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Effectiveness of Radon Concentration Features in Soil Gas for Specifying Hydrothermal Ascent Paths in the Wayang Windu Geothermal Field, Indonesia

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ABSTRACT

In Wayang Windu Geothermal Field (WWGF), which is one of the greatest geothermal potential areas in Indonesia, we have carried out measurements of a soil gas component to specify the hydrothermal ascent paths from the ground surface. Total 24 measurement wells up to the 5 m depth were constructed in WWGF. We focused on Rn-222 in soil gas, the longest half-life radon isotope, because Rn-222 is an effective indicator of volcanic activities, thermal manifestation, and fractures due to its chemical features. The periodical measurements using an electronic radon detector with real-time monitoring were repeated over one year including rainy and dry seasons. The remarkable result is a temporal variation of radon concentration with elapsed time within one hour, which is classified into two patterns, stable and decreasing patterns. In addition, several wells showed the seasonal variation of radon concentration. These variation patterns probably indicate differences in soil permeability including the fracture system and vapor amount derived from the geothermal reservoir. Thus, radon concentration can contribute to identify main flow path of geothermal fluids that is a target of drilling for geothermal power generation by integrating with short- and long-term variation. Furthermore, other gas components such as H_2S and O_2 were different among the wells. Satellite image analyses of WWGF support the interpretations from the soil gas measurements by indicating the presence of permeable fractures and hydrothermal alteration minerals. This integration of several analyses is expected to locate accurate high potential resource zones and to increase the success rate of production wells.

1. INTRODUCTION

Indonesia is a typical volcanic country with one of the world's largest geothermal resources, and the country plans to greatly increase geothermal power generation. The total potential of geothermal resources in Indonesia is estimated at about 28,617 MW, but only about 4.5% of the potential has been utilized (Nasruddin et al., 2016). High introduction cost for geothermal power generation, in particular the cost for exploration to identify the geothermal reservoir is a big issue. In order to optimally utilize the geothermal resources, it is indispensable to develop innovative methodologies to reduce the exploration cost and to increase the success rate of drilling. Based on that background, we started a collaboration research project between Kyoto University and Bandung Institute of Technology (ITB) from 2014 in a framework of Science and Technology Research Partnership for Sustainable Development Program (SATREPS) supported by JICA and JST. This project aims to develop advanced exploration schema for geothermal resources by a combination of remote sensing, mathematical geology, geochemistry, geophysics, and mineralogy. As one of the effective methods for our purpose, measurement of soil gas component has been applied to estimate the condition of geothermal reservoir from the ground surface. In particular, we focused on concentrations of Rn-222 in soil gas.

Rn-222, the longest half-life radon isotope, is an effective indicator of volcanic activity, thermal manifestation, and fractures. Koike et al. (2009) addressed the significant connection between Rn-222 gas concentration and fault structure. Rn-222 trapped deeply in the ground is carried to the surface by gases and groundwater rising from deeper depths through fluid flow paths such as permeable fracture. In geothermal areas, geothermal fluids derived from geothermal reservoirs are regarded as the major carrier of gas. Therefore, it is expected that the presence of hydrothermal ascent paths and the condition of geothermal reservoirs can be estimated through measurement and analysis of Rn-222 concentrations.

The purpose of this study is to evaluate effectiveness of radon measurement for geothermal explorations. The periodical measurements over one year was carried out in a geothermal area in Indonesia. As a result, we estimated a high potential resource zone for geothermal power generation in the study site by an integration of geochemical and remote sensing analyses.

2. STUDY SITE AND EQUIPMENT

2.1 Wayang Windu Geothermal Field (WWGF)

Wayang Windu Geothermal Field (WWGF), which is one of the greatest geothermal potential areas in Indonesia, was selected as the study site. WWGF is located in West Java Province, Indonesia, approximately 190 km southeast side from Jakarta and 40 km southern from Bandung (Fig. 1a). WWGF has been operated since 2000 with total capacity installed 227 MW and producing electricity supply for Java and Bali. This electricity power plant is supported by 22 production wells and three injection wells (Masri et al., 2015). WWGF is located at a mountain area with elevation range from 1400 to 2300 m above sea level. There are several geothermal manifestations such as fumaroles and hot/warm springs (Fig. 1b). As for surface geology, WWGF is composed of five formations (Bogie and Mackenzie, 1998); Wayang Windu Formation, Malabar Formation, Pangalengan Formation, Waringin Formation, and Loka Formation. Major components of their formations are andesite and altered lava.

2.2 Radon measurement equipment

Total 24 monitoring wells for the soil gas measurement were constructed in WWGF (Fig. 1c). These well locations were selected by considering the existence of geothermal manifestations and the regional geologic structure. However, it was not feasible to make a well in a fumarole because of high temperature and toxic gas. A monitoring well was made by a polyvinyl chloride tube with slits for collecting soil gas. The diameter of the well was 4.2 cm and the depth were up to 5 m. All wells are sealed with a cap. Monitoring wells are classified into two groups, named as K-series and NSD-series. The difference of these groups is explained in the next section.

Radon measurement was carried out using the DURRIDGE RAD7 equipment. This equipment is an active measurement machine with a built-in pump and can measure Rn-222 (radon) and Rn-220 (thoron) concentrations by detecting alpha decays of radon and thoron daughters. However, we only focused on radon concentration in soil gas because thoron measurement was sensitive to weather conditions and difficult to guarantee sufficient accuracy. Hereinafter, we will discuss only Rn-222 concentration and describe as "radon".

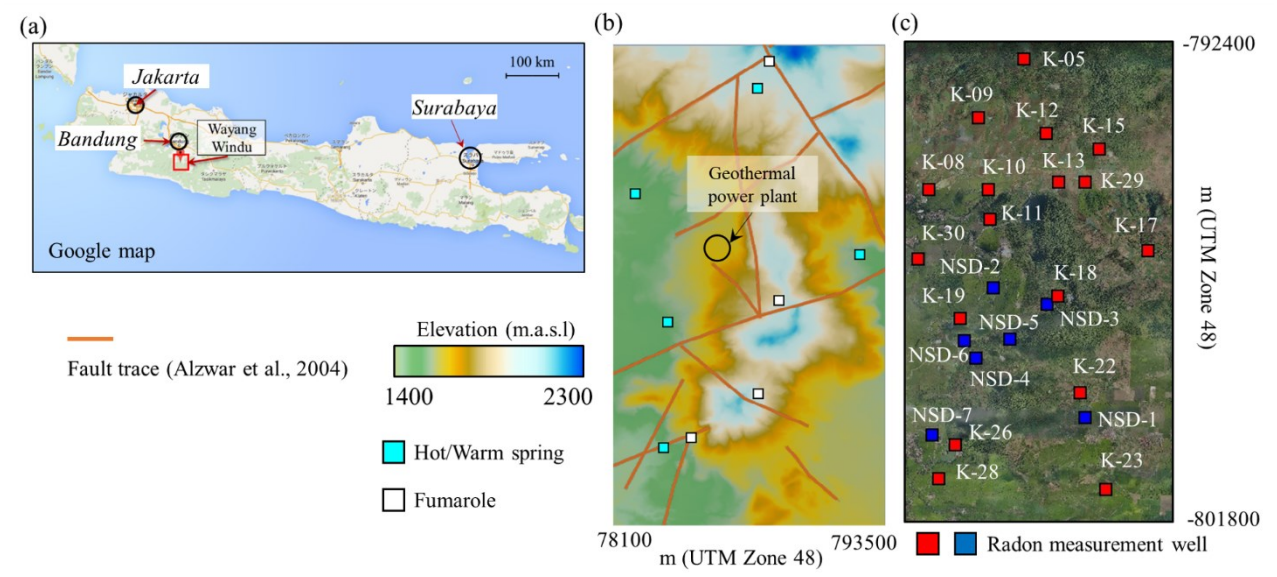

Figure 1: Location of the case study field, Wayang Windu geothermal field (WWGF) (a), geothermal manifestations distribution overlaid on topographical map and fault trace (Alzwar et al., 2004) (b), and monitoring wells distribution overlaid on an aerial photograph (c).

3. RADON MEASUREMENT

Seventeen monitoring wells indicated as K-series in Figure 1 were constructed in August 2016. Periodical measurements using those monitoring wells were carried out as the following four time periods.

- 1st period: October 2016 – November 2016
- 2nd period: January 2017 – March 2017
- 3rd period: March 2017 – April 2017
- 4th period: April 2017 – May 2017

Radon concentration in soil gas was measured using the monitoring wells. Interval of measurement cycle was five minutes. Basically, we carried out each measurement longer than 30 minutes, i.e. more than 6 cycles at one site. During the measurement, humidity and H_2S removable filter were attached to RAD7 to prevent a damage to electronics. Wells NSD-1 to 7 were constructed in May 2018 to clarify more detailed spatial feature of radon concentration. Their locations were selected by considering the measurement results of K- series wells. Depths of NSD-series wells were set up to 3 m. The schematic of a monitoring well and situations of measurement are shown in Figure 2.



Figure 2: Structure of a monitoring well which is composed a polyvinyl chloride tube (left) and sceneries of construction of a monitoring well and radon measurement using RAD7 (right).

4. RESULT OF RADON MEASUREMENTS

At first, we compared radon concentrations before and after the drilling of the monitoring well at three measurement points. A prior measurement was carried out using a 1 m hole drilled directly to the ground. As shown in Figure 3, radon concentrations measured using monitoring wells increased obviously as compared with the prior measurements. The largest difference was observed in the 1st cycle of K-10. However, the value of the first cycle is unreliable because the atmospheric air filled in the equipment is mixed. Excluding them, the average of difference between before and after the drilling was a factor of 5.2.

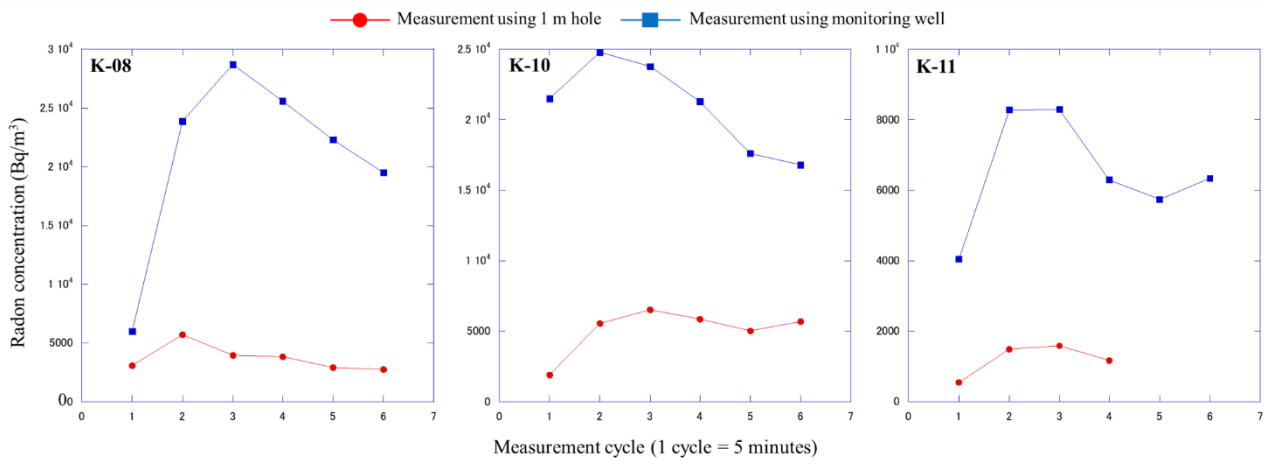

Figure 3: Comparisons of radon concentrations before and after the drilling of monitoring well at K-08, K-10, and K-11 points.

These changes may be caused by ascent of soil gas to the ground surface faster than the natural state by pumping into RAD7 through a monitoring well. Therefore, the measured depth is considered as a strong control factor on the concentration change of radon.

Figure 4 shows two representatives and remarkable examples of radon concentration features in WWGF. These two graphs indicate temporal variations of radon concentration with elapsed time. As the result of periodical measurements, the temporal variation of radon concentration measured in WWGF is classified into two patterns, stabile and decreasing patterns. K-15 is a representative measurement point bearing the typical stable pattern. Measurement value increases until the 3rd cycle and becomes stable state after that. On the contrary, K-10 shows a decreasing trend after the 3rd cycle.

Distribution of temporal variation patterns in all the K-series wells are shown in Figure 5 (a). The decreasing pattern is regarded as common in WWGF, because the stable pattern was observed at only four points. Although the measurement points which shows the stable pattern are located in an eastern part of the study area, there is no clear correspondence with the geothermal manifestations (see Fig. 1b). Figure 5 (b) shows distribution maps of radon concentrations in each period. The color of dots indicates the maximum value over the cycles of one measurement. K-15 is a measurement point which highlights the highest radon concentration and the values have been stable throughout all the periods. On the other hand, the values of K-5 were unstable and relatively low throughout all the periods. The reason causing these seasonal changes cannot be identified at this time. However, there are rainy and dry seasons in Indonesia, and the study site also had heavy rainfall during the rainy season. This may have increased the soil moisture and groundwater table due to the precipitation.

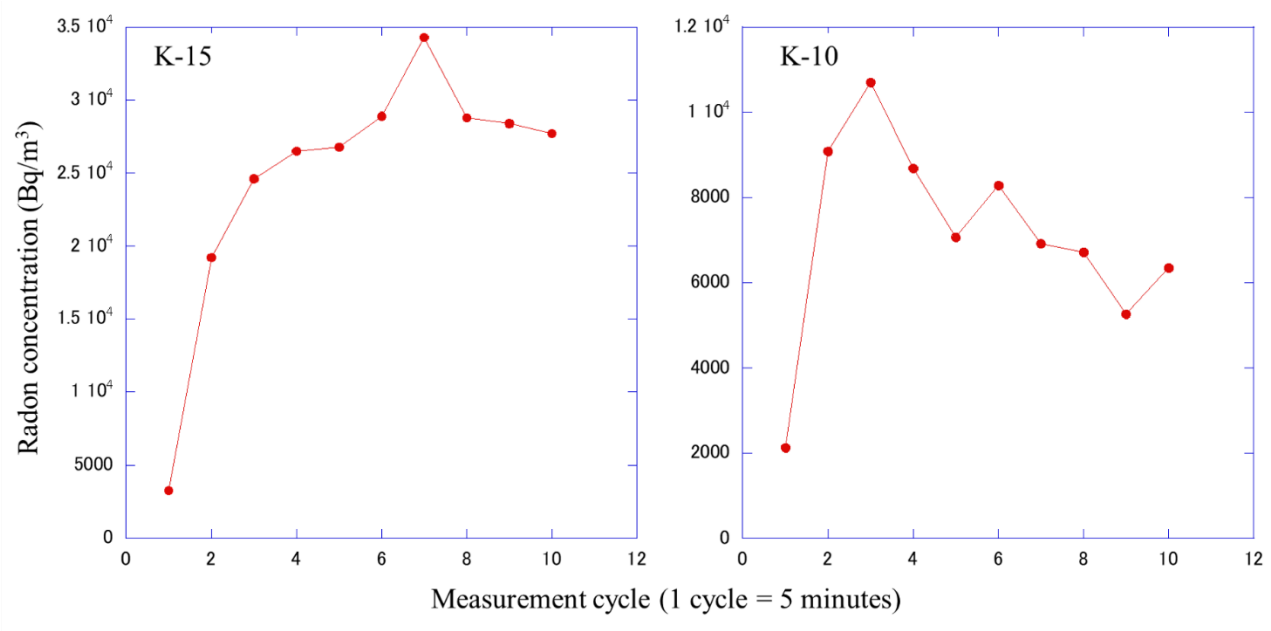

Figure 4: Temporal variations of radon concentration in 2nd measurement periods at K-15 (left) and K-10 (right) points.

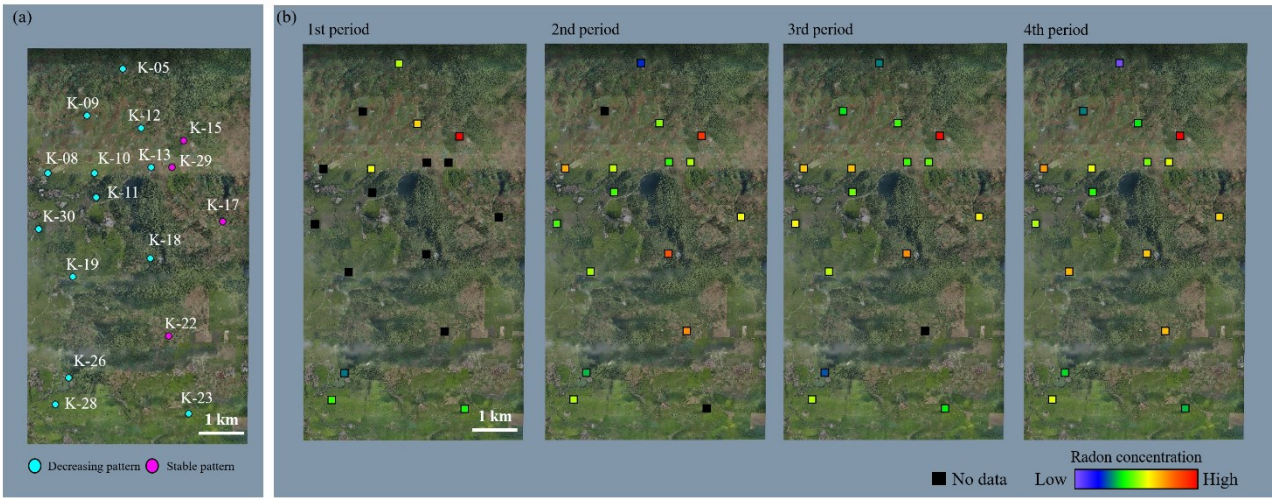

Figure 5: Distribution of decreasing and stable pattern wells at all K-series wells (a) and distribution maps of radon concentrations from the 1st to 4th period. Color of dots indicates the maximum value over the cycles of one measurement. Black dots mean wells with no measurement data (b). Each map is overlaid on an aerial photograph.

5. DISCUSSION

The periodical measurements suggest that K-15 is an important anomaly point from a view point of radon concentration. There is no geothermal manifestation such as a fumarole and a hot/warm spring around K-15. However, K-15 is consistent with the assumption, "presence of a fluid path increases radon concentration", because it is located near a fault intersection. Based on the results of K-series wells, additional measurement using NSD-series wells were implemented for a verification. The NSD wells located on faults or at fault intersections showed the stable pattern as shown in Figure 6.

Moreover, the results of gas component analysis of soil gases sampled from K-10, K-15 and atmospheric air using a gas chromatography are shown in Figure 7. Since the gas sample of K-15 contains a relatively larger proportion of H_2S than the others, it can be assumed that the sample contains a large amount of volcanic gas components. Hence, it is presumed that a fault or permeable fracture acting as hydrothermal ascent path exists around K-15 and the gas flow from the deep part is active.

Esaki et al. (2017) revealed that the hydrothermal alteration minerals are distributed along the fault around K -15 through the remote sensing analysis using optical-sensor satellite imagery. This finding suggests that thermal waters or vapors had ascended to the ground surface in the past, and can support an assumption of the presence of fluid flow paths connecting to a geothermal reservoir in the deeper part of K-15.

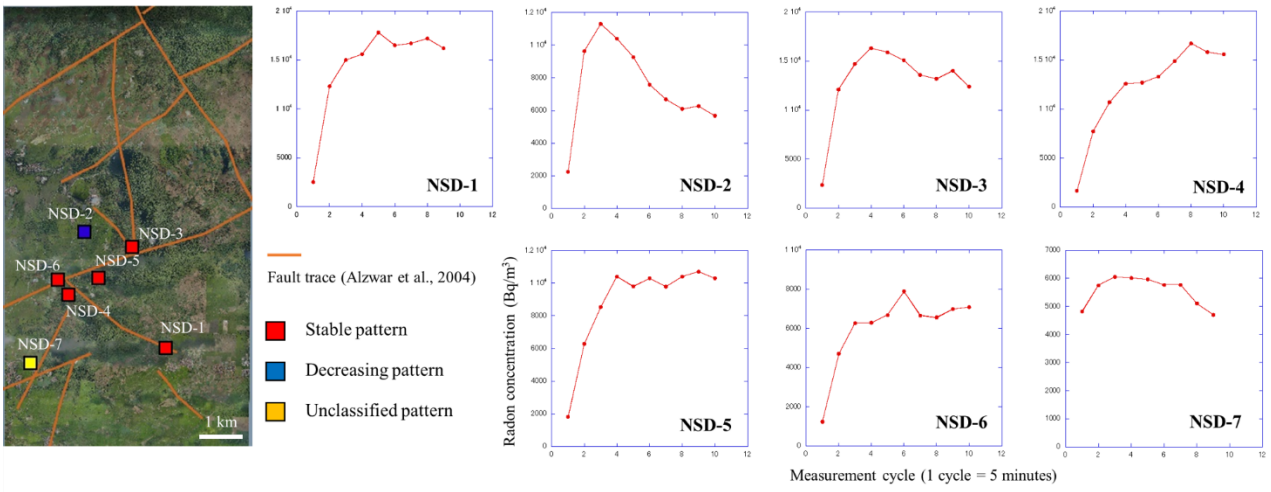

Figure 6: Distribution of decreasing and stable pattern wells overlaid on an aerial photograph with fault trace and temporal variations of radon concentrations at all NSD-series wells.

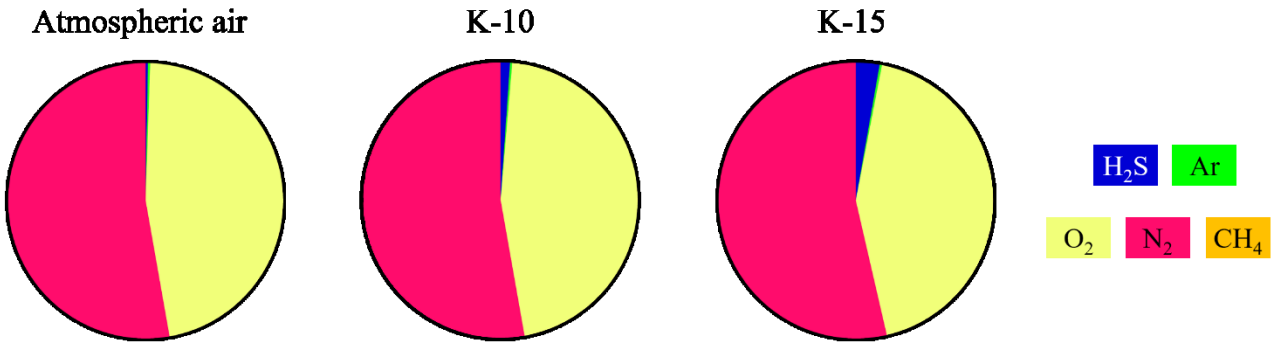

Figure 7: Gas component proportion of K-10, K-15, and atmospheric air analyzed by a gas chromatography.

5. CONCLUSION

We carried out the periodical measurements of radon (Rn-222) concentrations in soil gases over one year to clarify the hydrothermal ascent paths from the ground surface in Wayang Windu Geothermal Field, which is one of the greatest geothermal potential areas in Indonesia. From the results obtained from 24 monitoring wells in total, the features of radon concentration variation were revealed. The remarkable result was a temporal variation of radon concentration with elapsed time within one hour, which was classified into two patterns, stabile and decreasing patterns. Moreover, the K-15 well points which showed the highest radon concentration among all the monitoring wells was recognized as an important anomaly point. Integrated analyses with geochemical and remote sensing analyses suggested the presence of a fluid flow path connecting to a geothermal reservoir in deep part of K-15. Consequently, radon measurement is expected to locate accurate high potential resource zones and to increase the success rate of production wells.

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