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Hydrothermal Alteration Mineralogy of Well HLS-C, Hululais Geothermal Field, Bengkulu, Indonesia

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ABSTRACT

Hululais geothermal prospect is located at Bengkulu Province, Indonesia. The preliminary geoscientific survey (geology, geochemistry and geophysics) were completed in 1994. PGE carried out advance MT resistivity survey to get better understanding of the Hululais geothermal system and to provide assistance for well targeting. Geologically, the main prospect is consisting of quarternary rock of breccia, andesite and tuff. The Hululais prospect is situated within the Semangko Fault System (SFS) that trends NW-SE and divided onto several fault segments. One of the exploration well namely Pad C was spudded in 2011. Generally, the wells encountered interstratified of tuff, breccia and andesite. The rocks may part of the Hululais and Bt. Resam products. The alteration minerals are smectite, chlorite, illite, serisite, zeolite, quartz, calcite, anhydrite, epidote, actinolite and biotite. There are 5 (five) alteration zonations identified, which are: smectite, mixed layer clay, chlorite, illite, and epidote-actinolite. The permeability evidence was marked by the deposition of alteration minerals in veins, such as quartz, pyrite, chlorite, wairakite, calcite and epidote. Those minerals coincide with the presence of circulation losses during drilling. Partial circulation losses started at depth of -490 masl, followed by the total circulation losses from -808 masl until the total depth at -811 masl.

1. INTRODUCTION

Hululais geothermal prospect is located at Bengkulu Province, Indonesia. The exploration survey activity of geology and geochemistry in the Hululais prospect were carried out in 1994 by Pertamina. Then, in 2007, the MT survey was done. In 2011, the resurvey geochemistry by collected fluid sample from surface manifestation was done. The appearance of geothermal manifestation, such as fumarole, solfatara and hot spring also the distribution of rock alteration providing the early indication of the geothermal resource in this area.

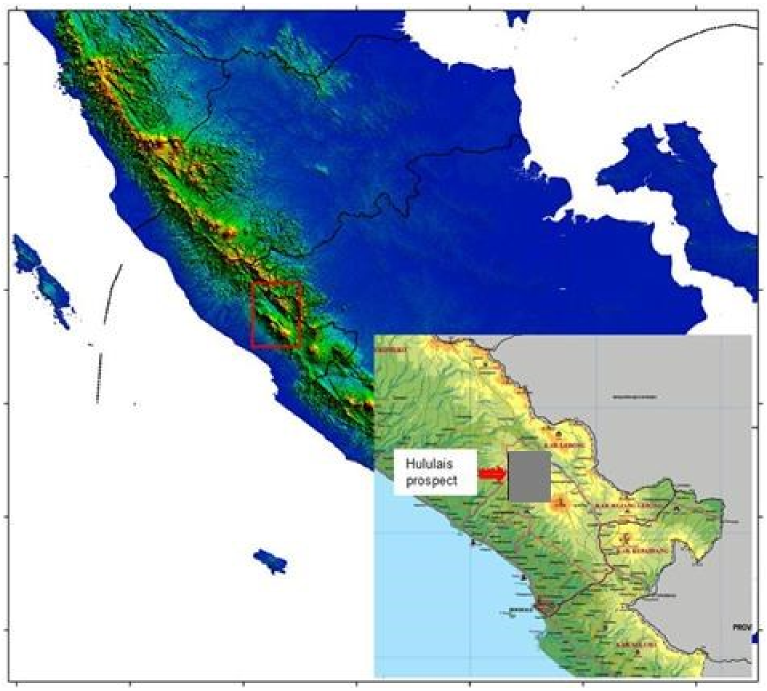

Figure 1. Location map of Hululais geothermal prospect.

Hululais geothermal prospect is situated at the western to southern side of Sumatran Fault Sytem (SFS) trending relatively NW-SE and composed of some fault segment system. The area is step-over system among Ketahun and Musi Segment which are same type with the dextral strike slip fault. The two segments movement were yielded depression that commonly called as pull apart basin. The depression is showed in the northeastern side of Hululais (Figure 2). This depression is bounded by the two main strike slip systems and normal faults with relatively perpendicular with the direction of the strike slip fault.

Three exploration wells have been drilled since 2011. The wells are encountered the two rock formation which are Hululais dan Bt. Resam product. The average depth of the wells drilled is about 2500 mMD to 3001 mMD. One of the wells in this prospect is HLS-C. The well is directional with depth of 3001 mMD. Subsurface hydrothermal alteration such as alteration mineralogy, alteration zone, feed zone, and paragenesis will be discussed in this paper.

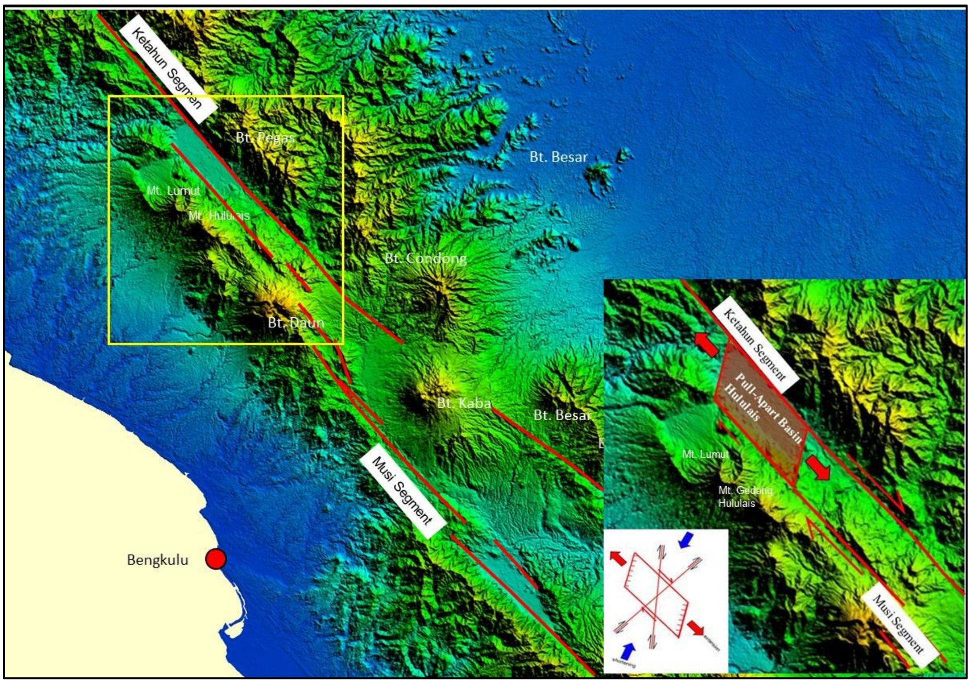

Figure 2. Geological structure model of Hululais shows that Hululais prospect is located in the sumatran fault system and relatively in the west side of the pull apart basin.

2. GEOLOGY

The geology and the formation of the Hululais geothermal prospect generally can be explained as follows. Budiarjo (1994) reported that there are three groups of formation; Tertiary marine sediment and igneous rocks, Pelistocene Igneous rocks and Holocene alluvium (Figure 3). The oldest formation was deposited Hulusimpang and Seblat Formation. The formations are composed of sandstone and turbidity mudstone with the volcanic product of Andesite Bt Cuguk dated 24 Ma. This product was followed by Bt Cogong Diorite which is the intrusion body that surrounded by younger volcanic product.

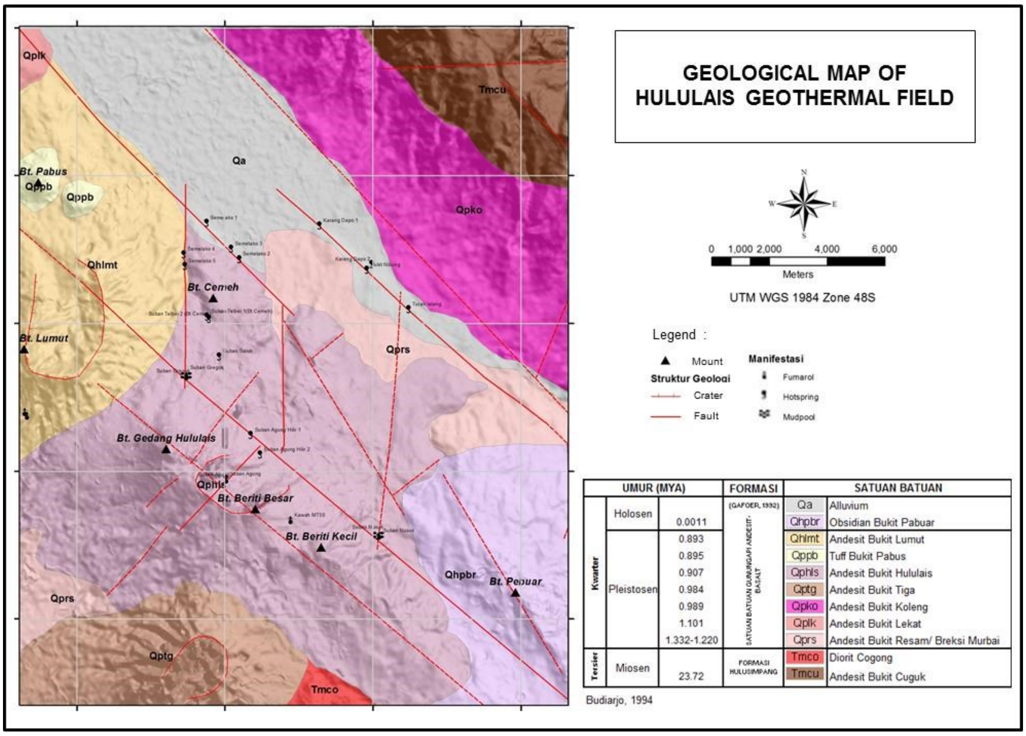

Figure 3. Geological map of Hululais Geothermal field.

In Pleistocene, the product was Bt Resam Andesite followed by Murbai Breccia dated 1.22 and 1.33 m.a respectively. These products were followed by Bt. Lekat andesite that part of the young volcanic complex of Bt. Lekat Basaltic andesite, Bt. Hululais and Bt. Beriti Kecil dated 1.1 to 0.89 Ma. The next series was the young unit from the Hululais graben that consists of andesite, breccia and tuff unconformable above Bt. Cuguk Andesite. The andesite lava and breccia from Bt. Tiga andesite dated 0.98 m.a were formed above Cogong diorite and unconformably overlied by Bt. Resam Andesite.

3. EXPLORATION ACTIVITY

The geology of Hululais Geothermal Prospect consists of the tertiary rock volcanic (andesite) and dioritic intrusion which is especially found in the mountains in the northeastern side of prospect. Therefore the main prospect area consists of the Quarternary volcanic formation which is composed of breccia, andesite and tuff.

The Hululais prospect is located in the western side of Semangko Fault system (Sumatran Fault) trending NW-SE and composed of some fault segmen systems. The area is step-over system among Ketahun Segment and Musi Segment that has same type dextral strike slip fault. The movement from the two fault systems yielded the depression or pulled apart basin (the eastern part of the Hululais and the Tambang Sawah Geothermal prospect (Figure 2). The depression is confined by the two main shear faults and the normal faults with the trend relatively perpendicular with the shear fault system.

The distribution of the reservoir permeability pattern in the Hululais prospect is essentially controlled by the graben system and the NW-SE fault system. These faults systems are parallel with the Sumatran fault system. The antitetic faults trend may also provide the permeability. The patterns structural trend is parallel with the N-S and NE-SW trend (Figure 3).

Based on the integrated data among the geological, geochemistry and geophysics, the Hululais geothermal system is belong to the hot water dominated system. The movement of hydrothermal fluid is mainly controlled by the N-S, NE-SW and NW-SE fault pattern with the top of the reservoir about 1000 m.

Three exploration wells were drilled in the location. The result of the three wells drilled in the location is used to give a better picture of the direction of the geothermal system, temperature distribution and permeability of prospect. The difference of the temperature distribution and the permeability of the wells is generally displayed through the drilling data such as mineral distribution, vertical distribution of the clay minerals, P and T profile and the well test.

The result of the drilling of well HLS-C gives evalution on the target of the geothermal potential and the concept of the drilling target trending around Suban Agung – Gedong Hululais. The lineament pattern of the mountain ridges that extending from Suban Nusuk, Suban Agung to Suban Gregok offers the priority target for developing the prospect.

4. BOREHOLE GEOLOGY

4.1 Lithology

Generally, the geology of the well is composed of interstratified rocks among andesite, basaltic andesite and breccia. In the depth ranging of near surface to about -85 masl, the formation is observed as dominantly breccia interstratified by andesite and few basaltic andesite. Below -85 masl, the formation consists of andesite, interstratified by breccia and small unit of basaltic andesite. These rock units are part of the Bt. Hululais formation in the upper part and Bt. Resam formation in the below part. Possible intrusion of microdiorite that was recognized from thin section below -795 masl maybe also important to provide the heat source nearby the exploration target.

4.2 Primary mineral

Based on the rock formation of the well, the rocks unit in the prospect is composed of interstratified rocks among andesite, basaltic andesite and breccia. Some depth of sample from thin section was recognized the appearance of microdiorite intrusion at depth below -795 masl.

Some alteration minerals were observed as replacement of primary rocks and minerals. Started at depth of 233 masl, chlorite commonly replaces glass in the andesite and breccia. Chlorite is found associated with epidote and sphene. Plagioclase is altered to quartz, calcite, smectite, pyrite and sphene observed at depth of 575 masl. Started at depth of 475 masl, plagioclase is replaced to epidote and at -390 m the ground mass of plagioclase is commonly replaced by actinolite. Pyroxene is altered to actinolite, quartz, pyrite and sphene at depth of -550 masl and at depth of about -785 masl pyroxene is replaced by epidote.

4.3 Hydrothermal alteration mineral

Interaction between primary rock minerals and geothermal fluids will produce hydrothermal alteration (Steiner, 1977). The formation of hydrothermal minerals is affected by temperature, pressure, parent rock types, reservoir permeability, fluid composition and duration of activity (Browne, 1978). In well HLS-C, the alteration minerals observed in the well are smectite, chlorite, illite, quartz, calcite, anhydrite, epidote, actinolite and biotite (Figure 4). The hydrothermal alteration mineralogy of the well is explained as follows:

Chlorite. Chlorite is found started at depth of 475 masl. Commonly replace clay, sfen, quartz, pyrite and calcite. Glass matrix from tuff breccia is

Quartz. Quartz is first observed at 674 masl. Commonly, it is found as replacement of glass matrix in tuff, feldspar and filling in the vein of andesite breccia.

Wairakite. Wairakite is found started at depth of -802 masl as replacement of mineral and filling in vein. It is coincide with the appearance of actinolite in the some depth.

Calcite. Calcite is found continuously started at shallow depth to total depth (TD). Calcite is commonly replacing phenocryst and plagioclase. Below 425 masl also associated with quartz, anhydrite and epidote and sometimes filling the vein such as at depth below -360 masl.

Anhydrite. Anhydrite is found uncontinously in the well started at 675 masl. Anhydrite is commonly found as replacement of phenocryst and sometimes filling vein and observed coincide with epidote.

Actinolite. Actinolite is found in the well intermittently below -327 masl. Reyes, 2000 reported that actinolite form at a temperature of above 280^{o}C.

Sphene/titanite. Sphene/titanite formed sporadically below near surface. It commonly distribute in the groundmass and replaces matrix. It appears continuously started at near surface to the bottom of the well.

Epidote. Epidote appears as replacement of plagioclase and as vein fillings. Epidote starts to form at temperatures above 250^{o}C (Browne, 1984). Epidote is first observed at 475 masl as vein fillings and found coincide with quartz. At depth of 375 masl, it appears as replacement of clay, anhydrite, and groundmass and associated with chlorite.

Biotite. Biotite is observed started at depth of -360 masl and shows brown to greenish brown, high pleochroic, yellow birefringence. Commonly found replaces phenocryst and plagioclase ground mass.

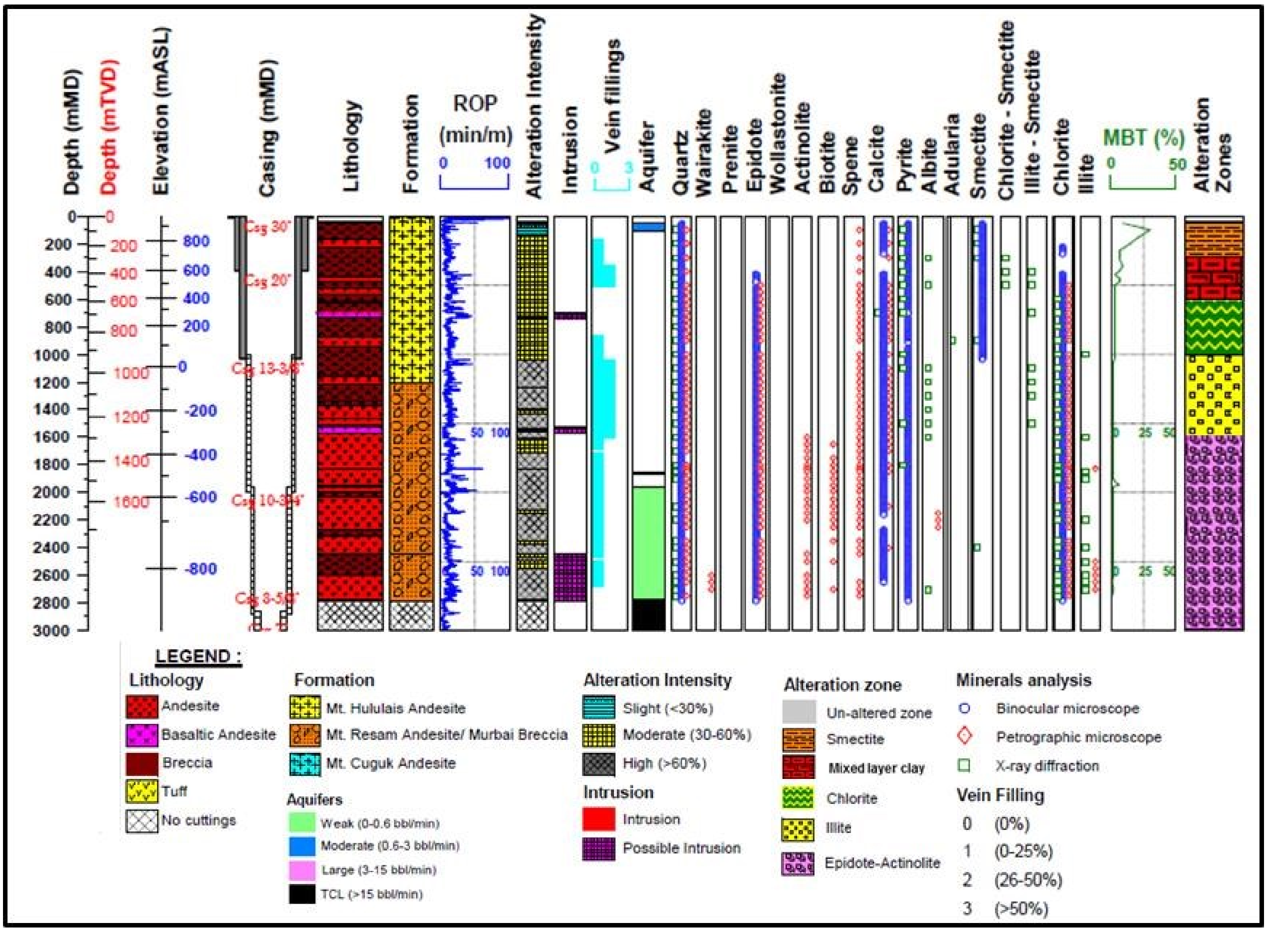

Figure 4. Composite log of HLS-C showing lithology, alteration mineral, and alteration zone.

4.4 Alteration zonation

Five alteration mineral zones were recognized based on clay minerals, index minerals and the mineral association. These zones are smectite, mixed layer clay, chlorite, illite, and epidote-actinolite. These five alteration minerals zones can be explained as follows:

Smectite zone. The zone is characterized by the appearance of the smectite minerals from near surface down to 675 masl. This zone is marked by the appearance of the quartz, calcite and smectite. The bottom of this zone is characterized by the appearance of the chlorite-smectite mineral.

Mixed layer clay zone. This zone ranges at depth between 675 to 375 masl. The upper part of the zone is marked by the appearance of chlorite-smectite and in the below part by chlorite. The zone is characterized by the appearance of quartz, albite, smectite, illite-smectite, chlorite-smectute, calcite, and epidote.

Chlorite zone. The zone is marked by the appearance of chlorite mineral in the upper part and illite in the bottom part. The zone ranges between 375 to 52 masl. The zone is presented by the illite-smectite, chlorite, quartz, epidote, calcite and pyrite.

Illite zone. The upper part of the zone is marked by the appearance of illite and actinolite in the below part. The zone is characterized by the appearance of illite, chlorite, quartz, epidote, calcite, albite and pyrite. The zone ranges between 52 to -327 masl

Actinolite-epidote zone. The zone interval is located about -327 to -808 masl. It is marked by the appearance of actinolite in the upper part. The bottom of the zone is observed by the total circulation loss. Actinolite was first found at depth of -327 masl. The zone is characterized by the appearance of illite, chlorite, quartz, epidote, actinolite, calcite and biotite. Biotite was found at depth of about -360 masl.

4.5 Feed zones

The indication of geothermal feed zones is observed by the presence of structural formations such as faults, fractures, and joints, lithological contacts, clasts and fragmented matrixes, and paleosols (Reyes, 2000). During drilling, the identification of the permeability is usually marked by the encountered of total circulation loss. The circulation loss is commonly associated with fracture, fault, joint, formation contact, rock intrusion, formation of breccia, and etc. It is also observed by the appearance of some alteration mineral that commonly fillings in the veins or vesicles such as quartz, adularia, wairakite, anhydrite, pyrite, calcite and epidote.

The permeability zone identification during drilling and after drilling is also important to identify the present of permeable zone, such as P and T survey, formation image, spinner survey, completion test, etc.

Common minerals in this well that found as fillings in veins are quartz, calcite, anhydrite, chlorite, epidote, wairakite, calcite and actinolite. These minerals are associated with andesite, breccia formation and microdiorite intrusions.

Based on the drilling result, the permeability indication in the well is marked by encountered partial circulation losses started from the depth of -490 masl and total circulation losses that started at depth of -808 masl. The target is interpreted to have correlation with the geological structure trending NW-SE and may also coincide with the appearance of microdiorite intrusion. These intrusions encountered the host rock of andesite and breccia and created some permeability as flow path for geothermal fluid.

4.6 Paragenesis

To understand the series of formation of mineral in geothermal system and to know the history of the field, the depositional mineral is important to recognize. The paragenesis in the well is commonly found as replacement and veins fillings. Successive stages of mineralisation process such as replacement or precipitation reflect the paleo-geothermal, present hydrothermal activities and environmental conditions where the water rock interaction occurs. Every field has different character and sequence. The sequences may vary from single to very complex series.

In well HLS-C, the paragenesis is analysed in some depth of cutting and core sample through thin section analysis. The alteration mineral depositional sequence of the well was observed as follows: Low temperature of smectite clay was found earlier and altered to chlorite and epidote at depth of 155 masl. Calcite mineral was altered to epidote as observed at 280 masl depth. Some depth of well also shows that wairakite altered to anhydrite and epidote at depth of -550 and -805 masl.

CONCLUSIONS

- The Hululais Geothermal systems is liquid dominated reservoir.
- The alteration minerals that observed in the well are smectite, mixed layer clay, chlorite, illite, pyrite, sphene/titanite, quartz, epidote, actinolite, biotite, wairakite, and anhydrite.
- The hydrothermal alteration zones are divided by five zones which are smectite zone near surface to 675 masl, the mixed layer clay zone occurs at 675 to 375 masl, chlorite occurs at 375 to 52 masl, Illite occurs at 52 to -327 masl, and actinolite-epidote occurs at -327 to -808 masl.
- The minerals indicating as good permeability in the well are quartz, chlorite, illite, calcite and epidote.

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