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Geochemical Signatures in Response to 6 Years of Production and Injection, Ulubelu Geothermal Field, Indonesia

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ABSTRACT

Ulubelu geothermal field has been in continuous production since 2012. The fluid is withdrawn from 22 production wells to supply 4x55 MW installed capacity power plants. The six-year geochemical monitoring program has been conducted to mitigate and examine the evolution of the physical and chemical parameters of the reservoir due to exploitation and injection strategies that were applied in this field. Around 6000 tons/hour extracted brine is injected back into the reservoir through 6 injection wells. Infield injection strategy was used to utilize non-productive wells as injection wells. Water and gas chemistry data are sampled regularly and simultaneously with the flow measurement by tracer dilution tests. During six years of monitoring, not only were chemical parameter changes observed, but also physical parameter changes. Although many chemical constituents have been analyzed, this paper exclusively focused on some of the major components such as chloride (Cl), SiO_2, and non-condensible gas (NCG). There is a significant change in the reservoir Cl content in several wells located nearby the injection sector. The Cl change is also followed by a decrease of the NCG and SiO2 content in the reservoir fluid. Declining reservoir temperature and production enthalpy were also observed as indicators of the thermal breakthrough. Even though all the injection wells are located in the streamline of the hydrology of the system, the effect of massive mass withdrawal may cause swabbing phenomena that lead to the injection breakthrough phenomena that was observed in the production sector. Mass change due to production and injection activity was also detected by a microgravity survey. The survey shows a correlation trend with the geochemical monitoring result where the injected fluid movement is contradictive with the natural hydrology of the system. An arrangement of an injection strategy has been proposed to encounter the injection breakthrough problem. Continuous monitoring programs are established to ensure the effectiveness of this strategy in maintaining reservoir performance to fulfill the 30-year energy sales contract.

1. INTRODUCTION

The Ulubelu geothermal field is located in the Lampung province in South Sumatra, approximately 150 km west of the city of Bandar Lampung. A 220 MWe geothermal power plant has been installed at the Ulubelu Field. Unit 1 and 2, with installed capacity of 2x55 MWe, were commissioned in 2012. Two 2x55 MWe power plants were further constructed over the following two years and by mid-2017, a power plant of 220 MW generation capacity was in full operation. Mass extraction came mainly from 22 production wells in the northern part of the system. Disposal of 6000 tons per hour separated brine was accommodated by six infield injection wells in an injection area located 1,5 km south of the production sector. Infield injection strategy is applied to utilize non-productive wells and minimize the project cost. During the early years of production, the proximity of the injection sector to the production sector favored quick and massive returns of injected brine to the producing wells. The injection strategy resulting from this situation was to move the injection sector as far as possible from the production sectors. Since 2016, the disposal of half of the waste brine has been accomplished through about five additional injection wells located 3 km from the production sector in Cluster R1 and R2 (Figure 1).

Changes in the chemical composition of water and steam, discharged from wells in exploited geothermal systems, provide information about the response of the reservoir to the production load concerning the source of the water recharging producing aquifers (Arnórsson et al., 2000). Monitoring geochemical trends has been instrumental in managing the reservoir change at Ulubelu. Injection breakthrough, meteoric water influx, and steam cap development have all impacted the reservoir chemistry during exploitation. During six years of monitoring, some of the chemical constituents have been analyzed such as chloride (Cl), sodium (Na), potassium (K), magnesium (Mg) SiO_2, and non-condensible gas (NCG), to identify the supply of the reservoir water. Moreover, this chemical data is utilized to determine the changes of the temperature by using geothermometers that are calibrated with the measured enthalpy data.

2. GEOLOGY AND HYDROLOGY

The Ulubelu-Waypanas Prospect is situated in the southern part of the Sumatra Fault Zone. The field is located in a volcanic-tectonic depression that lies north-south from Mt. Rindengan on the northern highland to Waypanas thermal springs on the southern lowland. Altered grounds and geothermal manifestations are recognized along northwest-trending faults or on its intersection with a northeast-trending fault. Acid sulfate springs and steam features are found along Pagar Alam Fault in the northern part of the field. The lateral flow outputs of the chloride hot springs are more to the south (Way Panas hot springs) on a lower elevation. The stratigraphy model controlled by graben structures where Pagaralam Fault and Talang Marsum Fault act as boundaries on the east and west.

The Ulubelu system is mainly composed of volcanic rocks, predominantly volcanic breccia and rhyolitic tuff (ignimbrite). The andesite lava, as the youngest unit, constructs mostly the northern part of the area where the G. Rindengan stratovolcano exists (Prasetyo et al., 2020). The most prominent rock unit in the Ulubelu field is the rhyolitic tuff. It is a matrix-supported rock with feldspars and quartz crystal fragments and the occasional rock fragments surrounded by volcanic glass rich matrix. Most of the wells feedzones are located within this rock unit. These volcanic rocks were cut predominantly by NW-SE striking faults. These sets of faults are the geothermally-significant structures as they provided the plumbing system for thermal fluid flow and circulation in the geothermal system (Trianggo et al., 2015)

Based on geochemical surface thermal manifestation and well data, the hydrology pattern of Ulubelu system can be determined. The main upflow zone is located beneath G. Rindengan, where benign hot fluid with the highest temperature and chloride zone is intersected by production wells in Cluster K. Hot fluid then flows laterally toward the southern area to the Waypanas chloride springs (Mulyanto et al., 2015). The natural recharge area is determined from the stable isotope study originated from the surrounding highlands on the west from about 900-1000 meters above sea level.

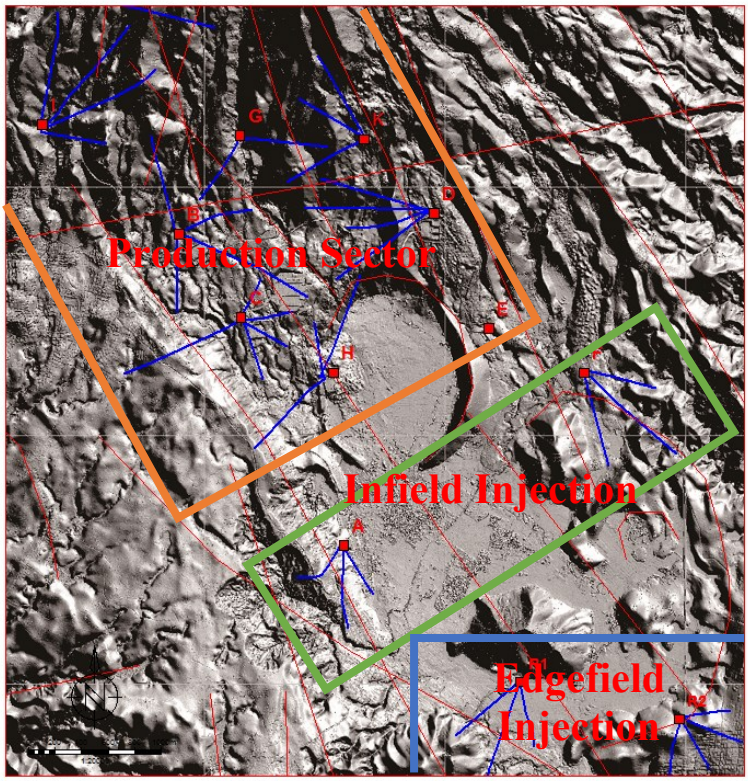


Figure 1: The current production and injection scheme at the Ulubelu Field. Production sector (orange box) is located in the northern part of the field. Infield (green box) and Edgefield injection sector (blue box) are located in the southern part of the system.

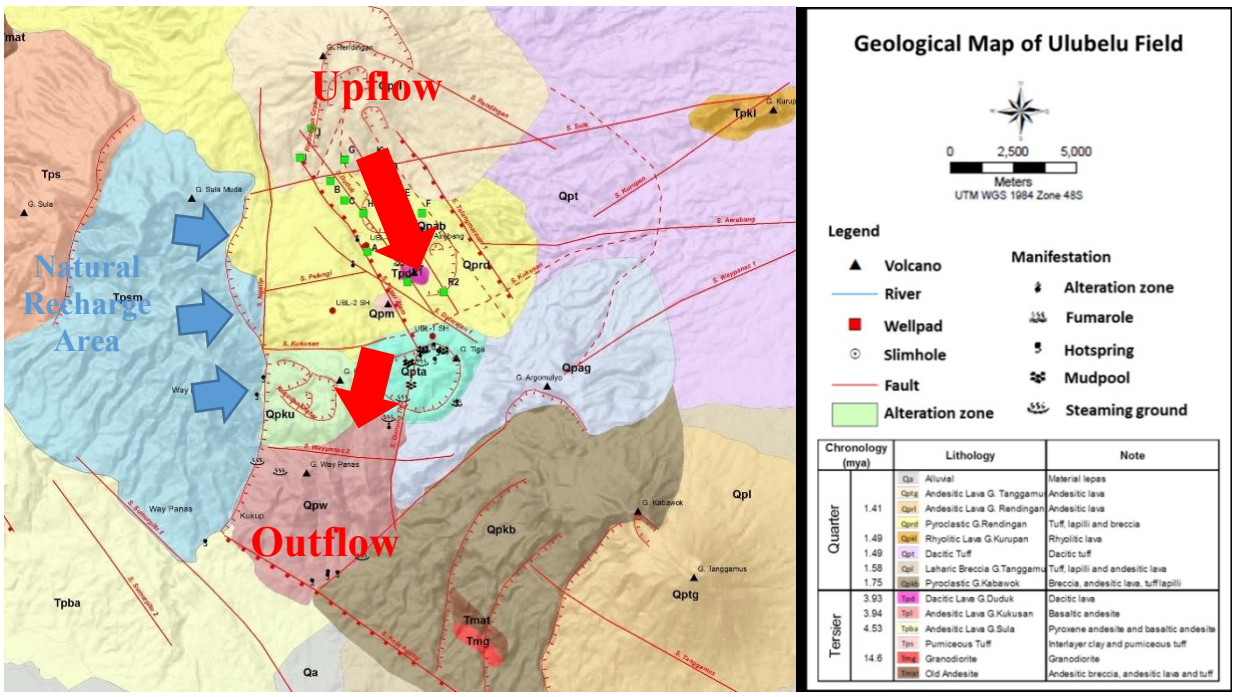


Figure 2: Geology map of Ulubelu-Waypanas Geothermal Prospect (modified from Masdjuk, 1997).

3. MONITORING PROGRAM

The objective of chemical monitoring of geothermal fields under production is to observe changes in the chemical composition of the reservoir fluid. Such changes can be due to natural processes, although they are more commonly related to the effect of production and injection.

Chemical monitoring of the Ulubelu field started in 2012 when unit 1 of the power plant was commercially operated. The monitoring program involves sampling from all the production wells. Samples are collected 2-3 times a year from each production well. Complete chemistry samples are taken during the flow measurement when tracer dilution test are conducted. Samples are collected using a portable Webre separator which is connected to the two-phase pipeline in the upstream of the production separator. Liquid samples are collected through a condenser and are analyzed for; pH, Na, K, Ca, Mg, Li, Fe, Cl, SO_4, HCO_3, Al, B, and As. Vapor samples for gas analysis (CO_2, H_2S, H_2, CH_4, N_2, O_2, Ar) are collected through a silicone rubber hose and condensed into the evacuated Rotoflo flask bottle containing caustic soda and zinc acetate.

Reservoir fluid composition is computed by combining the sampling pressure and the enthalpy that resulted from the tracer dilution test (Nicholson, 1993). The software WATCH (Arnorsson, 1982) is also used to control the results of the total discharge calculation. The excess enthalpy is determined from the reservoir temperature based on downhole measurements or geothermometers. Since excess enthalpy is less than 5%, it can be neglected.

Geophysical monitoring is also continuously conducted to monitor the evolution of the system. Eight stations of microearthquake sensors have been deployed to monitor seismicity triggered by fluid movement related to production and injection. Microgravity monitoring is also conducted annually to estimate the mass change in the reservoir. However, this paper only examines the significant changes in the microgravity signature.

4. EVOLUTION OF RESERVOIR GEOCHEMISTRY

4.1 Chloride

The Cl concentration in the reservoir liquid has increased since unit 2 was commissioned in 2013. Gradual increase of chloride was observed in wells UBL-5, UBL-6, UBL-7, and UBL-8 that are located in Cluster C, which is the closest production pad from the infield injection sector. The increasing chloride concentration in this cluster may be associated with the injection breakthrough (Harper & Jordan, 1985). Since unit 3 and 4 were commissioned in 2017, production wells in cluster H, I, and K have also been activated to increase the steam supply. An activation of a new injection pad is also proposed to accommodate additional brine.

Half of the injected fluid flowed towards the clusters R1 and R2, located on the southern edge of the field. These pads are chosen to cut the streamline of the hydrology of the system. It is somewhat surprising that after a two-year monitoring, the impact of injection breakthrough is still clearly observed. Wells in cluster H, which is the newly operated pad, are directly affected by the injection breakthrough (Figure 3). The closest production pad to the injection sector (Cluster C and H) shows the highest increase of chloride content. The highest increase can be seen in the UBL-5 well where the gradient has increased over 850 ppm compared with the initial concentration of 720 ppm. Increasing Cl can also be seen in cluster K and G, even though the distance of these clusters from the injection sector is about 4 km (Figure 4). Doubling the generation capacity may cause a massive increase of mass extraction that can lead to changes in streamlines and have a swabbing effect in the reservoir.

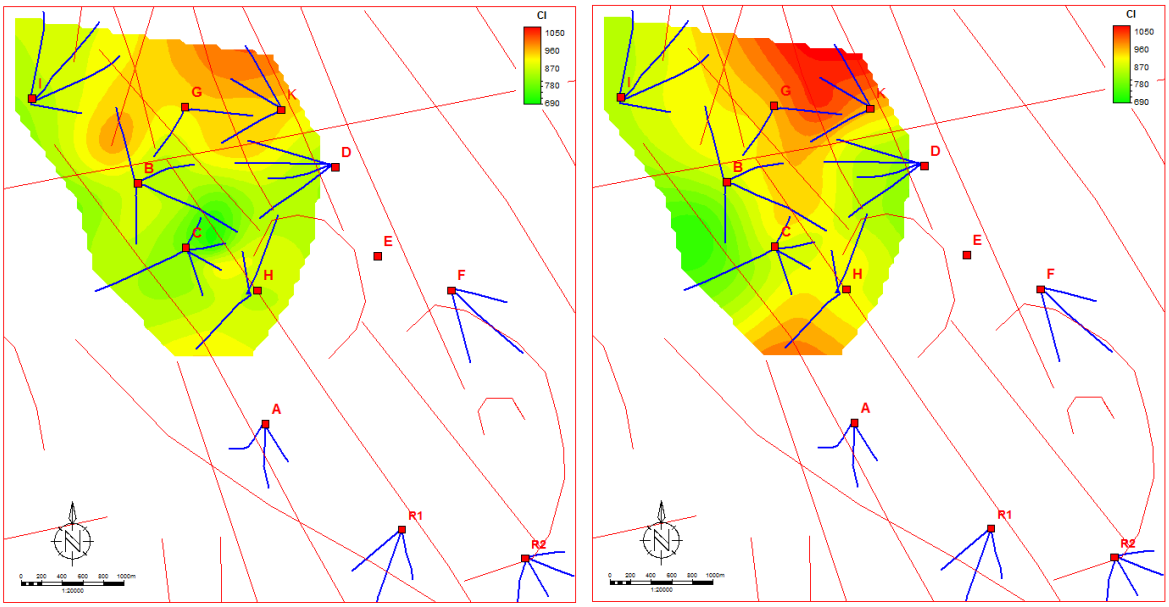


Figure 3: Maps showing chloride concentration in the deep liquid of the Ulubelu production wells at initial conditions (left) and recent conditions (right).

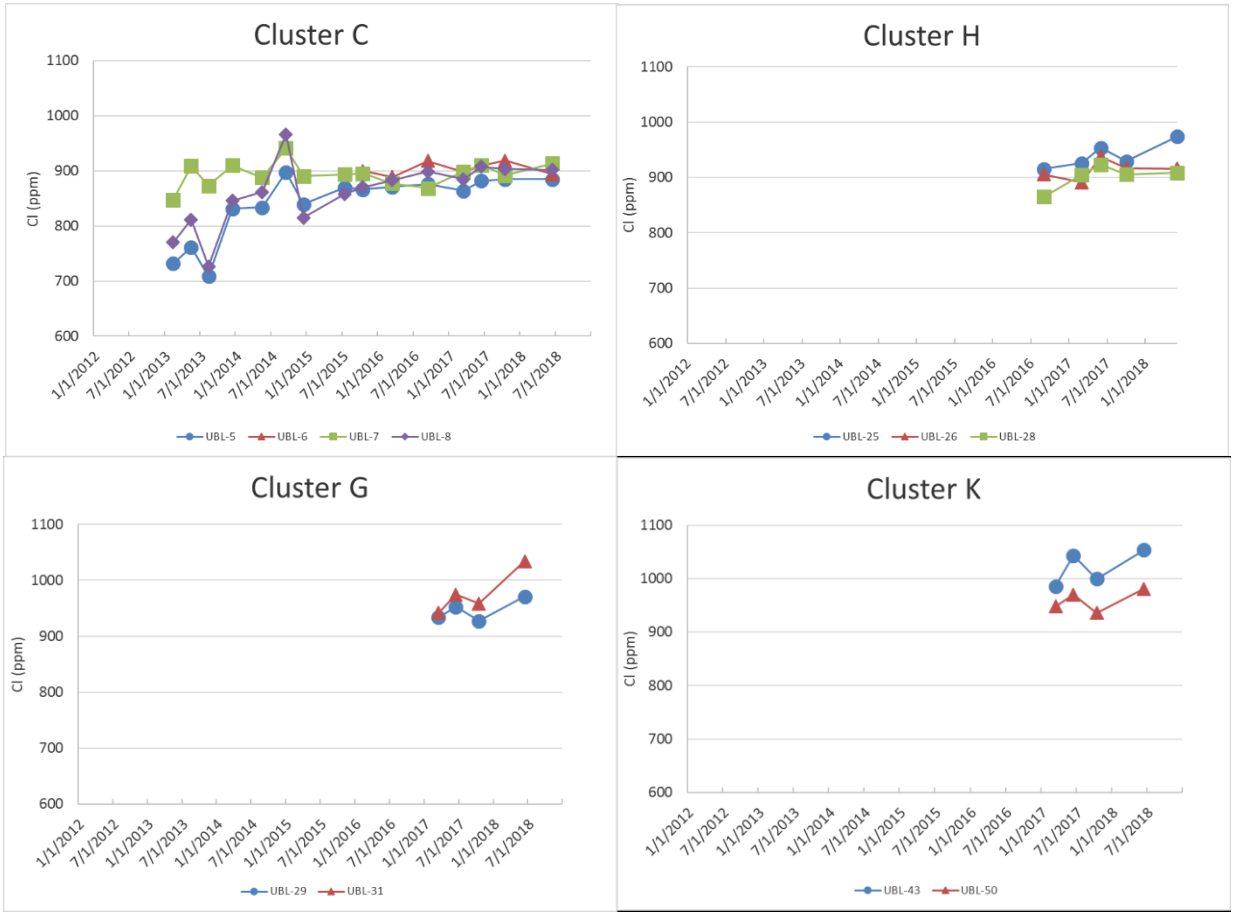


Figure 4: The diagram shows the evolution of the deep liquid Cl concentration of Ulubelu production wells from 2012 to 2018.

4.2 Non-Condensible Gas (NCG)

The evolution of the NCG content in the reservoir fluid can be used to monitor the changes in the reservoir due to production and injection activities. The NCG data was collected 3 or 4 times a year, coinciding with the tracer dilution test job. Some of the parameters have been analyzed, including CO_2, H_2S, NH_3, N_2, Ar, O_2, and CH_4. In this study, we only focus on the steam/gas ratio in the total discharge concentration. A decrease of NCG content was observed in most of the production wells. All the production wells in cluster C pad show decreases in NCG content over time. This trend is also seen in Cluster G, and K, where the NCG content in the reservoir has decreased gradually since production (Figure 5).

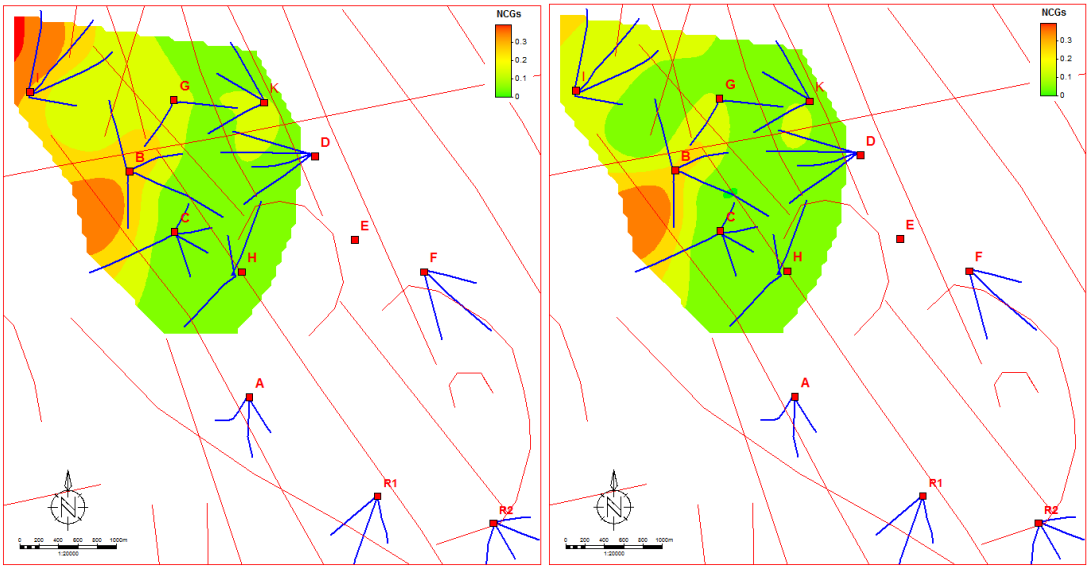


Figure 5: Maps showing NCG content in the deep liquid of the Ulubelu production wells at initial conditions (left) and recent conditions (right).

4.3 Geothermometer

Reservoir temperature monitoring is carried out using the geothermometer due to the limited downhole measurement data. Silica and Na-K-Ca geothermometers are used to observe changes in the reservoir temperature. There is a significant decrease in temperature, especially in clusters C and H that is observed from the silica geothermometer. The decrease in temperature ranges from 20-40ºC from 2012 to 2018. From the data in Figure 6, it can be seen that the highest decline of temperature was found in cluster H. However, there is a different inclination between silica and Na-K-Ca geothermometer trends due to the fast equilibrium of silica after mixing with cooler water.

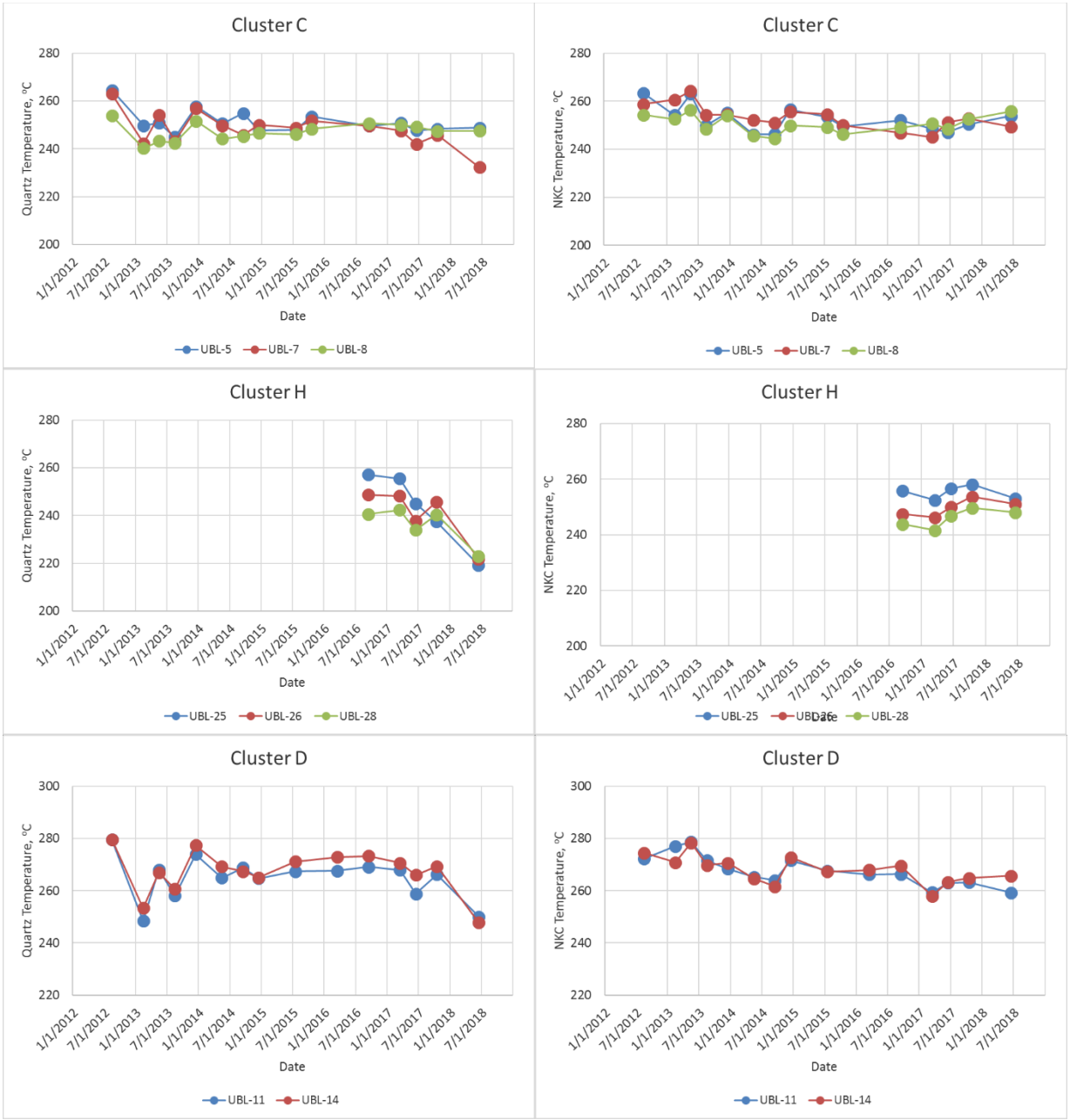


Figure 6: The diagram shows the evolution of the reservoir temperature of Ulubelu field.

4.4 Measured Enthalpy

The production enthalpy of each well is measured by using the tracer dilution test method. Overall, there is no indication of excess steam observed from all the production wells. From the data, it is apparent that there was a significant positive correlation between the temperature and measured enthalpy data. The decline of enthalpy is observed in the cluster where the temperature is decreased. As shown in Figure 7, the declining of enthalpy is observed in cluster C, D, H, and some of the wells in Cluster K. No significant differences were found between initial and present in cluster G. The observed correlation between temperature and enthalpy might be as strong evidence that the detrimental effect of injection breakthrough has impacted the productivity of the well.

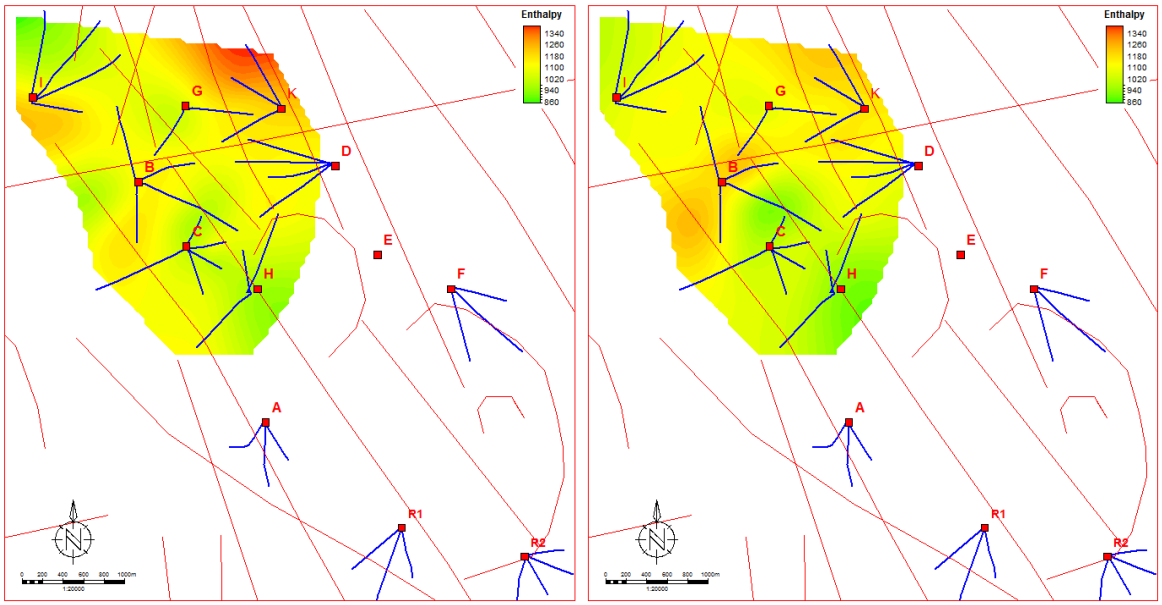


Figure 7: Maps showing the measured enthalpy distribution from the production wells at initial conditions (left) and recent conditions (right).

5. GEOPHYSICAL MONITORING

From results obtained from the microgravity monitoring during 2017-2018, negative gravity anomaly was observed in the center of the mass extraction in the production zone (Figure 8). Thus, it can be suggested that massive mass extraction cannot be balanced by the recharge. In contrary, positive gravity anomaly looks more widespread in the injection sector and flows toward the production zone (PGE,2018). The exploitation of the Ulubelu field has incurred a pressure decline in the central part of the reservoir that has induced an inflow of injected fluid toward the production sector. However, instead of creating pressure support, a huge amount of water that was injected nearby the production sector is now flooding the reservoir, with insufficient heating of the fluid. From this data it can also be concluded that there is no additional mass in the southernmost of the injection sector to follow the natural outflow of the system.

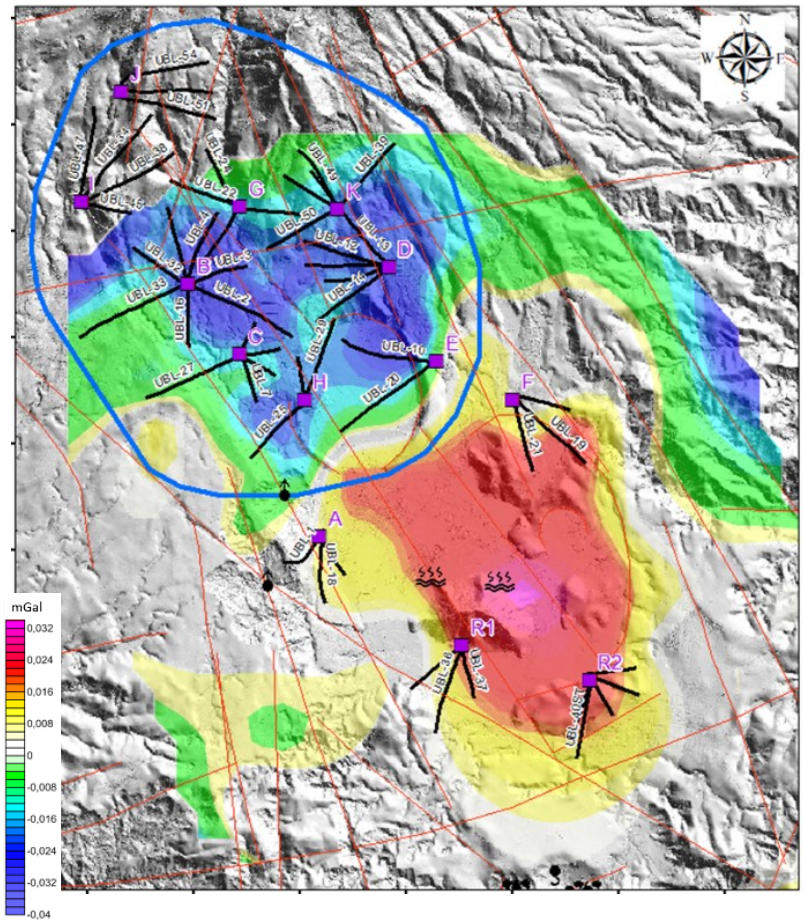


Figure 8: Corrected gravity changes from 2017-2018.

6. CONCLUSION

Since the start-up of the field, comprehensive monitoring of the Ulubelu reservoir has been conducted, not only of geochemistry parameters but also geophysical parameters. Several key geochemical indicator constituents have been evaluated and integrated with other geoscience parameters and engineering information to identify the reservoir processes that may affect the sustainability of the resource. Chemical monitoring in the Ulubelu field in the period from 2012 to 2018 has shown that the injection return has an inverse effect on the production reservoir. The increase in Cl concentration after the commissioning is explained by the brine injection breakthrough that is most pronounced in the wells in clusters C and H that are the closest production sector from the injection area. A decreasing in NCG content in these wells also support this interpretation. Temperature decline in some wells may indicate that the reservoir has experienced cooling due to the inflow of injection fluid. This coincides with the decrease of the production enthalpy for some wells in clusters C, H, D and also K. Even though reducing the injection flow in the infield injection sector has been conducted, massive mass extraction may cause an inflow of injection fluid to the production sector.

There was a significant correlation between geochemical and geophysical data where the microgravity monitoring result shows that massive mass extraction in the central part of the production sector may lead to decreasing microgravity anomaly. An imbalance between production and recharge may trigger the inflow of reinjection fluid toward the production sector.

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