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The Strategy of Reinjection Drilling at Lumut Balai Geothermal Field, Sumatera Selatan, Indonesia

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ABSTRACT

Lumut Balai geothermal field is in a volcanic setting, located in the Lumut Tua caldera which has a diameter of 9 km with elevations ranging from 913 - 1800 masl. Production wells with the lowest elevation are at 994 masl elevation. By considering the distance of the reinjection zone with the closest production zone as far as 3-4 kilometers, then the surface elevation difference between the production and reinjection well, the permeability target comes from primary and secondary permeability, so the strategy is to drill reinjection well in the north of the production zone.

Eight reinjection wells were drilled to meet the need for injection capacity of 4000 tons/hour from the planned generation of 2 x 55 MWe in Lumut Balai. The requirement of 4000 tons/hour can be achieved from 8 (eight) reinjection wells in 4 (four) reinjection clusters. Of the eight reinjection wells, four of them produced injection capacities more than 1000 tons/hour.

The large injection capacity is obtained from drilling in reinjection wells that are drilled inside the Lumut Tua caldera. The wells in the caldera, the loss zone is found at elevations 0 - (-200) masl, whereas for wells outside the caldera, it is very difficult to obtain permeability. The permeability found in drilling is estimated from the primary permeability obtained from the layering of metasediment rocks. So that, there is no large permeability that has connection with subsurface. This is very much different from the conditions of subsurface permeability within the caldera, where the structure on the surface correlates with the subsurface structure and is also highly developed. The result is that drilling the wells in the caldera is better than outside.

1. INTRODUCTION

The Lumut Balai Geothermal Field is administratively located in the Semendo and Tanjungagung Sub-Districts, Muara Enim, and parts are located in the Pengandonan Sub-District, Ogan Komering Ulu, South Sumatra Province, Indonesia. This location is ± 292 km southwest of Palembang the capital city of South Sumatra and can be reached by car in about 8 hours. The area of the Lumut Balai prospect is located around Bt. Balai, Bt. Lumut and Bt. Pagut. The average elevation of this location is around 1000 meter above sea level (masl). (Figure 1)

Lumut Balai geothermal field is one of the projects managed by PT Pertamina Geothermal Energy. Currently there have been 23 production wells and 8 reinjection wells drilled. The requirement for reinjection in the Lumut Balai geothermal field is 4000 tons/hour, which is planned to be obtained from 8 (eight) reinjection wells in 4 (four) reinjection wellpad, namely the LMB-B, LMB-C, LMB-19 and LMB-18. Geographically, this reinjection wellpad is at a distance of ± 4 km in the north of the LMB-A production well. Geologically the location of the LMB-B and C reinjection wellpad is outside the Lumut Balai Caldera and the LMB-18 and 19 located inside the caldera, which is the Lumut Balai caldera is a production zone that forms the Lumut Balai geothermal system (Figure 2). After drilling reinjection wells outside the caldera, the total injection capacity obtained was only 220 tons/hour. The small capacity results are caused by the lack of permeability of the drilling target outside the caldera, where the drilling target is the fault or geological structure with northwest-southeast (NW-SE) and northeast-southwest (NE-SW) direction which are outside the Lumut Balai caldera. On the other hand, the well drilling inside the caldera has produced an injection capacity of 1000 tons/hour per well.

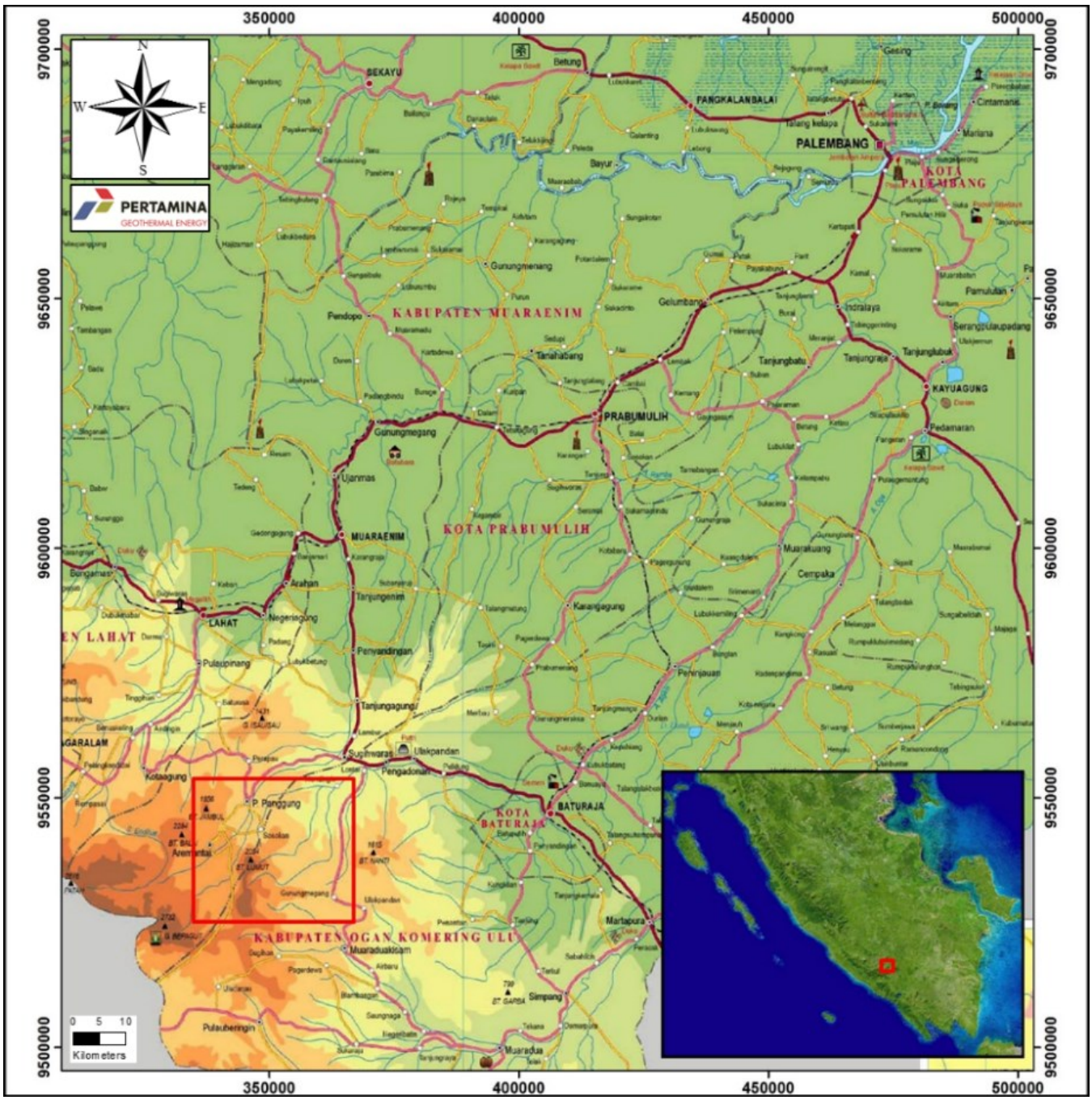

Figure 1: Location Map of Lumut Balai Geothermal Field

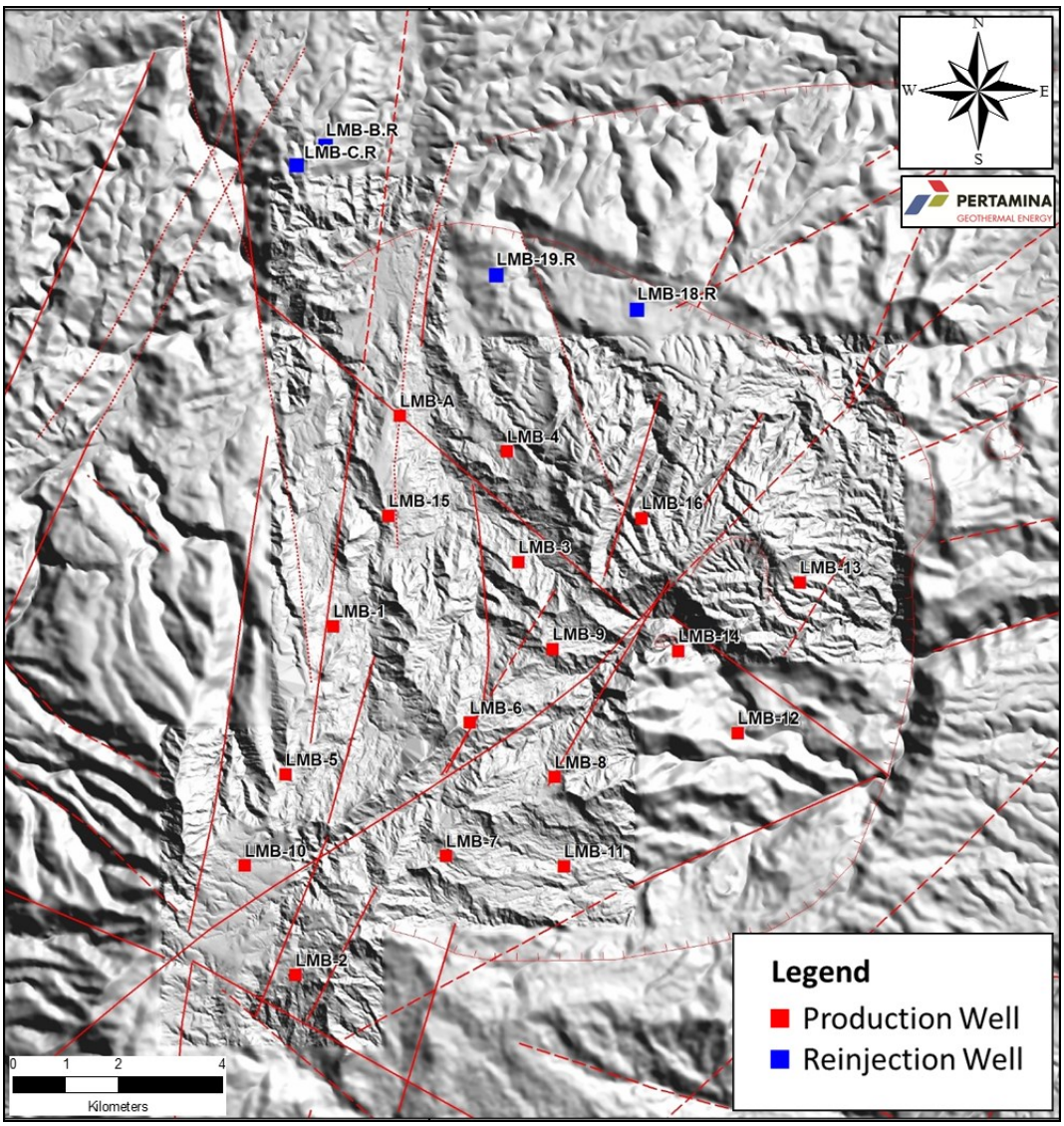

Figure 2: Wellpad distribution map of Lumut Balai Geothermal Field

2. GEOLOGICAL SETTING OF LUMUT BALAI

2.1. TECTONIC SETTING

Lumut Balai geothermal field is located in the northern part of the intersection of two segments of the Sumatran Fault with NW-SE direction, namely the Manna and Kumering segments (Figure 3). In the northeast end of the two faults, the Manna Fault has a narrow horse tail fault, while the Kumering Fault has a widening horse tail. A section of Kumering fault's horse tail has north direction. The entry of the southeast Manna Fault into the Kumering fault's horse tail caused the complex geological conditions in the intersection area.

The response from obligue subduction process of Indian-Australian Ocean Plate, the Sumatran Fault moves to the right (dextral) not simultaneously as a fault system, but segmented response. This segmented response that influences the development of geological structures in the Lumut Balai area.

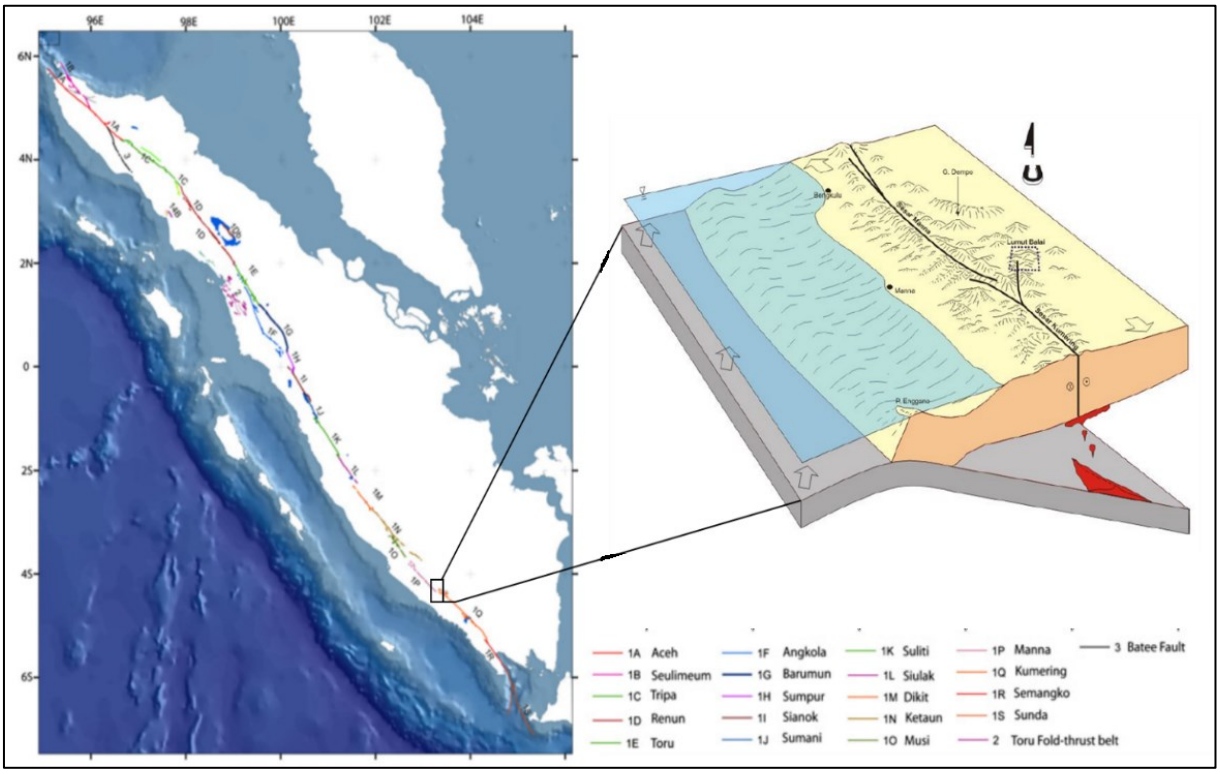

Figure 3: Tectonic setting of Lumut balai (modification from Natawidjaja & Triyoso (2007) and Studi Pola dan Kinematika Struktur Geologi, Hidrogeologi, dan Simulasi Reservoar Lapangan Panas Bumi Lumut Balai, PT Pertamina (Persero) Report (2014))

2.2. VOLCANOSTRATIGRAPHY

Based on the results of geological mapping by Pertamina in 1996, and modified by Pertamina Geothermal Energy in 2013 (Figure 4), the volcanostratigraphic sequence in the Lumut Balai area is as follows :

2.2.1. Tertiary Basement (TB).

Exposed in the southeast (NE) of the Lumut Balai field with elevations ranging from 500-600 masl. The lithology unit consists of clay and sand in the presence of local lignites. Referring to Gafoer, 1992, these rock units in some places have also been mapped into metasediment rocks, and when compared, it is estimated that these rocks are tertiary, but by looking at the regional geological map (1993), the closest tertiary sedimentary rocks are deposited around the Lumut Balai prospect area is part of the Tarap Formation (Pct).

2.2.2. Semendo Pyroclastic Rock Unit (TSP).

On the map is exposure on the west, north and east sides. This forms a plateau-like plain with a sloping dip to the north, the elevation 1400 masl in the south and 600 masl in the north. The lithology unit consists of pyroclastic flow (ignimbrite and tuff), pumice fragments and several hornblende andesite nodes as well as the intercalated of sedimentary rocks such as sandstones and claystone. Formed from the Late Pliocene or early Early Quarternary volcanism process. Based on regional geological maps, it is estimated that these rock units are part of the Kikim Formation (Tpok)

2.2.3. Dasit Bt. Asahan and Andesite Pandan Unit (QAP).

This unit is a products of Bt. Asahan (circular dome) and Bt.Pandan. The lithology unit consists of dacitic lava and lapilli tuff in the east (Asahan) and basaltic andesite lava in the western part (Pandan). From K-Ar's age-dating it is known that the age of the Asahan rock unit is around 1.52 Ma.

2.2.4. Lumut Tua Andesit Unit (QOL).

This lithology unit consists of basaltic lava to andesite, intercalated with volcanic breccia and tuff. The results of drilling in the borehole data which mostly penetrated this unit showed that this unit had a dominant lithology of volcanic breccia then followed by lava and tuff. The formation of this unit is probably related to a large strato-volcano (formed in the early Quaternary). Collapse of the Lumut Balai Caldera is likely a result of catastrophic eruptions. From K-Ar's age-dating it is known that the age of these rock units is around 1.1-1.28 Ma.

2.2.5. Post-caldera Volcanics (QPV).

This unit is related to the eruption center of volcanic complex, which covers most of the lower caldera. This unit consists of hornblende andesite and pyroxene andesite which overlapping with volcanic breccia and lapilli tuff. This formation hit by drilling at shallow depths.

2.2.6. Andesite Bt. Ringgit (QRG) Unit.

Exposed in the southern part of the Lumut Balai caldera. In the north, this unit is deposited above the product of Lumut Tua formation, while in the east this unit overlaps Semendo Pyroclastics. This unit generally consists of andesite pyroxene with minor pyroclastic intervals. From K-Ar's age-dating it is known that the age of the rock unit is around 1.01 Ma.

2.2.7. Andesite Lumut Muda Unit (QYL).

It is exposed in the western part, covering the western part of the rim of the caldera and forming elongated N-S direction of more than 15 km. There is a sloping dip to the east. Dominated by andesite pyroxene with subordinate pyroclastic produced from the center of the Bt. Lumut at an elevation of 2055 masl. From K-Ar's age-dating it is known that the age of these rock units is around 0.89-0.97 Ma.

2.2.8. Andesite Bt. Lumut Unit (QLD)

This unit is exposed to the northeast of LMB 2. Lithology consists of blocky lava, composition of basalt to basaltic andesite and it is the youngest volcanic activity (0.64 Ma).

2.2.9. Ignimbrite (QIG)

Small outcrops of ignimbrite that are as argillic zone (alterated), located along the road that connects LMB-5 and LMB-2. Have a relatively young age compared to the previous units. Formed on the top of Andesite Lumut Muda Unit.

2.3. GEOLOGICAL STRUCTURE

From the results of the analysis using LiDAR and IFSAR imagery, the geological structure in Lumut Balai shows an old volcanic complex that has collapsed and forms a large caldera, which is referred to as the Lumut Tua caldera. The diameter of the Lumut Tua Caldera is ± 9 km. This volcanic mountain complex was built by a chain of volcanic eruption centers namely Bt. Pandan, Bt. Ringgit, Bt. Lumut, and Bt. Balai. At the margin or the edge of the caldera there is a new eruption, in the southeast part of the caldera Bt. Lumut and in the northwest part are found Bt. Balai. Along the western part of the Lumut Balai caldera, there is a relative north-south fault, which is estimated to be the Lumut Balai geothermal prospect boundary in the west. In the middle of the Lumut Tua caldera there are two alignment patterns which are interpreted as faults with NE-SW and NW-SE direction. In some faults, large faults are found that are associated with the appearance of geothermal manifestations, such as the Air Ringkih fault, Gemuha Besar fault, Patahan fault, Udangan fault, Right Ogan fault and Tanjung Tiga fault. Whereas in the east side, the geothermal prospect area is bounded by the Lumut Tua caldera (Figure 4)

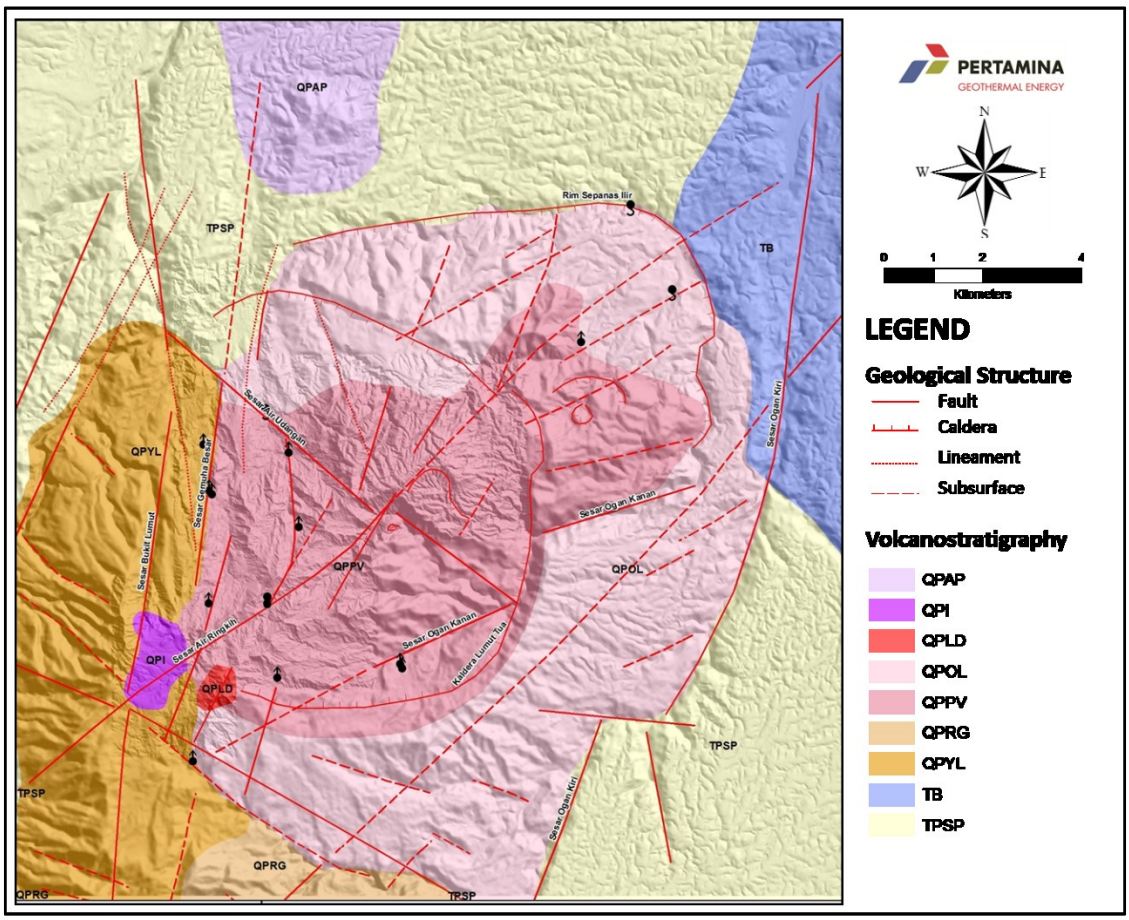

Figure 4: Geological map of Lumut balai (PT. Pertamina Geothermal Energy, 2013)

3. DISCUSSION & CONCLUSION

3.1. REINJECTION WELL

The drilling campaign in Lumut Balai geothermal field has carried out twenty-three production wells drilled inside the Lumut Tua caldera, and eight reinjection wells drilled outside the Lumut Tua caldera, precisely in the northern part of the prospect area with a distance of ± 3 km from the production well in wellpad A.

The evidence for reinjection drilling outside the caldera, is based on several geoscience technical considerations, such as geological structure distribution, gravity and resistivity anomalies based on geophysical survey, and production and reinjection management so that cold water intrusion into the reservoir zone from the injected brine does not occur.

Then from the subsurface data, technical considerations are based on the results of gravity and resistivity measurements that have been carried out by the PGE geophysical team, where it can be seen from the results of gravity acquisition that there is a low gravity anomaly that contrasts with the surrounding rocks in the west and east from locations of wellpad B and C. This gravity anomaly illustrates the existence of a rock density value that is lower than the rock density value around it. With a low rock density value can be interpreted the existence of rocks that have alteration process, causing the rock density to be lower. The low gravity anomaly in the eastern part of the reinjection wellpad, there is a clear anomaly boundary, which is estimated to be the alignment of the Gemuha Besar fault with a relatively NE-SW direction. In the low gravity anomaly in the western part of the reinjection wellpad, the anomaly boundary is bounded by the Enim fault which is a synthetic fault from the Gemuha Besar fault. So that from geological surface analysis, both regional and detailed analysis, which is also combined with subsurface analysis, it is known that the Gemuha Besar and Enim fault can and feasible to be targeted for reinjection well drilling. Based on the technical considerations presented above, it is planned to carry out reinjection drilling as many as 8 drilling wells, with a target to complete injection capacity requirements.

From the results of drilling wells outside the caldera (Wellpad B and C) show poor permeability, with the result that based on the evaluation that has been done, the reinjection drilling strategy is carried out from within the caldera while looking at reservoir management. Drilling is carried out in wellpad 18 and 19 located in the north-east part of the Lumut Balai field. (Figure 5).

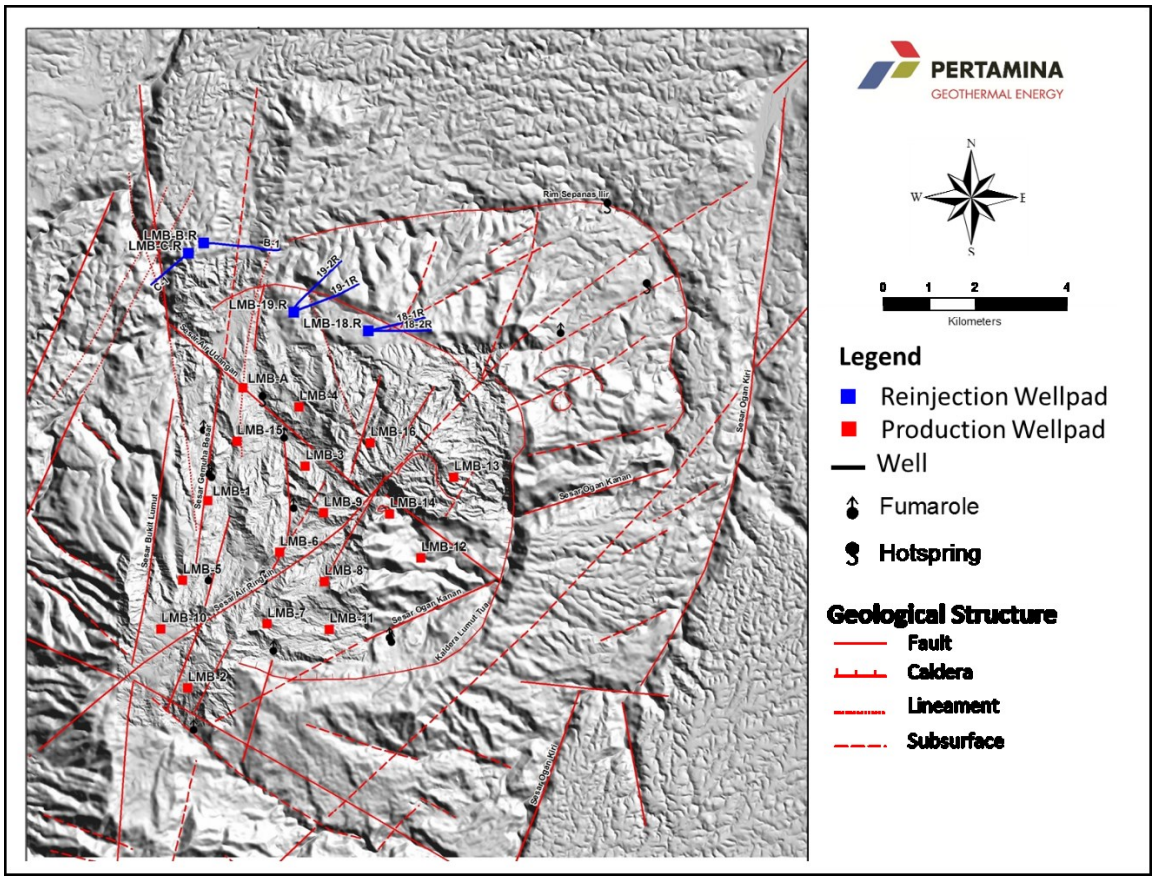

Figure 5: Reinjection distribution map

3.1.1. LMB-B

The well LMB-B1 is N 95 ° E / 45 ° direction, with a total depth of 2979 mD. This drilling is targeted at the NNE-SSW geological structure which is the lineament of the Gemuha Besar fault, the alignment of geological structures can be seen from the existence of alignment or LiDAR lineaments and IFSAR. The loss zone of well LMB-B1 is found at a depth of 1609-1620 mD (Target#1 @ 1610 mD / -371 masl) with a PLC rate loss reaching 15 bpm. Cutting obtained at this time is altered andesite breccia.

But, when the drilling continued to the 1621 mD, the rate of the PLC dropped to 1-3 bpm. At the depth of 2020-2290 mD the PLC rate increased to around 4-5 bpm, then at the next depth, while drilling at LMB-B1 continued to a depth of 2979 mD, the loss value decreased to 1-4 bpm, and the static loss value 1.6 bpm.

In drilling well LMB-B1, metasediment (MS) rocks are present from a depth of 1688 mD / -425 masl to the total depth (Figure 6a). In the well LMB-B1, logging image acquisition was also carried out and from the image it was found that the distribution of geological structure was continuous conductive fracture (CCF) which is dominated by the NE-SW direction pattern. The direction pattern is similar to the pattern of geological structures that develop on the surface, but from the results of logging image there is no major fault structure that hit on the LMB-B1 well, the minor fault is only present at the depth of 2756-2759 mD with NE -SW and NNW-SSE direction. So that the permeability obtained is estimated to be dominated by the presence of fractures which developed quite intensively in Metasediment rocks (Figure 6b).

From the results of the Well Completion Test (WCT) carried out by the PGE reservoir team, it was found that the injection capacity of well LMB-B1 was around 50 tons/hour, but by looking at the potential fracture, jetwash and hydrofracture programs were carried out, so that capacity injection at LMB-B1.R increased to 183 ton /hour.

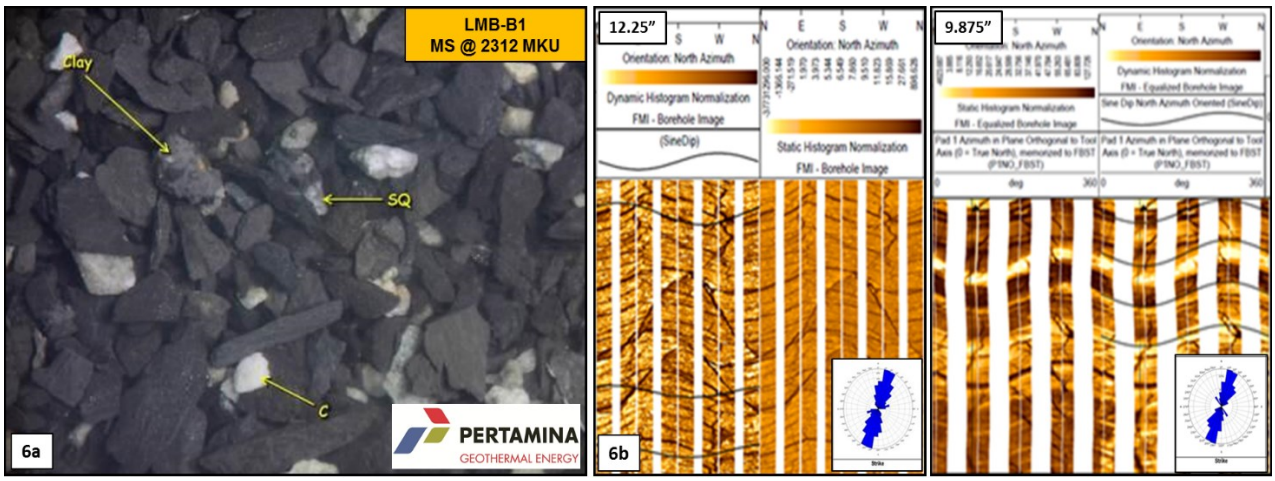

Figure 7: (a) Metasediment cutting sample at Well LMB-B1. (b) Borehole image in 12.25" & 9.875" section.

3.1.2. LMB-C

The LMB-C1 reinjection well is the first well in the LMB-C wellpad with the direction N 230ºE / 36º and the total depth of 2972 mD. This LMB-C1 well targets the NE-SW direction of Patahan fault which cuts across the diagonal Lumut Balai field. Patahan faults on the surface are clearly cut starting from the southwest to the northeast of the prospect area, which is characterized by the presence lineament of the valley, as well as the appearance of manifestations.

In the drilling process, in some sections at certain depths were found a good loss zone. For example, at a depth of 1210 mD, there was a zone of total loss circulation (TLC>20 bpm) for approximately 10 hours when stand-down was carried out on lithology altered andesitic breccia. Due to the loss zone found in the 17-1/2" section, to secure the loss circulation the combat loss with material plugging is done to set the 13-3/8" casing.

After plugging and the 13-3/8" casing setting-up , the drilling is continued on 12-1/4" section, but when drilling is carried out, there is no more TLC zone found. From the results of drilling until total depth well, the potential loss zone is at the depth of 2657 - 2663 mD which reaches 12-13 bpm. This is indicated by the drilling parameters, at this depth indicating anomalies where the WOB and ROP values drop suddenly.

In LMB-C1 wells, borehole image logging was not carried out, but geophysical logging (resistivity and DSI) was run. Resistivity logging is carried out to get formation resistivity values and is expected to be a marker in resistivity from MT data and can be used as a subsurface correlation. DSI logging is carried out to get a image of the distribution of the subsurface fracture. From the results of logging is known that at certain depths have potential fractures or as major fractures, but in general, the fractures found are dominated by minor fractures that are less permeable (Figure 8). The results of Well Completion Test obtained injection capacity of 10 tons/hour.

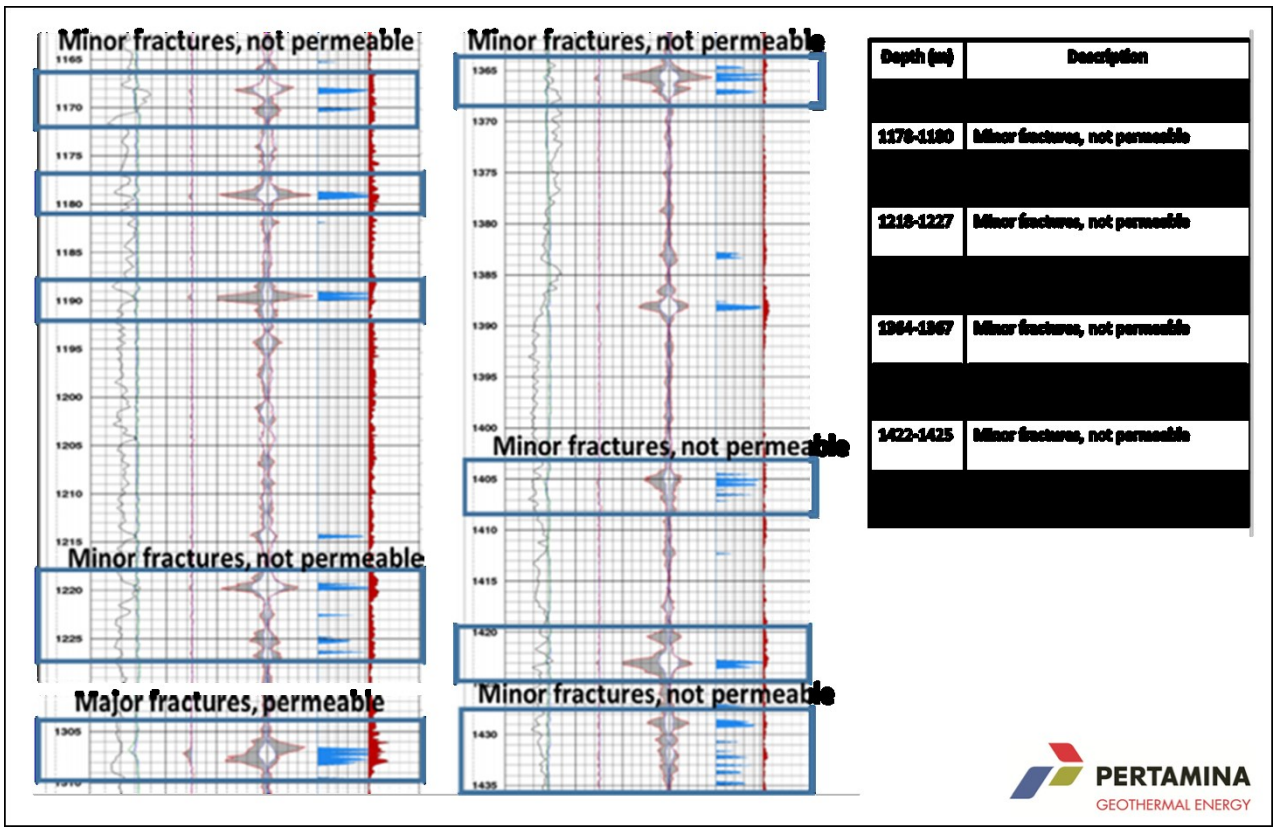

Figure 8: DSI Logging result of LMB-C1 (depth 1167-1435 mKU)

3.1.3. Wellpad LMB-19

In the wellpad LMB-19 drilled two wells, LMB-19.1 & 19.2. The well LMB-19.1 is the first reinjection well drilled in Lumut Balai inside of the Lumut Balai caldera with direction N 069° E / 39° , was drilled until 3003 mD. This well targets are NW-SE fault and Rim Lumut Balai Caldera and also density anomaly which obtained from the Lumut Balai caldera gravity data. Well LMB-19.2 drilled with azimuth N 045° E with inclination of 42.59° and total depth 3001 mD, hit the similar target with LMB-19.1.

The lithology was compiled by altered tufa breccia (BTT), altered andesite breccia (BAT), altered basaltic andesite (ABT) and altered andesite (AT). Lithology of 26" section is dominated by tufa breccia with andesite breccia and andesite (basaltic) intercalated at the top. The 17.5" section is dominated by andesite and intercalated andesite breccia with altered tufa breccia. In 12.25" section lithology is arranged by intercalated altered andesite breccia and altered tufa breccia, and metasediment was found at a depth of 1705 mD. The cutting of 9,875" section could not rise to the surface because drilling has undergone TLC so it can be said that the target on this well has been successfully hit.

In the LMB-19.1 complete logging was carried out on 12.25" and 9,875" section, consisting of logging borehole image and sonic. From the results of logging borehole image on 12.25" section, NNW-SSE trending fracture was found, while on 9.875" section the trend had NE-SW direction. From the results of sonic logging, there are several indications of open fracture on 12.25" and 9.875" section (Figure 9).

After the well had been drilled, a logging spinner was carried out and the largest feedzone was obtained at 2643-2692 mD by 41% injection and 1645 - 1686 mD by 32% injection. Then from the results of WCT measurements the calculation of injection capacity is 1059.37 ton/hours.

In the well LMB-19.2.R, borehole image logging and geophysical logging (Sonic and Resistivity) were not run. From the WCT results of LMB-19.2.R the injection capacity potential is relatively equal with LMB-19.1, amounting of 1059.73 ton /hours.

3.1.4. LMB-18

After drilling in the LMB-19.1 and LMB-19.2 it was declared successful. To supply the reinjection needs, drilling continued to the LMB-18 wellpad two wells LMB-18.1 and 18.2. The drilling campaign in the wellpad LMB-18 is intended to minimize the occurrence of interference between wells and to divide the injection discharge. The LMB-18.1 and 18.2 reinjection well was drilled to target the NW-SE direction fault and the Rim of Lumut Balai Caldera as well as the depth where anomalies from Lumut Balai Caldera gravity data.

In general, the lithology of LMB-18.1 and 18.2 is similar to LMB-19.1, compiled by altered tufa breccia (BTT), altered andesite breccia (BAT), altered basaltic andesite (ABT) and altered andesite (AT). On 26" section lithology is dominated by tufa breccia with andesite breccia and andesite (basaltic) intercalated at the top. Section 17.5" is dominated by andesite and intercalated andesite with altered tufa breccia, but at 429 - 462 greywacke rock was found. In 12.25" section lithology is arranged by intercalated andesite

breccia and altered andesite. At a depth of 1092 mD drilling meet the TLC and the cuttings from the 9,875" section did not rise to the surface.

In LMB-18.1, well logging is done on the 12.25" section, consisting of borehole images, sonic and resistivity logging. But on the 9,875" section, logging was not done because the tool has a problem at a 970 mD. From the results of borehole image logging on 12.25" section, NNE-SSW direction fracture was found. From the results of sonic logging, there are several indications of open fractures on 12.25" section at the depth: 1186 – 1191 mD, 1364 – 1367 mD, 1723 – 1728 mD, 1739 - 1742 mD, 1917 - 1920 mD and 1957-1959 mD (Figure 10).

After the well had been drilled, a logging spinner was carried out, showing that the feed zones are in the depths of 1969 mD (7.5%), 2321 mD (9%), 2724 mD (46%) and 2924 mD (29%). The major feed zone in the well LMB-18.1 is at a depth interval of 2924 mD. From the results of WCT, the calculation of injection capacity shows that the well LMB-18.1 can be injected with a rate of 1059.73 tons/ hour as well as LMB-18.2.

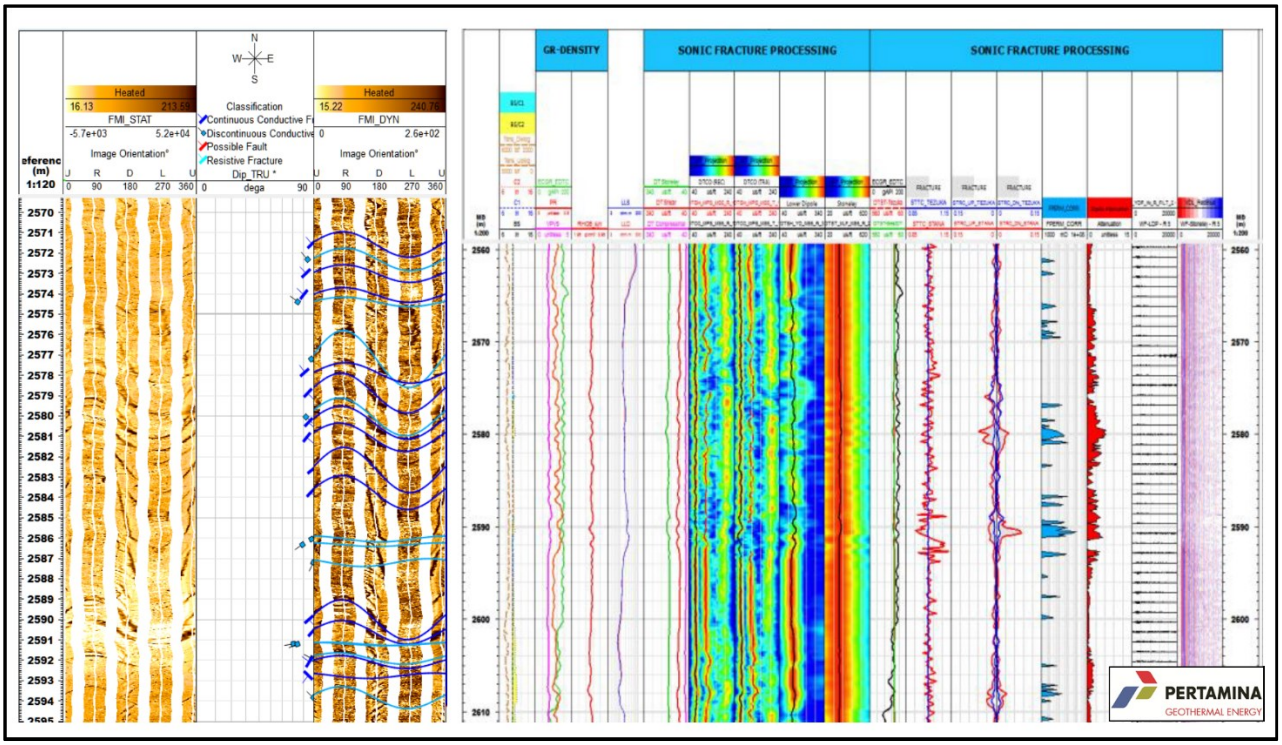

Figure 9: Borehole image & DSI Logging result of LMB-19.1 (9.875" section)

3.2. CONCLUSION

From the results of reinjection drilling that has been done in wellpad B and C, it is known that permeability (zone of loss circulation) in each well does not indicate a correlation between one well and another and has not shown large permeability.

On the other hand, the LMB-19 and 18 wellpads show the same target correlation, both from geological structure, caldera and horizontal permeability that shows large permeability with evidence the injection capacity is more than 1000 tons/hour in each well.

When reinjection drilling was carried out in the caldera, exactly in the northern margin of the Lumut Tua caldera, which is the outflow zone of the Lumut Balai geothermal system in 18 and 19 wellpad, the results were very good, that is, each well received an injection capacity of 1059 tons/hour, where the number is the maximum number of injection capacity calculations in big hole wells.

The wells in the caldera show that the loss zone has been found at an elevation of 0 - (-200) masl, whereas for wells outside the caldera, it is very difficult to obtain permeability. The permeability found in drilling outside the caldera is estimated to be the primary permeability obtained from the layering of metasediment rocks. So, there is no large permeability that has a subsurface connection. This is very much different from the subsurface permeability conditions within the caldera, where the structure on the surface correlates with the subsurface structure, and the control of the geological structure is also very significant.

The distribution of epidote minerals in wellpad B and C is interesting, because there is a similar distribution pattern with metasediment. From the results of drilling in LMB-B1 which has east direction, epidote minerals begin to appear at depth -1029 masl. Whereas in well LMB-C1 that has southwest direction, or near towards Lumut Balai caldera, epidote has begun to appear at depth -885 masl. The data shows that there is a pattern of epidote presence that rises upward as it approaches the caldera, and the presence of the epidote is further downward when away from the caldera, while the metasediment spread increases outside the caldera than inside the caldera.

The geothermal system in the Lumut Balai area develops intensively in the caldera, this is indicated by the presence of alterations at elevations higher than alterations outside the caldera which are at a deeper elevation. This shows that heat of the geothermal system can reach rocks that are at high elevations.

Permeability in the Lumut Balai geothermal field is well developed within the Lumut Tua caldera. So for further drilling to achieve a large injection capacity it is recommended to drill in the margin of Lumut Tua caldera.

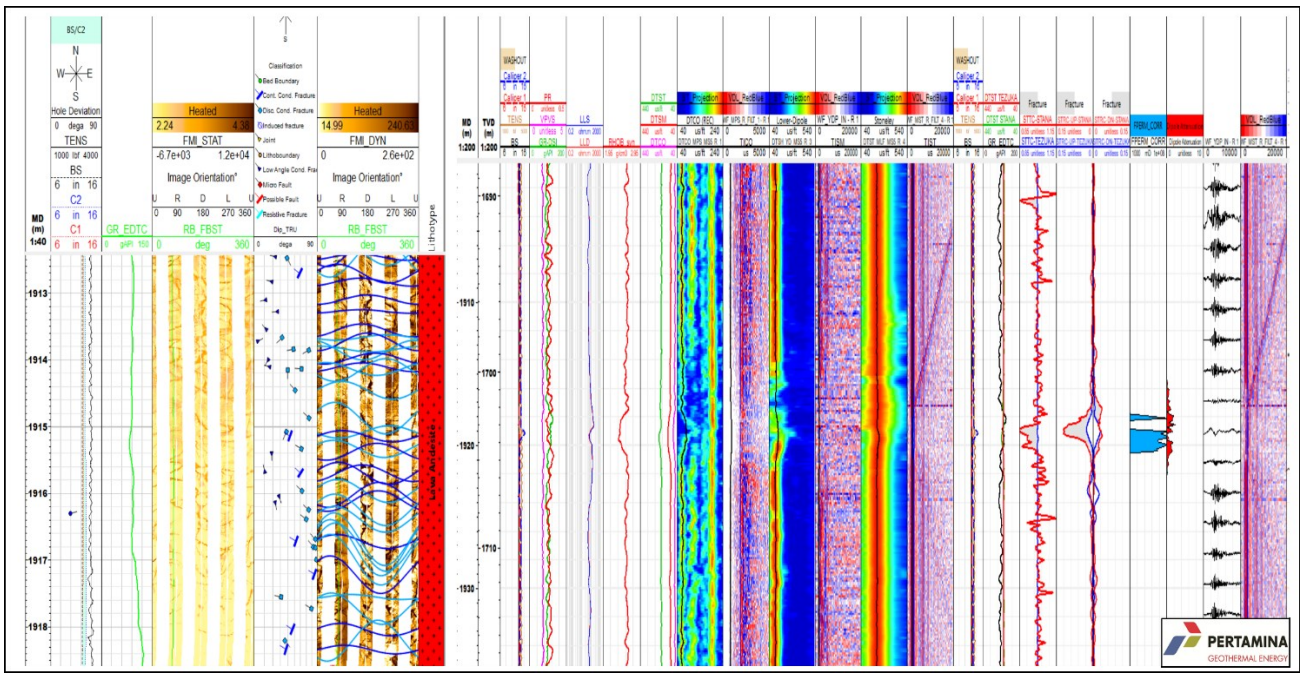

Figure 10: Borehole image & DSI Logging result of LMB-18.1 (12.25" section)

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