3D GEOLOGICAL MODELLING : AN ADVANCED METHOD TO BUILD GEOLOGICAL BASELINE MODEL IN HULULAIS GEOTHERMAL PROSPECT, BENGKULU, INDONESIA

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ABSTRACT

Pertamina Geothermal Energy (PGE) conducts exploration and exploitation stages of geothermal energy in 14 working areas owned by Pertamina throughout Indonesia, one of them is Hululais geothermal project in Bengkulu, Sumatra.

Exploration stage of Hululais geothermal project is proven by drilling campaign activities since 2010 in order to fulfill steam production and injection capacity of 2 x 55 Mwe units. The subsurface geological data obtained through the exploration wells is integrated into a geological model, using 3D geological modelling software.

The result of this analysis and modelling is a 3D geological model that integrates various data as a lithology model, alteration model, and temperature distribution model. 3D geological modelling is an important step in Hululais post drilling evaluation. With the increasing data acquired during both surface and subsurface exploration activities, this 3D geological model will evolve with the dynamism of the exploration and exploitation process in Hululais project.

This 3D geological model will be made as the baseline in the early phase of development of Hululais geothermal project. In the future, any changes that occur during its exploitation process can be monitored and recorded from time to time.

1. INTRODUCTION

1.1 Backgrounds

Hululais geothermal project located in Lebong district, 80 km north of Bengkulu city, Sumatra, Indonesia. It is located in The Great Sumatra Fault trending NW-SE as a graben system covered by quartenary volcanic products.

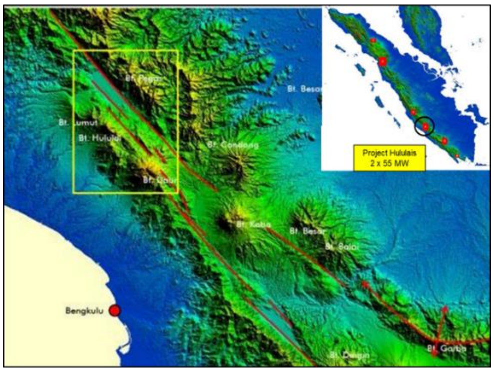


Figure 1: Hululais geothermal project is located in Bengkulu, Sumatra, Indonesia.

Pertamina Geothermal Energy (PGE) conducts drilling campaign since 2010 in Hululais geothermal prospect resulting in 11 geothermal deep wells (Total Depth up to 3300 mmd). It delivers subsurface data that is used to build an integrated geological model.

Along with its development, geological modelling can be done using a 3D modeling software that integrates all data in more detail, controlled, bound, calculated, and well visualized.

3D modelling work is done by collecting and integration of all data sets in a single software platform, to create an initial geological model as the baseline data of exploration condition prior to future exploitation activities.

1.2 Method

3D geological model of Hululais geothermal project obtained by using surface and subsurface data. The data are interpreted and analyzed systematically before registered in to 3D geological software as shown in the workflow diagram below.

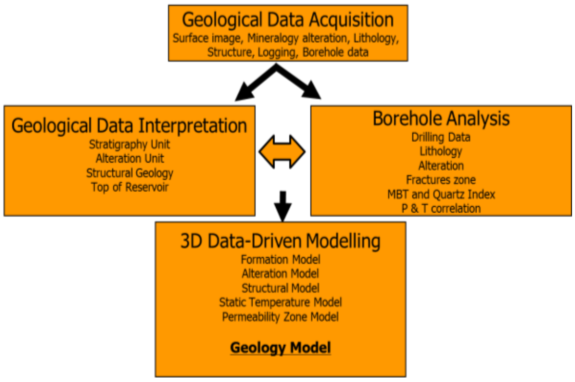


Figure 2: Hululais 3D Modelling Workflow Diagram

The 3D model derived from all of the geological data should be able to demonstrate initial formation/lithology model, alteration model, permeability zone, and static temperature distribution of the field.

2. GEOLOGICAL SETTING

Hululais field is a liquid dominant geothermal system situated in Sumatra Fault System (SFS). Overlap between the segmented SFS created a pull apart basin that covered by quaternary volcanic product.

Hululais geothermal system is controlled by two major structures directed NW-SE and NE-SW. Both of structures control the permeability and conduit hydrothermal fluid as a discharge on the thermal surface manifestation. This system has an upflow zone around Great Suban with outflow to the north towards the hot springs in Semelako area. (2016, Internal report).

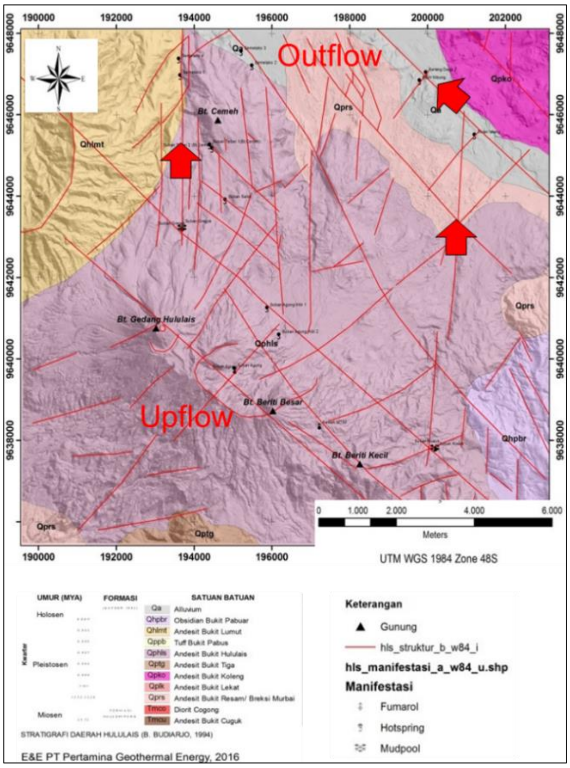


Figure 2: Geological map of Hululais geothermal project shows the upflow zone around Great Suban manifestation complex in Beriti hills with outflow to the north of prospect boundary. The surface manifestation controlled by NW-SE and NE-SW structures covered by quaternary volcanic product.

3. RESULT; 3D MODEL OF HULULAIS GEOTHERMAL PROSPECT

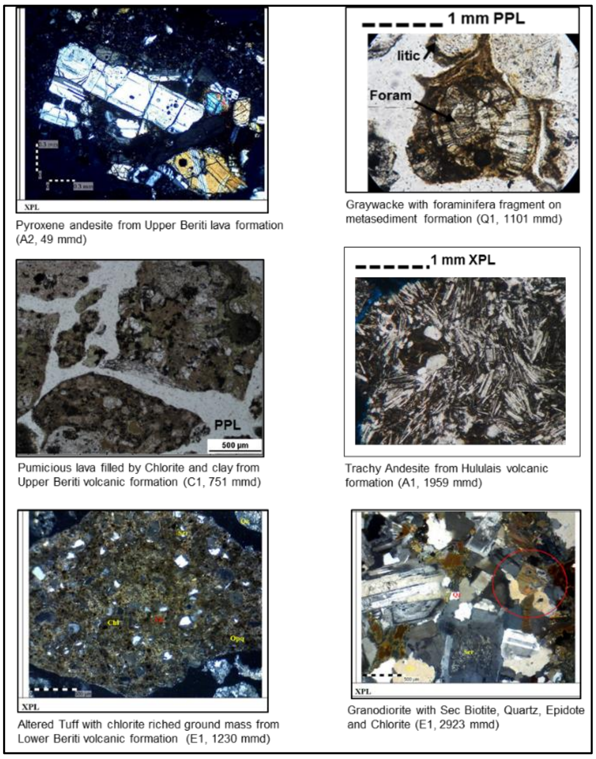
Hululais lithology 2D model was done in 2016 from rock cutting and cores in every borehole data well. There are at least three standard rock samples analysis that can be done to define the rock formation in Hululais for initial subsurface modelling; they are petrography, X-ray diffractometry and fluid inclusion analysis.

3D model of Hululais derived from borehole data shows 6 types of lithology formation. Sequentially from older to younger is; Granodiorite dome (G), Hululais volcanic (THv), Metasediment (TMs), Lower Beriti volcanic (QLBv), Upper Beriti volcanic (QUBv), and Upper Beriti Lava (QUBl) which is exposed into the surface.

Granodiorite dome (G) consists of phaneritic Granodiorite rock type. The intrusion determined from core data in total loss zone condition and also from borehole image data. It is fractured, brittle, filled with Quartz - Epidote veins and highly altered. Granodiorite dome formation is an essential part of reservoir rock in Hululais. Hululais volcanic (THv) formation characterized by its trachyte textures in andesite breccia composition.

Metasediment (TMs) identified as a metasedimentary rock originated from mixed volcaniclastic materials of vitric crystal and dark colored sedimentary rock classified as graywacke and wackestone. Its distinctive character as a key bed that is thickening in the western part of Hululais field.

Lower Beriti (QLBv) and Upper Beriti (QUBv) volcanic formation contain intercalations of pyroxene andesite and andesite breccia in clay cap zone. Upper Beriti lava (QUBl) exposed to the surface in Beriti and Gedang hills as andesite lava with sheeting joint structure, indicated in borehole data as shallow total loss zone (Nusantara, 2016).



Pyroxene andesite from Upper Beriti lava formation (A2, 49 mmd)

Graywacke with foraminifera fragment on metasediment formation (Q1, 1101 mmd)

Pumicious lava filled by Chlorite and clay from Upper Beriti volcanic formation (C1, 751 mmd)

Trachy Andesite from Hululais volcanic formation (A1, 1959 mmd)

Altered Tuff with chlorite riched ground mass from Lower Beriti volcanic formation (E1, 1230 mmd)

Granodiorite with Sec Biotite, Quartz, Epidote and Chlorite (E1, 2923 mmd)

Figure 6: Thin section microphotograph of 6 lithology formations derived from core and cutting samples in Hululais geothermal wells.

Formasi	Depth (masl)		Characteristics	Drilling Condition
Upper Beriti Lava	surface	850	Pyroxene Andesite, dark colored, sheeting joint structure in the surface, quartz and pyrite rich vein. Fresh. Lava.	Partial to Total Loss Circulation in shallow depth.
Upper Beriti volcanic	surface	850	Pyroxene andesite, red colored, oxidized, pyrite rich vein, pumicious, tuff content in ground mass, washed out. Index of alteration 0-0.25 IA.	Partial to Total Loss Circulation in shallow depth. MBT ranges 12-20%.
Lower Beriti volcanic	850	-250	Altered andesite breccia, porfyr andesite, Plagioclase rich, glass and aphanitic ground mass. Chlorite rich. Index of alteration 0.3-0.5 IA.	Reactive Clay, MBT ranges 18-40%. Bit Balling hazard.
Metasediment	0	-250	Wackestone, graywacke, foraminifera fossil content (N14-N18) middle-upper Miosen. Dark colored, brittle, silica rich vein. Index of alteration 0 IA.	Partial loss circulation, discontinuous trace Epidote zone ranges 1-3%.
Hululais volcanic	-250	-750	Altered tuff breccia with Trachy andesite fragmen, volcanic glass as ground mass, Index of alteration 0.5-1 IA.	Reservoir zone, Total loss circulation, silicified cutting. Continuous epidote zone 5-20% Epidote content.
Granodiorite Dome	-750	-1200	Granodiorite, phaneritic, equigranular, coarse sized Plagioklas and primary Quartz content, primary Biotite, Hornblende rich. Fractured, brittle, secondary Quartz rich vein. Massive. Interpreted as a heat source of Hululais system.	Total loss circulation, drilling temperature increased significantly, Rate ofdrilling penetration dropped.

Figure 4: Lithology formation defined from rock characterization and its distribution in Hululais deep geothermal wells.

Borehole image data are provided in several total loss zones to be interpreted and correlated to build a lithology formation model. The contact between each formation are visible in Gamma Ray and Resisitivity log. These data contibutues to lithology and fractures identification along the wells.

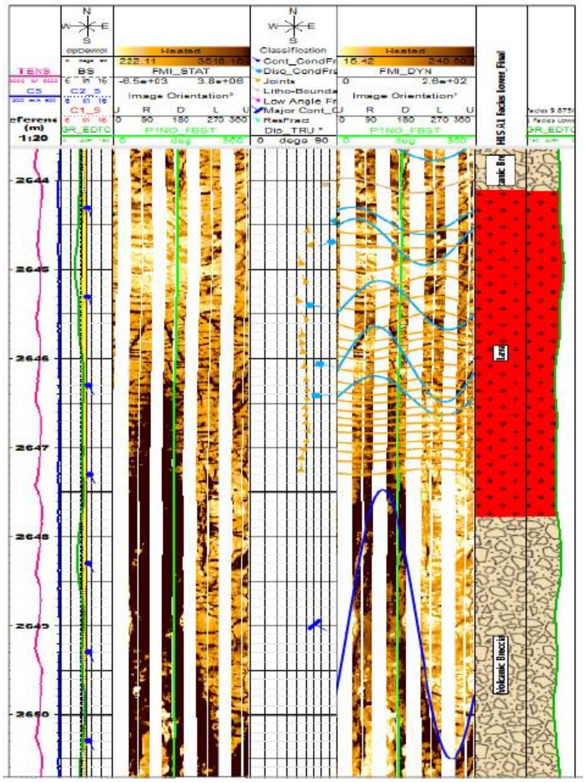


Figure 5: Borehole image data shows contrast resistivity in well A1 at 2646 mmd indicating lithology contact boundary between lava and volcanic breccia. The picture also shows a significant major fault at 2646 mmd as one of the potential production feed zone.

Lithology formation model generated from integrated borehole petrology and borehole image log analysis provides information about lithology type and formation and its subsurface distribution to be modelled as geological static model as below.

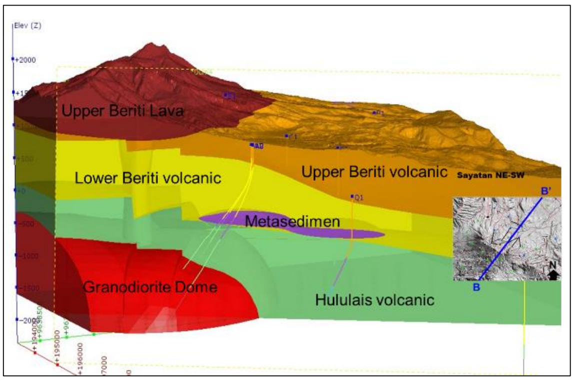


Figure 6: 3D model of lithology formation Hululais geothermal system sliced northeast – southwest.

Geology structures from the surface are correlated with permeability data along the well to provide subsurface structural model. The Suban Agung fault are strongly proven in borehole data as in borehole image, drilling break parameter, and geophysics log data.

Permeability distribution in Hululais production feed zone controlled by Suban Agung fault. Suban Agung fault penetrate from the surface deeper into Granodiorite body as a conduit of neutral thermal fluid from the reservoir. Therefore, Suban agung fault are the most prominent target in Hululais production wells up until now.

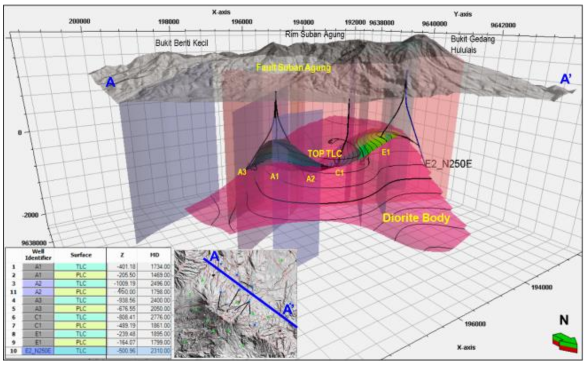


Figure 7: Permeability distribution in Hululais geothermal system controlled by Suban Agung fault trending NW-SE in Beriti hill as the upflow zone.

Hydrothermal alteration zone in Hululais geothermal prospect defined from clay content and hydrothermal mineral characterization. The alteration zones in Hululais correspond with measured temperature data obtained in each well. Based on mineral geothermometer, hydrothermal alteration in Hululais are divided into 4 zones.

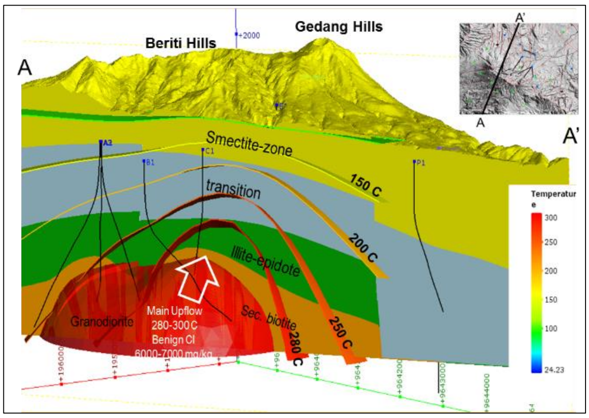


Figure 8: 3D alteration model overlays with Temperature model obtained from clay analysis and well temperature measurement in Hululais geothermal prospect.

Smectite zone identified from smectite riched clay distribution. It is compatible with Methylene Blue Test (MBT) data acquisition during drilling ranging from 12-40% in Smectite to transition layer. Calcite, Quartz, Pyrite and Fe Oxide is abundant. This zone interpreted as a low temperature clay cap of the system.

Illite – Epidote zone begins when Smectite disappears in reservoir layer. This zone is up doming near Beriti hill which is interpreted as an upflow zone.

Secondary Biotite encountered in very high reservoir zone is related to Granodiorite dome beneath Beriti hills as a heat source. The static temperature in this zone reaches more than 280 ^oC. Fluid inclusion (FI) analysis conducted in some rock vein samples in this zone shows average FI homogenization temperature (Th) ranges from 230-285 ^oC (Nusantara, 2016).

4. CONCLUSION

3D subsurface model driven from geological data interpretation and borehole analysis in Hululais geothermal prospect is a substantial part in post drilling evaluation activity phase or pre-production phase of the field. The model will be made as baseline model in the next field development scenario. The model also will be referenced in the next well planning and well targeting in prospect future development.

The model simply points out geothermal system static condition in Hululais prospect area. It shows that the main upflow prospect boundary lays beneath Beriti hill with Suban Agung fault as the most reliable drilling target. Reservoir zone belongs to Illite - Epidote and Secondary Biotite zone in fractured Granodiorite and Hululais volcanic formation.

The model will change with the increasing data obtained in the future development activities. As a baseline model, it will have a significant value in the history of Hululais field development. To prevent a misleading geological framework, the data acquisition phase should be done thoroughly since the beginning of the modelling process.

In a more advanced multidisciplinary approach to obtain optimum benefit of this model, Hululais 3D model should be updated and integrated with other geoscience and reservoir data.

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