# THE FEASIBILITY STUDY
# ON
# KERINCI GEOTHERMAL DEVELOPMENT PROJECT
# IN
# THE REPUBLIC OF INDONESIA

## SUMMARY

MARCH,1989

JAPAN INTERNATIONAL COOPERATION AGENCY

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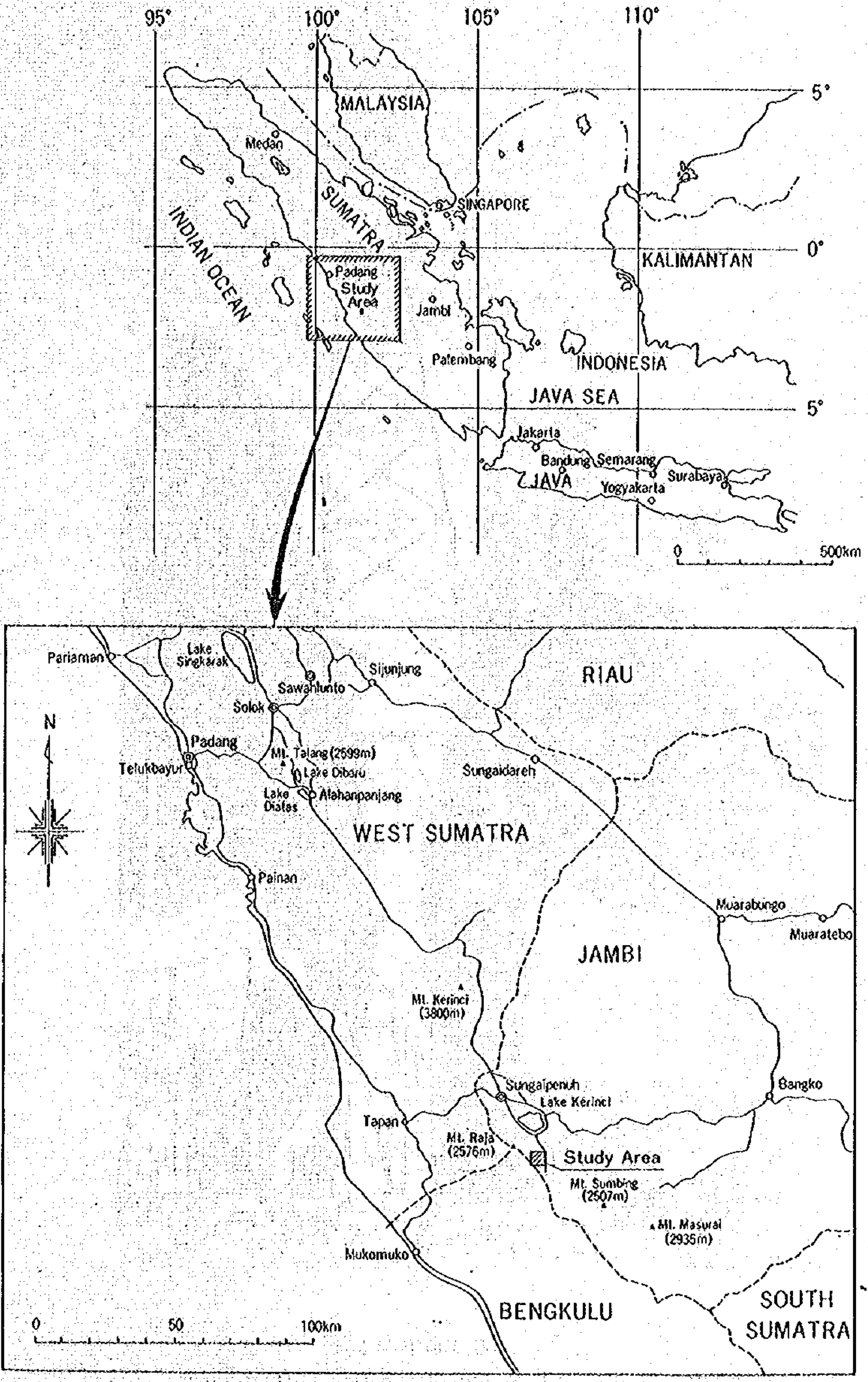
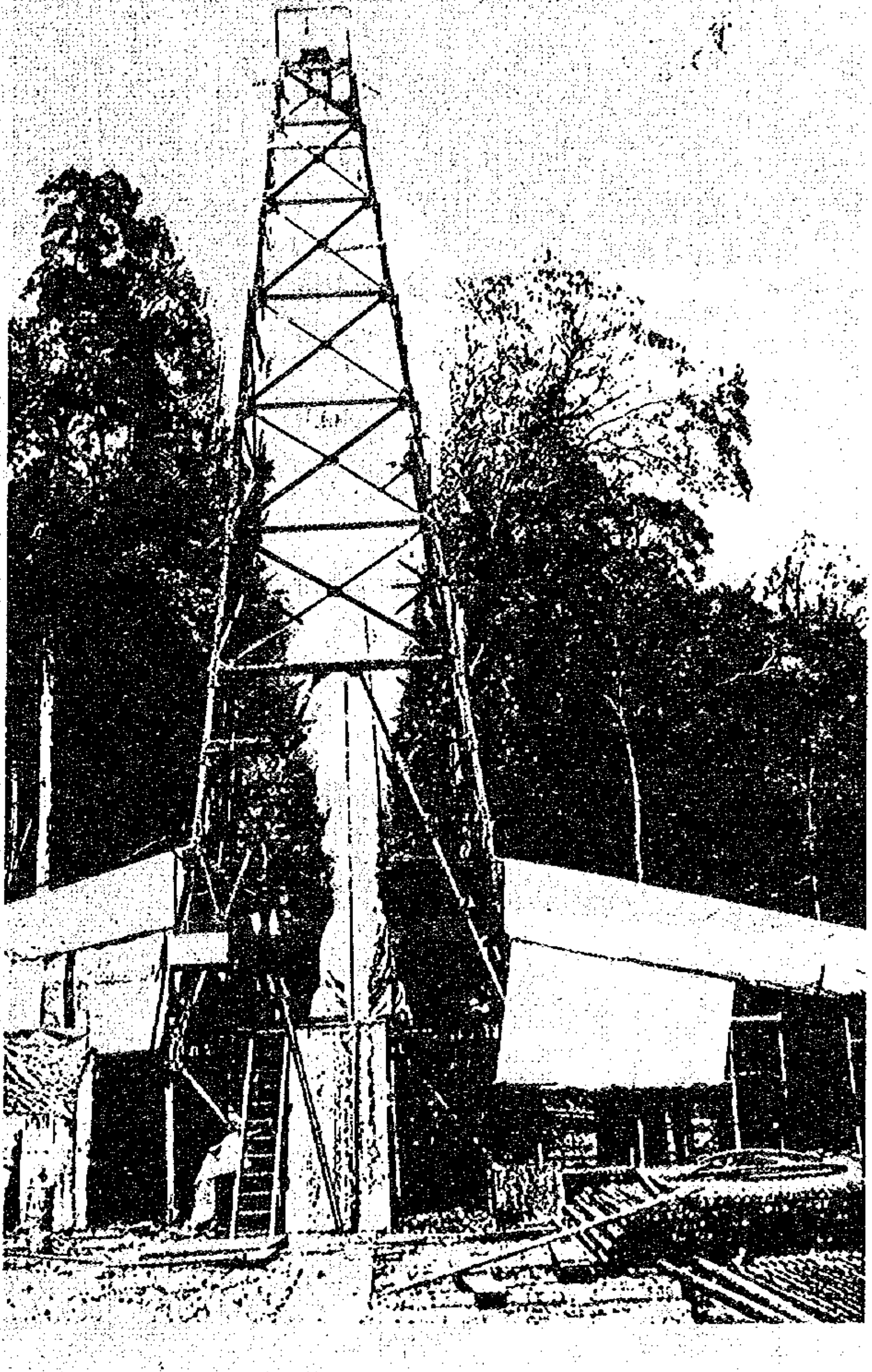
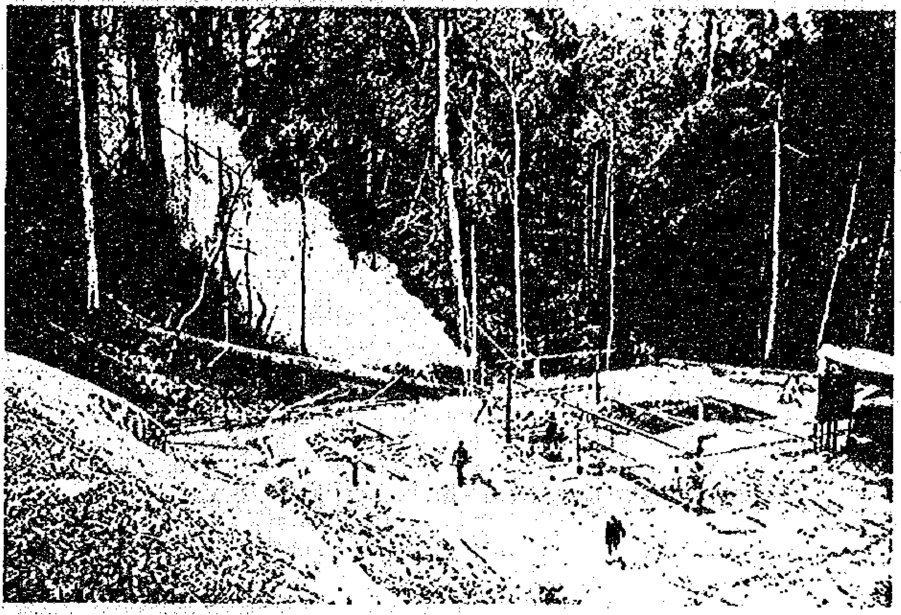


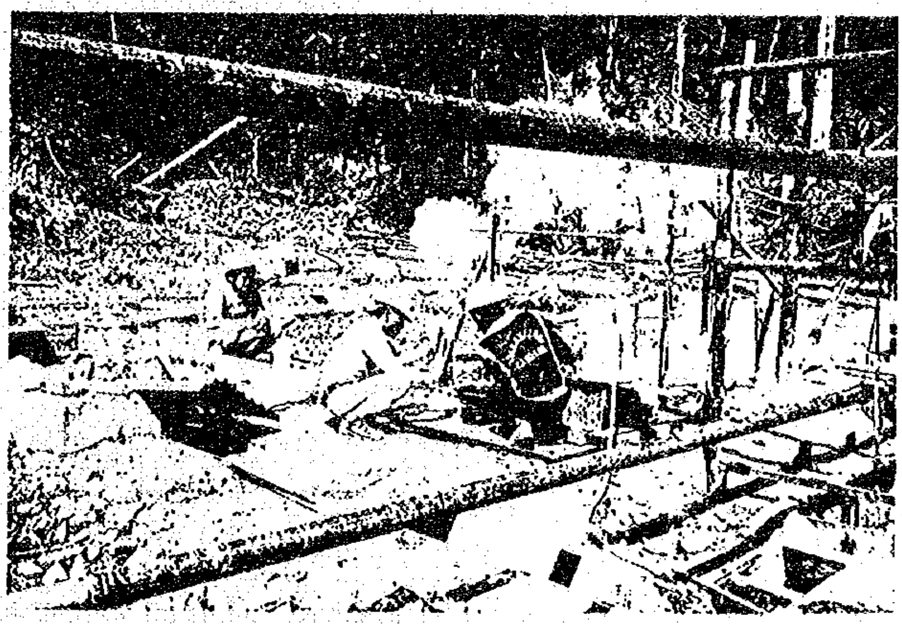
Location map of kerinci geothermal field



Exploratory well LP-2
(about 1hour after swabbing, 17Feburuary1988)



Discharging geothermal fluid from LP-2
(16 March 1988)



Gas sampling
(18 March 1988)

# Conclusion and Recommendation

# Conclusion and Recommendation

## Conclusion

The resource feasibility study confirmed that the Duabelas geothermal system has a potential for power generation of more than 5 MW. The following feasibility study for geothermal power plant, however, concluded that of 5 MW in the total potential, the development of 2.35 MW is appropriate for the time being to meet the power demand in the project area. Although the study revealed that the project is financially feasible and effective to alleviate the PLN's financial burden, the economic viability is not so sufficient. But in consideration that the project area is located in rural area remote from the PLN's transmission lines, the majority of the power demanders is residential customer, and the existing power sources are mostly diesel power units with a higher fuel cost due to long transportation from Padang, the study concludes that the project be continued for realization of geothermal power plant which will effectively utilizes the indigenous energy resources and contribute to economic and social development in the rural areas. The reasons for the conclusions and necessity of the project are summarized in the following.

### 1. Use of Available Geothermal Steam

The existing LP-2 well drilled as an exploratory well under the survey is producing the steam with an electricity energy of about 350 kW. It is advisable to formulate effective utilization of important geothermal energy as soon as possible. And the geothermal steam production by the production well is highly promised by a variety of the geothermal resource survey.

### 2. Power Demand

According to the demand forecast by PLN, the Kerinci area will need a new power source in addition to planned 2.5 MW x 2 units of new diesel power units before 1994 since PLN has no specific plan for interconnection of its Sumatra trunk line with the area. Introduction of the geothermal power plant to the area is significant for effective utilization of non-oil energy resource, or fuel saving amounting to 32,700 ton, or US$545,000 annually (at US$16/bbl.) and for diversification of power sources in the area. And the geothermal units formulated under the project can be properly operated as base load power units as a result of study on the estimated load curve.

## 3. Stable Power Supply

The power supply in the Kerinci area relies mostly on diesel power sources with the fuel transported on the long, ragged road from Padang. In rainy seasons, the transportation route is occasionally closed by the land slide and that endangered the stable and reliable power supply in the area. And the higher fuel cost and low efficiency of these diesel power engines make the power rate in the area (about 103.38 Rp/kWh in 1988) higher than the average rate in the whole Indonesia (about 92.50 Rp/kWh). Since the geothermal power plant generates the power with the geothermal steam available in the area, the fuel supply is not effected by the natural weather conditions. Because the geothermal power unit is usually operated with carrying the base load in the area owing to the geothermal well characteristics, the higher the capacity factor, the cheaper the generating cost. That will advance the 24-hour operation of power supply in the whole Kerinci area while only Sungai Penuh power system attained 24-hour operation some years ago.

## 4. Promotion of Rural Electrification

The electrification rate in the Kerinci area in 1987 stands only 19% which is one of the lowest figure in the whole Indonesia. Of 54,000 households, only about 10,300 households could receive the electricity. Since this project will improve the financial conditions of power business in the area by lowering the generating cost and attain the stable power supply, the project will contribute to substantial increase of electrification rate followed by well being of people's livelihood. In the economic theory, the willingness to pay for the electricity increases and so the electrification rate rises as the price of electricity becomes lower.

5. Development from Rural Area

The government emphasized the economic development not only in the urban areas in Java Islands but also rural areas in the islands other than Java. It is said there scattered many geothermal resources mostly in the remote area from the major power transmission lines in Indonesia. The successful development of the geothermal power source in the Kerinci area will become a model case for electrification and modernization in the rural area by geothermal power development.

6. Economic and Financial Feasibility

The project financial evaluation registered its FIRR at 4.32% and the With/Without financial evaluation (a comparison between the case of Project implementation and the case without the project) at 6.37%. Both the FIRRs exceed the financial opportunity cost of capital at 3.61%. That means the project is financially viable. Especially, the With/Without evaluation reveals that the project implementation is well effective to lessen the financial burden in PLN's Sungai Penuh power system and to realize the cheaper power rate.

Meanwhile, the economic internal rate of return by comparison with the close alternative of diesel power unit did not provide a favorable figure at 3.78% mostly because of high project initial investment and low oil price. Regarding the oil price, the unfavorable affection to the project will be alleviated by increase of oil price since it is hard to believe that the current low oil prices will continue.

The sensitivity analysis of EIRR to the cost for power unit revealed that if the cost should be reduced, the EIRR becomes more favorable. The project will become economically feasible if the project cost estimate would be made more in detail toward the reduction of the project cost when the project implementation program will be prepared.

Though the project implementation will bring about somewhat hardship for PLN in view of financial conditions, PLN could solve this problem by seeking for the loans with the softest term and conditions. In order to attain further electrification at the same power rate as the average power rate in the whole Indonesia it is desired to advance the project as soon as possible.

## Summary of the Study

### 1. Results of Resource Evaluation Stage

The Kerinci geothermal field is situated in the depression zone of which western margin is limited by the Great Sumatran Fault. This depression zone, which is an active Quaternary volcanism field, was resulted from subsidence of Pre-Neogene basement rocks, originated with the eruption of Neogene volcanic rocks. Geothermal manifestations such as fumarole and hot spring are recognized mainly along the Duabelas fault and along the Sikai fault. It is considered that geothermal activity in this field is mainly controlled by these faults. The geothermal features in this field are summarized as follows.

1) There are two geothermal systems, with a common heat source, of hydrothermal convection type, the Duabelas geothermal system along the Duabelas fault and the Sikai geothermal system along the Sikai fault. There are deep hot water reservoirs of neutral chloride type, with overlaying vapor-dominated zone, along the faults in both the systems.

2) The last eruption of Mt. Kunjit is considered to happen 0.06 million years ago, from the rock dating data. Therefore, it is considered that the heat source is the magma from which Kunjit volcanic rocks were resulted. Judging from the volume of Kunjit volcanic rocks, temperature of the magma is still as high as about 500°C.

3) The origin of deep hot water in the Duabelas geothermal system is meteoric water recharging from the southeastward area of the Duabelas area and a circulation time is more than 30 years. The origin of deep hot water in the Sikai geothermal system is also meteoric one, but its recharge area is not identified because there is no water sample from the deep reservoir.

4) Temperature of the deep reservoir in the Duabelas system is 200°C to 300°C and that in the Sikai system is more than 261°C. The deep reservoirs in both the systems are considered to be at nearly same horizon each others, their bottom and top are considered to be at the boundary between Pre-Neogene basement rocks and Neogene system and at about 800 m in elevation, respectively.

5) Although temperature of the vapor-dominated zone in the Duabelas system is relatively low (135°C to 160°C), that in the Sikai system is considerably high (about 224°C).

The results of the evaluation of geothermal resource in the Duabelas area are summarized as follows.

1) The extent of the geothermal reservoir is delimited as about 2 km$^2$ including Grao Duabelas, Grao Bujang and Grao Rasau, from the distribution of hydrothermal alteration zone, of mercury anomaly in soil and soil-gas, and of low resistivity.

2) Exploratory well LP-2 was drilled to 1,026.50 m in depth, and total lost circulation zones below 974.05 m in depth was considered as production zone. Well completion was succeeded to discharge geothermal fluid by swabbing method.

3) The characteristics of LP-2 is about 6 ton/hour of steam flow rate and 35 ton/hour of hot water flow rate at wellhead pressure of 5.2 ata. If the casing program of LP-2 were the production well size, the flow rates of steam and hot water are supposed to be about 4 or 5 times of measured flow rates.

4) Maximum generating output by the steam of LP-2 is estimated as 370 kW for back pressure steam turbine and 830 kW for condensing steam turbine, respectively.

5) Reservoir potential of Duabelas area is estimated by Volume Method and by Lumped Parameter Model Method, and both estimation show that exploitable potential is about 5 MW for 40 year's operation by back pressure steam turbine and about 5 MW for 90 year's operation by condensing steam turbine.

Duabelas area, which was selected as the most promising area in Kerinci geothermal field and was investigated in detail by exploratory wells, was evaluated as feasible to develop for the purpose of power generation from a viewpoint of resource development.

On the basis of the results of Resource Evaluation Stage, it is recommended to proceed the Study to Feasibility Study Stage.

## 2. Summary of Development Plan

### 1) Capacity of geothermal power plant

The demand forecast for this Project was prepared by categories of residential, commercial, public & others, and industry by the Planning Department of PLN, based on the past records of demand in PLN Sungai Penuh Sub-branch.

This demand forecast is a long-range forecast covering 1988 through 2000, and shows that the energy consumption at the consumer end will increase about four times from 6,043.7 MWh in 1987 to 24,385.2 MWh in 2000, and the required generation from 10,430.5 MWh to 31,669.0 MWh, or about 3 times, and the peak load is estimated to increase from 2,950 kW to 8,407.4 kW, or about 2.85 times.

As described in Chapter 3, approximately 5,000 kW of geothermal resources are confirmed in the Project Site, and it would be appropriate to build the geothermal power plant which utilizes the indigenous geothermal energy effectively to save the petroleum.

From the geothermal potential of the Project Site, an output of 5,000 kW can be expected, but in view of the advisability of operating the geothermal power plant as the base load supplying plant, it is planned to develop half of the assumed potential, or a total of 2,350 kW, of geothermal power plant will be built, in consideration of the load conditions in Kerinci Area.

2) Unit capacity

The system load and influence to the system by the unit shutdown at troubles or periodical overhaul are the major items for determination of the unit capacity.

a. System load

The peak load in 1994 when some new power sources will be needed is forecasted to be about 6 MW. From the view point that the unit capacity will be about 10 to 20 percent of the peak load, the unit capacity of the additional power source lies in a range from 600 kW to 1,200 kW. And the geothermal power unit is usually operated as a base load power plant for maximum use of geothermal energy. Finally, it is judged from the minimum load of Sungai Penuh system as refereed to the daily load curve appeared in Chapter 5 that the unit capacity of 1,000 to 1,200 kW is appropriate.

b. First unit

In order to use steam produced from the exploratory well of LP-2 as early as possible, first, a power unit with the back-pressure turbine of 350 kW, which is cheaper in the initial investment than the condensed type, will be installed.

c. Second and third units

The generating cost of each unit capacity of geothermal power plant when the plant is operated with a capacity factor of 80% as a base load plant is calculated with the result of

48.30 Mills/kWh, 31.26 Mills/kWh, and 34.30 Mills/kWh for 350 kW, 1,000 kW and 2,000 kW units. The 350 kW unit becomes highest because of high equipment cost for its small unit capacity. The cost of 350 kW unit is cheaper by only 10% than that of 1,000 kW unit. While the cost of 2,000 kW condensed unit is nearly double of that of 1,000 kW back pressure unit. It is judged that the 1,000 kW unit is the most economic one.

### 3) Outline of the Project

This Project includes production well drilling, civil works, construction of power generating facilities and high voltage distribution line. Outline of the Project is as follows.

a. Production well drilling

|  |  |  |
|---|---|---|
| a) | LP-3 drilling and wellhead equipment | : 1,200 m of drilling depth |
| b) | LP-4 drilling and wellhead equipment | : 1,200 m of drilling depth |

b. Civil works

|  |  |  |
|---|---|---|
| a) | Access road | : Width 4 m x 7,000 m |
| b) | Land reclamation | : 1,189 m², 1,800 m², 1,800 m² |
| c) | Foundations | : 1 lot for turbine generator, etc. |
| d) | Powerhouse | : 1 lot |
| e) | Intake and water pipe line | : Length 600 m |

c. Power generating facilities

|  |  |  |
|---|---|---|
| a) | Silencer | : 3 sets |
| b) | Steam/water pipe line | : 1 lot |
| c) | Separator | : 3 sets |

d) Turbine generator : 350 kW x 1
(Backpressure turbine)
1,000 kW x 2
(Backpressure turbine)

e) Electrical equipment and control panel : 1 set

f) Transformer : 437.5 kVA x 1
1,250 kVA x 2

e. High voltage distribution line

a) Wiring system : 20 kV x 1 cct, 50 Hz, 3-phase 3 wiring system

b) Conductor : AAAC 240 $\mathrm{mm}^2$

c) Length : 40 km

d) Interconnected switching station : Sungai Penuh switching station

4) The project development schedule is formulated taking into account the earliest possible use of LP-2 which has already been producing geothermal steam, matching the power demand increase in Kerinci area, and the shorter construction period.

The project development schedule in which the commissioning of No. 1 Unit using the existing LP-2 is set in June 1993, and commissioning of No. 2 and No. 3 Units using the new production wells of LP-3 and LP-4 is set in September 1993 and December 1993 respectively.

5) Cost estimate

(Unit: 1,000 US$)

| Items | FC | LC | Total |
|---|---|---|---|
| 1. Well Drilling and Wellhead Eqt. | 1,846 | 462 | 2,308 |
| 2. Power Plant | | | |
| Power generating eqt. | 4,946 | - | 4,946 |
| Installation | 438 | - | 438 |
| Civil/Arch. works | - | 423 | 423 |
| Subtotal | 5,384 | 423 | 5,807 |
| (Unit cost per kW) | | | (2,471 US$/kW) |
| 3. HV Distribution | - | 615 | 615 |
| 4. Engineering Fee | 769 | - | 769 |
| 5. Total | 7,999 | 1,500 | 9,499 |
| 6. Contingency | 1,192 | 231 | 1,423 |
| 7. Grand Total | 9,191 | 1,731 | 10,922 |

## 3. Summary of Financial and Economic Evaluation

### 1) Financial evaluation

a. FIRRs

The project is financially feasible since the obtained FIRR at 4.32% exceeds the opportunity cost of capital at 3.61%. However, the financial conditions will be deficit for about 8 to 10 years after commissioning. Though the Project will become profitable finally, this project will be a hard project. Though the Project FIRR does not show an implicit financial feasibility of the Project, the With/Without FIRR registered 6.56% over the case without project implementation. The value well clears the WMCC at 3.61% and this shows that the implementation of the project is highly effective and feasible to minimize the financial deficit of PLN's Ranting Sungai Penuh.

b. Sensitivity of FIRR to project cost

Because the project initial investment is greater than that of other type of thermal and internal combustion power plant, the sensitivity of FIRR to the project cost is tested in a range of plus and minus 15%. If the cost should increase by about 8 to 9 percent, the FIRR value can not exceed the hurdle rate of 3.61%. This study also reveals that one percent variation of the cost affects approximately 0.1 percent FIRR value.

c. Financial statements

The project income and cashflow statements show that the net profit of the project at the final year after repayment of loans will stand at US$1,243 thousand, or over Rp.2 billion. If the net profit at the final year is compared with that of Without case, the profit of PLN, or decrease of PLN's financial deficit will approximately amount to US$12,961 thousand or Rp.22 billion.

2) Economic evaluation

The economic feasibility of the Project was evaluated by Economic Internal Rate or Return (EIRR) Method between the project and its close alternative, diesel power units.

a. EIRR and sensitivity analysis

The obtained EIRR registered as low as 3.68% which is not sufficient as compared with the economic opportunity cost of capital at 9%. This insufficient EIRR is derived from a substantially higher construction cost of the project than that of the alternative since the project cost includes cost for access road and special design for small scale geothermal power units to meet the Kerinci geothermal field. The sensitivity of EIRR to project cost reveals that variation of the project cost greatly affects EIRR and if the project cost is reduced, the EIRR becomes more favorable. Therefore, if the project should be continued and the subsequent units constructed, the total project EIRR will become very favorable over the alternative.

b. Fuel save

As the Project will provide the electricity generated by geothermal energy, if it is implemented, it will save the consumption of fuel amounting to about 32.7 thousand barrel per year, or about US$545 thousand per year, or increase export value of about US$545 thousand per year at an unit oil cost of 16 $/bbl.

c. Rural development

Since Sungai Penuh area is located at high elevation of about 800 m a.s.l. and surrounded by the mountain ranges, the transportation route of the fuel oil is sometimes closed due to the land slide especially in the rainy season. These conditions make the power supply unstable at present. The Project, on the contrary, using the local energy, could provide the stable and reliable electricity to the society. In addition, the stable and reliable power supply will lead to the industrization of the agriculture and forestry and develop the rural areas. This will accord to the government policy of equalized development of the country.

d. Summary

Though the EIRR obtained is not sufficient, since the Project will provide said merits with the rural society and country, and the development and use of non-exportable and indigenous energy resource is a national objective, the implementation of this project should be determined in the stand point of national economy.

## 4. Technical Transfer

The JICA team carried out the Study in close cooperation with Indonesian counterparts. Through the Study, the JICA Team transferred geothermal exploration technologies to their Indonesian counterparts, such as purpose, analyzing method and interpreting method of each survey, in addition to operating system and maintenance method of equipments donated by JICA. The Indonesian counterparts now understand fully the methods and technologies needed to carry out geothermal development by themselves in other areas in Indonesia.

The Study contributed to the improvement geothermal exploration techniques in Indonesia, and will then effectively promote geothermal development in Indonesia.

## Recommendation

### 1. Recommendations from Resource Evaluation Stage and Feasibility Study Stage

As results of Resource Evaluation Stage, the Duabelas geothermal system, which is the most promising area in Kerinci geothermal field and is explorated in detail by surface survey and exploratory wells, is evaluated to have enough potential to develop a geothermal power plant of 5 MW.

As results of Feasibility Study stage, it is concluded that the optimum capacity of power plant at the Duabelas geothermal system is about half of 5 MW, which is the initial objective of the Project, by considering that the Project area is located at mountain area, its power supply system is isolated from the PLN's trunk lines, its power demand is limited and is almost for house lighting, and there are no factories. However the capacity is supposed to increase to 5 MW responding to the increase of power demand in the future.

### 2. Recommendation Prior to the Power Plant Development

The project is recommended to continue to install a portable packaged unit (back pressure type) of 350 kW by utilizing the steam of LP-2, to drill production wells LP-3 and LP-4, and then to install a portable packaged unit (back pressure type) of 1,000 kW at each site of production well.

The following items should be implemented prior to execute the Project.

1) Preparation of the Project budget

It is recommended to procure foreign currency of low interest such as OECF soft loan, in considering that FIRR of the Project is as low as 4.32%.

2) Projection well drilling

It is recommended to arrange the organization among PLN, VSI and PERTAMINA, prior to allocate the budget.

3) Meteorological survey

Meteorological survey of rainfall, atmosphere temperature, humidity, wind direction, wind velocity at the Project site is recommended to design the detailed layout of the power plants, especially for considering the $H_2S$ gas diffusion.

4) Monitoring of well characteristics of LP-2

It is recommended to continue the monitoring of well characteristics of LP-2, because well characteristics are basic data for power plant designing and are usually changing with time.

# Chapter 1. General

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## 1.1 Project Background

The Republic of Indonesia (hereinafter referred to as "Indonesia") is developing the country in according to the Five Year National Developing Plan (PELITA) to improve the living standards. Main purposes of the plan are to prevent the increasing population of big city and then to transmigrate the population from the overpopulated areas to the unpopulated areas.

For these purposes, the Government is improving the infrastructures such as road, irrigation facilities, water resource, power source, school, hospital and communication system (including radio and television network) and is promoting the local industries such as tea, coffee, coconut, tobacco, rubber, etc. at the unpopulated area.

Energy policy of Indonesia is also based on the PELITA and its main objects are as follows,

1. Oil and gas are main products to gain foreign currency
2. Energy resources for domestic demand depend on hydro, coal and geothermal.

Indonesia is one of the world-famous volcanic countries, in which most of volcanos and associated geothermal fields are distributed on Sumatra, Java, Nusantara islands and Sulawesi, and the potential of geothermal resource is estimated as 8,000 - 10,000 MW in total.

With this background, the Government of Indonesia requested the Government of Japan to implement the Pre-Feasibility Study on geothermal project at Kerinci area, West Sumatra.

In response to the request of the Government of Indonesia, Japan International Cooperation Agency (JICA) dispatched the Survey Team composed of West Japan Engineering Consultants, Inc., Nittetsu Mining Consultants Co. and Nikko Tankai Co. to implement the surface surveys and to drill an exploratory well (LP-1) at Lempur, Kerinci, West Sumatra from 1981 to 1983.

This well was located at the boundary of prospective geothermal reservoir because of restraints of access road, and the characteristic of producing fluid (steam flow rate 3.5 t/h at wellhead pressure 0.58 atg) was not suitable for the purpose of power generation.

The Survey Report recommended that the potential of Duabelas area is estimated as more than 30 MW and it is preferable to carry out further field surveys and feasibility study to develop mini geothermal power plant of 5 MW.

In accordance to this recommendation, the Government of Indonesia requested the Government of Japan to continue the project to the next stage, and simultaneously conducted additional surveys, monitoring the well characteristics of LP-1 and preparation of access road.

In response to the additional request from the Government of Indonesia, JICA carried out the preparatory study to continue the project in October 1986, then decided to implement the project with cooperation of Volcanological Survey of Indonesia (VSI) and State Electricity Corporation (PLN).

## 1.2 Project Objective

The objective of the study is to prepare an optimum developing program of geothermal resource at Kerinci area, West Sumatra, and to implement a feasibility study to develop a mini geothermal power plant such as 5 MW, and then to contribute to an electrification program at isolated villages.

The Study consists of two stages; namely the Resource Evaluation Stage and Feasibility Study Stage.

Resource Evaluation Stage and Feasibility Study Stage consist of the following items respectively;

Resource Evaluation Stage

1. Collection and compilation of well characteristics records of LP-1
2. Electrical survey (Mise-a-la-masse and CSAMT methods)
3. Supplementary survey for geology and geochemistry
4. Drilling of the exploratory well LP-2
5. Well Logging and core analysis
6. Well test
7. Well chemical characteristic test

Feasibility Study Stage

1. Power situation in Project area
2. Socio-economic survey
3. Power development plan
4. Project development plan
5. Economic and Financial evaluation

## 1.3 Survey Team and Schedule

In accordance with the Scope of Work, the following organization were in charge of the Study.

| Japan | Indonesia |
|---|---|
| Japan International Cooperation Agency (JICA) | Ministry of Mines and Energy |
| West Japan Engineering Consultants, Inc. (JICA Team) | Volcanological Survey of Indonesia (VSI) |
| | Perusahaan Umum Listrik Negara (PLN) |

JICA Team, VSI and PLN were organized into the following staff to carry out the Study.

JICA Team

| | | |
|---|---|---|
| Project manager | Tadahiko<br>*(Tamotsu | SHIMOIKE<br>IWAKI) |
| Geologist | Hideo | AKASAKO |
| Geochemist | Kanichi | SHIMADA |
| Reservoir engineer | Tetsuya | YAHARA |
| Geophysicist | Shigeo<br>Yusuke<br>Mitsuru | MATASAKA<br>MATSUDA<br>HONDA |
| Drilling engineer | Yoshikazu<br>Toyomatsu<br>Kyuya | SUEYOSHI<br>SUGAWARA<br>FUJII |
| Generating equipment | Masakazu | NAKAMOTO |
| Generating and Transmission Equipment | Ginjiro | MATSUO |
| Economic and Financial | Kenji | FUJII |

* From December 1986 to January 1988

## VSI

| | | |
|---|---|---|
| Coordinator | W. Subroto | MODJO |
| Geologist | Nikmatul | AKBAR |
| | Dang | ASWIN |
| Geochemist | Djoko | HADISUDEWO |
| | Abdul | SOMAD |
| Geophysicist | Firdausj | DJAZULI |
| | Yanes | SIMANJUNTAK |
| Drilling engineer | Kartijoso | SOEMODIPOERO |
| | A. BARIDJI | |
| | Komar | DJAYAPERMANA BSc |
| Reservoir engineer | Susilo | BACHRI |
| | Reighman | SIHONBING |

## PLN

| | | |
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| Geologist | Sigit | WITONO |
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| Electrical engineer | WIDODO | |
| | Poerba | HUTAPEA |
| Mechanical engineer | PURWANTO | |
| | Sapto | TRIONO |
| Civil engineer | SIHABUDIN | |
| | Budi | SUKMANA |
| Padang office | Andy | SUNARYO |
| | Syahril | MULUK |

The Study was implemented in two steps in accordance with the Scope of Work.

## Table 1-1 Progress of the survey

| | | F.Y. 1986 | F.Y. 1987 | F.Y. 1988 |
|---|---|---|---|---|
| | | 1986<br>1987 | 1987<br>1988 | 1988<br>1989 |
| Resource evaluation stage | Data collection and compilation of well characteristics records of LP-1 | ▬ 15 Dec. – 28 Dec.<br>▭ 1 Feb. – 6 Feb. | | |
| | Electrical survey | ▬ 7 Jan. – 28 Mar. | ▭ 1 Jun. – 30 Jul. | |
| | Supplementary survey for geology and geochemistry | ▬ 26 Feb. – 28 Mar. | ▭ 1 Jun. – 1 Jul.<br>▭ 18 Jul. – 24 Jul. | |
| | Preparation of progress report | | ▭ 18 Jul. – 24 Jul.<br>▬ 27 Jul. – 5 Aug. | |
| | Drilling of LP-2 | | ▬ – 5 Mar.<br>▭ 6 Mar. – 31 Mar. | |
| | Well logging and core analysis — logging | | ▬ 5 Jan. – 24 Jan.<br>▬ 3 Feb. – 28 Feb. | ▭ 9 May. – 30 May. |
| | Well logging and core analysis — core analysis | | ▬ 22 Dec. – 14 Jan.<br>▬ 3 Feb. – 28 Feb. | ▭ 9 May. – 30 May. |
| | Well test | | ▬ 26 Feb. – 26 Mar. | ▭ 9 May. – 30 Jun. |
| | Well chemical characteristic test | | ▬ 26 Feb. – 26 Mar. | ▭ 9 May. – 30 May. |
| | Integrated analysis and preparation of interim report | | | ▭ 1 Jun. – 30 Jun.<br>▬ 4 Jul. – 13 Jul. |
| Feasibility study stage | Electric power survey | | | ▬ 1 Aug. – 31 Aug.<br>▭ – 30 Sept. |
| | Socio-economic survey | | | ▬ 1 Aug. – 31 Aug.<br>▭ – 30 Sept. |
| | Formulation of optimum power output | | | ▭ 1 Sept – 30 Sept. |
| | Selection of optimum site | | | ▬ 1 Aug. – 31 Aug.<br>▭ – 30 Sept. |
| | Feasibility design | | | ▭ 1 Oct. – 28 Dec. |
| | Cost estimation | | | ▭ 1 Dec. – 28 Dec. |
| | Formulation of Implementation schedule | | | ▭ 1 Dec. – 28 Dec. |
| | Economic and Financial analysis of the project | | | ▭ 1 Dec. – 31 Jan. |
| | Comprehensive evaluation | | | ▭ 4 Jan. – 31 Jan.<br>▬ – 15 Feb. |
| Report | Inception report | ▼ 16 Dec. | | |
| | Field report | ▼ 25 Mar. | ▼ 12 Jan.<br>▼ 21 Jan.<br>▼ 26 Feb.<br>▼ 2 Mar.<br>▼ 21 Mar. | ▼ 30 Aug |
| | Progress report | | ▼ 28 Jul. | |
| | Interim report | | | ▼ 2 Jul. |
| | Draft final report | | | ▼ 2 Feb. |

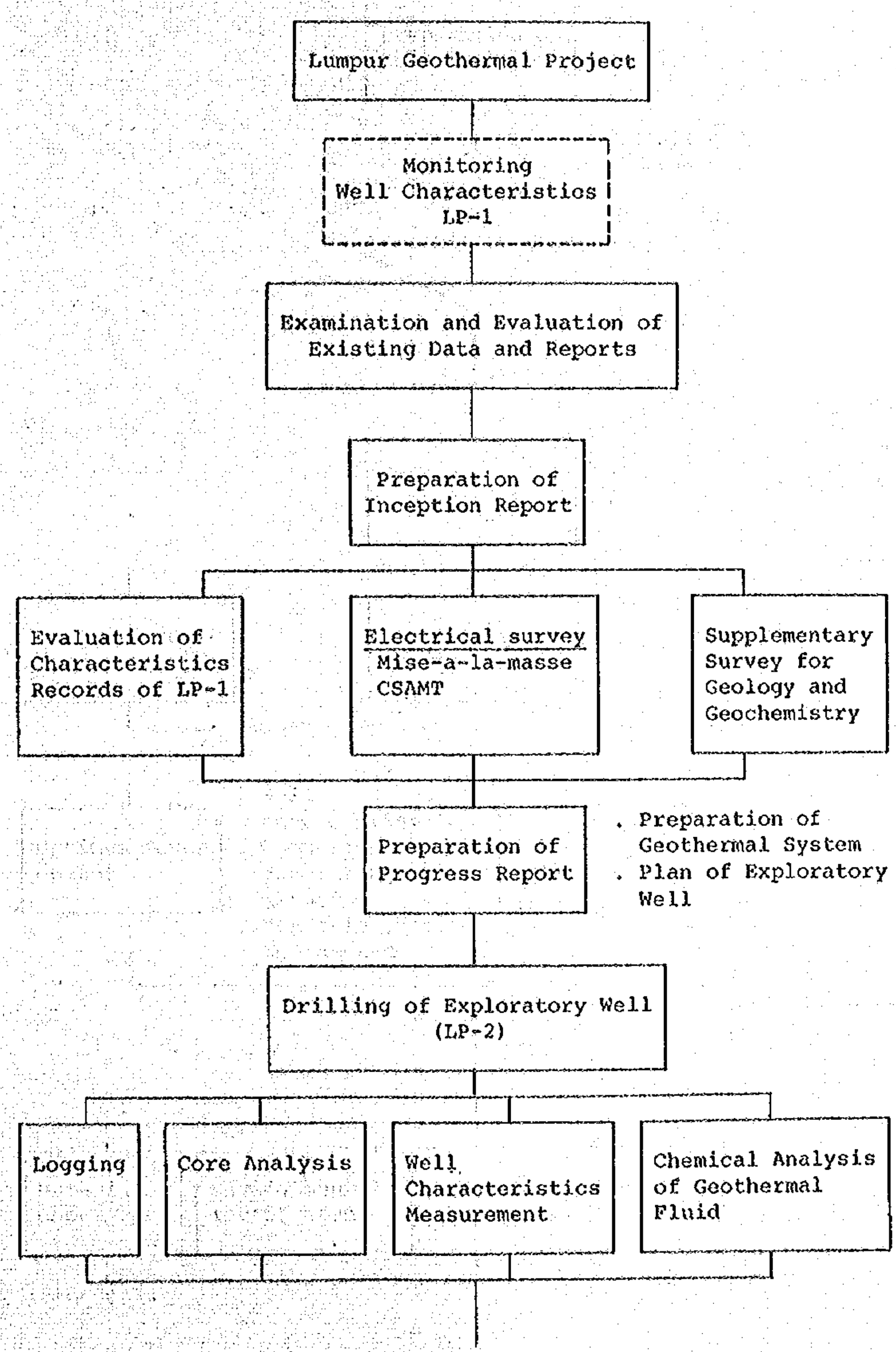
▬ : Works in Indonesia. ▭ : Works in Japan.

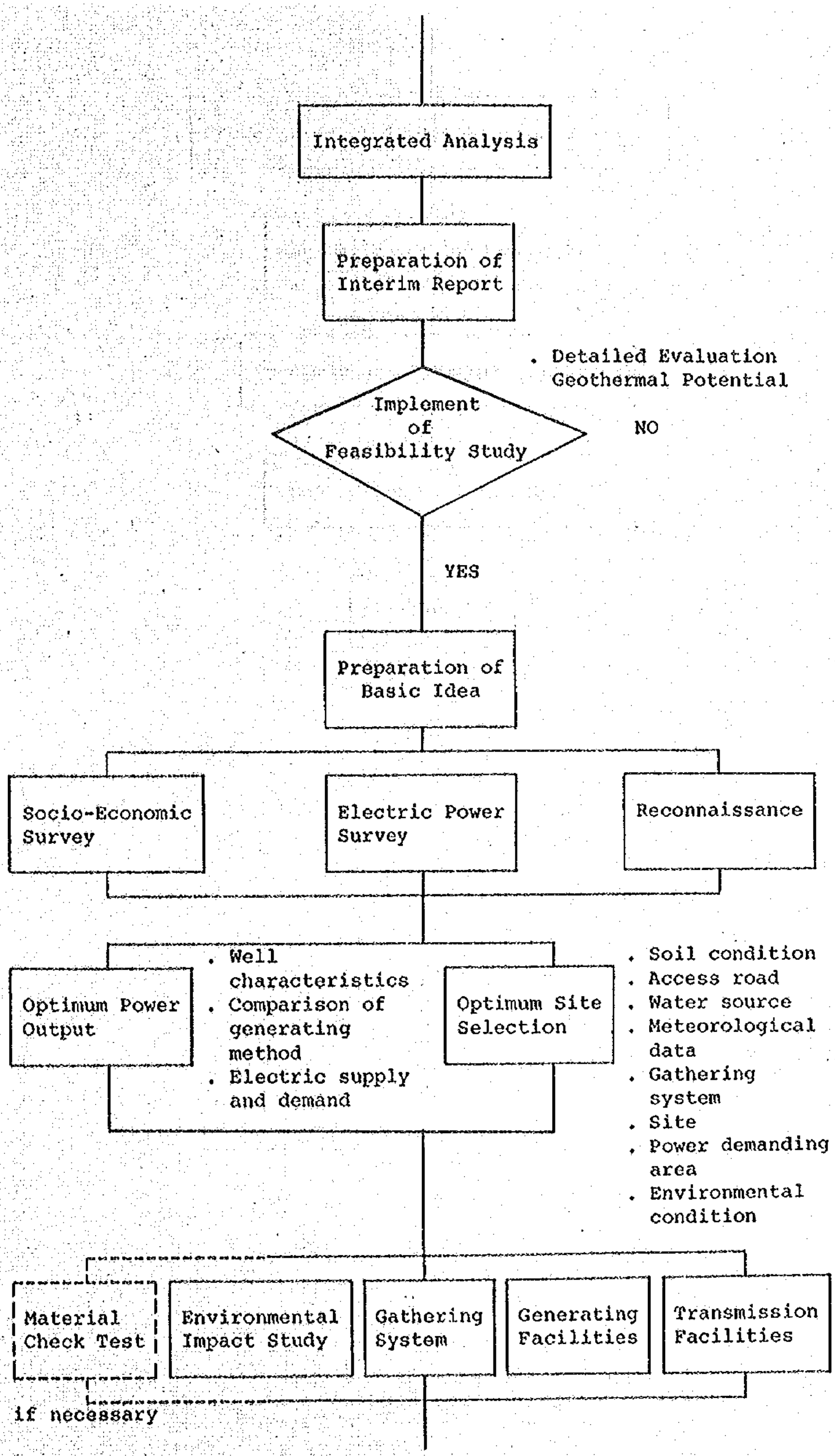
## 1.4 Procedure of the Project

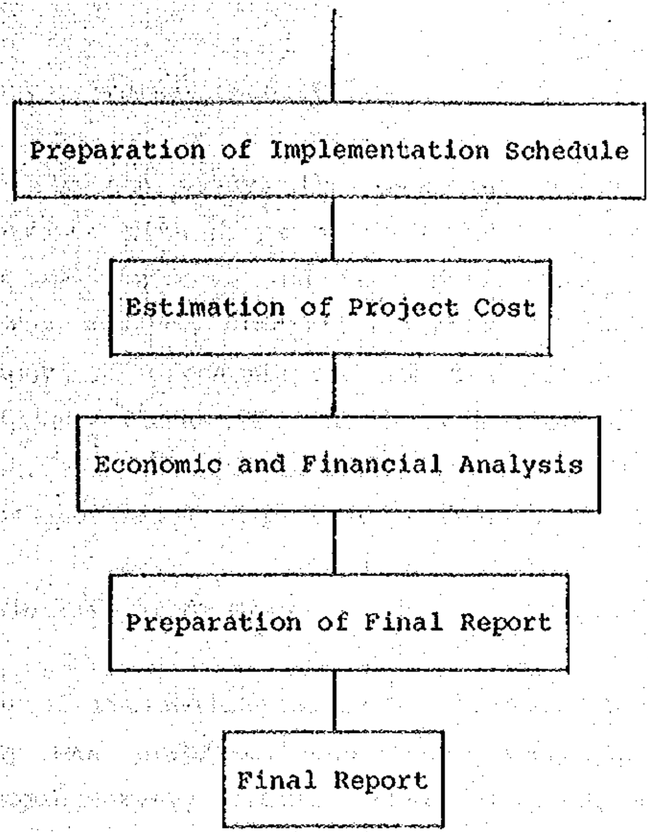
The Project was planned in accordance with the result of Lumpur Geothermal Project (1981 - 1983, by Japan International Cooperation Agency and Volcanological Survey of Indonesia), and proceeded step by step in accordance with the Flow Chart of the Study (Fig. 2-1) which was formulated to evaluate the exploitable potential of the Duabelas geothermal system in Kerinci geothermal field by supplementary surveys and drilling exploratory well, and then to implement a Feasibility Study to construct a portable packaged generating unit of 5 MW. Outlines of each stage are as follows;

Fig. 1-1 Flow Chart of the Study

Survey Flow for the Feasibility Study on Kerinci Geothermal Development Project




Integrated Analysis
Preparation of Interim Report
Implement of Feasibility Study
. Detailed Evaluation Geothermal Potential
NO
YES
Preparation of Basic Idea
Socio-Economic Survey
Electric Power Survey
Reconnaissance
Optimum Power Output
. Well characteristics
. Comparison of generating method
. Electric supply and demand
Optimum Site Selection
. Soil condition
. Access road
. Water source
. Meteorological data
. Gathering system
. Site
. Power demanding area
. Environmental condition
Material Check Test
Environmental Impact Study
Gathering System
Generating Facilities
Transmission Facilities
if necessary


Preparation of Implementation Schedule
Estimation of Project Cost
Economic and Financial Analysis
Preparation of Final Report
Final Report

1) Resource Evaluation Stage

Prior to the Study, the Inception Report was prepared in accordance with Scope of Work and by reviewing of existing data and reports, and then Evaluation of Characteristics Records of LP-1, Electrical survey, Supplementary survey for Geology and Geochemistry, and drilling of exploratory well LP-2 were conducted. As a result of Resource Evaluation Stage, it is concluded that Duabelas geothermal system has enough potential to proceed to Feasibility Study Stage.

2) Feasibility Study Stage

Prior to Feasibility Study Stage, Basic Idea of Feasibility Study was prepared, and then reconnaissance for Socio-Economic Survey, Electric Power Survey was conducted. Developing program and Economic/Financial evaluation of the Project were implemented.

It is concluded that the Project is not suitable to develop a conventional geothermal power plant such as 30 MW or 50 MW from points of electrical power demand of the Project area, and then the Project has difficulties from points of economic and financial view, however the development of portable package type power units is recommended in consideration of geographical and social conditions of the Project area.

## 1.5 Acknowledgement

JICA Team wish to express their sincere appreciation of the supports and assistance given by Mr. Soebadi M. SANYOTO, Director of Bureau of Foreign Cooperation, Dr. Adjat SUDRADJAT, Director of VSI, Ir. Mohd SINGGIH, Director of Planning of PLN, and Dr. Nengah SUDJA, Deputy Director of Planning of PLN.

The readiness to provide available data and information and the efficient cooperation given during the Study were very valuable. Without their supports and assistances, it were hardly possible to complement the Study successfully.

# Chapter 2. Geothermal Resource

# Chapter 2. Geothermal Resource

## 2.1 Geothermal Development in Indonesia

Indonesia is one of the world-famous volcanic countries, and almost half of these volcanoes bear evidence of geothermal activities, such as fumaroles and surface activities. Up to now, development of geothermal resource in Indonesia is divided into four stages.

1) First stage (Before World War II)

In 1926, scientific research on geothermal resource started at Kamojang field in West Java, and then at Dieng field in Central Java. Several exploratory wells were drilled at both areas, and one of these wells in Kamojang field is still producing dry steam.

2) Second stage (Between 1964 and 1974)

In 1964, Volcanological Mission of UNESCO visited Indonesia to reconnoiter the geothermal fields.

In 1968, French team sponsored by French government conducted preliminary survey and made recommendations of further investigation.

In 1970 - 1972, the United States Agency for International Development, with Geological Survey of Indonesia and Power Research Institute of PLN conducted preliminary survey in Sumatra, Java, Bali, Sulawesi, etc., and reported the high potential of Dieng field.

3) Third stage (Between 1974 and 1984)

In 1974, based on Presidential Decree, PERTAMINA was appointed to undertake exploration and development of steam fields, and PLN was appointed to generate power. Six fields, namely Kamojang, Banten, Cisolok, Dieng, Salak, in Java and Bali, were given the priority of exploration.

In 1975, the Kamojang Geothermal Project was started with New Zealand government fund and 41 wells were drilled and its installed capacity is 140 MW (30 MW x 1 unit, 55 MW x 2 units). PERTAMINA has drilled 11 production size exploratory wells at Dieng field.

In 1982, PLN started the survey for the site selection of power plant at Dieng field.

4) Fourth stage (up to 2000)

Preliminary inventories have been carried out by the Volcanological Survey of Indonesia (VSI) and Pertamina for: Nusatenggara, 9 areas; Mollucos, 4 areas; Bali, 1 area; Sumatera, 18 areas; Java, 29 areas; and Sulawesi, 16 areas. Geothermal resources that could be developed for electrical power generation between 1995 and the year 2000 are estimated to be 550 MW, especially from Dieng, Ijen (Java), Kotamobagu (Sulawesi), Bali, Flores (Nusatenggara), Kerinci and Souh (Sumatera). In line with the government energy diversification policy, the electric energy generated from geothermal resources is estimated to reach nearly 1,500 MW in the year 2000.

However, due to a shortage of funds, the development of several fields in Java will be carried out mainly through a Joint Operation and Energy Sales Contract with foreign contractors. Joint Operation and Energy Sales Contracts were made with Union Geothermal of Indonesia for Salak field in 1982, and Amoseas for Darajat field in 1984.

## 2.2 Resource Evaluation of Kerinci Geothermal Field

### 2.2.1 Geological Model

#### 1) Tectonics around the Sumatra Island

Indonesia is a world-famous volcanic country. The islands, from Sumatra to Sumba, constitute the island-arc system on the margin of the Southeast Asia plate, where the Indian Ocean plate is subducting. Around the Sumatra Island, a typical double island-arc system is observed as shown in Fig. 2-1. There is large-scale strike-slip fault, Great Sumatran fault, in the western part of the Sumatra Island. Quaternary volcanism is not recognized on the western side where Pre-Quaternary basement rocks (mainly Tertiary) crop out extensively. In the western part of the inner arc, a depression zone was resulted along the Great Sumatran fault by tectonic movement which began in Miocene and there became active Quaternary volcanism field. This is characteristic features of volcanic row in the tectonic field where the plate is subducted obliquely to the extending direction of trench. Judging from the above condition, there is a high geothermal potential in the depression zone, because it is considered that there is very active magmatism resulted from subduction of the Indian Ocean plate under the Southeast Asia plate in a deep part in the depression zone. The study area, Kerinci geothermal field, is just situated in this depression zone.

#### 2) Geology around Kerinci geothermal field

As shown in Fig. 2-2, the study field is covered widely by Quaternary volcanic rocks (Tua volcanic rocks, Raja volcanic rocks, and Kunjit volcanic rocks). Neogene acidic volcanic rocks and Pre-Neogene sedimentary rocks (mainly Mesozoic) crop out in the surrounding area. Therefore, these rocks are considered to be distributed widely under the Quaternary volcanic rocks in this field.

Kunjit lava of Kunjit volcanic rocks is formed as a dome and the age of this lava was deduced to be 0.06 x $10^6$ Year to 0.25 x $10^6$ Year from rock dating by fission track method. Especially, the lavas cropping out at the top of Mt. Kunjit (0.06 x $10^6$ Year) and at Mt. Setangis (0.07 x $10^6$ Year) are very young.

As shown in Fig. 2-3, NW-SE trending faults and NNE-SSW trending faults are significantly recognized in this field. The trend of the former is nearly same as that of the volcanic row composed of Mt. Raja, Mt. Kunjit, Mt. Sumbing and Mt. Masurai. The trend of the latter is nearly same as that of the Great Sumatran fault. Active geothermal manifestation and alteration zone are recognized along the Duabelas fault and the Sikai fault, of this trend.

### 3) Geothermal manifestation and alteration zone in Kerinci geothermal field

Geothermal manifestation is recognized at Grao Kunjit and Grao Sikai in the Sikai area and at Grao Duabelas, Grao Bujang, Grao Rasau, Grao Bulan and Abang hot spring in the Duabelas area. Grao Kunjit and Grao Sikai, in the Sikai are, are situated on the Sikai fault and there are active fumaroles which discharge considerable amount of steam and gas. Hydrothermal alteration zone is also recognized at Grao Sikai but its extent is relatively narrow, comparing the geothermal activity.

In the Duabelas area, geothermal manifestation is recognized mainly along the Duabelas fault, though Grao Bulan is not situated on the Duabelas fault. Hot water with temperature of about 60°C is flowing out at Abang hot spring but hydrothermal alteration zone is not recognized there. At Grao Duabelas, Grao Bujang and Grao Rasau, there are active fumaroles and boiling mud pools, accompanied with the alteration zone of relatively wide extent.

### 4) Geological model of Kerinci geothermal field

Kerinci geothermal field is situated in the depression zone of which western edge is limited by the Great Sumatran fault. This depression zone is considered to be resulted from subsidence of Pre-Neogene basement rocks, which began with the eruption of acidic volcanic rocks (Neogene system, cropping out in the surrounding area). This volcanic rocks accumulated thickly on the basement rocks.

Basic to neutral magma of high fluidity was extruded in the Quaternary. Tua volcanic rocks were resulted from this magma and covered widely Neogene system in the early to middle Pleistocene. Judging from the data of LP-1 and LP-2, thickness of Tua volcanic rocks in the Duabelas area is considered to be more than 1,000 m. In the middle to late Pleistocene, Raja volcanic rocks covered them.

Thereafter, composition of the magma became acidic one. Kunjit volcanic rocks were resulted from this acidic magma in the late Pleistocene. Mt. Kunjit, Mt. Setangis and other dome-shaped volcanos had been resulted from this volcanism. The remained magma after this volcanism is regarded to be the heat source of the geothermal system in this field.

For the geothermal system in this field, it is considered that NNE-SSW treading faults in the Duabelas area (Duabelas fault and the fault of f2 estimated from CSAMT survey) and the Sikai area (Sikai fault) are the most important geological structure; they are considered to control geothermal activity. And the Quaternary volcanic rocks in this field are relatively rich in joints and hydrothermal alteration is sometimes recognized along them. Therefore, it is considered that the joints are additional factor to control the geothermal activity in this field.

### 2.2.2 Model of Geothermal System

#### 1) Model of geothermal system

The model of geothermal system in the Kerinci geothermal system is prepared from the results of surface exploration data and exploratory well data (Fig. 2-3 and Fig. 2-4) and it is shown in Fig. 2-5, as a three-dimensional model.

There are two geothermal systems in the Kerinci geothermal field; the Duabelas geothermal system along the Duabelas fault and the Sikai geothermal system along the Sikai fault. The both systems are considered to be hydrothermal convection system resulted from water of meteoric origin and upflowing heat and gases from the remained acidic magma after the volcanism, from which Kunjit volcanic rocks were resulted. And the temperature of the magma is estimated to be about 500°C.

For the Duabelas geothermal system, recharge area of meteoric water is in the southeastward area of the Duabelas area. Recharged meteoric water is considered to flow toward the west or the northwest upon the Pre-Neogene basement rocks. The flowing meteoric water will be heated by conductive heat from the magma and change to neutral chloride type hot water by interaction with surrounding rocks. This hot water will contain upflowing gases from basement rocks and flow up along the Duabelas fault and the fault of f2. And this hot water is considered to be reserved mainly in a fracture zone along the faults. The data from LP-2 indicate that circulation time of water from the recharge area to the reservoir is more than 30 years. Temperature of this reservoir is estimated to be 200°C to 300°C. On the other hand, temperature of the basement rocks or around the heat source is estimated to be 330°C to 480°C in the Duabelas area. Solubility of silica increases with increasing temperature of solution until 320°C, but it decreases inversely with the increasing temperature in the condition of higher temperature than 320°C. Therefore, it is considered that silica deposition (silica sealing) occurs at the bottom of this reservoir, presumably near the boundary between the Neogene system and the Pre-Neogene basement rocks, and the deepest part of the reservoir is limited by this sealing zone because liquid phase cannot flow across this zone.

It is also considered that sealing zone is resulted from deposition of secondary minerals around the reservoir, near the top of the reservoir, due to the change of physical and chemical conditions by the effect of ground water. This sealing zone is regarded to be upper limit of the reservoir. Judging from the data of LP-2, the level of this upper limit is considered to be about 600 m in depth. According to chemical data of hot water from LP-1, it is considered that this sealing zone around LP-1 is not complete and hot water of relatively low temperature come into the reservoir from a shallower part. Moreover, it is considered that the northern limit and the southern limit in the lateral extent of the reservoir are respectively around LP-1 and around Grao Rasau, judging from the distribution of temperature estimated by geochemical thermometers, from distribution of alteration zones on the surface and from distribution of low resistivity zone detected by CSAMT survey.

The vapor-dominated zones reaching the fumaroles such as Grao Duabelas, Grao Bujang, and Grao Rasau are resulted by steam flowing up through sealing zone. Temperature of steam in the vapor-dominated zone is estimated to be 135°C to 160°C. A secondary acidic hot water is resulted near the ground surface from ground water heated by upflowing steam and oxidation of gases such as hydrogen sulphide upflowing together with steam. Especially, acid-sulfate water is induced around the fumaroles. Alteration near the surface is brought about by interaction of these secondary acidic hot water with surrounding rocks and by deposition of secondary minerals from the hot water. Alunite zone is produced around the fumaroles by the acid-sulfate water and kaolinite zone is produced around the alunite zone by acidic water. According to the data from

LP-2, this acidic water around LP-2 is considered to exist in the part shallower than 50 m. Temperature of acidic water decreases in lateral flowing and halloysite zone is produced around kaolinite zone. Moreover, acidic water changes to neutral one in lateral flowing by interaction with surrounding rocks and montmorillonite zone is produced around halloysite zone.

There is reservoir of neutral bicarbonate type water at a shallow level in the Duabelas area. This reservoir is considered to be the secondary one resulted from percolation of the upflowing steam from the deep reservoir into ground water aquifers. The hot water from this secondary reservoir flows out at Abang hot spring. Temperature of this secondary reservoir is estimated to be 145°C to 168°C, from silica content in the hot water from Abang hot spring.

For the Sikai geothermal system, although its detailed characteristics are not clear (for example, recharge area, circulation time of water and so on), because there is no well in the Sikai area and water sample from the deep water reservoir cannot be collected, nearly same condition of the geothermal system as that of the Duabelas geothermal system is considered from chemical composition of fumarolic gas. Meteoric water flowing upon the basement rocks is heated by conductive heat from the same heat source as that of the Duabelas geothermal system and changes to hot water of neutral chloride type by interaction with surrounding rocks. This hot water flows up along the Sikai fault and the deep water reservoir is resulted in a fracture zone along the fault. Geothermal gases upflowing from the basement rocks is considered to come into this reservoir. Gas isotope thermometer indicates higher temperature condition (more than 261°C) of the deep reservoir than that of the Duabelas geothermal system. It is considered that sealing zone is resulted around the top of the reservoir by deposition of secondary minerals. The top of the reservoir is considered to be at nearly same elevation as the top of the reservoir in the Duabelas area from the electrical survey data in the previous works. Judging from the distribution of alteration zone, it is considered that overlaying rocks above the reservoir are relatively poor in fractures and upflowing of steam along the fault occurs only at limited parts, at Grao Sikai and around Grao Kunjit. And there are vapor-dominated zones above the reservoir at Grao Sikai and around Grao Kunjit. Temperature of this zone is estimated to be about 224°C. Around Grao Kunjit, there is a secondary reservoir of acid-sulfate type near the surface. This secondary reservoir is resulted from ground water heated by upflowing steam from a deeper part and from oxidation of hydrogen sulphide upflowing together with steam. Temperature of this reservoir is about 100°C. Large-scale alteration around Grao Kunjit is considered to be resulted from this acidic hot water.

2) Promising prospect in the Kerinci geothermal field

There are two geothermal systems in this field, with nearly same characteristics. One is the Duabelas geothermal system along the Duabelas fault. The other is the Sikai geothermal system along the Sikai fault. In the both systems, there are deep water reservoirs of neutral chloride type and overlaying vapor-dominated zones. Judging from estimated reservoir temperature, it is deduced that the deep reservoirs in the both systems have enough potential for geothermal development. Moreover, identified quality of the geothermal fluid from LP-1 and LP-2 is available for power generation; considerably low concentration of noncondensable gas and not serious scale problem. Therefore, the main target for the geothermal development in this field is the deep water reservoirs of neutral chloride type in the Duabelas area and the Sikai area. Although the vapor-dominated zone in the Duabelas area is not available for geothermal development because of low potential (temperature is considered to be 135°C to 160°C), the vapor-dominated zone in the Sikai area has relatively high potential (estimated temperature is about 224°C). Therefore, the vapor-dominated zone can be regarded as an additional target for geothermal development in the Sikai area.

From some exploratory data, it is considered that the deep water reservoir exists along the Duabelas fault between around Grao Duabelas and Grao Rasau and along the fault of f2 from around Grao Duabelas to the valley between Grao Bujang and Grao Rasau, in the Duabelas area. And in the Sikai area, the reservoir is considered to exist along the Sikai fault, at least from Grao Sikai to Grao Kunjit. The existence of the reservoir along the Duabelas fault is already confirmed by LP-1 and LP-2, though those along the fault of f2 and along the Sikai fault are not yet confirmed by the drilling of exploratory well. Therefore, promising areas in this field are summarized as shown in Fig. 2-6. The most promising area is in the Duabelas area and along the Duabelas fault, because it is already confirmed by the exploratory wells. Its northern limit is around Grao Duabelas and the southern limit is around Grao Rasau. And it is considered that the top of the reservoir is at the elevation of about 800 m and its bottom is at the level of boundary between the Pre-Neogene basement rocks and the Neogene system. In the Duabelas area, there is also promising area on the eastern side of the above promising area. This area is along the fault of f2, but it is not yet confirmed. Although the bottom of the reservoir is also considered to be at the level of the boundary between the basement rocks and the Neogene system, its top is considered to be at a lower level than that along the Duabelas fault. In the Sikai area, although it is not yet confirmed, the area from Grao Sikai to Grao Kunjit, along the Sikai fault, is considered to be promising. The top of the reservoir is considered to be at about 800 m in elevation and its bottom is around the boundary between the basement rocks and the Neogene system. In this promising area, it can be expected that there is production zone (vapor-dominated zone, mentioned before) above the deep water reservoir.

### 2.2.3 Evaluation of Geothermal Resource

The objective of geothermal resource evaluation is to estimate the possible resource from the quantity of heat and fluid stored in geothermal reservoir. The data obtained from LP-1 and LP-2 drilled in the Duabelas geothermal system are not enough to evaluate the structure and physical characteristics of geothermal reservoir. Consequently, the Volume method and the Simulation method using Lumped Parameter Model were applied for the evaluation of this field.

1) Resource evaluation by Volume method

The Volume method is convenient and is usually adopted at the beginning stage of geothermal development.

The promising reservoir for geothermal development in the Duabelas geothermal system was synthetically discussed from the results of geological survey, geochemical survey and electrical survey. Consequently the area and the thickness of promising geothermal reservoir was inferred to be 2 km$^2$ (1 km x 2 km) and 800 meters (the center of reservoir is 1,000 meters above sea level), respectively as shown in Fig. 2-5 and Fig. 2-6.

The temperature, rock density and porosity of geothermal reservoir were inferred as shown in the following by the measurement of homogenization temperature of fluid inclusion, geochemical thermometer, core analysis and well logging.

| | | |
|---|---|---|
| Geothermal reservoir temperature | : | 224°C |
| Rock density | : | 2,500 kg/m$^3$ |
| Hot water density | : | 850 kg/m$^3$ |
| Porosity | : | 10 % |

The heat capacity of rock and water including in the eq. (1) became about 2,400 kJ/kg°C assuming the volumetric heat capacity of rock and water to be 900 J/kg°C and 4,600 J/kg°C, respectively. The recoverable resource (heat energy) is assumed as $2.0 \times 10^{14}$ (kJ).

In case of utilize the steam for generation the recovery efficiency of energy recovered from production steam, which means the rate between the produced steam energy and the produced fluid energy, and the conversion efficiency of recovered heat energy to electric power must be considered.

In case of separating the hot water of 1 ton with the enthalpy of 230 kcal/kg (224°C) at the wellhead pressure of 5.2 ata, which was inferred as the optimum turbine inlet pressure, only the steam of 0.15 ton with the enthalpy of 656 kcal/kg contribute to the generation of electric power because the quality of steam at the wellhead is 0.15. Accordingly the recovery efficiency becomes 0.43.

The conversion efficiency depends on the system of electric power generation. In case of using the non-condensing turbine with the inlet pressure of 5.2 ata, the outlet pressure of 1.1 ata and total generation efficiency of 0.8, the rate between the heat energy contributing to the generation of electric power and that of the steam of 1 ton (conversion efficiency) is 0.077. Further the conversion efficiency in case of using the condensing turbine with the inlet pressure of 5.2 ata, the outlet pressure of 0.1 ata and total generation efficiency of 0.8 is 0.172.

Consequently the recoverable heat energy to contribute to the generation of power supply in non-condensing turbine system is as follows.

$$
\begin{aligned}
2.0 \times 10^{14} \text{ (kJ)} \times 0.43 \times 0.077 &= 6.62 \times 10^{12} \text{ (kJ)} \\
&= 1.58 \times 10^{12} \text{ (kcal)}
\end{aligned}
$$

Further, the recoverable heat energy in condensing turbine system is 3.54 x $10^{12}$ (kcal).

Accordingly the possible operation period for 5 MW in non-condensing turbine system and condensing turbine system becomes 42 years and 94 years, respectively.

The heat supplied from reinjection water, the outer side and the bottom of promising reservoir for development are out of consideration in this method. Therefore, the inferred operation period may be prolonged.

2) Resource evaluation by Simulation with Lumped Parameter Model

a. Equations

The change of pressure and temperature in geothermal reservoir can be calculated using the Mass Balance equation and Energy Balance equation.

Once the geothermal fluid produces, the reservoir pressure decreases gradually, and the hot water stored outside the reservoir boundary is recharged into the reservoir in accordance with the pressure gradient at the boundary.

Though the area and height of the promising reservoir in the Duabelas geothermal system was inferred to be 2 $km^2$ (1 km x 2 km) and 800 meters, respectively, the cylindrical reservoir model with the same volume with the real reservoir is applied to this simulation.

b. Model and condition for simulation

The reservoir model and condition necessary for simulation were assumed as mentioned below.

### Reservoir model

1) Reservoir radius : 800 meters
2) Reservoir thickness : 800 meters
3) Reservoir temperature : 224°C
4) Reservoir pressure : 48.5 ata (at 400 meters above sea level)
5) Reservoir permeability : 5 md - 10 md

### Condition for calculation

1) Power output : 5 MW
2) Turbine type : non-condensing turbine
3) Initial production flow : Steam flow 85 ton/hour
Water flow 475 ton/hour
4) Initial reinjection flow : 475 ton/hour

The reservoir permeability calculated from the permeability-thickness product of 16 darcy m measured in well LP-2 is 20 md assuming the reservoir thickness of 800 meters. This value is largely effected by the sectional lost circulation zone with large permeability and is not average permeability of reservoir. Consequently, the average permeability of reservoir was assumed to be 5 md to 10 md.

Though the turbine type for generation will be discussed in detail at the step of the engineering feasibility study, the non-condensing turbine type was adopted as this simulation condition for severe evaluation. Because the steam flow rate necessary to keep the this power output in non-condensing turbine is larger than that in condensing turbine.

The steam and hot water flow rate necessary for the power output of 5 MW in non-condensing turbine system were estimated from the actual production flow rate from LP-2.

c. Calculation results

The results calculated by above conditions are shown in Fig. 2-7 and Fig. 2-8. These figures shows the results with and without the reinjection condition, respectively. Further the calculation results in case of the permeability of 1 md in addition to 5 md and 10 md is also shown.

In case of reinjection condition, the drop of reservoir pressure becomes bigger according as the reserver permeability is smaller. Though the hasty pressure drop in the reservoir with the permeability of 5 md and 10 md occurs in the initial five years, the reservoir pressure on and after ten years is almost stable. The reservoir temperature changes in unrelation to the reservoir permeability and decreases in accordance with the elapsed time. This drop of reservoir temperature is cased by much more reinjection water flow than the recharging water flow.

In case of no reinjection the change of reservoir pressure shows that the fluid in the reservoir with the permeability of 1 md and 5 md becomes to be two phase state of steam and hot water and the fluid in the reservoir with the permeability of 10 md maintain the hot water state. The change of the fluid pressure in the reservoir with the permeability of 10 md is large even after 30 years elapsed. This indicates that the recharging flow rate is smaller than the production flow rate. The reservoir temperature is almost stable because of no reinjection. A little drop of the fluid temperature in the reservoir with the permeability of 1 md as revealed in Fig. 2-8 is caused by the change of saturation pressure in the two phase state.

The evaluation of possible power output needs to judge whether the production from the well is possible or impossible in accordance with the change of reservoir pressure and temperature. The production flow rate from well depends on not only the reservoir temperature and pressure but also the permeability of lost circulation zone, the diameter of casing and the well depth and so on. Consequently it is difficult to determine the minimum reservoir temperature and pressure necessary to produce the geothermal fluid from well generally. Therefore, the only minimum reservoir temperature necessary for production was assumed to be 200°C based on the experience. (In fact this temperature depends on the pressure.)

Though the reservoir temperature in case of no reinjection hardly changes, the pressure drawdown even in the reservoir with the permeability of 10 md is 17 at and is large. Therefore, it is predicted that the number of production well necessary to keep the constant power output becomes large even if the production is possible. Because the production flow rate per one well becomes small. Accordingly the execution of reinjection is desirable for the long utilization and the cultivation of reservoir.

The reservoir temperature in case of reinjection becomes 200°C at 38 years later. At this time the production is considered to be possible because of the low pressure drawdown; for example pressure drop in the reservoir with the permeability of 5 md and 10 md is 6 kg/cm$^2$ and 4 kg/cm$^2$, respectively. Accordingly the possible operation period with reinjection and non-condensing turbine system for 5 MW is inferred to be about 40 years.

The steam and hot water flow rate necessary for generating 5 MW in the condensing turbine system is about 45 percents of that in the non-condensing turbine system. In addition, the drop speed of reservoir temperature in the condensing turbine system is considered to change in accordance with the rate of reinjection flow rate. Therefore, the possible operation period with reinjection and condensing turbine system for 5 MW is inferred to be about 90 years.

### 3) Inference of possible operation period

As the results of analysis by the Volume method and the simulation method with the Lumped Parameter Model, the possible operation period in case of non-condensing turbine system for the power output of 5 MW was estimated to be 42 years by the Volume method and about 40 years by the simulation method. Further the possible operation period in case of condensing turbine system was estimated to be 94 years by the Volume method and about 90 years by the simulation method. As above mentioned the possible operation period estimated by two kinds of analysis method is almost same to each turbine system. Accordingly the possible operation period in case of non-condensing turbine system and condensing turbine system with reinjection was inferred to be about 40 years and 90 years, respectively.

These analysis methods include many unknown factors; for example the development area and depth, porosity, reservoir temperature and the possibility of fluid production and so on.

The Volume method takes no account of the heat supply of reinjection water and recharging hot water, and that from the side boundary and the bottom of reservoir. Therefore, the inferred power output or operation period is inferred to be prolonged.

The simulation method with the Lumped Parameter Model also takes no account of the heat supply from the bottom of reservoir. Consequently the possible operation period in this method is inferred to be also prolonged. Accordingly the estimated operation period by these method is considered to be minimum.

Therefore, this estimated operation time should be reconsidered as the reservoir model and reservoir characteristics becomes more clear by new survey.

## 2.3 Development of Kerinci Geothermal Field

Development of Sikai geothermal system and Duabelas geothermal systems, which are evaluated as equivalently promising from view points of surface manifestation and surface exploration data, is planned as follows.

1) Duabelas geothermal system is confirmed by exploratory wells LP-1 and LP-2 and is supposed to extend from LP-1 to Grao Rasau. Its potential is evaluated as feasible to develop maximum 5 MW. Therefore, developing program is planned from LP-2 to Grao Rasau gradually in accordance with the power demand of the Project area.

   Topographical conditions around Sikai geothermal system is very steep, and no exploratory wells are drilled. Developing program of this system will be studied after the evaluation of the reservoir potential. Therefore it is recommended to construct an access road to approach to Sikai geothermal system, carry out supplementary explorations and to drill exploratory wells.

2) Development program of Duabelas geothermal system is divided into three steps.

   The first step is to utilize the steam discharging from LP-2. LP-2 has been discharging geothermal fluid since February 1988 and its well characteristics are as follows, namely steam flow rate 6 ton/hour, hot water flow rate 35 ton/hour at well head pressure 5.9 atg, and its potential is estimated as 370 kW by using back pressure type turbine.

   The second step is to drill production wells and to construct power plants to supply power for the present power demand of Project area. Considering power situations of the project area, generating capacity of the second step will be about 2,000 kW by using back pressure type turbine. Steam flow rate from production well is estimated as 4 - 5 times of LP-2.

If next wells are production well size, the steam flow rate from one production well will be equivalent to 1,000 kW output or more by using back pressure turbine, and therefore 2 production wells should be drilled for the second step.

The existing access road to drill LP-2 is too steep to carry in heavy equipment such as drilling machine for production size well, and generating facilities. New access road should be prepared in the second step program. Production wells should be drilled at the southward from LP-2 in order.

The third step is to develop for the future power demand. If the power demand of the Project area is increased in future, the Duabelas geothermal system can be developed to generate further 2,000 kW, however, the locations of projection wells (LP-5, -6...) will be studied by the comprehensive analysis of existing exploration data and drilling data of LP-3 and LP-4.

Separated hot water will be discharged to Grao Duabelas or will be reinjected to LP-1 which was discharging geothermal fluid until May 1988. If the reinjecting capacity is not enough for the flow rate of separated hot water, additional reinjection wells should be drilled around LP-1.

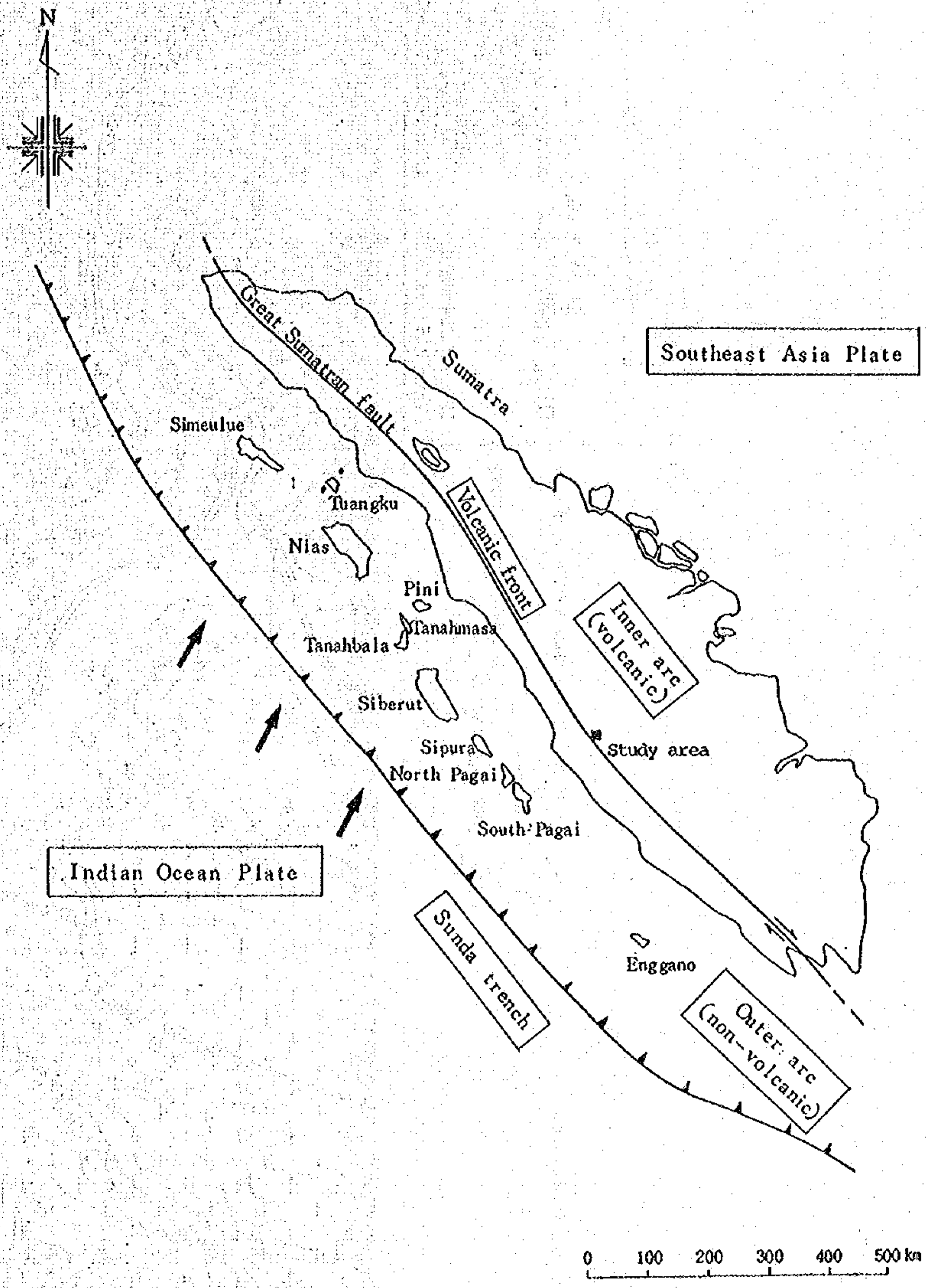


Fig. 2 - 1 Tectonics around the Sumatra Island

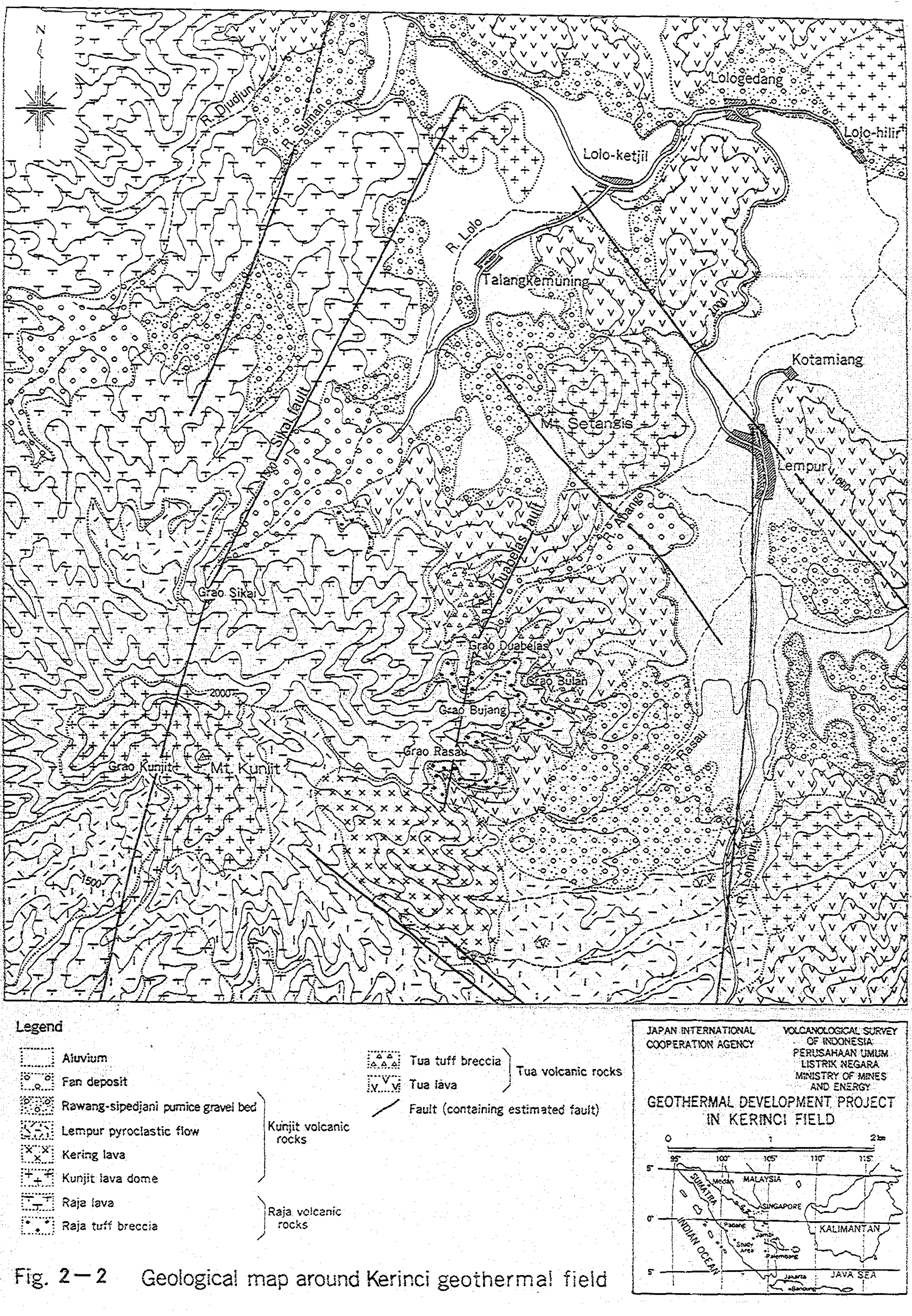
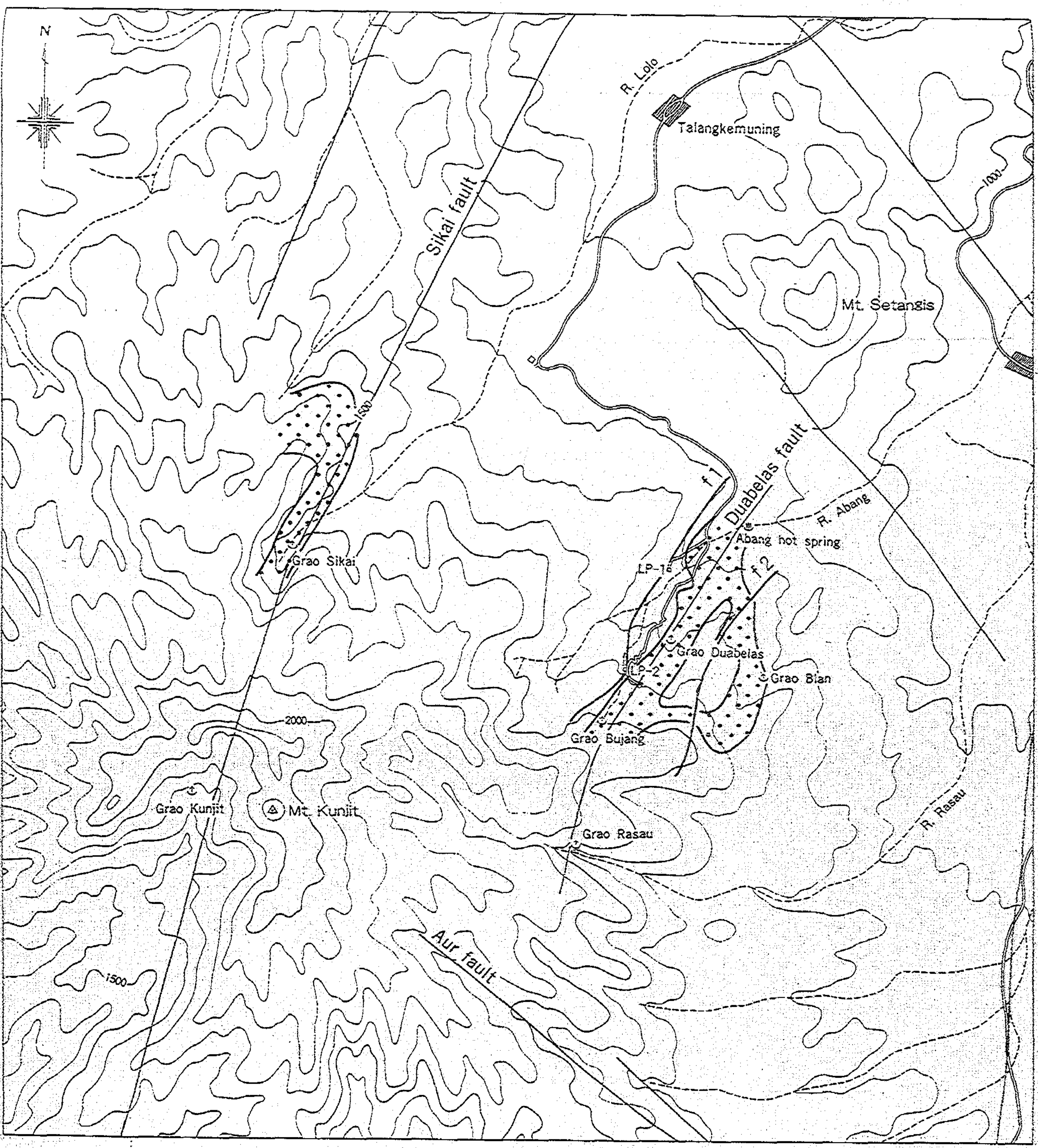


Fig. 2—2 Geological map around Kerinci geothermal field



Legend

- Fault
- Electrical discontinuity
- High concentration area of Hg and $CO_2$ in soil air

Fig. 2—3 Detected structural discontinuity

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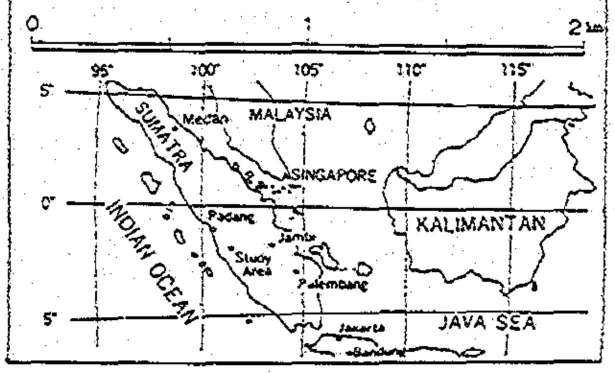
IN KERINCI FIELD



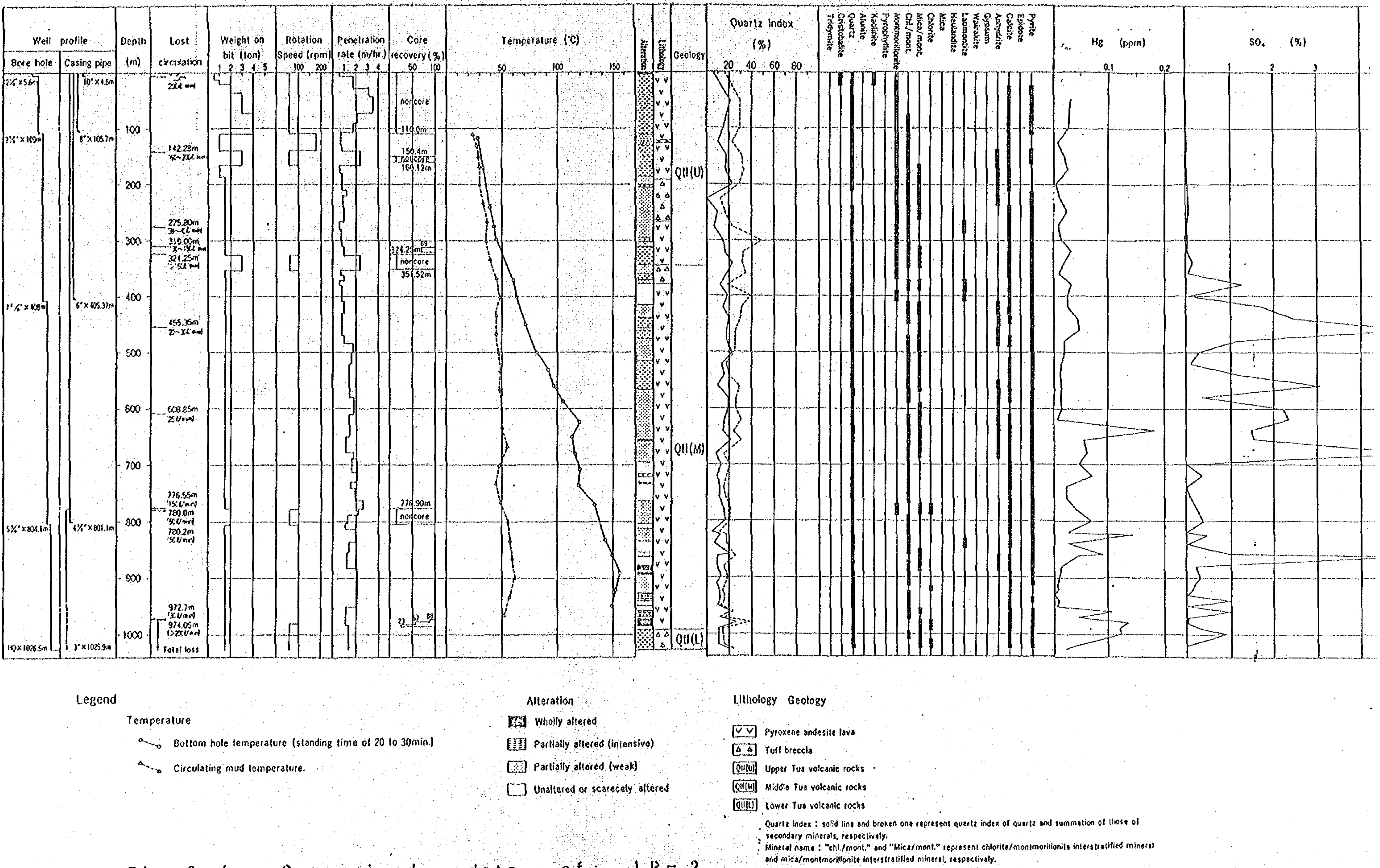
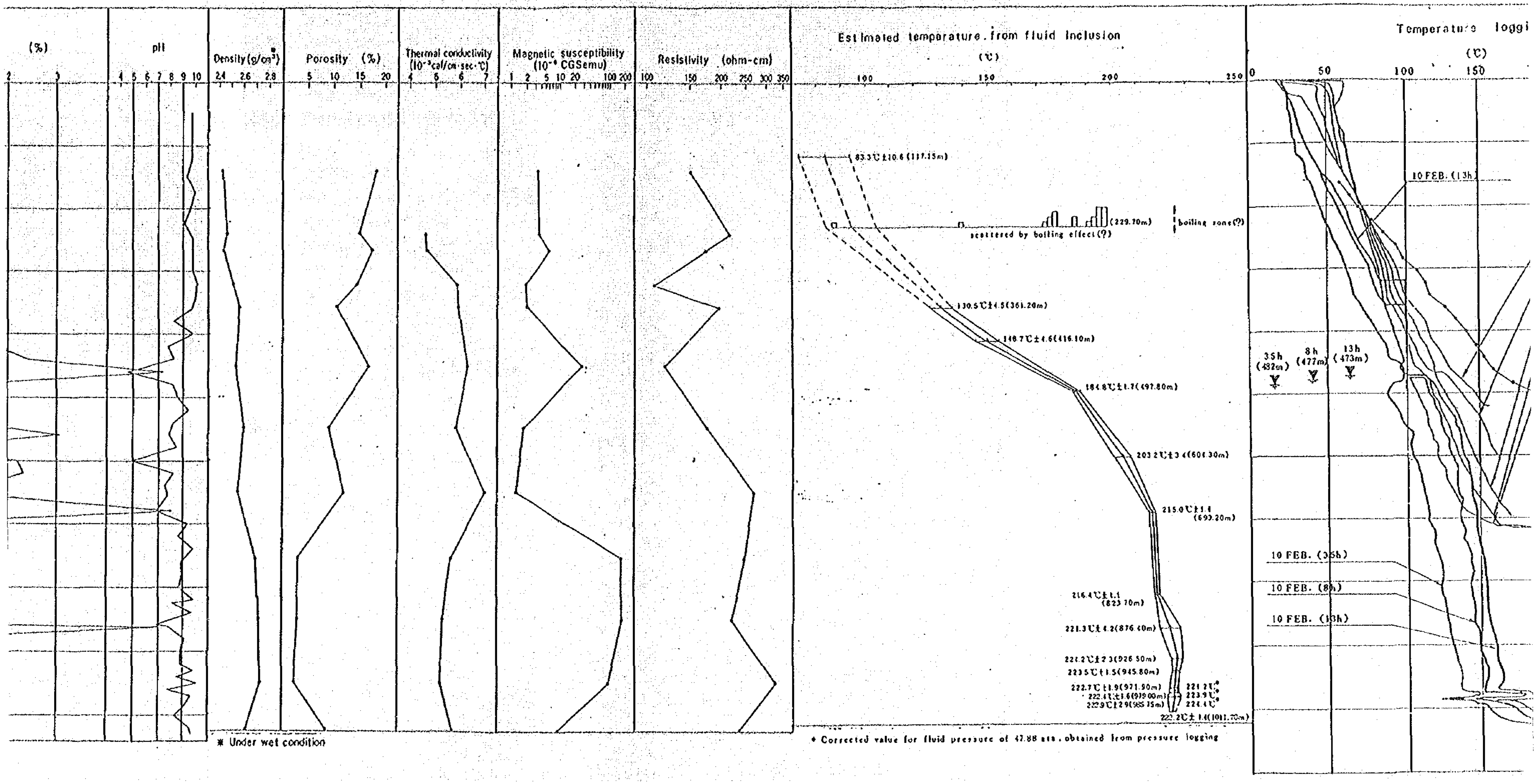
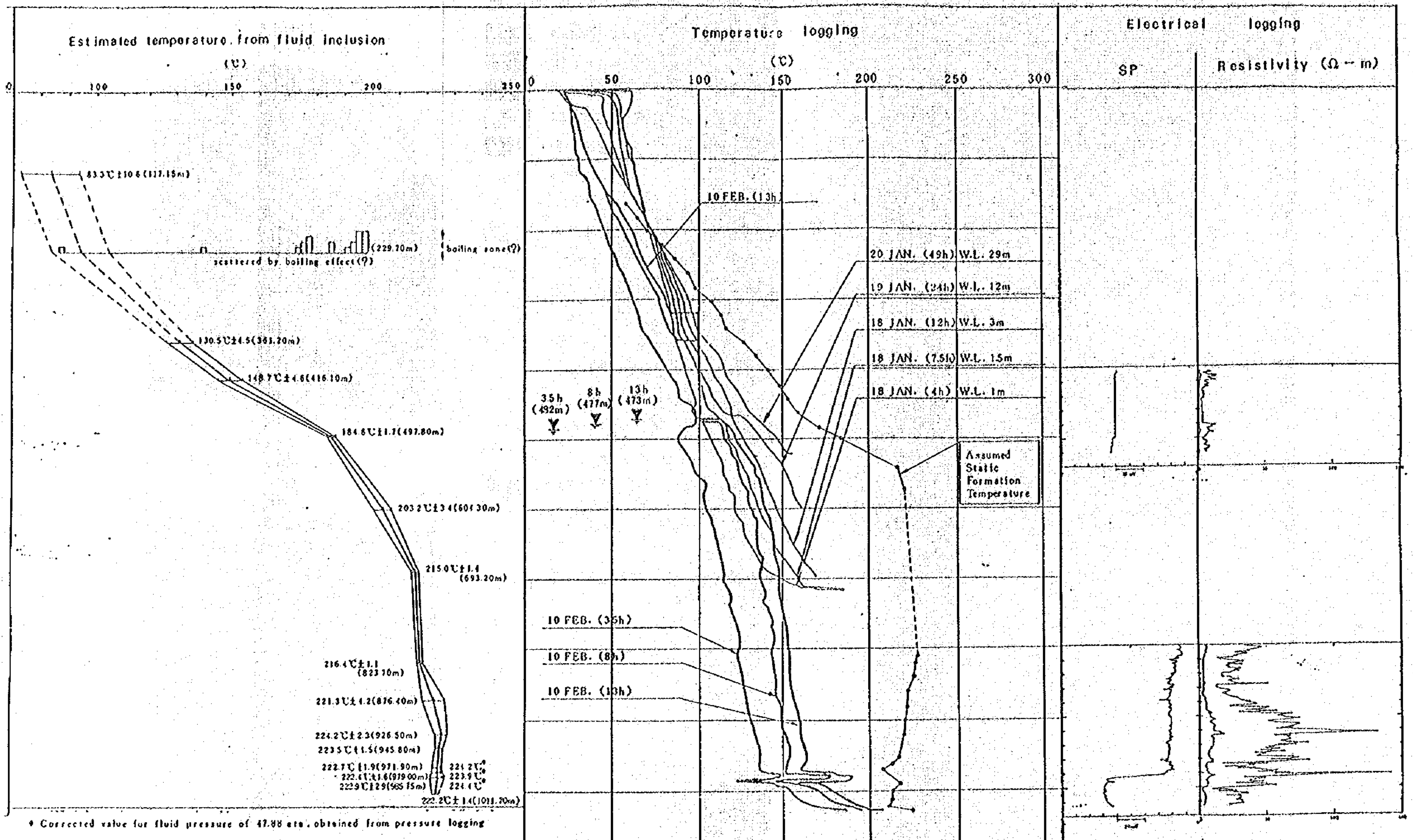


Fig. 2-4 Summarized data of LP-2



* Under wet condition

* Corrected value for fluid pressure of 47.88 ata, obtained from pressure logging



* Corrected value for fluid pressure of 47.88 ata. obtained from pressure logging

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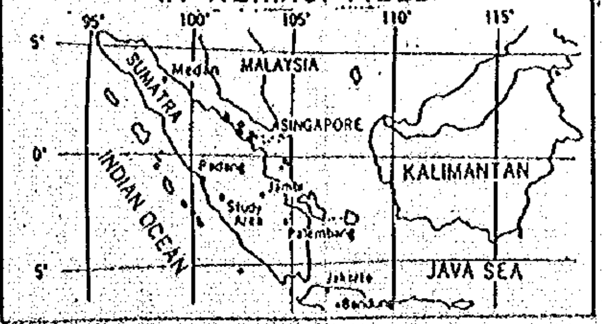


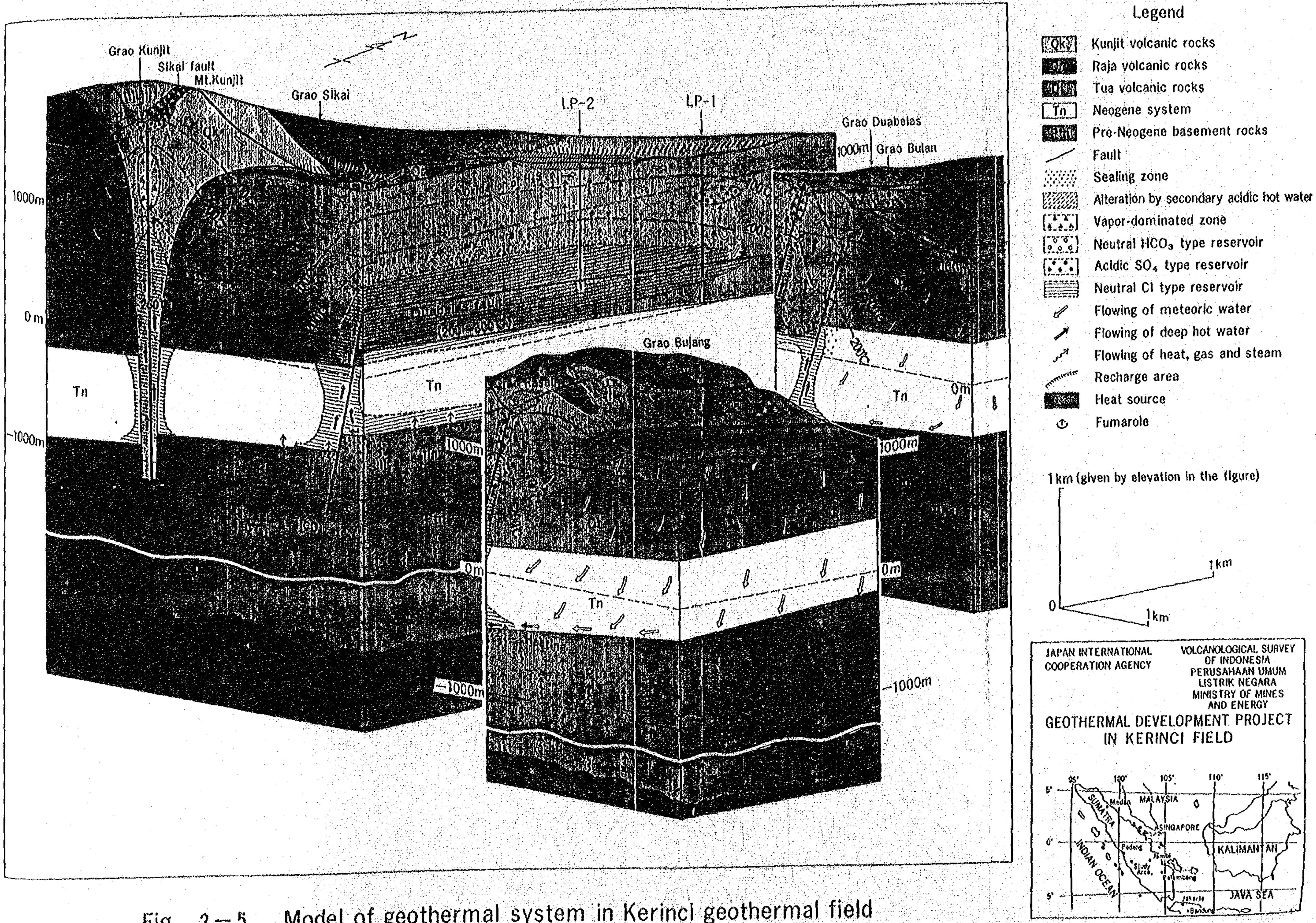


Fig. 2-5 Model of geothermal system in Kerinci geothermal field

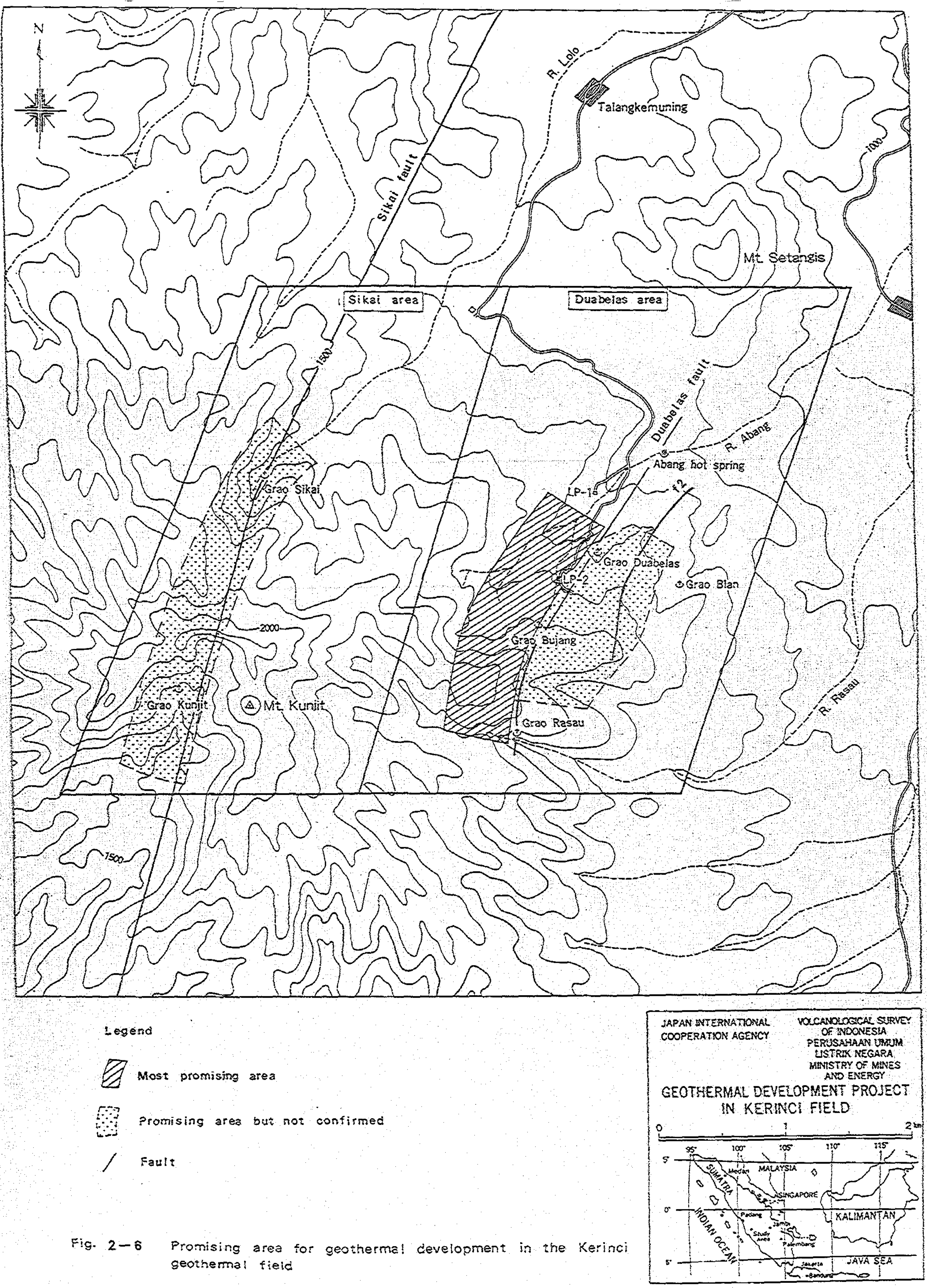


Fig. 2-6 Promising area for geothermal development in the Kerinci geothermal field

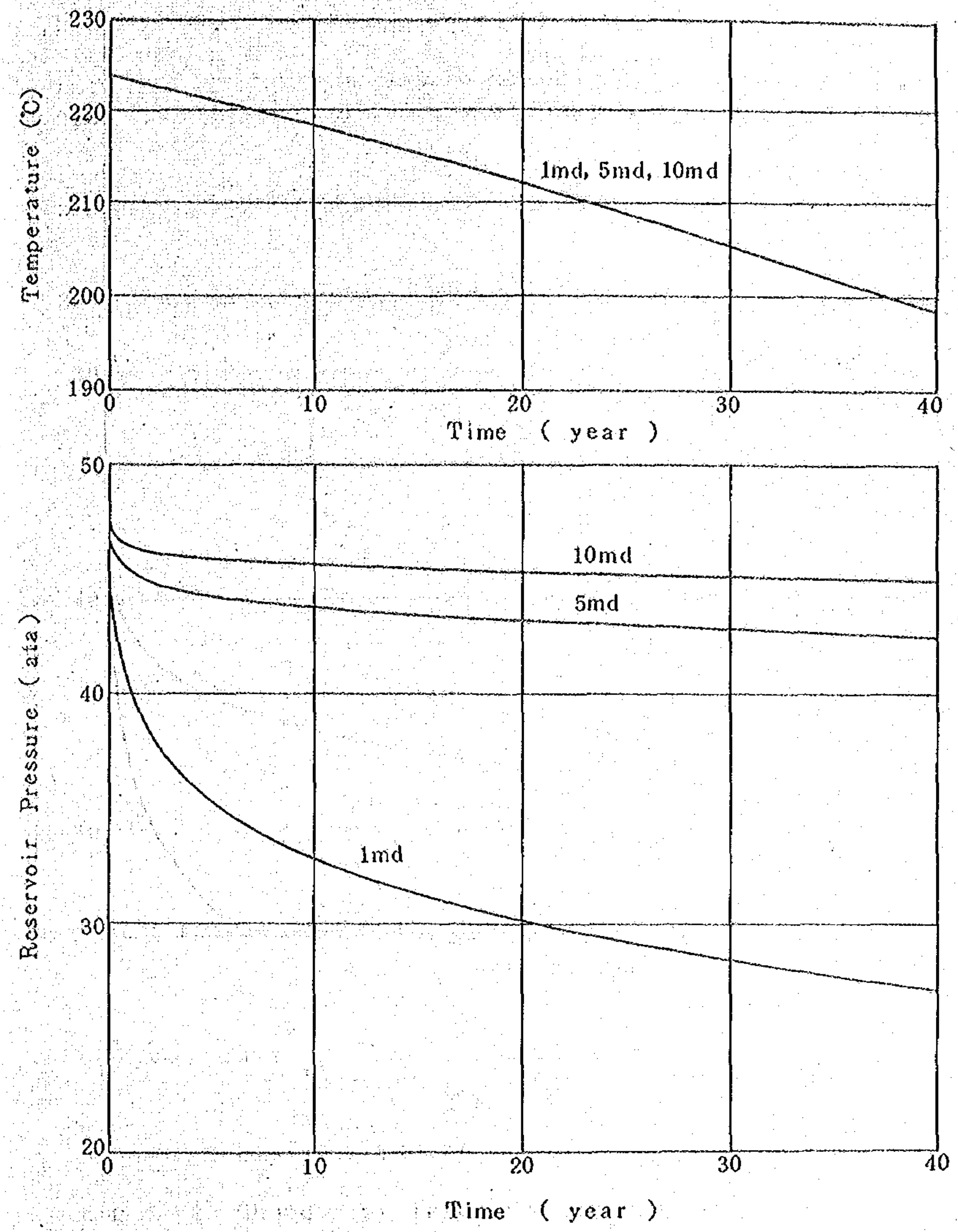


Fig. 2-7 Change of reservoir pressure and temperature in case of reinjection

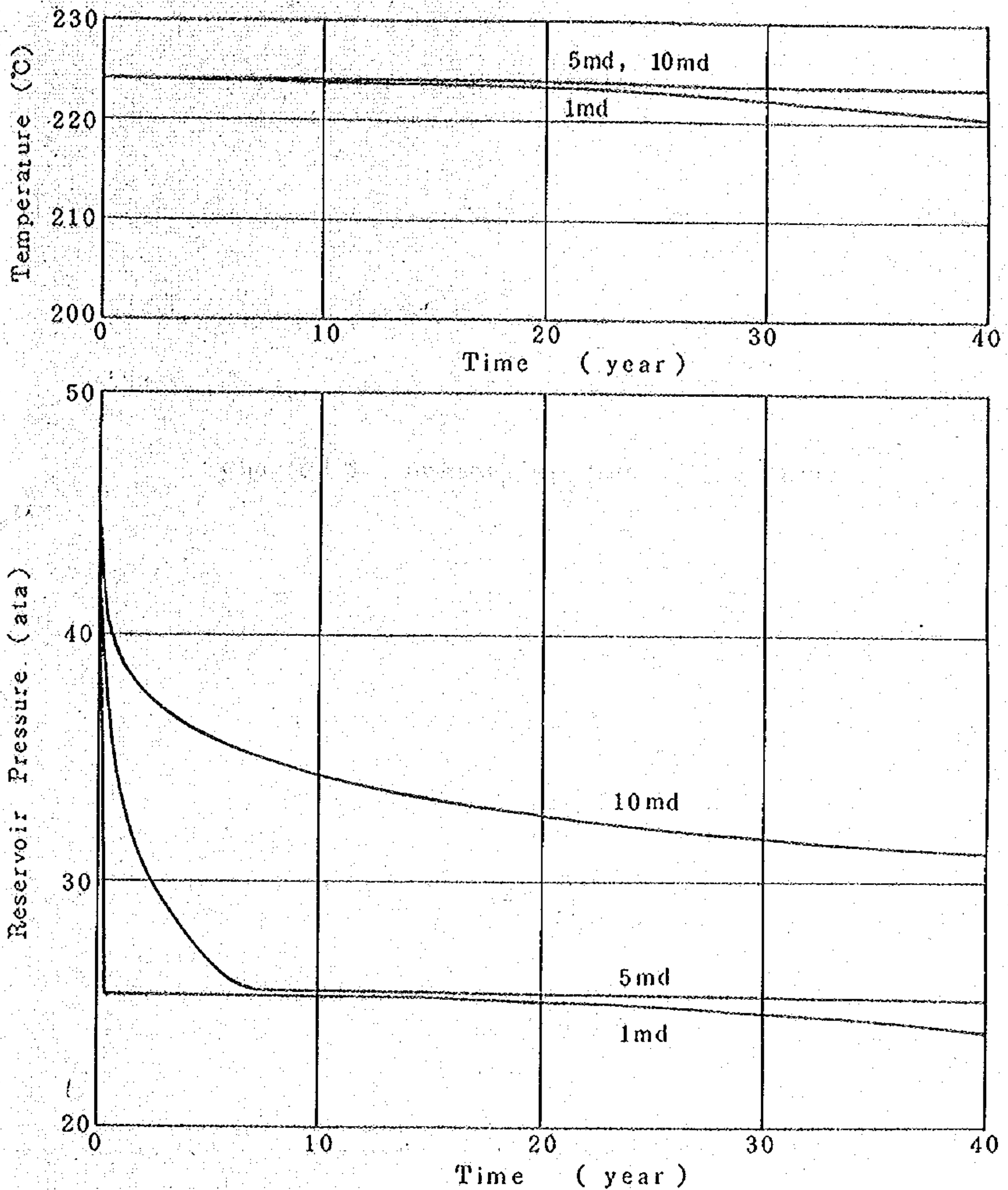


Fig. 2-8 Change of reserroir pressure and temperature in case of no reinjection

# Chapter 3. Summary of Feasibility Study

# Chapter 3. Summary of Feasibility Study

## 3.1 Electric Power Situation in The Project Area

### 3.1.1 Project Area

The proposed site for the geothermal power plant of this Project is located at approximately 7 km southwest of Desa (Village) Lempur, Kecamatan (Sub-regency) Gunung Raya, Kabupaten (Regency) Kerinci, Propinsi (Province) Jambi in Sumatra. The site is at the elevation of about 1,400 m above sea level, and is located at about 40 km to the south-east of Sungai Penuh, the main city of Kerinci Regency, and at about 320 km to the south-east of Padang City.

Kerinci Regency is in Jambi Province administratively, but is included under Padang Branch (Wilayah III) of PLN which is responsible for electric power supply over West Sumatra Province.

The electric power supply in Kerinci Regency is in the charge of PLN Ranting (Sub-branch) Sungai Penuh, and the electric power generated by geothermal power in this Project will be distributed by 20 kV high-voltage distribution lines to the consumers in Kerinci Regency.

The existing power sources and distribution systems are as shown in Fig. 3-1.

Although Sungai Penuh City and vicinity are covered with the high-voltage distribution lines, the other areas are supplied locally by isolated diesel power plants. These isolated distribution systems will be interconnected with the Sungai Penuh System one by one in the near future. In this connection, in this Project, the demand forecast and the power sources development program are prepared for the whole area of Kerinci Regency.

### 3.1.2 Existing Power Generating Facilities

Most of the power generating facilities in Kerinci Regency are owned by PLN, excepting the captive power plant (2,065 kVA) of the State Tea Factory and small power plants in remote countrysides. The latter power plants will be absorbed by PLN as its power sources and distribution lines are expanded.

The existing PLN-owned power generating facilities are shown in Table 3-1. The generating facilities are mostly diesel-engine power plants put into operation after 1986, but judging from the conditions of the facilities and the efficiencies, some of the facilities seem to have been relocated from other power plants.

In addition to the existing power plants tabulated in the foregoing, PLN has a plan to add 2.5 MW x 2 diesel power generating units in the premises of Koto Lolo Power Plant in 1989/1990 by British financing.

Operating situations of the existing power plants are as follows.

| | |
|---|---|
| In Sungai Penuh power system: | 24 hour operation |
| In other areas : | 12 hour operation<br>from 6 p.m. or 7 p.m.<br>to 6 a.m. or 7 a.m. |

The daily load curve on June 5, 1988 in Sungai Penuh power system is shown in Fig. 3-2. The maximum load of 2,610 kW and the minimum load of 610 kW were recorded around 7 p.m. and 3 p.m., respectively.

### 3.1.3 Power Distribution Facilities

The existing power distribution facilities in Kerinci Regency as of March 1987 consisted of 51,674 m circuit length of high-voltage distribution lines, 81,639 m of low-voltage distribution lines, and pole transformers of 4,515 kVA of total capacity.

In addition, diesel generating facilities and related distribution facilities were installed at Kersik Tuo, Sanggaran Agung and Tamiai after March 1987.

Padang Branch of PLN has a plan to add 51.8 km of 20 kV high voltage distribution lines, 36.9 km of 220 V distribution lines and 100 kVA x 21 and 150 kVA x 7 pole transformers in Kerinci Regency in 1988 through 1989.

Figure 3-1 shows the power system in Kerinci Regency as of August 1988. The broken lines show the 20 kV distribution lines, and it is seen that the distribution system is formed around Sungai Penuh. The isolated systems will gradually be interconnected with the Sungai Penuh system as the above-mentioned extension program progresses.

### 3.1.4 Demand Forecast

The demand forecast for this Project was prepared by categories of residential, commercial, public & others, and industry by the Planning Department of PLN, based on the past records of demand in PLN Sungai Penuh Sub-branch.

The demand forecast prepared in September 1988 is given in Table 3-2. This demand forecast is a long-range forecast covering 1988 through 2000, and shows that the energy consumption at the customer end will increase about four times from 6,043.7 MWh in 1987 to 24,385.2 MWh in 2000, and the required generation from 10,430.5 MWh to 31,669.0 MWh, or about 3 times, and the peak load is estimated to increase from 2,950 kW to 8,407.4 kW, or about 2.85 times.

The demand forecast will be reviewed and revised every year based on the actual records, but the electric power sources development program described in the following section is based on the demand forecast given in Table 3-2.

### 3.1.5 Demand and Supply Balance

#### 1) Necessity of New Power Sources

As seen in Fig. 3-3 Demand and Supply Balance, it will be up to 1994 that the available capacity, with the maintenance shutdowns and failures taken into consideration, of the existing power plants and 2.5 MW x 2 diesel units to be added at Koto Lolo Power Plant can meet the increasing demand. In other words, the new power source must be added by 1994.

#### 2) Construction of Geothermal Power Plant

Approximately 5,000 kW of geothermal resources are confirmed in the Project Site on the basis of geothermal resource study, and it would be appropriate to build the geothermal power plant which utilizes the indigenous geothermal energy effectively to save the petroleum.

From the geothermal potential of the Project Site, an output of 5,000 kW can be expected, but in view of the advisability of operating the geothermal power plant as the base load supplying plant, it is planned that 350 kW x 1 and 1,000 kW x 2 units, or a total of 2,350 kW, of geothermal power plant will be built, in consideration of the load conditions in Kerinci Area.

#### 3) Demand and Supply Balance

When the 350 kW x 1 and 1,000 kW x 2 geothermal power plant is built in 1993, the demand and supply balance will be as shown in Fig. 3-3, and the demand up to 1998 will be met in the available capacity and up to 2000 in the dependable capacity.

## 3.2 Power Development Plan

### 3.2.1 Plant Cycle and Optimum Unit Capacity

The back pressure turbine cycle that has the advantage of simple system formation, easy operation and less initial investment is adopted.

The unit capacities of the plant generating facilities are planned as follows.

- No. 1 unit: 350 kW of unit capacity corresponding with existing LP-2 exploration well capacity.
- No. 2 and 3 units: 1,000 kW of unit capacity each for the following reasons.
  - The production of LP-3 and LP-4 production wells is estimated to be from 1,000 kW to 1,300 kW in the back pressure turbine cycle respectively.
  - The unit capacity of a range of 1,000 kW to 1,200 kW is appropriate in view of the systems power demand.
  - Limitation in the equipment/facilities transportation conditions.
  - Economic study on the following cases.

| Case | Unit Capacity (kW) | Type | Wells |
|---|---|---|---|
| Case-1 | 350 | Backpressure | LP-2 |
| | 2,000 | Condensed | Add. well |
| | 2,000 | Condensed | Add. well |
| Case-2 | 350 | Backpressure | LP-2 |
| | 1,000 | Backpressure | Add. well |
| | 1,000 | Backpressure | Add. well |
| Case-3 | 350 | Backpressure | LP-2 |
| | 1,000 | Backpressure | Add. well |
| | 2,000 | Condensed | Add. well |

The generating cost of each unit capacity of geothermal power plant when the plant is operated with a capacity factor of 80% as a base load plant is calculated to be 48.30 Mills/kWh, 31.26 Mills/kWh, and 34.30 Mills/kWh for 350 kW, 1,000 kW and 2,000 kW units, respectively. The generating cost of 350 kW unit is the highest because of high equipment cost for its small unit capacity. The cost of 350 kW unit is cheaper by only 10% than that of 1,000 kW unit. On the other hand, the cost of 2,000 kW condensed unit is nearly double that of 1,000 kW back pressure unit. It is judged that the 1,000 kW unit is the most economical choice.

### 3.2.2 Plant Sites and Distribution Line Route

The power plant sites must be selected at locations that fulfil the site selection criteria.

Thus the power plant equipment will be installed adjacent to each production well, the plant sites are shown in Fig. 3-4.

| Production Well | Power Plant Equipment |
|---|---|
| LP-2 | No. 1 Unit (  350 kW) |
| LP-3 | No. 2 Unit (1,000 kW) |
| LP-4 | No. 3 Unit (1,000 kW) |

In consideration of the transmission loss and the construction cost, the distribution line route from plant sites to Sungai Penuh City via west side of Kerinci Lake along the existing road is selected. Distribution line route is shown in Fig. 3-5.

### 3.2.3 Scope of the Project

The scope of the Project is as follows.

Construction and improvement of access road
(approximately 7 km)

Land reclamation for the power plants
(approximately 4,800 m$^2$ for 3 sites)

Construction of water intake and supply facilities

Drilling of the production wells, LP-3 and LP-4

Installation of turbine-generators and auxiliary equipment
(350 kW x 1, 1,000 kW x 2)

Construction of powerhouses and appurtenant buildings

Construction of 20 kV high-voltage distribution line system

Communication facilities

### 3.2.4 Design Conditions of Major Equipment

#### 1) Basic Design Conditions

a. The following items shall be considered in planning and designing.

- Power plants will be operated as the base load plant so that the geothermal steam may be utilized effectively.

- The geothermal power plants will be operated for two years without a turbine overhaul with the output decline of less than 5 to 6% of the rated output in spite of scaling on the turbine blades and nozzles.

- The portable package units of turbine and generator will be mounted on the common bed and be installed at the wellheads, for easy transportation and erection.

- The units will be self-start units without the necessity of external supply of electricity and water. And the operating conditions will be monitored on the turbine-generator control panels.

b. The material selection, in planning and design of equipment and facilities, will be done in consideration of $H_2S$ gas (0.255 wt%) in the geothermal fluid.

c. Steam

The steam conditions at wellhead and turbine inlet are specified below.

Wellhead steam conditions
Pressure : 5.2 ata
Temperature : 152.6°C

Turbine inlet steam conditions

Pressure : 5.0 ata

Temperature : 151.1°C

Wellhead separator outlet conditions

Steam wetness: 1% or less

Total solid : 5 ppm or less

2) Technical Standards

The technical standards to be applied to the material selection and the equipment design in the project are Japanese Standards and/or the equivalent international standards.

3) Site Conditions

a. Topography and geology

The elevations of the project sites are as follows.

No. 1 unit: EL + 1,390 m

No. 2 unit: EL + 1,420 m

No. 3 unit: EL + 1,435 m

Power distribution lines: EL + 800 m ~ 1,435 m

The geology of LP-2 site consists of soft layer for several meters from the ground surface and hard rock body (Tua Volcanic Rock) that lies below. And the geology of LP-3 and LP-4 sites is similar to that of LP-2 site.

b. Meteorological conditions

There is no meteorological data at the project site. Therefore, meteorological data (from 1983 to 1987) at Hiang Meteorological Station located at approximately 30 km to the north-north-east and at the elevations of about 800 m above sea level are shown in the following for reference.

Monthly average dry bulb temperature

- Maximum temperature : 28.8°C (June)
- Average maximum temperature : 28.3°C
- Average temperature : 21.6°C
- Average minimum temperature : 16.7°C
- Minimum temperature : 15.5°C (July)

Monthly average humidity

- Maximum humidity : 90.6% (April)
- Average humidity : 88.3%
- Minimum humidity : 85.6% (November)

Rainfall

- Average annual : 1,933 mm
- Average monthly : 161.1 mm

Wind velocity

- Maximum : 40 m/s (Tua 1985)

Atmospheric pressure

- At LP-2 site : 0.9 ata

### c. Transportation of equipment and materials

Equipment and materials for this Project will be unloaded at Teluk Bayur Port, Padang City, Sumatra, and will be transported to the power plant sites at about 280 km from the Port via the coast road.

Since the existing road in 6 km from the plant sites is not in good conditions, a new access road will be constructed. The transportation route is shown in Fig. 3-6.

#### d. Rated voltage

- High voltage distribution line, switchyard : 20 kV 3 phase
- Generator, Main transformer : 4.16 kV 3 phase
- Station transformer : 220 V 3 phase
- Auxiliary equipment and lighting: 220 V 3 phase & single phase
- Instruments and control devices : 110 V Single phase
- Control and emergency lighting : 120 V DC

#### e. Environmental criteria

Environmental criteria for waste water discharged from power plants are shown in the following.

pH : 6 - 9
Oil: 10 ppm or less

### 3.2.5 Production Well Development Plan

Geothermal steam from the existing LP-2 exploration well will be supplied to No. 1 unit (350 kW).

Geothermal steam to No. 2 unit (1,000 kW) and No. 3 unit (1,000 kW) will be supplied from LP-3 and LP-4 production wells respectively. LP-3 and LP-4 production wells will be drilled at 100 m to the west and 150 m to the south-west of LP-2 production well along Durables Fault, respectively.

### 3.2.6 Power Plant Plan

#### 1) Plot Plan

Each unit including the main transformer will be installed at the place adjacent to each production well.

The consolidated switchyard for three units will be installed at No. 2 unit site.

The head tank for the plant service water will be installed at the nearest place to the water intake point in the No. 3 unit site, which is located at the highest elevation of the three power plant sites.

2) Layout of power generating equipment

The powerhouse consisting of the turbine-generator section and the operating section will be constructed at each power plant site.

In the turbine-generator section, the portable package type turbine-generator with the accessories of the lubrication and control oil system, the gland ejector, the main stop valve and the governing control valve will be installed. The exhaust silencer will be installed at the outside of the powerhouse, adjacent to the turbine-generator section, and on the well side.

In the operating section next to the turbine-generator section, such electrical equipment as the main circuit panel, the auxiliary equipment panel, the DC power source panel and the turbine-generator control panel will be installed.

The main transformer will be installed at the outside of the powerhouse, adjacent to the operating section, near to the main circuit panel and the auxiliary equipment panel.

The layouts of the power generating equipment of 350 kW and 1,000 kW units are shown in Figs. 3-7 and 3-11.

### 3.2.7 Civil Works

1) Access road

A new access road will be constructed along R. Abang, branching off from the existing road situated at the north of Lempur Village. In consideration of the construction cost and the traffic of the heavy duty vehicles for transportation of the drilling rig, generating facilities, etc., the new access road is planned as follows.

| | |
|---|---|
| Road length | : 7 km |
| Road width | : 4 m |
| Average slope | : 9% |
| Minimum radius of curvature | : 15 m |
| Road finish | : Gravel, compact-paved |

2) Site leveling

The existing drilling site of LP-2 will be used for the power plant site for LP-2 and new sites for LP-3 and LP-4 will be leveled. The new power plants for these two wells will be built in each site after removal of the drilling rig.

In consideration of the use of a large-sized drilling rig for production well drilling, the site area of LP-3 and LP-4 will be larger than LP-2 site.

| | | |
|---|---|---|
| Site elevation | LP-2: | EL +1,390 m |
| | LP-3: | EL +1,420 m |
| | LP-4: | EL +1,435 m |
| Site dimensions | LP-2: | Width 29 m, Length 41 m (1,189 m²) |
| | LP-3: | Width 30 m, Length 60 m (1,800 m²) |
| | LP-4: | Width 30 m, Length 60 m (1,800 m²) |

Site finish : Gravel, compact-paved

### 3) Power plant

#### a. Foundation of power plant

The main equipment such as the turbine and generator will be installed on the reinforced concrete foundation built on the soil bed with sufficient soil bearing capacity. The total weight of the package type power plant is not so heavy, and judging from the geology of LP-2 site, no supplemental reinforcement of the foundation by piling or mat foundation would be needed.

#### b. Powerhouse

The powerhouse will be designed with a view to realizing the merits of reducing of the building weight, shortening of the construction period and reducing of the construction cost. In consideration of the above factors, the wood construction will be adopted for the structure and walls, and corrugated asbestos cement sheets will be adopted for the roof.

### 4) Water-intake facilities

Fresh water for the power plant will be taken from a water-intake point on R. Abang situated at approximately 600 m southwest from the LP-4 site. A small water-intake dam will be built at the water-intake point and fresh water will be transmitted to LP-4 site through a pipeline.

## 3.2.8 Power Plant Facilities

### 1) Mechanical Equipment

The portable package type back-pressure turbine is adopted, and the turbine and generator are set on a common bed together with control devices, protection devices, oil system, etc.

The major specifications of the turbine are as follows.

Type : Single casing, single flow, back pressure, portable package type mounted on common bed together with the generator

Rated output x Number: 350 kW x 1 set
1,000 kW x 2 sets

Steam pressure and temperature : 5.0 ata, 151.1°C at main stop valve inlet

Atmospheric pressure : 0.9 ata

Accessories

| | |
|---|---|
| Control devices | 1 set |
| Protection devices | 1 set |
| Lubricating oil system | 1 set |
| Steam seal system | 1 set |

The following mechanical equipment will be installed.

- Wellhead separator, wellhead silencer
- Steam relief devices
- Main stop valve, governing valve
- Main steam and auxiliary steam system
- Exhaust steam system (including exhaust silencer)
- Turbine oil system

The steam system diagram is shown in Fig. 3-12.

2) Electrical and control system

The generator will be of the open air cooled type with brushless excitation system. The turbine and the generator will be connected directly or through the reduction gear.

The specifications of the generator will be as follows.

| | |
|---|---|
| Capacity x Quantity | 437.5 kVA x 1 set<br>1,250 kVA x 2 sets |
| Type | Horizontal, rotating field, open air cooled with inlet air filter, drip proof, three phase synchronous generator |

Rating

| | |
|---|---|
| No. of phases | Three (3) |
| No. of poles | Four (4) |
| Capacity | 437.5 kVA x 1 set<br>1,250 kVA x 2 sets |
| Voltage | 4,160 V |
| Current | 60.72 A (437.5 kVA)<br>173.49 A (1,250 kVA) |
| Frequency | 50 Hz |
| Revolution | 1,500 rpm |
| Power factor | 0.8 (lagging) |

The starting of the turbine shall be possible at the local turbine gauge board located at the turbine side. After the start up of the turbine, synchronizing and load variation of the generator and the monitoring of the turbine during the normal operation will be made at the control panel in the control room.

Emergency operation to secure the safety of the operator and the plant will also be possible in the control room.

The normal shut down of the turbine will be conducted at the local turbine gauge board.

3) Others

The plant service water will be taken from the dam built in the stream near the plant sites and will be storaged in the head tank. The raw water will be used as the plant service water, drinking water, and fire fighting water.

The fire fighting system consisting of diesel engine driven fire pumps, outdoor water hydrants and piping will be installed.

The hot water separated in the separator will be the discharged into the fumarole near the sites. The drain from the exhaust silencer will also be discharged into the fumarole.

### 3.2.9 High Voltage Distribution System

A high voltage distribution system of 40 km line length will be installed from the switchyard located at No. 2 Unit site to the switching station in the compound of Sungai Penuh Power Station.

The high voltage distribution line will directly transmit the generated power of the power plant to Sungai Penuh switching station without any branch supplying to the load on the way, and thus it is of the nature of a transmission line. The conductor of the line will be AAAC 240 mm². The power transmission capacity is enough to cover not only 2,350 kW to be provided by this project but also 2,000 kW by future expansion.

Concrete poles, available in Padang City on the Island of Sumatra, will be used as the support structure of the high voltage distribution line.

The outline of the high voltage distribution facility is as follows;

| Item | Quantity |
|---|---|
| Concrete poles 11m, 200 daN | 800 pcs |
| AAAC 240 mm² | 120 km |
| Insulators (Pin type) | 2,160 pcs |
| Insulators (Tension type) | 960 pcs |
| Strain clamps 240 mm² | 400 pcs |
| Connectors 240 mm² | 240 pcs |
| Other materials | 1 lot |

## 3.3 Project Development Schedule

### 3.3.1 Procurement Plan

Drilling bits, wellhead valves, power generating facilities out of the equipment and materials for this Project will be imported, but Indonesian local products will be used for the others.

The equipment/materials and construction works for this Project will be procured in the following three (3) packages.

- . Steam production facilities
- . Power generating facilities
- . High voltage distribution facilities

A Consultant will be employed for smooth advancement of this Project. The consultant will perform the basic design, preparation of tender documents, review and approval of manufacturers' drawings and construction supervision including witness of tests.

### 3.3.2 Project Development Schedule

Existing LP-2 exploration well will be used for No. 1 unit. And LP-3 and 4 production wells will be drilled for No. 2 unit and No. 3 unit respectively.

Power Plant facilities for the 3 units will be installed at each site according to the following schedule.

| Major Event | Months from agreement with contractors |
|---|---|
| Start of site preparation | 2 months |
| Start of production well drilling | 10 months |
| Completion of production well drilling | 12 months |
| Completion of HV distribution lines | 15 months |
| Commissioning of No. 1 Unit | 22 months |
| Commissioning of No. 2 Unit | 25 months |
| Commissioning of No. 3 Unit | 28 months |

### 3.3.3 Construction Cost

The foreign currency portion of the construction cost for this Project will be borrowed from an International Financing Institution and the local currency portion will be covered by the Indonesian Government budget.

The scope of cost estimation is as follows.

- Access road, about 7 km
- Land leveling, about 3,000 m²
- Construction of plant service water intake facilities
- Drilling of LP-3 and -4 production wells
- Procurement and installation of back-pressure turbine generating facilities
  - No. 1 unit: 350 kW
  - No. 2 unit: 1,000 kW
  - No. 3 unit: 1,000 kW
- Power plant building
- 20 kV high voltage distribution system
- Communication facilities

Construction cost is estimated in US dollar and the following exchange rate is used.

1 US$ = Yen 130 = Rp.1,700

(Unit: 1,000 US$)

| Items | FC | LC | Total |
|---|---|---|---|
| 1. Well Drilling and Wellhead Eqt. | 1,846 | 462 | 2,308 |
| 2. Power Plant | | | |
| Power generating eqt. | 4,946 | - | 4,946 |
| Installation | 438 | - | 438 |
| Civil/Arch. works | - | 423 | 423 |
| Subtotal | 5,384 | 423 | 5,807 |
| (Unit cost per kW) | | | (2,471 US$/kW) |
| 3. HV Distribution | - | 615 | 615 |
| 4. Engineering Fee | 769 | - | 769 |
| 5. Total | 7,999 | 1,500 | 9,499 |
| 6. Contingency | 1,192 | 231 | 1,423 |
| 7. Grand Total | 9,191 | 1,731 | 10,922 |

## 3.4 Economic and Financial Evaluation

### 3.4.1 Financial Evaluation

Regarding the financial viability of the Project in the stand point of PLN, assumptions and provisions for economic and financial evaluation were first formulated based on the technical study, cost estimate, development plan, present operating conditions discussed and confirmed with PLN during the site survey. Then the project FIRR with benefits by electricity sales revenue and With/Without FIRR with benefits by sales losses in the Without case in addition to the sales revenue were calculated.

The geothermal power plant is generally said that it needs a large amount of initial investment and less operation and maintenance cost. Since the initial investment for this project is especially larger as compared to the unit capacity, the sensitivity analysis of FIRR to the project cost was also analyzed.

#### 1) Financial Internal Rate of Return

As Table 3-3 shows, the calculated FIRR becomes 4.32% which slightly exceeds the financial opportunity cost of capital at 3.61%, weighed mean capital cost of foreign currency portion at 2.6% and local currency portion of 9%. This result implies that PLN could, based on the assumed conditions, account about net profit of about US$1.2 million upon completion of these loan repayments after 25 years operation. However, as the financial statements show, the project financial conditions will continue to be deficit for 8 to 10 years after commissioning. Although the project itself is feasible, PLN's operation of the project is forecasted to get somewhat difficulties.

In view of the average power rate in th PLN's Sungai Penuh power system at about 103.38 Rp./kWh against the generating cost of diesel power plants at about 127.41 Rp./kWh, PLN has been operating the power business at deficit. Thus, the FIRR in comparison between the With and Without project becomes 6.37% and the net profit after 25 years operation increased to about US$13 million. From this fact, the project is highly effective for PLN to lessen the deficit in power business of Ranting Sungai Penuh and feasible for implementation.

2) Sensitivity of FIRR to Project Cost

Sensitivity of FIRR to the project cost is tested in a range of plus and minus 15%. As the result is exhibited in Fig. 3-15, if the cost should increase by about 8 to 9 percent, the FIRR value can not exceed the hurdle rate of 3.61%. It is advisable to make more detail cost estimate toward reduction when the project implementation program will be formulated.

### 3.4.2 Economic Evaluation

The project identity and speciality lies at its energy source for power generation; that is, the project utilizes indigenous, non-exportable oil-alternative energy for power generation and avoids the existing diesel engine power generation consuming oil energy. Thus, the alternative to the project is specified to be a diesel power generating system which could provide the equivalent services (power) to the Project. The economic feasibility of the Project was evaluated by Economic Internal Rate or Return (EIRR) Method.

The EIRR will be calculated where costs of the alternative project for the project life (25 years) are regarded as "Project Benefit" and costs of the Project as "Project Cost". The obtained EIRR will be compared with the economic opportunity cost of capital, or discount rate at 9% which is usually applied for PLN's small scale power development and rural electrification project.

In addition, the sensitivity of EIRR to the project construction cost and unit oil cost of the alternative, which is deemed to affect the EIRR greatly, will be tested and is exhibited in figure.

1) Economic Internal Rate of Return

The obtained EIRR registered as low as 3.78% as shown in Table 3-8, which is not sufficient as compared with the economic opportunity cost of capital at 9%. This insufficient EIRR is derived from a substantially higher construction cost of the project than that of the alternative since the project cost includes cost for access road and special design for small scale geothermal power units to meet the Kerinci geothermal field. As shown in Fig. 3-17, the sensitivity of EIRR to project cost reveals that variation of the project cost greatly affects EIRR and if the project cost is reduced, the EIRR becomes large. Therefore, if the project should be continued and the subsequent units constructed, the total project EIRR will become very favorable over the alternative.

2) Sensitivity Analysis

As the oil reservoir is limited, it is hard to believe that the present low oil price will continue. The price may rise, but it is also hard to forecast the future oil price. While EIRR calculation in this study is greatly affected by the oil price, the sensitivity of EIRR to the oil price is tested and the result is exhibited in Fig. 3-2. As shown in the figure, if the project EIRR could reach the hurdle rate of 9%, the oil price should be more than a 27 $/bbl. level.

### 3.4.3 Other Economic Benefits

#### 1) Fuel Save

As the project will provide the electricity generated by geothermal energy, if it is implemented, it will save the consumption of fuel amounting to about 32.7 thousand barrel per year, or increase export value of about US$545 thousand per year at an unit oil cost of 16 $/bbl.

#### 2) Rural Development

Since Sungai Penuh area is located at high elevation of about 800 m and surrounded by the mountain ranges, the transportation route of the fuel oil is sometimes closed due to the land slide especially in the rainy season. These conditions make the power supply unstable at present. The project, on the contrary, using the local energy, could provide the stable and reliable electricity to the society. In addition, the stable and reliable power supply will lead to the industrialization of the potential agriculture and forestry and develop the rural areas. This will accord to the government policy of equalized development of the country.

### 3.4.4 Summary

Though the EIRR obtained is not sufficient, since the project will provide said merits with the rural society and country, and the development and use of non-exportable and indigenous energy resource is a national objective, the implementation of this project should be determined in the stand point of national economy.

Fig. 3-1 Power System in Kerinci Regency

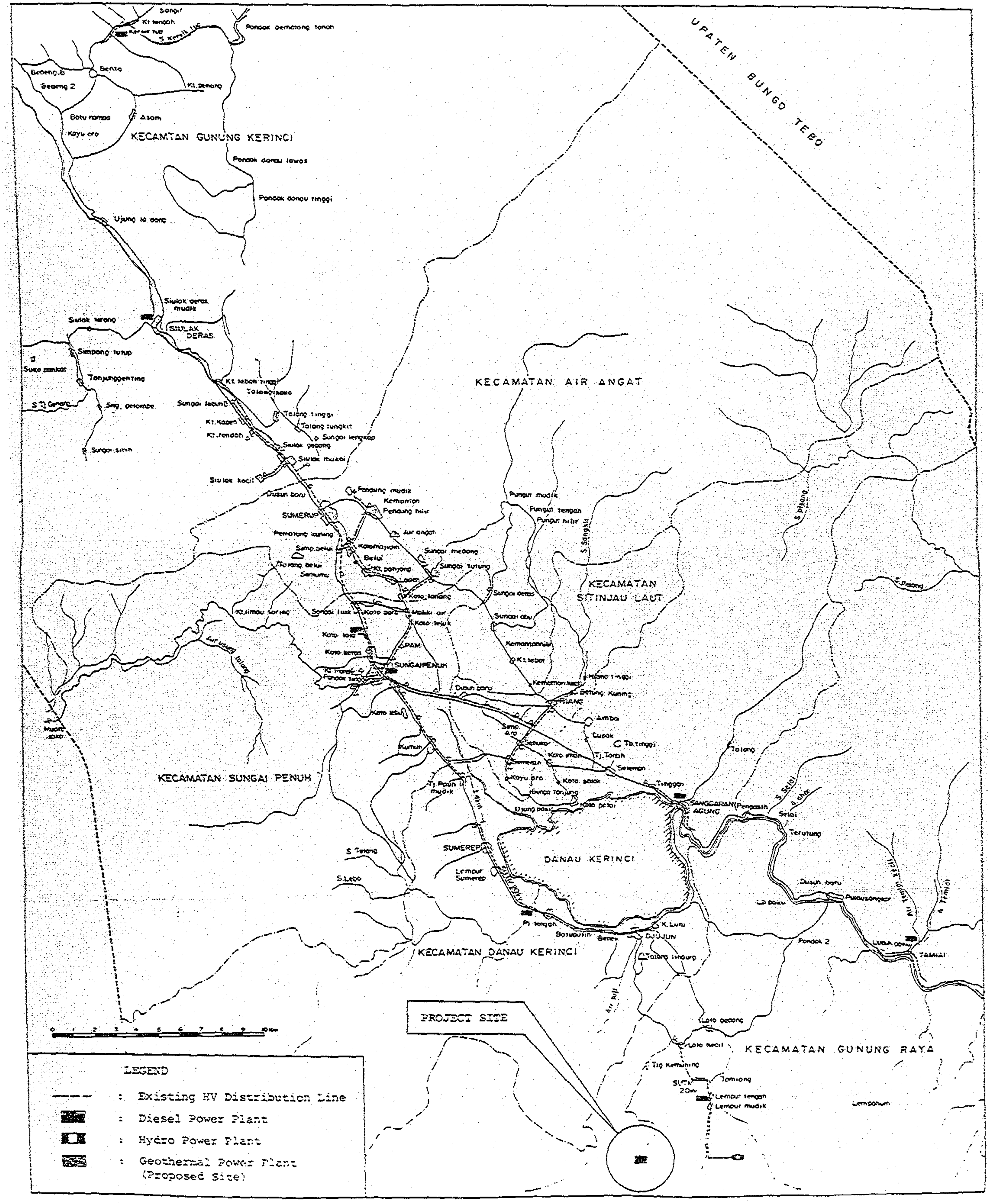


Fig. 3-2 Daily Load Curve (June 5, 1988)

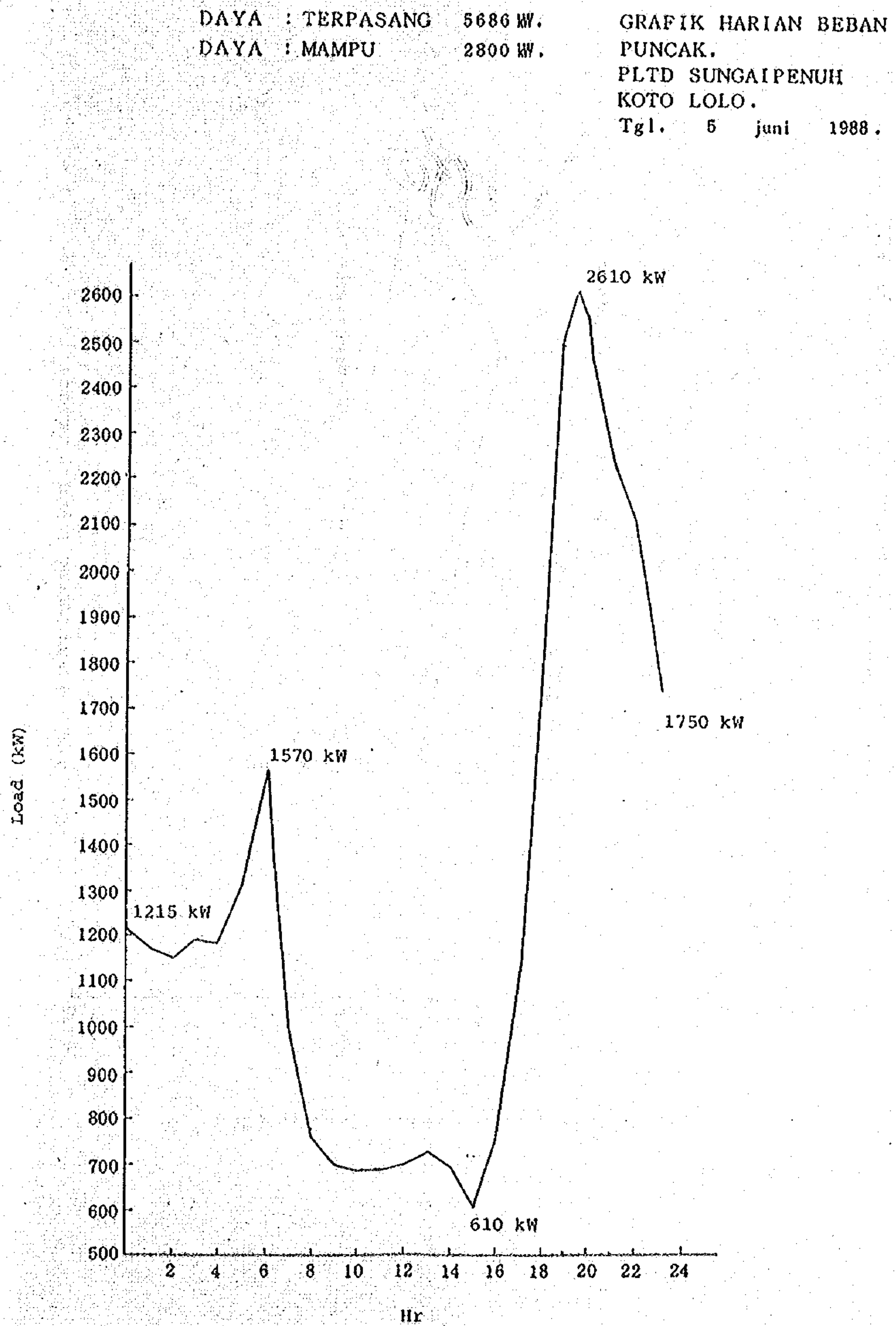
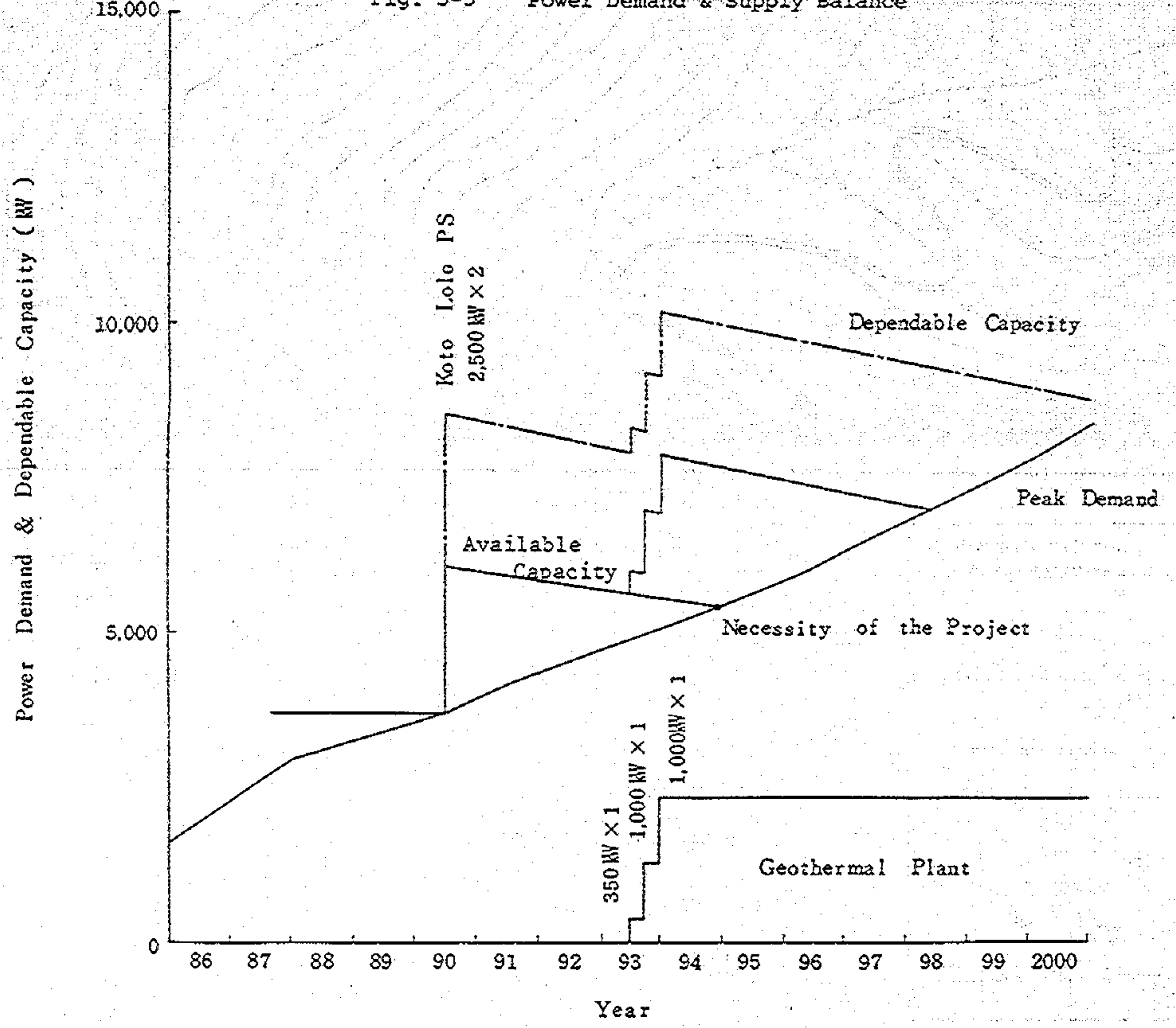


Fig. 3-3 Power Demand & Supply Balance



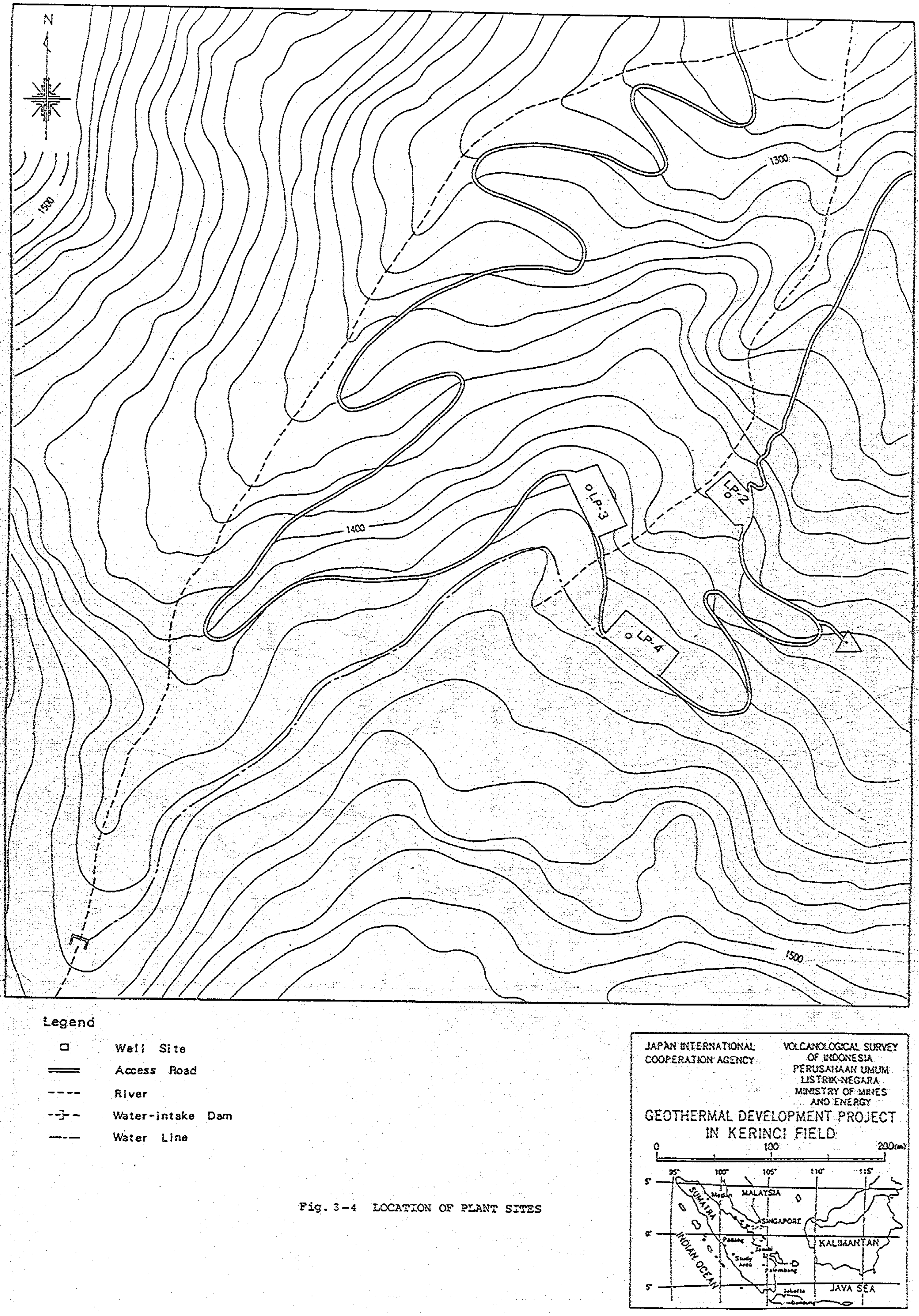


Fig. 3-4 LOCATION OF PLANT SITES

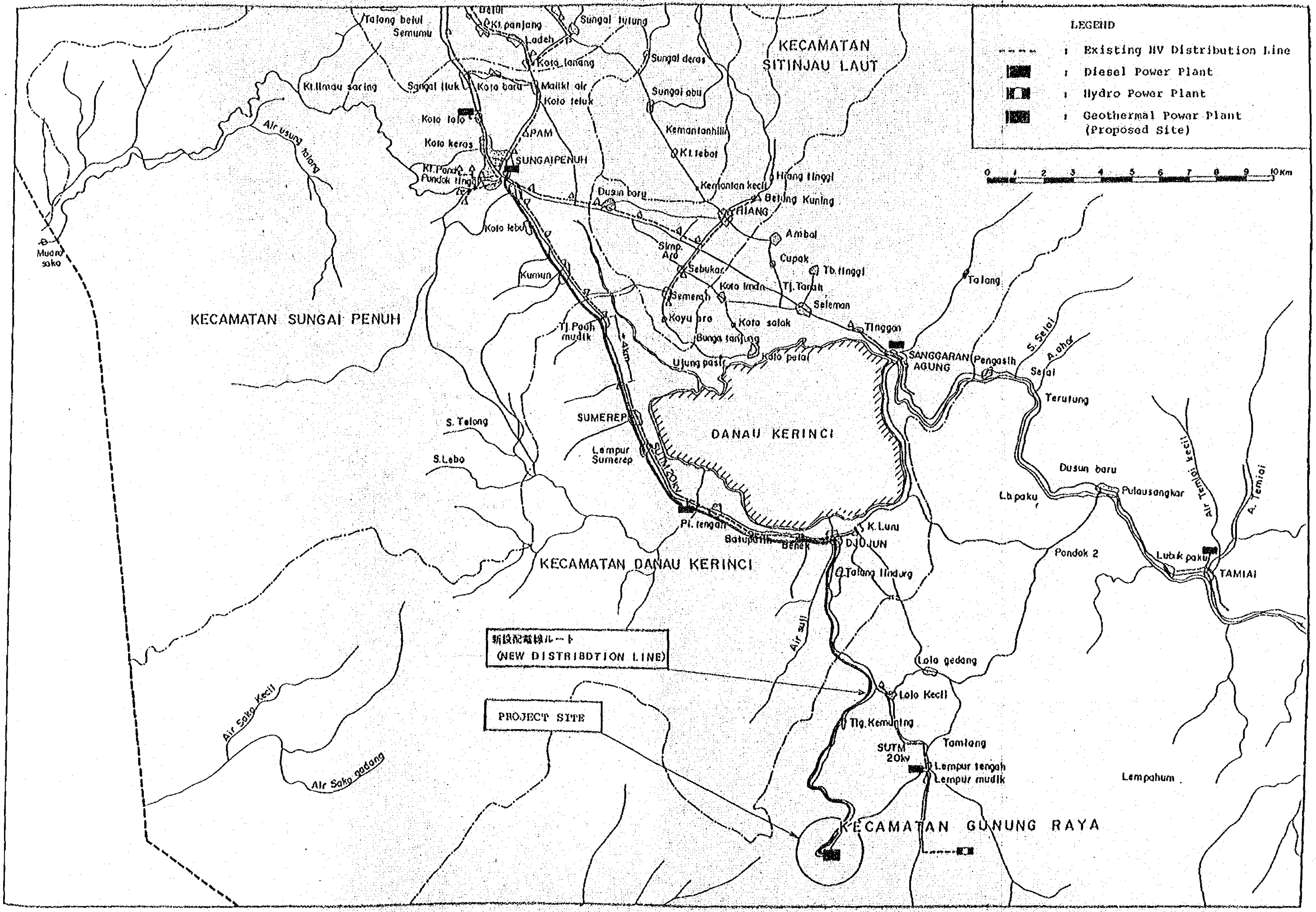
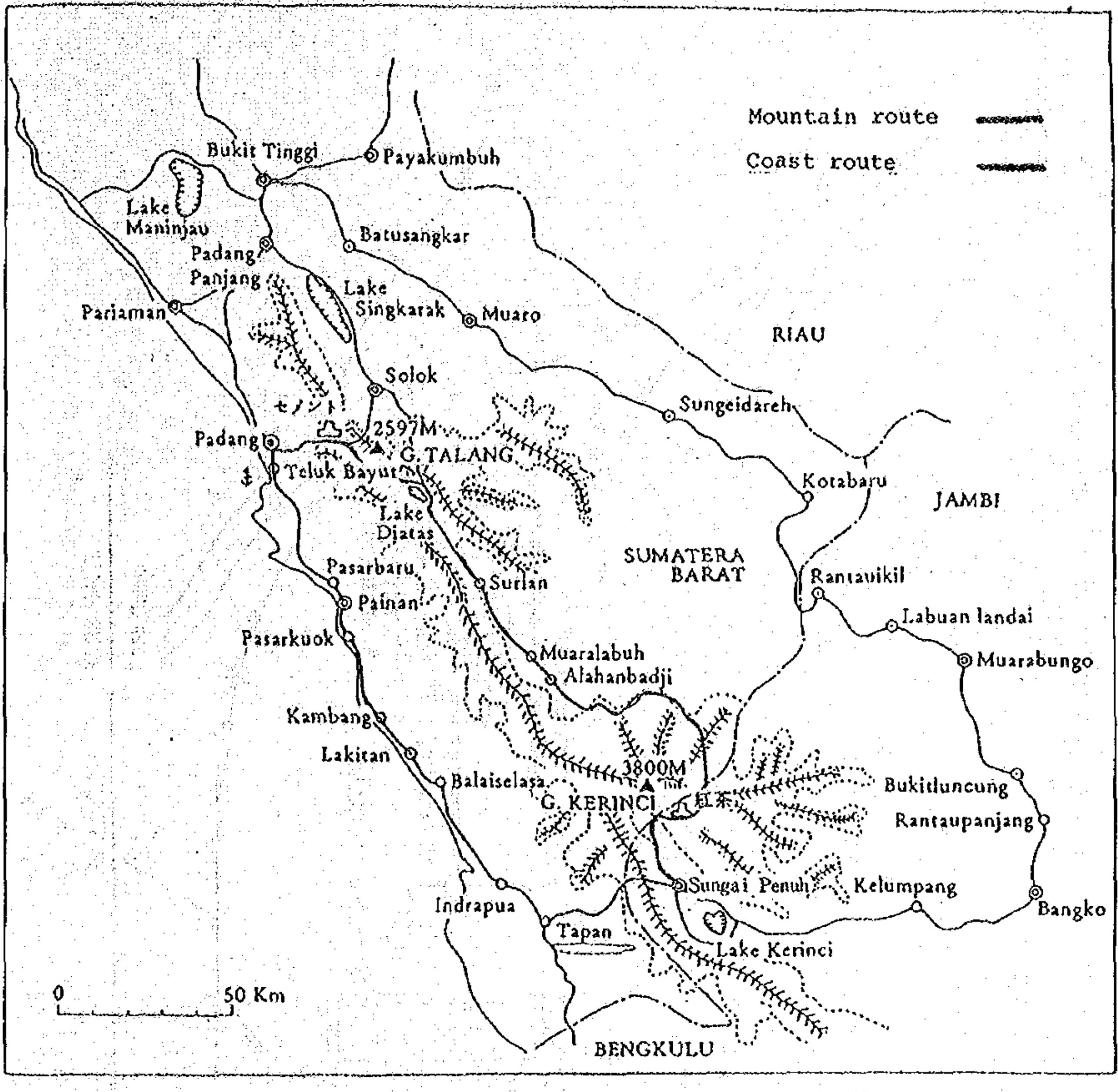


Fig. 3-5 DISTRIBUTION LINE ROUTE

Fig. 3-6 Route to Sungai Penuh



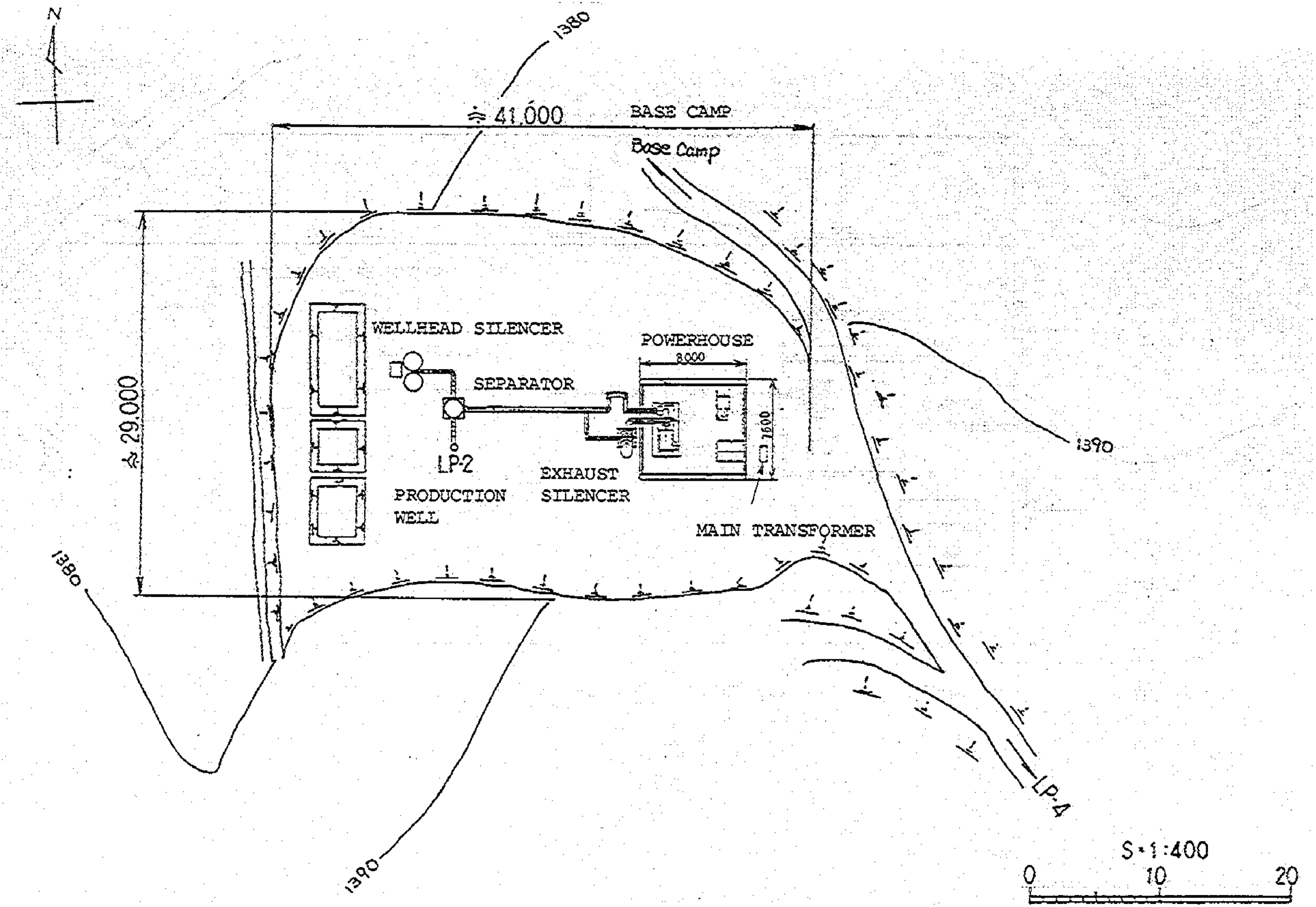


Fig. 3-7 PLOT PLAN OF NO. 1 UNIT POWER PLANT

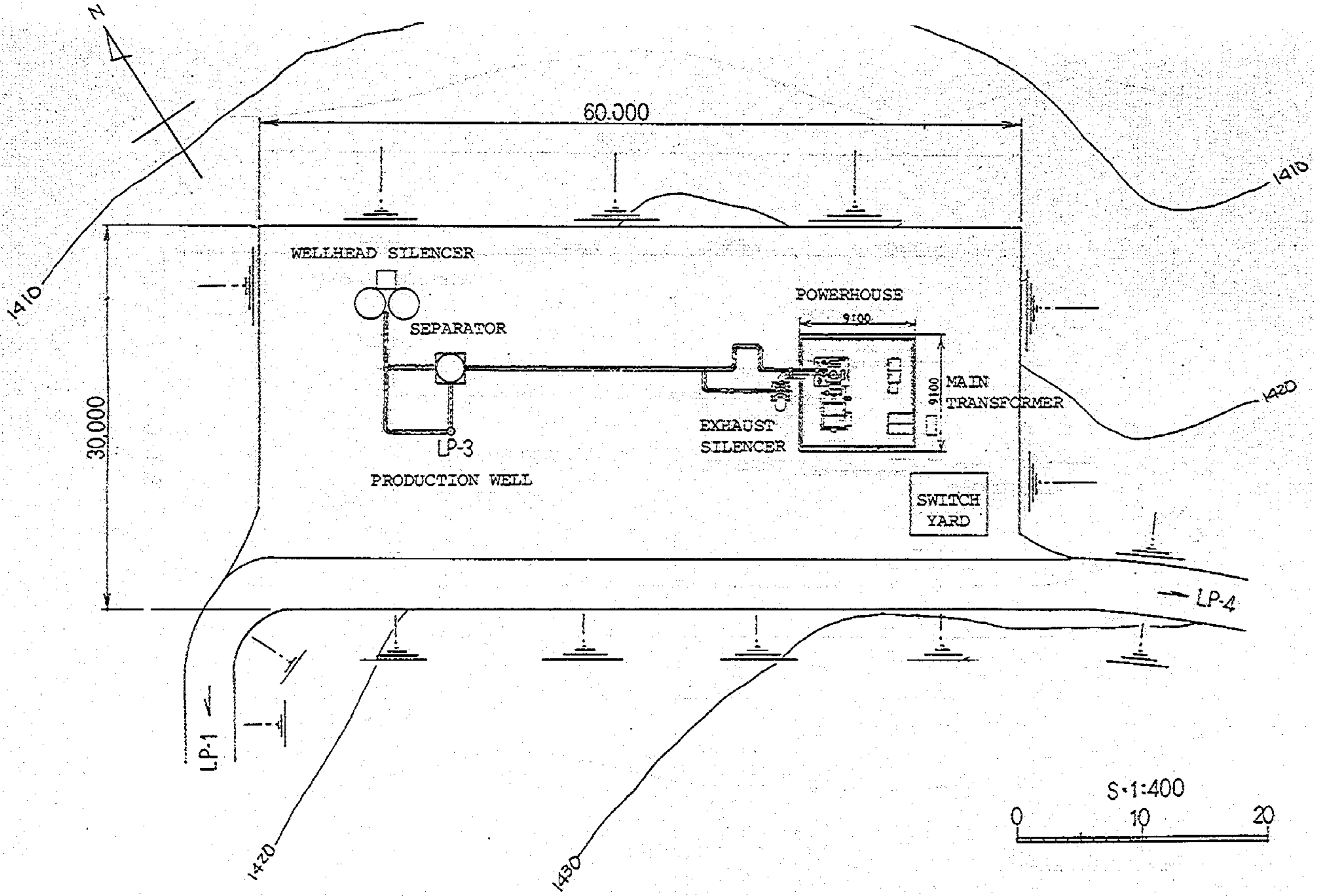


Fig. 3-8 PLOT PLAN OF NO. 2 UNIT POWER PLANT

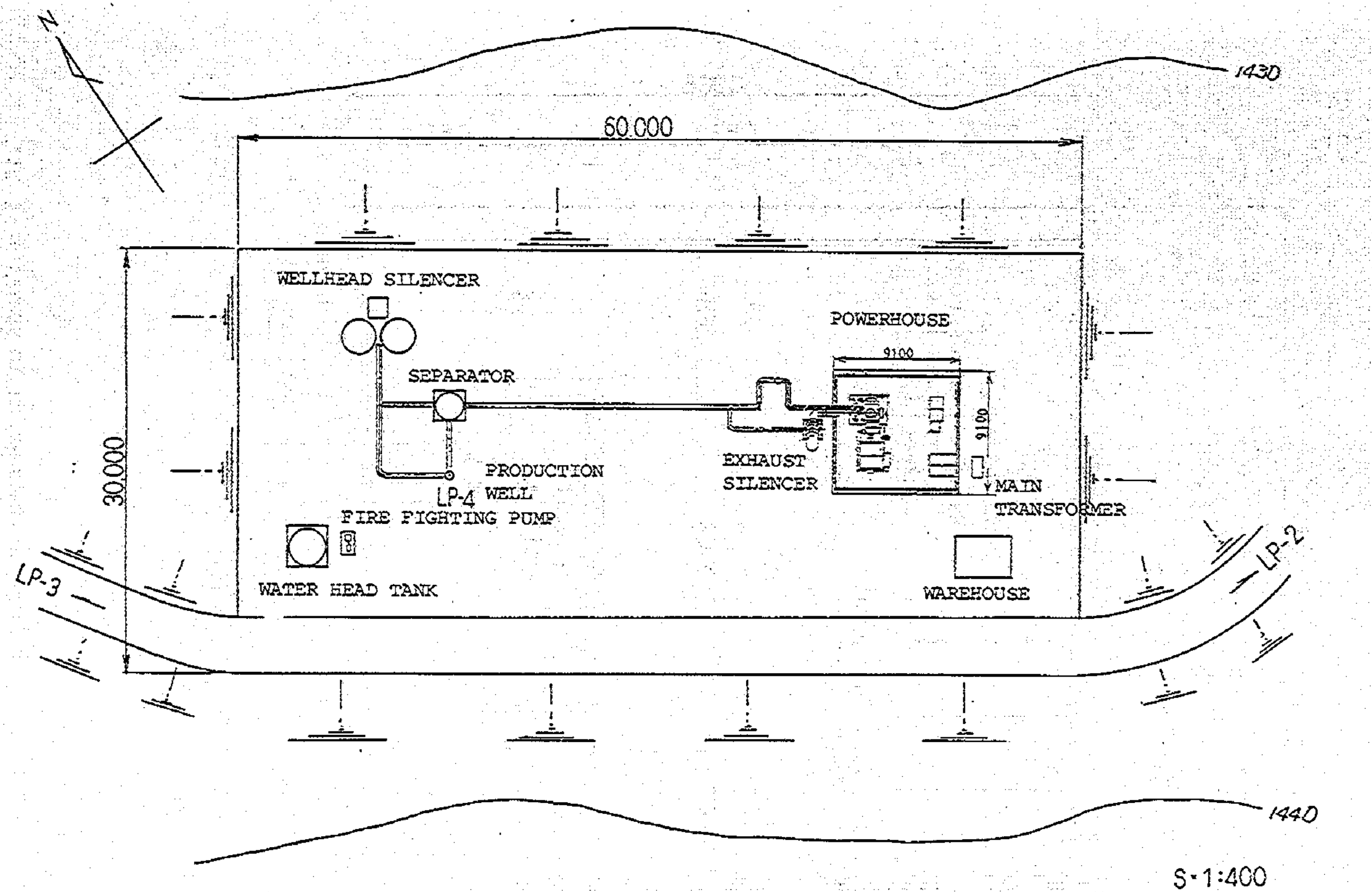


Fig. 3-9 PLOT PLAN OF NO. 3 UNIT POWER PLANT

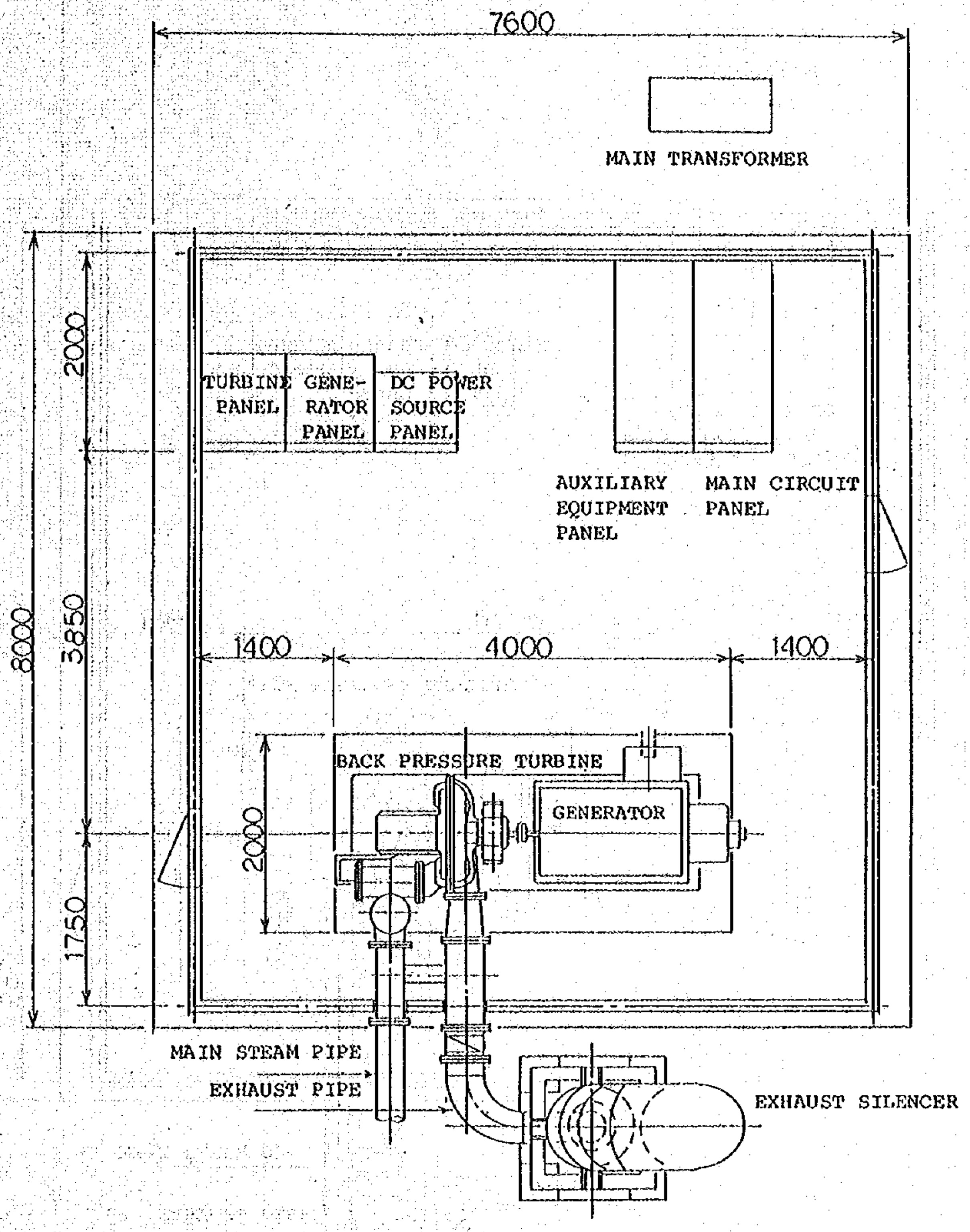


Fig. 3-10 LAYOUT OF 350 KW POWER GENERATING EQUIPMENT

S = 1/60

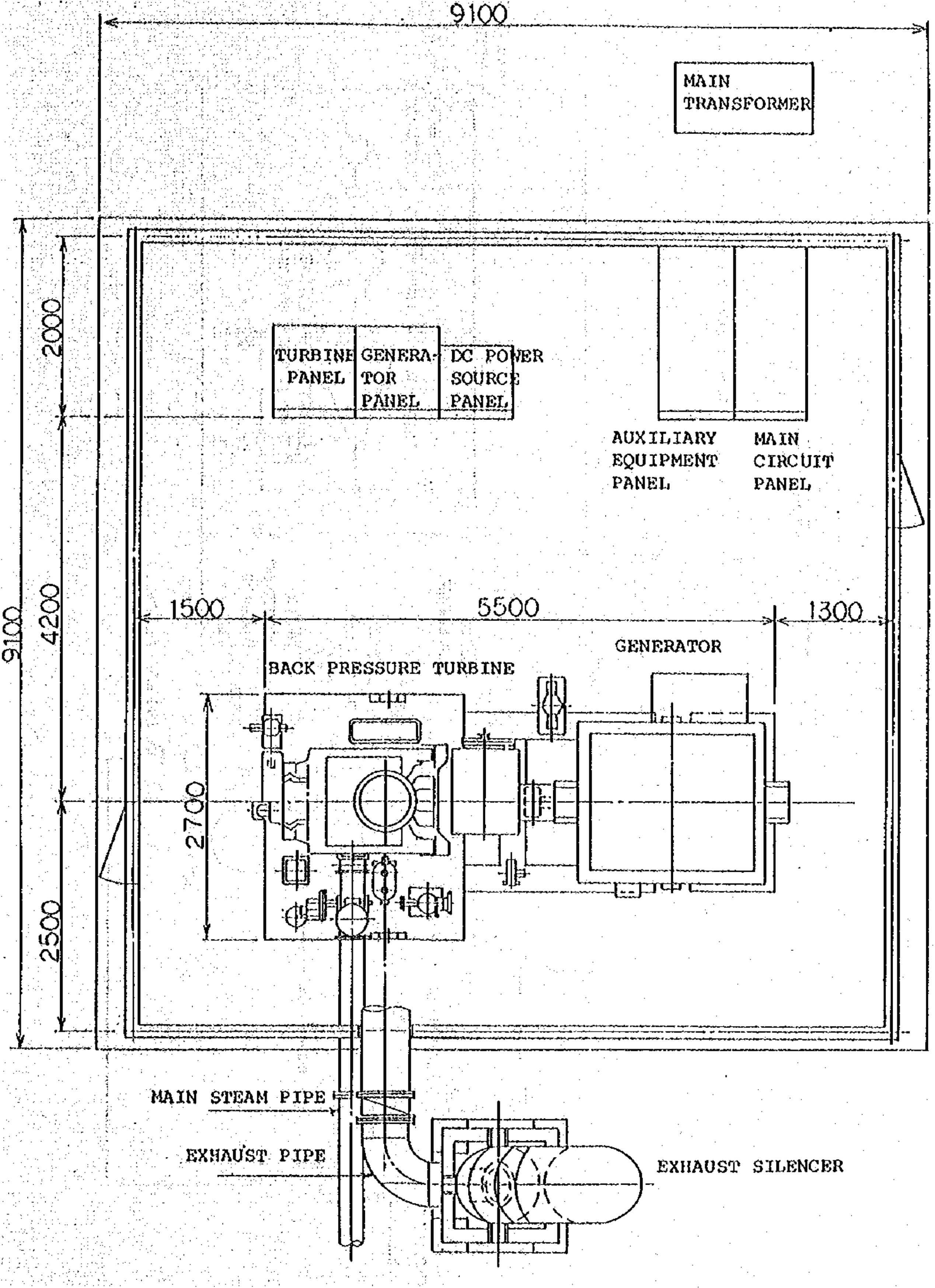
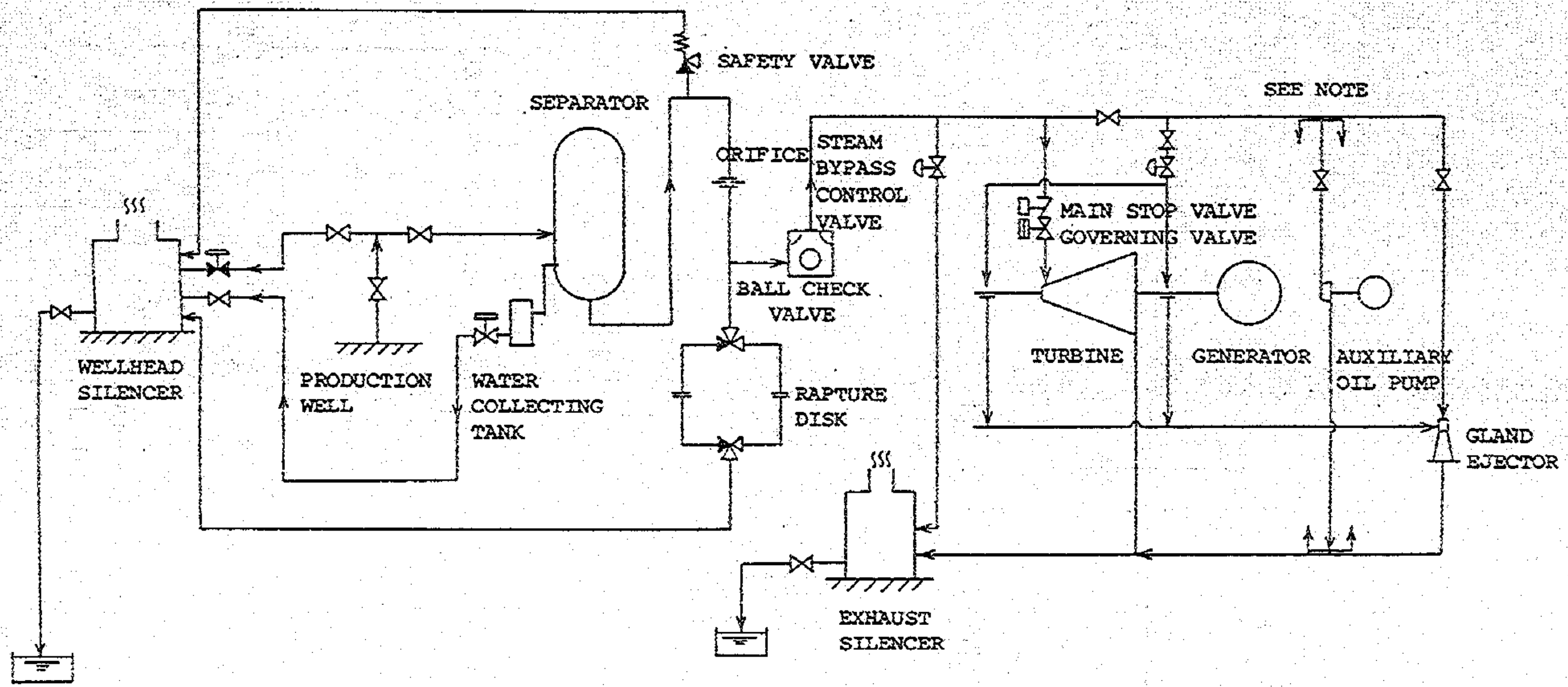
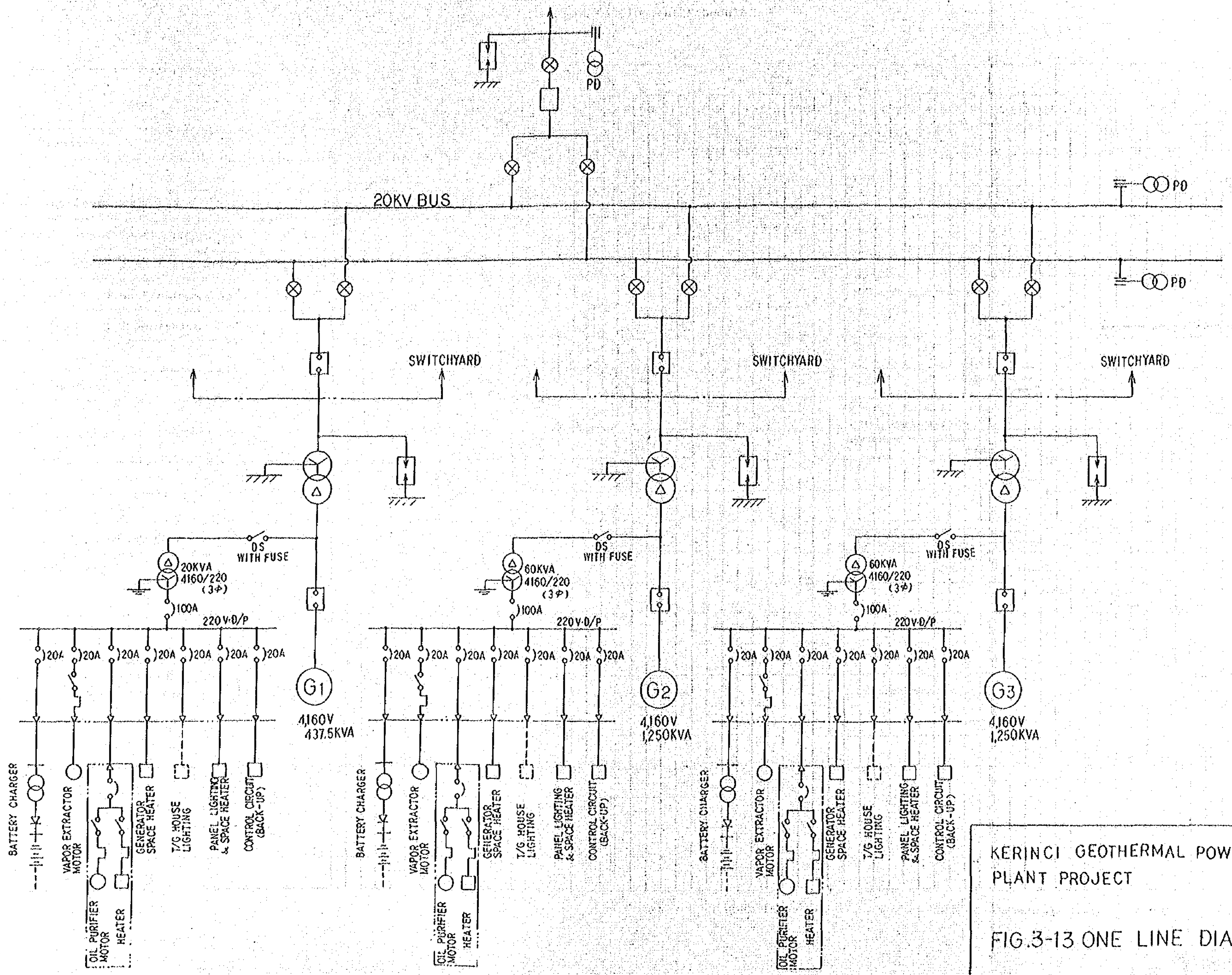


Fig. 3-11 LAYOUT OF 1,000 KW POWER GENERATING EQUIPMENT



NOTE: FOR 1,000 KW UNIT ONLY

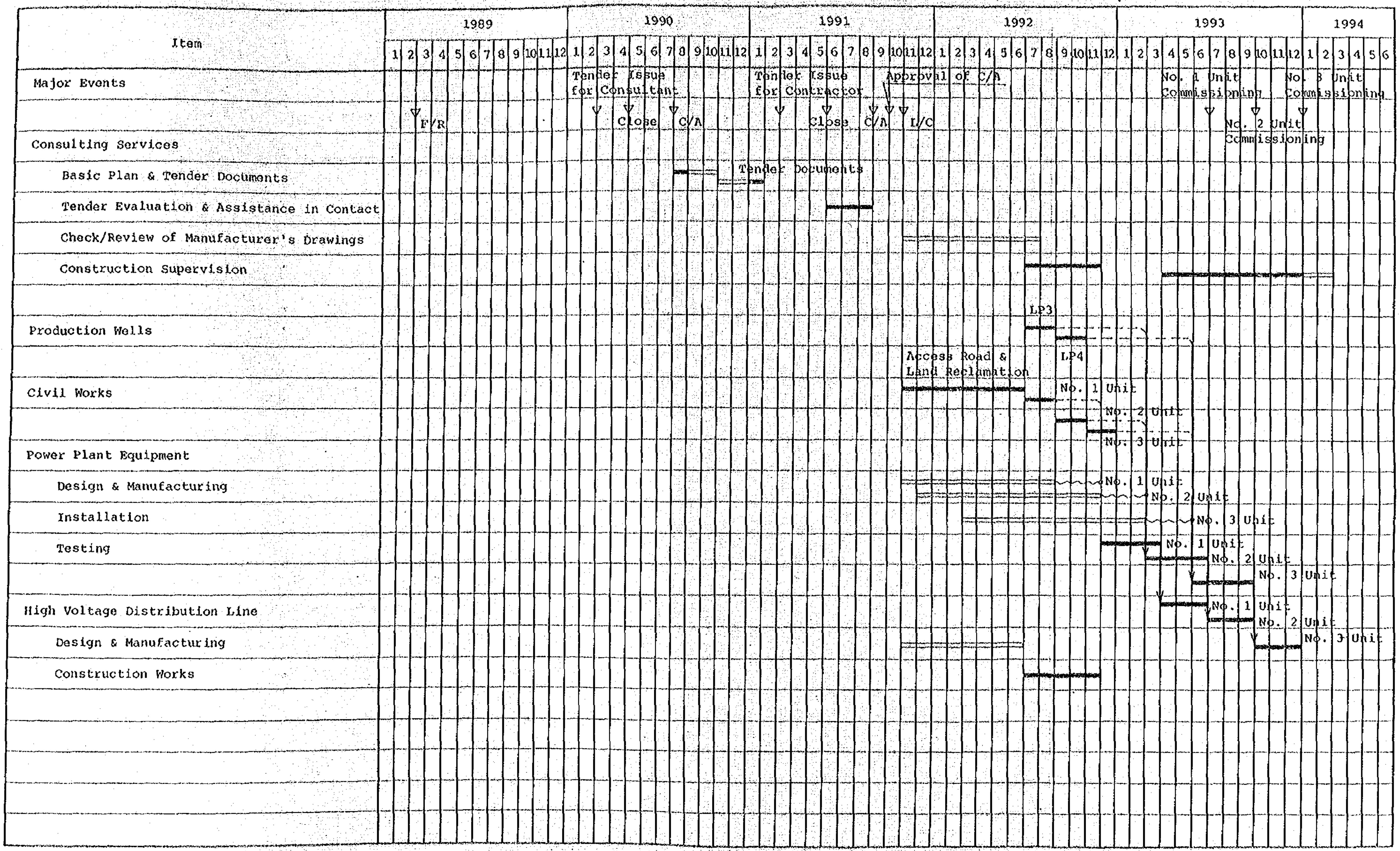
Fig. 3-12 FLOW DIAGRAM OF BACK PRESSURE TURBINE



KERINCI GEOTHERMAL POWER PLANT PROJECT

FIG.3-13 ONE LINE DIAGRAM

Fig. 3-14 Project Development Schedule



Note) ═ : Work in Japan, ▬ : Work in Indonesia, 〰 : Transportation

Fig. 3-15  Sensitivity of FIRR to Project Cost

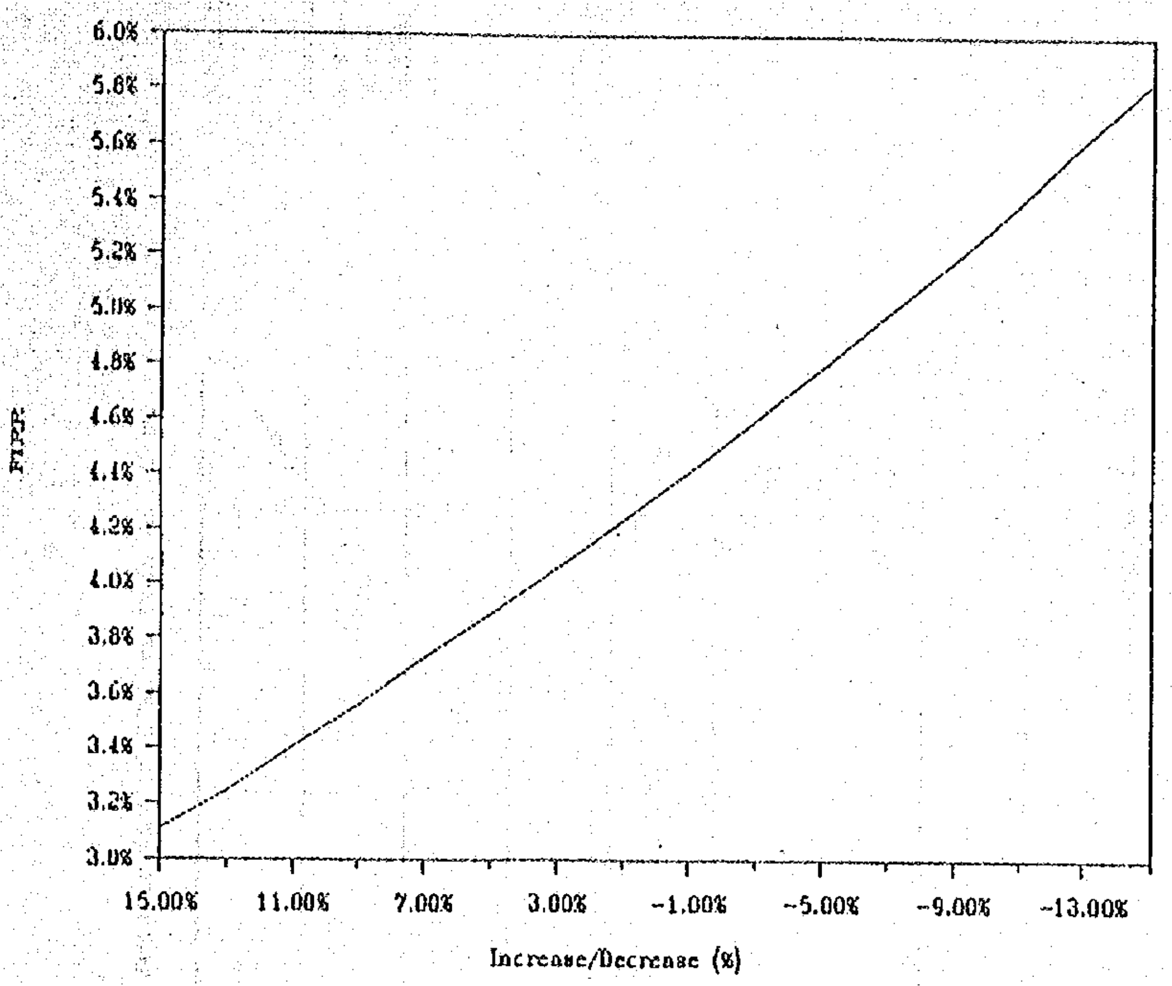
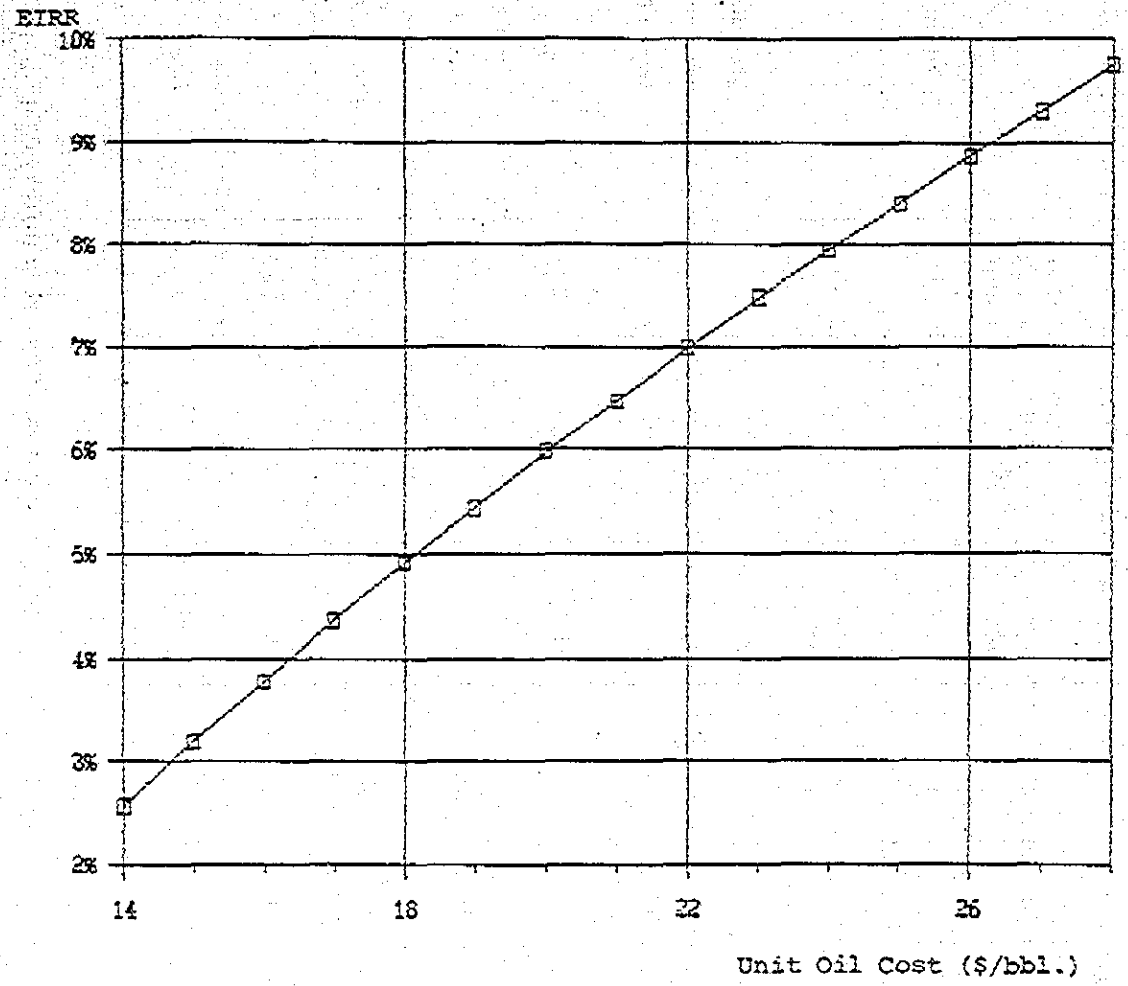


Fig.3-16 Sensitivity of EIRR to Unit Oil Cost



**Sensitivity of EIRR to Oil Cost**

| Unit Cost of Oil [US$/bbl.] | EIRR [%] | Fuel Save *1/ [$] |
|---|---|---|
| 14 | 2.56% | 476,919 |
| 15 | 3.19% | 510,984 |
| 16 | 3.78% | 545,050 |
| 17 | 4.36% | 579,116 |
| 18 | 4.92% | 613,181 |
| 19 | 5.45% | 647,247 |
| 20 | 5.98% | 681,312 |
| 21 | 6.48% | 715,378 |
| 22 | 6.99% | 749,444 |
| 23 | 7.47% | 783,509 |
| 24 | 7.95% | 817,575 |
| 25 | 8.41% | 851,641 |
| 26 | 8.87% | 885,706 |
| 27 | 9.31% | 919,772 |
| 28 | 9.76% | 953,837 |

Note: *1/: Fuel + Lub. oil

Table 3-1. Existing PLN Generating Facilities

| Power Plant | Type | Year Commissioned | Rated Capacity (kW) | Available Capacity (kW) | Fuel Consumption (l/kWh) |
|---|---|---|---|---|---|
| Sungai Penuh System | | | | | |
| Sungai Penuh | Diesel | 1977 | 336 | 268 | 0.360 |
| | Diesel | 1977 | 336 | 268 | 0.360 |
| | Diesel | 1982 | 520 | 470 | 0.320 |
| | Diesel | 1982 | 600 | 542 | 0.310 |
| Koto Lolo | Diesel | 1986 | 560 | 560 | 0.290 |
| | Diesel | 1986 | 560 | 560 | 0.300 |
| | Diesel | 1986 | 560 | 560 | 0.280 |
| Subtotal | - | - | 3,472 | 3,228 | - |
| Tapan | Diesel | 1982 | 100 | - | 0.398 |
| | Diesel | 1986 | 260 | - | 0.354 |
| | Diesel | - | 260 | - | - |
| Subtotal | - | - | 620 | 360 | - |
| Lempur | Diesel | 1986 | 100 | 85 | 0.350 |
| | Hydro | 1980 | 88 | 50 | - |
| Subtotal | - | - | 188 | 135 | - |
| Pulau Tengah | Diesel | 1981 | 220 | 200 | 0.351 |
| Siulak Deras | Diesel | 1985 | 100 | 87 | 0.439 |
| Kersik Tuo | Diesel | 1987 | 100 | 100 | 0.439 |
| Sanggaran Agung | Diesel | 1988 | 100 | 100 | 0.439 |
| Tamiai | Diesel | 1988 | 40 | 40 | 0.357 |
| Total | - | - | 4,840 | 4,250 | - |

Note: Tapan power plant is not located in Kerinci Regency, but in South Sumatra Province.

## Table 3 – 2 Energy Demand Forecast

Energy Demand Forecast
Location: SUNGAI PENUH (KERINCI)

PLN Wilayah : III
Cabang : PADANG

| Fiscal Year | 1985* | 1986* | 1987* | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residential | | | | | | | | | | | | | | | | |
| Population(10^3) | 278.9 | 285.8 | 292.9 | 300.2 | 307.6 | 315.3 | 323.1 | 331.2 | 339.4 | 347.8 | 356.5 | 365.3 | 374.4 | 383.7 | 393.3 | 403.0 |
| Person/Household | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Household (10^3) | 55.8 | 57.2 | 58.6 | 60.0 | 61.5 | 63.1 | 64.6 | 66.2 | 67.9 | 69.6 | 71.3 | 73.1 | 74.9 | 76.7 | 78.7 | 80.6 |
| No.of Consumers | 4924 | 7904 | 11316 | 13013 | 14835 | 16764 | 18776 | 20841 | 22925 | 24759 | 26740 | 28879 | 31189 | 33684 | 36379 | 39289 |
| Electr. Ratio(%) | 8.8 | 13.8 | 19.3 | 21.7 | 24.1 | 26.6 | 29.1 | 31.5 | 33.8 | 35.6 | 37.5 | 39.5 | 41.6 | 43.9 | 46.3 | 48.7 |
| Unit Consumpt.(kWh) | 552.2 | 400.8 | 407.9 | 414.3 | 420.8 | 427.5 | 434.2 | 441.1 | 448.1 | 455.1 | 462.3 | 469.6 | 477.0 | 484.6 | 492.2 | 500.0 |
| Energy Consumpt.(MWh) | 2719.3 | 3168.3 | 4615.4 | 5391.5 | 6243.4 | 7166.4 | 8153.1 | 9192.9 | 10271.9 | 11268.8 | 12362.5 | 13562.3 | 14878.5 | 16322.6 | 17906.7 | 19644.6 |
| Commercial | | | | | | | | | | | | | | | | |
| Constituent Ratio | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Energy Consumpt.(MWh) | 324.1 | 284.2 | 371.7 | 409.2 | 448.0 | 487.7 | 528.0 | 568.4 | 608.5 | 643.9 | 681.4 | 721.1 | 763.1 | 807.5 | 854.5 | 904.3 |
| Public & Others | | | | | | | | | | | | | | | | |
| Constituent Ratio | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Energy Consumpt.(MWh) | 445.4 | 364.6 | 571.4 | 629.1 | 688.7 | 749.8 | 811.7 | 873.8 | 935.4 | 989.8 | 1047.5 | 1108.5 | 1173.0 | 1241.3 | 1313.6 | 1390.1 |
| Industry | | | | | | | | | | | | | | | | |
| Captive Power(MWh) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 50.00 | 100.00 | 150.00 | 200.00 | 310.00 | 430.00 | 560.00 | 600.00 | 650.00 | 700.00 | 750.00 |
| Energy Consumpt.(MWh) | 148.9 | 369.5 | 485.2 | 524.0 | 565.9 | 661.2 | 764.1 | 875.2 | 995.3 | 1184.9 | 1399.7 | 1641.6 | 1813.0 | 2008.0 | 2218.7 | 2446.1 |
| Total | | | | | | | | | | | | | | | | |
| Energy Consumpt.(MWh) | 3637.6 | 4186.6 | 6043.7 | 6953.8 | 7946.0 | 9065.2 | 10257.0 | 11510.4 | 12810.9 | 14087.4 | 15491.0 | 17033.4 | 18627.6 | 20379.4 | 22293.5 | 24385.2 |
| Growth Rate (%) | 19.6 | 15.1 | 44.4 | 15.1 | 14.3 | 14.1 | 13.1 | 12.2 | 11.3 | 10.0 | 10.0 | 10.0 | 9.4 | 9.4 | 9.4 | 9.4 |
| Losses+ Plant Use (%) | 33 | 50 | 42 | 40 | 38 | 36 | 34 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 |
| Energy Product.(MWh) | 5406.6 | 8370.5 | 10424.0 | 11589.7 | 12816.1 | 14164.3 | 15540.9 | 16927.0 | 18301.3 | 19841.4 | 21515.2 | 23333.5 | 25172.4 | 27172.5 | 29333.5 | 31669.0 |
| Load Factor (%) | 39 | 42 | 40 | 40 | 41 | 41 | 41 | 41 | 41 | 42 | 42 | 42 | 42 | 42 | 43 | 43 |
| Peak Load (KW) | 1570.0 | 2268.0 | 2950.0 | 3307.5 | 3568.4 | 3943.7 | 4327.0 | 4713.0 | 5095.6 | 5392.9 | 5847.8 | 6342.0 | 6841.8 | 7385.4 | 7787.4 | 8407.4 |

di,spenuhl *) Actual DKL, September 1988

## Table 3-3 Project Financial Internal Rate of Return

IRR = 4.32%

| No. | Year | Capacity<br>[kW] | Capacity Factor<br>[%] | Generated Energy<br>[MWh] | Losses *1/<br>[%] | Energy Sold<br>[MWh] | Av.Unit Cost<br>[Rp/kwh] | Revenue<br>[K$] | Project Cost<br>[K$] | <--- O and M Cost ---><br>Well<br>[K$] | Power Plant<br>[K$] | Distrib. line<br>[K$] | Total Cost<br>[K$] | Profit<br>[K$] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1989 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1990 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 192 | 0 | 0 | 0 | 192 | (192) |
| 3 | 1991 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,096 | 0 | 0 | 0 | 3,096 | (3,096) |
| 4 | 1992 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5,031 | 0 | 0 | 0 | 5,031 | (5,031) |
| 5 | 1993 | 2,350 | 80% | 5,344 | 15.09% | 4,538 | 103.38 | 276 | 2,603 | 7 | 24 | 2 | 2,636 | (2,360) |
| 6 | 1994 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 7 | 1995 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 8 | 1996 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 9 | 1997 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 10 | 1998 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 11 | 1999 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 12 | 2000 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 13 | 2001 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 14 | 2002 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 15 | 2003 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 16 | 2004 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 17 | 2005 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 18 | 2006 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 19 | 2007 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 20 | 2008 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 21 | 2009 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 22 | 2010 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 23 | 2011 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 24 | 2012 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 25 | 2013 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 26 | 2014 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 27 | 2015 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 28 | 2016 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 29 | 2017 | 2,350 | 80% | 16,469 | 15.09% | 13,984 | 103.38 | 850 | 0 | 23 | 74 | 6 | 103 | 747 |
| 30 | 2018 | 2,350 | 80% | 11,125 | 15.09% | 9,446 | 103.38 | 574 | 0 | 16 | 50 | 4 | 70 | 504 |
| Total | | 61,100 | | 411,725 | | 349,600 | | 21,250 | 10,922 | 575 | 1,850 | 150 | 13,497 | 7,753 |

Note:*1/: Combined losses of station servaice and distribution losses

*** Cost Sensitivity ***

| Inc. % | T. Cost | FIRR |
|---|---|---|
| 15% | 12,560 | 3.11% |
| 13% | 12,342 | 3.25% |
| 11% | 12,123 | 3.41% |
| 9% | 11,905 | 3.56% |
| 7% | 11,687 | 3.73% |
| 5% | 11,468 | 3.89% |
| 3% | 11,250 | 4.06% |
| 1% | 11,031 | 4.23% |
| -1% | 10,813 | 4.41% |
| -3% | 10,594 | 4.60% |
| -5% | 10,375 | 4.79% |
| -7% | 10,157 | 4.99% |
| -9% | 9,939 | 5.19% |
| -11% | 9,721 | 5.40% |
| -13% | 9,502 | 5.62% |
| -15% | 9,284 | 5.84% |

## Table 3-4 Economic Internal Rate of Return

EIRR = 3.78%

| No. | Year | Sold Energy | [-- Cost of Project [COST] |  |  | ---] Total Cost (A) | [-- Cost of Alternative Project [BENEFIT] |  |  |  | ---] Total Cost (B) | [PROFIT] (B)-(A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Project Cost | O and M Cost |  |  | Project Cost | O and M Cost |  |  |  |  |
|  |  |  |  | Well | Power Plant |  |  | Power Plant | Fuel Cost | Lub.Oil Cost |  |  |
|  |  | [MWh] | [K$] | [K$] | [K$] | [K$] | [K$] | [K$] | [K$] | [K$] | [K$] | [K$] |
| 1 | 1989 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1990 | 0 | 179 | 0 | 0 | 179 | 0 | 0 | 0 | 0 | 0 | (179) |
| 3 | 1991 | 0 | 2,736 | 0 | 0 | 2,736 | 863 | 0 | 0 | 0 | 863 | (1,873) |
| 4 | 1992 | 0 | 4,479 | 0 | 0 | 4,479 | 863 | 0 | 0 | 0 | 863 | (3,616) |
| 5 | 1993 | 4,538 | 2,321 | 7 | 24 | 2,352 | 0 | 8 | 172 | 8 | 188 | (2,164) |
| 6 | 1994 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 7 | 1995 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 8 | 1996 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 9 | 1997 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 10 | 1998 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 11 | 1999 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 12 | 2000 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 13 | 2001 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 14 | 2002 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 15 | 2003 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 16 | 2004 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 17 | 2005 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 18 | 2006 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 19 | 2007 | 13,984 | 0 | 23 | 74 | 97 | 416 | 26 | 529 | 24 | 995 | 898 |
| 20 | 2008 | 13,984 | 0 | 23 | 74 | 97 | 416 | 26 | 529 | 24 | 995 | 898 |
| 21 | 2009 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 22 | 2010 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 23 | 2011 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 24 | 2012 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 25 | 2013 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 26 | 2014 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 27 | 2015 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 28 | 2016 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 29 | 2017 | 13,984 | 0 | 23 | 74 | 97 | 0 | 26 | 529 | 24 | 579 | 482 |
| 30 | 2018 | 9,446 | 0 | 16 | 50 | 66 | 0 | 18 | 357 | 17 | 392 | 326 |
| Total |  | 349,600 | 9,715 | 575 | 1,850 | 12,140 | 2,558 | 650 | 13,225 | 601 | 17,034 | 4,894 |