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The Benefits of Surface Thermal Features Monitoring in Darajat Geothermal Field

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ABSTRACT

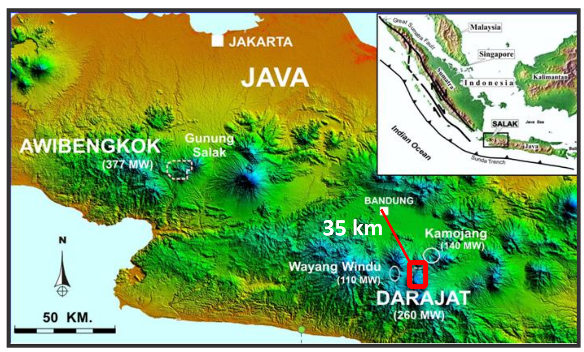
Monitoring of the Darajat surface thermal features has been conducted since 2008 on an annual basis. Thermal manifestation monitoring includes geotechnical investigation and geochemical sampling of liquid and gas discharges from both hot/warm springs and fumaroles. Geotechnical examination is normally conducted to monitor changes in the intensity, size and geometry of the surface manifestations including the assessment of potential associated geological hazards such as landslides and thermal ground hazards. Visual inspection of the surface thermal features including accurately mapping of their locations, especially the fumaroles, is done to determine if these natural features are moving and to investigate their potential negative impact on nearby surface facilities. The geochemical monitoring is aimed at determining changes, if any, in the relationship between the surface thermal features and the Darajat steam reservoir. The geochemical and geotechnical analyses are then merged to provide an integrated interpretation of the thermal manifestations.

INTRODUCTION

Darajat Geothermal field is located about 35 km South East from Bandung (Figure 1) with elevation at 1750-2000 meters above sea level. This geothermal field operated initially in October 1994 and commenced commercial production in November 1994. Darajat is one of the biggest vapor dominated geothermal fields in the world with total capacity currently are 271 MWe generated from three units. Unit I owned and operated by PT. Indonesia Power with capacity 56 MWe and Unit II/II operated by Chevron Geothermal Indonesia with capacity 94 Mwe and 121 MWe respectively. Since the first investigation in the early 1970's, Chevron Geothermal Indonesia has drilled 47 wells during 7 campaigns. Recently, Darajat Geothermal field have 34 production wells, 4 injection wells, 3 monitoring wells, and 8 wells already plugged and abandoned.

Darajat Geothermal field geographically is laid on the eastern side of Mt. Kendang which is part of an arcuate range of Quaternary volcanoes. Several volcanic activities have occurred along this volcanic range, e.g Guntur Volcano (1840), Papandayan Volcano (1772, 1923-1926).

Darajat area is dominated by several hundreds to greater than 1000 meters of pyroclastic rocks (breccias and tuff) interbedded with minor andesitic lava flows. This sequence pyroclastic rocks cover andesite complex which consist of relatively fresh andesitic lava flow and intrusions. Most of the steam reservoir found in Darajat is encountered in this andesite complex.



Source: SRTM West Java BSL 1841_Z48S

Figure 1: Location of the Darajat Geothermal Fields in relation to other cities and geothermal fields.

Structure in Darajat dominantly has trends toward NE-SW, NW-SE, and N-S (Figure 2). The most significant structural feature in the area is the Kendang fault which strikes northeast from Darajat along the high axis of the volcanic range, disappearing on the north side of the Kamojang field 10 kilometers away. To the west of Darajat field, the Kendang fault is slightly offset by the Gagak fault, which is considered to control major permeability within the field. Other structures which have NE-SE trending are Gagak, Cibeureum, Cipandai and S Faults. The major structure which has NW-SE trend is the Ciakut Fault although there is unnamed faults located south of production area which has same trend. The N-S trending structure was confirmed by the result of surface mapping (Stimac et. al, 2010 op. cit. Pasaribu et.al, 2012) and recent interpretations of geochemical observations and fluid flow during drilling combined with the tracer test results. The occurrences of those structures control the appearance of thermal features in Darajat.

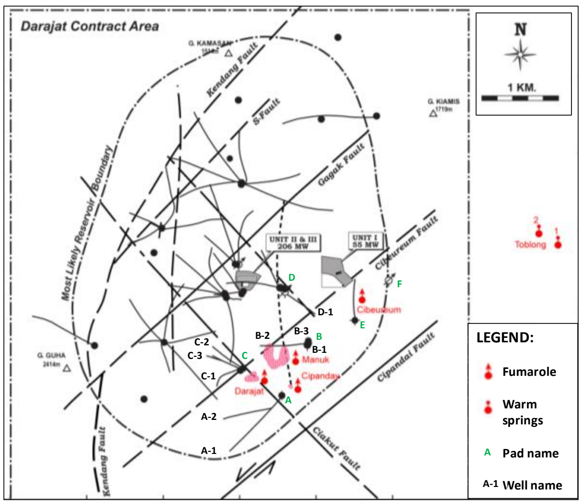


Figure 2: Map of Darajat Geothermal field

METHODOLOGY

Surface thermal monitoring is a part of surveillance program to monitor chemical and physical geometry changes of thermal features during field extraction at Darajat. This activity is regular activity which has been conducted annually since 2008. This activity usually conducted during dry season to prevent the sample impacted by surface water.

Five locations are visited during the surface thermal monitoring, namely, the three fumarole areas (Manuk, Darajat, and Cipandai) and two hot springs (Cibeureum and Toblong). All of thermal areas are situated in south east of production area at Darajat. The distribution of manifestation thermal features at Darajat can be looked at Figure 2.

In the fumarole areas, geochemist team collected gas, steam condensate, and stable isotopes sample from condensate. Gas sample is collected at least with one duplicate during each survey, preferably the fumarole with the highest sampling superheat value or new sampling location, for QA/QC purpose. Appropriate sampling point and proper technique in sampling is very important because both of them will influence the data quality. For the sampling point, team selects safe location with the gas vents associated with the highest discharge rate and superheat in each fumarole area to represent the best fumarole data. High temperature spot, especially superheated sample, assumed will lower the risk of a poor sample because the sample gets less the influence of surface processes, e.g. condensation. In term of geotechnical observation, geologist team observes and maps the distribution of surface alteration surrounding the fumarole area. This result will be compared with previous geotechnical monitoring to identify the changes of the surface manifestations in intensity, size and geometry.

In hot springs location, geochemist team collects liquid and stable isotopes samples. As fumaroles, teams select the highest sampling point in order to obtain the best sample which represents the characteristic of source of liquid. Prior to fill liquid sample into the bottle, the bottle samples have to be flushed several times to wash and condition the bottle as sample.

Samples are then sent and analyzed by other business partner. Field record of sampling activity is well documented in history for other future purposes. The laboratory data is subsequently input into geochemistry application software before being interpreted. The application is an interpretation software package developed by Unocal Geothermal, is used to create geochemical plots.

QA/QC process is conducted prior to interpret the geochemistry data to know how good data quality from sampling activity. The parameters which is used to check data quality from gas sample, namely, %air contamination, estimated superheat, some of gas species (NCG, Ar, N2) etc. For liquid samples data quality, team uses ion charge balance analysis.

DARAJAT THERMAL FEATURES

Hot Springs

Cibeureum Hot Spring

The Cibeureum Hot Spring is located near the main entrance of the Darajat Geothermal Field (Figure 3). This spring is categorized as acid warm spring because Cibeureum Spring has measured temperature of 54.6°C and pH of 3.3 based on last observation in 2012 (Figure 4).

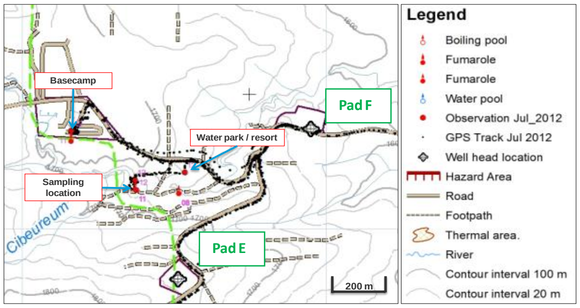


Figure 3: Map of sampling locations at the Cibeureum Hot Spring complex.

The chemistry of the Cibeureum spring is monitored mainly for environmental issues because this warm spring is used to supply water for the nearby commercial hot pools/resorts since 2010. Simatupang (2010) believed that the spring is a product of the mixing of near-surface condensed steam with rainwater/groundwater that migrates downhill.

Figure 4: Sampling activities at the Cibeureum Hot Spring; temperature measurement (right) and liquid sampling (left).

Toblong Hot Spring

The Toblong Hot Springs are located in Toblong Village which is actually outside the current Darajat contract boundary. However, samples from this hot spring are still collected because they are considered valuable in maintaining a record of historical discharge fluid chemistry for environmental purposes. As recommended in Kristianto and Molling (2011), Toblong 2 should be included as a new sampling point and was sampled in 2012. This new sampling point is located ~400 m northwest of Toblong 1 (Figure 5). Both of these hot springs are used for bathing by the local community.

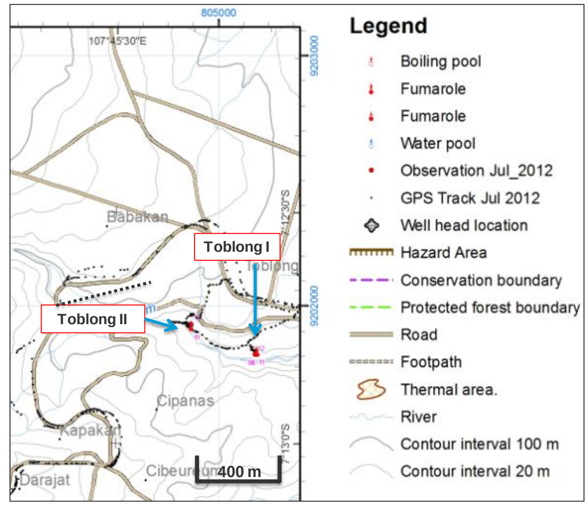


Figure 5: Location map of the Toblong 1 and II Hot Springs.

The Toblong Hot Spring 1 has milky appearance and it is believed to be the result of suspended silica particles in the water as mentioned by Molling (2006) (Figure 6). The green color is probably due to the algae growing extensively at the bottom of the hot springs. Based on the measurements done on site in 2012, the temperature of this hot spring is low at 51.6 °C with a pH of 5.5. Similar with the Cibeureum Hot Spring, the Toblong 1 Hot Spring can be categorized as slightly warm acid spring.

Figure 6: Pictures showing sampling at Toblong 1 Hot Spring. Temperature was measured by lowering the thermoprobe near the perceived source of the spring indicated by vigorous bubbling.

The Toblong 2 Hot Spring is located at an elevation of 1,354m ASL (Figure 7). The fluid is being discharged in a fissure in a lahar deposit. This hot spring is hotter and more acidic than Toblong 1. The measurement in the field shows this hot spring has a temperature of 55.7 °C and a pH of 4.4. However, Toblong 2 can also be categorized as a warm acid spring. Toblong 2 has the same milky appearance as Toblong 1 suggesting suspended silica particles in the spring water.

Figure 7: Pictures showing the Toblong 2 Hot Spring. The hot spring pond has milky color because suspended silica particles.

Fumaroles

Kawah Manuk

Kawah Manuk is the biggest and most dangerous thermal area because of many boiling mud pools and altered ground that occur within the general vicinity of this fumarolic area. This fumarole complex covers an area approximately 400 m (NS) x 400 m (EW). It can be looked at figure 8. From the geotechnical survey, there are minor landslide and subsidence potential in the north and NW portions of the thermal area. The landslide hazard is a result of extensive fumarolic activity which has weakened the land/soil surface and felled trees and dried/withered the general vegetation (Figure 9).

The last sampling point in 2012 is the same as previous year and the intensity of fumarolic activities has not changed. However, the size of the Kawah Manuk fumarole area appears to be 5-10 m wider than when measured in 2008. It is possible that the thermal activity in this area will change in the future because the local community pipes water in and out of the fumarole area to supply several water parks in Darajat.

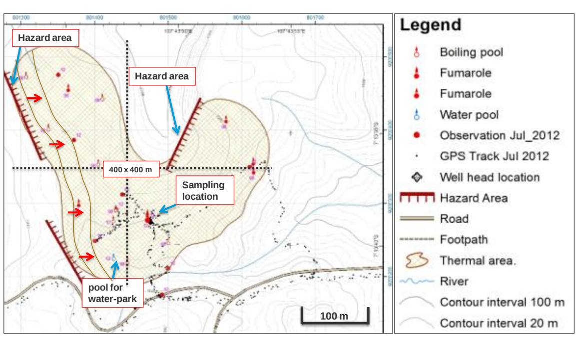


Figure 8: Sampling point location at Kawah Manuk. The thick brown lines show the areas with landslide potential due to extensive fumarolic activity and natural loss of vegetation.

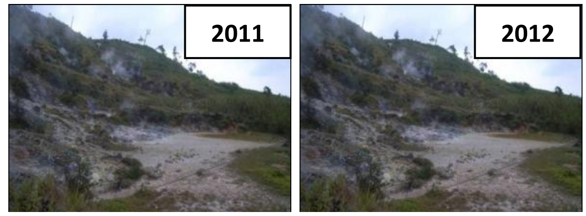


Figure 9: Felled trees and dry/withered vegetation in the northern and western of the Kawah Manuk fumarole area due to extensive fumarolic activity. There may be landslide potential in this area in the future. This fumaroles area has not significantly changed since last monitoring in 2011.

Measured temperature of this fumarole in 2012 was 95.2°C with the calculated boiling point based on elevation at 93.6°C hence the calculated superheat is about 1.6°C. The discharge rate is quite strong at about 115 ml in ~15 minutes and 500 ml in ~75 minutes. Field pH of the steam condensate is 4.6

Kawah Darajat

Kawah Darajat is not as big as Kawah Manuk but still covers an approximate area of about 200m (NS) x 200m (EW). It can be accessed easily since it is used as a special area of interest for tourism. A cleared pathway and some fencing exist in this area. Boiling mud pools and altered ground are widely distributed in this area hence using a walking stick is important especially for the Leadman during the sampling activity.

The sampling point at Kawah Darajat is located near a cliff and surrounded by boiling mud pool and unstable ground (Figure 10). This sampling point location is slightly different from the previous year because there is no steam discharge in the sampling point during the recent visit. Based on thermal features monitoring which was conducted in 2012, the measured temperature in this fumarole was 93.4°C while the boiling point based on elevation is calculated at 93.5°C suggesting that there is no superheat. Actually, the superheat has slightly decreased from the 2011 value of ~0.8°C. The estimated discharge rate at Kawah Darajat is very similar to that at Kawah Manuk at 115 ml in ~15 minutes. Steam condensate pH was measured at 4.0.

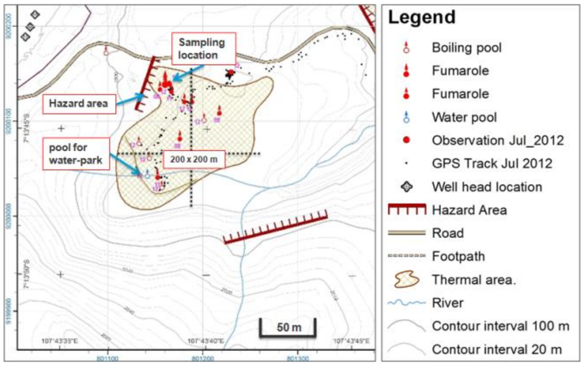


Figure10: Location map of the Kawah Darajat area. The 2012 sampling location is at the NW edge of thermal area and surrounded by boiling mud pools and altered ground. The thick brown lines show the potential landslide areas.

Kristianto and Molling (2011) recognized a minor landslide potential in the northern edge of Kawah Darajat and the southern wall associated with the Batukareta Hill, about 200m south of the sampling site (Figure 11). Similar to Kawah Manuk, the landslide hazard at Kawah Darajat is likely to be triggered by the extensive fumarolic activity which has weakened the soil and made the slope unstable; unfortunately, these happened in areas very close to the Pad C road. Incessant rain will soak the surface soil and add significant weight that may induce landslides. There is a need to develop a mitigation plan which may include rerouting the road if the thermal features enlarge/move and make the road un-passable in the future.

Qualitatively, the Kawah Darajat fumarole area dimensions have not changed significantly. However, this fumarole area should be monitored frequently because cliff towards the Pad C road is already covered by altered ground and any soil movement may damage existing surface facilities.

Figure11: Pictures showing extensive fumarole activity at Kawah Darajat which may cause potential landslide. Note: A & B: 2012 photo landslide plane near the road Pad C. C: 2011 photo landslide hill at Batukareta and D: 2012 photo landslide hill at Batukareta

Kawah Cipandai

Kawah Cipandai is located near Pad A (Figure 12). Both fumarole activity and discharge rate of Kawah Cipandai are less compared with Kawah Manuk and Kawah Darajat. However, a significant amount of preparation is still necessary prior to sampling this fumarole, e.g., there is a need to divert the creek flow before collecting both steam condensate and NCG sampling.

Based on last observation in 2012, the estimated discharge rate of Kawah Cipandai is about 115 ml in ~20 minutes and 500 ml in ~108 minutes. The calculated boiling point based on elevation is 93.7°C; Kawah Cipandai is at saturated conditions because its measured temperature is 93.2°C. Field pH measured from steam condensate is 4.0. Simatupang (2010) concluded that Kawah Cipandai chemistry is indicative of edge field fluids that are affected by steam condensation.

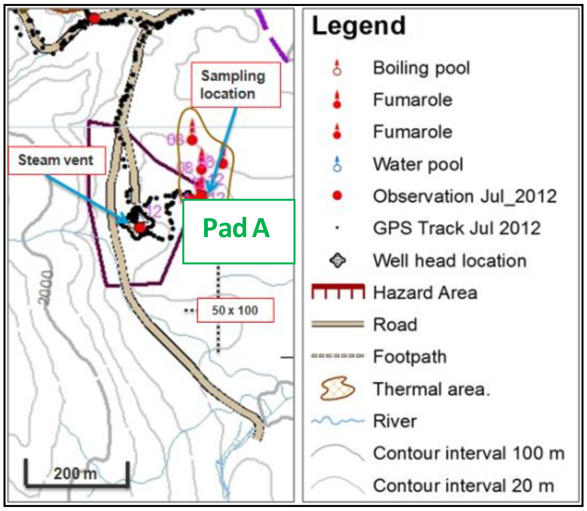


Figure12: Sampling site in Cipandai Fumarole

BENEFITS OF THERMAL FEATURES MONITORING AT DARAJAT

Thermal features sampling is common activity in exploration stage because this activity is the simplest and cheapest way in identifying geothermal prospect. In development stage, geotechnical observation is also incorporated in thermal features monitoring. There are several benefits in monitoring thermal features in development filed.

Geological Hazard Assessment

The geotechnical survey is normally conducted to monitor changes in intensity, size and geometry of the surface manifestations including the assessment of potential geological hazards associated with them, such as effects of field operations, landslides and other thermal ground hazards. Fumarolic activity capable weakens soil surrounding that area. Therefore, landslide is very potential occurred near fumarole area. All landslides, minor or major, which were found during thermal features survey, have to be documented because it'll be used as reference in observing that area specifically. Team ought to report to facility/operation team if the landslides potentially harm facility or local community. The significant findings during assess geological hazard in thermal area are the potential extension of Kawah Darajat and steam vent occurrence near the wellpad.

Potential extension of Kawah Darajat initially was found around 2006. This phenomenon is potentially damage nearby road to Pad C. This observation proceeds during thermal feature monitoring in 2008. At that time, team notice Darajat Fumarole fissure which found on the top of cliff near 2008 sampling point was disappeared. The fissure is approximately located 1-2 meters from the edge of the cliff and it produces steam. The fissure does not longer exist as the cliff face failed and fell into the thermal boiling pool adjacent to the sampling site. Team observed that there was mud splashed on the rock wall surrounding Kawah Darajat with height about more than 10 meters (Figure 13). This mud splash evident is hypothesized to be related to the failure event of the Kawah Darajat fissure previously mentioned. There is possibility migration of thermal activity at this site does pose a serious risk to undercutting both the road and pipeline nearby (East part). As mentioned in the 2006 report by Molling that the altered ground on the east side of the pipeline and road may easily be a continuation of the altered ground of the current Kawah Darajat area. This observation suggests that probably the eastern alteration area was much more active. It can be seen by the mud splash into the cliff near the road and pipe line at East side including the wispy steam that observed came from ground North of the pipeline and near the Kawah Darajat (Figure 14). This possibility heightens the risk that the thermal activity including the Kawah Darajat fumarole fissure is going to negatively impact the road and pipeline. Therefore, team recommend to frequently monitor Kawah Darajat as the extensive fumarolic activity in this area may weaken the land/soil surface (and potentially lead to landslides) nearby Pad C road. Also, develop a contingency plan if the thermal feature moves/grows thus making the current road impassable.

Figure13: Mud splashed to the cliff from Kawah Darajat

Figure14: Wispy steaming from the ground (red dash line)

Another findings regarding geotechnical monitoring for thermal areas is the occurrence of steam vent near wellpad. Geotechnical monitoring observed a steaming ground formed by an unfinished shallow hole during inclinometer installation (9m depth) at well A-1 (Figure 2). The steaming ground appeared besides the well and continuously discharged steam and deposited sulphurous deposit (Figure 15). Analysis indicated that there is hydrothermal activity at a shallow depth under the pad and the borehole simply provided a path to the surface. Presumably the hydrothermal activity may be part of the existing Kawah Cipandai about 150-200m east of the well.

Prior to conducting the investigation, there were three concerns regarding the steaming ground at A-1 namely:

- There is active fumarolic activity below A-1 which may hydrothermally alter the soil, weaken it and make the soil more susceptible to movement (believed to be one of the root causes of the long-term ground movement at the pad A area);
- The Kawah Cipandai may be moving or even enlarging (similar to the Craters of the Moon experience in New Zealand); and
- There may be shallow casing leakage at A-1 which may be heating near surface groundwater.

Geochemical data indicate that the steam from the steaming ground at A-1 has similar characteristics with the fumaroles at Kawah Cipandai hence it was concluded that there is fumarolic activity below Pad A (Kristianto et al., 2012). Additionally, Rohrs (pers. comm., 2012) noticed gas seepages surrounding Pad A thus validating the above conclusion.

Although the inclinometer monitoring showed that the deep drain and combination bore-pile gabion succeeded in stabilizing the A-1 area, it was recommended to the Darajat team to P&A Pad A because of the hazards/risks associated with ground stability and future fumarolic activities.

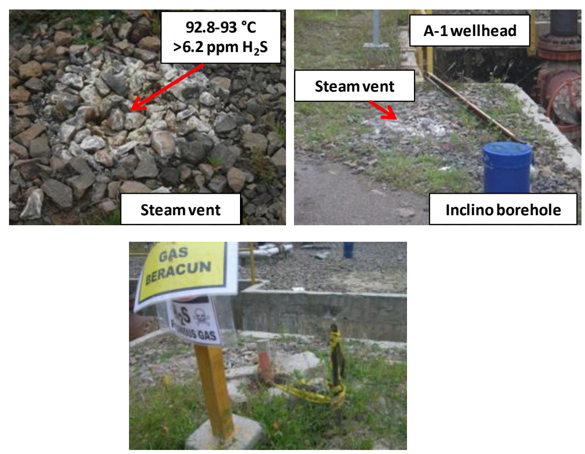


Figure 15:Pictures showing the status of the steaming ground at Pad A in 2011 (top) and 2012 (below). Currently, there is no more steam coming from the ground.

Based on last observation in 2012, the three fumarole areas did not change significantly in terms of their geographic location, physical characteristics and associated hazard potential when compared with last year. The main changes were the following:

- Cooling of the man-made pool at Kawah Manuk;
- Shifting of the mud pool by about 5-10m to the east (compared with the 2008 GPS data) at Kawah Manuk; and

- The disappearance of steam discharge in the 2011 vent sampled at Kawah Darajat.

It is expected that the fumarolic activity and sampling quality at both Kawah Manuk and Darajat may change because the local community is erecting man-made structures to utilize the heated water in the existing (and, possibly, additional) water parks/resorts in eastern Darajat. Table 1 in appendix is a summary of the 2012 geotechnical observations on the Darajat fumaroles.

Table 1: 2012 geotechnical and hazard observations on the Darajat fumaroles

Thermal Area	Dimension	Observation	Geology Hazard	Facility Impacted
Manuk	about 160,000 m^2 (400x400)	Highest intensity fumarole with mud pool, mud pot, steaming ground, artificial pool (found cooler than last year) Some thermal features appear to have shifted No significant change in fumarole intensity	Landslide Subsidence Weakened soil Road damage	Road Pipeline in Pad C
Darajat	about 40,000 m^2 (200x200)	High intensity fumarole with mud pool, mud pot, steam ground, artificial pool No significant change from previous year		Road Pipeline in Pad C
Cipandai	about 5,000 m^2 (100x50)	Low intensity fumarole with mud pool, mud pot No significant change from previous year		Road Drainage Pipeline in Pad A Darajat Camp water source at Cipandai

Assist in Identifying Reservoir Procesess during Field Operation

The geochemical sampling aims to investigate the relationship, if any, between the surface thermal features and the Darajat steam reservoir. Surface thermal in Darajat has relation with vicinity well, such as well B-2, C-1 and D-1. Figure 16 shows the historical NCG content of Kawah Manuk, Kawah Darajat and nearby wells with shallow entries. Notice that the NCG concentration in the fumaroles follows the same trend as exhibited by B-2, C-1 and D-1. This relationship suggests that there is direct connection between Kawah Manuk, Kawah Darajat and the shallow wells (Simatupang, 2010). The consistently slightly higher NCG content in the Kawah Darajat may be due to condensation caused by influx of MR (Marginal Recharge)/cold water down flow along the Ciakut Fault. Based on this relationship, surface thermal geochemistry data can be utilized as MR penetration monitoring because surface thermal located in the most of southern west of Darajat field which was assumed that MR derived from that direction.

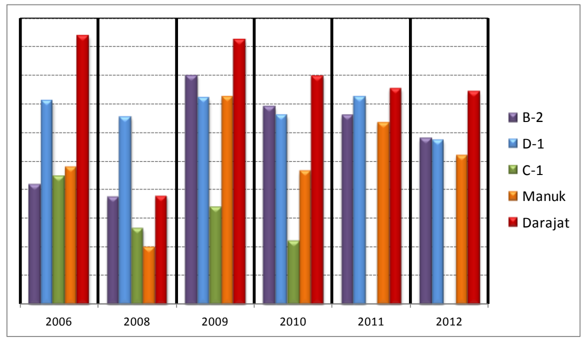


Figure 16: Historical NCG content (wt. %) in steam for selected fumaroles and wells

Another reservoir process which can be identified by utilizing surface thermal is drilling activity effect. Based on figure 16, the NCG content of all fumaroles showed significant decrease from 2009 to 2010. Simatupang (2010) attributed the low NCG in 2010 to boiling of condensate injectate from B-3 which already stopped about a year and/or marginal recharge (i.e., fluid characterized with low NCG). Another process that could lower NCG in 2010 was the drilling of C-3. The decrease in NCG coincided with increasing N_2 and Simatupang et al. (2011) alluded the significant increase in N_2 (and Ar) to the introduction of aerated drilling fluids during the 2009-2011 drilling campaign. The increase in N_2 was captured by the thermal sampling in 2010 (Figure 17). This drilling effect decreases through the times. It can be looked in figure 17 that N_2 content in all fumaroles depleted.

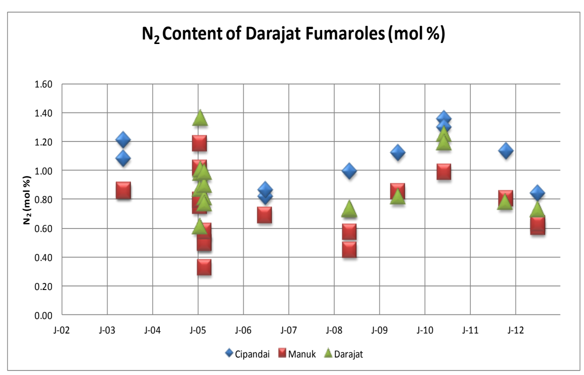


Figure 17: Historical N_2 (in steam) contents measured in Darajat fumaroles. High N_2 value in 2010 suggests related with drilling activity.

Recovery process of Darajat Fumaroles from drilling effect also validated in figure 18 and 19. Figure 18 shows that the Darajat fumaroles' gas chemistry is shifted now towards the N_2-Ar intersection (or the area in the N_2-CO_2-Ar plot that hosts geothermal fluids). In 2010, the gas chemistry of the fumaroles was away from this N_2-Ar intersection. This behavior suggests that the fumaroles are rebounding from the impact of the entry of aerated drilling fluids (i.e., N_2 and Ar) in the reservoir.

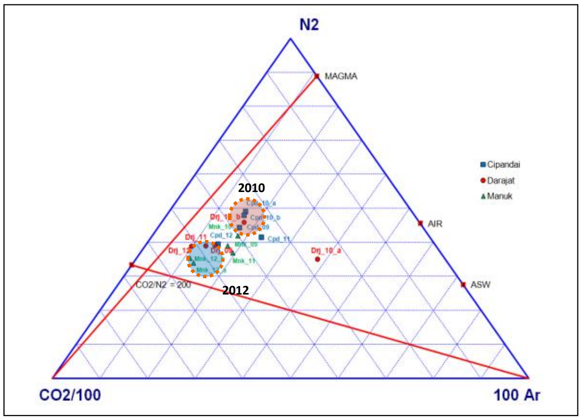


Figure 18: N2-CO2-Ar ternary plot showing 2009-2012 fumaroles samples

The above observation is confirmed by the HAR-CAR plot where the data plot in the Ar-loss region (upper right portion of the chart) (Figure 19). Based on those two geochemical plots, the fumaroles exhibit a general decrease in both N_2 and Ar which suggests that most of the aerated drilling fluids have been produced or discharged in the thermal features.

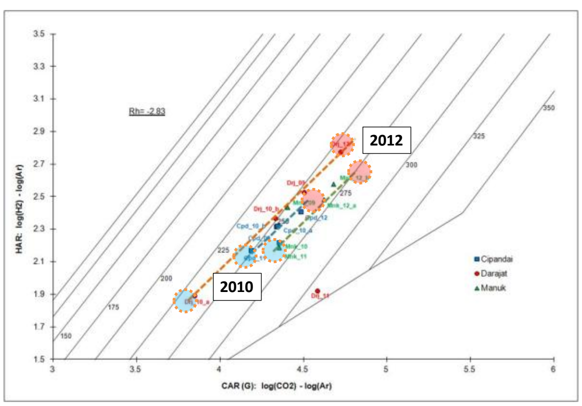


Figure 19: HAR-CAR gas grid of 2009-2012 fumaroles samples. The dashed gradient lines represent the change in Ar content (i.e., orange for Darajat, blue for Cipandai and green for Manuk). Note: blue circle for 2010 and red circle for 2012.

The process of boiling condensate injectate is also can be shown in monitoring surface thermal features. According to figure 16, NCG was decreased in the most of Darajat Fumaroles in 2012 (Kawah Manuk and Cipandai). Kawah Darajat is not showed the decrease of NCG possibly due to some local (near surface) condensation. There is probably no single process to explain fully the lowering of the NCG but a combination of processes. Among others, the preferred model to explain that phenomenon is injection at D-1 probably produced steam with low NCG as the condensate migrated along the Cibeureum Fault. The connection of D-1 to B-2 is obvious as boron in B-2 increased two weeks after injection in D-1 was terminated (Figure 19). B-2 is very near Kawah Manuk and the increase in boron in B-2 corresponds to the decrease in NCG in the fumarole.

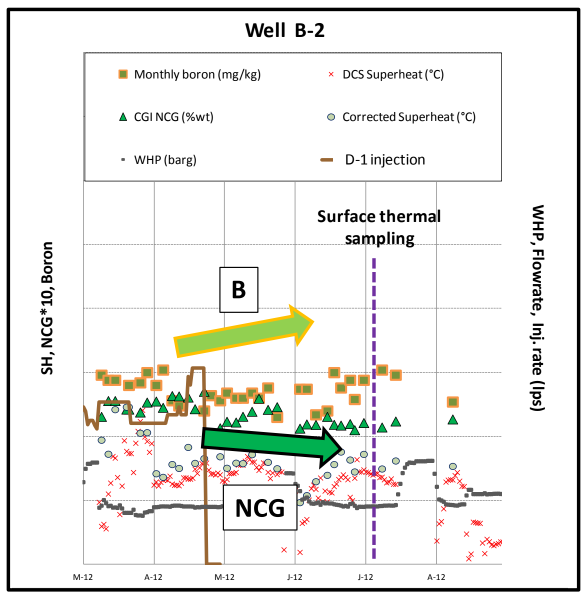


Figure 20: Geochemical plot of B-2, the nearest production well to Kawah Darajat, showing the increase in boron after injection at D-1 is terminated. Injectate derived steam (IDS) is inferred to influence the NCG content of Kawah Darajat.

Environmental Issue Purposes

Liquid samples from all hot springs are collected regularly because they are considered valuable in maintaining a record of historical discharge fluid chemistry for environmental purposes. As explained before, Darajat Geothermal field is located near local community. Several water parks and bath house which are located near Darajat field utilize water from surface thermal area (e.g. Manuk Fumarole, Cibeureum and Toblong Hot Spring). Therefore, this historical data have to be well documented because it is very useful as evidence that Chevron do not contaminated the environment during operate Darajat geothermal field. It can be looked at figure 20 that based on Cl-HCO_3-SO_4 ternary diagram there is no significant change through the times. Toblong hot spring seems has more wide range than Cibeureum hot spring in HCO_3. However, the exact gap value in HCO_3 only ~3-6ppm from each years.

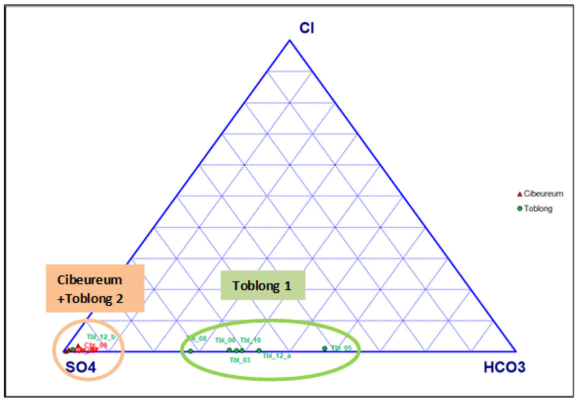


Figure 20: Cl-SO4-HCO3 ternary plot shows that no significant changes in liquid chemistry over the years.

CONCLUSION

Thermal features monitoring in Darajat has several benefits for geotechnical side, geochemistry side and environmental purposes. Geotechnical survey mainly focus on assess geological hazard and observe the changes of surrounding thermal areas, especially fumarole area. Minor landslide usually occurs near fumarole area because fumarolic activity weakened soil. Significant finding regarding of fumarolic activity in Darajat are potential extension of Kawah Darajat and steam vent occurrence in Pad A. Investigation of potential extension of Kawah Darajat results recommendation to monitor frequently Kawah Darajat and develop a contingency plan if the thermal feature moves/grows thus making the current road impassable. For steam vent occurrence in Pad A, team recommend the Darajat Resource Team to consider to P&A Pad A because of the hazards/risks associated with ground stability and future fumarolic activities. Anyway, Pad A is unlikely to be used in drilling future producers and injectors.

The objective of geochemical monitoring is investigating the relationship, if any, between the surface thermal features and the Darajat steam reservoir. Location of fumaroles which situated in the most of southern west of Darajat field can be utilized as MR penetration monitoring because MR assumed derived that from that direction. It means that if dramatic increases of NCG found in surface thermal, it can be used as red flag that probably MR start condensed severely SW area. Based on NCG data, there is relationship between fumarole and nearby shallow wells. This connection explains why the processes like drilling fluid effect and the boiling injectate process can be captured in fumaroles gas chemistry. Drilling effect is showed by decreases of NCG, elevated N_2 and Ar content. This effect showed in 2010 (align with Darajat drilling campaign) and depleted through the times. The boiling injectate processes is indicated with the decreases of NCG at fumaroles and increase boron in vicinity well (B-2). This phenomenon occurred in 2012 after near injection well (D-1) terminated. Injectate derived steam (IDS) is inferred to influence the NCG content of Kawah Darajat.

Surface thermal features indirectly also contribute with environmental purposes, especially for hot spring features. Documentation of surface thermal data is important for environmental monitoring purposes because most of water from thermal features is utilized by local community. This data can be utilized as evidence that operation in Darajat Geothermal field is not contaminated surrounding local community.

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REFERENCES

Kristianto, B., F.J. Putra and D. Rohrs, *Wellpad DRJ – 5: Geotechnical & Geochemistry Study, Status Update and Decision on Use:* CGI presentation, May 1, 2012, 35 slides.

Kristianto, B and P.A. Molling, *2011 Darajat Surface Thermal Geotechnical Report:* CGI Report, September 4, 2011, 14 pages.

Molling. P. A., *2006 Geochemical Review of Surface Thermal Features of Darajat Geothermal Field, Indonesia,* G7geochem Report to Chevron Geothermal, October 19, 2006, 36 pages.

Molling. P. A., *Update to the Geochemical Conceptual Model of the Darajat Geothermal Field, Indonesia:* CGI Report, July 4, 2007, 42 pages.

Molling. P. A., C.H. Simatupang and Ngadi, *2010 Darajat Thermal Features Chemistry Report:* Chevron Geothermal Memo, May 11, 2011, 21 pages.

Molling. P. A., and C.H. Simatupang, *2009 Darajat Thermal Features Chemistry Report:* Chevron Geothermal Memo, January 27, 2010, 20 pages.

Simatupang, C. H., G. Golla and P.A. Molling, *'Gas Breakthrough' During Dilling at Darajat Geothermal Field, Indonesia and Implications to The Conceptual Model:* Proceedings The 11th Annual Indonesian Geothermal Association Meeting & Conference, December 12-14, 2011, 6 pages.

Simatupang, C.H., F.J. Putra and P.A. Molling, *2011-2012 Darajat Annual Geochemical Update:* CGI Report, July 13, 2012, 21 pages.

Putra, F.J., B. Kristianto and P.A. Molling, *2012 Darajat Thermal Features Report:* CGI Report, December 13, 2012, 26 pages.

Pasaribu, F., et.al, *The Darajat Conceptual Model: 2012 Update*: CGI Report, December 7, 2012, 46 pages.