Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geology of Lumut Balai Geothermal Field

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Keywords: Geothermal, Lumut Balai, Geological Model, 3D Modelling.

ABSTRACT

Lumut Balai Geothermal Field is operated by Pertamina Geothermal Energy, located in Penindaian Village, Muara Enim Regency, South Sumatra Province. Research in Lumut Balai has been conducted since 1993, exploration wells were drilled in 2008, followed by development wells, reaching a total of 29 wells. The geological model should provide ample information and interpretation of subsurface geological conditions such as the lithology distribution, alteration distribution, reservoir zone, heat source, and permeability.

A combination of surface and subsurface data are required in order to construct a geological model. On the surface, outcrops provide information regarding lithology, alteration type, and geological structures. Whereas manifestations provide fluid geochemistry data. Subsurface data are acquired from rock cuttings and core samples (which are then further analyzed through petrographic analysis and XRD analysis), drilling parameter, and borehole image logging.

The methods above result in an interpretation of Lumut Balai geological model. Lumut Balai is a geothermal system located within the Lumut Balai caldera. It's composed of andesite, andesite breccia, basaltic andesite, basalt, limestone, metasediment, tuff, and tuff breccia, which are all altered to certain extents. There are five stratigraphic units, starting from the oldest to youngest they are Tertiary Basement Unit, Pre-Old Lumut Unit, Pre-Caldera Unit, Caldera Unit, and Post-Caldera Unit. Alteration zones in Lumut Balai can be classified into smectite+chlorite zone, silica+chlorite zone, and chlorite+epidote zone. Productive faults in Lumut Balai are Air Ringkih Fault with NE-SW trend, Air Udangan Fault trending NE-SW, Old Lumut Caldera, and Air Gemuha Besar which trend N-S.

1. INTRODUCTION

Lumut Balai is located approximately 292 km southwest of Palembang (Figure 1), around 8 hours of driving from the Palembang airport. Regionally, Lumut Balai lies 60 km east of the Komering Segment, eastern side of Sumatra fault. The volcanism in Lumut Balai is closely related to the Sumatra Fault System's activity. Lumut Balai geothermal field itself is located within Old Lumut Caldera, approximately 9 km in diameter.

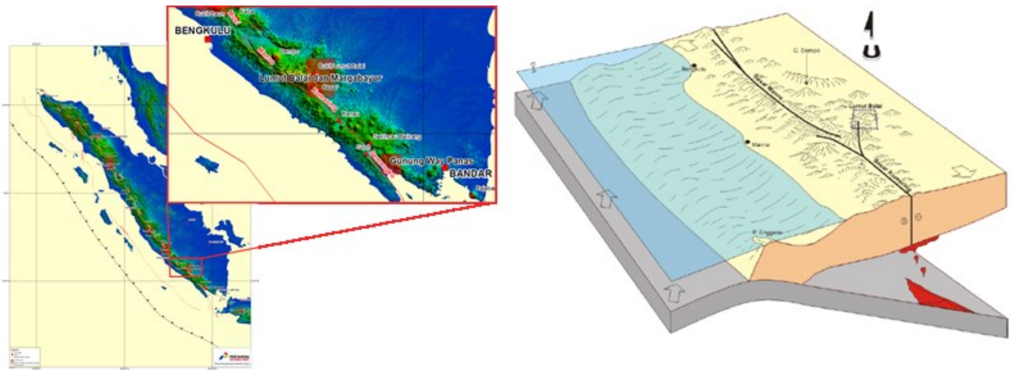

Figure 1: Lumut Balai Geothermal Field's Location (modified from Sieh, K. and D. Natawidjaja, 2000). Lumut Balai is situated approximately 60 km east of Komering Segment of the Great Sumatra Fault.

Geoscientific research in Lumut Balai has been ongoing since 1993. The first exploration wells were drilled in 2008, currently PGE has drilled a total of 29 wells in Lumut Balai and is planning to carry out CoD with 2 x 55 Mwe capacity.

2. DATA AND METHOD

This study combines surface and subsurface data for interpreting the geology Lumut Balai.

Surface data used in this research includes LiDAR and IFSAR image analysis. These images are then analysed through Aspect, Slope, and Hillshade method. The Aspect analysis will show the dipping direction of slope, which are classified by colours in order to efficiently separate different slopes. Meanwhile Slope analysis uses DEM data to map out different gradient colours based on slope inclination, starting from green (0°) to red (>55°). Lastly, Hillshade analysis is carried out in order to know the true topographical relief and distinctly differentiate hills and valleys.

Geological mapping was also done to better understand the surface geology of Lumut Balai. This covers outcrop observation and measurements from Lumut Balai field. The data from geological mapping are compiled into a Lumut Balai Composite Log and any joint or slicken line trend measurement are plotted onto Lumut Balai structure map. The hand specimens from the outcrops are then taken to the laboratory to be further analysed through XRD and petrography analysis.

Subsurface data used in this research are acquired from cuttings, cores, drilling parameters such as loss circulation zones, and borehole image logging. XRD and petrographic analyses of cuttings and cores from Lumut Balai drilling campaign, enables a better understanding of the subsurface lithologies and alteration zones. Drilling parameter in the form of loss circulation zones and borehole image logs from each wells, could confirm the present of faults and lineaments inferred from surface data. Loss circulation zones provides ample information regarding the permeable zones created by major faults or fracture zones in the subsurface, while borehole image logs could give information concerning the conductive zones in the well to be interpreted as strike-dip trends of subsurface faults and fractures to be plotted on the Lumut Balai structure map and to be correlated with the faults and fractures found on the surface.

The surface and subsurface data are then compiled and inputted to 3D modelling software to construct Lumut Balai's 3D geological model.

3. RESULT AND DISCUSSION

3.1 LiDAR and IFSAR Analysis

3.1.1 Aspect Analysis

From the Aspect analysis (Figure 2) a circular feature could be inferred, which is thought to be the radial structure of Lumut Balai's caldera, known as Old Lumut Caldera.

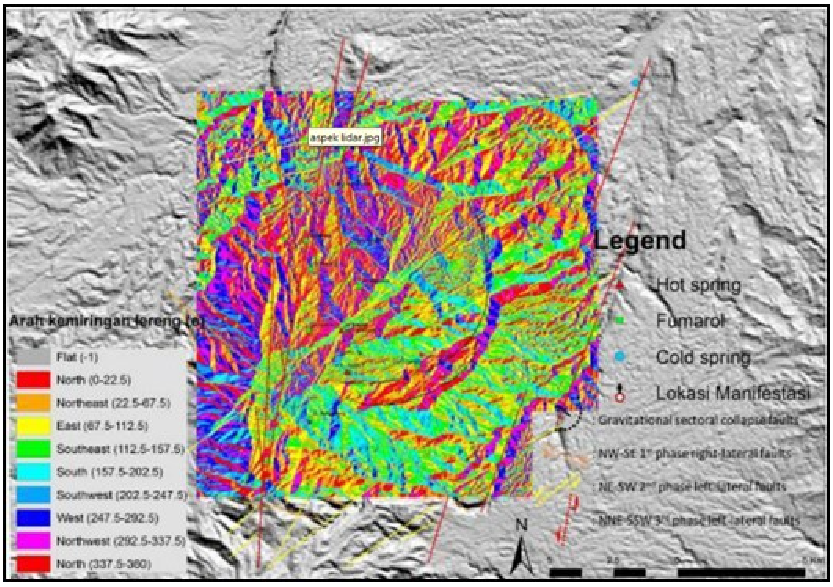

Figure 2: Aspect analysis of Lumut Balai's IFSAR and LiDAR images.

3.1.2 Slope Analysis

From the Slope analysis (Figure 3), a variation of slope inclination could be seen, where the steepest slopes could be found on the center of the caldera and on the caldera's rim as well. It also shows a radial distribution of steep slopes.

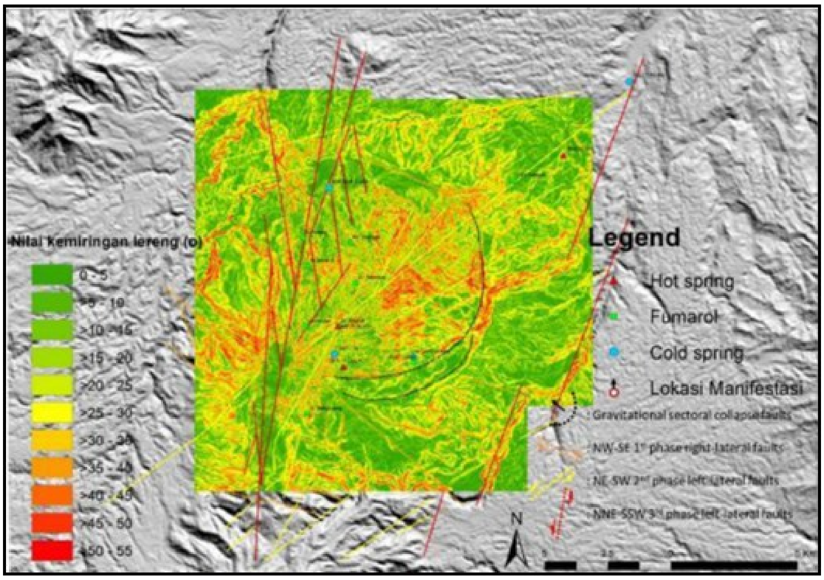

Figure 3: Slope analysis of Lumut Balai's IFSAR and LiDAR images.

3.1.3 Hillshade Analysis

The presence of Old Lumut Caldera and several other lineaments could be distinguished through hillshade analysis. There are several main geological structures that could be identified through hillshade analysis (Figure 4) such as Old Lumut Caldera, Gemuha Besar Fault trending N-S, Air Ringkih Fault with NE-SW trend, Udangan Fault trending NE-SW, Fault Patahan trends NW-SE, Ogan Kanan Fault trending NE-SW, and Tanjung Tiga Fault trending NW-SE.

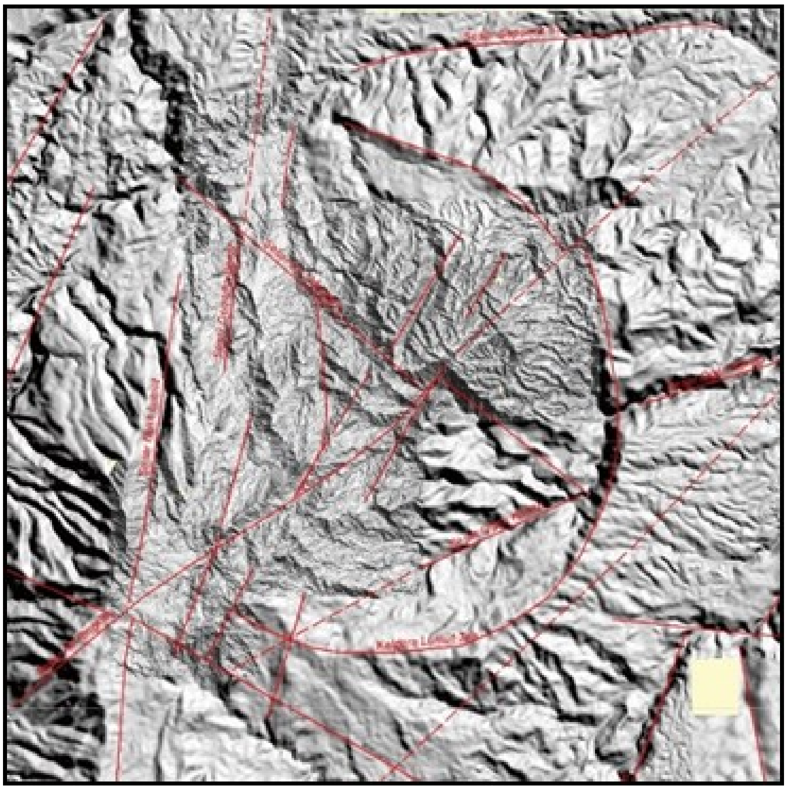

Figure 4: Hillshade analysis of Lumut Balai's IFSAR and LiDAR images.

3.2 Geological Mapping

From the geological mapping, it is discovered that Lumut Balai surface lithologies are composed of andesite, andesite breccia, basaltic andesite, basalt, limestone, metasediment, tuff, and tuff breccia, which are all altered to certain extents.

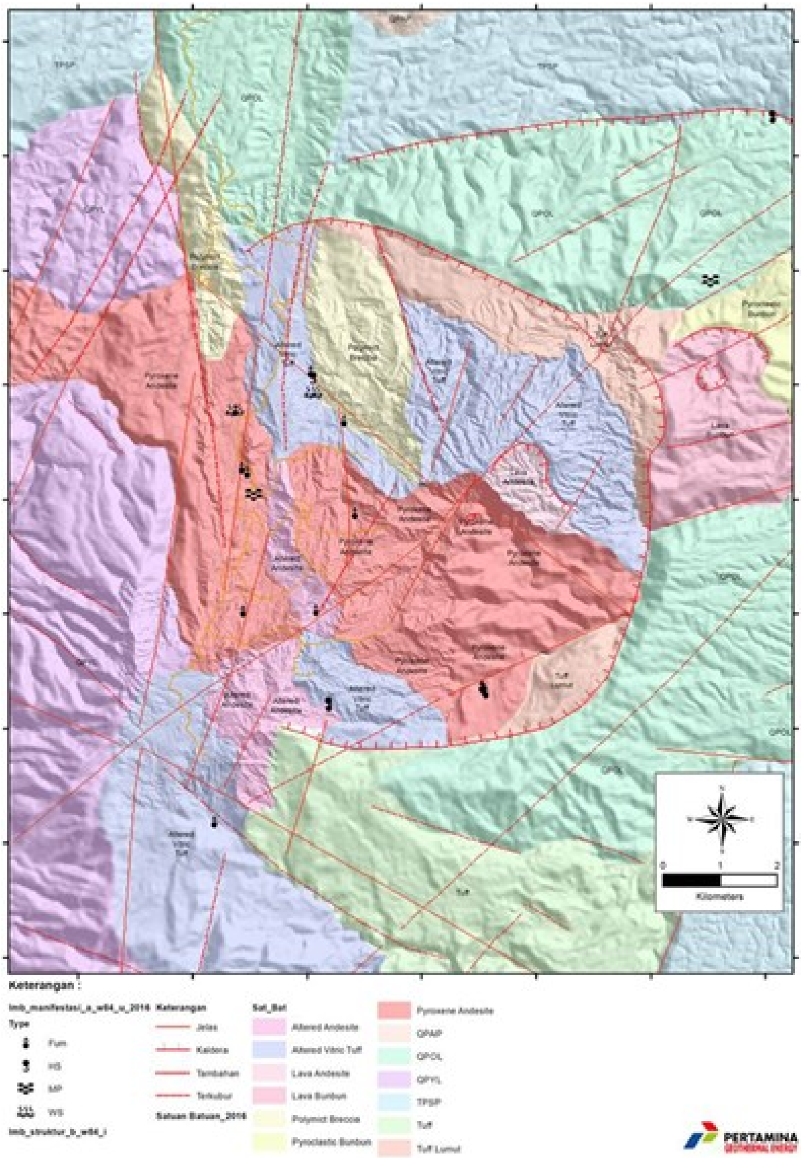

Figure 5: Geological map of Lumut Balai.

A wholesome Lumut Balai composite log (Figure 6) was constructed from surface mapping data, which includes information concerning lithologies, joints, faults, and alteration distribution. Trends and rosette diagram from the fault and joints measurements are also plotted onto Lumut Balai Structure Map.


PERTAMINA
GEOTHERMAL ENERGY
MEASURED SECTION LOG
LUMUT BALAI
EXPLORATION & EXPLOITATION DIVISION
EXPLORATION & DEVELOPMENT DIRECTORATE
PT. PERTAMINA GEOTHERMAL ENERGY
Elevation (mASL)
Age
Formation
Volcanostratigraphy
Lithology
Grainsize
Fine Tuff
Coarse Tuff
Lapilli
Bomb/Block
Alteration
Vein Type
Alteration Zone
Alteration Intensity
Hardness
Fracture Intensity
Weathering Intensity
Alteration Minerals
Quartz
Clay
Smectite
Kaolinite
Chlorite
Illite
Pyrophillite
Calcite
Iron Oxide
Zeolite
Description
Photo
Structural Trend
Facies
1800
1700
1600
1500
1400

Figure 6: Lumut Balai Composite Log.

Figure 7: Outcrop documentations, slicken line, and joint measurements.

3.3 Subsurface Data

3.3.1 Lumut Balai Subsurface Geology

From cutting and core data, Lumut Balai rock unit can be divided into five stratigraphic units, starting from the oldest to youngest are Tertiary Basement Unit, Pre-Old Lumut Unit, Pre-Caldera Unit, Caldera Unit, and Post-Caldera Unit (Figure 8).

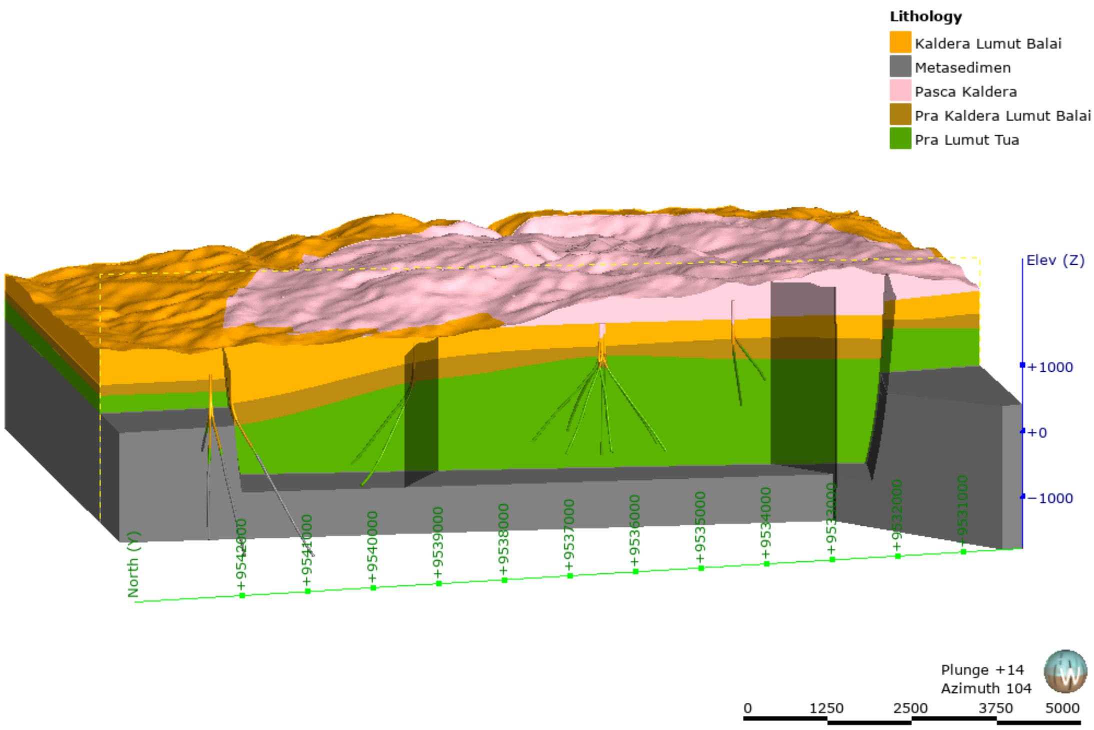

Figure 8: 3D geology model of Lumut Balai geothermal field

The Tertiary Basement Unit is composed mainly of metasediment lithology, while this unit was not found on the wells within the Old Lumut Caldera, Tertiary Basement Unit is found more commonly in the wells outside of Old Lumut Caldera, such as in the B, C, 18.R and 19.R clusters starting from elevation ±500 mASL.

Figure 9: Metasediment found in thin section, slight foliation and grains that has been slightly deformed.

Pre-Old Lumut Unit consists of tuff breccia with foraminifera fossil content. Inside the caldera rim, Pre-Caldera Unit could be found from 500 mASL to -1000 mASL, while outside of the Old Lumut Caldera, it could be found on elevation as shallow as 1000 mASL to 500 mASL.

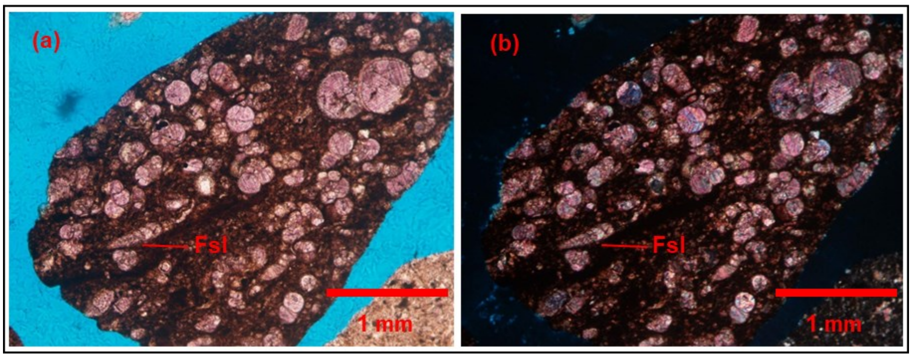

Figure 10: Foraminifera fossil fragments in Pre-Old Lumut Unit.

Pre-Caldera Unit is composed of tuff breccia with lithic andesite fragments, crystal tuff, and andesite lava. Within the caldera, this unit could be found at 1000 mASL to 0 mASL, and around 1200 mASL to 1000 mASL outside of the caldera rim.

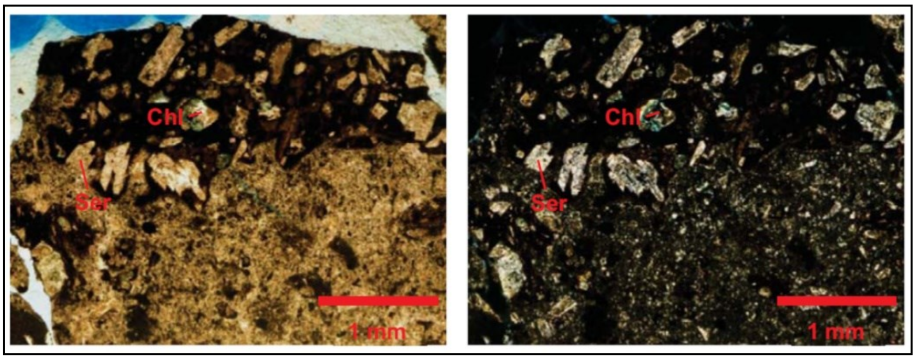

Figure 11: Andesite fragments within tuff in Pre-Caldera Unit.

Caldera Unit consist of tuff breccia with lithic fragments, crystal tuff, and pumice. This unit could be found at 1200 mASL to 500 mASL inside the caldera, and approximately 1500 mASL to 1200 mASL outside of Old Lumut Caldera.

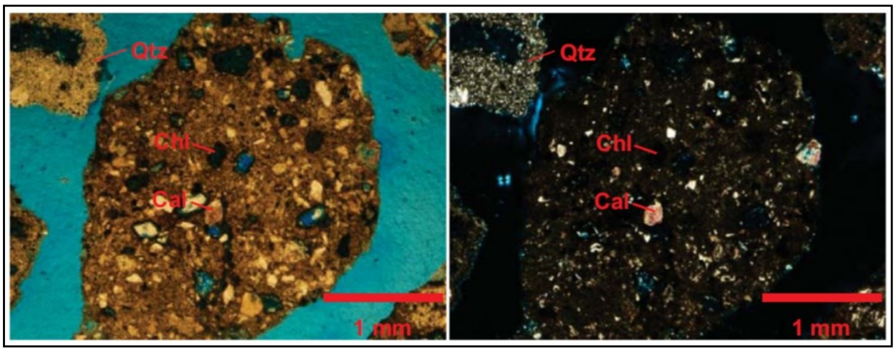

Figure 12: Pumice in thin section from Caldera Unit

Post-Caldera Unit is constructed by intercalation of tuff breccia and andesite lava. This unit could be found to the southwest of the field with 500 – 1000 meters thick.

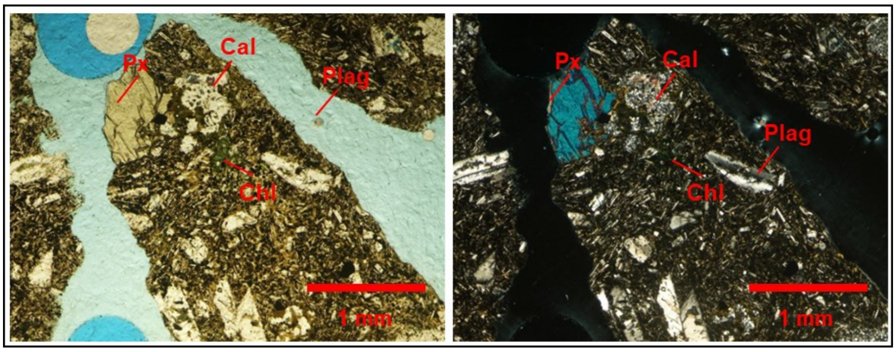

Figure 13: Andesite from Post-Caldera Unit

3.4 Lumut Balai Alteration Zones

After compiling alteration mineral assemblage from petrographical and XRD analyses of Lumut Balai cuttings and cores it could be interpreted that there are three different alteration zones in Lumut Balai; smectite+chlorite zone, silica+chlorite zone, and chlorite+epidote zone (Figure 14). The smectite+chlorite zone could be found from elevation 2000 mASL to 1000 mASL, and are the thickest outside of the caldera's rim. This zone is dominated by clay minerals in the form of smectite and chlorite. While the silica+chlorite zone is present from elevation ranging from 1000 mASL to 0 mASL. This zone is differentiated by the abundance of chlorite and quartz. Lastly, the chlorite+epidote zone appeared starting from elevation of 500 mASL. This zone is contrasted by the dominance of chlorite and epidote, while several other high temperature minerals such as garnet, actinolite, and prehnite were also found in several wells, especially the wells on the western part of the field along the Air Gemuha Besar Fault. This zone thins out at the outside of the caldera, insinuating that the highest temperature zones are concentrated within the Old Lumut Caldera

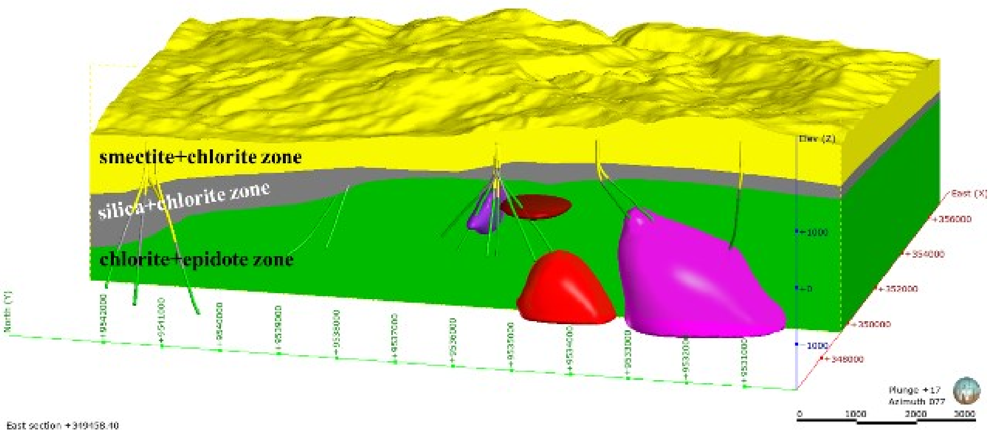

Figure 14: 3D alteration model of Lumut Balai geothermal field

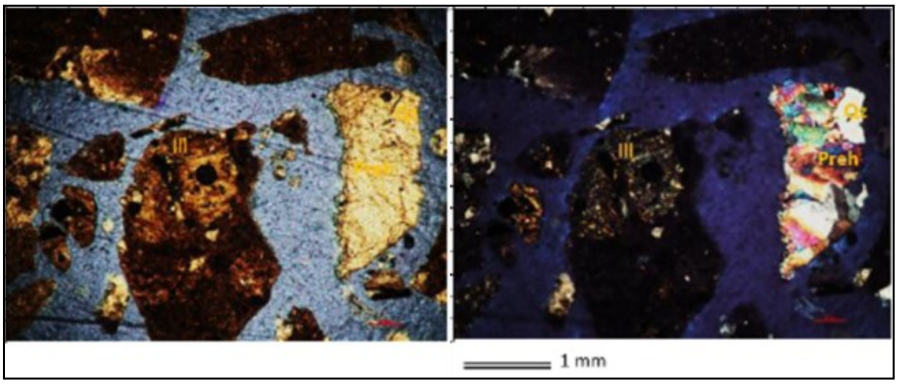

Figure 15: Prehnite vein in cutting sample from one of Lumut Balai's wells

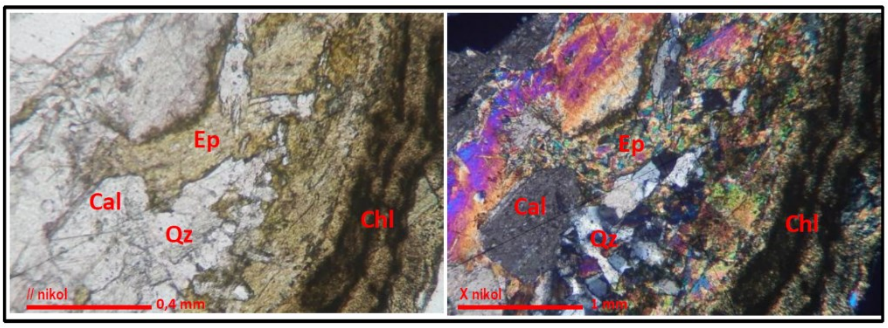

Figure 16: Epidote, calcite, quartz, and chlorite vein in one of Lumut Balai's wells

3.5 Lumut Balai Subsurface Faults and Fractures

The inferred faults have already been established from surface data, namely the Old Lumut Caldera, Gemuha Besar Fault trending N-S, Air Ringkih Fault with NE-SW trend, Udangan Fault trending NE-SW, Fault Patahan trends NW-SE, Ogan Kanan Fault trending NE-SW, and Tanjung Tiga Fault trending NW-SE.

These inferred faults could be confirmed or proven by the subsurface data, such as borehole image logging, and presence of total loss circulation zones in each wells (Figure 17), which gives information regarding subsurface faults zones and fracture zones. Borehole image logs (Figure 18) also provides ample information regarding the trends of the subsurface faults and fractures, enabling a correlation between the subsurface faults and fractures with the inferred faults and lineaments on the surface (Figure 20).

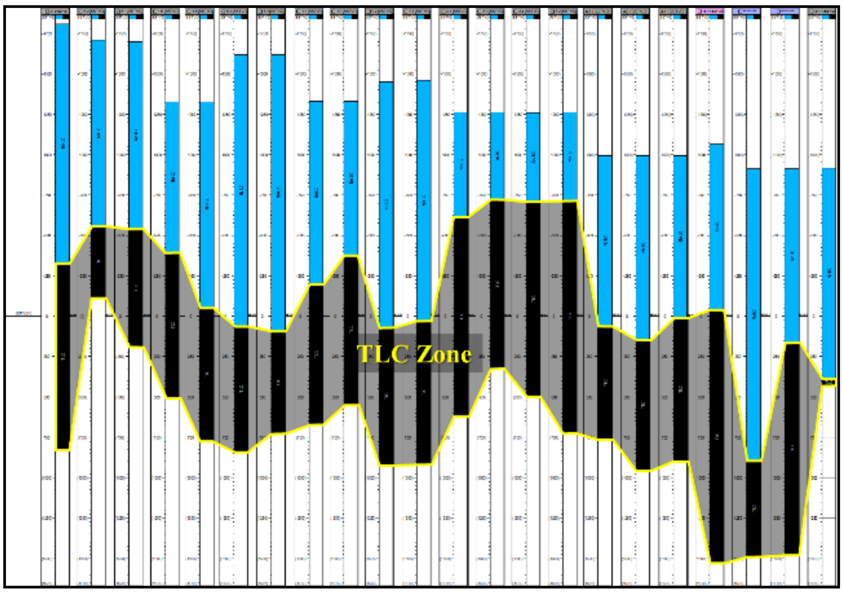

Figure 17: Correlation of total loss circulation zones in Lumut Balai’s wells

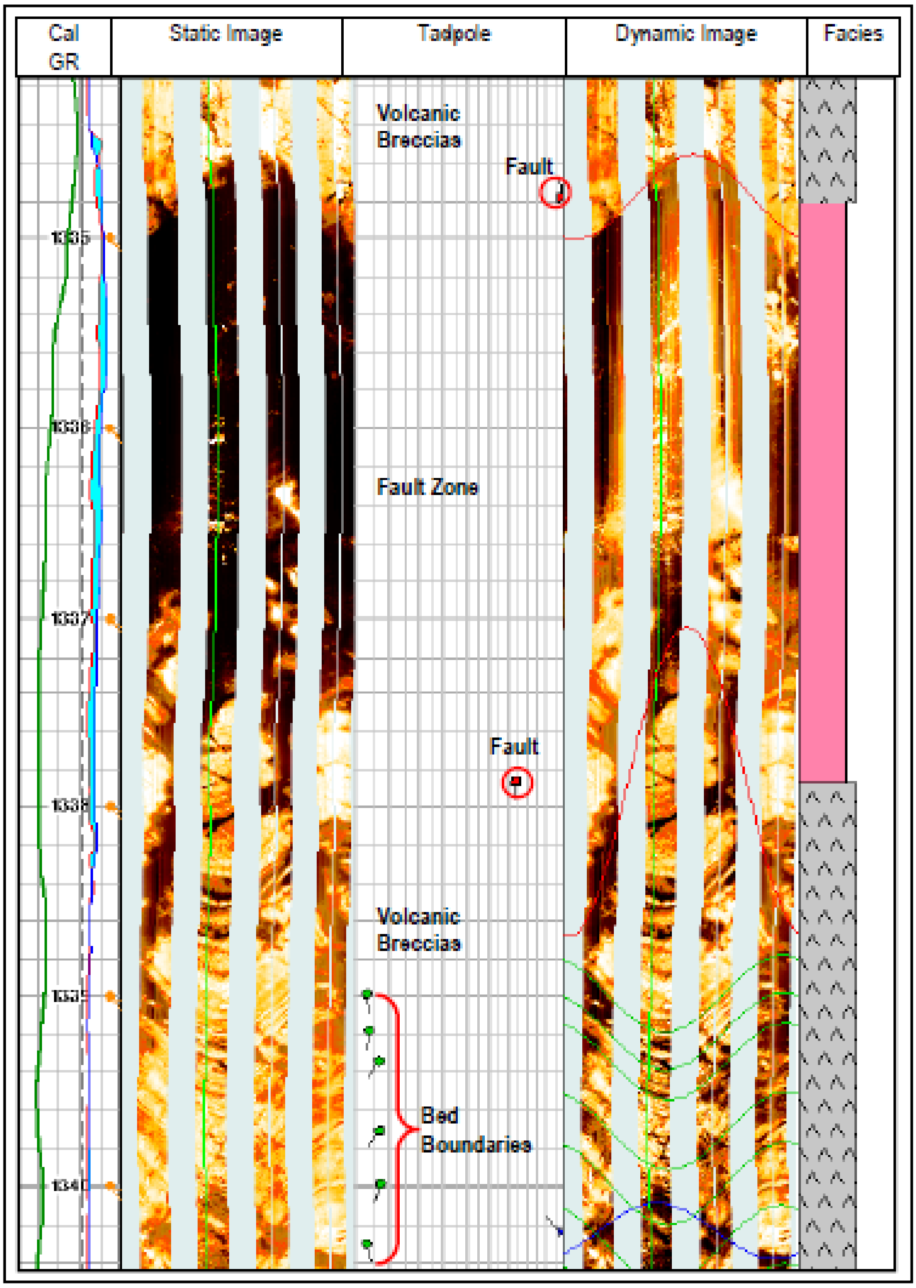

Figure 18: Borehole image data shows fault zone in volcanic breccia lithology in well LMB-5, the fault appeared black meaning the fault is conductive.

A correlation of surface and subsurface data results in Lumut Balai Fault Assessment (Figure 20). From the fault assessment it could be concluded that the productive faults in Lumut Balai are Air Ringkih Fault, Air Udangan Fault, Old Lumut Caldera, and Air Gemuha Besar.

Air Ringkih Fault is proven through field observation, drilling activities in the form of drilling break and borehole image logging, while from geochemical aspect Air Ringkih Fault provides a conduit for Air Ringkih and Bunbun manifestations, and is proven in geophysics' gravity measurements. Meanwhile, Air Udangan Fault is proven by field measurements and lithological offsets, gravity measurements, also by drilling parameters in Cluster A wells. Air Udangan Fault is the main permeability path for Air Patahan and Air Udangan manifestations. Old Lumut Caldera is proven by drilling activities in cluster 19.R, gravity data, and lithological offsets found in the field. Lastly, Gemuha Besar Fault is proven by field measurements, lithological offsets, loss circulation zones in Cluster A, gravity data, and by the presence of Gemuha Besar and Air Abang manifestations.

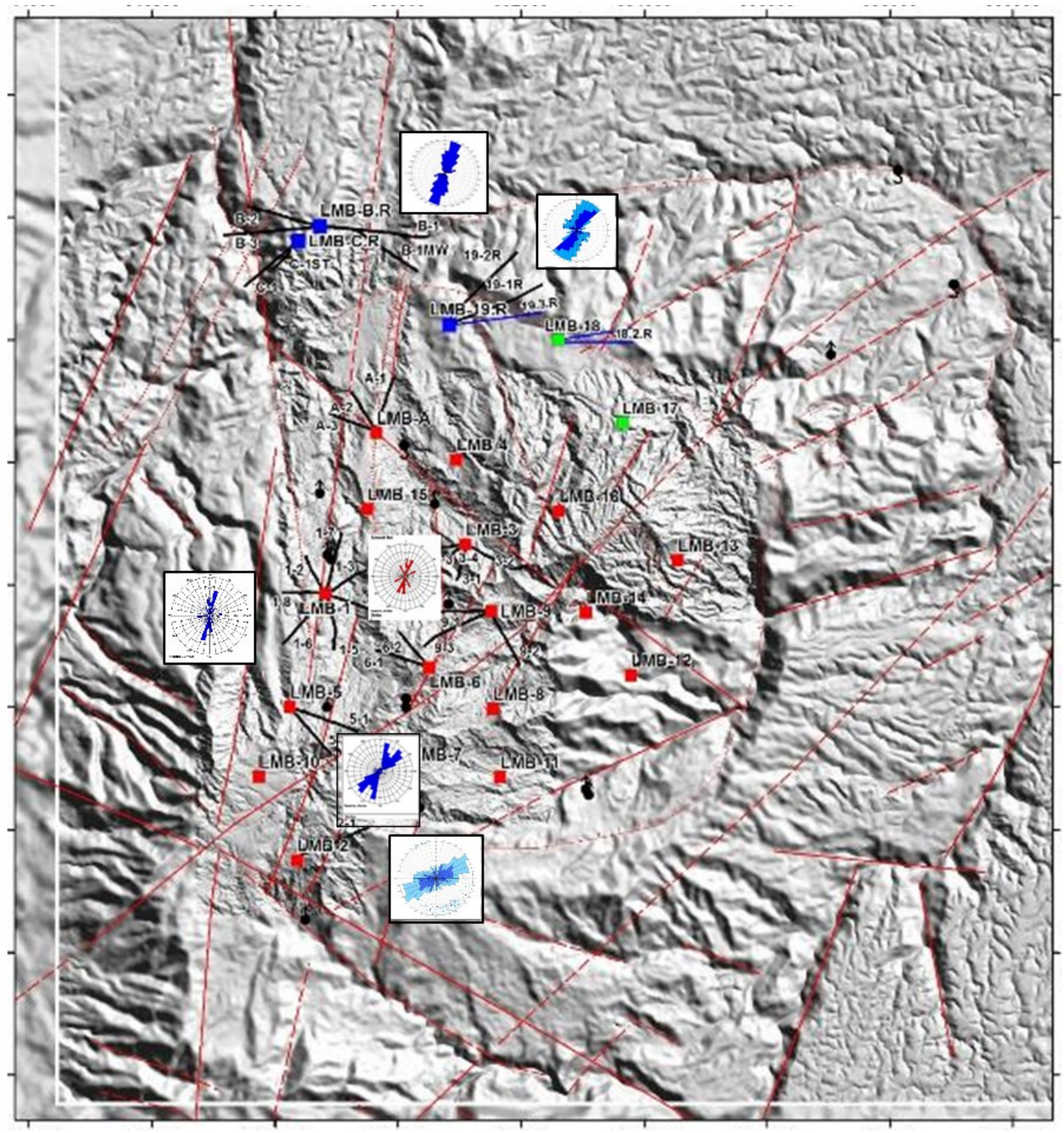

Figure 19. Rosette diagram of fractures inferred through borehole image logging overlain on top of Lumut Balai structure map

Lumut Balai Fault Assessment														
	Geology						Geochemistry		Geophysics		Reservoir		Assessment	
No.	Fault	Field Measurement	Remote sensing Image	Lithological Offset	Drilling Evident	Borehole Image	Tracer Test	Manifestation	MEQ	Gravity	PLT Feedzone	Impact for Reservoir	Level of confidence	Impact for Geothermal System
1	Air Ringkih	Azimuth, Dip, No slicken line found, scarp measurement	Distinct	Not Found	TLC/drilling break	LMB-5	-	Air Ringkih and Bunbun Complex	-	Confirm	Yes	conduit / barrier / compartement	High	High
2	Air Udangan	Surface Geological Mapping Data (PGE-UGM)	Distinct	Yes	TLC confirm on LMB-A	-	-	Air Patahan and Air Udangan	-	Confirm	Yes	-	High	High
3	Old Lumut Caldera	-	Distinct	Yes	TLC confirm on LMB-19.R	LMB-19.R	-	No	-	Confirm	Yes	Barrier	High	High
4	Gemuha Besar	Surface Geological Mapping Data (PGE-UGM)	Distinct	Yes	LMB-A	Yes		G. Besar and Air Abang	-	Confirm	Yes	-	High	High
5	Bukit Lumut	Surface Geological Mapping Data (PGE-UGM)	Distinct	-	-	-	-	No	-	Confirm	-	-	High	Low
6	Penindaian	Slickenside measurements, fracture measurements, and Surface Geological Mapping Data (PGE-UGM)	Distinct	-	LMB-B	Yes	-	No	-	Confirm	No	Barrier	High	Low
7	Ogan Kanan	-	Distinct	-	-	-	-	G.Ogan Kanan 1, 2	-	No	-	-	Low	Low

Figure 20: Lumut Balai Fault Assessment

4. CONCLUSIONS

Lumut Balai is a geothermal system located within the Lumut Balai caldera, composed of andesite, andesite breccia, basaltic andesite, basalt, limestone, metasediment, tuff, and tuff breccia, which are all altered to certain extents.

There are five stratigraphic units, starting from the oldest to youngest are Tertiary Basement Unit, Pre-Old Lumut Unit, Pre-Caldera Unit, Caldera Unit, and Post-Caldera Unit.

Alteration zones in Lumut Balai could be classified into smectite+chlorite zone, silica+chlorite zone, and chlorite+epidote zone.

Productive faults in Lumut Balai are Air Ringkih Fault with NE-SW trend, Air Udangan Fault trending NE-SW, Old Lumut Caldera, and Air Gemuha Besar which trends N-S.

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