CHARACTERIZATION OF HULULAIS SUBSURFACE ROCK FORMATION AND ITS IMPLICATION TO STRATO VOLCANO FACIES MODEL HULULAIS GEOTHERMAL FIELD, INDONESIA

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ABSTRACT

Hululais geothermal field is located in Lebong district, Bengkulu province, Sumatera island, Indonesia. As one of the exploration field operated by Pertamina Geothermal Energy (PGE), Hululais geothermal field targeted to generate 2 x 55 MW electricity by the end of 2020. 24 wells have been drilled since 2010. Retrieved cutting and cores from the drilling wells are the primary data for subsurface modeling. Thus, its identification and characterization is important for the next field development scenario.

An updated new subsurface rock formation is successfully established. They are identified as Upper Suban Agung Volcanic (USAV), Lower Suban Agung Volcanic (LSAV), Hululais Volcanic (HV), Hululais Granodiorite Intrusions (HGI), and Seblat Metasediment (SM). Its unique characters and its huge implications for the field development scenario will be explained in this paper. The knowledge to identify these rock formations will increase success ratio of well drilling, and reduce potential hazard and loss.

1. INTRODUCTION

Hululais geothermal field is located in Lebong district, Bengkulu province, Sumatera island, Indonesia (See Figure 1). Based on its tectonic setting, Hululais geothermal field lays along the Barisan mountains as the fore arc mountain ranges in Sumatera island.

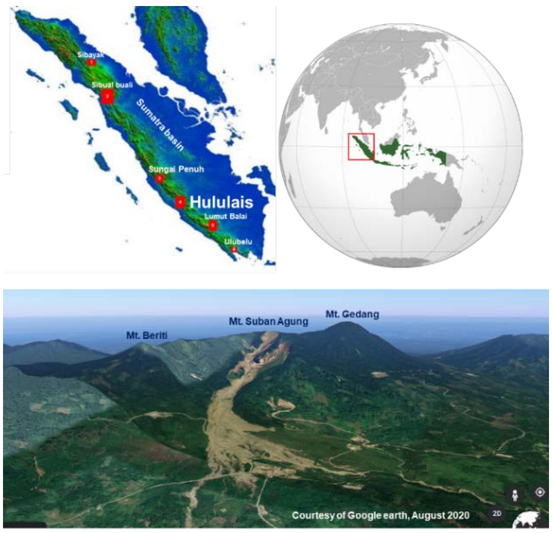

Figure 1: Location and satellite view of Hululais geothermal field. Mt. Suban Agung, Beriti, and Gedang are the major volcanism controlling geothermal system of Hululais.

Numerous geothermal prospects are discovered in The Barisan mountains zone. Hululais, Sibayak, Sibual – Buali, Sungai Penuh, Lumut Balai, and Ulubelu are some of these geothermal prospects that belong to Pertamina Geothermal Energy (PGE) concession area. As one of the exploration field operated by Pertamina Geothermal Energy (PGE), Hululais geothermal field is targeted to generate 2 x 55 MW electricity by the end of 2020. 24 wells have been drilled since 2010. Retrieved cutting and cores from the drilling wells are substantial data for subsurface geology modelling. Thus, its identification and characterization is important for the next field development scenario.

A simple geology model was constructed in 2017 (Nusantara et. al., 2017). With the increasing number of new data and advance analysis, the latest subsurface rock formations are successfully established. They will be used to update a new geology model for Hululais geothermal field.

This paper will discuss how to characterize these subsurface rock formations based on their physical properties, and their significance for the geothermal system in Hululais. Moreover, by acknowledging their characters, we are able to define their position and implication to the stratovolcano facies model that was developed by Bogie & McKenzie (1998) as illustrated in Figure 2.

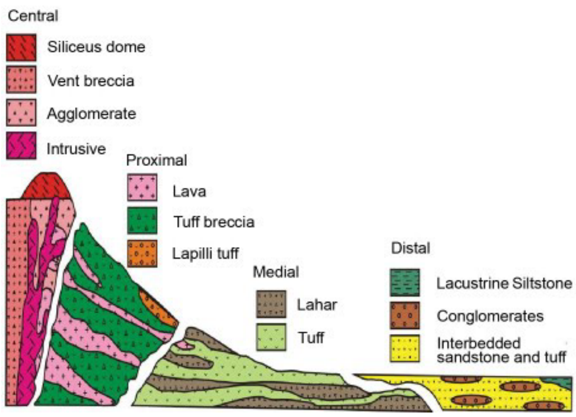

Figure 2: Four facies model of a structurally undisturbed andesitic stratovolcano (Bogie & Mackenzie, 1998).

2. REGIONAL SETTING

The Hululais geothermal field is controlled by NW-SE and NNW-SSE structures. These two main structural trends act as permeable pathways in which reservoir fluids manifest into the surface (Nurseto et. al., 2020).

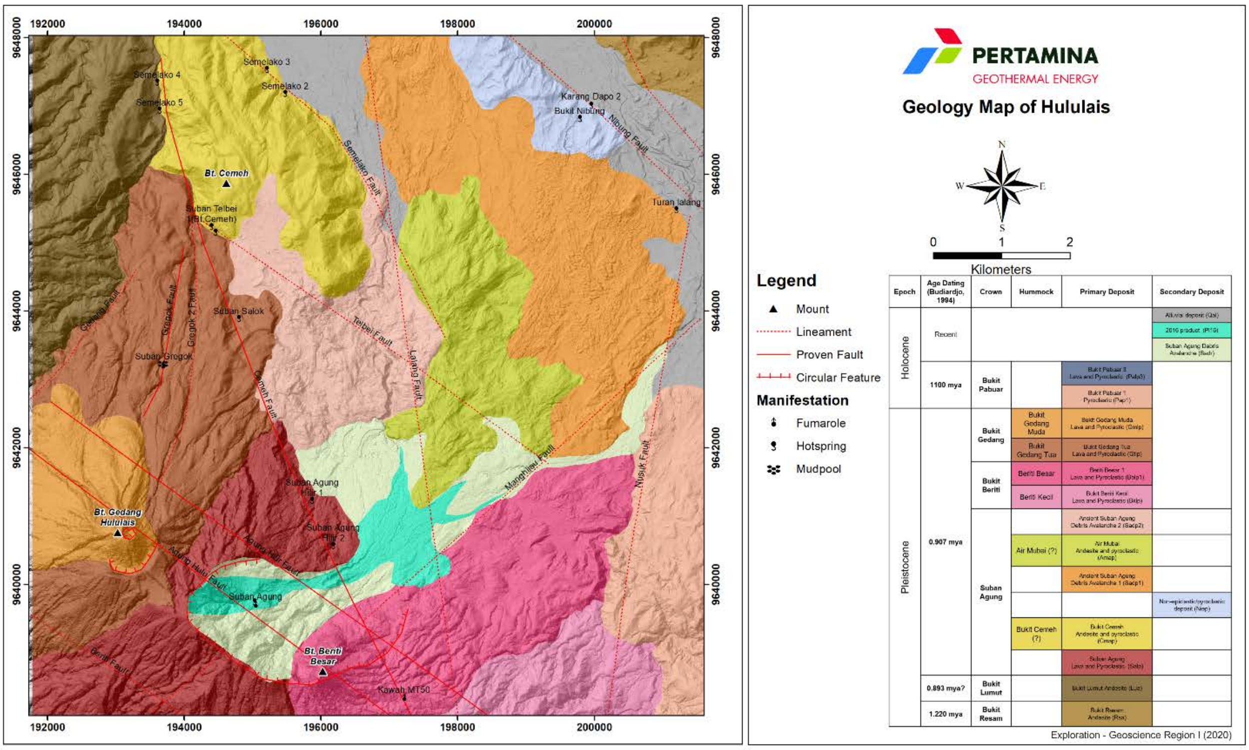

Figure 3: Geological map and volcano stratigraphy of Hululais geothermal field (Modified from Nurseto et. al., 2020).

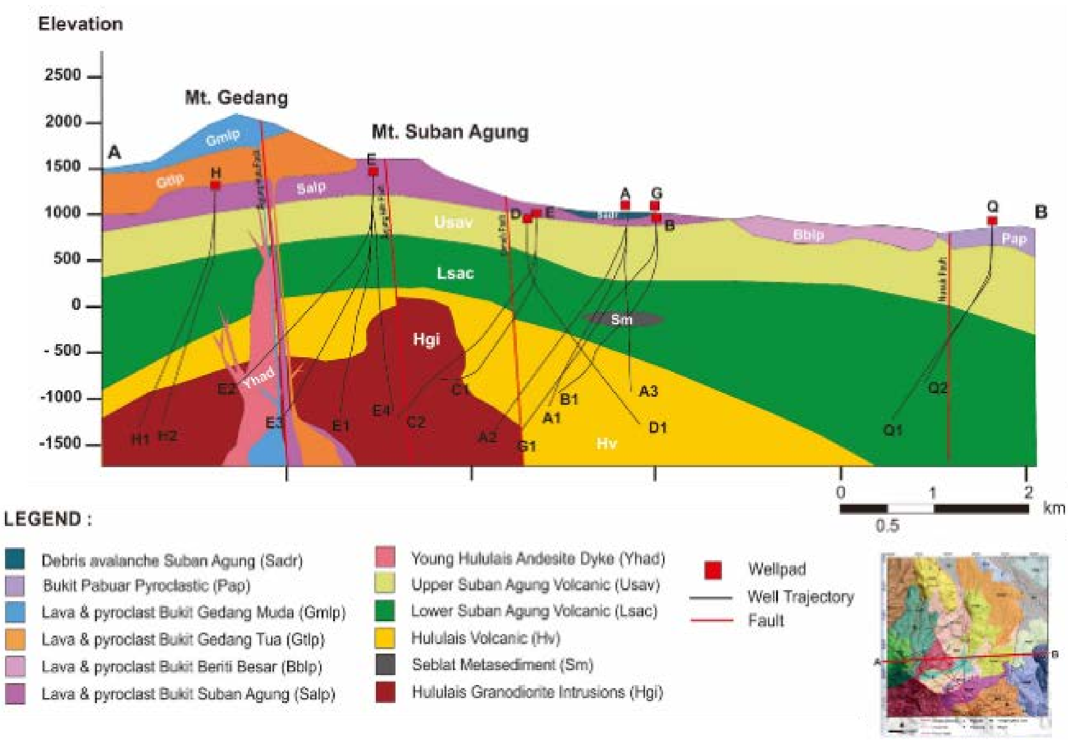

Figure 4: Geological cross section of Hululais geothermal field (Pratama et. al., 2020).

Three major Quaternary volcanisms control the Hululais geothermal system and in the order from the oldest to the youngest, they are Mt. Suban Agung, Mt. Beriti, and Mt. Gedang. Their products compose the geology of Hululais geothermal system. In the surface, this field is covered by alluvial and colluvium deposits. Figure 3 shows the geological map of Hululais geothermal field and its cross section with the information of subsurface stratigraphy of the field (See Figure 4).

3. METHOD & DATA PROCESSING

The primary data used for this study are rock samples (cutting & core) retrieved from several boreholes, wireline log records (borehole image, resistivity, gamma ray, pressure, temperature, and spinner log), final well report, and drilling parameter data. Physical rock data are identified under binocular and polarization microscope, examined with X-ray diffractometry test, and micropaleontology analysis.

All the data were collected and compiled as integrated borehole logs. Characterization, categorization and zonation process were performed by grouping the rock facies based on its physical properties. Accordingly, each subsurface rock formation can be established in further detail.

4. RESULTS

Subsurface rock formations derived from borehole data in Hululais are divided into 5 types of facies. From shallowest to deepestst, Upper Suban Agung Volcanic (USAV), Lower Suban Agung Volcanic (LSAV), Hululais Volcanic (HV), Hululais Granodiorite Intrusions (HGI), and Seblat Metasediment (SM).

4.1 Upper Suban Agung Volcanic (USAV)

The Upper Suban Agung Volcanics (USAV) are composed of pyroclastic products, tuffs, tuff breccia, andesite breccia, and lahars. This is a clay-rich formation with a high smectite content in its rock matrix. Mineralogical composition in this formation is dominated by smectite, kaolinite, zeolite, chalcedony, and sulphur. Physical features and microscopic image of lithology unit in USAV is showed in Figure 5.

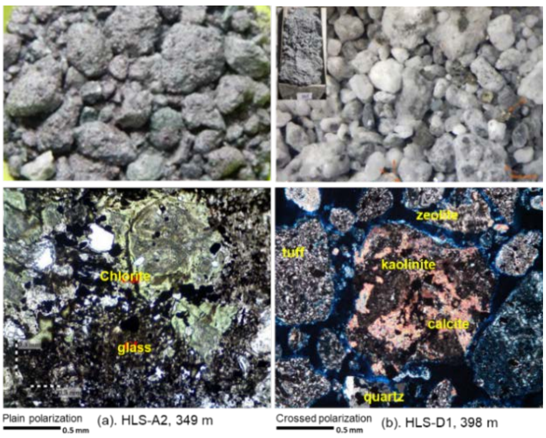

Figure 5: Microscopic image of tuff and volcanic breccia from Upper Suban Agung Volcanic (USAV) associated with low temperature secondary minerals including kaolinite, zeolite, calcite, and smectite.

Permeability in this formation is low to impermeable due to its abundant clay content, reflecting the role of USAV as the clay cap zone for the Hululais geothermal system. Resistivity values in borehole walls show consistently low trends ranging from 10 – 50 ohms.

Bogie & McKenzie (1998) described an undisturbed stratovolcano facies model based on its constituent rock characteristics. The presence of tuff, breccia, lava, and lahar in this formation suggests that USAV was part of the medial facies of Suban Agung volcanism.

4.2 Lower Suban Agung Volcanic (LSAV)

Lower Suban Agung Volcanic (LSAV) formation consists of an intercalation of andesite lavas, andesite breccia, and lithic tuffs. The andesite component in this formation is defined as vitrophyric andesites with plagioclase and pyroxene phenocrists. Typical secondary minerals in this formation are epidote, albite, adularia, illite, and chlorite. Mixed layer clays (MLC) at this depth are identified as smectite – illites. Figure 6 shows the intensity of alteration in cutting sample from LSAV formation from depth of 1100 m. Plagioclase altered by albite and higher temperature indicator minerals such as adularia, chlorite, fine grained epidote, and mixed layer clays.

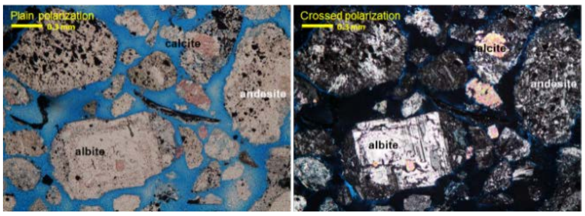

Figure 6: Microscopic image of a Lower Suban Agung Volcanic (LSAV) formation sample retrieved from a wellbore at a depth of 1100 m.

LSAV is interpreted as a transition zone of Hululais geothermal system. In this zone, smectite contents are significantly decreasing, while the first trace epidote appears indicating the top of the reservoir zone.

Refer to the volcano stratigraphy model, the LSAV is interpreted as part of the proximal zone of Suban Agung volcanism. This is justified by its rock facies type which is dominated by andesitic lava products.

4.3 Hululais Volcanic (HV)

Hululais Volcanics (HV) is identified by its andesitic lava with trachytic texture, and ignimbrite. In this formation, fragments of Seblat Metasediment (SM) are found as thin formation lenses.

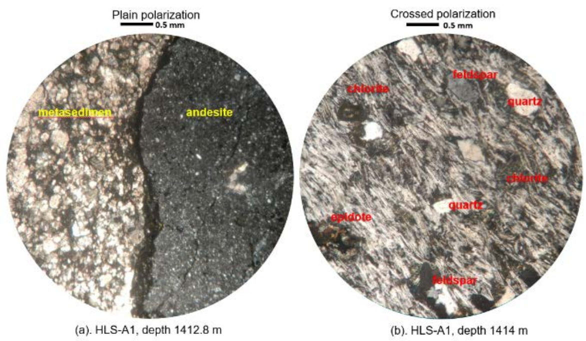

Figure 7: Microscopic image shows lithology contact between andesitic ignimbrite and fossiliferous metasedimentary rock (a), and trachytic texture in tuff from Hululais Volcanic (HV) formation.

Figure 7a shows the evidence of lithology contact between andesitic ignimbrite and fossiliferous metasedimentary rock from HV formation. This contact is visible in core sample analysis. Figure 7b displays how the trachytic texture are dominant in tuff and andesitic lava in this formation. Both fossiliferous metasedimentary rock, and trachytic texture are the properties that distinguish HV formation from the others.

High temperature indicator minerals are common in this formation, including euhedral epidotes, anhydrites, actinolites, and secondary biotites. Chlorite and illite clays are formed in this zone.

Distinctively, gamma ray value shows spiking trend in this formation. It is rising up to 800 API in wireline log. In the formation boundary zone between LSAV and HV, resistivity rates drastically increased from 100 to 800.

HV formation is only distributed surrounding production wells near Suban Agung, Beriti, and Gedang mountain ranges. Productive feed points were general encountered below the top layer of HV formation as shown in Figure 8. Spinner data suggests that HV has an excellent permeability rate. Feed points in this formation contribute around 67% of 1000 gpm injected water into the wells during the test. This permeability is related to the faults system trending NW-SE and NNW-SSE combined with primary permeability from its rock type. In essence, HV are interpreted as the productive reservoir zone for the Hululais geothermal system.

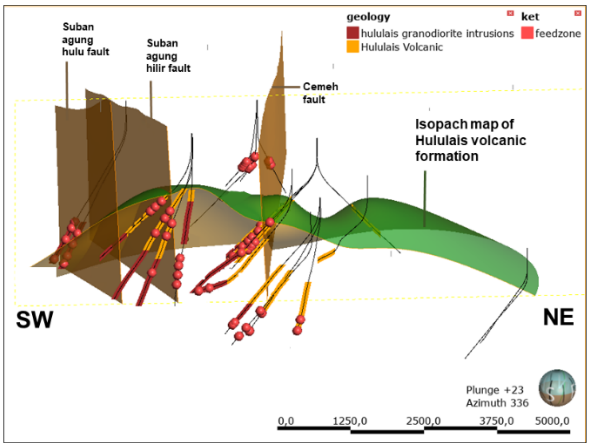

Figure 8: Distribution image of Hululais Volcanic (HV) formation in vertical section of NE-SW. It shows that the intensity of feed points (plotted as red bubbles) in Hululais are increasingly found after the drilling hit the depth of HV formation top layer.

HV represents a proximal zone of Suban Agung volcano stratigraphy. Andesitic lava and breccia dominate the rock composition in this formation. Autoclastic breccias are commonly encountered within this zone, but difficult to identify through rock chip observations.

4.4 Hululais Granodiorite Intrusions (HGI)

Hululais Granodiorite Intrusions (HGI) is a massive granodioritic batholith body existing beneath the Mt. Suban Agung crater, Mt. Gedang, and Mt. Beriti. HGI has primary coarse grained crystals of plagioclase, quartz, and hornblende (Figure 9).

Figure 9: Core sample at depth 2300 m from well HLS-E3 shows granodiorite with coarse plagioclases, quartz, and hornblendes in its composition.

Secondary minerals including epidotes, actinolites, secondary biotites, chlorites, and illites abundantly fill the fractures and open spaces in HGI, all of which are indicators of high temperature zone (See Figure 10).

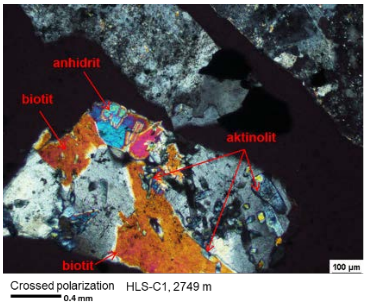

Figure 10 Microscopic image of high rank hydrothermal alteration mineral from borehole depth 2749 m.

HGI is intensively fractured by some faults. In consequence, total loss circulation (TLC) zone are generally found within this intrusive rock body. This formation is a good target for heat and permeability, along with HV formation.

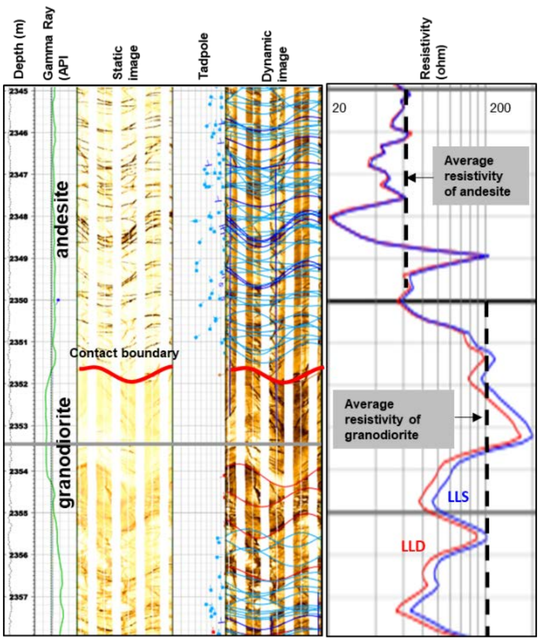

Figure 11: Image of rock facies boundary between granodiorite and andesite from borehole image log at depth 2351,2 m. It shows increasing of resistivity and contrast color in static log image, which is higher in granodiorite compare to andesite.

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Due to its association with the TLC zone, rock samples are difficult to retrieve from cutting samples. Core, borehole image, and wireline logging data substitute the absence cutting. Contrast of resistivity value and static image color in borehole image can be used accurately to identify this formation in TLC zone. HGI has extreme higher value in resistivity and slightly brighter color expression in borehole static imagery compared to other rock types (See Figure 11).

HGI is interpreted as a Miocene intrusive body beneath the mountain ranges of Suban Agung, Beriti, and Gedang. HGI is associated with regional pluton rock formation from Sumatra basement. It is uplifted by tectonic and massive volcanic activity of the region, and fractured by younger NW-SE trending faults. HGI represents a central zone of Suban Agung volcanostrato facies. Both HGI and HV formations are interpreted as reservoir rocks for Hululais geothermal system.

4.5 Seblat Metasediment (MS)

The Seblat Metasediment (SM) Formation is compose of discontinued lenses of metasedimentary rocks inside of lower Suban Agung Volcanic (LSAV) and Hululais Volcanic (HV) formation layers. In a megascopic observation, the type of Seblat Metasediment is similar to slate. In advance microscopic analysis, it is identified as wackestone as its host rock.

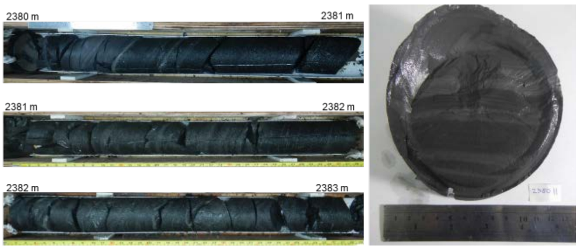

Figure 12: Full core sample of Seblat metasediment recovered at depth 2380 – 2383 m. Foliation, lamination, and cross bedding structures are dominant in this lithology.

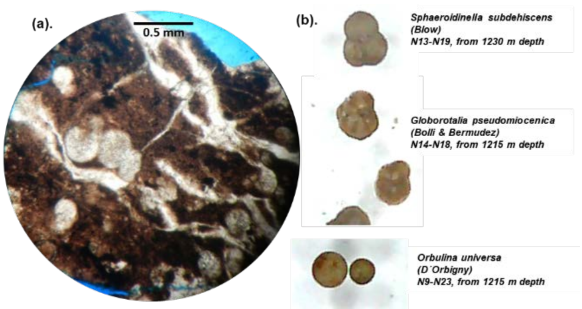

Figure 13: Microscopic image of biogenic fragment in thin section (a) surrounded by matrix clay. This biogenic fragment can be identified as planktonic microfossils from certain age after paleontology preparation (b).

Seblat Metasediment are dark coloured, with strong foliation structures, brittle, and rich in biogenic cast of microfossils (See Figure 12). Micropaleontology analysis obtains the relative age of this formation range around N14-N18 (middle to upper Miocene) through the recognition of the fossils *Globorotalia pseudomiocenica, Globigerina nephentes, Sphaeroidinella subdehiscens*, and *Globotalia plesiotumida* (See Figure 13).

Secondary minerals are rarely found in Seblat metasediment. In fact, this formation has low levels of alteration intensity, but has a higher type of alteration rank especially when lenses of this formation are found within the Hululais Volcanic (HV) layer. Granular epidote, carbonate, quartz, and chlorite, are found in this formation.

Seblat Metasediments are impermeable, but is not recorded to have any content of reactive clay, and is brittle. This could potentially create collapse formation hazard inside the wellbore. It is suggested to secure this formation with blind casing.

It is interpreted that Seblat metasediment is the product of uplifted deep sedimentary rocks, which is formed in destructive stage of Suban Agung volcanism. Its position in stratovolcano conceptual model is difficult to determine.

5. DISCUSSION

In borehole analysis, especially in altered rocks, it is challenging to determine rock structures, source of the volcanism, and the formation age. This is caused by the limitation of cutting chips recovered from the well and also the intensity of alteration process in the rock composition.

In contrast to the outcrop formation where its texture and structure can be observed directly, subsurface rock formations are more complicated to identify. If the outcrop formations are identified based on its geological genesis and source of volcanism, subsurface rock formations were identified in many cases, only based on its physical properties description. These physical properties including, color, composition, texture, hardness, grain size, rock fabric, resistivity, porosity, permeability, etc.

To have a precise data of formation geological age and stratigraphy, K-Ar and Ar-Ar age dating analysis should be done to the rock sample. Age dating were failed to perform in Hululais core sample, due to its massive intensity of alteration in the rock sample that makes error reading in its result.

To identify subsurface formation in Hululais, several borehole logs were created and displayed in this paper in Figure 14 and Figure 15. From these logs, some attribute minerals represent specific rock types. Each of these rock types delivers different geology information regarding to temperature and permeability of Hululais geothermal system.

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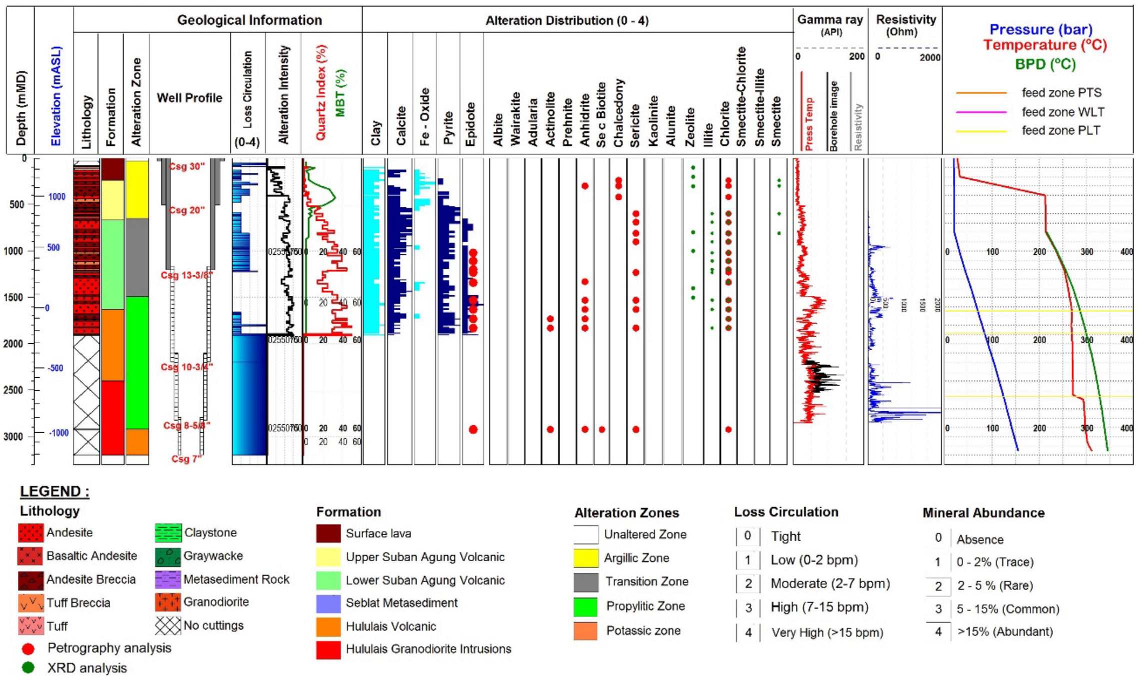

Figure 14 Borehole log sample from Hululais production well. Rock type characterization is determined from mineral distribution trend along the well. In loss circulation zone, mineral data were substitute by wireline logging data and was confirmed by core samples.

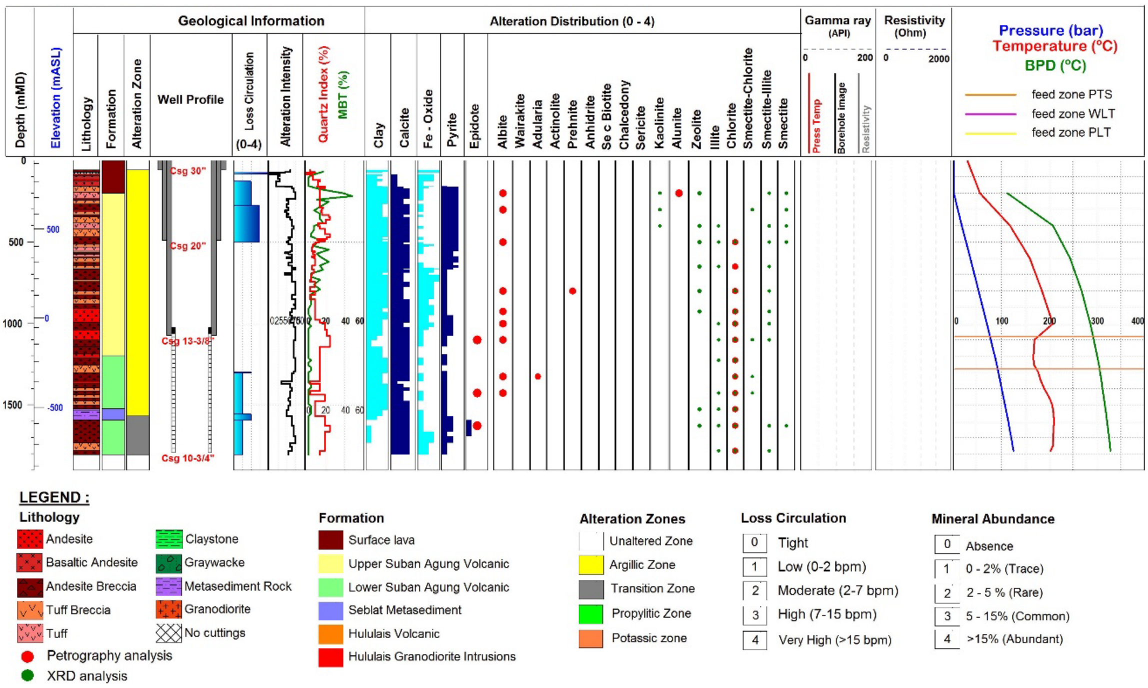

Figure 15: Borehole log sample from Hululais injection well in outflow zone. This image shows the depth of USAV Formation (yellow bar) correlate with the thickness of clay cap of the system which is hit by the wellbore.

In the geothermal system of Hululais, USAV plays a big role as the clay cap formation due its high content of reactive clay and its low permeability. This formation represents medial facies of a stratovolcano. LSAV associated with a transition zone of Hululais system. HV and HGI act as the reservoir rocks in the upflow area beneath Mt. Suban Agung. LSAV and HV formations have physical characteristics representative of a proximal zone. On the other hand, HGI with its intrusive rock facies represents the central stratovolcano. SM is the only subsurface rock formation with known relative age, being older than the volcanism in Hululais. Hence, SM is interpreted as a basement block fragment that was uplifted by the volcanic activities in this area. Its position in the stratovolcano model is not defined, since it is resembling the basement of Quaternary volcanism in Hululais.

5. CONCLUSIONS

Subsurface rock formation derived from borehole data can be characterized based on its physical properties. Every type of subsurface rock formation in Hululais suggests specific role in its geothermal system. There are 5 subsurface rock formation that can be used to build a geology model of the field.

These subsurface rock formations have typical characters in its rock facies that can give significant information to reconstruct stratigraphy of a stratovolcano model for a geothermal high terrain system as Hululais.

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