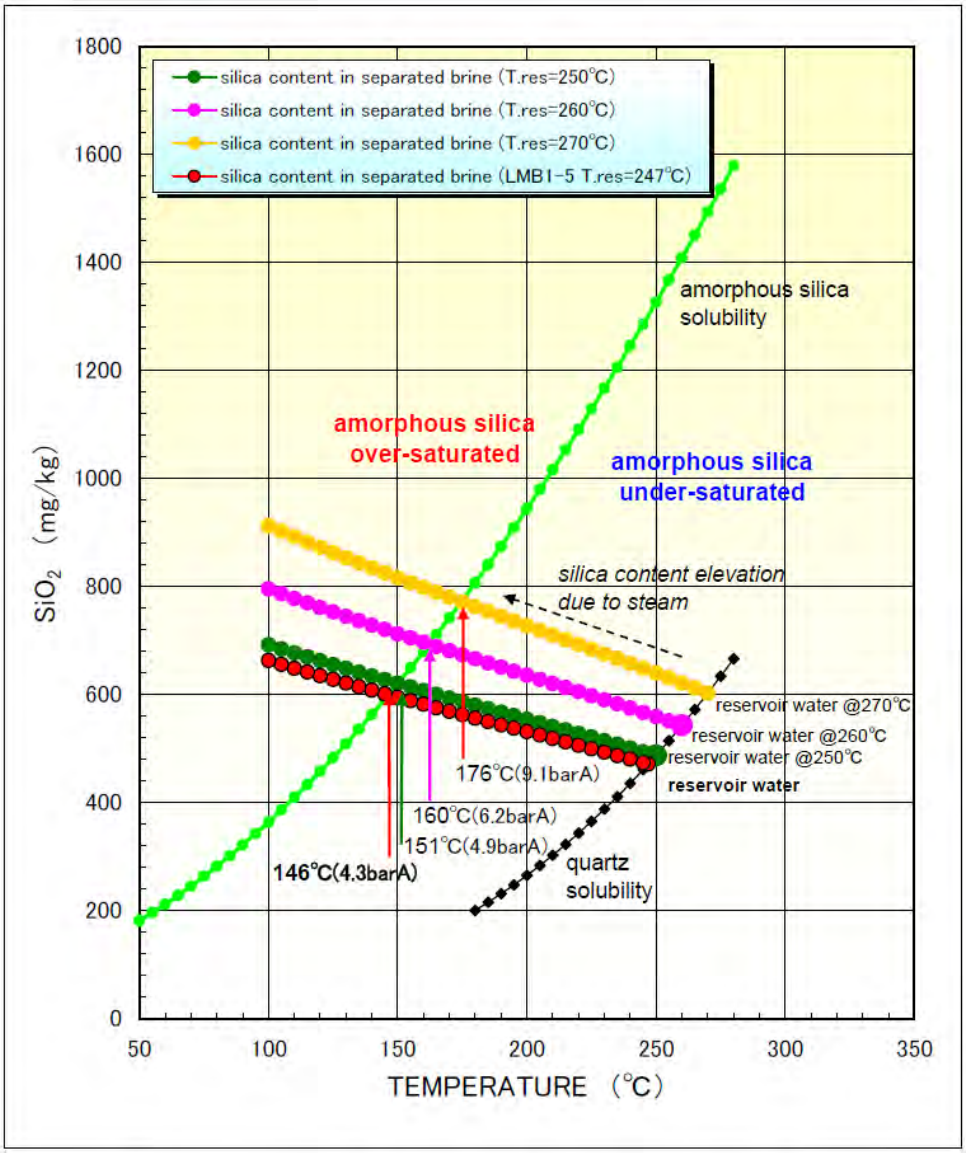


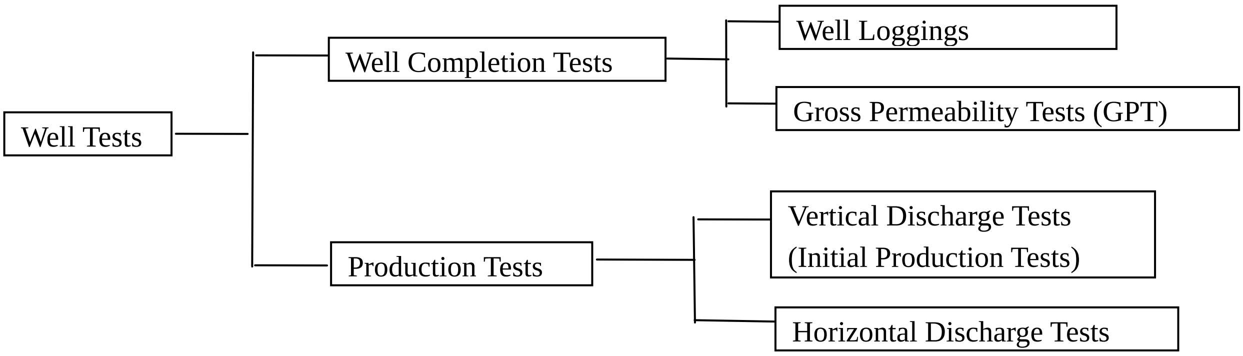
Fig. 3.1-23 Silica Saturation in Separated Brine

Concerning Carbonate Scale Deposition from Geothermal Water

Calcium carbonate scale, which causes production wells to clog, tends to deposit with degasification of CO_2 from geothermal brine in sedimentary rock reservoirs or volcanic rock reservoirs of relatively low temperature due to the richness in carbonate ions and relatively high pH of the brine. Since the geothermal reservoir seems to extend into volcanic rocks of high temperature, and considering the Cl/B ratio related to the reservoir rocks, the calculated geochemical temperatures and log data of exploratory wells, there is a low possibility that carbonate scale trouble will occur in the production system in this field. It is not necessary to consider countermeasures against carbonate scale at the present time. Anyway, after well discharge tests and chemical analysis of the well discharge, a detailed investigation of scale deposition and the gas content in the steam should be conducted. Judging from the LMB 1-5 data for short-term discharge testing, a calcite scale problem will not occur.

(3) Well Tests

Well tests are generally classified into two kinds: well completion tests and production tests. Furthermore, Production tests can be also classified into two subtypes: vertical discharge tests and horizontal discharge tests, as follows.



When the well-drilling is completed, well completion tests are conducted to evaluate reservoir properties such as pressure, temperature and gross permeability in the formation around the wells. After the well completion tests are finished and the drilling rig is removed from the well pad, production test equipment consisting of a separator, weir box and so on is installed at the site. Then the production test equipment is used to conduct production tests to evaluate the productivity of the well. Therefore, production tests are usually conducted in a series for the wells on the same pad. In PGE's standard procedure for production tests, vertical discharge tests are conducted as a first step to confirm a well's self-discharge and roughly estimate the productivity of the well. The vertical discharge tests are usually conducted in a short period of time, using simplified equipment for production tests. In the next step, horizontal production tests are conducted using regular equipment for production testing over a relatively long period to evaluate productivity with an analysis of chemical properties such as non-condensable gas contents in the discharged fluid from the well.. In Lumut Balai, the horizontal production tests have not been conducted yet, although the vertical discharge tests have already been conducted for the existing wells.