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

CHARACTERISTICS OF THE KAMOJANG GEOTHERMAL RESERVOIR (WEST JAVA) AS REVEALED BY ITS HYDROTHERMAL ALTERATION MINERALOGY

Pri Utami
Dept. of Geological Engineering and Geothermal Research Center , Faculty of Engineering, Gadjah Mada University
Jalan Grafika 2, Yogyakarta 55281 Indonesia. Phone & Fax: 0062-274-902216

Key Words: geothermal reservoir, hydrothermal alteration, Kamojang field

ABSTRACT

Kamojang, the first Indonesian operating geothermal field, has been producing electricity since 1983. The estimated field area is about 21 km^2, and its potential is about 300 MWe. Seventy wells had been drilled by the end of 1996. The field is currently producing 140 MWe from 24 production wells, with 4 make-up and 3 reinjection wells (Sudarman, *et al*, 1995).

The reservoir rocks encountered by drilling comprise interbedded pyroclastics and lavas of andesitic composition with some basaltic andesite and lacustrine tuffs. There are two hydrothermal mineral assemblages present, namely those produced by "acid" and "neutral" pH fluids. The "acid" assemblage occupies shallow levels (from surface down to 100 - 300 m) and comprises kaolin, smectite, alunite, quartz, cristobalite, and pyrite. The "neutral" assemblage, which occupies deeper levels, consists of varying proportions of quartz, adularia, albite, epidote, titanite, wairakite, laumontite, calcite, siderite, hematite, pyrite, anhydrite, smectite, chlorite, illite, and interlayered clays.

The present-day measured downwell temperatures are lower than those indicated by the alteration mineralogy by about 10 - 50^{o}C and fluid inclusion homogenisation temperatures by about 60^{o}C. This may record a previous hotter regime, but alternatively the measured temperatures may be too low.

The field is now vapor-dominated but the hydrothermal minerals show that the rock-altering fluid was dominantly a liquid. At the time the observed mineral assemblages were formed, the depth of the boundary between the steam-condensate layer and the deep reservoir fluid may have been located at about 200 - 300 m depth, but this has now dropped to depths varying from 544 to 1700 m. The depths of the sulfate-rich water penetration in the past varied irregularly from 200 down to 1800 m.

Vein assemblages mark the presence of high channel permeability in the past. The domination of conduit flow type is supported by the absence of well-defined interlayered clay sequences. Although the permeability has decreased due to mineral deposition, petrographic evidence, such as sheared cores and secondary minerals with deformed cleavages indicate a deformation events after their deposition. This may have created new permeability that helped sustain the system .

1. INTRODUCTION

The Kamojang geothermal field is located in high volcanic terrain in West Java (Indonesia), 1500 m above sea level. It is the first operational field in Indonesia and has been producing electricity since 1983. This research aims to reveal the characteristics of the Kamojang reservoir based on its hydrothermal mineralogy. This includes its thermal regime, fluid chemistry, structure, the nature of its permeability, and possible changes that happened during its lifetime, mainly based on integrated petrologic observations of cores and cuttings from 7 wells drilled to depths ranging from 536 - 1804 m. These wells are KMJ-7, KMJ-10, KMJ-12, KMJ-53, KMJ-59, and CHR-1.

The field lies on the Rakutak - Guntur volcanic chain, 1500 m above sea level. The surface manifestations, which consist of hot pools, fumaroles, mud pots and hot springs, are located in the so called Kawah Kamojang area. The major lithologies in the studied wells are andesite ash, andesite lava, andesite breccia, and andesite tuff.

This paper presents the characteristics of the Kamojang reservoir based on its hydrothermal mineralogy. This includes its thermal regime, fluid chemistry, structure, the nature of its permeability, and the possible changes that happened during its lifetime. The materials used for this study were cores and cuttings recovered from wells KMJ-7 (monitor well, 536m), KMJ-10 (dry, 763m), KMJ-11 (production well, 1029m), KMJ-12 (production well, 1500 m), KMJ-53 (exploration/production well, 1300m measured depth), KMJ-59 (exploration/production well, 1298m measured depth) and CHR-1 (exploration/production well, 1804m). The samples were kindly provided by PERTAMINA. Since some samples are no longer now available, the descriptions made by other workers (Wood, 1975; Browne, 1977; Healy, undated; Purba, 1994) are incorporated into the discussion. The location map of the studied wells is presented in Fig. 1.

2. METHODS

In this study the identifications of rocks and minerals were made by using a hand lens, a binocular microscope, a petrographic microscope, an X-ray diffractometer (XRD), an electron microprobe (EMP), and a scanning electron microscope (SEM). The petrographic microscope was used to identify minerals based on their optical properties, to determine their textural relationships and to estimate the intensity of rock alteration. The XRD used oriented clay samples and an SEM was used to identify the clay minerals. Fluid inclusion geothermometry was utilised to deduce the temperatures of the trapped reservoir fluids as well as their apparent salinities.

3. RESULTS

3.1. Hydrothermal Alteration

The primary minerals present in the Kamojang subsurface rocks are mainly feldspar (andesine-labradorite), pyroxene (hypersthene and augite), and olivine (forsterite). The subsurface rocks are mostly intensely or very intensely altered. There are 2 styles of alteration, namely direct deposition and replacement. The hydrothermal minerals present are silica, feldspar, calc-silicates, zeolites, carbonates, iron oxide, and iron sulfides, sulfate, and clay groups. Interlayered clays are very common in Kamojang but they do not vary systematically downwell. The hydrothermal minerals and their general occurrences are summarised in Table 1.

3.2. Nature of permeability in reservoir rocks

Vertical permeability is probably due to normal faults and their associated joints. These structures have been recognised from lineaments on aerial photographs and LANDSAT images, as well as from mapping. Their presence is also recorded in the subsurface rocks; for example, core from 465-657 m depth in well KMJ-12 contains slickenslides.

Most of the subsurface rocks have vugs and veins. The width of the veins ranges from 0.25 to 3 cm. Most of the veins are partly or completely sealed with hydrothermal minerals. The vugs have maximum diameters of 6 mm, with averages of 1.5 - 2.5 mm. Most of them are also filled with hydrothermal minerals.

Hydrothermal mineral deposition may cause channel blockages, but tectonic activity has created new joints and re-opened sealed channels. This process is recorded by some veins. Bent calcite cleavages and quartz with undulose extinction suggests that some deformation occurred after these minerals were deposited.

3.3. Fluid Inclusion Geothermometry

Double-sided polished anhydrite crystals from veins were prepared for fluid inclusion geothermometry, ie. two from well CHR-1 (1725m) and four from well KMJ-12 (995m). The fluids in all samples were predominantly of 2 phases (liquid plus vapor), with the vapor to liquid ratios ranging from 0.2 to 0.4.

For well KMJ-12 (995 m) the homogenisation temperatures (T_hs) mostly fall within the range of 240-245^oC, which is about 30^oC higher than the present well temperature (190^oC) at this depth. The T_hs mode for well CHR-1 (1725 m) is within the range of 245 - 250^oC, ie., about 60^oC above the downhole temperature (185^oC). Figures 2A & B plots the fluid inclusions' homogenisation temperatures, hydrostatic boiling point versus depth curve, and borehole temperature profiles.

The ice melting temperatures (T_m) of the fluid inclusions from well KMJ-12 (995) fall into the range of -0.2 to -4^oC; these values correspond to apparent salinities of 0.35 to 6.43 wt% NaCl (calculated using the formula of Potter *et al*, 1978). The T_ms for well CHR-1 (1725 m) range from -0.2 to -0.9^oC, which correspond to apparent salinities of 0.35 to 1.56 wt% NaCl.

4. RESERVOIR CHARACTERISATION

4.1. Hydrothermal Minerals & the Altering Fluid

There are two distinctive hydrothermal mineral assemblages at Kamojang, namely the "acid" and the "neutral" assemblages, which occur in shallower and deeper levels, respectively. The "acid" assemblage occupies the shallower level of the system (from near surface down to 100-300 m), and is characterised by the presence of kaolin with or without smectite, alunite, quartz, cristobalite, and pyrite. The deeper, "neutral" assemblage comprises quartz, adularia, albite, epidote, titanite, wairakite, laumontite, calcite, siderite, titano-hematite, pyrite, anhydrite, smectite, chlorite, illite, and interlayered clays. Both assemblages indicate that the altering fluid was liquid.

Hydrothermal mineral parageneses and cross-cutting vein relationships at deeper levels (below the "acid" assemblage zone) suggest that although this field has undergone at least three hydrothermal episodes (Utami and Browne, 1999), the composition of the altering fluid was always of neutral pH. For example, some veins, filled with only quartz, or quartz+wairakite-/+calcite-/+anhydrite, are cut by others of quartz+ pyrite,

4.2. Hydrothermal Alteration and Reservoir Structure

The presence of two distinctive assemblages can also be utilised to help characterise the possible hydrological structure of the reservoir at the times of their formation, i.e., the depth of the boundary between the steam-condensate layer and the deep reservoir fluid and the maximum depth of the sulfate-rich water penetration.

The shallowest occurrence of calcite in wells seems to coincide with the deepest occurrence of kaolin (Table 2). Kaolin forms from the steam-heated water, and calcite will not survive in the resulting acid conditions. Therefore, the deepest occurrence of kaolin should mark the base of more acidic condensate layer, and the shallowest occurrence of calcite may indicate the top of neutral pH, sodium sulfate-bicarbonate water. The depths of this boundary (at the time the observed mineral assemblages formed) in wells KMJ-7 and KMJ-10 is possibly at around 100 m depth. In well CHR-1 it may be located at about 220 m. In wells KMJ-11, 12, 53, and 59 it is likely to occur at around 300 m depth.

In the wells studied anhydrite occurs irregularly from 200 down to a maximum depth of 1800m. Anhydrite forms due to the presence of sulfate water that percolates down to these depths and then becomes neutralised by reacting with host rocks and conductively heated.

4.3. Hydrothermal Alteration & Reservoir Temperature

Among the calc-silicates minerals, wairakite, laumontite, and epidote are usually used as temperature indicators. A comparison of borehole and calc-silicate mineral formation temperatures in Kamojang is presented in Table 3.

At Kamojang, there some clay zonations apparent in the studied wells. The shallowest part (down to about 300m) of wells CHR-1, KMJ-12, KMJ-7, and KMJ-53 is dominated by kaolin and smectite, which are stable at ambient temperature to about 80^oC. The intermediate depths are dominated by chlorite, or chlorite plus smectite (sometimes with illite), or chlorite plus interlayered clays. In well KMJ-10 chlorite is stable at < 100 - 150°C, but chlorite, illite, and smectite with interlayered clays are present together at < 75 - 100°C. In other wells, chlorite plus other clay species are stable at varied measured temperatures. The alteration mineralogy in the deeper parts of wells CHR-1, KMJ-53, and KMJ-59 is dominated by chlorite and illite; here the temperatures range from 200 - 23°C. Illite is usually stable above 220°C (Browne, 1995). Illite and chlorite occur at 1725 m in well CHR-1 where the measured temperature is about 185°C, but the fluid inclusion Ths range from 230 -257°C. These also suggest cooling at this depth, or alternatively the well was not thermally stable when the temperatures were measured. Interlayered clays present do not show progressive sequences, and so they can not be used to deduce temperatures.

4.4. Hydrothermal Alteration &Reservoir Permeability

Aside from the presence of sheared rocks and deformation features in some vein minerals, the following hydrothermal minerals indicate high permeability because they are common in known permeable zones elsewhere: quartz, calcite, and anhydrite in cavities.

The absence of well defined interlayered clay sequences indicates that the permeability in the reservoir was dominated by open channels. Mass transfer analysis (Utami, 1998) shows that the rocks have undergone extensive fluid-rock interactions. This is possible only where the rocks are open to allow the removal and addition of constituents.

In Kamojang, quartz, calcite, and anhydrite are commonly associated in cavities. Their presence in vugs and veins mostly matches the occurrences of partial losses of circulation, and in the intermediate and deep levels it matches the feed zones recognised from injection tests. At shallow levels, circulation losses occur at around 200 m depth (eg wells KMJ-12, and CHR-1), at intermediate levels around 400-700 m depths (eg wells KMJ-7, KMJ-10, KMJ-11, KMJ-12, and KMJ-53), and at deep levels around 800 m or deeper (eg wells KMJ-11, KMJ-12, KMJ-53, KMJ-59, and CHR-1). At the depths where quartz, calcite, and anhydrite are present, but no circulation losses occur, e.g at shallow depths in the wells KMJ-7, KMJ-10, and KMJ-11, the permeability is now low, and the high intensity of the alteration reflects the presence of former permeable features now sealed through mineral deposition.

5. CONCLUDING DISCUSSION

Information provided by the subsurface geology, hydrothermal alteration, and fluid inclusions are utilised to establish a model of the Kamojang reservoir and its hydrology at the times the minerals formed. The difference between conditions at these times and now provides a clue to the changes that have happened.

5.1. Reservoir

The reservoir rocks encountered by drilling comprise interbedded pyroclastics and lavas of andesitic composition with some basaltic andesite. The subsurface sequences are similar from well to well, and so are their alteration styles. Therefore, exploratory well CHR-1, which was drilled in the western part of the main field, may indicate the reservoir extends in this direction. The rocks have undergone intensive fluid-rock interactions producing hydrothermal “neutral” and “acid” mineral assemblages in deeper and shallower levels, respectively.

The permeability of the reservoir is mainly provided by normal faults and their associated joints; primary permeability comprises vesicles in lavas, intergranular pores between clasts in pyroclastic rocks, as well as contacts between different lithologies. Most of them are now blocked by mineral deposition, but tectonic activity seems to have reopened the vertically permeable features so that the system is sustained. The domination of conduit-flow type is supported by the absence of well-defined interlayered clay sequences.

The deep reservoir fluid is now vapor-dominated as proved by discharges of steam with water saturation of 25-30% from producing wells (Tim Pokja Kamojang, 1995). However, fluid inclusions from wells KMJ-12 and CHR-1 are liquid rich, and the secondary mineral assemblage in the reservoir suggests that the altering fluid was liquid. This leads to a conclusion that probably the reservoir has evolved from hot water or liquid-dominated system into a vapor-dominated system.

The reservoir is capped by a steam-heated layer. The water in the upper part of this layer is steam condensate of acid sulfate composition, as is indicated by water sampled at 160 m depth in well KMJ-6 (Healy & Mahon, 1982).

The water in the lower part of this steam-heated zone is of near neutral pH type. Its major constituents are sodium, calcium, sulfate, bicarbonate, and silica, as they are indicated by the water sampled from intermediate depths (500-730 m) and the surface discharge of wells KMJ-6 and KMJ-7 (Healy & Mahon, 1982).

The main steam zone is located underneath the steam-heated layer. The top of the present-day main steam zone in the studied wells is located at 640 m asl in well KMJ-11 and 710 m asl. in well KMJ-12, at 900 m asl and 1040 m asl in wells KMJ-53 and KMJ-59, respectively, and at 100 m asl in well CHR-1 (Tim Pokja Kamojang, 1995).

5.2. Reservoir Evolution

The changes of the reservoir conditions compared with some unknown time in the past are as follows:

Fluid phase

At Kamojang, the present-day vapor-dominated fluid may have evolved from the previous hot water system, as is indicated by the mineralogy and fluid inclusions. The intensive water-rock interactions in the previous hot water system have sealed the permeable features by deposition of secondary minerals. With the reduced permeability (although some new permeability might be formed during that period) and the potent magmatic heat supply, hot water boiled off more water than the recharge could replace. The boiling process is recorded by the coexistence of calcite, quartz, and chlorite in cavities, as well as coexisting vapor-rich and liquid-rich fluid inclusions trapped in anhydrite.

Hot water is present in the reservoir since the discharged steam contains 25-30% water. This water is possibly contained within pore spaces and has low mobility, so that only small amounts of it enter the producing wells.

Temperature

The thermal change is inferred by comparing the measured downhole temperatures and mineral-deduced as well as fluid inclusion homogenisation temperatures. In the wells studied epidote occurs in well KMJ-12, KMJ-53, and CHR-1. The measured thermal profile in well KMJ-12 indicates that the well was not thermally stable at the time the measurements were made, so it can not be used for comparison. The shallowest appearance of epidote in wells KMJ-53 and CHR-1 coincides with measured temperatures of 245^{o}C and 200^{o}C, respectively. The measured temperatures seem to be reliable, but note that the epidote here probably formed during the previous hot water regime.

In general, temperatures indicated by other calc-silicates and clays at Kamojang are higher than the stable downhole temperatures. This may testify to cooling, although under estimation of the present-day temperatures is also possible.

No detailed information about thermal changes could be obtained from the mineral parageneses because temperature indicator minerals are not always present in the cross cutting veins. However, assuming that the measured temperatures in well CHR-1 represent the present-day thermal conditions, then fluid inclusions hosted by anhydrite (which formed later than epidote) may record cooling in this part of reservoir by about 60 ^{o}C since the anhydrite deposited. However, it is difficult to judge the thermal changes throughout the field based only on this information.

Due to multiple-stage mineralisation events, the hydrothermal mineral thermometry should be applied with care when assessing the subsurface temperatures at Kamojang.

Permeability

The presence of pores, vugs and veins filled with secondary minerals in the reservoir rocks suggests a decrease in permeability. Some fractures in the main part of the reservoir (eg in well KMJ-12, 650 m) are partly sealed by hydrothermal minerals, decreasing their permeability. On the other hand, some sheared cores and secondary minerals with deformed cleavages (eg in wells KMJ-7, 433 m, KMJ-12, 650 m, CHR-1, 1725 m) indicate a deformation event (probably due to faulting) after their deposition may have created new permeability. Some open cavities are present in some cores. These, together with intergranular pores, provide the present-day permeability in the field.

Fluid composition

The hydrothermal mineral parageneses and vein cross-cutting relationship suggest that although there were possibly several mineralisation episodes, the fluid composition in deep levels (below the “acid” mineral zone) was the same, ie of near neutral pH chloride water. The sulfate-rich water, possibly derived from steam condensate, seems to have come later, after the deposition of the “neutral” pH assemblage. The fluid inclusion ice melting temperatures suggest that a slight increase in salinity had occurred during deposition of the anhydrite hosts and the healing in their fractures, probably as a consequence of concentration of the liquid by boiling.

The present-day fluids sampled from intermediate levels have pH values near neutral and their major constituents are sodium, calcium, and silica. These constituents probably resulted from water-rock interactions in which they were mostly removed to solution, as is indicated by mass transfer calculations (see Utami, 1998). The slightly high concentrations of sulfate and bicarbonate may result from mixing of this water with that from the shallower depths.

5.3. Comparison with Other Vapor-dominated Fields

The characteristics of the Kamojang reservoir are compared with those of other vapor-dominated fields, ie Darajat (Whittome & Salveson, 1990; Hadi, 1997), Larderello (eg.White *et al*, 1971, Celati *et al*, 1973; Cathelineau et al, 1995), The Geysers (e.g. Thompson, 1989; McNitt et al, 1989; Sternfeld, 1989; Moore *et al*, 1995), and Matsukawa (Sumi, 1968; Sumi & Takashima, 1975).

These fields have similar physical characteristics, ie reservoir temperatures of 235-245 ^{o}C (except the deeper part of the Geyser’s reservoir), and pressures of 31-38 kg/cm^2. All these fields have a cap rock hydrology. Recharge water of these fields is of meteoric origin, and the circulation of fluid is controlled mainly by fractures. The heat source for Larderello and the Geysers is of magmatic type. A magmatic type heat source may also provide a potent heat supply to Kamojang. At Larderello and The Geysers, the present thermal regimes are interpreted to have evolved from a preceding hot water (or liquid-dominated) hydrothermal system. Kamojang possibly experienced the same fate, as is indicated by its mineralogy and fluid inclusions.

6. ACKNOWLEDGEMENTS

This research was carried out at The University of Auckland with funding from The New Zealand Ministry of Foreign Affairs and Trade. The author extends her gratitude to PERTAMINA for permission to publish this paper. A/Prof. P.R.L. Browne is thanked for reviewing the manuscript. Mr. Doko Subagyo is thanked for formatting the figures.

7. REFERENCES

Browne, P.R.L. (1975) *Petrological Report: Samples from Indonesia (Kawah Kamojang Well 7)*. Report for Dept. of Scientific and Industrial Research, New Zealand Geological Survey.

____________ (1977) *Petrologic Report: Kawah Kamojang Drillhole 12*. Report for Dept. of Scientific and Industrial Research, New Zealand Geological Survey.

____________ (1995) Hydrothermal Alteration Lecture Notes, Geothermal Institute, The University of Auckland.

Cathelineau, M., Marignac, C., Boiron, M.C., Yardley, B., Gianelli, G., and Puxedu, M. (1995) Use of Fluid Inclusions for the Discrimination of Multi-source Components and P-T-X Reconstruction in Geothermal Systems: Application to Larderello. *Proc. of the World Geothermal Congress (Florence)* Vol. 2. pp. 1093-1097.

Celati, R., Noto, P., Panichi, Squarci, P., and Taffi, L. (1973) Interactions Between the Steam Reservoir and Surrounding Aquifers in Larederello Geothermal Field. *Geothermics* 2, pp. 174-185.

GENZL and PT. Trimitra Nusa Engineering (TE) (1991) *Kamojang Geothermal Power Plant Unit 4 Resource Feasibility Study*. Final Report.

Hadi, J. (1997) *A Hydrothermal Alteration Study to Assess Temperature and Overprinting From S-1 Exploration - North Darajat Field, Indonesia.* Diploma Project Report, Geothermal Institute, The University of Auckland.

Healy, J. (undated) *Kawah Kamojang Geothermal Field*. Geological Progress Report for Dept. of Scientific and Industrial Research, New Zealand Geological Survey.

Healy, J. and Mahon, W.A.J. (1982) Kawah Kamojang Geothermal Field, West Java, Indonesia. *Proc. Pacific Geothermal Conference incorporating the 4th New Zealand Geothermal Workshop*. Vol. 2, The University of Auckland, pp. 313-319.

McNitt, J.R., Henneberger, R.C., Koenig, J.B., and Robertson-Tait, A. (1989) Structural Controls of the Occurrence of Steam at The Geysers. *Geothermal Resources Council Transactions* 13, pp. 461-465.

Moore, J.N., Hulen, J.B., and Norman, D.I. (1995) Evolution of The Geysers (US) - Data from Fluid Inclusion Microthermometry and Gas Geochemistry. *Proc. 17th NZ Geothermal Workshop*, The University of Auckland, pp. 77-82.

Potter, R.W., Clyne, M.A., and Brown, D.L. (1978) Freezing Point Depression of Aqueous Sodium Chloride Solutions. *Econ. Geol.* 73, pp. 284-285.

Purba, S. (1994) *Hydrothermal Alteration of Core and Cutting Samples from Wells KMJ-48 & 53, Kamojang Geothermal Field, West Java, Indonesia*. Diploma Project Report, Geothermal Institute The University of Auckland.

Sternfeld, J.N. (1989) Lithologic Influences on Fracture Permeability and the Distribution of Steam in the Northwest Geysers Steam Field, Sonoma County, California. *Geoth. Res. Coun. Trans* 13, pp. 437-479.

Sudarman, S.,Boedihardi, M., Pudyastuti, K., and Bardan (1995) Kamojang Geothermal Field: 10 Year Operation Experience. *Proc. of The World Geothermal Congress (Florence) Vol. 2, pp. 1773-177.*

Sumi, K (1968) *Hydrothermal Rock Alteration of the Matsukawa Geothermal Area, Northeast Japan*. Geological Survey of Japan Report No. 225.

Sumi, K., and Takashima, I. (1975) Absolute Ages of the Hydrothermal Alteration Halos and Associated Volcanic Rocks in Some Japanese Geothermal Field. *Proc Second United Nations Symposium on the Development and Use of Geothermal Resources*. Vol 2.

Thompson, R.C. (1989) Structural Stratigraphy and Intrussive Rocks at the Geysers Geothermal Field. *Geoth. Res. Counc. Trans*. 13, pp. 481-485.

Tim Pokja Kamojang (1995) *Evaluasi Kelayakan Pengembangan Area Panasbumi Kamojang*. Divisi Panasbumi Direktorat E.P. PERTAMINA. 66 pp.

Utami, P. (1998) Mass Transfer During Hydrothermal Alteration: A Case Study of the Kamojang Geothermal Field, West Java. *Proc. of 27th Association of Indonesian Geologists Annual Meeting*, pp. 83-100.

Utami, P. & Browne, P.R.L. Subsurface Hydrothermal Alteration in the Kamojang Geothermal Field, West Java, Indonesia, *Proc. 24th Workshop on Geothermal Reservoir Engineering*, Stanford University, pp. 383-390

White, D.E., Muffler, L.J.P., and Truessdell, H.A. (1971)Vapor-dominated Hydrothermal Systems Compared with Hot Water Systems. Econ. Geol. 66, pp. 75-97.

Whittome, A.J., and Salveson, J.O. (1990) Exploration and Evaluation of the Darajat Geothermal Field West Java, Indonesia. *Geothermal Resources Council Transaction* 14, part II, pp. 999-1005.

Wood, C.P. (1975) *Petrological Report: Cores from Kawah Kamojang 10*. Report for Dept. of Scientific and Industrial Research, New Zealand Geological Survey.

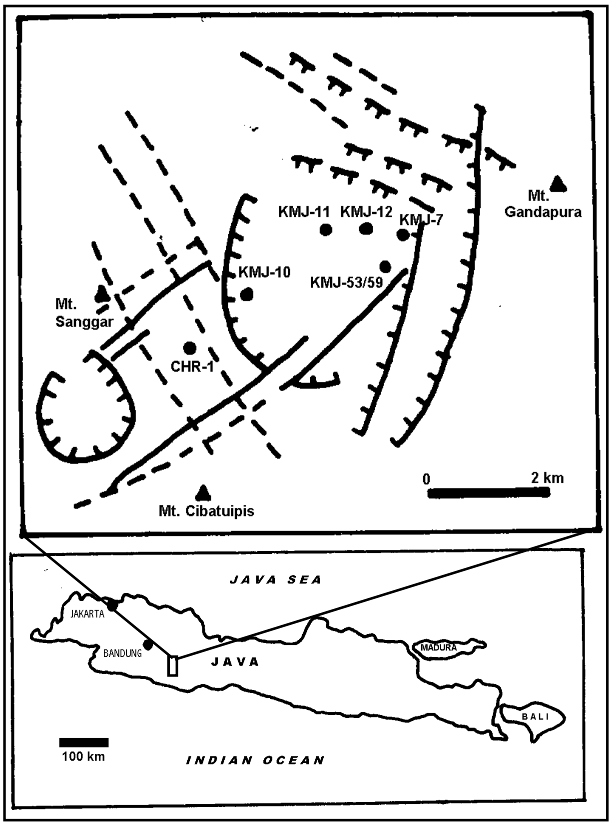

Fig. 1. Map showing the location of the wells studied. Inset: index map of the Kamojang geothermal field.

Table 1. Occurrence and abundance of hydrothermal minerals in the studied wells. R=replacement, D=direct deposition, A=abundant, C=common, Rr=rare.

Hydrothermal	Occurrence		Abundance		
mineral	R	D	A	C	Rr
Cristobalite	X				X
Quartz	X	X	X		
Albite	X				X
Adularia		X			X
Epidote		X			X
Titanite	X				X
Wairakite		X			X
Laumontite	X	X			X
Calcite	X	X	X		
Siderite	X	X		X	
Hematite	X	X		X	
Titano-hematite	X	X			X
Pyrite	X	X		X	
Anhydrite		X		X	
Gypsum	X				X
Jarosite	X				X
Alunite	X				X
Kaolin	X				X
Smectite	X		X		
Chlorite	X	X			
Illite	X			X	
Chlorite/smectite	X		X		
Illite/smectite	X		X		
Illite/chlorite	X		X		

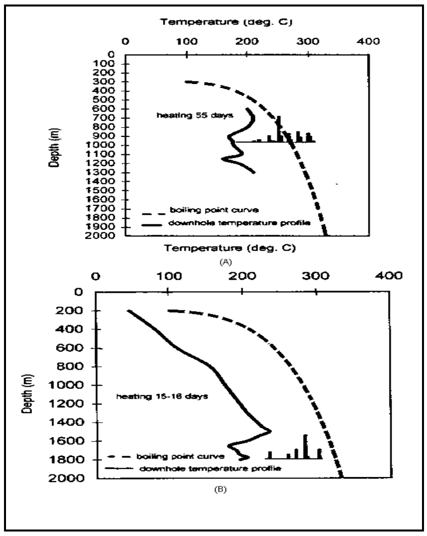

Fig.2. Plots of hydrostatic boiling point versus depth curve, borehole temperature profile, and histogram of fluid inclusion Th values from 995 m in well KMJ-12 (A) and from 1725 m in well CHR-1 (B).

Table 2. The deepest occurrences of kaolin and the shallowest occurrences of calcite in the studied wells.

Well No	Deepest occurrence of kaolin (m)	Shallowest occurrence of calcite (m)
CHR-1	223	223
KMJ-10	100	112
KMJ-11	300	300
KMJ-12	318	318
KMJ-7	100	100
KMJ-59	110 (?)	300
KMJ-53	325	300

Table 3. Comparison of borehole and calc-silicate mineral formation temperatures in the Kamojang field. 1=Healy (1977), 2=Browne (1977), 3=Purba (1994), 4= GENZL & TE, 1991).

Mineral	Usual formation T (^{o}C)	Borehole T (^{o}C), depth and well no.
Wairakite	210-320	**220** (433m/KMJ-7) **180** (550m-603m / KMJ-11)[1] **210** (705-751.5 m/ KMJ-12, unstable)[2] **180-200** (1000 m, **1086** m/KMJ-12)[2] **240** (710m/KMJ-53)[3] **150-160** (1725m/ CHR-1)
Laumontite	120-210	**140** (96m/KMJ-7)[2] **110** (351m / KMJ-11)
Epidote	≥ 250	**245** (692.5m, 711m, 902m/KMJ-53) **175** (1191m / CHR-1)[4] **175-210** (600-**951**m/KMJ-12, unstable)[1,2]