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AN UPDATE ON THE FLUID INCLUSION GAS STUDY AT AWIBENGKOK GEOTHERMAL FIELD, INDONESIA

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ABSTRACT

A pilot project has been initiated at the Awibengkok (aka Salak) Geothermal Field that investigates the applicability of fluid inclusion gas analyses for exploration and development of geothermal fields. Fluid inclusion gas analyses are widely used in the oil and gas industries as an exploration tool using borehole profiles of fluid chemistry for delineating reservoir compartmentalization and fluid contacts but the application to geothermal systems has not been thoroughly tested.

An initial fluid inclusion study in Awibengkok was conducted in 2011. Fluid inclusion gas chemistry from seven edgefield wells was reviewed and correlations extracted in this initial analysis. This study adds the fluid inclusion gas chemistry from five wells within the Awibengkok reservoir. The goal of this study was to discover definitive chemical relationships in fluid inclusion gases that distinguish zones above or within the reservoir compared to outside or peripheral to the reservoir.

Ratios of gases on ternary plots and groupings on histograms were used to distinguish between areas of the Awibengkok reservoir. Methane decrement in ratios of methane-hydrogen and methane-carbon dioxide appears to be associated with regions above or within reservoir compared to chemistry of fluid inclusions at similar depths outside or peripheral to the reservoir. In addition, fluid inclusion gases inside or above reservoir show consistently tighter groupings between Air-ASW on the N2-CO2-Ar ternary plot compared to outside the reservoir.

The results from this study suggest these three chemical "signals" are associated with fluid inclusion gases in rocks above the Awibengkok geothermal system. As a test of these correlations, a similar study will be undertaken at the Darajat Geothermal System. Preliminary results from fluid inclusion gas chemistry from within and above the reservoir compared to edgefield and outside the reservoir warrant more detailed review focusing on individual host minerals, relationships to measured temperatures and, for potential exploration applications, chemical differences referenced to location relative to an active geothermal system.

1. INTRODUCTION

The Salak (Awibengkok) field is located 60 km south of Jakarta in the West Java province, Indonesia (**Figure 1**). Salak is one of the world's largest liquid-dominated geothermal fields with a current total installed capacity of 377 MWe (Stimac et al., 2007). Six power plants are found in Salak with 180 MWe from the PLN Units-I/II/III and 197 MWe from the Chevron Geothermal Indonesia Units IV/V/VI.

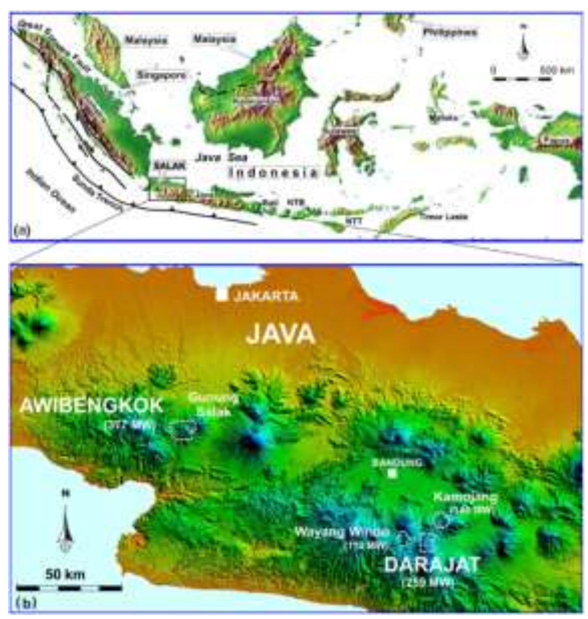

Figure 1: Location map of the Salak geothermal field in relation with other geothermal fields in West Java (Aprilina et al., 2011).

The Salak geothermal system is located in a mountainous area with elevation ranging from about 950 to 1500 m above sea level (ASL). The highest peaks are the inactive andesitic volcanoes of Gunung Salak, Gagak, Perbakti and Endut that lie along the main trend of the Sunda Volcanic Arc. These peaks border the development site on the east, northwest, southeast and south sides, respectively, and give way to lower hill country in the north and south (at 600 to 950 m ASL). The Cianten Caldera, a collapsed andesitic stratocone lies further to the west with a floor at ~850 to 950 m. Western Awibengkok and the Cianten Caldera are drained by rivers that flow to the north via a gap in the northeastern part of the caldera rim.

The idea that the scatter of fluid inclusion gas ratios is important was introduced in a previous study in Salak that was conducted by Aprilina et al. (2011). In this study, several ternary diagram analyses were applied to the fluid inclusion gas data from the 12 wells. Two of seven ternary relationships proved to be promising. The CO_2-CH_4-H_2 and N_2-CO_2-Ar ternaries consistently showed different trends between the wells within the reservoir and those that are outside/edgefield. Based on the CO_2-CH_4-H_2 plot, the CH_4/H_2 ratio is consistent for well inside the reservoir. It appears that CH_4 is an important chemical compound that can be used to distinguish the areas inside and outside the geothermal reservoir. Subsequently in this study, it was suggested to review the CH_4/CO_2 ratio as it may provide similar results with the CH_4/H_2 ratio. Interestingly, the ternary plots and CH_4/H_2 ratio of fluid inclusion data above and below clay cap show similar patterns. However, this study tested only data at shallow depths to get information about the geothermal system in that zone.

2. METHODOLOGY

Fluid inclusion is a microscopic bubble of liquid and gas that is trapped within crystals and/or minerals. As minerals that often form from liquid or aqueous medium, tiny blebs of that liquid can become trapped within the crystal structure or in healed fractures within a crystal.

Fluid inclusion refers to any inclusion that trapped a phase that was a fluid at the temperature and pressure of formation, regardless of the phase state of the inclusion as observed at laboratory conditions. The trapped fluid may be liquid, vapor or supercritical fluid, and the composition of the trapped fluid may include essentially pure water, brines of various salinity, gas or gas - bearing liquids, and silicate, sulfide or carbonate melts, among others (Bodnar, 2003).

Initially, the fluid inclusion gas analyses were conducted on seven Salak delineation wells since their formations are less permeable compared to the wells located inside the reservoir (Aprilina et al., 2011). In this update study, new fluid inclusion gas data from five wells inside the Salak reservoir were analyzed (**Figure 2**). The goal of this study was to discover definitive chemical relationships in fluid inclusion gases that distinguish zones above or within the reservoir compared to outside or peripheral to the reservoir. The gas compositions of fluid inclusions in rock samples from both the seven edgefield and five wells within the Salak reservoir were determined by Fluid Inclusion Technologies (FIT) under a contract with Chevron Geothermal Indonesia.

Analyses were performed by first cleaning the samples, if necessary, then crushing a gram-size sample in vacuum. The volatiles released are pumped through multiple quadrupole mass spectrometers where molecular compounds are ionized and separated according to the mass/charge ratio (m/e-). Electronic multipliers detect the signal, which was processed creating a mass spectrum for each sample. The data were plotted on mud log plots using the Rockware LOGGER software.

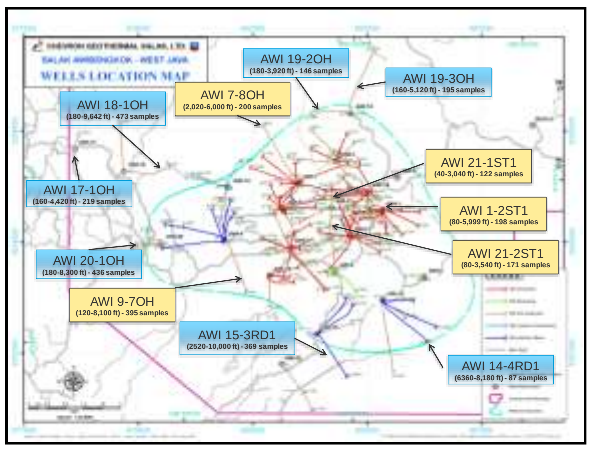

Figure 2: Map showing the edgefield (or delineation) wells (blue) and wells within the Salak reservoir (yellow) that were used in this fluid inclusion study (modified Aprilina et al., 2011).

3. FLUID INCLUSION GAS ANALYSIS

The compositions of all fluid inclusion gas analyses for each well are plotted on gas ternary diagrams (CO_2-CH_4-H_2 and N_2-CO_2-Ar). By using these ternaries, it is possible to determine patterns or trends between wells located at within and edgefield/outside of the reservoir. In addition, plots of data above and below the clay cap were analyzed.

In the CO_2-CH_4-H_2 ternary diagram, the wells within the reservoir tend to have consistent CH_4/H_2 ratio at <40% (**Figure 3**). Almost all of these wells appear to be controlled by fewer reservoir processes. Meanwhile, wells located outside the reservoir tend to have higher CH_4/H_2 ratio at about 10-50% (**Figure 4**). Edgefield wells Awi 15-3RD1 and Awi 19-2OH show the transition trend between the wells inside and outside the reservoir (**Figure 5**).

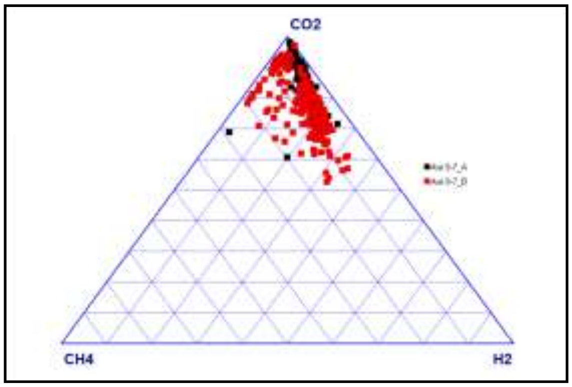

Figure 3: Awi 9-7OH (located inside the Salak reservoir) has CH_4/H_2 ratio <40%. Black squares denote data above the clay cap and red squares are data below the clay cap.

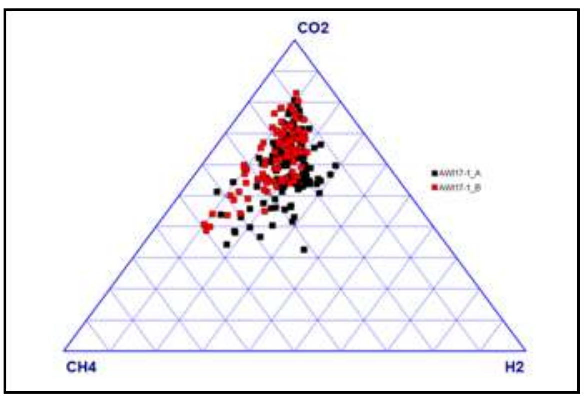

Figure 4: Awi 17-1OH (located outside the Salak reservoir) shows CH_4/H_2 ratio >40%. Black squares denote data above the clay cap and red squares are data below the clay cap.

CH_4 appears to be an important chemical compound that can be used to distinguish the areas inside and outside reservoir. Thus, further analysis of the CH_4/CO_2 ratio was conducted. This ratio was calculated from the average of all fluid inclusion data of each well. Results show that the average CH_4/CO_2 ratio for wells inside the reservoir appears to be very consistent <0.2 and less scattered. Both edgefield and wells outside the reservoir have CH_4/CO_2 ratios >0.2 with more scattering (**Figure 6**). The very high average CH_4/CO_2 ratio at Awi 15-3RD1 is probably due to the organic matter content from the carbonate rocks that it intersected. Generally, the results of the CH_4/CO_2 ratio are consistent with the CO_2-CH_4-H_2 ternary relationship.

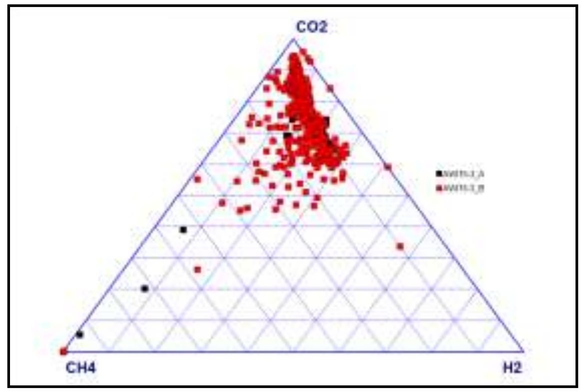

Figure 5: Edgefield well, Awi 15-3RD1, appears to have transition trend of CH_4/H_2 ratio between wells inside and outside the reservoir. Black squares denote data above the clay cap and red squares are data below the clay cap.

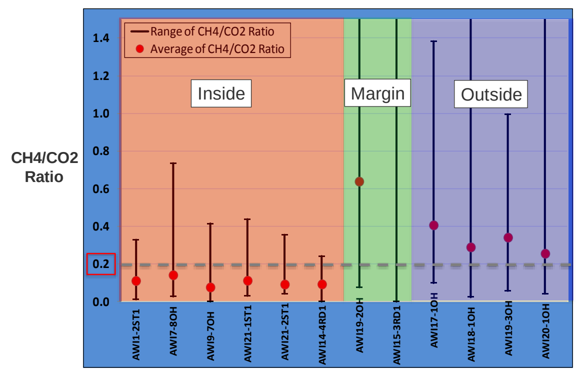

Figure 6: Chart showing the average CH_4/CO_2 ratios (red circles) of wells inside the reservoir (consistently <0.2) and edgefield/outside wells (>0.2-0.6). Lines represent the range of CH_4/CO_2 ratio for all fluid inclusions of each well.

The behavior of the fluid inclusion gases in the CO_2-CH_4-H_2 ternary diagram is probably due to the particular rocks encountered by the wells. In Salak, sedimentary formations (the basement of the reservoir) were considered to have high organic content. Due to the high temperatures (maximum measured was ~327°C) inside geothermal system probably burned out all the organic matter. Consequently, the CH_4 content inside the reservoir decreased lower than at the edge and outside the reservoir. In addition, source of CH_4 inside or above the geothermal system may be controlled only by chemical reaction (say, Fischer-Tropsch Reaction). At the periphery or outside the geothermal reservoir, CH4 does not only come from chemical reactions in the geothermal system but also from other organic sources at outside reservoir area.

In the N_2-CO_2-Ar ternary diagram, the relationship between CO_2 and N_2/Ar ratio from all fluid inclusion gas data also appears to have some promises. Gas composition of the fluid inclusions from wells inside the reservoir show consistently less scatter and within the range of the Air and ASW ratios along the N_2-Ar axis of the N_2-CO_2-Ar ternary diagram (**Figure 7**). Meanwhile, outside wells show a scattered pattern without any distinct trend (**Figure 8**).

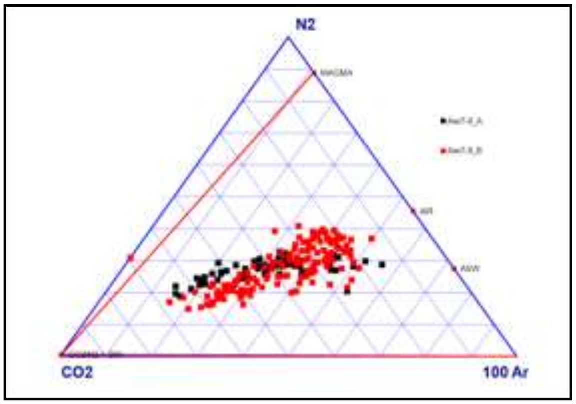

Figure 7: Fluid inclusion gas compositions from Awi 7-8OH, located within the reservoir, plot in a compact trend within range of Air-ASW ratios in the N2-Ar axis. Black squares denote data above the clay cap and red squares are data below the clay cap.

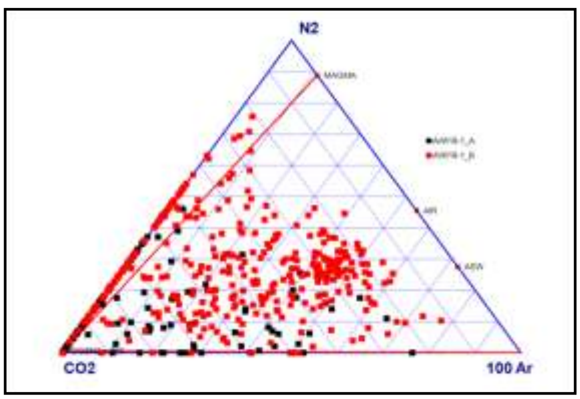

Figure 8: Awi 18-1OH where located outside reservoir area shows very scatter in Air-ASW trend. Black squares denote data above the clay cap and red squares are data below the clay cap.

Edgefield wells appear to exhibit a transition trend between within and outside reservoir wells (**Figure 9**). An exception is Awi 19-2OH which was drilled inside the reservoir but appears to have a similar trend like outside wells. Further analysis of Awi 19-2OH is needed because current interpretation indicates that this well is located in the outflow of the Salak geothermal system.

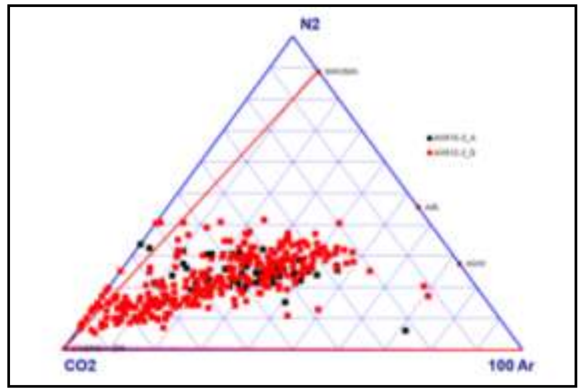

Figure 9: Fluid inclusion gas compositions from Awi 15-3RD1, an edgefield well, show similar trend with wells inside the reservoir data although showing more scatter. Black squares denote data above the clay cap and red squares are data below the clay cap.

Fluid inclusion data show that a narrow trend in the N_2-CO_2-Ar ternary diagram between the Air-ASW indicates that the samples are taken from inside or above geothermal system. Based on the N2-CO2-Ar ternary, N2 and Ar occurrence in geothermal system was considered to have N2/Ar ratio around 38-84% (between the Air and Air Saturated Water (ASW) along the N2-Ar axis). This tight data trend between the Air-ASW in wells inside the reservoir suggests that the main reservoir process is boiling with less influence from shallow depths or surface processes. Additionally, the narrow trend may indicate that these samples are taken from above the geothermal system. The edgefield and outside reservoir data plot wider (compared to wells inside and above the reservoir) suggesting that these samples were possibly influenced by shallow or surface process at the periphery or outside the reservoir. Again, this N_2-CO_2-Ar ternary diagram analysis supports the CH_4-CO_2-H_2 ternary diagram and CH_4/CO_2 ratio analyses.

4. DISCUSSION

Interesting relationships were observed in the Salak fluid inclusion chemical data set. The results of this study suggest that three chemical “signals” are associated with fluid inclusion gases rock above the Awibengkok geothermal system. These fluid inclusion chemical parameters are the following: CH_4/H_2 ratio <40% in the CO_2-CH_4-H_2 ternary diagram, CH_4/CO_2 ratio <0.2 and narrow trend between the Air-ASW range in the N_2-CO_2-Ar ternary diagram. If fluid inclusion gases satisfy these three chemical parameters, it would suggest that the fluid inclusion gases are associated with a geothermal reservoir below.

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