RELICT AND MODERN EPIDOTE: LESSONS FROM RANTAU DEDAP, SUMATERA

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ABSTRACT

Epidote is an important hydrothermal alteration mineral; it is readily visible in drill cuttings, and generally indicates where temperatures are sufficient for setting production casing in geothermal wells. At the Rantau Dedap project in Sumatera, relict epidote was identified at the surface prior to drilling the first well. The relict epidote forms small, dull brownish crystals that persist in most cuttings samples, even where overprinting by the active geothermal system has produced low temperature minerals like smectite, halloysite, opal and chalcedony. At depth, coarser, yellow epidote crystals occur, some of which may be in equilibrium with the current geothermal system.

Determining which epidote is in equilibrium with current conditions is essential if epidote is to be used as a geothermometer for guiding drilling decisions, but is only possible with detailed petrographic studies. In systems where it is suspected there might be relict epidote, rapid and accurate petrology is strongly recommended.

1. INTRODUCTION

The Rantau Dedap geothermal prospect is located in South Sumatera, Indonesia (Figure 1), on the northern side of Bukit Besar volcano at elevations ranging from about 1100 m to over 2500 m above sea level (asl). It is some 25 to 30 km west of the Lumut Balai geothermal project that is being developed by Pertamina Geothermal, and 40 km southeast of Dempo, an active andesitic volcano. The Rantau Dedap prospect was first identified from surface fumaroles and neutral alkali chloride springs that extend over an area of approximately 9km by 6 km.

Following a thorough surface exploration programme comprising geological mapping, geochemical sampling, and geophysical surveys, six deep exploration wells were drilled in 2014 – 2015. Well pad elevations were between 1750 masl and 2400 masl, and wells were drilled to measured depths of 2250 to 2730 m (+200 to -50 m asl).

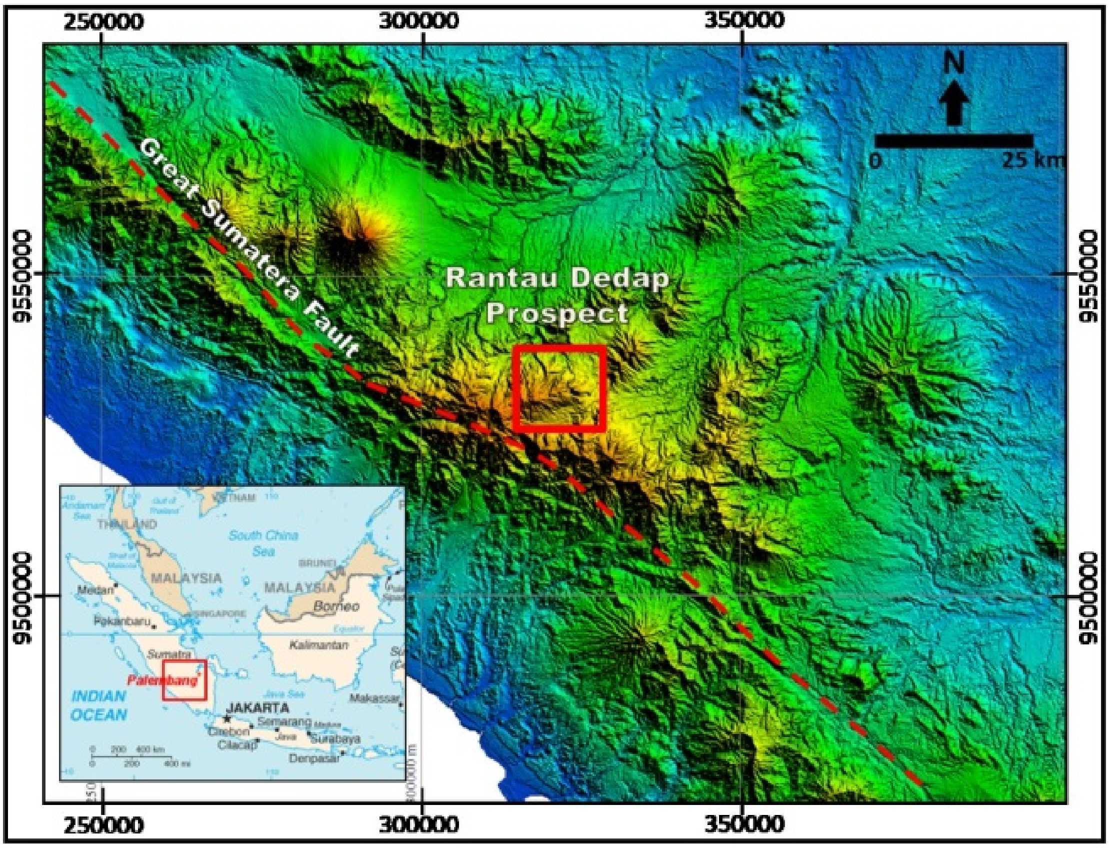

Figure 1: Location map of Rantau Dedap prospect.

2. EPIDOTE AT RANTAU DEDAP

Geological mapping by LIPI (2008) and LAPI (2011) had identified epidote in surface outcrops at Rantau Dedap prior to drilling, and additional locations were found after the civil works for road and wellpad construction. The epidote occurs in a sequence of folded and faulted andesitic lava flows, pyroclastic and epiclastic rocks with interbedded marine sediments that are exposed beneath young andesitic to rhyolitic lava flows and pyroclastic deposits sourced from identifiable volcanic centres.

Hence, it was known that there was relict epidote at Rantau Dedap before the first well (RD-X) was drilled. However, it was perhaps not fully appreciated how much that would affect the decisions during drilling.

3. IDENTIFYING RELICT EPIDOTE

Clearly, epidote that is exposed at or near the surface where temperatures are less than 100°C is relict. In fact, all epidote where temperatures are less than about 240°C will be relict. Unless we can confidently identify which epidote is relict, epidote should not be used to determine production casing depth.

3.1 Identification at the rig site

Minor epidote was found throughout these wells, starting in some of the shallowest cuttings samples. On the first wellpad, where there is only a thin (<50 m) cover of young andesitic volcaniclastics, epidote was found virtually from the surface. In later wells, which were drilled from higher elevation wellpads with a greater thickness of young andesitic cover, epidote first appeared at greater depth, but at about the same elevation. Epidote is initially very minor and intermittent, but continuous epidote was logged below approximately 1300 masl.

The first epidote with depth in each well tends to be dirty greenish-brown, and is associated with alteration minerals like opal, chalcedony and zeolites (which extend to at least 315 mMD in RD-X). These minerals indicate that this epidote is relict. Likewise, where methylene blue (MeB) analyses indicate a high smectite content, the epidote is almost certainly relict.

Deeper in these wells, epidote generally becomes more common, coarser, yellower and fresher looking. However, the experience at Rantau Dedap is that it is not possible to distinguish relict from stable epidote with only a binocular microscope at the rig site.

3.2 Thin section petrology

A total of 35 thin sections were cut from the six wells, and these sections all gave a consistent picture of relict epidote in altered rocks and in veins, which had been partially replaced by chlorite, calcite and in places, quartz.

Six thin sections were examined from the first well (RD-X). Due to total circulation losses over much of the production section, there is a large sampling gap from 760 mMD to where a core was cut at 1839-1843 mMD (1464-1466 mVD). Epidote was seen in every thin section from below 350 mMD, but those grains were dirty brownish, with irregular ragged outlines and surrounded by chlorite, titanite and opaque minerals, even in the core.

Core from 2141-2147 mMD (328-333 masl) in well RD-Y contains vein epidote crystals and replacement epidote in the host rock, especially within altered plagioclase phenocrysts. In thin section, the vein crystals are tightly packed, clear, pleochroic yellow epidote crystals that are intergrown with quartz and in places, prehnite. Some of these vein crystals have euhedral prismatic shapes, and most look very fresh. However, replacement epidote crystals in the same rock, as little as 1 mm from the vein epidote have irregular, corroded outlines, and are surrounded by chlorite ± calcite and titanite (Figure 2). Many of these replacement epidote crystals are now barely recognisable as epidote.

Thus, even in samples that contain fresh, euhedral yellow epidote crystals, there is evidence in thin sections that not all of the epidote is stable, but has been partly replaced by other hydrothermal minerals. Accordingly, the recognition of clear yellow epidote crystals in cuttings, including prismatic vein epidote crystals intergrown with quartz, does not necessarily mean that the field of epidote stability has been reached.

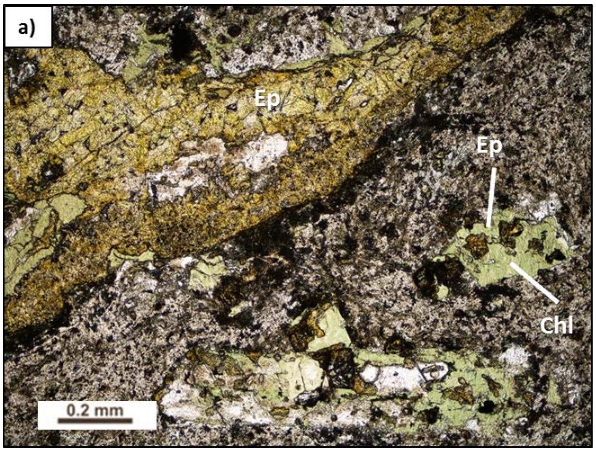

Figure 2: Fresh vein epidote vein crystals, and dirty corroded epidote in the host rock (RD-Y core, 2142.7 m).

3.3 Fluid inclusion analysis

Analysis of fluid inclusions in quartz from two of the Rantau Dedap wells yielded some useful data. A sample from a depth of 616 mMD (603 mVD) in well RD-X contains two populations of liquid dominated fluid inclusions; one having homogenisation temperatures of 285-310°C, and the other with homogenisation temperatures of 200-215°C (Figure 3). From the fluid inclusion data alone, it is impossible to distinguish which population of inclusions is older, but together with the petrographic evidence, it makes a convincing argument for cooling/overprinting within a geothermal system.

The higher temperature inclusions (~300°C) are consistent with epidote stability, but are incompatible with the depth of this sample. Even if the water level was at the surface (an impossibility at 1750 m elevation on a dissected, sloping volcanic terrain), a boiling point for depth profile means that the temperature at this depth can be no more than 265°C. Hence, the water level and the land surface must have been higher when these inclusions were trapped, and significant erosion and cooling has occurred since. Assuming an average temperature of 300°C for the high temperature group, a minimum of 485 m of erosion has occurred since those inclusions formed.

The low temperature group of inclusions lies close to the measured downhole temperature at this point after one month heating, and is consistent with the observed water level at about 400 mMD (400 mVD) and a boiling point for depth profile below that. However, a temperature of 200-215°C is significantly less than the generally accepted stability range for hydrothermal epidote (>~240°C), meaning that the epidote at this point is probably also relict. Thus the low temperature group of fluid inclusions probably formed after the epidote.

A similar pattern was revealed in fluid inclusions from well RD-Y, where again there are two groups of fluid inclusions. Most have homogenization temperatures of 260-284°C, but a few have much higher homogenisation temperatures (>365°C, Figure 3), possibly due to boiling, and trapping of vapour-rich inclusions. In this case, both groups are consistent with epidote stability, and neither is consistent with current downhole temperatures. If there were inclusions that had formed under the current temperature regime, then there would be a third group of inclusions, indicating a complex thermal history.

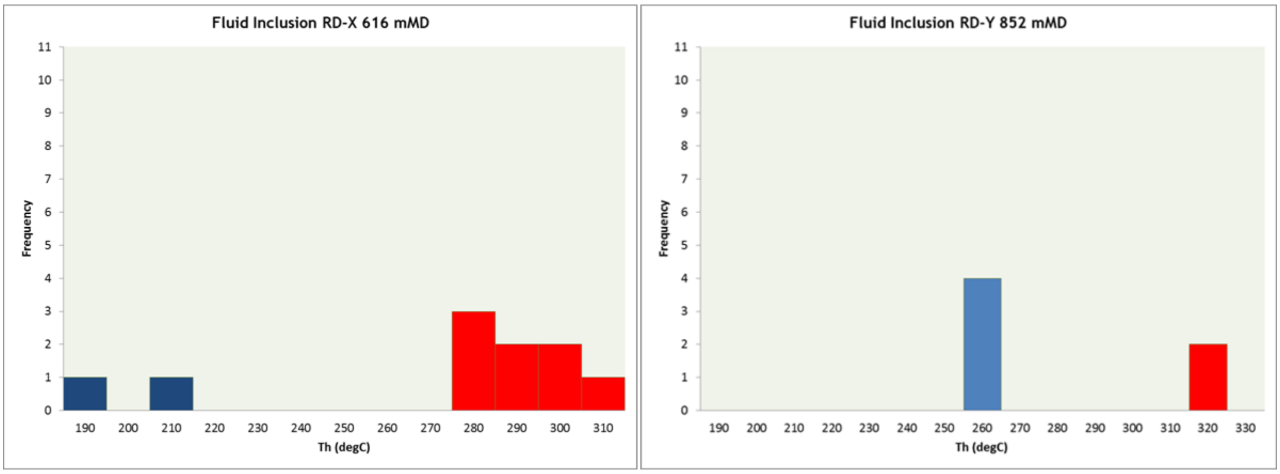

Figure 3: Fluid inclusion homogenisation temperatures from RD-X 616 m and RD-Y 852 m.

4. IMPLICATIONS OF RELICT EPIDOTE

The recognition of extensive relict epidote at Rantau Dedap means that epidote can not be readily used to determine the appropriate depth for production casing, unless the rig geologist is supported with good, rapid petrology that looks specifically at epidote stability. It also has implications for interpretation of the geophysics, the regional geology and future well siting.

4.1 Setting production casing

Prior to drilling the first well, the MT resistivity 3-D model was used to interpret the depth of the smectite-rich clay cap above the geothermal system. The depths to the base of the conductor (BOC) and top of (stable) epidote (TOE) were interpreted from the 3 and 50 ohm-meter contours, respectively. After drilling, it was found that the base of the argillic zone, as identified by the change from smectite to interlayered clays, was slightly higher than the BOC, and continuous epidote was at about the same depth as the TOE interpretation, but the top of reservoir (TOR) from actual temperature measurements was significantly deeper than the TOE (Figure 4). This is because the presence of relict epidote means that continuous epidote is not the same as stable epidote, with petrology data indicating that in some of these wells, stable epidote was not reached at all. What this means is that the MT profile indicates a past thermal regime, and it has not yet re-equilibrated to current conditions.

Likewise, methylene blue analysis, which indicates the total smectite content with depth in the well, is generally consistent with the MT profile. For example, in the first well, the interpreted base of the MT conductor is at a depth of about 400 (1D) to 500 m (3D), while the peak MeB value was at 260 m, and MeB values were consistently less than 5 from 540 mMD. In some of the higher elevation wells, the entire conductor (and the high MeB values) is above the subsequently measured water level, meaning that the clay cap formed under different hydrological and thermal conditions, and has not re-equilibrated with current conditions.

Because of these complications, with a relict clay cap and relict epidote, the standard methods for determining production casing depth (e.g. MT, MeB, epidote as identified by binocular microscope) were not considered to be reliable at Rantau Dedap. After the first few wells had been drilled, and temperature and pressure profiles were available from those, then they provided good data for determining casing depths in nearby wells. For the first few wells, static formation temperature tests (SFTT) were used to estimate the formation temperatures when potential casing depths were reached, with some success.

In hindsight, good petrology with a rapid turn-around could have assisted by identifying relict epidote. Because of the remoteness of the Rantau Dedap site, that would probably mean having thin section making equipment, a petrographic microscope and a trained petrologist at the rig site.

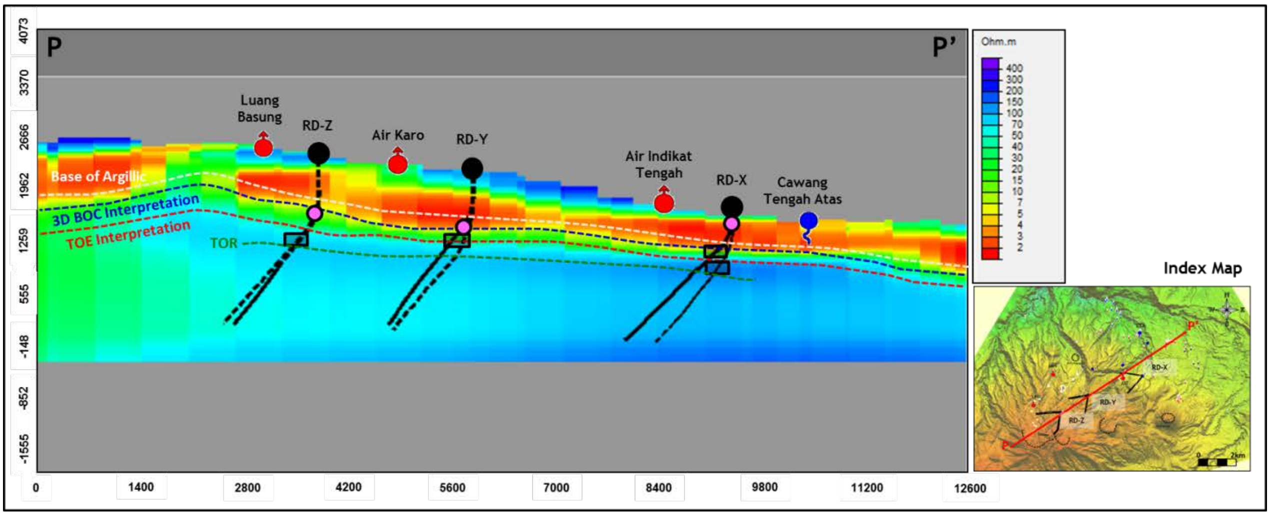

Figure 4: SW-NE cross section showing fumaroles (red), springs (blue), wells (black), first epidote (circles), first continuous epidote (rectangles), base of argillic alteration (from MeB, XRD and petrography), base of the conductor (from 3D MT), top of epidote interpretation (from resistivity >50 Ωm), and top of reservoir (from well completion testing).

4.1 Regional geology model

The three dimensional extent of epidote is clearly tied to the stratigraphy, as the first appearance in wells corresponds to a change from weakly altered andesitic lavas and pyroclastic deposits to underlying intensely altered andesitic lavas, pyroclastics and epiclastic deposits that in outcrop are seen to have moderate to steep dips.

One of the consequences of recognising relict epidote at the surface at Rantau Dedap is that this fossil alteration is incompatible with previous geological interpretations of this area as a caldera. Westerveld (1942) first recognised thick (at least 50 m) welded ignimbrites beneath andesitic deposits near Dempo volcano, and suggested that they originated from "…somewhere south of the Dempo volcano". The Semendo Caldera was subsequently postulated as an 18-20 km diameter feature (though 35-40 km wide on many maps) on the northeast side of the Sumatera Fault that encompassed all of Rantau Dedap and parts of the Lumut Balai and Margabayur geothermal systems.

If Rantau Dedap were situated within a caldera, the land surface should have dropped, so that if there was originally relict epidote at the surface, it should now occur at some depth, beneath intra-caldera eruption deposits and post-caldera volcanics. The presence of relict epidote at the surface means that there has been uplift and erosion rather than subsidence, and that Rantau Dedap field is not situated within a caldera. A caldera setting is also incompatible with the absence of ignimbrite deposits, and the presence of marine sediments (containing foraminifera) at shallow depths (to 1350 m asl) in several wells.

2. CONCLUSION

Epidote is commonly used as a geothermometer, and an indicator of temperatures greater than 240°C in active geothermal systems. However, relict epidote can occur, especially in high elevation geothermal systems, which are more prone to erosion, cooling and changes of water level over time. Without good petrology, it may be impossible to distinguish relict from stable epidote in drill cuttings. In systems where it is suspected there might be relict epidote, rapid and accurate petrology is strongly recommended.

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REFERENCES

LIPI, 2008. Geological structure and alteration at geothermal prospecting area Rantau Dedap, Muara Enim, South Sumatera. Internal Report for Supreme Energy Rantau Dedap.

PT. LAPI ITB, 2011. Geological mapping and structural analysis at geothermal prospect area Rantau Dedap, Muara Enim, South Sumatera. Internal Report for Supreme Energy Rantau Dedap.

Westerveld, J. 1942. Welded rhyolitic tuffs or 'ignimbrites' in the Pasoemah region, West Palembang, South Sumatera. *Leidsche Geol. Meded.* 13, 1, p. 202-217.