HYDROTHERMAL ALTERATION OF THE GARUNG BANTEN GEOTHERMAL AREA, WEST JAVA

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SUMMARY - The Garung hydrothermal system is located within a positive gravity anomaly in the northern margin of the Rawa Danu caldera, 125 km to the west of Jakarta. The area studied is composed of porphyritic andesite belong to the Pre-Danu Volcano of Pleistocene age. Altered rocks in the area have been studied using a polarizing microscope, XRD, SEM and fluid inclusion geothermometry. Four distinct alteration types occur. An early event produced by alkali chloride water converted the primary rocks to an illite-chlorite assemblage. This alteration occurred at temperatures between 180 and 220°C and at fluid pHs between 4 and 5. The progressive drop of the reservoir water allowed an overprint of kaolinite-illite onto the illite-chlorite assemblage. Fluid inclusion geothermometry of quartz from this later assemblage indicated the altering fluid was at temperatures between 200 and 240°C. This suggests erosion as deep as 300 m has occurred. Descending acid sulphate and sulphate-bicarbonate fluids mixed with reservoir fluid to precipitate quartz and form pyrophyllite at low pH (2.5-4) and at temperatures above 250°C.

1. INTRODUCTION

The Garung geothermal system is located about 125 km west of Jakarta (figure 1). It lies in a positive gravity anomaly, north of the Rawa Danu caldera. Surface altered rocks are now the only geothermal features and these mainly outcrop along the Cikoneng, Cicukang and Cisampangtiga Streams. The Garung geothermal area is thus an extinct geothermal system.

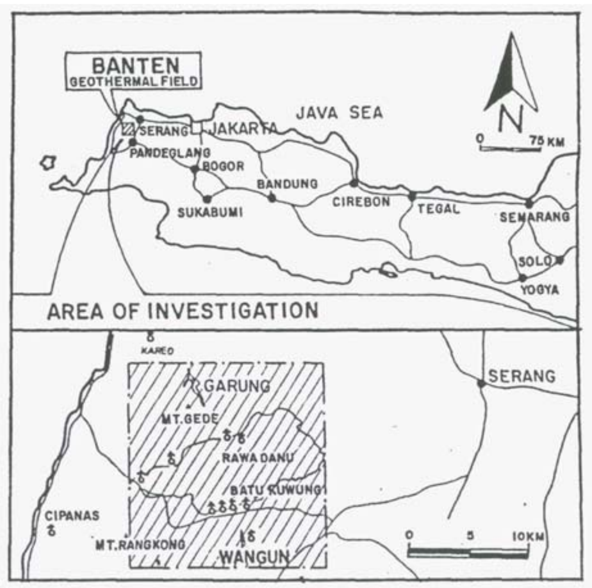

Figure 1: Location of the Banten geothermal area.

Mapping and detailed study of hydrothermal alteration in the area identified the extent of the former activity. In addition, the shallow paleohydrology, temperatures, chemical environment and the evolution of the system is described in this Paper.

2. METHODS OF STUDY

Twenty one altered samples of pyroclastic rocks and lavas were examined by using a polarising microscope, XRD, SEM and fluid inclusion geothermometry methods. XRD was used to identify the clay minerals fiom oriented, glycolated and samples heated to 550°C. Silicate and sulfide minerals were identified by XRD of bulk samples and using SEM techniques. Both the temperatures and apparent salinity of fluid inclusions trapped in a quartz vein from one sample were measured.

3. GEOLOGICAL SETTING

The geology of the area has been reported by previous workers (Van Bemmelen, 1949; Hayashi, 1975; Delarue et al, 1979; Suryadarma, 1990). The Rawa Danu volcanic complex was an eruption centre of pumice tuff which covers a large area, particularly in its northern part, and it is highly permeable but generally unaltered. Volcanic collapse formed the present Danu Caldera which has E-W and N-S diameters of 13 and 15 km respectively. The caldera was progressively filled by alluvial deposits approximately 400 m thick. The Rawa Danu eruptions were also accompanied by doming and block faulting.

Figure 2 shows a geological map of the area. The host rocks exposed mainly comprise basaltic andesite and andesite of Quaternary age. There are many faults confirmed or presumed present in the Banten area. Two major faults trend NW-SE and NE-SW, and minor faults trend ENE-WSW and N-S. The NW-SE fault is believed to control the Occurrence of the Garung alteration zone in the north and the Wangun area in the south.

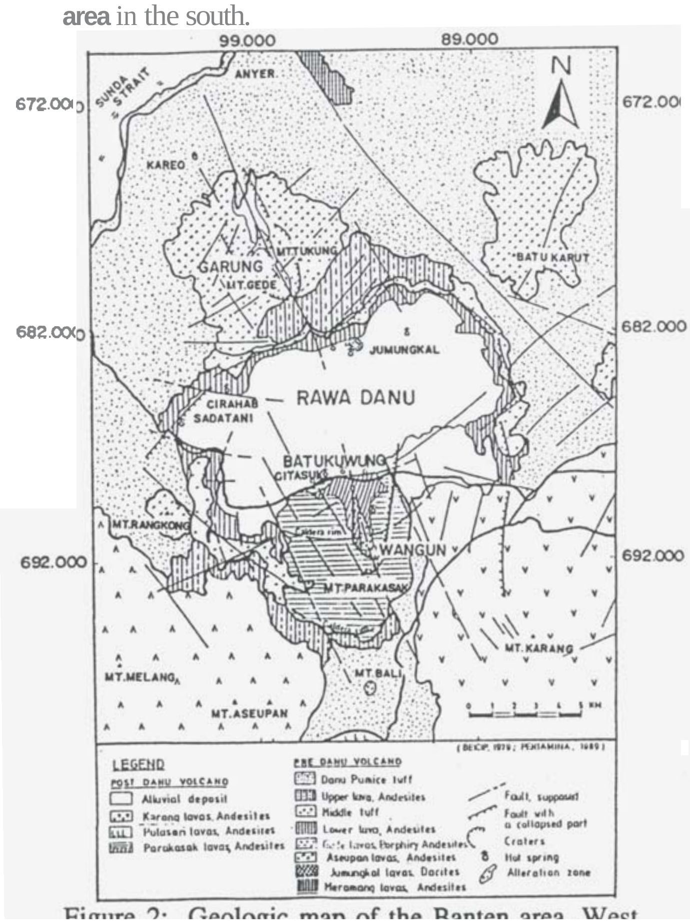

Figure 2: Geologic map of the Banten area, West Java.

4. HYDROTHERMAL ALTERATION AT GARUNG

The Garung hydrothermal zone is associated with andesite lavas of the G.Tukung and Gede centres. K/Ar dating indicates that these are 1.8 million years old. Figure 3 and Table 1 summarizes the zonation of their hydrothermal alteration and its characteristics.

Megascopically, the altered rocks consist of locally silicified patches, kaolin and disseminated pyrite. The rank of alteration and its intensity varies from moderate to strong. Narrow veins have been infilled by silica, iron oxides and pyrite. At the Cikoneng and Cisampangtiga Streams, the alteration produced yellow-green coloured clays associated with extinct solfataras. The altered rocks here contain abundant pyrite.

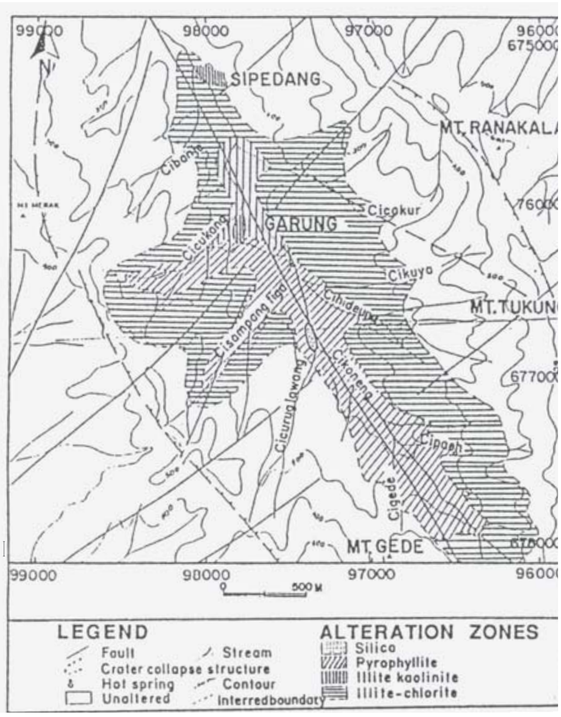

Fig. 3. Distribution of alteration zones in Garung, Banten geothermal area

The different types of alteration correspond to the the compositions of the fluids that produced them and their temperatures, as follows:

4.1 Silica zone

Local silicification of the Mt. Gede-Tukung pyroclastic rocks occurs in the Cicukang and Cikoneng Streams. The rock matrix and fragments are now completely filled and replaced by silica. These rocks are very resistant to erosion and weathering.

The main hydrothermal minerals identified are tridymite, cristobalite and minor quartz. The presence of tridymite, cristobalite and quartz is attributed to steam heating, such as occurs in Tongonan and solfataras on Davao, Philippines (Reyes, 1984).

4.2 Pyrophyllite zone

This zone is characterised by an assemblage of pyrophyllite + kaolinite + alunite + silica (dominantly quartz) ± *diaspore* ± gypsum ± anhydrite + abundant pyrite ± illite. The distribution of this zone is intense and mainly elongated along the Cikoneng Stream in the central part (figure 3). XRD and SEM study indicates that the most abundant minerals are alunite followed by pyrophyllite and kaolinite. SEM examination also confirmed the presence of minor jarosite and diaspore. Both jarosite and *diaspore* are products of acid alteration of the abundant pyrite present in rocks of the pyrophyllite zone.

Kaolinite is stable to temperatures of about 120°C, but can persist to 180°C. Alunite occurs at shallow depth where the temperature ranges from below 100°C to 230°C in association with quartz at Matsukawa (Hayashi, 1973) and at a temperature of about 280°C in southern Negros, Philippines (Reyes, 1984). Pyrophyllite may form at temperatures above 220°C from fluids supersaturated with respect to quartz. This assemblage is interpreted at Gurung to result from the descent of acid sulphate fluids. Rocks now exposed have been subject to erosion for 1.8 million years.

Figure 3 shows that the pyrophyllite zone is dominantly overlain by the chlorite-illite zone.

4.3 Kaolinite-illite zone

This alteration zone is characterised by the assemblage kaolinite ± dickite ± chlorite ± silica (quartz, minor cristobalite) ± illite ± calcite ± smectite. Rocks exposed in this zone have mostly undergone intense alteration and are highly fractured with veins of pyrite and quartz.

This type of alteration is characteristic of shallow zones with acid sulphate steam condensate (Henneberger & Browne, 1987), in which H_2S, separated from a deeper chloride water, has oxidised to H_2SO_4. This water then mixes with meteoric water and reacts with country rock to form an acid alteration assemblage. Hayashi (1973) concluded that the association of kaolinite + cristobalite or quartz is typical of fluid/rock interactions at temperature between 100 and 200°C where the fluid is acid. Chlorite and smectite are stable at temperatures to 140°C, while illite-montmorillonite is stable at temperature to about 180°C (Henley et al., 1984).

The kaolinite-illite alteration zone is most intense at lower elevations. XRD analyses revealed that the most abundant mineral here is kaolinite. This zone is interpreted to be transitional between kaolinite and illite at temperature between 120°C to 200°C.

4.4 Chlorite-illite zone

This alteration type is characterised by the assemblage chlorite + illite + silica (quartz, minor cristobalite) ± smectite ± apatite ± pyrite. This is predominant in the area and surrounds the three other alteration zones. It occurs at higher elevation along an axis trending NW-SE. Altered rocks exposed at higher elevations in the Cikoneng and Cicukang Streams have undergone weathering which indicates that the chlorite-illite zone formed earlier than the other three alteration zones.

The assemblage of chlorite-smectite-illite is stable in fluids of neutral to slightly acid pH and at elevated temperatures of the reservoir containing alkali chloride fluids. The presence of abundant illite, indicates that in this field it formed within an impermeable zone at temperatures above 220°C.

5. FLUID INCLUSION GEOTHERMOMETRY

Several quartz samples were doubly polished in order to make fluid inclusion studies. These derive from quartz veins in the pyrophyllite-illite alteration zone. No daughter minerals were seen, but inclusions measured were two phase and liquid rich. Homogenisation temperature data range from 202-230°C with most between 211 and 210°C. These temperatures correspond to the mineral temperatures indicated by the presence of pyrophyllite, quartz and illite which are usually stable together at temperatures >220°C (Browne, 1978).

Four measurements of Tm vary from -0.5 to -0.0°C which is equivalent to an apparent salinity of 1.0 wt% NaCl. However, the altering fluids were more likely to have been of acid sulphate type rather than alkali chloride type.

6. DISCUSSION AND MODEL OF THE GARUNG HYDROTHERMAL SYSTEM.

The four alteration zones of the Garung hydrothermal system are the silica, kaolinite-illite, pyrophyllite and chlorite-illite zones. These different types of alteration are due to different stages of activity, temperature and different depths, but they also record some changes in the nature of the system during its lifetime.

6.1 Stages of activity

The early activity started by the interaction of the andesites with near neutral to neutral pH recorded by the mineral assemblage of chlorite+illite+smectite+apatite of the illite-chlorite zone. The widespread illite-chlorite alteration is interpreted to have been produced by rocks interacting with neutral pH fluids. Thermal fluid may have reached this level at any time in the past 2 million years, i.e. following deposition of the lavas. The kaolinite-illite zone formed next. This activity was related to the descent of acid condensate fluids to transform illite to kaolinite. The distribution of the transition zone is believed to have been controlled by a NW-SE trending fault.

The presence of kaolinite in the kaolinite-illite zone was produced from rocks altered by steam heated waters as the piezometric surface descended after illite formed.

The descent of the alkali chloride water surface is believed to have allowed the pyrophyllite zone to form above it. This type of alteration also occurs in other active geothermal system e.g. Southern Negros (Reyes, 1984), Otake (Hayashi, 1973), Matsukawa (Sumi, 1968), Bacon-Manito (Leach et al., 1985) and Thames-Tapu area (Merchant, 1978). These writers agree that the diaspore-pyrophyllite assemblage formed under hot acid conditions. In addition, there is evidence from its fluid inclusions that pyrophyllite formed at temperatures >220°C.

6.2 Model for the generation of acid fluids

Several factors may have contributed to generate acid fluids in Garung, e.g oxidation of H_2S and their downward percolation through fissures. We propose the following model to account for the observed alteration in the Garung hydrothermal system; a schematic diagram is shown in figure 4.

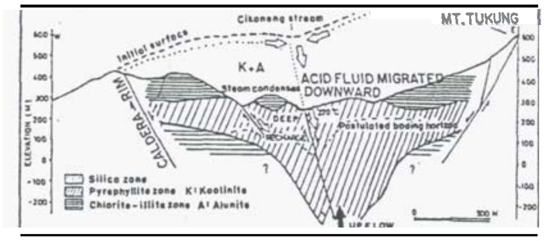

Figure 4: Proposed hydrological model of Acid Alteration in the Garung hydrothermal system.

Rocks now exposed at Garung are believed to be preferentially eroded along a NW-SE trending fault. This suggests that the zonation of acid minerals is consistent with the descent and progressive neutralization and heating of acidic fluids generated by oxidation of H_2S. The acid fluid penetrated down the NW-SE fault and associated fractures to produce a narrow zone of pyrophyllite alteration at greater depth. Mixing of cool acid fluid and hot silica saturated alkali chloride water in the reservoir precipitated quartz and anhydrite.

Local silicification on the margins of the Garung hydrothermal system may be due to the strong leaching of other constituents from the rocks by acid fluid or deposition of silica during alteration by neutral pH fluids in the earlier stage of activity.

7. CONCLUSIONS

The alteration observed at Garung indicates the following:

1. The Garung hydrothermal system is related to activity of the Rawa Danu Caldera and is controlled by a SW-NE fault along which fluids passed.

2. The surface hydrothermal alteration at Garung records changes in thermal activity. Most minerals formed at >220°C as is shown by the homogenisation temperatures of inclusions present in a quartz vein of between 202-236°C.

3. The early stage of activity in Garung involved neutral pH fluids. Upon cooling, the reservoir water level progressively dropped and the cool acid sulphate and acid sulphate-bicarbonate fluids descended, via the NW-SE fault, into the deeper reservoir. There, mixing of waters precipitates quartz and other hydrothermal minerals. Deeper penetration of acid sulphate fluid down the fault trace produced the pyrophyllite.

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TABLE. 1 : SUMMARY OF SECONDARY MINERALS IN THE GARUNG HYDROTHERMAL SYSTEMS

No.	SAMPLE No.	QUARTZ	CRISTOBALITE	TRIDYMITE	SMECTITE	KAOLINITE	DICKITE	PYROPHYLLITE	CHLORITE	PLAGIOCLASE	PYRITE	GYPSUM	ALUNITE	ILLITE	ANHYDRITE	CLAY	HEMATITE	CALCITE	IRON OXIDE	DIASPORE	APATITE	OPAQUES	HYDROTHERMAL ALTERATION TYPE	TEMPERATURE & ENVIRONMENT
		SECONDARY MINERALS																						
1	126	o	-	■	-	-	-	-		-		-			-	-	-	-	o	-	-	-	SILICA ZONE	T<180°
2	79	Xo	-		-	X	-	-	X	X	Xo	-			-	-	-	-	X	-	-	X	KAOLINITE ZONE	pH : 4
3	22	●	●	-	-	●	-	-	-	●	-	-		●	-	-	-	-		-	-	-		T:120"
4	23	X	-		X	X	-	-		-		-		X	-	-	-	X		-	-	-		
5	24	●o	-	■	-	●o	●	-		-		-			-	-	-	●		-	-	-		
6	56	+●o	-		-	●		●		-	+o	-	●		-	-	-	-		●	-	-	PYROPHYLLITE ZONE	pH : 3. T<220°
7	62	Xo	-	X	-	-	-	X	X	-	X	-		X	-	-	-	-		-	X	-		
8	50	X	-		-	-	-	X		-		-		X	-	-	-	-		-	-	-		
9	81	-	-	■	-	●	-	●		-		-	●		-	-	-	-	o	-	-	-		
10	110	●o	●		-	-	●	●		-	o	-	●		-	-	-	-		●	-	-		
11	72	●o	-		-	-●	-	+		-	o	o	●		●	-	●	-		-	-	-		
12	94	●o	-		-	-	-	-		-		-			-	-	-	-		-	-	-		
13	27	Xo	-		-	-	-	-	X	-		-		X	-	-	-	X		-	-	X	CHLORITE-ILLITE ZONE	pH : 4 - T<220°
14	33	Xo	-		-	-	-	-	X	-		-		X	-	-	-	-		-	-	X		
13	36	-	●		●	-	-	-		●	o	-		■	-	-	-	-		-	-	-		
16	48	X	-		-	-	-	-	X	-		-		X	-	-	-	-	-	-	-	-		
17	84	●o	●		●	-	-	-		●	o	-		■	-	-	-	-		-	-	-		
18	96	X	-		-	-	-	-	X	-	X	-		X	-	-	-	-		-	X	X		
19	99	X	-		-	-	-	-	X	-	X	-		X	-	X	-	-		-	-	X		
20	117	X	-		-	-	-	-	X	-		-		X	-	X	-	-		-	-	-		
21	122	X	-	-	-	-	-	-	X	-		-	-		-	X	-	-		-	X	X		

NOTE : : PETROGRAPHIC ANALYSES :X-DO ANALYSES o : MEGASCOPIC ANALYSES + : SEM ANALYSES