# The Impact of Massive Exploitation in the Surface Manifestations at Ulubelu Geothermal Field, Indonesia

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**Keywords**: Geochemistry, monitoring, manifestations, Ulubelu

**ABSTRACT**

Ulubelu Geothermal Field has been operating since 2012 with an installed capacity of for install capacity 110 MW. The baseline geochemistry of surface manifestations determined in 2012. Due to the necessity of electricity in Indonesia, the addition of 2 x 55 MW for Unit 3 and 4 has been commissioning since 2016 and 2017. Monitoring geochemistry of surface manifestation conducted in 2017. The increasing of fumaroles temperature and steam fraction, which postulated as upflow zone, shows that meteoric fluid decreased compared to the contribution of reservoir fluid. The reinjection breakthrough was affected by fumaroles, it remarked by the dropping of NCG and was proved by the geochemical production monitoring as well. Declining temperature and dilution of chloride was occurred at neutral chloride hot springs in Way Panas, which postulated as an outflow zone area. It indicates that the reduction of reservoir fluid was occurred in the too hot springs due to the massive mass extraction in the upflow zone through the outflow zone.

## 1. INTRODUCTION

Ulubelu Geothermal Field is located in Tanggamus District, approximately 100 km from Tanjung Karang City, The Capital of Lampung Province (Figure 1). Manifestations survey was conducted in 2012 when installing capacity 2 x 55 MW. In 2017, monitoring geochemistry of surface manifestations was held when installed capacity became 4 x 55 MW. Surface manifestations in Ulubelu Geothermal Field consist of hot springs which have a temperature above 50oC, warm springs which have a temperature below 50ºC, fumaroles, mud pools, and steaming grounds. Figure 2 shows the distribution of surface manifestations.


**Figure 1: Ulubelu Geothermal Field Location Map**

## 2. GEOLOGY

Ulubelu Geothermal field is surrounded by Sula Mountain in the west, Rendingan Mountain in the north, Korupan Mountain in the east, Kukusan Mountain in the south, and Duduk Mountain in the centre. Tectonically, it related to the dextral Semangko segment of the Sumatran fault system, which produced a pull-apart basin. Figure 3 shows that identified three sets of fault, the NW-SE striking Muara Dua in the west and Talangmarsum fault in the east as boundaries of the depression, the ENE-WSW striking Sula in the North and Gunung Tiga faults in the opposite direction and other NW-SE striking Datarajan, Karangrejo, and Duduk faults. The NNW-SSE Rindingan 1 and 2, and the NNE-SSW Rendingan 3 in the northern part of Sula fault faults were identified as short strike-length faults, which are productive permeability (Trianggo et al., 2015).

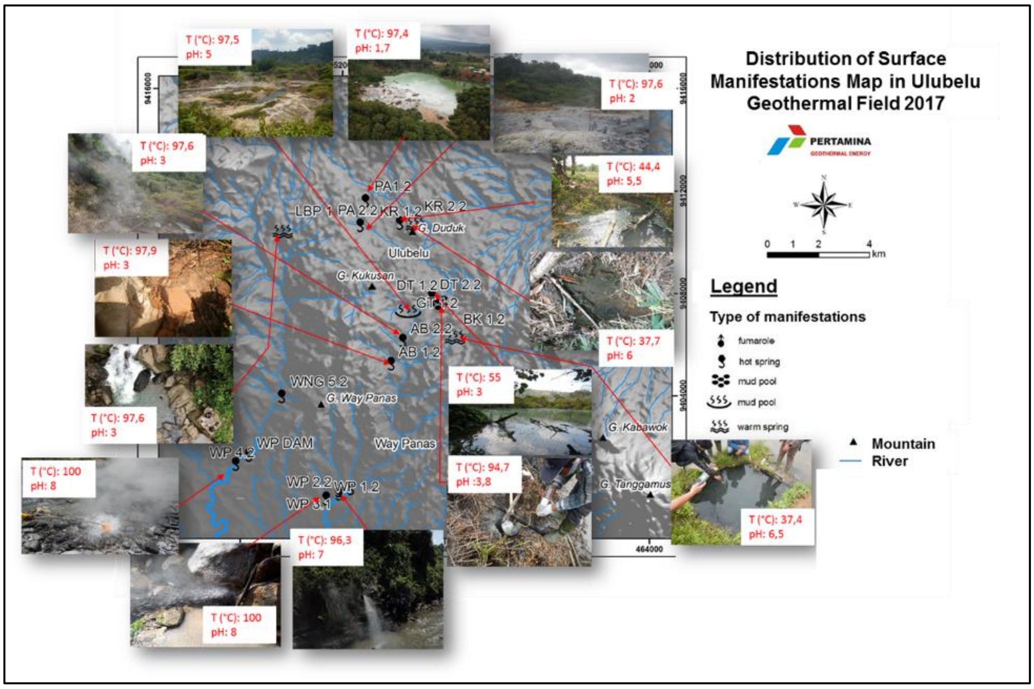


**Figure 2: Distribution of Surface Manifestations Map**

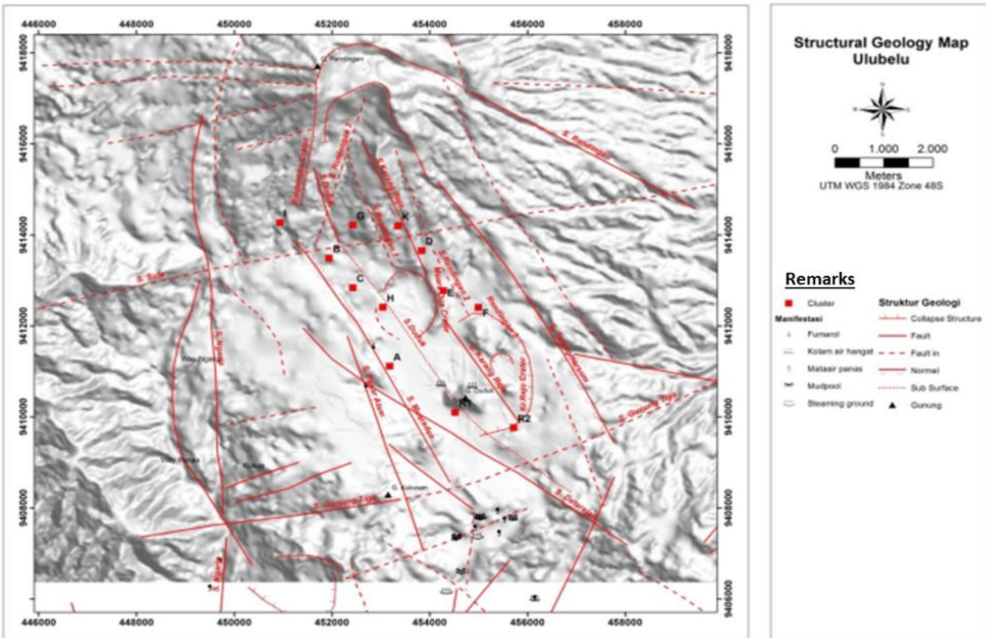


**Figure 3: Structural Geology Map of Ulubelu Geothermal Field**

## 3. GEOCHEMICAL PRODUCTION MONITORING

In fulfilling the 4 x 55 Mwe electricity, twenty-two wells from cluster B, C, D, G, H, I, and K supplied to four steam turbines, and six wells from two clusters acted as reinjection wells where are located in the eastern and southern part of production wells. Chemical breakthroughs appeared at production wells in clusters C & H where are located in the south part of Ulubelu Geothermal Field. It remarked by increasing chloride and declining NCG. Beside chemically, the same clusters show enthalpy decrease downhill due to the temperature breakthrough. The close distance between production wells in cluster C & H and reinjection wells in cluster A where is approximately 2 - 2.5 km and the contribution of Muara Dua productive fault which striking NW where is located in the western part of Ulubelu Geothermal Field caused the reinjection breakthrough effect (Mulyanto et al., 2019).

## 4. GEOCHEMICAL MANIFESTATIONS MONITORING

### 4.1 Surface Temperature and pH

The 2012 manifestations data was the baseline for this paper. The temperature of manifestation slightly declines in the hot springs at Way Panas as the outflow zone of the system (Figure 4). Meanwhile, the hike up of heat occurred in relatively higher elevations such as Datarajan and Karang Rejo. The pH measurement shows a stable stance except in Datarajan (Figure 5), maybe because of the higher gas solubility in the water-rich system.

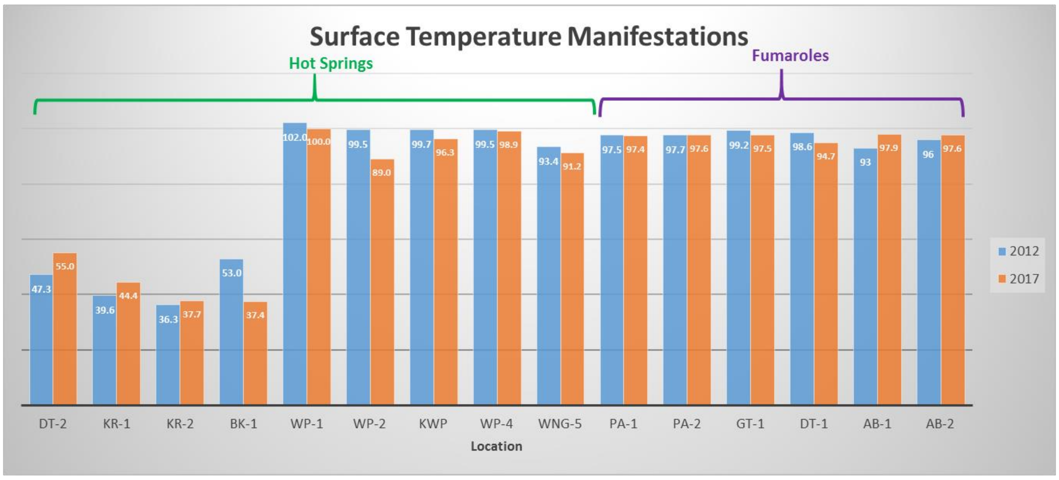


**Figure 4: Surface Temperature of Manifestations**

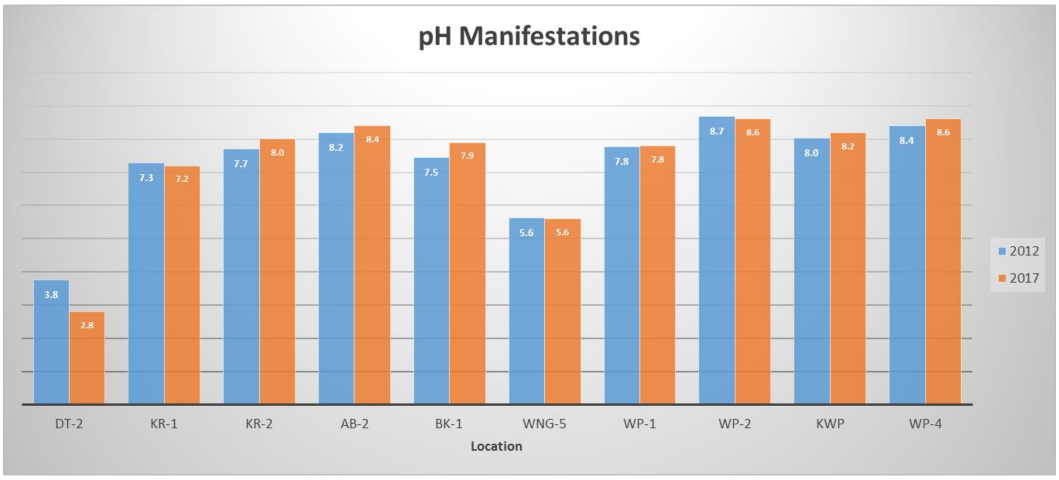


**Figure 5: pH of Manifestations at 25ºC**

### 4.2 Dissolved Elements

Datarajan warm spring, Gunung Tiga mud pool, and Way Ngarip hot spring determined as sulfate water by the ternary diagram of Cl-$SO_4$-$HCO_3$ (Figure 6). Furthermore, Aik Besak hot spring, Karang Rejo, and Batang Kluwak warm springs found as bicarbonate water. These two types of water acted as an upflow zone in Ulubelu (Mulyanto et al., 2015). In the meantime, neutral chloride water is found at the lower elevated in Way Panas where is located in the southern part of Ulubelu Geothermal Field (Figure 7), which is postulated to be the possible outflow (Mulyanto et al., 2015).

Neutral chloride hot springs at Way Panas were partial equilibrium fluids (Figure 8), which means the water circulated from a more in-depth system mixed with the groundwater while rose up. At the same time, upflow zone manifestations were magnesium-rich fluids, which indicated as immature water. The dilution by groundwater caused a higher concentration of magnesium (Nicholson, 1993).

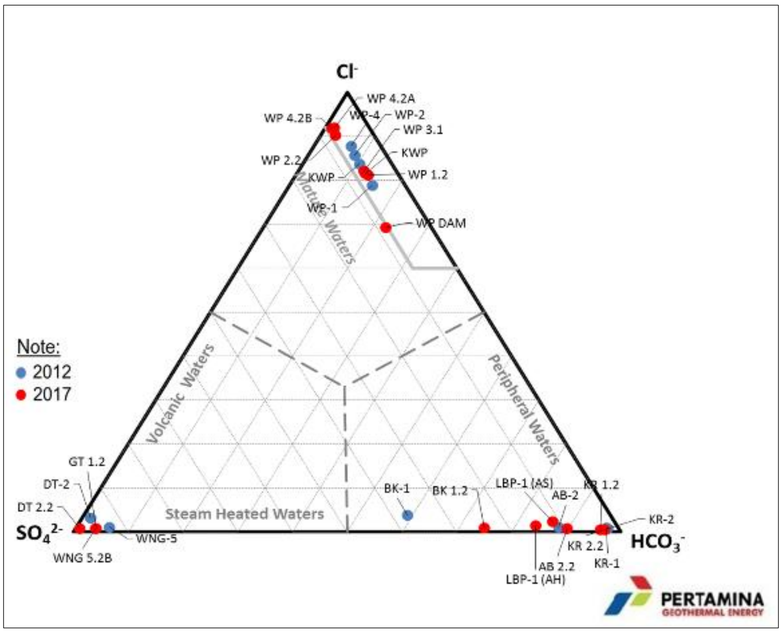


**Figure 6: Ternary Diagram Cl-$SO_4$-$HCO_3$**

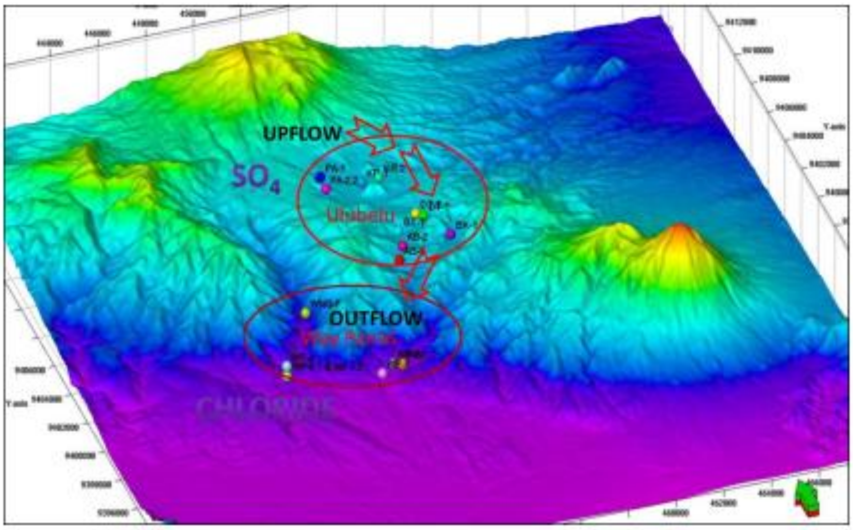


**Figure 7*:* Postulated Upflow and Outflow Zone**

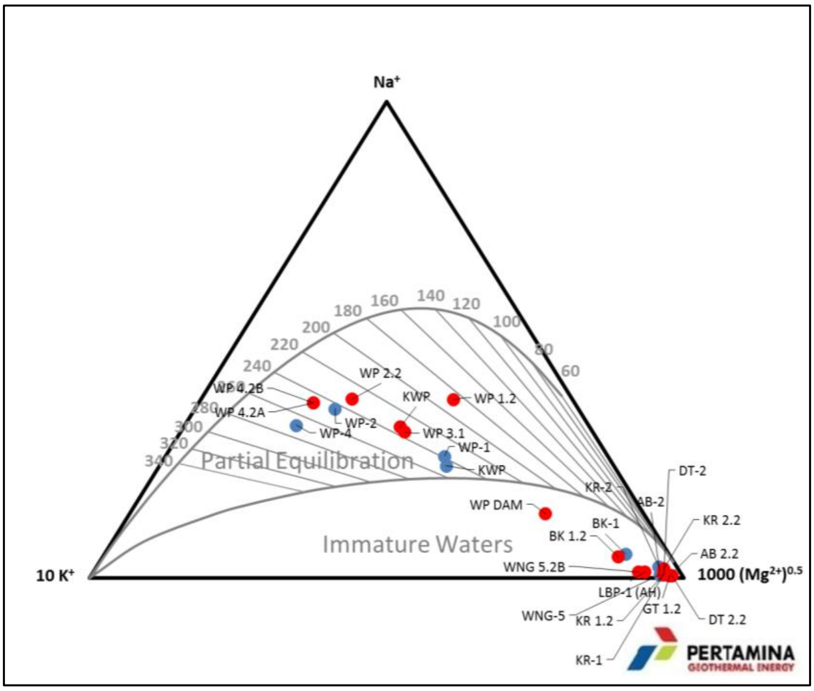


**Figure 8: Giggenbach, W. F. (1988). Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. Geochimica et Cosmochimica**

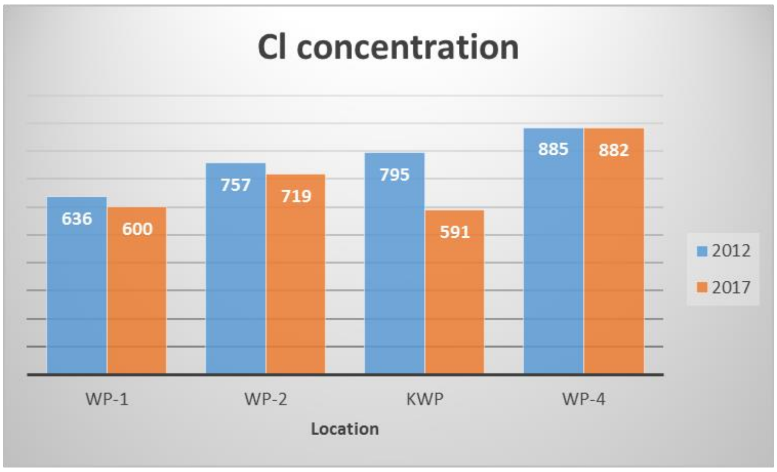


**Figure 9: Monitoring of chloride concentration**

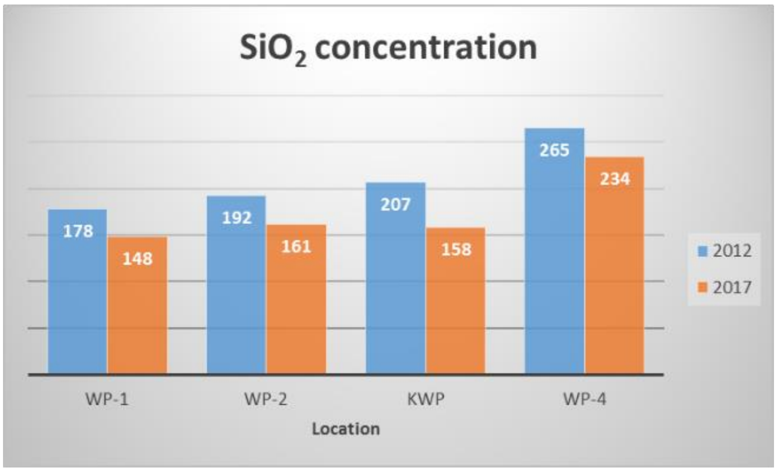


**Figure 10: Monitoring of silica concentration**

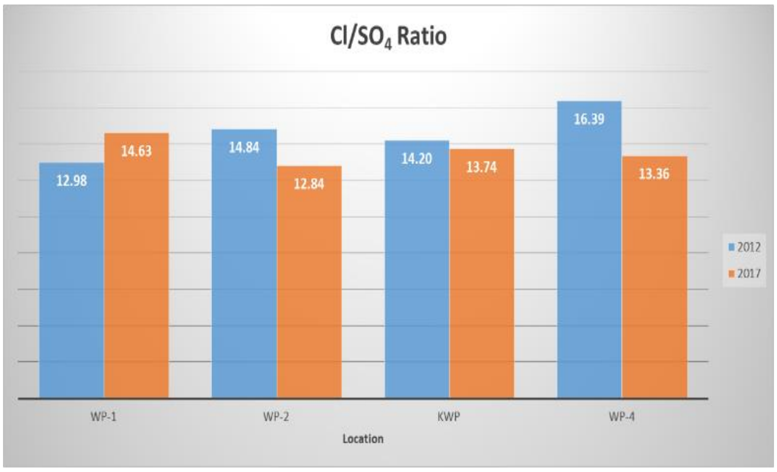


**Figure 11: Monitoring of $Cl/SO_4$ ratio**

The highest concentration of chloride at the Way Panas hot springs originated directly from the deep reservoir through permeable zones. Chloride is a conservative element that tends to remain in solution and unreactive by rock-fluid interaction (Nicholson, 1993). The changing concentration of chloride caused by boiling or mixing in the reservoir. Silica is an element that has fast equilibrium and controlled by temperature. When fluid ascends rapidly to the surface, the concentration of silica in the water will increase due to boiling and loss of steam (Nicholson, 1993).

Moreover, chloride over sulfate ($Cl/SO_4$) ratio indicated the process in the reservoir due to sulfate is formed by condensation $H_2S$ into near-surface water or oxygenated groundwater. $H_2S$ dissolved in the deep fluid but separated from chloride water following boiling at depth (Nicholson, 1993). Decreasing chloride (Figure 9), silica (Figure 10), and $Cl/SO_4$ ratio (Figure 11) appeared in Way Panas. It indicated that the reduction of reservoir fluid was occurred due to the massive mass extraction in the upflow zone through the outflow zone.

#### 4.3 Non-Condensable Gas (NCG)

Most nitrogen in the geothermal system is derived from dissolved in meteoric recharge water or can be of magmatic origin. It may be obtained from the gradation of organic matter in the crust when it comes into contact with the magma (Nicholson, 1993). Argon is contributed to the geothermal fluid by meteoric recharge water. It used as a conservative species in ratios, in much the same Way that chloride in water chemistry (Nicholson, 1993). Fumaroles were located in the upflow zone came from meteoric fluids, which has heated in the reservoir (Figure 12).

Data from 2012 plotted near air point, which confirmed that groundwater more dominant than reservoir fluids. Gas chemistry data in 2017 shifting towards to magmatic line, which indicated the reduction of groundwater (Figure 12).

$CO_2$ is the most abundant gas in the geothermal system, often representing over 85% by both volume and weight of the total gas content of discharge (Mahon et al., 1980). The gas is less soluble than hydrogen sulfide and ammonia (Ellis, 1962; Ellis and Golding, 1963). Increasing $CO_2$ is shown on the $CO_2$-$H_2S$-$NH_3$ ternary diagram (Figure 13) and indicates that the contribution of groundwater decreased.

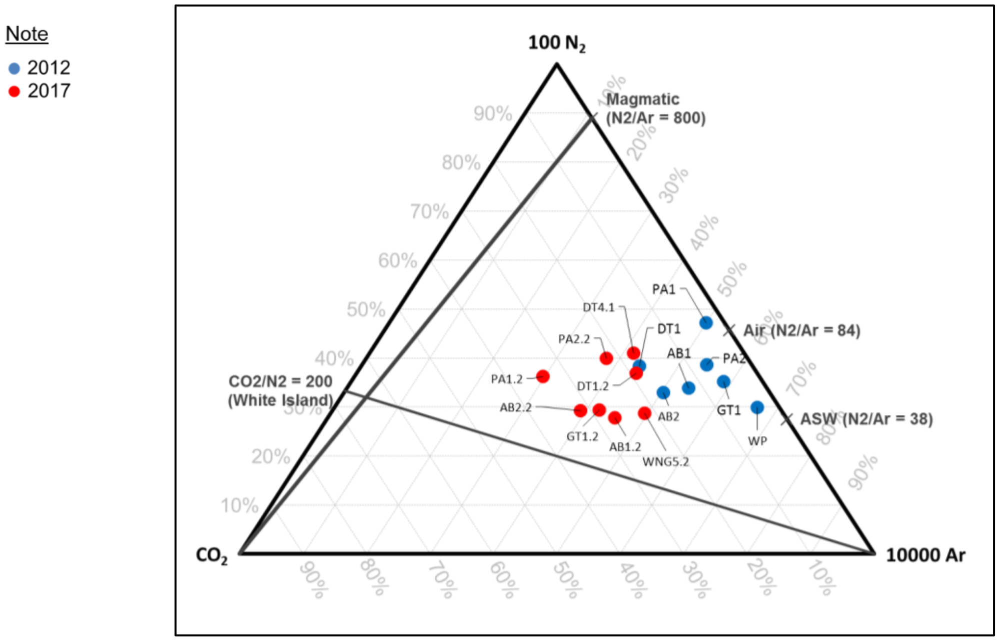


**Figure 12: Ternary Diagram $N_2$-$CO_2$-Ar**

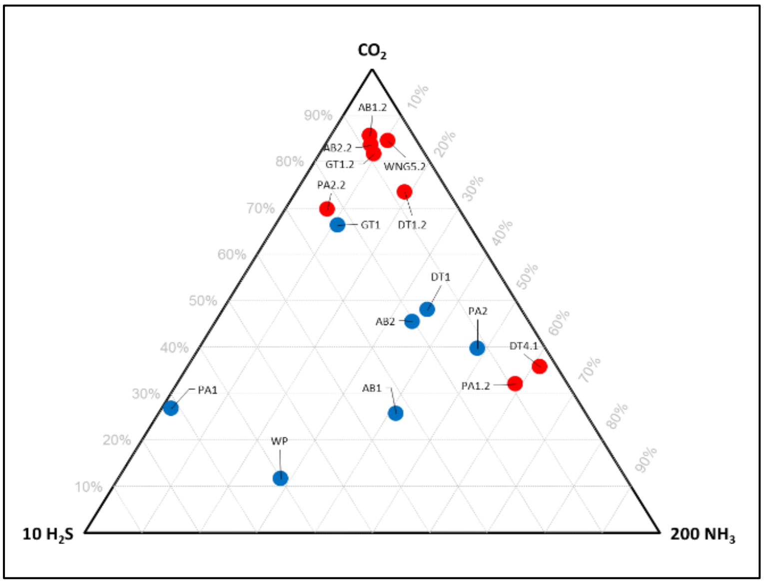


**Figure 13: Ternary Diagram $CO_2$-$H_2S$-$NH_3$**

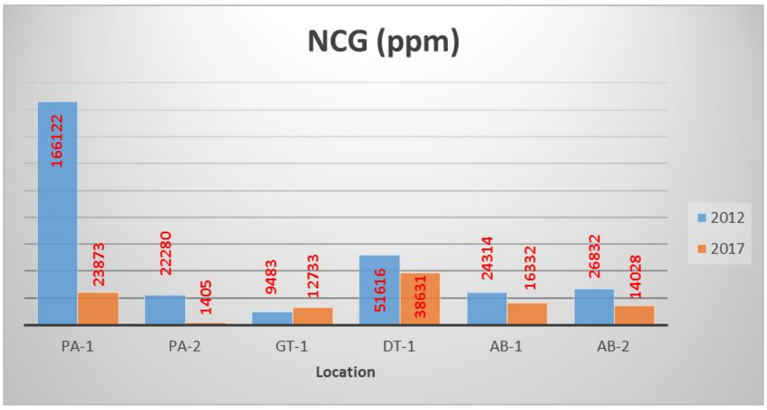


**Figure 14: Monitoring of NCG**

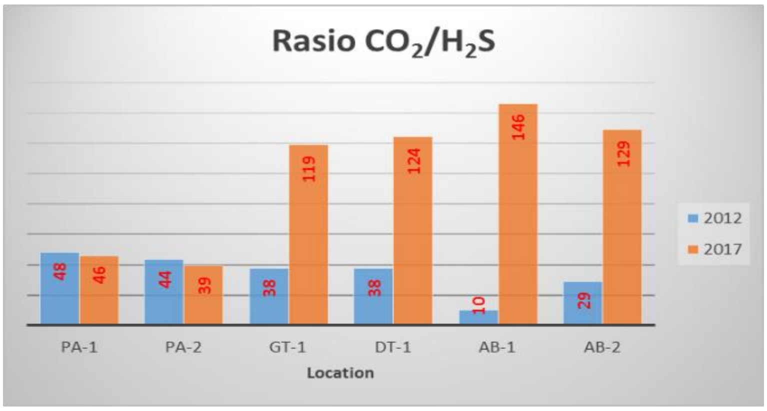


**Figure 15: Monitoring of $CO_2/H_2S$ Ratio**

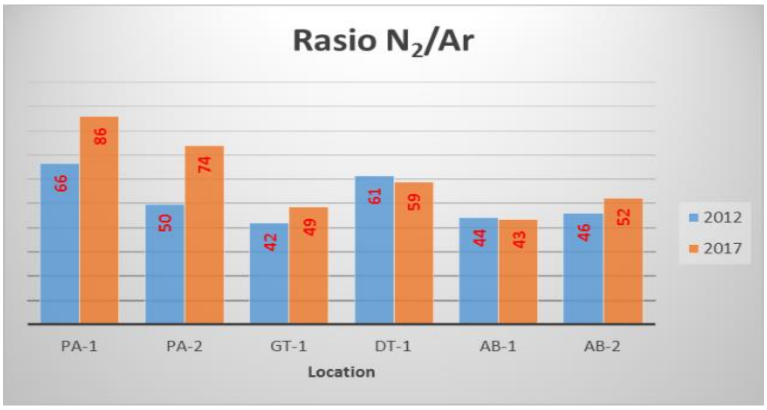


**Figure 16: Monitoring of $N_2$/Ar ratio**

Boiling affected to gas separation rate, the more fluid migration, the higher the amount of near-surface boiling and hence the lower gas content of the system (Nicholson, 1993). Decreasing NCG occurred at fumaroles in Ulubelu Geothermal Field, except GT1 (Figure 14), and the similar indication was seen in the production wells in cluster C and H due to reinjection breakthrough from cluster A (Mulyanto et al., 2019). Increasing the $CO_2/H_2S$ ratio (Figure 15) occurred due to the addition of $CO_2$ concentration. It approved that those fumaroles already saturated with reservoir fluid in 2017. Increasing $N_2$/Ar (Figure 16) due to decreasing argon as a conservative species in meteoric fluid reinforced the conclusion.

### 4.4 Reservoir Temperature

Reservoir temperature from manifestations carried out by geothermometer calculation, either using water or gas geothermometer. Monitoring of reservoir temperature from Way Panas hot springs used silica (Fournier & Potter, 1982b) and Na-K-Ca geothermometer (Figures 17 and 18). In 2012, reservoir temperature from WP-1, WP-2, KWP, and WP-4 by silica geothermometer range between 155-178$^oC$ while Na-K-Ca geothermometer is 197-227 oC. In 2017, the reservoir from Way Panas hot springs was 145-172$^oC$, and the Na-K-Ca geothermometer is 161-217$^oC$. Both of water geothermometer showed that decreasing reservoir temperature occurred at WP-1, WP-2, KWP, and WP-4 and reinforces the decreasing contribution of reservoir fluid.

Furthermore, monitoring of reservoir temperature was using CAR-HAR geothermometer at AB1, AB2, GT1, PA1, PA2, and DT1. Reservoir temperature increased from 225-250ºC in 2012 to 250-275ºC at the upflow zone of Ulubelu Geothermal Field, which remarked at those fumaroles (Table 1). A decrease in the concentration of argon caused plotting displacement in the CAR-HAR geothermometer graph (Figure 22) and confirmed that the contribution of meteoric fluid reduced.

## 5. CONCLUSION

The reinjection breakthrough effect in the production wells appeared and remarked by decreasing NCG at the fumaroles in the upflow zone of Ulubelu Geothermal Field. While increasing $CO_2/H_2S$, the $N_2/Ar$ ratio and reservoir temperature based on the CAR-HAR geothermometer occurred in this zone. It indicated that those fumaroles saturated by reservoir fluids, which came from reinjection wells in cluster A. The difference of geochemical characteristics showed in Way Panas hot springs, which postulated as outflow zone. Concentration of chloride, silica, and $Cl/SO_4$ ratio followed by reservoir temperature based on silica and Na-K-Ca geothermometer declined and remarked as dilution. It proved that the contribution of reservoir fluid decreased to outflow zone and reinjection breakthrough effect invisibled.

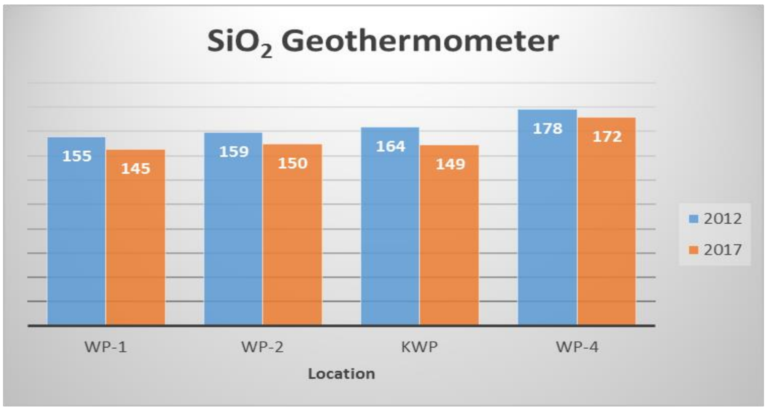


**Figure 17: Monitoring of Silica Geothermometer**

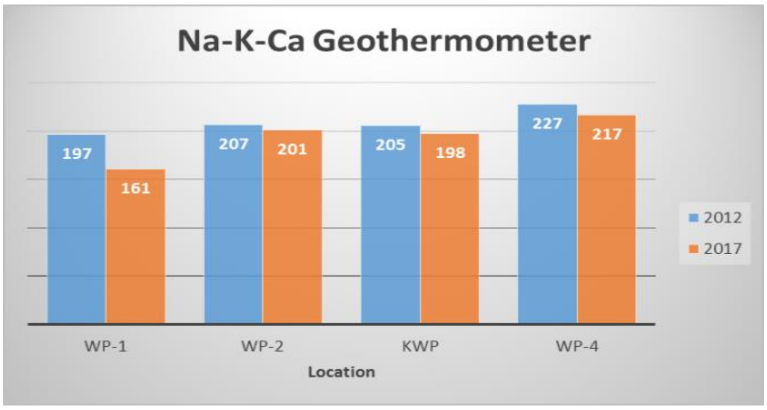


**Figure 18: Monitoring of Na-K-Ca Geothermometer**

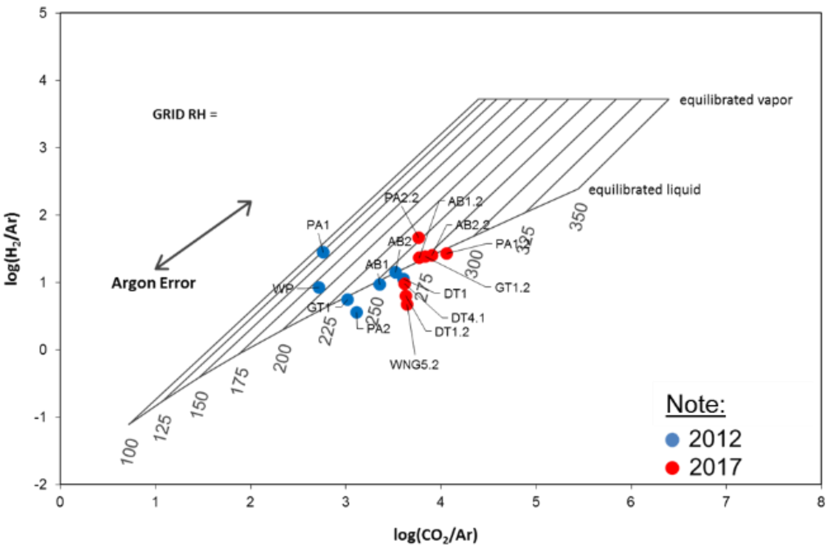


**Figure 19: CAR-HAR Geothermometer**

**Table 1 Monitoring of Reservoir Temperature & CAR-HAR Geothermometer**

| Fumaroles | Temp (degC) | |
|---|---|---|
| | 2012 | 2017 |
| AB-1 | 250 | 275 |
| AB-2 | 250 | 275 |
| GT-1 | 225 | 275 |
| PA-1 | 125 | 275 |
| PA-2 | 225 | 250 |
| DT-1 | 250 | 250 |

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