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COOLING INDICATIONS OF THE ULUBELU GEOTHERMAL SYSTEM, SOUTH SUMATRA, INDONESIA

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ABSTRACT

The Ulubelu geothermal field is located about 100 km northwest of the Southern Sumatra capital city of Bandarlampung. Pertamina has conducted exploration surveys in the area since 1990 and drilled three slim wells, i.e. UBL-1, UBL-2, and UBL-3, to determine its geothermal potential. Hydrothermal minerals such as limonite, kaolin and anhydrite were met in well UBL-1 at depths of about 650-800 m.This indicates mixing of deep hot water with cooler water. A zone of high temperature is indicated by wollastonite and epidote at a depth of about 940 m, while wairakite, prehnite and laumontite show that a lower temperature regime once occurred at the same depth. Fluid inclusions in quartz and anhydrite have a homogenization temperature of about 250-300°C and 270-305°C at both shallow and deep levels. The homogenization temperatures of fluid inclusions are much higher than measured temperatures but are consistent with the occurrence of hydrothermal minerals such as epidote in veins, prehnite, and wairakite. It is likely that the geothermal system of Ulubelu has already cooled but its deeper regions are still hot, at least 240°C.

1. INTRODUCTION

The Ulubelu geothermal area is located in Lampung Province, Southern Sumatra. It is at about 100 km west of Tanjungkarang. The town of Tajungkarang is about 1 hour flight from Jakarta (Figure 1). The area is an exploratory prospect that may become a producing geothermal field.

Pertamina investigated this area from 1990 to 1993 to assess its geothermal resources; this included reconnaissance surveys of the geology, fluid chemistry and analyses and a geophysical survey. By assessing the data, the investigators concluded that the area of the Ulubelu geothermal prospect is about $30km^2$ and has an electricity generation potential of 300 Mwe.

To confirm the geothermal system, Pertamina has also drilled three slim holes to depths of 1200 m, beginning in 1995. Unfortunately, only one well reached its target depth but the others reached almost 1000 m. However, after evaluating all the exploration data, the Ulubelu is assessed as capable of generating 2 x 20 MWe of electricity.

Cooling has taken place in many geothermal systems in Indonesia, although not in Lahendong whose heat source, (G.Lokon) is an active volcano.

The Ulubelu prospect is a geothermal system whose reservoir is controlled by the presence of structures and stratigraphically controlled permeability, respectively. This produces good permeability in both lateral and vertical directions. Fluid is heated as it moves within the reservoir. Where it does so the fluids separate naturally, because of pressure and temperature conditions, into two phases both derived from the parent fluid in the reservoir. Locally they heat up, or cool down, changing the thermal conditions in the reservoir.

Cooling takes place, in the upper part of the Ulubelu geothermal system, or at shallow depth in wells. The distribution of hydrothermal minerals from early activity to the present shows a cool water influx from a previous event. This paper records these events and relates them to the geothermal potential of the field.

2. DATA COLLECTING

2.1 Methods

Several methods were used to collect data, including microscope examination of cuttings and cores from wells, petrography of thin sections, X-ray diffraction, petrochemical mineral analysis, fluid inclusion geothermometry and measured downhole temperature.

2.2 Materials

Eighty-five samples, consisting of cuttings and cores recovered from the three slim holes were examined. The depth of well UBL-1 is 1200 m, UBL-2 927 m and UBL-3 967 m. Subsurface temperature data were collected during drilling and other data after completion of wells and their heating.

3. HYDROTHERMAL MINERALS AND DOWNHOLE TEMPERATURE

3.1 Hydrothermal minerals

Browne (1998) has shown that hydrothermal alteration may give an appreciation and understanding of the temperature, pressure and permeability, fluid and host rock composition and duration of thermal activity within a reservoir. Furthermore, the presence of a certain mineral assemblage has been applied to predict cooling, scaling, corrosion tendencies and to estimate the thickness of the eroded overburden (Reyes, 1989).

Minerals distribution and alteration zones

Some key hydrothermal minerals are laterally distributed in the reservoir. These are; sheet silicates (smectite, mixed layer clays, illite, chlorite and kaolin), framework silicates (wairakite, albite,

adularia and quartz) and orthosilicates (titanite, and epidote). The others are calcite, haematite, pyrite, wollastonite and actinolite.

The distribution of hydrothermal minerals, especially some key phases indicate a zonation pattern. The standard classification is that of Kristmannsdottir (1978), who is a famous Icelandic geothermalist; others refer to the New Zealand classification which also applies to Indonesia. The hydrothermal mineral zones are as follows:

Smectite zones; this covers depth of < 120 m where abundant smectite occurs supported by accessory pyrite, and chalcedony.

Mixed layer clay (MLC) zone: MLC zone or interlayer smectite-illite zone. This is indicated by the presence of interlayer smectite-illite in UBL-1 but this is absent in UBL-3. This zone is about 120 m thick and lies between the smectite and chlorite zones.

Chlorite zones; indicated by the appearance of abundant chlorite at a depth of 240-550 m. The accessory minerals are quartz, pyrite, carbonate, and hematite.

Chlorite-epidote and albite-adularia-epidote zones: These occur below 550 m. The bottom part (800-950 m depth) of UBL-3 also contains wairakite and prehnite. Past boiling is indicated by platy calcite at depth of 941 m in UBL-1 and 650-850 m depth in UBL-3.

Mineral and fluid inclusion geothermometry:

Browne (1978) described the distribution of calc-silicate minerals in terms of their temperatures of occurrence in active geothermal field. Bird et al. (1984) state that progressive dehydration during increasing temperature generates a series of temperature dependent calc-silicates. Calc-silicate minerals at Ulubelu include epidote, wairakite, prehnite, and titanite (sphene). Besides the calc-silicate minerals, the clay minerals are also useful for geothermometry. Some clays, such as kaolin, chlorite, monmorillonite, illite, and mixed layer clays provide information about their formation temperatures because of their structure. Harvey, at. al (1991) stated that these are sensitive to changes in temperature so that they are indeed, useful mineral geothermometers.

Based upon available data, the reservoir temperatures in the Ulubelu geothermal area can be estimated from the occurrence of some key minerals, as follows:

Epidote, which is abundant at 553 m depth, with its acicular crystals, indicates a temperature of about 250-330 °C (Browne, 1978; 1998). The mineral has an average size < 0.01mm and it replaces plagioclase in the matrix and also occurs in veins. This epidote is type 2-3 Reyes (1989).

Prehnite, which has a diagnostic bowtie texture has deposited in vesicle and vein fractures, as shown in cores from below 500 m depth. The temperature of occurrence ranges from 220-350°C (Browne, 1978;1998), 250-310°C (Reyes, 1989) 0r 250-350°C (Elders et al, 1984).

Illite, is a typical mineral for temperatures above 220°C (Browne, 1998). It appears initially in wells from the MLC zone to the chlorite-epidote zones.

Smectite, has a temperature range of 150-225°C (Harvey, et. al., 1991). It appears alone and sometimes together with illite, such as in the chloride zone.

Fluid inclusion studies have been conducted to assess whether a geothermal system is heating or cooling. A few cutting and core samples showed the presence of fluid inclusions in hydrothermal quartz and anhydrite. Quartz from cuttings of UBL-3 (475 m depth) host fluid inclusions that homogenised between 250 and 300°C. The others are trapped in anhydrite veins (695 m depth) and indicate homogenization temperatures of 270-304°C. Fluid inclusion in quartz (857m depth) give homogenization temperatures of around 240-260°C.

3.2 Measured Downhole Temperatures

By using Custer temperature logging equipment, downhole temperature data have been collected. The data is incomplete for wells UBL-3 and UBL-2, because of downhole problems like mixing of cuttings but UBL-1 data is more complete.

4. DISCUSSION

4.1. Comparison of present and the past temperatures

The present mineral temperatures match the measured temperature in some places, as indicated by the distribution of some key minerals (Figure 2).

Steam is discharged from the upper part of the reservoir, 500-650 m depth, through well UBL-1, at a measured temperature of about 200-212°C where the pressure is about 14 Kg/km^2. This indicates boiling. Minerals that appear in this zone include epidote, adularia, wairakite, and illite. This assemblage indicates temperatures above 220°C, so there has been no significant cooling in this zone since these minerals formed.

In the depth range 650-800 m, the measured well temperatures show a reversal down to 150-170°C, but the mineralogical temperatures are higher than 240°C as indicated by presence of epidote, prehnite, adularia, and illite. This phenomenon indicates cooling from an earlier state to the present situation.

Below 900 m depth the downhole temperatures are more or less isothermal vertically, around 220°C to 235°C or else indicate a small thermal gradient. The temperatures indicated by thermally sensitive minerals range from 260-300°C, i.e. epidote in veins, prehnite, amphibole, and wollastonite. The latert indicates a temperature of around 300°C. Wollastonite at the bottom of the well shows either that greenschist facies equivalent alteration occurred or it is due to low-grade calcareous metamorphism. The last mineral depositing event indicates cooling of about 50-60°C since the earlier episode.

4.2. Cooling in the Ulebelu geothermal system

Evidence of cooling in the Ulubelu geothermal system is described below (Figures 3 and 4).

Depth estimates

There is only one sure method to learn about subsurface conditions, namely drilling. We did not find any association between a subsurface resistivity layer and the cooling depth., The location of the top of the geothermal reservoir could however be estimated through subsurface resistivity soundings, some drilling parameters and minerals distribution. The cooling depth is indicated by minerals and also by the temperature against depth profile. Based on these features, cooling in the reservoir occurs from 650-800 m and below 950 m depth. The last location did not cool as much as the upper one because of the presence of convective fluid flow that continued.

Rock and mineral indicators

The andesite breccia unit at a depth of 650-800 m has been altered at medium intensity. It is dark brown in colour and predominantly composed of oxidation minerals, mainly limonite and haematite that indicate that cooler fluids entered here from the surface. Besides these, the presence of both kaolin and zeolite supports this interpretation. .Laumontite was also present in this zone as well as the chlorite-epidote zone or illite-epidote-adularia zone. The of Laumontite is thermally stable below 210°C. Cool water influx could promote the formation of this mineral. Other indications that cooling in the upper part of the reservoir is unconnected to the lower part is that gas geothermometry indicates a temperature of 240-260 °C.

Downhole temperature reversal

The present situation in the wells, especially UBL-1 is that there is a reversal found in the temperature profile, at about 650-850 m depth indicating cooling. There are two possible rasons for this. The first is that the reversal could be due to water used during drilling entering the formation at a total circulation loss. The water may have accumulated in the permeable zone and cooled the nearby system. The second possibility is that reversal is due to a cool water influx from the surface descending down a fault plane into the reservoir and accumulating in the permeable zone. Such an inflow would also cool the rocks there.

Thermal evolution

Several features indicate that cooling has occurred in the Ulubelu geothermal system. This is indicated, for example, by the sequences of hydrothermal minerals that occur in veins and vesicles (Kamah et. al., 1997). The presence of smectite in places indicates a temperature lower than about 150°C with interlayered illite-smectite representing temperature from 150°C to about 210°C. The highest temperatures (300 °C) are marked by occurrence of wollastonite. This is analogous to conditions of low-grade calcareous metamorphism (300-350 °C). Temperatures of 200-250 °C are indicated by prehnite which was the most recently deposited mineral. Its presence reflects thermal conditions now prevailing but some of the earlier deposited minerals show that cooling by perhaps 50 °C has occurred within some parts of the Ulubelu reservoir.

Plotting the fluid composition on a Chloride-Enthalpy diagram and a log CO_2-Temperature diagrams

Cooling in geothermal system could also be detected by plotting the composition of the well fluids on a chloride-enthalpy diagram. The chloride concentration is 1028 ppm and enthalpy of nearby 1000 kJ/kg. Both data show that the geothermal system is cooling down (figure 5).

The last minerals that were deposited, such as prehnite, indicated decreasing CO_2 partial pressure due to its earlier degassing during boiling (200-220°C). These conditions indicate cooling from the chlorite-epidote zone where the temperature is higher than 240°C. This process can also be seen in the log pCO_2-temperature diagram, adapted from Chiba (1991) as in Sawaki, at. al., 1997), and given in Figure 6.

5. CONCLUSIONS

Based on available data we conclude:

- That there has been cooling in the Ulubelu geothermal system, at depths down to 1000 m or –300 m depth with respect to sea level.
- The cooling has largely ceased as the measured temperature of 220°C is compatible with the presence of the youngest hydrothermal minerals in the reservoir.

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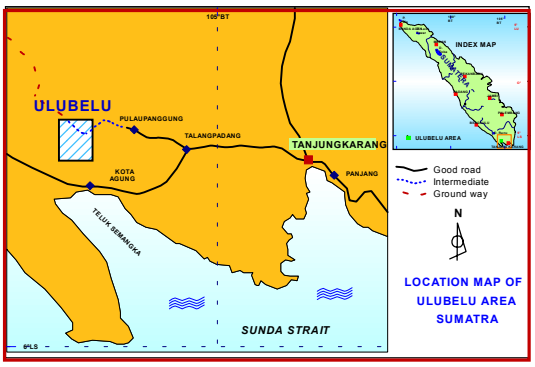

Figure 1. Ulubelu geothermal area, southern Sumatra, Indonesia.

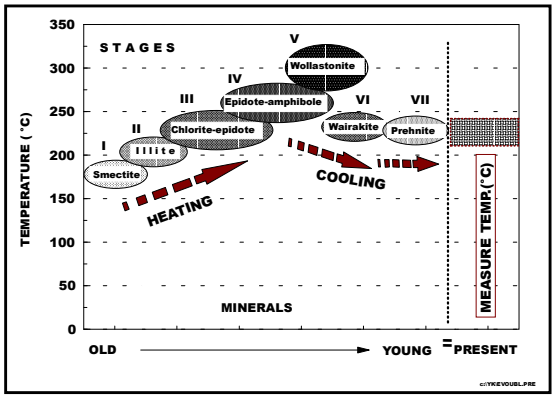

Figure 2. Thermal evolution of the Ulubelu geothermal field, Southern Sumatra, Indonesia

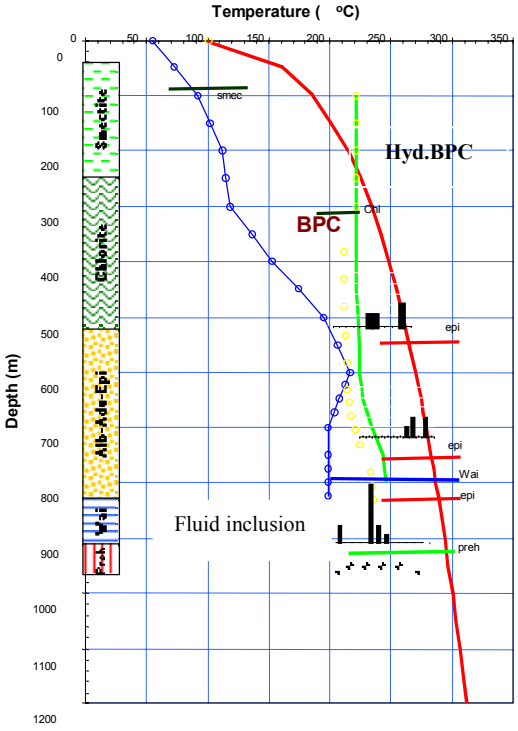

Figure 3. Fluid inclusion homogenization temperatures, mineralogy, measured temperature profiles and cooling indicators in well UBL-03, Ulubelu, Sumatra

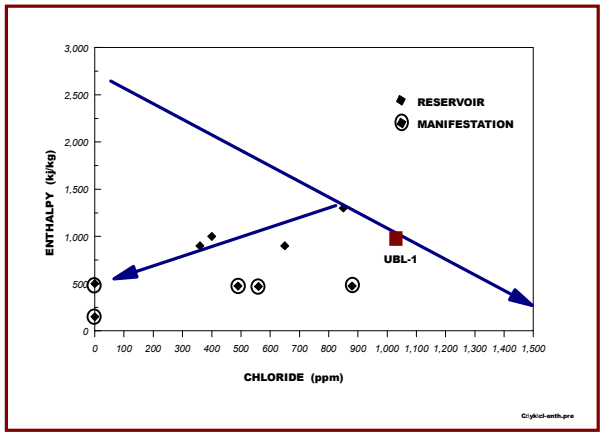

Figure 5. The Ulubelu reservoir setting in the chloride-enthalpy diagram

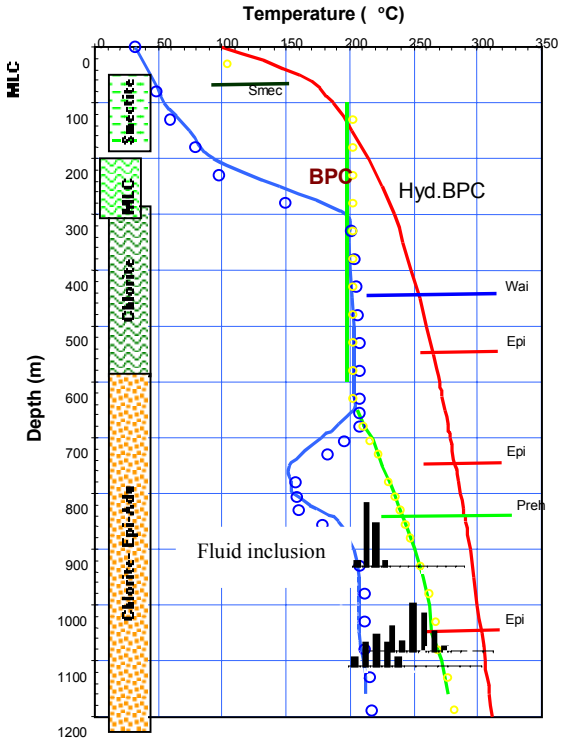

Figure 4. Fluid inclusion homogenization temperatures, mineralogy, measured temperature profiles and Cooling indicators in well UBL-01, Ulubelu, Sumatra

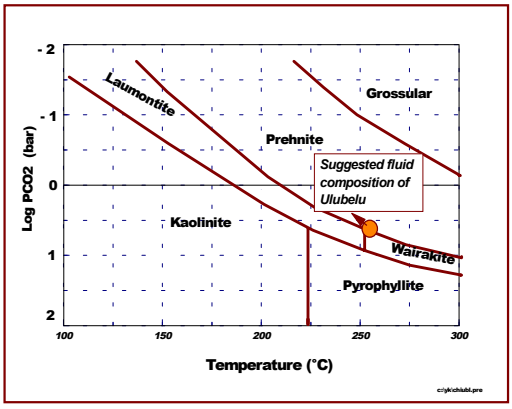

Figure 6. The last mineralogical evolution of Ulubelu geothermal systems in the K_2O-CaO-Al_2O_3-SiO_2-H_2O diagram.