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Evolution of Rendingan-Ulubelu-Waypanas (RUW) Geothermal System Lampung, Indonesia

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ABSTRACT

The conditions in the RUW geothermal system are recorded by its surface and subsurface alteration and ground magnetic modeling. In particular, the changes in the hydrology of the reservoir are recorded by the hydrothermal minerals and fluids inclusions. The petrography reveals the sequence of the reservoir changes during the lifetime, albeit incompletely. The magnetic modeling indicates fresh (unaltered) rocks in shallow depths. The major secondary minerals consist of pyrite, calcite, smectite, quartz, titanite, epidote and iron oxides, with minor adularia, albite, wairakite, hematite, prehnite and laumontite.

1. INTRODUCTION

The Rendingan-Ulubelu-Waypanas (RUW) geothermal system is located in Tanggamus District, Lampung Province, Southern of Sumatra, Indonesia (Figure 1). The Rendingan-Ulubelu-Waypanas (RUW) geothermal system is a large system was formerly known as the Ulubelu prospect (Suharno, 2003). It is a large system, covering an area of about 150 km^2. comprise of the Rendingan (RI), Ulubelu (RII) and Waypanas (RIII) fields (Figure 1).

Samples were selected and collected as cores and cuttings from wells Rd, Kk1, Kk2, UBL1, UBL2, and UBL3, and hand collected from surface field BT1, UA, UB, UC, UKR and SLF/SNT (Figure 1). These were analyzed by X-ray diffraction and were examined by thin section petrography.

Glimpses of previous chemico-physical conditions in the RUW geothermal system (Figure 1) are recorded by its surface and subsurface alteration. In particular, the identities and textural relations of the hydrothermal minerals and the thermal characteristics of fluids trapped in inclusions record changes in the hydrology of the reservoir. Although the ages of the minerals and fluid inclusions are unknown, petrography reveals the sequence and directions of changes, albeit incompletely, I attempt to deduce trends in the evolution of thermal activity during the lifetime of the RUW geothermal system.

Thin sections were examined and XRD analyses made of cores, cuttings and surface samples. The alteration intensity of the rocks is mostly from 50% to 85%. Most primary minerals, mainly plagioclase and pyroxene, have been intensely altered. The major secondary minerals consist of pyrite, calcite, smectite, quartz, titanite, epidote and iron oxides, with minor adularia, albite, wairakite, hematite, prehnite and laumontite.

2. SURFACE ALTERATION

Most surface rocks are weathered but some have also been altered hydrothermally. The alteration includes both replacements of primary phases and the products of processes that affected ascending thermal fluids. Alkali chloride water of near neutral pH once deposited silica sinter at the surface but now acid steam condensate is forming kaolin, silica residue and other phases. Petrography shows, for example, that sample UKR collected near thermal manifestations close to Karangrejo village (Figure 1) is basalt lava containing hydrothermal pyrite, hematite and calcite. Sample UD, by contrast, contains illite produced in the subsurface but now exposed, and samples SLF and SNT (Figure 1) contain secondary quartz that deposited at the surface first as Opal-A (Herdianita, et al., 2000)

3. HYDROTHERMAL MINERALS

The identities of the hydrothermal minerals reflect the new environment in which reservoir rocks find themselves. The occurrences of hydrothermal minerals are as follows.

a. Calc-silicates

Calc-silicates (epidote, prehnite, wairakite, laumontite and titanite) are present in all six wells. Epidote is present in wells UBL1 from 220 to 1200 m depth, Kk1 at 175 m, Kk2-175 m, Rd at 225 m depth and UBL3 from 100 to 860 m; it is absent in UBL2. Wairakite is present in wells Rd at 275 m and UBL3 from 725 to 800 m depths. Prehnite occurs in wells UBL1 from 570 to 1080 m, Kk1 at 175 m, Rd at 225 and 275 m, and UBL3 at 860 m depths. Laumontite occurs in wells UBL2 at 200 m. They both replace primary minerals and occur in veins. Titanite is a secondary mineral present in the RUW geothermal system. It occurs in all wells, except UBL2 and Rd, usually associated with epidote.

b. Clays

Twenty-nine samples of cuttings from wells Kukusan I (Kk1), Kukusan II (Kk2) and Rd were analyzed by X-ray diffraction. Clay samples were air-dried, then treated with glycol and heated. The samples were first crushed into a fine homogeneous powder using a mortar and pestle. The clay minerals were dispersed in distilled water with the $\leq$ 2.0 µm fraction collected by gravitational settling and mounted onto glass slides and allowed to dry below 40 ^{o}C, ethylene glycol solvated (overnight) and heated (550 ^{o}C for 1 hour). A Philips PW 1050/25 diffractometer utilizing CuKα radiation analyzed all samples. Interpretation of the X-ray diffraction profile data is based on Brindley and Brown (1980) and Moore and Reynolds (1989).

The results in wells Rd, Kukusan I (Kk1) and Kukusan II (Kk2) indicate that the clay minerals present are chlorite, illite, smectite, kaolinite, illite/smectite and illite/vermiculite. Both chlorite and illite occur below 150 m and 100 m depths respectively.

Suharno et al. (1999) and Suharno (2000) reported the occurrence of clay minerals in wells Ulubelu I (UBL1), Ulubelu II (UBL2) and Ulubelu III (UBL3). These are chlorite, illite, kaolinite, illite/vermiculite and illite/smectite. In well UBL1 illite and chlorite occur deeper than 520 m; in well UBL2, illite occurs below 400 m, chlorite below 120 m and kaolinite at 80 m depths; well UBL3 has illite and chlorite below 400 m, kaolinite above 400 m depths.

c. Calcite

Calcite is present in all six wells. It is most abundant in samples from wells Kk1, Kk2 and Rd. It is present shallower than 600 m in well UBL1, occurs above 300 m in well UBL2 and is present at 225 m, 800 m and 860 m depths in well UBL3.

d. Quartz

Hydrothermal quartz is present in all six wells in the study area. Some quartz is overprinted by calcite.

e. Pyrite

Pyrite is common in all six wells. It partly or completely pseudomorphs pyroxene and/or magnetite.

f. Hematite

Hematite is a very rare secondary mineral in the study area and only occurs in two samples, from wells UBL2 and Kk1. Nevertheless, it is common at the surface.

g. Feldspars

The hydrothermal feldspars consist of albite and adularia. Albite is present in well UBL1 between 840 m and 920 m depths and in well Kk1 at 175 m depth. Adularia occurs in both well UBL1 and UBL3 below 108 m and 600 m depths respectively.

4. FLUID INCLUSION GEOTHERMOMETRY

Freezing and homogenisation temperatures were measured using a "Fluid Inc." stage mounted on a Leitz Labourlux 12HL microscope (Suharno, 2000), using the system instruction manual of Reynolds (1994). The stage was calibrated by using synthetic inclusions (Sterner and Bodnar, 1984). Crystals were hand picked from cores and cuttings and double side polished. Crystals are very tiny (around 1 mm diameter) and so they were held down by the thermocouple during measurement.

The homogenisation temperatures (Ths) were estimated by heating the host crystal until the trapped fluid became homogenous.

4.1. Types of Fluid Inclusions

Primary two-phase inclusions occur. Many vapor rich inclusions are present, both two-phase primary and secondary. The inclusions are mostly two-phase i.e. liquid and vapor but most are liquid rich. Primary inclusions are large and irregularly distributed, and secondary inclusions are oriented in planar groups, possibly along sealed fractures (Figure 2). No daughter minerals or clathrates were seen.

The Th values are within the liquid phase. Possibly dissolved CO_2 lowered the boiling temperatures but no clathrates were seen when the inclusions were frozen. However, the Th values are higher than the present well temperatures suggesting cooling has occurred since the inclusions formed. However, it is possible that the well had not thermally stabilized after only 7 days before the downwell temperatures were measured (Figure 3).

4.2 Homogenisation Temperatures (Th)

The homogenisation temperatures (Ths) were mostly between about 200 ^oC and 250 ^oC (Figure 3). The inclusions in deeper samples recorded the higher temperatures but all homogenized below the boiling temperature. The Th values are from 245 ^oC to 250 ^oC and are therefore close to boiling. Boiling is indicated where vapor rich and two-phase inclusions occur in the same sample. This shows that the homogenisation temperatures are near those of hydrostatic boiling, but the Th values of the deeper samples are below boiling temperatures as only liquid was trapped.

4.3 Ice Melting Temperature

To measure the ice melting temperatures (Tm), the inclusions were first frozen using N_2 gas. Heating was done until the last ice melted. The relationship between Tm and equivalent wt % NaCl is given by:

$$\text{NaCl wt \%(equiv.)} = 1.76958(-Tm) - 4.2384\times10^{-2}(-Tm)^2 + 5.2778\times10^{-4}(Tm)^3$$ (Roedder, 1984).

The last ice melting Tm values of 159 inclusions in samples from the wells are between -0.4 ^oC and 0.0 ^oC. Most have Tm average values of -0.2 ^oC. The inclusions therefore contain very dilute water with salinities between 0.0 % and 0.9 % equivalent. Fifty-three representative values from 159 inclusions achieved.

5. COMPARISON OF TEMPERATURES

Well temperature data are from Pertamina (1993) and Kemah and Yunis (1997). The hydrothermal minerals and fluid inclusions in Rendingan-Ulubelu-Waypanas, as discussed by Suharno (2003) indicate mostly higher temperatures than those now measured. Laumontite indicates temperatures between 120^o and 210^o C, illite above 220^o C, wairakite above 210^o C, prehnite above 220^o C, and epidote indicates temperatures above 250^o C (Reyes, 1985; Reyes, 1990; Chi and Browne, 1991; Browne, 1998). The fluid inclusion homogenisation temperatures (Ths) are between 200 ^oC and 250^o C.

A comparison of the measured well temperatures (T.bore) and these deduced from the hydrothermal minerals (T.mineral) and fluid inclusion (Th) geothermometers for well UBL1 are given in Table 1. The present piezometric surface seems to be at about 500 m depth, with vapor or perched water above it (Figure 3B). The measured temperature reversal at about 700 m probably marks a lateral inflow of oxygenated water which is consistent with the presence of kaolin from 520 to 840 m. The homogenisation temperatures of fluid inclusion are up to 40 ^oC above the measured bore temperature and this indicates cooling by at least this amount has occurred since the inclusions were trapped. Reservoir cooling is also indicated by the distribution of epidote. This mineral is present in cuttings from as shallow as 225 m indicating cooling by as much as 50 ^oC since it formed. Cooling by 30 – 40 ^oC is evident below this depth to well bottom.

6. GROUND MAGNETIC STUDY

Negative magnetic anomalies caused by topographic effects are often small in amplitude and wavelength, and show some correlation with topographic contours. Those caused by hydrothermally demagnetised rocks are usually broader and often stronger than the topographic effects. Such hydrothermal demagnetisation anomalies can often be recognised where they are associated with an active geothermal system. In some cases where the association with the geothermal system is less obvious, hydrothermal demagnetisation anomalies may be difficult to distinguish from those caused by reversely magnetised rocks.

The presence of reversely magnetised rocks can be determined by taking rock samples and measuring their magnetic polarities, or estimated using magnetic interpretation results and comparing them with the ages of the rocks (Duff, 1993). Only the latter was done in this study, since no magnetisation measurements of rock samples were carried out.

The magnetic anomalies were obtained from an upward continuation of ground magnetic data. These data are not suitable for making a detailed qualitative magnetic interpretation. Therefore, only simple two-dimensional magnetic modeling was attempted in this study with the purpose of delineating the gross magnetic structure of the RUW geothermal system and determining its dimensions. The modeling was carried out using the MAG2D-Win program written by S. Soengkono (Geothermal Institute, University of Auckland).

The summary of the 2-D interpretation results indicate the normally magnetised rocks, reversely magnetised rocks the demagnetised rocks, recognised by positive anomalies, negative anomalies and magnetised body (0 A/m) respectively, see Figure 1. The hydrothermally magnetised body (0 A/m) deduce from demagnetised rocks of reversely and normally magnetised rocks that reversely magnetised rocks become to not negative and normally magnetised rocks become to not positive.

In the RUW geothermal system, hydrothermally demagnetised rocks are probably present in the northern part of the magnetic study area (Area III), within the Mt. Rendingan andesite lavas and pyroclastics, and southern part (Area V), within the Mt. Kukusan basaltic andesite lavas, with magnetised body (0 A/m), where magnetised body (0 A/m) are associated with surface thermal manifestations. This area is also characterised by a zone of low (10 Ωm) Schlumberger apparent resistivity (Suharno, 2000).

Reversely magnetised rocks present on where negative magnetic anomalies are not associated with any thermal activity. Mt. Sulah andesite lavas cover this area. these are appear to exist in the southwestern part of the study area (Area I) consisting of Mt. Sulah andesite lavas, with magnetised body (-8 A/m), in the south parts of the magnetic study area consisting of Mt. Kukusan basaltic andesite lavas with magnetised body (-4 A/m).

The positive anomalies in the northeastern part of the study area suggest that normally magnetised rocks are dominant. The normally magnetised body (6 A/m) near the northeastern magnetic study area (Area IV) is associated with Mt. Rendingan pyroclastics and possibly Mt. Rendingan andesite lavas. Similar bodies of 6 A/m are also shown near the central part (Area II). These are all associated with Mt. Rendingan pyroclastics. The results indicate that Mt. Rendingan pyroclastics and Mt. Rendingan andesite lavas is normally magnetised.

7. RESERVOIR CONDITIONS

The RUW reservoir contains vapor, two phases and liquid water dominated domains but is overall a liquid dominated system. This is revealed by the hydrothermal alteration and fluid inclusion geothermometry. In the area near UBL3 vapor occurs at about 250 m to 550 m, two-phase condition from about 600 m to 800 m depths and dilute alkali chloride water below this. Probably perched rain water occurs above 250 m depth. Convection occurs below 800 m depth in wells UBL1 and UBL3 (Figure 3). Mulyadi (2000) also suggested that the Ulubelu geothermal prospect is liquid dominated with a shallow steam cap. The RUW geothermal system seems to be changing from a liquid to a vapor dominated system, as occurs at Darajat, West Java, Indonesia and reported by Riza and Berry (1998), Utami, (2000) and Hadi, (2001).

At present, surface manifestations are characterized by fumaroles and boiling acid springs some of which once discharged neutral pH water as indicated by the presence of ancient silica sinter overprinted by kaolin. RUW is a liquid dominated system with a two-phase heat transfer zone. Cooling has affected this system and the piezometric surface has descended. Comparison between present day conditions and those of the past deduced from the fluid inclusion geothermometry and hydrothermal alteration is presented in the following paragraphs.

Changes with time

A change in a thermal regime can often be inferred, not only by comparing the measured downwell temperatures with those indicated both by fluid inclusions and hydrothermal mineral geothermometry, but also from changes in the surface manifestations.

(1) The measured well temperatures (Table 1) are lower than 250 ^{o}C, which is the usual lower stability temperature of epidote. So, either cooling has occurred since the epidote formed or else the measured temperatures are too low, i.e. the wells were not thermally stable when the measurements were made.

(2) The presence of silica sinter in the study area, probably older than 20,000 years since it is now quartz (Herdianita, et al., 2000), and the hydrothermal minerals in the cuttings, indicate alteration and deposition by alkali chloride water. However, there are no alkali chloride waters now discharging, so the piezometric surface has dropped. The measured downwell pressures and temperatures suggest a lowering by about 600 m (150 m a.s.l) (Figure 3).

(3) The occurrence of some hydrothermal minerals at the present surface and in well samples suggests that even before the sinter deposited there was considerable erosion. This is not surprising in such steep terrain. The presence of albite at the surface and at very shallow depths (e.g. at 175 m) together with shallow epidote, chlorite, illite, wairakite, prehnite, adularia, albite and laumontite indicate erosion of perhaps several hundred meters.

8. CONCLUSIONS

The measured drillhole temperatures are generally lower than those indicated by the fluid inclusions and hydrothermal mineral geothermometers. This implies that cooling has occurred since the minerals deposited. Overprinting locally of hydrothermal quartz by kaolinite and calcite also supports the suggestion that the thermal system has cooled since the alteration occurred.

The magnetic modeling indicates fresh (unaltered) rocks in shallow depths at area II (6 A/m), so hot waters did not reached this area (Figure 1). The magnetic interpretation is consistent with the geology conditions. The demagnetised rocks present in areas III and V (0 A/m). The normal magnetization of Mt. Rendingan pyroclastics occur at area IV (6 A/m). The reversely magnetization of Mt. Sulah andesite lavas and Mt. Kukusan basaltic andesite lavas are at areas I (-8 A/m) and VI (-4 A/m) (Figure 1).

Boiling has occurred in the reservoir, as shown by the presence of coexisting vapour-rich and liquid-rich inclusions but mostly the dominant fluid was liquid, as it is now. Alkali chloride waters close to boiling temperature and of neutral pH water once discharged but have not done recently. So the water level in the main reservoir has lowered, as revealed by the occurrence together of silica sinter and acid waters, discharging CO_2 but with low chloride, at temperatures between 45 and 100 ^oC. Epidote, wairakite, prehnite and laumontite could only have deposited directly from a liquid (Browne, 1998) of close to neutral pH of alkali chloride composition and low in dissolved CO_2. The widespread calcite indicates CO_2 loss from boiling or the effervescing CO_2 rich water.

Erosion has exposed hydrothermal minerals at the surface that was formed within the geothermal reservoir during an earlier stage of activity. This is similar to events that occurred at the Te Kopia field where uplift along the Paeroa Fault and erosion have exposed hydrothermal minerals that formed several hundred meters below the former ground surface (Bignall and Browne, 1994; Clark and Browne, 2000).

9. ACKNOWLEDGEMENTS

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10. REFERENCES

Bignall, G., and Browne, P.R.L., 1994, Surface hydrothermal alteration and evolution of the Te Kopia thermal area, New Zealand: Geothermics, v. 26 (5/6), p. 645-658.

Brindley, G.W., and Brown, G., 1980, Crystal structure of clay minerals and their X-ray identification: London, Mineralogical Society, 495 p.

Browne, P.R.L, 1998, Hydrothermal alteration lecture notes, Geothermal Institute, the University of Auckland: New Zealand, p. 70.

Chi, M., and Browne, P.R.L., 1991, Alteration mineralogy of sediments in the Huka Faults formation of the Te Mihi area, Wairakei: Proceedings 13th New Zealand Geothermal Workshop, p. 185-191.

Clark, J.P., and Browne, P.R.L., 2000, Past and present-day themal activity between the Orakeikorako and Te kopia gethermal areas, New Zealand, Twenty-fifth Workshop on Geothermal Reservoir Engineering, Stanford University: Stanford, California.

Hadi, J., 2001, The Darajat geothermal field conceptual model, a vapor dominated system, Proceedings of the 5th INAGA annual scientific conference & exhibitions: Yogyakarta, Indonesia, p. 1-6.

Herdianita, N.R., Browne, P.R.L., Rodgers, K.A., and Campbell, K.A., 2000, Mineralogical and textural changes accompanying ageing of silica sinter: Mineralium Deposita, v. 35, p. 48-62.

Kemah, M.Y., and Yunis, 1997, Evaluasi geologi-geokimia pemboran sumur Ulubelu Lampung: Jakarta, Pertamina, 69 p.

Masdjuk, M., 1997. Laporan geology detil daerah Ulubelu, Lampung, Pertamina, Jakarta.

Moore, D.M., and Reynolds, R.C.J., 1989, X-Ray diffraction and the identification and analysis of clay minerals: Oxford, Oxford University Press, 39 p.

Mulyadi, 2000, Ulubelu the most developed geothermal area in South Sumatra, Proceedings World Geothermal Congress 2000: Kyushu - Tohoku, Japan, p. 1463-1468.

Pertamina, P.T.J., 1993, Slim hole and temperature in Lampung Province, Indonesia: Jakarta, Pertamina, p. 77.

Reyes, A.G., 1985, A comparative study of 'Acid' & 'Neutral pH' hydrothermal alteration in the Bacon-Manito geothermal area, Philippines [MSc thesis]: Auckland, the University of Auckland.

Reyes, A.G., 1990, Petrology of Philippines geothermal systems and the application of alteration mineralogy to their assessment: Journal of Volcanology and Geothermal Research, v. 43, p. 279-309.

Reynolds, T.J., 1994, Fluid Inc. adapted U.S.G.S. gas-flow heating/freezing system instruction manual, Fluid Inc.: USA, p. 33.

Riza, I., and Berry, B.R., 1998, Slimhole drilling experience at Darajat geothermal field, West Java, Indonesia: Proceedings 20th New Zealand Geothermal Workshop, p. 183-189.

Roedder, E., 1984. Fluid Inclusions. Review in Mineralogy, 12. Book Crafters Inc., 644 p.

Sterner, S.M. and Bodnar, R.J., 1984. Synthetic fluid inclusions in natural quartz I. compositional types synthesised and applications to experimental geochemistry. Geochim. Cosmochim. Acta, 48: 1650-1668.

Suharno, 2000, A Geological and Geophysical Study of The Ulubelu Geothermal Field in Tanggamus, Lampung, Indonesia. [M.Sc. thesis]: Auckland, The University of Auckland.

Suharno, Browne, P.R.L., Soengkono, S., and Sudarman, S., 1999, Hydrothermal clay minerals in the Ulubelu geothermal field, Lampung, Indonesia: Proceedings 21st New Zealand Geothermal Workshop, p. 95-100.

Suharno, 2003. Geophysical, Geological and Paleohydrological Studies of the Rendingan-Ulubelu-Waypanas (RUW) geothermal system, Lampung, Indonesia. [Ph.D. Thesis]:Auckland, The University of Auckland.

Utami, P., 2000, Characteristic of the Kamojang geothermal reservoir (West Java) as revealed by its hydrothermal alteration mineralogy, Proceedings World Geothermal Congress 2000: Kyushu - Tohoku, Japan, p. 1921-1926.

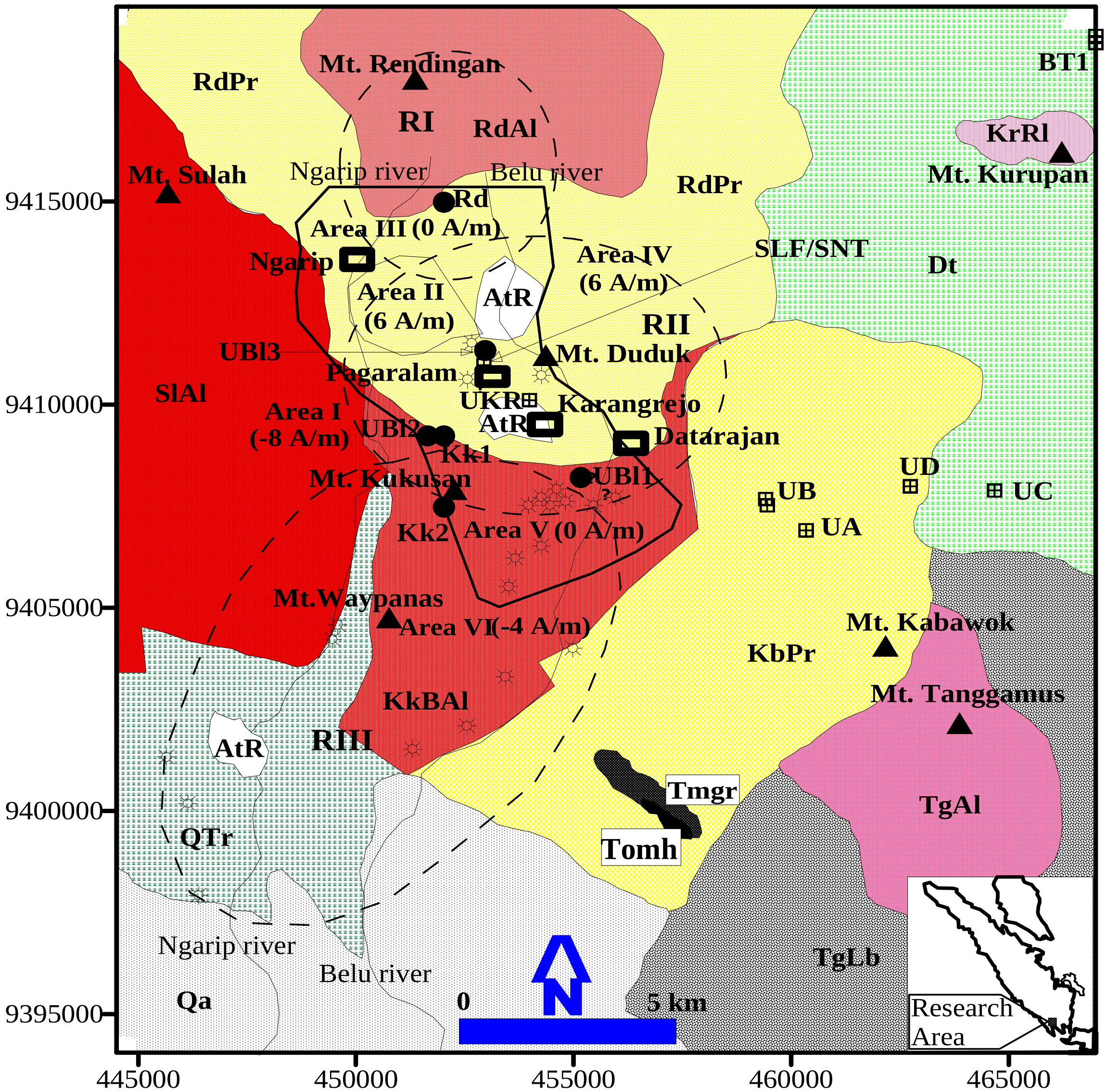

Figure 1. The Rendingan-Ulubelu-Waypanas (RUW) geothermal system. Dashed line ellipses are geothermal prospects (RI, Rendingan; RII, Ulubelu; RIII, Waypanas). Qa: Alluvium, AtR: Altered rocks, TgAl: Tanggamus andesite lavas, KrRl: Kurupan rhyolite lavas, Dt: Dacite tuff, RdAl: Rendingan andesite lavas, RdPr: Rendingan pyroclastics, TgLb: Tanggamus laharic breccia, KbPr: Kabawok pyroclastics, DdDl: Duduk Dacite lavas, KkBAl: Kukusan basaltic andesite lavas, SlAl: Sulah andesite lavas, QTr: Pumiceous tuff (Ranau Formation), Tmgr: Granodiorite, Tomh: Hulusimpang Formation. Filled circles (Kk1): bore holes; stars: hot springs or fumaroles; triangles: summits of mountains; squares: petrographic samples. Boxes are villages. Closed full lines are magnetic interpretation; magnetisation values are in A/m indicated by areas (I – VI). The coordinates are expressed in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980). Modified after Masdjuk (1997) and Suharno (2000).

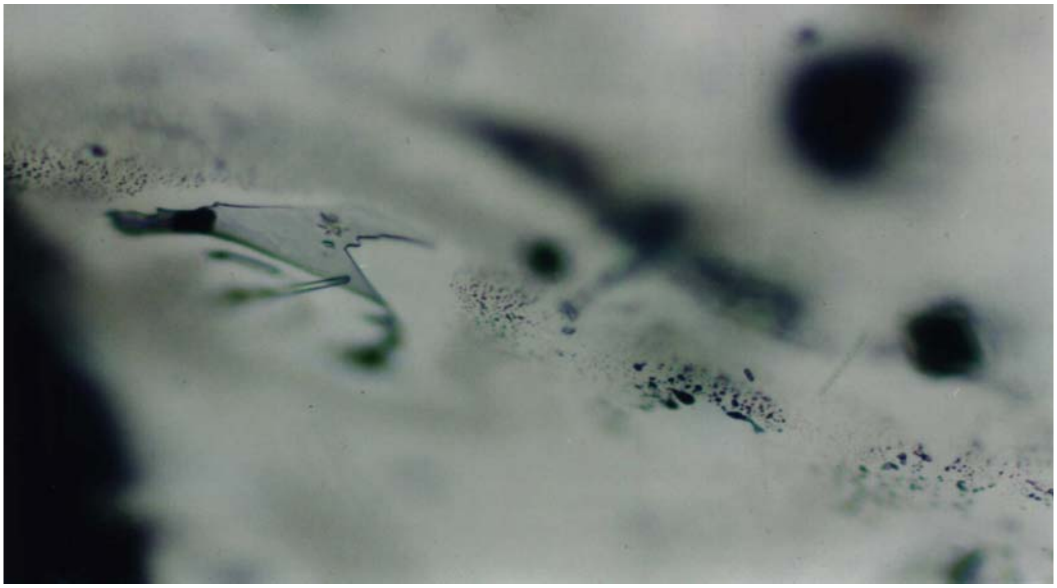

Figure 2. Two phase and vapor rich primary and secondary inclusions in a quartz host from well UBL3 at 480 m depth.

Table 1. Comparison of T.bore, T.mineral and Th in well UBL1

Well depth (m)	T.bore (°C) Two	T.bore (°C) Four	T.mineral (°C) Ep	Pr	Ilt	Sm	Ko	Th (°C)
0	34	53						
25								
50								
75								
100	57	190				<140		
125								
150								
175						<140		
200	94	198						
225			250					
250								
275								
300	191	202	250			<140		
325								
350			250					
375								
400	198	203	250					
425								
450			250					
475			250					
500	200	202						
525					220		<120	
550	200	203						
575			250	>220				
600	201	202						
625								
650	194	182						
675			250	>220			<120	
700	169	177						
725								
750	144	203	250	>220			<120	
775								
800	146	213						
825			250	>220			<120	
850	168	214						
875								
900	199	215	250	>220				225-245
925								
950	201	217						
975			250	>220				
1000	202	220						
1025								
1050	202	221						
1075					220			
1100	206	221						
1125								
1150	208	222						
1175			250		220			
1200								

T.bore hole: (°C)
Two: measured after 2 months heating
Four: measured after 4 months heating

Thermaly sensitive minerals and their usual temperature range (°C)
Ep (epidote): 250
Pr (prehnite): >220
Ilt (illite): 220
Sm (smectite): <140
Ko (kaolinite): <120

Th: (°C)
225-245: homogenisation temperatures

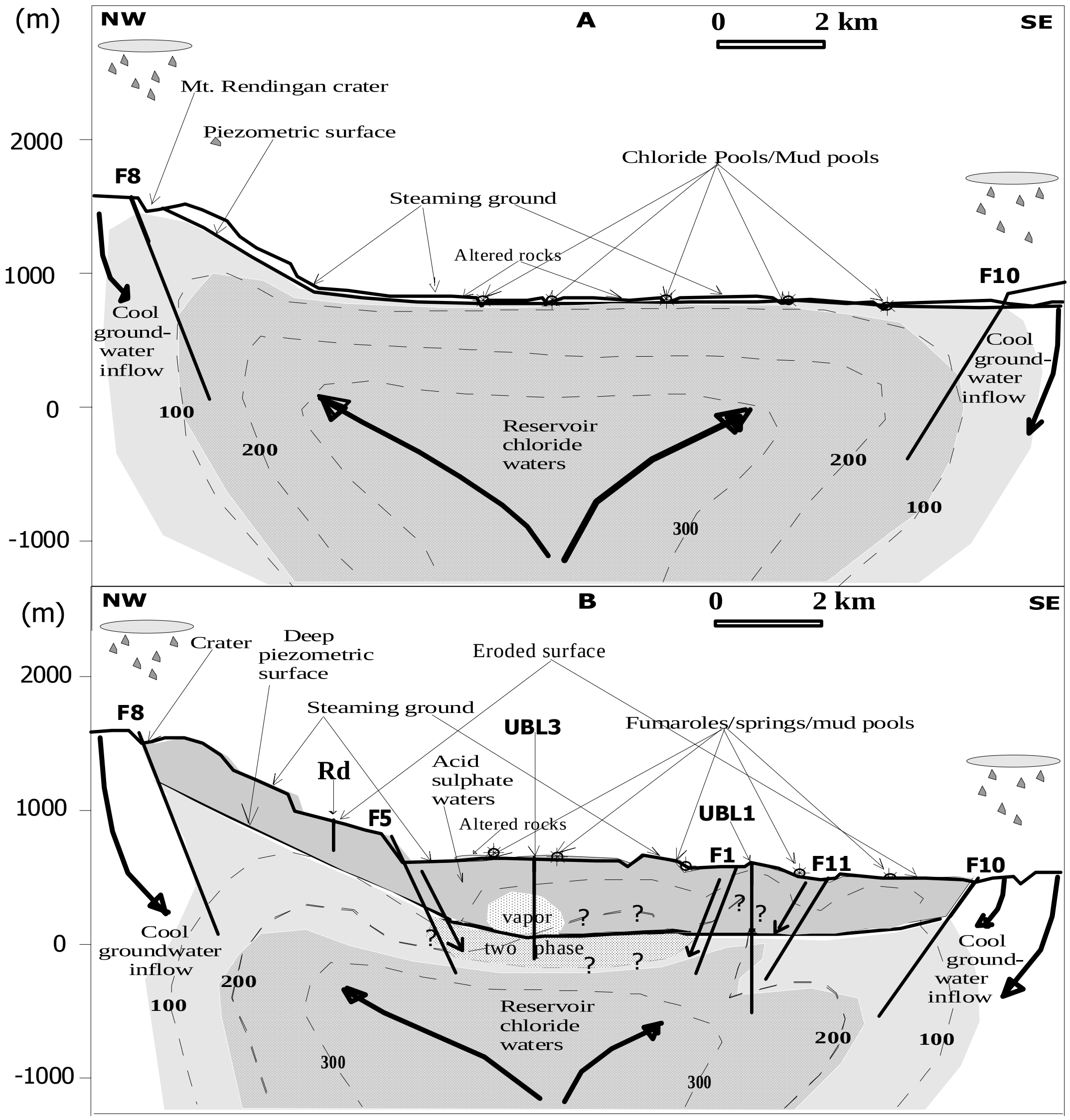

Figure 3. Summary of hydrological changes that have occurred in the RUW geothermal system. (A) Former condition. (B) Recent condition. Contour values are temperatures in ^{o}C.