Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

ULUBELU, THE MOST DEVELOPED GEOTHERMAL AREA IN SOUTH SUMATRA.

Mulyadi
Pertamina, Divisi Panasbumi, Dinas Eksplorasi,
Jalan Merdeka Timur No. 6, Lantai 6, Jakarta
Phone (021)3502150 ext. 1658, Fax : (021)3508033
Email : DVPABEP@CBN.NET.ID

Key Words: Sumatra, Ulubelu, case history, conceptual model, geophysics, drilling.

ABSTRACT

Pertamina has explored the Ulubelu geothermal prospect in southernmost Sumatra, with extensive geological, geophysical, and geochemical surveys since 1989; the surveys indicated the potentially productive area cover over 50 km^2. The regional and topographic distribution of hot springs and fumaroles, and drilling results from three slim holes 900 to 1200m deep suggest that there is a liquid dominated reservoir overlain by a steam zone. The slimholes encountered temperatures as high as 210°C in hydrothermally altered andesite rocks. Numerous geochemical and mineralogical temperature indicators suggest the shallow part of the reservoir has recently cooled from 260-300°C to 210-225°C. The heat source for the reservoir appears to lie beneath either Mt. Rindingan in the northern part of the area and/or Mt. Kukusan in the southern part of the area.

Development of the Ulubelu prospect has been temporarily stopped by the Indonesian economic and political crises. Within the next five years, it is anticipated that development work will recommence at Ulubelu.

1. INTRODUCTION

The Ulubelu geothermal prospect is located in Lampung Province, in southernmost Sumatra (Figure 1). It is 80 km west (two hours by automobile) of the town of Tanjungkarang. Abundant hot springs, fumaroles, mud pots, and spatially associated hydrothermally altered rocks are found through the over 50km^2 prospect area at elevations ranging from 140 to 720m. As is commonly found through the world, the hot springs at lower elevations at Ulubelu have near neutral pH and discharge rates of 40 to 60 l/min. Thermal features at higher elevation have little or no discharge, and with pH's of 2 to 3, indicate the presence of a shallow steam zone above a deeper liquid reservoir. In 1989, Pertamina began performing a variety of reconnaissance geothermal exploration surveys in the area. In 1991, detailed surveys of DC-resistivity, gravity, and ground magnetic commenced. This was followed up with geochemistry surveys in 1992. A MT survey was further performed in 1993 to define deeper exploration targets. In 1995, the first of three slim holes was drilled to a depth of 1200 meters. Two other holes later reached depths of 900m. This limited work suggests that the area should be capable of generating at least 40 MW of electricity during the next five-year plan.

2. GEOLOGICAL SETTING

The Ulubelu area is located near the southern end of the strike-slip Sumatra Fault (Bemmelen, 1970). It is located in a volcano-tectonic depression at an elevation of 700 meters above sea level (Figure 2). During the Lower Miocene, volcanism deposited an andesitic breccia and tuff sequence locally intercalated with shale and limestone. This sequence was uplifted later in the Miocene during the intrusion of a granodiorite, which resulted in localized silicification and propylitization. Magmatism has continued into the Quaternary with andesite lava flowing from Mts. Sula, Rindingan, and Tanggamus. Dacite has been extruded from Mt. Duduk (Muchsin, 1989; PT Geoarsi, 1992; Pertamina, 1993).

The drilling encountered formations of andesite, dacite, black claystone, and compact sandstone. The black clay stone was encountered in holes UBL-1 and UBL-2. In UBL-1 and UBL-3, fresh andesite dikes with thickness of 40 to 60 cm were encountered.

Carbon dating of altered rocks indicates that some of the rock alterations occurred as recently as 2000-3000 years ago. An altered dike cutting through altered rocks in UBL-1 and UBL-2 has been dated at 0.23-0.560Ma, showing that hydrothermal alteration has occurred over a period of hundreds of thousands of years. Most of the formations in UBL-1 and UBL-2 showed evidence of hydrothermal alteration. This implies a that a large heat source is or has been present in the area.

3. GEOPHYSICS

3.1. DC-resistivity and MT

The DC-resistivity surveys consisted of 39 head-on stations, sounding Schlumberger stations, and 143 mapping Schlumberger stations. These results suggested the primary structural trend was NW-SE and parallel to the regional strike of the Sumatra Fault. The three wells were then targeted at the tentative NW-SE trending structures.

Although all three locations were inside the conductive area of the DC-resistivity map, hole UBL-2 was in a more resistive area of the MT-resistivity map (Figure 3). The MT survey contained 40 stations within an area of 150 km^2. The MT resistive area seems to act as an impermeable barrier separating the prospect area into north and south parts. Unfortunately, the slimholes are not in the most conductive areas due to time constraints in obtaining land use permits. MT resistivity sections are shown on Figure 4.

Some DC-resistivity sounding curves showed high resistivities beneath a shallower conductive layer but generally the upturned part of the curves consisted of only a few points. These anomalous curves may result from lateral variations of near-surface resistivity at the sounding spreads or due to AC effects. Therefore, there is not yet confirmation of the depth and the value of true resistivity of such a higher resistivity layer, which was obtained from UBL-2.

The locations of electrically conductive areas were delineated differently by DC-resistivity and MT (Figure 3); this may be more a reflection of their different depth of penetrations. Both techniques are presumably locating areas of hydrothermal alteration, which may define the border of the prospect area.

3.2. Gravity

A total of 413 stations were occupied to define both the regional and local gravity anomalies (Figures 5). Of these, 368 were in the immediate vicinity of the prospect area. The Bouguer gravity anomaly based on a density of 2.67 gr/cc is primarily related to topography. The gravity anomaly was high at the highest elevations when a density of 2.0 gr/cc was assumed. Therefore, it is important that the density of proper overall rock in the prospect area be determined so that the data can be reprocessed to give the most realistic results. An assumed density of among 1.8 and 2.0 gr/cc has the lowest dependence upon elevation (Pertamina, 1993).

3.3. Ground Magnetic

A total of 345 ground magnetic data points were obtained at the same places and times as the gravity and resistivity stations (Figure 6). Two types of total magnetic anomalies are present. A group of magnetic highs are present surrounding Mt. Rindingan, these are known as the North anomaly. A second group is a combination of magnetic's highs and lows and are known as the south anomaly, which appears to represent graben-like structures.

The low magnetic anomalies in the southern part of the Ulubelu area may be caused by altered or intruded rocks. These anomalies are within the MT low resistivity area. The low magnetic anomalies in the northern area may result from topographic effects or the presence of a reverse-magnetized andesite lava flow from Mt. Rindingan with a date of 1.41Ma (Mankinen and Dalrymple, 1979).

4. DRILLING RESULTS

4.1. UBL-1

Slimhole UBL-1 is located in the northern part of the southern low resistivity MT anomaly (Figure 3). Temperature, pressure, and lithological data from UBL-1 are shown on Figure 7. A static fluid level is present at depths between 600 and 800 m on the pressure logs. The pressure at 1160 m is 47 ksc.

Kuster-tool temperature profiles from well UBL-1 show evidence of both conductive and convective heattransfer. The maximum temperature is 210°C at depth of 1160 m in well UBL-1. Below the fluid level, the temperature gradient is quite low, but extrapolates to 250-260°C at a depth of 1750 m. An abnormally cold temperature that was found in the interval between 650 and 850m may represent either fluid lost during drilling or an influx of cold near-surface water into the reservoir.

The locations of four hydrothermal mineral assemblages from UBL-1 and the other two wells are shown on Figures 8. The three upper zones, smectite, mixed layer clays, and chlorite are interpreted to form an impermeable cap rock. These are similar to the first and second layers of the resistivity model (Figure 4), the overburden and a shallow conductive layer. The hotter chlorite-epidote zone with higher resistivity is interpreted to include the geothermal reservoir.

Lost circulation of drilling fluid occurred between depths of 400 and 800m. The permeability of this zone, calculated from pressure buildup data, is 3.55 mDarcy with a skin factor of + 1.53.

The UBL-1 slimhole was flow tested at a flow rate of 9ton/hr total mass with a 95% steam fraction at a wellhead pressure of 3.5ksc. However, a chloride content of 600-1000ppm indicates the actual steam fraction was probably in the range of 20% to 40%. The gas content was 0.006 mol% or 0.01 % by weight of the total mass; CO_2 was 92 mol% and H_2S was 1.5 mol%.

4.2. UBL-2

Slimhole UBL-2 is located between the two low resistivity MT anomalies (Figure 3) and encountered temperatures comparable to UBL-1, but failed to find significant permeability between depths of 600 and 800m. These impermeable zone correlates with the resistive substratum detected by MT survey (Figures 3 and 8).

4.3. UBL-3

Slimhole UBL-3 is located in the southern part of the northern MT low resistivity area (Figure 3). It was drilled to a depth of 950 m and encountered a maximum temperature of 215°C at a depth of 600 m. Below a depth of 700 m, the temperature is isothermal at 200°C.

5. GEOCHEMISTRY AND GEOTHERMOMETRY

Thermal springs at low elevations in the Ulubelu prospect have chloride contents of 600 to 900ppm and bicarbonate contents near 135ppm. This suggests that the primary reservoir is liquid dominated. Thermal features at high elevations have low content of fluoride, boron, and chloride indicating that they most likely originated from boiling of the primary reservoir. The HF and HCl contents of the gases are low, indicating that there is little or no magmatic gas contribution to the geothermal system.

The maximum temperature measured to date at UBL-1 is 210°C at a depth of 1160m. Extrapolating its temperature gradient to a depth of 1750m indicates formation temperatures of 250-260°C.

There are numerous chemical indications of higher temperatures. Gas geothermometry from samples obtained from UBL–1 (D'Amore and Panichi, 1980) suggest a reservoir temperature of 240-250°C. The Na-K-Mg (Figure 9) and the Na-K geothermometers suggest temperatures of 210-240°C and 220-250°C, respectively, for downhole samples collected from UBL-1. Chloride-enthalpy relationships suggest temperatures above 250°C (Pertamina, 1993).

The presence of epidote and platy calcite below depth of 600m in UBL-1 and UBL-3 suggests recent formation temperatures of 250-300°C (Kamah, pers. Comm, 1999). The discrepancy between the actual measured temperature and the predicted or inferred temperatures can be explained by some recent cooling of the shallow part of the geothermal system. Plotting the water and gas analyses from well UBL-1 in the CaO-K_2O-Al_2O_3-SiO_2-H_2O diagram (Figure 10) suggest that the temperature above a depth of 1160 m have recently cooled down from 260-300°C to 210-225°C.

6. THE ULUBELU GEOTHERMAL RESERVOIR

A tentative model of the Ulubelu geothermal system is shown on Figure 11. The primary liquid reservoir is located in permeable andesitic rocks below a depth of 1500m. The anticipated temperature is near 250°C. Above the deep liquid reservoir, there is a shallower and cooler reservoir with both steam and liquid in 1.5Ma andesitic lava flows from Mt. Sula. Altered basaltic and andesitic lavas from Mts. Rindingan, Duduk, and Kukusan may form the cap rock of the reservoir.

The MT survey suggests that a less permeable region separate two conductive anomalies, which is still quite hot. Heated fluids may be flowing through intrusive rocks beneath Mts. Rindingan in the northern part of the area and Mt. Kukusan in the southern part of the area. The fluids discharged from UBL-1 could be non-corrosive, since there is no indication of magmatic fluids in the geothermal system.

7. BUSINESS ASPECT & FUTURE DEVELOPMENTS

DATRA, an Indonesian company, teamed with a New Zealand company to propose a steam sales contract to Pertamina. Under terms of this contract, Pertamina would conduct exploration activities and drilling and provide steam to the DATRA/New Zealand partnership. The partnership would be responsible for financing of the plant and construction, and marketing the power to PLN, the Indonesian state-owned electrical power company. Unfortunately, the project appears to have stalled.

Recently, The Japan International Development Organization (JAIDO) and ORMAT Ltd., have proposed a power plant with third party funding, perhaps from the World Bank or from Japanese institutions. Pertamina and ORMAT have signed a MOU agreeing to cooperate in both upstream and downstream aspects. However, due to Indonesia's crises this project is not progressing.

Restarting geothermal development at Ulubelu requires waiting until the economic and political crises have been overcome. The crises and their impact on electrical demand have resulted in postponement of plans at several prospective geothermal areas. Now there is only single customer for geothermal electricity in Indonesia, PLN. Perhaps a partnership, with Pertamina and its partner, and PLN with its partner can perform to develop the Ulubelu prospect. Pertamina and its partner would be responsible for steam field development and PLN and its partner would be responsible for the power plant development. ORMAT is interested in working with PLN.

8. CONCLUSIONS

1. The Ulubelu prospect area is over 50km^2 and divided into northern and southern areas based on MT results.

2. The geothermal reservoir may be located in Lower Miocene andesitic rocks overlaid by younger andesitic rocks acting as a cap rock.

3. The geothermal system is liquid dominated with a shallow steam cap. Fluid temperatures of 250-260°C may be at depths below 1750m. The heat source may be intrusive bodies beneath Mt. Rindingan in the northern part and/or Mt. Kukusan in the southern part of the area.

4. The standard geophysical exploration methods have been used to try to define the boundaries of the Ulubelu prospect; three shallow slimeholes have provided information on subsurface conditions. In spite of this work, additional exploration wells or deeper slimeholes are needed to verify the tentative model.

5. Restarting geothermal development at Ulubelu may take five or more years, as investors are still waiting for economic and financial crises to subside.

ACKNOWLEDGEMENTS

We would like to thank the Management's Directorate of Exploration and Production, Pertamina, and especially the Management of the Geothermal Division for permitting publication of this work.

We are grateful to Dick Benoit, Oxbow Power Services, Inc., Reno Nevada, for reviewing and providing helpful critiscm of this manuscript.

REFERENCES

Bemmelen, Van, R.W., (1970). Gen. Geo. Of Ind. & Adjacent Arc. In : *The Geology Of Indonesia*, Vol.1A., Second Edit., Printed in Netherlands, pp. 732.

Mankinen, E. A., and Dalrymple, G. B., (1979). On the revised geomagnetic polarity time scale for the interval 0-5MA. *Jnl. Geophysics Res.*, No. 84, pp. 615-626.

Muchsin M., (1989*). Laporan geologi detil daerah Ulubelu, Lampung*. Report for Pertamina.

PT Geoarsi (1992). *Analisis foto udara dan landsat, daerah Ulubelu.* Report for Pertamina.

Pertamina (1993). *Scientific Model Of Geothermal System Of Ulubelu, Way Panas – Lampung*. Report for Pertamina,Unpubl.

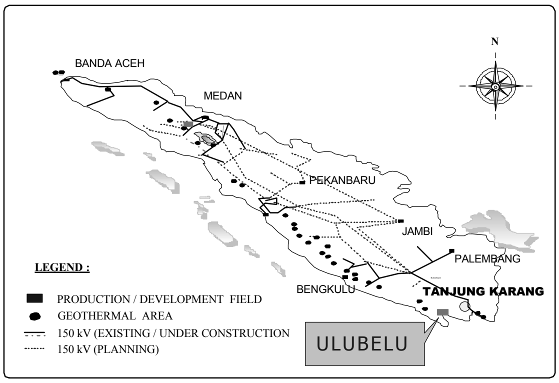

Fig. 1. Location of the Ulubelu geothermal area.

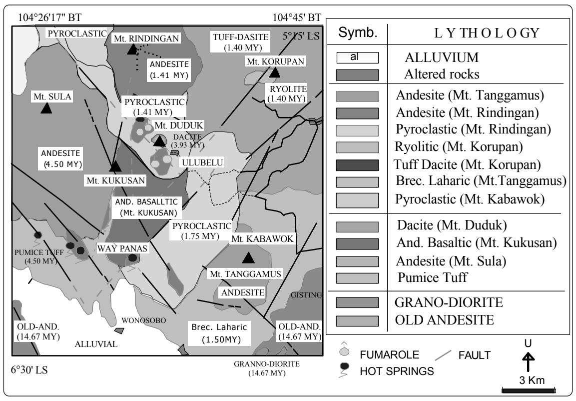

Fig. 2. Geological map of the Ulubelu area.

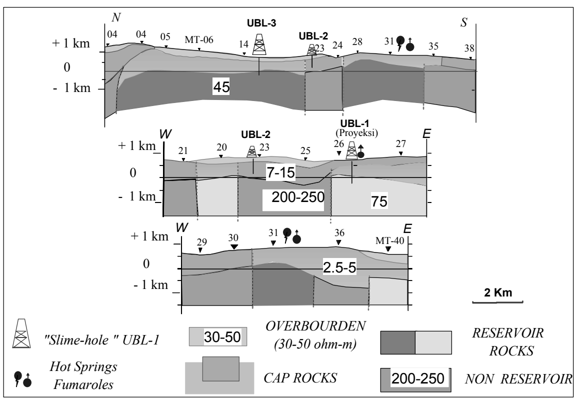

Fig. 4. MT-Resistivity sections of the prospect area.

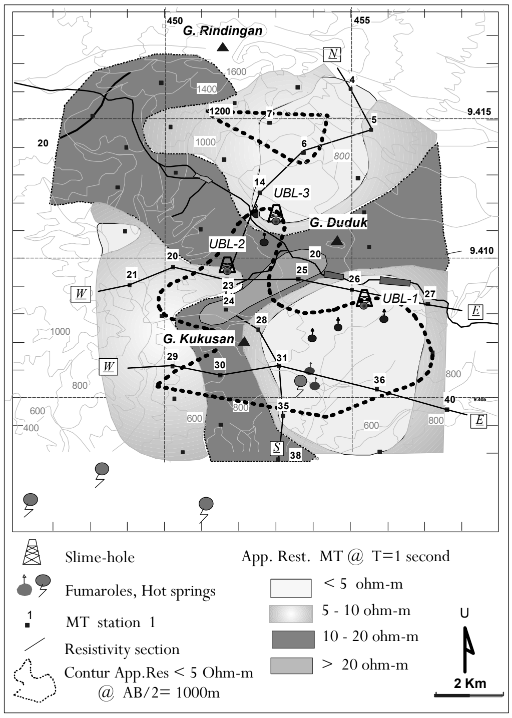

Fig. 3. Apparent resistivity map of the Ulubelu area.

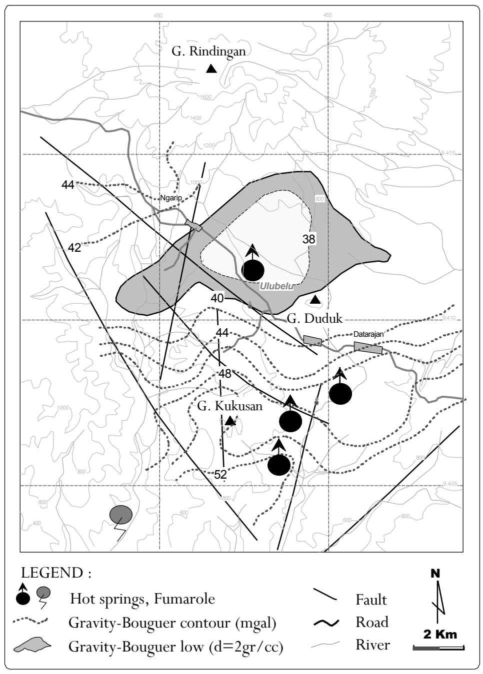

Fig. 5. Map of the gravity anomaly.

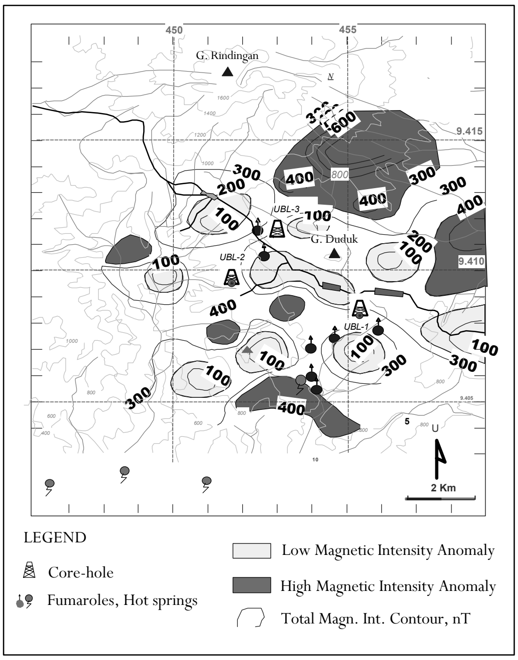

Fig. 6. Map of the magnetic anomalies.

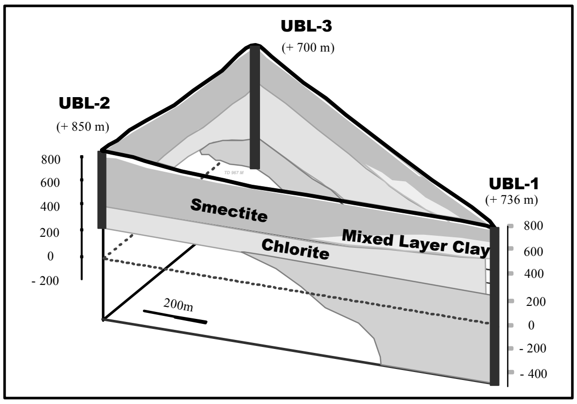

Fig. 8. Correlation between mineral zones.

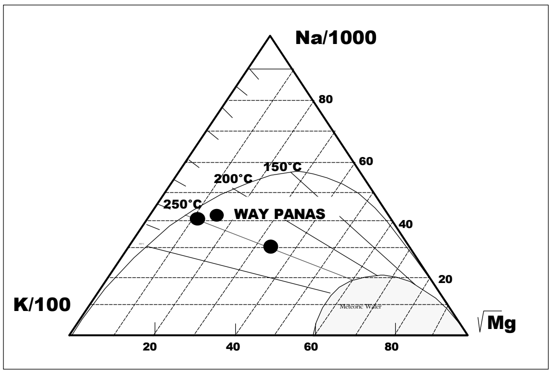

Fig.9. Chemical content of the springs in a Na-K-Mg diagram.

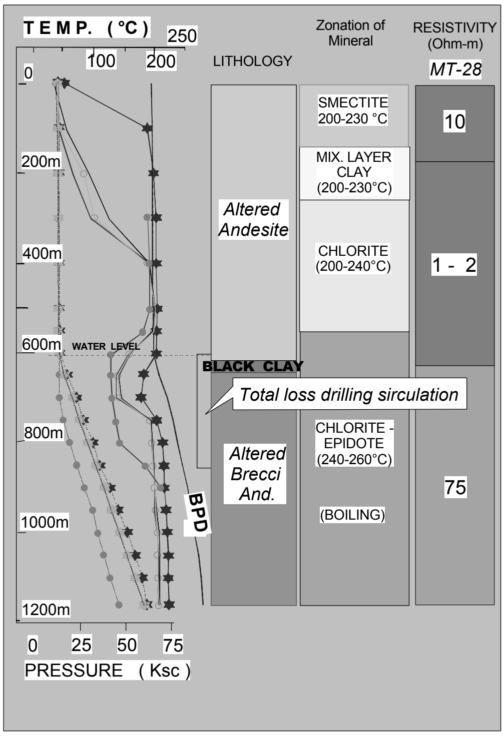

Fig. 7. The correlation of MT with UBL-1.

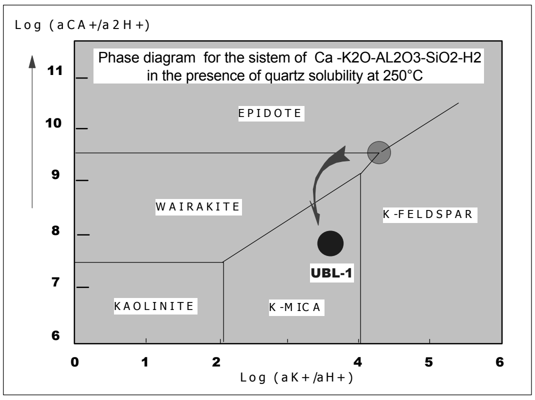

Fig.10. Chemical content of water from UBL-1 in a phase diagram.

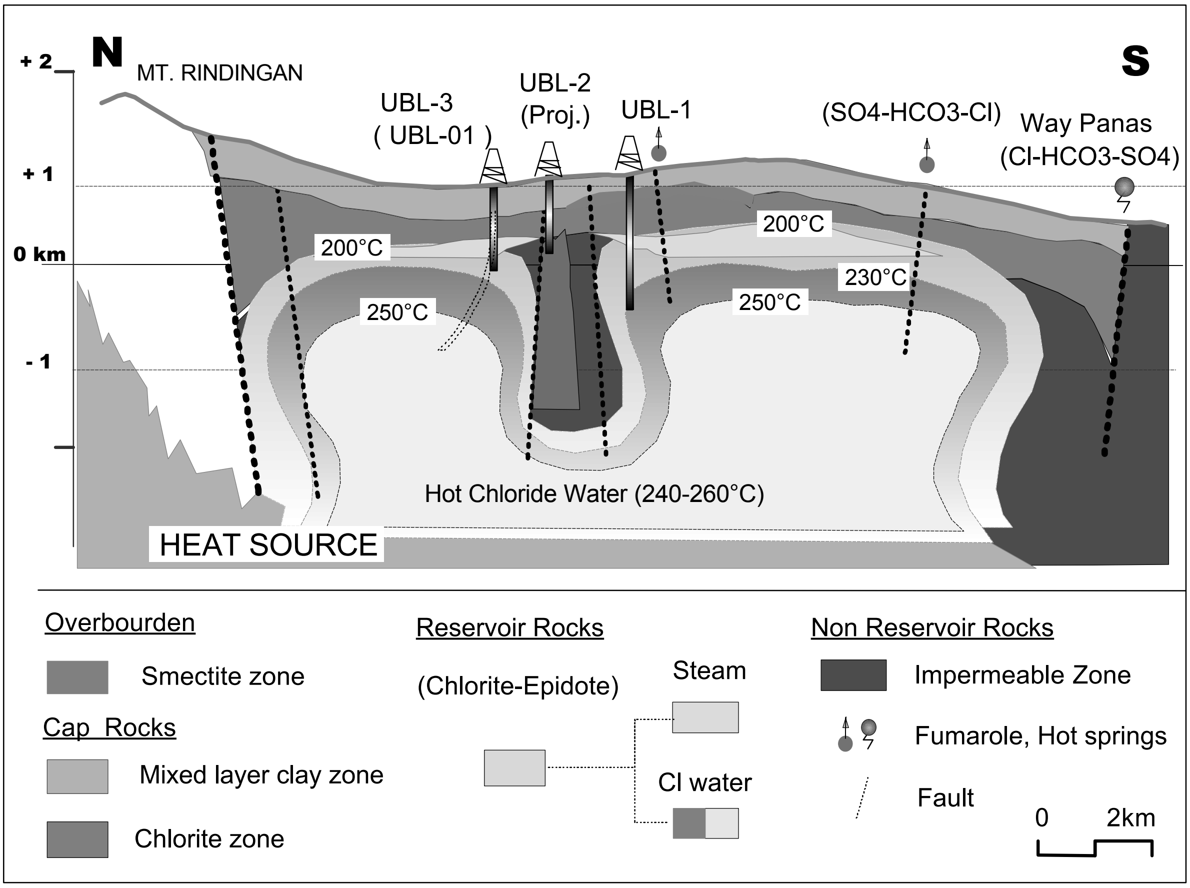

Fig. 11. Tentative model of the geothermal system of the Ulubelu area.