Subsurface Geology of the North Sector of Ulubelu Geothermal Field, Lampung, Indonesia

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ABSTRACT

The Ulubelu Geothermal Field is located in the southern tip of Sumatera Island. The field currently generates 220 MW of electricity from 4 Units of single flash geothermal power plant. The earliest 2 Units were commissioned in 2012 and followed by the third and fourth units in 2016 and 2017 respectively. The 2017-2018 make-up wells program was to drill delineation well further north closer to the postulated upflow. Strong geoscientific rationales were made to justify the campaign. It covers the UBL-J well pad in an elevated terrain of Mt. Rendingan. The UBL-J wells were planned to target the reservoir beneath Mt. Rendingan. The UBL-J consists of three wells in a well pad. All the wells intersected the rhyolitic tuff reservoir encountered from depth about 1350 to 2100 mMD. The maximum average temperature of the wells about 275°C.

This report study the subsurface geology from the northest well pad drilled in Ulubelu field. UBL-J2 is one of the make-up well in UBL-J wellpad that aim to maintain the steam supply for Ulubelu geothermal power plants. It is the second well drilled in UBL-J wellpad to expand the prospect further to the north, near the upflow zone beneath Mt. Rendingan. The well is reached total depth of 2101 mMD. UBL-J2 penetrates through three different lithological units which are: Oxidized Andesite Lava 10-470 mMD, Mixed Volcaniclastic Breccia 470-1200 mMD, and Rhyolitic Tuff 1200-2101 mMD. A numbers of alterated minerals are also identified in the cuttings and core samples of UBL-J2. Furthermore the altered minerals assemblages were classified according to the clay minerals zonation which are: Smectite zone at around 0-970 mMD, Transition mixed-layer clay at 970-1200 mMD, and Illite+epidote zone 1200-2101 mMD.

1. INTRODUCTION

Ulubelu geothermal field is situated in Lampung province, approximately 125 km west of Tanjung Karang. Ulubelu geothermal field has been studied since 1991 based on surface manifestation and gravity surveys. In 1997, geological survey and manifestation sampling was carried out. MT and TDEM analyses was done in 2009 by constructing 3D inverse model to complete the existing data. Geochemical data has been resampled in 2011. Fifty four wells have been drilled in Ulubelu to supply 4 x 55 MW power plant units and to further comprehend the subsurface geology of Ulubelu.

Figure 1: Location of Ulubelu-Waypanas Geothermal Prospect.

The need for make-up wells was starting from 2014 after 2 years of production. The UBL-J wellpad was selected due to its attractive subsurface target beneath Mt. Rendingan as the postulated upflow. It is the northest wellpad in Ulubelu field. Strong geoscientific rationales for well targeting include geological target (rhyolitic tuff Unit and Rendingan & Karang Rejo Fault); geophysical target (sub-resistive stratum and high seismicity zone); and geochemical target (high chloride concentration trend).

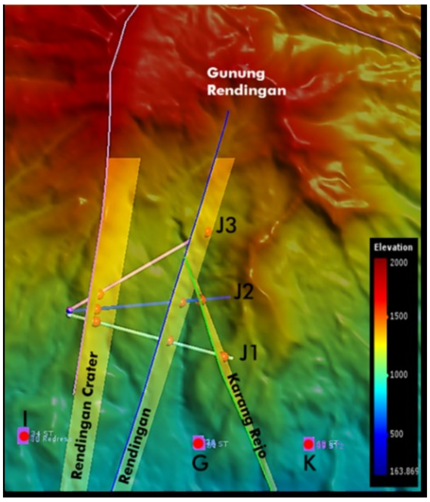

Figure 2: Map and subsurface targets of well UBL-J2.

2. GEOLOGY OF THE FIELD

Ulubelu Geothermal field is located near Sumatra Fault System in a volcanic depression system. The evolution of volcanism in Ulubelu geothermal field could be inferred through numerous circular and semi circular features present along the Rendingan-Tanggamus axis, including the semicircular feature remnants of Mt. Sula caldera (Figure 2). The appereance of these circular features suggest the older volcanoes such as Mt. Sula underwent a catastrophic collapse during its destructive phase, forming the Old Sula Rim identified today. Post caldera tectonic event results in tensional faulting in which the NE-SW trending Pagaralam and Talang Marsum faults developed. The Sula caldera collapse followed by tectonic episode, gives way for the younger volcanic bodies to form namely the Muaradua Rim, Mt. Aekabang, Mt. Duduk, and Mt. Mas within the Ulubelu depression, and Mt. Kukusan, Mt. Tiga, Mt. Rendingan, Mt. Argomulyo around the Sula rim. The youngest volcanoes are Mt. Kabawok and Mt. Tanggamus to the southeast, judging by its conical shape of its stratovolcano morphology (Prasetyo et al, 2020).

Period	Epoch	Age	Units
			Mt. Tanggamus
			Mt. Young Rendingan
Quaternary			Mt. Kabawok Andesite
		1.4 Ma	Mt. Old Rendingan
			Mt. Argomulyo
	Pleistocene		Mt. Tiga
			Mt. Kukusan
			Mt. Mas
		3,9 Ma	Mt. Duduk
			Mt. Aekabang
Tertiary	Pliocene		Mt. Waypanas
		4.5 Ma	Mt. Sula Muda Mt. Kurupan
			Mt. Sula

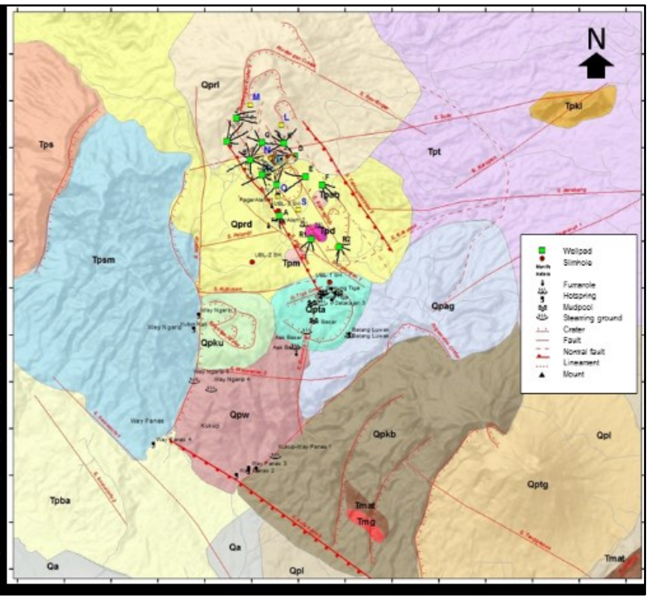

Figure 3: Geology map and volcano-stratigraphy of Rindengan-Tanggamus volcanics (modified from Masdjuk, 1997).

Composed mostly of volcanic rocks, volcanic breccia, and rhyolitic tuff, to the northern part of Ulubelu andesite lava could also be found. Most likely the andesite lava is product of Mt. Rendingan, with porphyritic and vesicular texture, composed of plagioclase and pyroxene phenocryst, glassy and microcrystalline feldspar groundmass.

Underlying the andesite lava are Mixed Volcaniclastic Breccia with interlayers of sediments, some in the form of black organic-rich mudstone and lenses of fossil-rich carbonates. The organic mudstone is the product of lacustrine sediment deposits, while the carbonates are thought to be fragment of reworked basement rocks, blown to exposure during the eruption of Sula volcano.

A continuous layer of rhyolitic tuff acts as Ulubelu's main reservoir. White and quartz rich in characteristic, Ulubelu's rhyolitic tuff could be described as matrix supported ignimbrite with quartz and feldspar fragments, glass rich matrix, and has good permeability. In this lithology, epidote could be found in abundance replacing the matrix and fragments, also filling voids such as veins/fractures. Rhyolitic tuff in Ulubelu are present from 0 to -500 mASL in the northern compartment and 0 to -1100 mASL in the southern compartment.

Most of the wells in Ulubelu encounter slaty-brittle, dark colored, dull lustre, organic-rich metasediment rock after penetrating through the rhyolitic tuff. These brittle rocks are the cause of most drilling issues due to its unstable characteristic, in some cases, the lithology could even pack-off causing the drill pipe to stuck. During the drilling campaign, attempts to drill through the metasediment layer are unsuccessful. Ergo, the metasediment is currently established as the bottom boundary for the reservoir.

3. BOREHOLE GEOLOGY

Subsurface data of the northen sector of the Ulubelu field is acquired through wells at the UBL-J wellpad. There are 3 (three) wells have been drilled, namely well UBL-J1, UBL-J2 and UBL-J3 in this area. UBL-J2 was selected for this study as representative for the subsurface geology in northern Ulubelu sector.

The UBL-J2 is a big hole well which is the second well drilled in the J Cluster located in the northern part of Ulubelu geothermal field, right at the flanks of Mt. Rendingan. This well is drilled toward the east, targeting the Karang Rejo and Rendingan Caldera Fault. Well UBL-J2 reached total depth of 2101 mMD. The well served its purpose as make-up well to maintain the steam supply and as a delineation well to further expand the prospect to the northern part of Ulubelu, near the upflow zone beneath Mt. Rendingan.

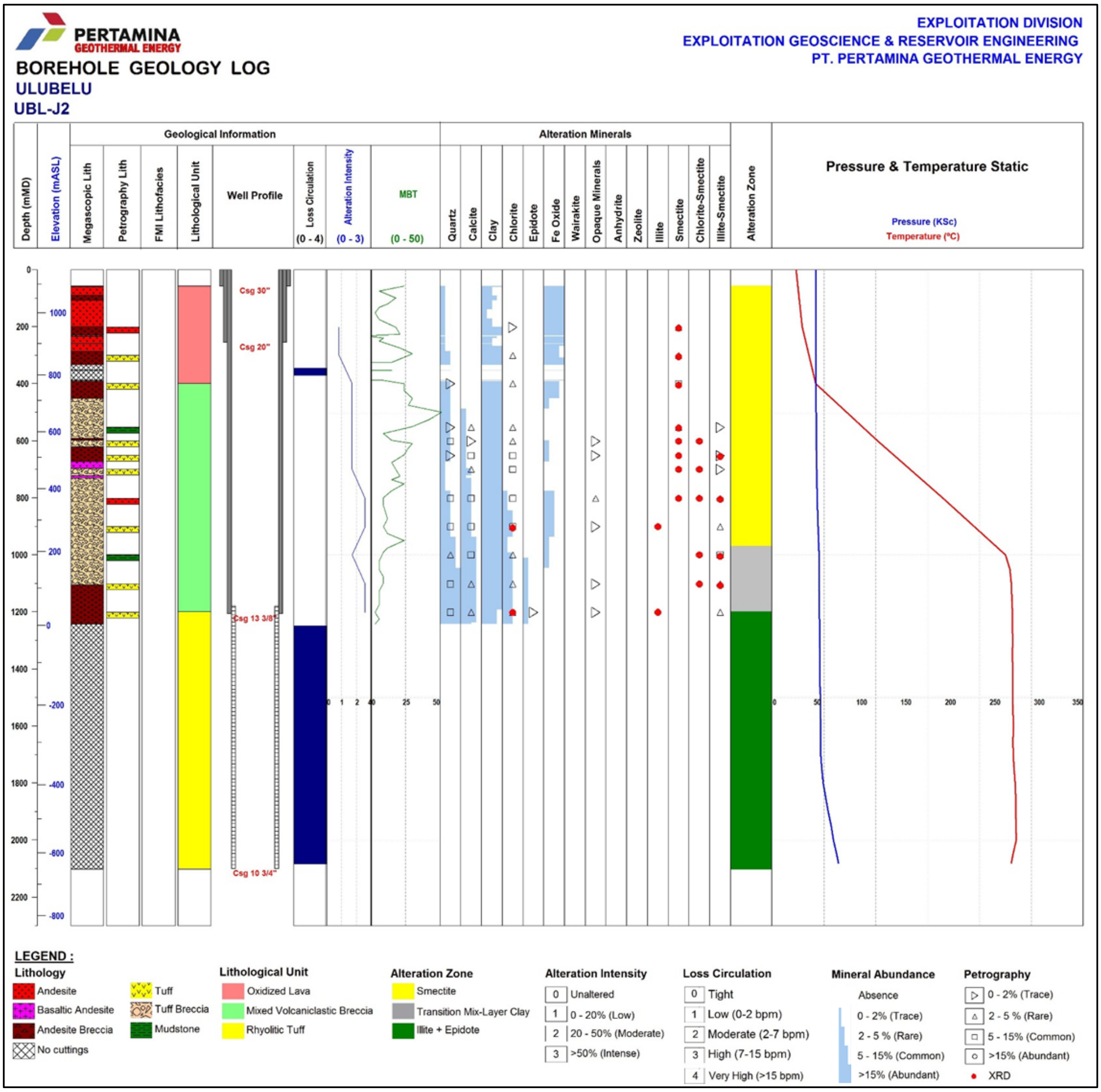

Figure 4: UBL-J2 Borehole geology log.

Stratigraphically, UBL-J2 could be divided into three different lithological units, namely the Oxidized Andesite Lava lithological unit, Mixed Volcanic Breccia, and Rhyolitic Tuff lithological unit. Oxidized Andesite Lava is consist of intercalation among andesite lava and andecite breccia. The lithology could be found from depth around 10-400 mMD, reddish grey in appearance and rich with iron oxides. Petrographical examination of the cuttings show that the andesite lava are mostly comprised of trachytic lava, with placioglase and pyroxene phenocrysts, its groundmass consists of plagioclase microlith and volcanic glass. Alteration and clay minerals present in this lithological unit are iron oxides, smectite clay, and a small percentage of the existance of quartz and chlorite.

Figure 5: Oxidized Andesite Lava lithological unit in UBL-J2.

The second unit of the lithology found in the well is Mixed Volcaniclastic Breccia. Mixed Volcaniclastic Breccia in UBL-J2 could be encountered at depth ranging from 400-1200 mMD. This lithological unit covers an intercalation of altered tuff breccia, and altered andesite breccia, and thin layers of mudrock. Alteration minerals that present in this lithological unit are quartz, calcite, chlorite, with small amount of iron oxides. Clay minerals identified through XRD analyses are smectite,chlorite-smectite, and illite-smectite mixed layer clays. Traces of first epidote could also be found at depth 1000-1200 mMD, characterized by small granular appereance, yellowish green in colour, commonly present replacing tuff matrix and andesite groundmass in andesite breccia.

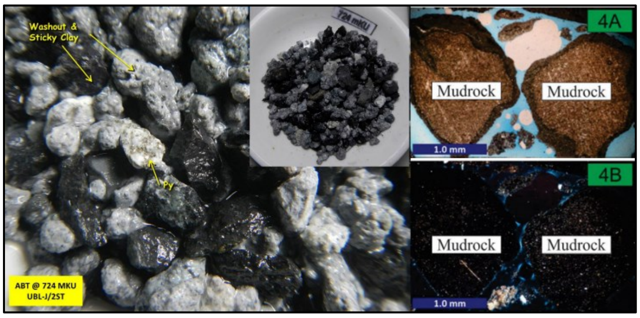

Figure 6: Mixed Volcaniclastic Breccia lithological unit in UBL-J2.

Rhyolitic Tuff is present from 1200 mMD to the total depth of UBL-J2 (2101 mMD). Cutting data for this lithological unit is only present for about 40 meters before encountering total circulation losses. The continuation of the rock unit is determined through correlation from adjacent wells. Considering the elevation and lateral lithological distribution, rhyolitic tuff should remain lithological unit throughout the loss circulation zone. Rhyolitic tuff can be distinguished by its quartz-rich, white color appereance. High temperature altered minerals and clays such as epidote and illite are found in higher intensity in this lithological unit. They reflect high-temperature reservoir zone with temperature reaching 270°C. The appearance of epidote is ubiquitous. It replaces groundmass and also filling the fracture/veins. The Rhyolitic Tuff or ignimbrite deposit is distiributed evenly inside Ulubelu basin boundary and it is highly permeable.

4. ALTERATION MINERALS

Alteration minerals are the result of interaction between primary minerals from the formation with geothermal fluids. The mineral formations are influenced by several factors, such as temperature, pressure, parent rock types, permeability, fluid composition, and the duration of activity (Browne, 1978). There are variety of altered minerals identified within UBL-J2 cuttings which are:

4.1 Smectite

Smectite is present in UBL-J2 starting from 57 mMD to 802 mMD. It mainly present replacing andesite groundmass and tuff matrix. Smectite's presence is confirmed and compiled form three different data: petrographical description, XRD analysis, and MeB analysis. Smectite common found in the formation unit of andesite lava and volcanic breccia. Common found to be associated with iron oxide, small number of quartz and chlorite.

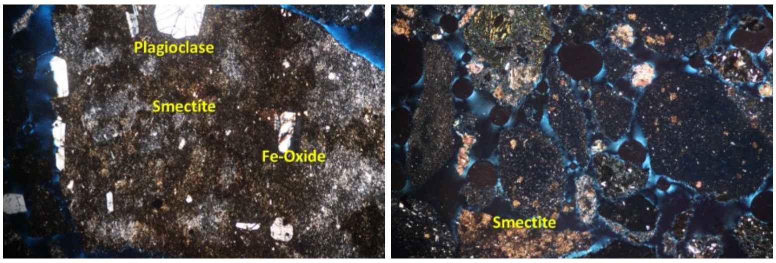

Figure 7: Smectite altering andesite groundmass and tuff matrix at UBL-J2 depth 202 mMD.

4.2 Secondary Quartz

Secondary quartz differs from primary quartz by its polycrystalline morphology, it is present replacing rock's andesite's groundmass and tuff matrix, also filling voids such as fractures and vesicules. The minerlas recognized by binocular and petrographic analysis. Secondary Quartz could be found starting from 57 mMD and grows larger in abundance with increasing depth. Quartz is common minerals that can be found along the depth of the well.

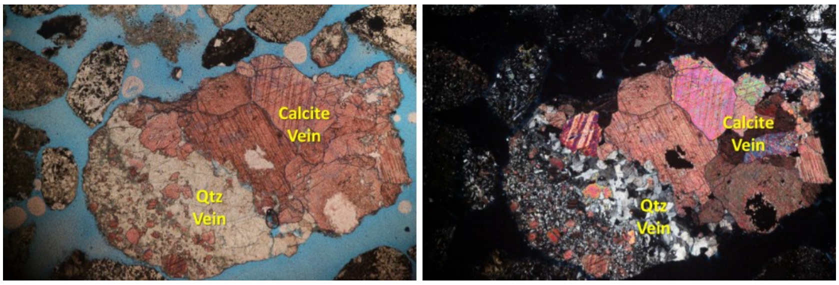

Figure 8: Quartz and Calcite as vein filling mineral in andesite lithology at 802 mMD.

4.3 Calcite

Calcite in UBL-J2 could be found from around 700 mMD to 1200 mMD. The appearance the calcite is characterized by its rhomohedral cleavage, high birefringence, and wavy relief. Calcite present as vein-filling mineral, replacing andesite groundmass, tuff matrix, and both plagioclase phenocrysts and fragments in andesite breccia, tuff breccia, and basaltic andesite of the Mixed Volcaniclastic Breccia lithological unit. Similar with secondary quartz, calcite's abundance also grows with increasing depth.

4.4 Chlorite

Chlorite could be identified in UBL-J2 through petrographical analysis, and XRD analysis. The first appearance of chlorite is found at 202 mMD through thin section analysis. Cutting description recorded the first appearance of chlorite at around 700 mMD, and the first chlorite identified in XRD clay analysis is at 901 mMD. Chlorite is present replacing pyroxene phenocrysts, andesite groundmass in the Andesite Lava unit, and tuff matrix in the Mixed Volcaniclastic Breccia unit.

4.5 Illite

Illite is solely identified through XRD clay analysis. Illite is first present at 901 mMD. It is not found in thin section and megascopic cutting description. Illite is encountered commonly in tuff lithology of the Mixed Volcaniclastic Breccia lithological unit.

4.6 Mixed Layer Clay

Mixed Layer Clay in UBL-J2 are present in the form of chlorite-smectite and illite-smectite,which are identifiable through XRD analysis. Chlorite-smectite is first found at 601 mMD and then at 700, 802, 1000, and 1102 mMD. Meanwhile illite-smectite could be found at 652, 802, 1000, and 1102 mMD. Both types of mixed layer clays are present in Mixed Volcaniclastic Breccia lithological unit

4.7 Epidote

The first presence of trace incipient epidote is at 1009 mMD where epidote could be seen replacing andesite groundmass and tuff matrix of the Mixed Volcaniclastic Breccia unit. Epidote could then be found continuously starting from 1207 mMD where it can be found replacing andesite groundmass and tuff matrix of the Rhyolitic Tuff lithological unit.

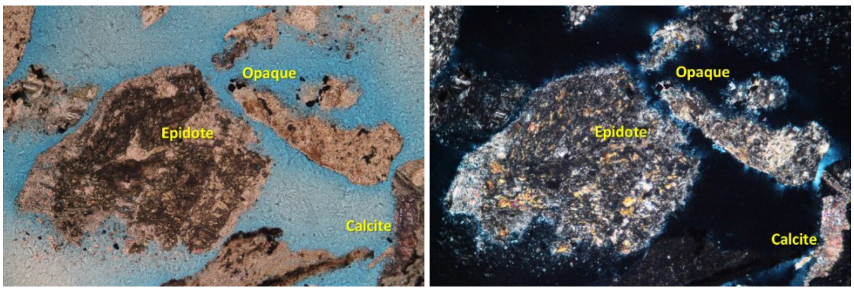

Figure 9: Epidote at 1201 mMD altering tuff fragments.

5. ALTERATION ZONATION

The altered minerals assemblages give hint to the subsurface condition. Clay minerals were used as the basis for classifying the alteration zonation. Clay minerals are known to be sensitive of temperature changes. Based on the altered mineral assemblage particularly the identification of clay minerals, There are at least 3 (three) alteration minerals zonation which are:

5.1 Smectite Zone

The zone is marked by the appearance of the Smectite clay minerals. High percentage of smectite around 0-970 mMD became the main reason that this depth interval is classified into the Smectite Zone, with its characteristically low temperature. Methylene Blue Analysis (MeB) data in this depth range also confirms the high presence of smectite with %smectite reaching until 51% at 499 mMD.

5.2 Transition Zone

Transition zone is marked by the first apperance of incipient epidote at 970 mMD, and the presence of mixed layer illite-smectite and chlorite-smectite. The present of those minerals is used to differentiate the transition zone with Smectite zone. MeB data also shows a decrease in reactive smectite percentage, while alteration intensity increases with the larger presence of quartz, calcite, and chlorite minerals. The zonation is found in the unit of mixed volcanic rock.

5.3 Illite + Epidote Zone

Illite and epidote abundance found at around 1009 mMD, first continuous epidote is found at 1200 mMD marking the top of reservoir zone in UBL-J2. MeB data shows the absence of smectite starting from 1021 mMD and until total circulation losses is encountered. This zone is found in associated with the rock unit of rhyolitic tuff.

6. DISCUSSION

Ulubelu geothermal field is located within a tectono-volcanic depression surrounded by circular features which are remnants of old volcano caldera rims, and younger volcanic bodies to the southeast. The main structural trend in Ulubelu are the NW-SE faults. There are four main lithological units in Ulubelu which are the Oxidized Andesite Lava, Mixed Volcanic Breccia, Rhyolitic Tuff, and Metasediment which serves as the basement of the field. This paper focuses on the subsurface conditions of UBL-J2 well, which is the second well drilled in Cluster-J on the northern part of Ulubelu geothermal field, near the upflow zone at the flanks of Mt. Rendingan. Reaching total depth of 2101 mMD, 1808 mTVD and at -657 mASL UBL-J2 penetrates through three different lithological units which are: Oxidized Andesite Lava 10-470 mMD, Mixed Volcaniclastic Breccia 470-1200 mMD, and Rhyolitic Tuff 1200-2101 mMD. A few types of alteration minerals could also be found in the cutting and core samples of UBL-J2 which results in the classification of UBL-J2 alteration zones: Smectite zone at around 0-970 mMD, Transition mixed-layer clay at 970-1200 mMD, and Illite+epidote zone 1200-2101 mMD.

Comparison between the actual shut-in temperature and the altered mineral assemblage reveals that the mineral geothermometry generally agrees with the current reservoir condition. Increasing secondary quartz over depth indicates that the permeability may developed particularly starting on top of reservoir. Illite together with epidote suggests that high temperature prophylitic reservoir have been encountered by the well. Moderate intensity of calcite over depth suggests boiling may occur and also a warning of calcite scaling deposition during the production of the well.

7. CONCLUSION

This study concluded that the well successfully delineate the northern part of Ulubelu geothermal resource. The subsurface data gives strong indication of high temperature reservoir beneath Mt. Rendingan. Total loss circulation zone encountered and high intensity of secondary quartz above the reservoir zone also confirms good permeability of the nothern area. Thus, plans for make-up wells could be targeted at the northern area beneath Mt. Rendingan.

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