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Feedzone Characterization in Geothermal Reservoir: Integration of Borehole Image, Spinner and Loss Circulation Data

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ABSTRACT

It is believed that the contributing factors that provide permeability in a volcanic hosted geothermal reservoir are fault and fracture. However, it does not rule out the presence of other that may also provide the conduit for the fluid to flow. To locate these permeable zones, borehole image data together with the spinner and loss circulation data from drilling are used. The data were taken from wells of different geothermal fields operated by PT. Pertamina Geothermal Energy (PGE).

From this study, fracture and fault are the main sources of permeability that can drain the fluid with the greatest amount. However, The spinner response also occured on the lythological contact as seen on the borehole image. It shows no fault or fractures develop within this depth range. From the drill cuttings and image logging analysis, It suggests that the permeability derived from lithological contact zone is commonly composed of two lithology that genetically have different forming process (eg lava and pyroclastic or intrusive body contact). In addition, permeability also exists in a particular lithology such as pyroclastic. The void between the fragments and/or matrix that play a major role in providing the primary permeability. The outcome of this study is to understand the contributing factors that provide the permeability in a volcanic hosted geothermal reservoir. It also complements for geothermal well targeting by probing the best possibilities in the subsurface that potentially provide a productive aquifer.

1. INTRODUCTION

1.1 Background

At this time it does have widespread geophysical logging, as borehole imaging to measure the value of rocks resistivity and display it on the rock surface images and spinner logging to measure the zones of productive aquifer (feedzone) in the subsurface by injecting water and calculate the amount of water lost or increased in each of wellbore depth. So far, both of this logging is very helpful in interpreting subsurface conditions and to estimate the productive zones in the geothermal field. Both of these data can be used to identify permeability controls and reservoir characteristic of a geothermal field by correlating them with the loss circulation data during drilling.

There are 4 wells that observed in this study where KRH – 4.3 & KRH – 5.2 are located in Karaha field, West Java and LMB – 5.2 & LMB – 3.1 are located in Lumut Balai, South Sumatera. All of these well are operated by PT. Pertamina Geothermal Energy in Indonesia. Generally, stratigraphy of Karaha field that penetrated by the boreholes consist of two formation, as the youngest Fm. Volcanic Breccia G. Putri – Eweranda deposited together with variation of several lithology like tuff breccia, tuff and andesite Lava. Second, the older Fm. Volcanic Breccia G. Sadakeling deposited with tuff breccia and tuff. In the same way, stratigraphy of Lumut Balai field is consist of 2 formation, at the top begin with Fm. Post Calderic Product as the youngest that consists of andesite breccia and lapilli tuff and Fm. Old Lumut Volcano that consist of volcanic breccia layering with andesitic & basaltic lava and tuff.

2. BRIEF THEORY

2.1 Borehole images

Borehole image is are electronic pictures of the rocks and fluids encountered by a wellbore. Such images are made by electrical, acoustic, or video devices which have been lowered into the well. Image are oriented, they have high vertical and lateral resolution and they provide critical information about fractures, faults, lithology, lithological contact and other geological features. Case studies have shown that borehole images are best used in conjunction with other available wellbore data, such as others log, cuttings, cores and production data.

In borehole image, fractures are shown as planar features with no apparent displacement along their planes. They may be open, tight (closed) or filled with mineral precipitates such as clays, calcite, pyrite etc. On the borehole image, fractures tend to occur as linear features that generally have a steeper dip and cut bedding. Open fractures have a dark appearance on the image due to invasion by conductive drilling mud. Mineralized or sealed fractures appear white if the filling material of their apertures is resistive e.g. calcite or silica. Fractures having clay or pyrite filling have a conductive response and any additional information (e.g. core, petrography) should be taken into consideration in order to distinguish between open and healed conductive fractures.

To interprete a faults on borehole image, there are factors taken into account for identifying faults are as follows:

• Abrupt change in dip attitude, either magnitude or azimuth, across the fault plane.

• Abrupt change in lithology or facies across the fault plane.

• Sudden change of borehole drift or deviation azimuth.

• High angle resistive or conductive events developed across the wellbore.

• Enlarged hole at the fault \ borehole intersection.

• Shift in the trend of in-situ stress.

• Abrupt termination of layers against a fault plane.

• Changing thickness of the fault bounded layer across the wellbore.

• Occurrence of fractures.

• Abrupt changes in log response across the features interpreted as fault.

Faults were locally identified and appear similar to fractures but with sense of movement along a fault plane and associated with fracture occurring as brecciated zones.

In geothermal well, open fractures and faults are of primary importance with regard to their flow characteristics and contribution to steam production. Apart from the fracture and fault classification and orientation, fracture density was computed from the conductive fractures and resistive fractures to show their distribution over the study interval. Densities of open and closed fractures were computed to represent the number of fractures per meter normal to the fracture planes (i.e. taking into account the dips of the fractures). A visual estimation of fracture and fault aperture from the image are provided for both continuous and discontinuous conductive fractures and faults that might be open and may well contribute to flow.

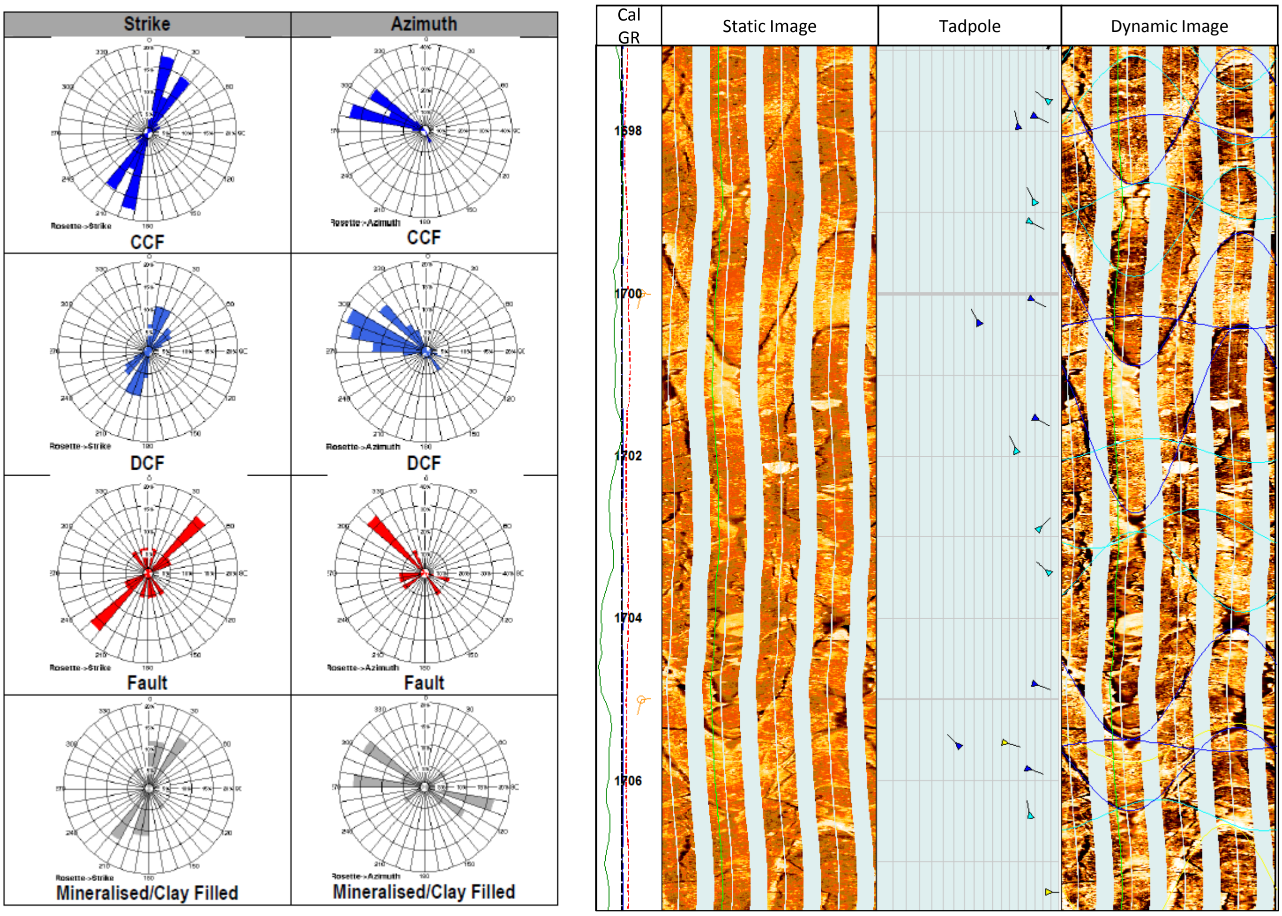


Figure 1: Example of borehole image data with dominant orientation

2.2 Spinner

Spinner is a device for measuring in situ the velocity of fluid flow in a production or injection well based on the speed of rotation. The spinner can be helical, that is, longer than it is wide, or like a vane, which is similar to a fan blade. In both cases, the speed of rotation is measured and related to the effective velocity of the fluid. Friction and fluid viscosity cause the relationship to be slightly nonlinear at low effective velocities and introduce a threshold velocity below which the spinner does not turn. Results are interpreted using the multipass, two-pass or single-pass methods. There are several types of spinner flowmeter. The most common device uses a small vane-like spinner, about 1.5 in. [3.8 cm] in diameter, allowing thelogging tool to pass through the tubing and other restrictions before reaching the reservoir interval. The small spinner captures only part of the fluid flow in the casing, too little to make it turn in some low flow-rate wells and possibly unrepresentative in multiphase flow settings. Other devices have been designed to capture more of the flow, for example the fullbore spinner and various types of flow-concentrating or diverter spinners, such as the packer flowmeter and the basket flowmeter. Commonly, how the spinner work is similar with tool that used in Gross Permeability Test (GPT) activity where the injection rate of water will be adding if there are empty space for fluid to fill in the formation along the borehole.

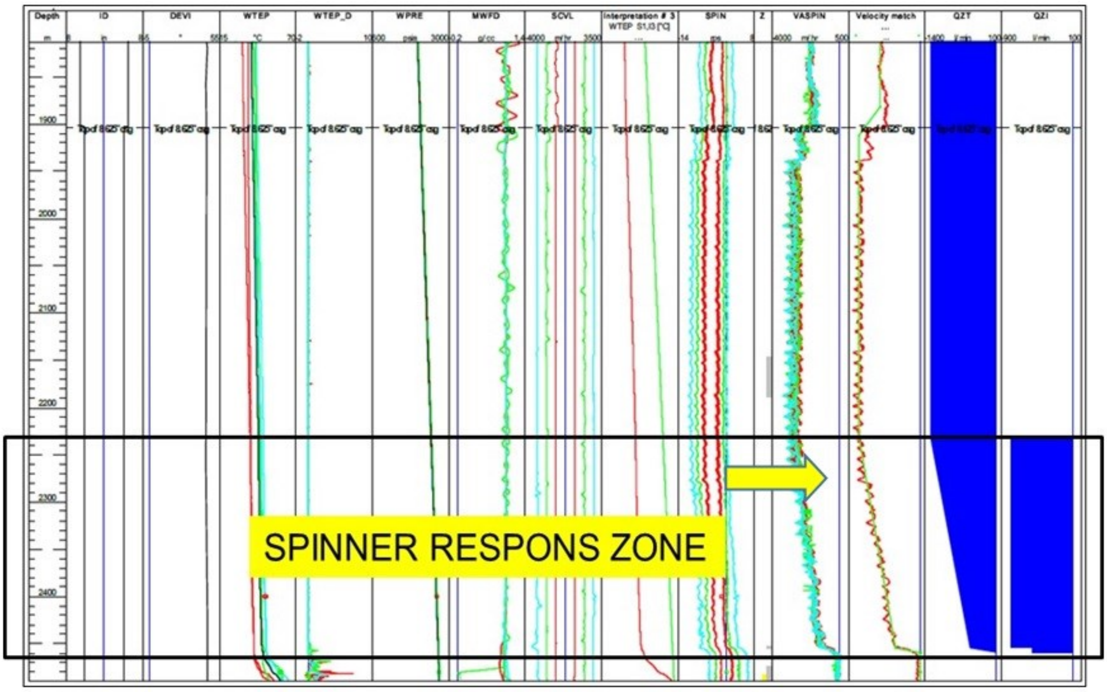


Figure 2: Example of spinner data

3. CASE STUDY

3.1 Karaha Field

A detail geological survey in Karaha Field has gave a result that quarter volcanic product almost completely cover the volcanic complex. Fm. Gunung Putri – Eweranda & Fm. Gunung Sadakeling deposits altered rocks, tuff, volcanic breccia and andesite lava in the middle and western part of this field. The surface structure interpretation that resulted from Landsat data assumes that the structures orientation of this field is dominantly NW – SE and NE – SW. Both of these structures are dominantly interpreted as a strike slip fault and act as the permeable structures that penetrated by KRH – 5.2 & KRH – 4.3 wells. The WNW – ESE section that illustrates subsurface feature trough the both of wells is below.

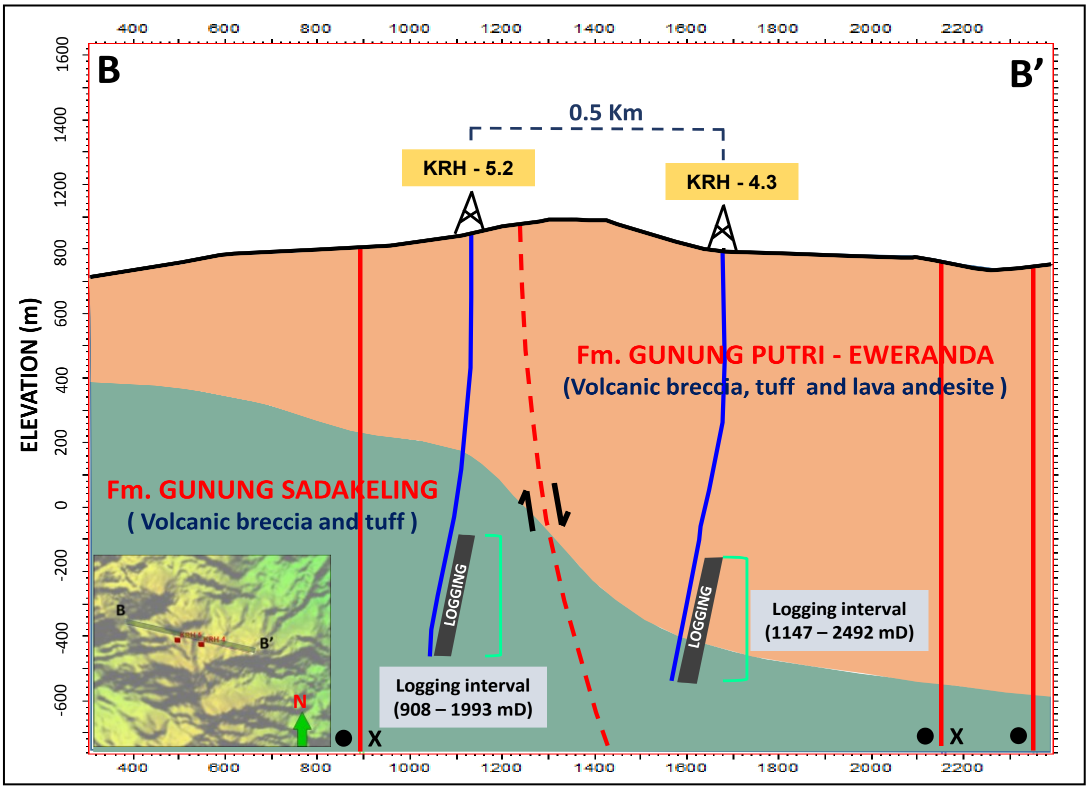


Figure 3: WNW – ESE section of Karaha Field

3.1.1 KRH – 4.3

The borehole imager tool was logged in well KRH – 4.3 and the interpretation is carried out for interval 1147 – 2492 mD. The spinner data showed two zones are expected to play a role in fluid flow seen from the two depth zones that have a response when injected by water that is first on the depth interval from 2232 to 2454 mD with injection rate of 60.2 % and the second at depth interval 2455 - 2459 mD with injection rate of 39.8 % . The appearance of borehole image in the first zone (2232 - 2454 mD) indicates that in this interval found open fractures intensively and expected that secondary permeability plays a major role in the response of the spinner that appeared in this depth interval.

As for the zone with the second spinner response (in the 2455-2459 mD interval), the borehole image data showed no intensive fracture or fault so it is estimated that the permeability that contribute to the spinner response is the primary permeability of the rock matrix. The possibility is also supported by lithology data at this depth intervals. The results of borehole image interpretation by looking at the texture of rocks where shown on the image shows the volcanic breccia lithology from Fm. G Sadakeling Volcanic Breccia as reservoir formation.

With these lithologies can be presumed the role of a primary permeability rock matrix in which the volcanic breccia with an open texture pack is expected to drain the fluid. Permeable zone at these depth is also evident at the time of drilling where the partial loss circulation in the 2313 - 2500 mD depth interval.

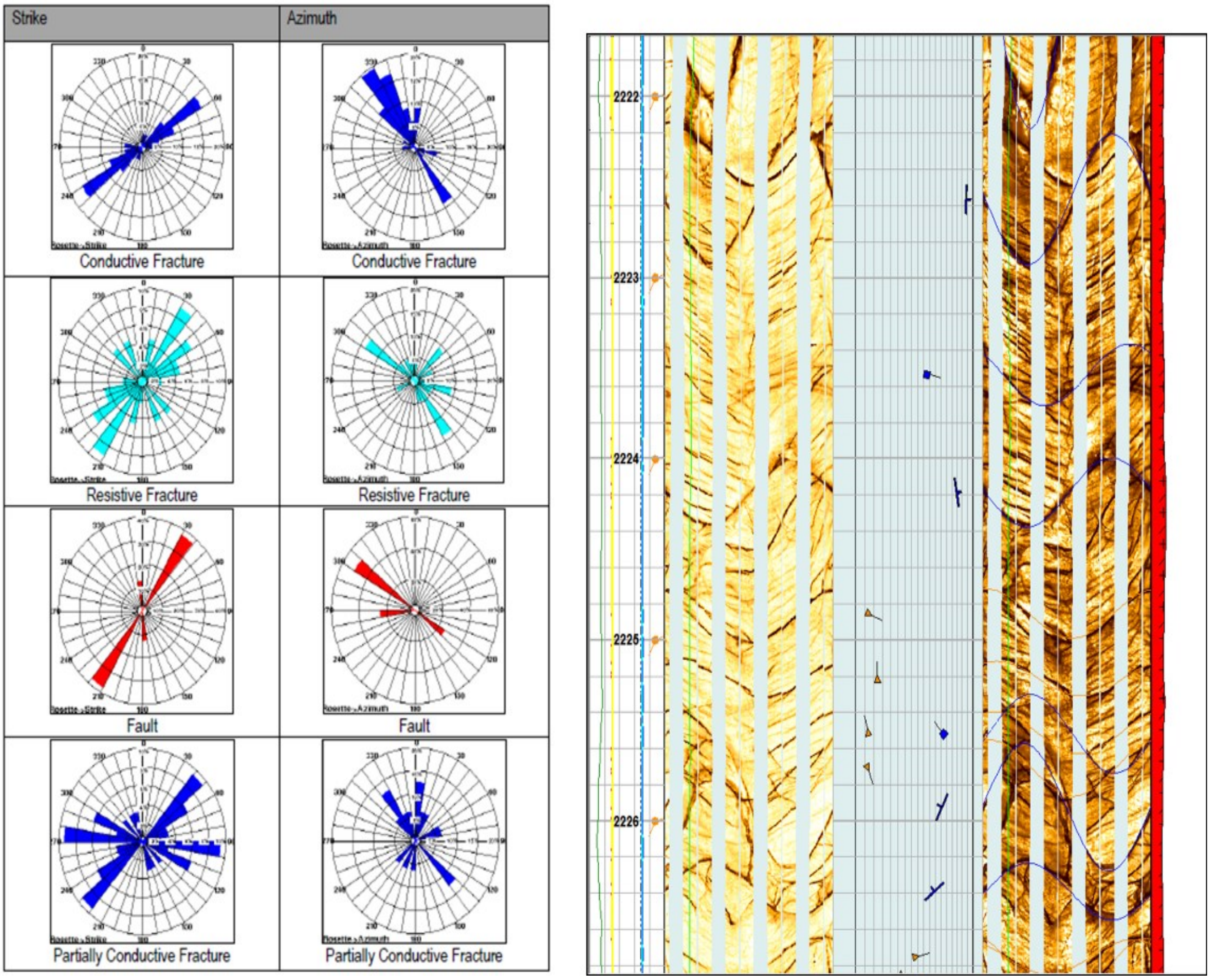


Figure 4: Borehole image data with dominant orientation at interval 2221 – 2227 mD in KRH – 4.3. Open fracture might be responsible to the spinner response.

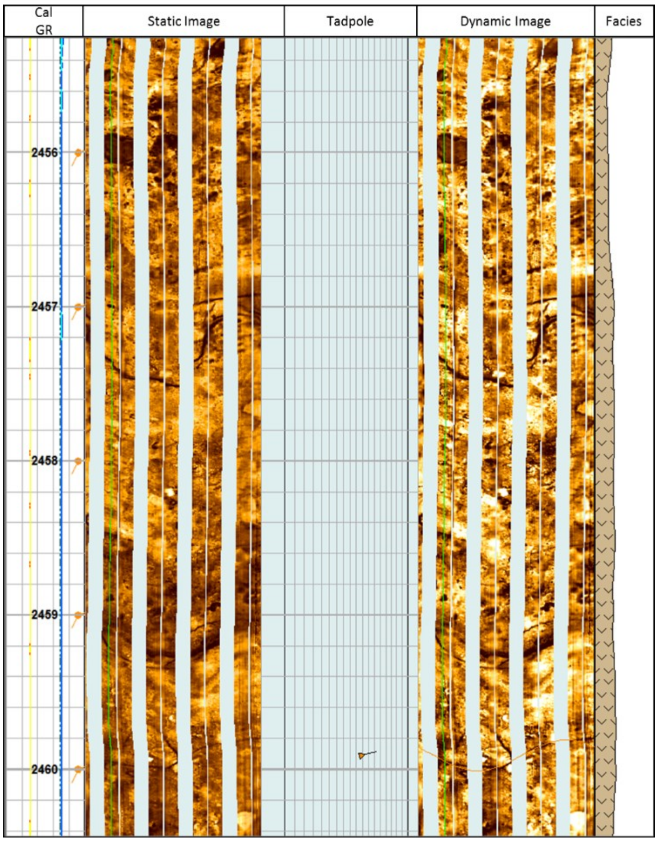


Figure 5: Borehole image data with rare fracture feature at interval 2455 – 2460 mD in KRH – 4.3. Matrix permeability might be responsible to the spinner response.

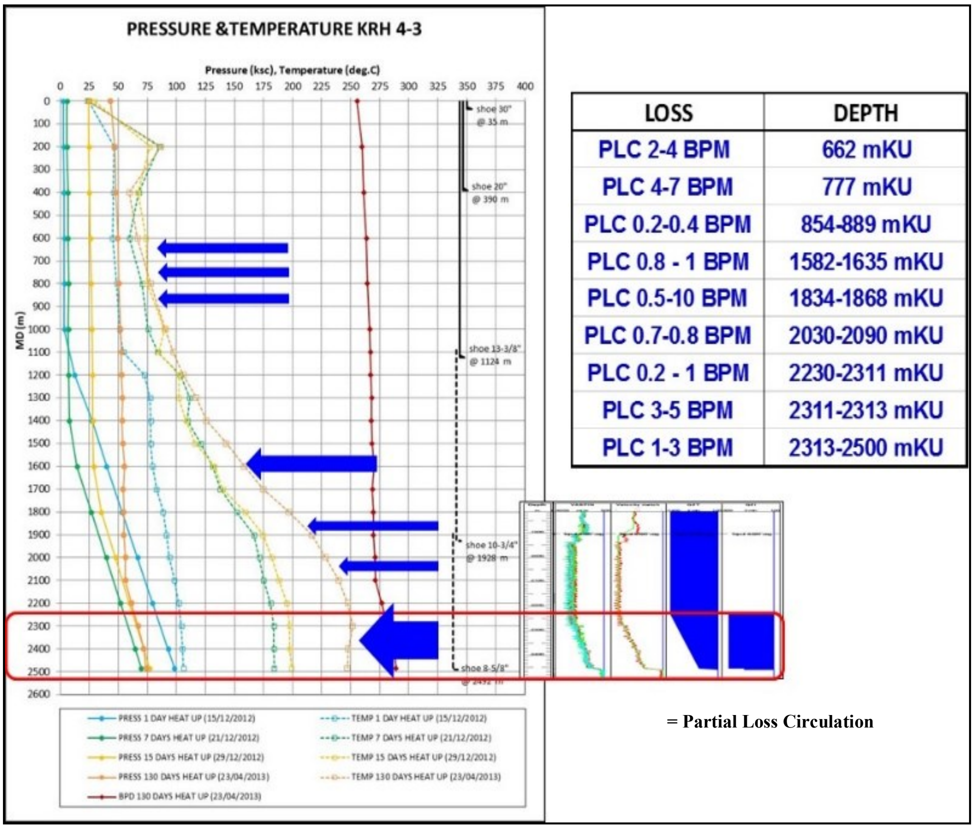


Figure 6: Correlation between loss zone and spinner data in KRH – 4.3

3.1.2 KRH – 5.2

In KRH - 5.2, the tool logged for interval 1971 – 2402 mD. Based on the spinner data on these wells , there are 4 zones that have spinner response , ie the depth interval from 2062-2486 mD by injection at 50.3 % , then the depth interval from 2105 -2182 mD by injection at 13.2 % , then the interval 2270 - 2232 mD with injection of 4.45 % and at depth below 2400 mD with injection 32% . Permeability zone at the first interval is a zone with the greatest response to injection so it is assumed that this zone is the greatest permeability and contribute to the production wells . From FMI image data showed that the fracture that develops in these depth interval is not too intensive, but at a depth of 2078 there is a zone with a thickness of about 0.3 - 0.5 m which is interpreted as a lithological contact zone between tuff and tuff breccia which is these lithology are belong with Fm. G Sadakeling as the reservoir. As there is no intensification of fractures that develop in the depth interval so the lithological contact zone is believed to be the main permeability zones that contribute to the response the injection of the spinner was 50.3 % . In the second interval permeablitas zone (2105 - 2182 mD) , the FMI image data shows that in these interval there was no suspicion other than open fractures and faults that developed quite intensively on the lithology of lava that is expected to provide contribution the permeability and cause the spinner response of 13.2 %. Likewise with the third interval permeable zone (2270 - 2320 mD) the appearance from the FMI image is dominated by closed or open fractures in the breccia and lava lithology.

This lithological contact between the two seems to have been covered by the alteration minerals that does not produce good permeability zones . Therefore, the resulting of response spinner is not too significant, which was only 4.45 % . While the case is interesting to take a look at the interval permeability zone 4 (2348 - 2402 mD) the depth interval where the FMI image data showed a resistive or closed fractures is quite intensive in volcanic breccia lithology, but if we look at the response spinner generated in the depth interval large enough that is equal to 32 % then there is a suspicion that the permeability in the depth interval is controlled by a primary permeability rock matrix . If we look at the form of volcanic breccia lithology then there is the possibility of control permeability of the rock matrix breccias are given the lack of uniformity of grain size making up the rock so as to form an open texture pack which can be interpreted fluid flow . Whereas if we compare with the actual data drilling ,permeability zone is quite reasonable because of the depth of 172 mD to TD the well drilling activities have entered a total loss circulation zones.

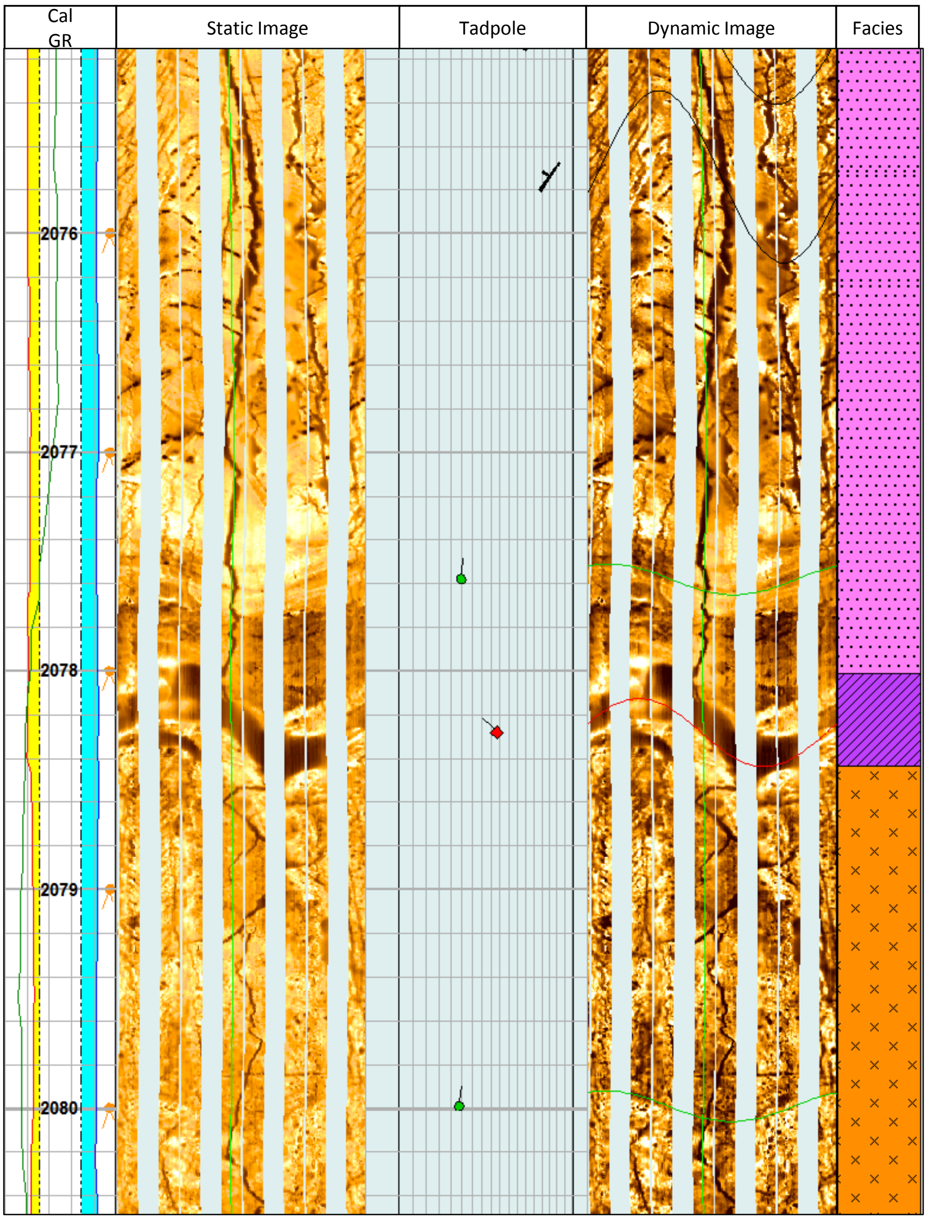


Figure 7: Borehole image data at interval 2075 – 2080 mD in KRH – 5.2. Lithological contact between tuff and tuff breccia might be responsible to the spinner response.

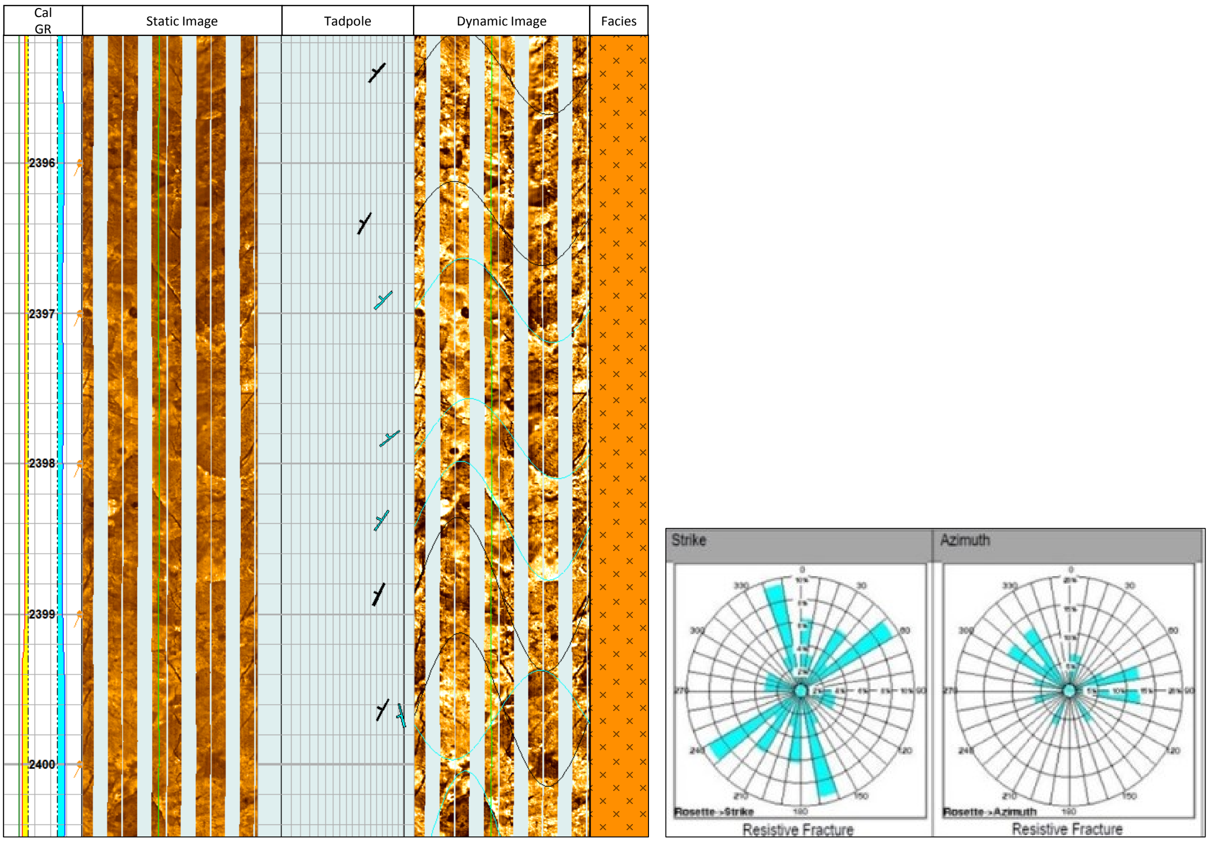


Figure 8: Borehole image data with RF dominant orientation at below 2395 - 2400 mD in KRH – 5.2. Matrix permeability in tuff might be responsible to the spinner response.

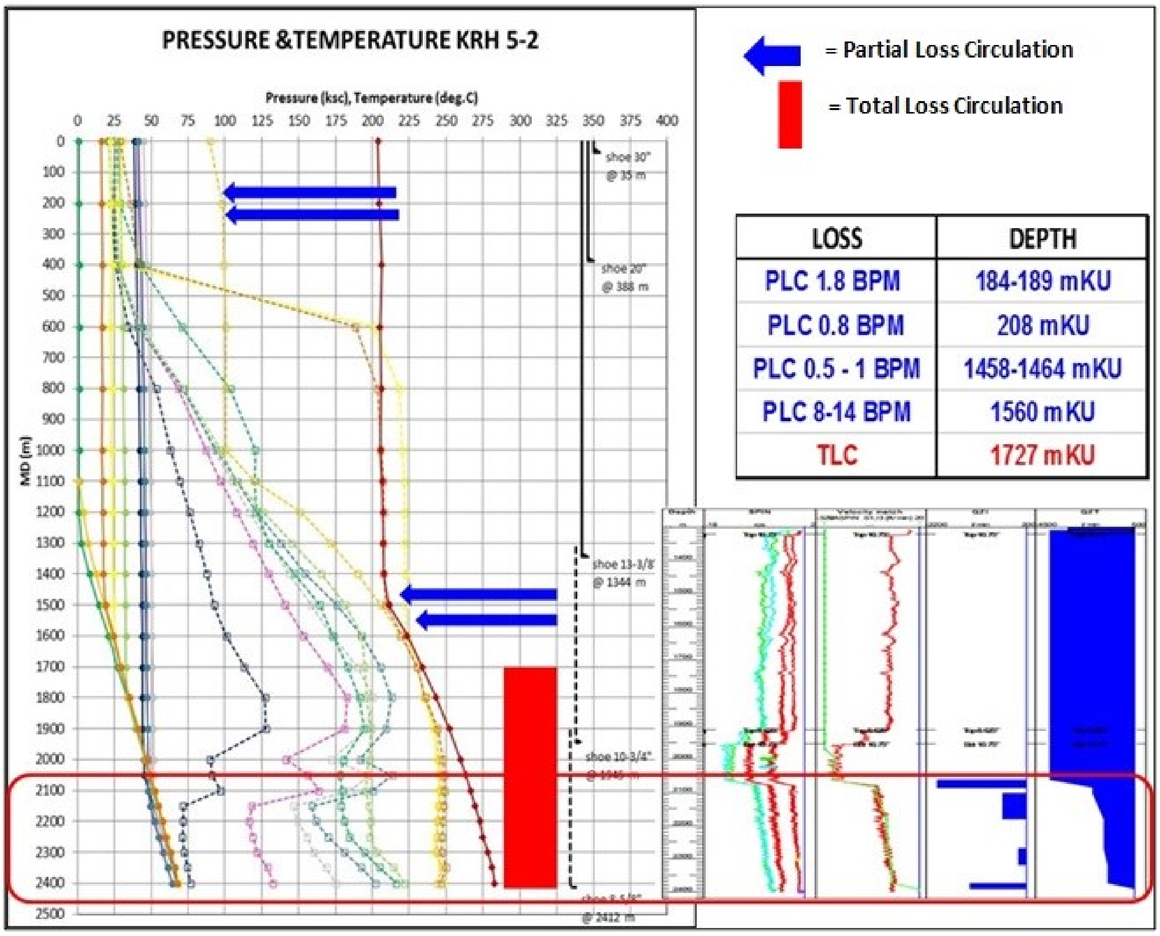


Figure 9: Correlation between loss zone and spinner data in KRH – 5.2

3.2 LUMUT BALAI FIELD

From the geological mapping, Fm. Post Calderic Unit & Fm. Old Lumut Volcano consist of lava andesite and pyroclastic product that lay in the middle and eastern part of this field. From borehole data that dominantly penetrate this formation, Fm. Post Calderic shows the litology is dominated with volcanic breccia and followed with lava and tuff. A large scale of stratovolcano has assumed correlate with this formation. Earlier, Fm. Old Lumut Volcano is interpreted as a product of central volcanic eruption complex and covers a lower part of caldera. This formation consists of andesite and layering with tuff lapilli and volcanic breccia. N-S and NE-SW structures are believed as a permeable structure and contribute to the fluid flow in this field. The NE – SW section that illustrates subsurface feature trough the both of wells is below.

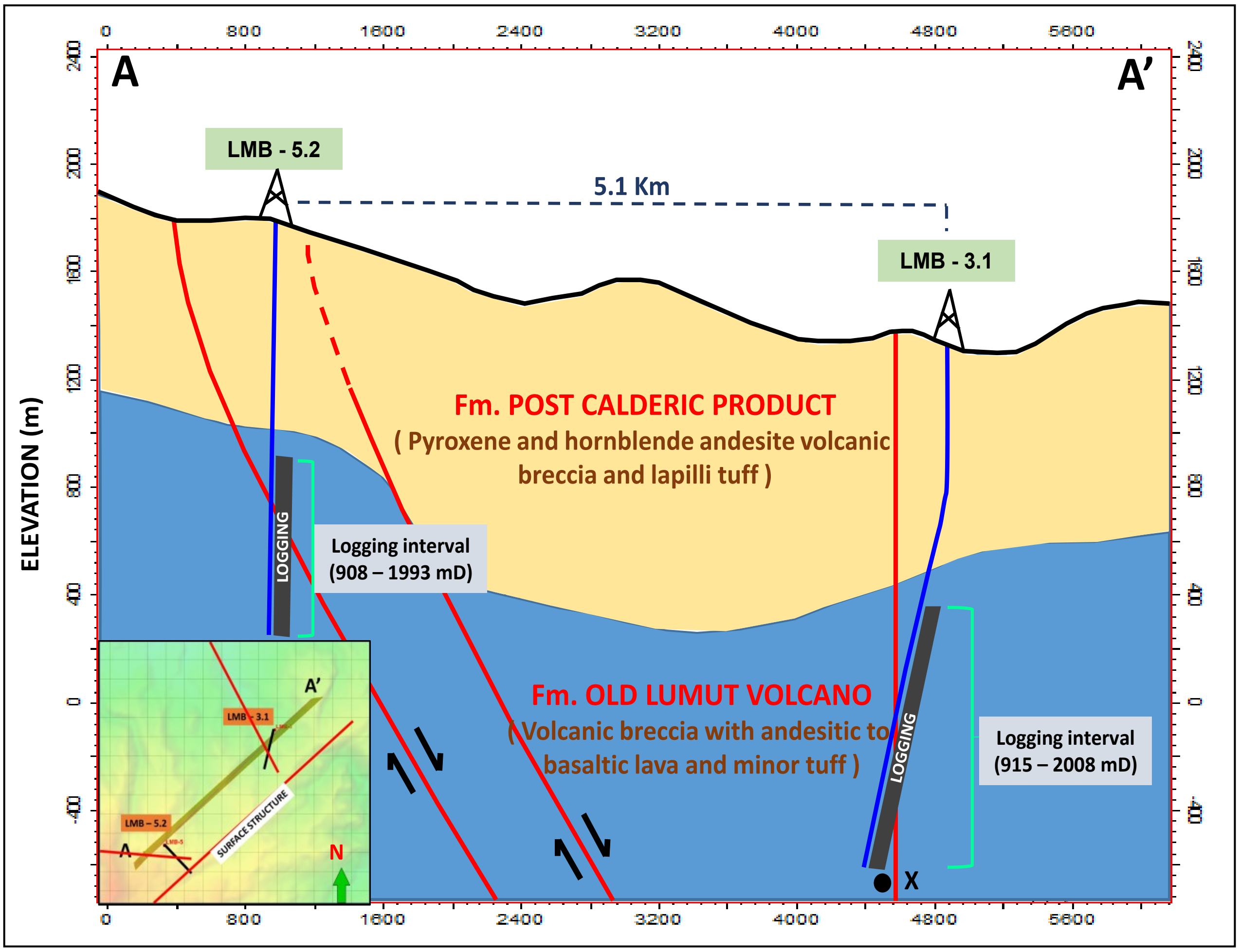


Figure 10: NE - SW section of Lumut Balai Field

<u>3.2.1 LMB – 5.2</u>

LMB – 5.2 logged for interval 908.5 – 1993 mD. Based on spinner data from the well LMB - 5.2 there are 2 zones which provide a response that is in PLT 1 zone in 1640 to 1727 mD depth interval with the injection 85.97 % and the PLT2 zone in the interval 1785-1865 mD with injection 14:03 % . From the appearance of the FMI data, PLT 1 fracture zones that develop effective enough that consists of an open fracture which is expected to drain the fluid. The major fractures are NE - SW and NNE – SSW at lava lithology. Likewise with the FMI appearance PLT 2 zone where the opening fracture can be interpreted quite intensive to drain fluid. Then, if we have correlated with loss circulation data, In the well LMB - 5.2, the loss circulation zones have been found since 1386 mD to TD. Zone which gets the spinner response is included in the loss circulation zones . In the process of drilling, which is the target of future drilling will likely be focused to the target structure that associated with intensification of open fractures in the well LMB - 5.2 .

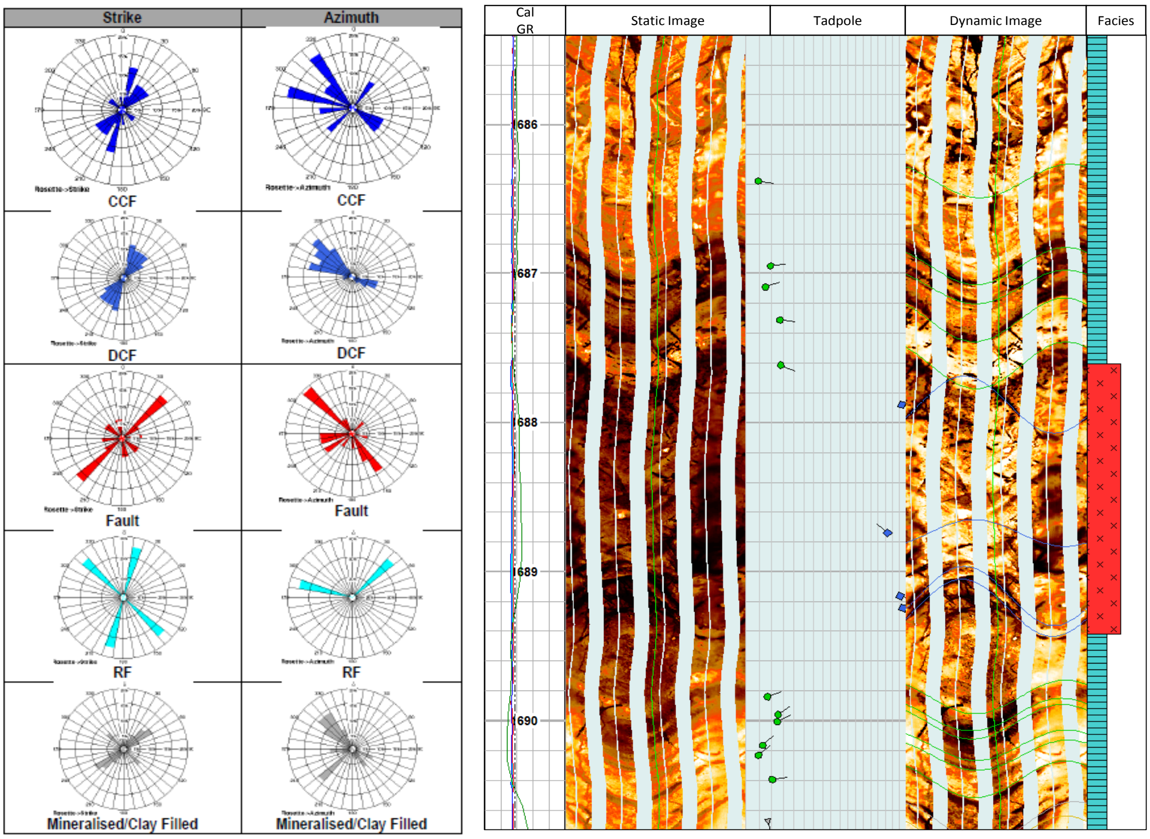


Figure 11: Borehole image data with dominant orientation at interval 1686 – 1690 mD in LMB – 5.2. Open fracture might be responsible to the spinner response.

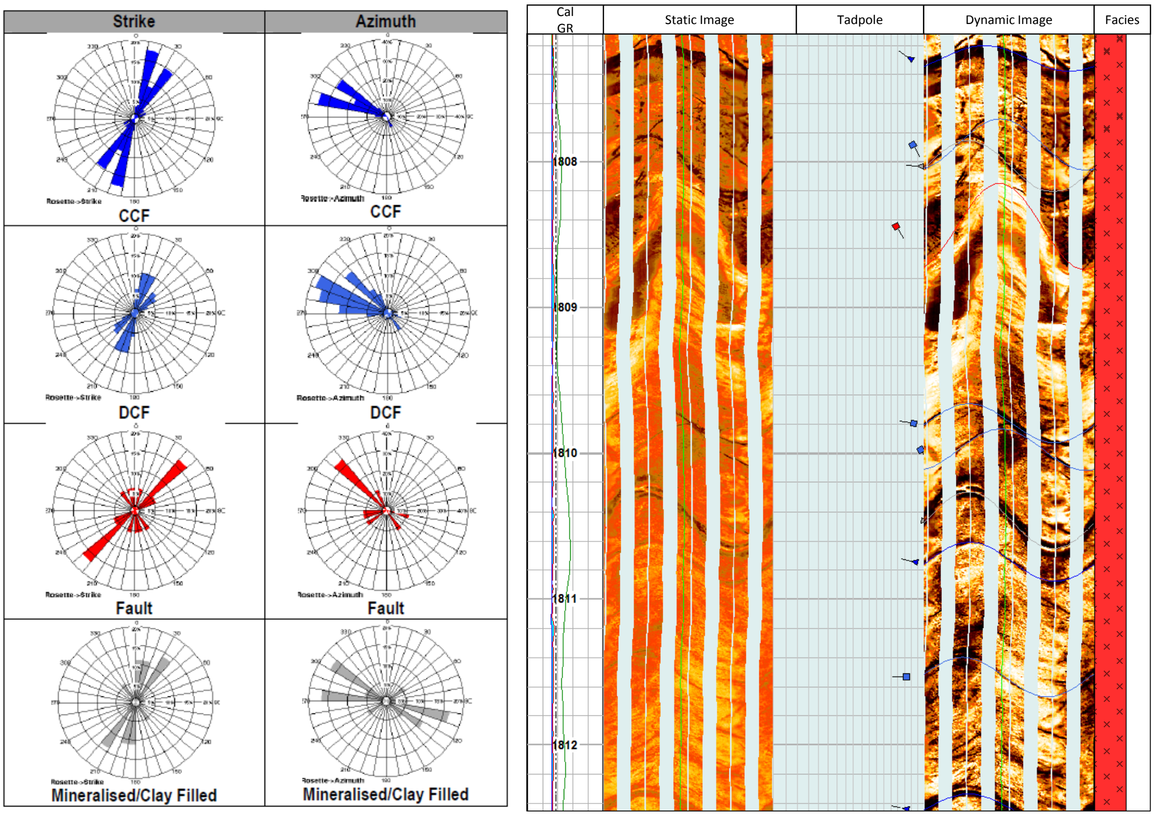
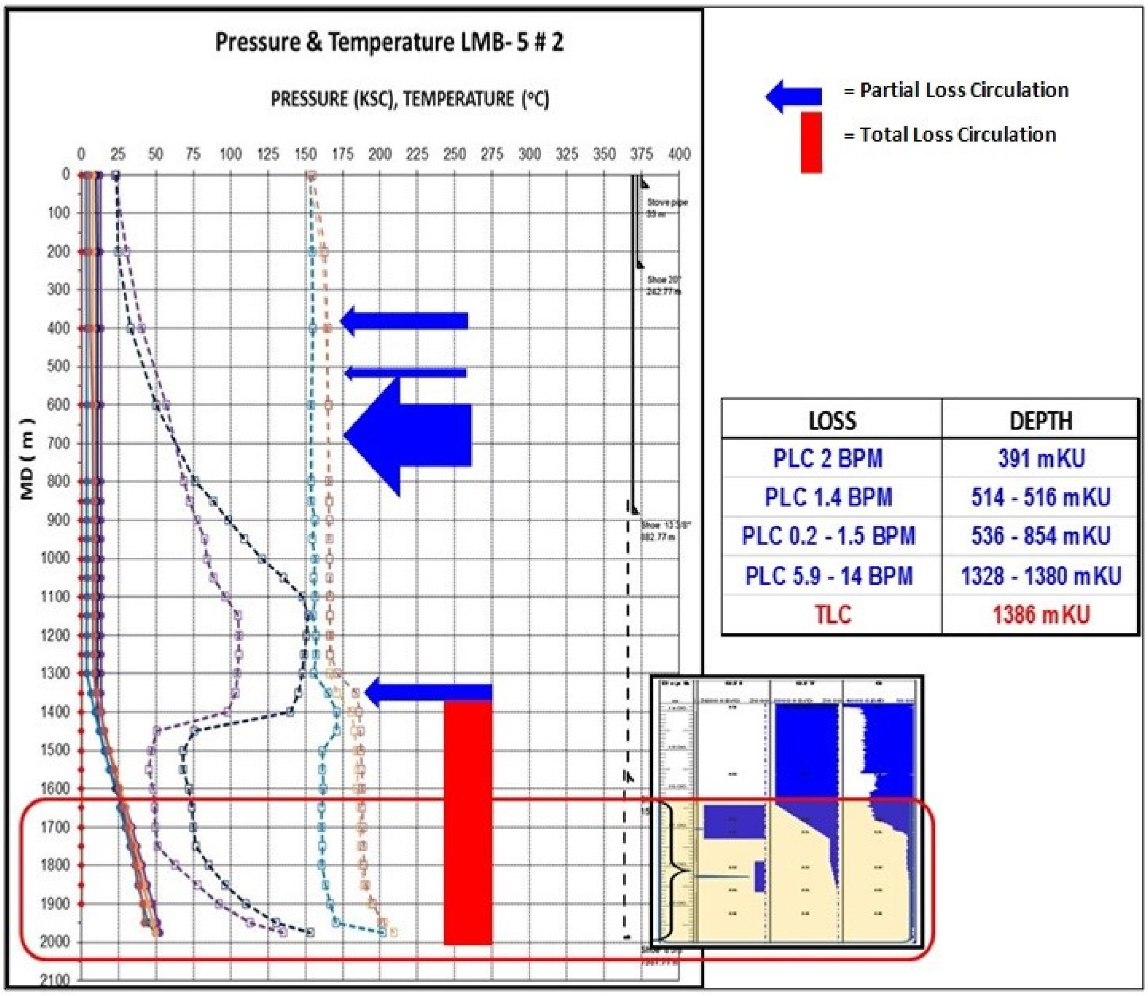


Figure 12: Borehole image data with dominant orientation at interval 1807 – 1813 mD in LMB – 5.2. Open fracture might be responsible to the spinner response.



LOSS	DEPTH
PLC 2 BPM	391 mKU
PLC 1.4 BPM	514 - 516 mKU
PLC 0.2 - 1.5 BPM	536 - 854 mKU
PLC 5.9 - 14 BPM	1328 - 1380 mKU
TLC	1386 mKU

Figure 13: Correlation between loss zone and spinner data in LMB – 5.2

3.2.2 LMB – 3.1

LMB 3 -1 logged for interval 915 – 2008 mD. Based on the spinner data that conducted on these wells, there are 4 zones that have spinner response , ie the 995-1182 mD interval are injection by 19 % , then the interval 1443-1452 mD with the injection of 3% , then the interval 1498 - 1517 mD with injection of 10% and at depth in the interval 1731-1739 mD with the injection of 100 %. Permeability zone at the last interval is a zone with the greatest response to injection, so it is assumed that this zone is the zone with the greatest permeability and contribute to the production wells . FMI image of the data showed that the fracture that develops in the depth interval is not too intensive, but at a depth of 1734 there is a conductive zone with a thickness of about 1 m which is interpreted as a fault with large openings. As there is no intensification of fractures that develop in the depth interval of the fault zone is believed to be the main permeability zones that contribute to the response to the injection of 100 % spinner.

In the first interval permeablity zone (995 - 1079 mD), the FMI image data shows that in the interval there is no open fractures and faults that develop in response to expected spinner that appears due to the permeability of the rock matrix is controlled by the lithology of the volcanic breccia. This lithology is the part of Fm. Old Lumut Volcano that dominated with volcanic breccia then act as reservoir formation. Then in the second interval permeable zone (1443 - 1452 mD) the appearance for the FMI image is dominated by closed fractures. The fault seems to have been covered by the alteration minerals that does not produce good permeablity zone. Therefore spinner response generated was not very significant, which is only 3%. There is also the possibility of the spinner response generated by the fault zone at a depth of 1132 mD is an open fracture. While in the third interval permeability zone (1443 - 1517 mD) the depth interval where the FMI image data showed a conductive or open fractures fairly intensive on tuff lithology, it is estimated that 10% spinner response generated by the secondary permeability . If we compare with the drilling actual data, the depth of the permeability zones is accordance with a depth of total loss that was found at the time of drilling, which is at a depth of 962 mD.

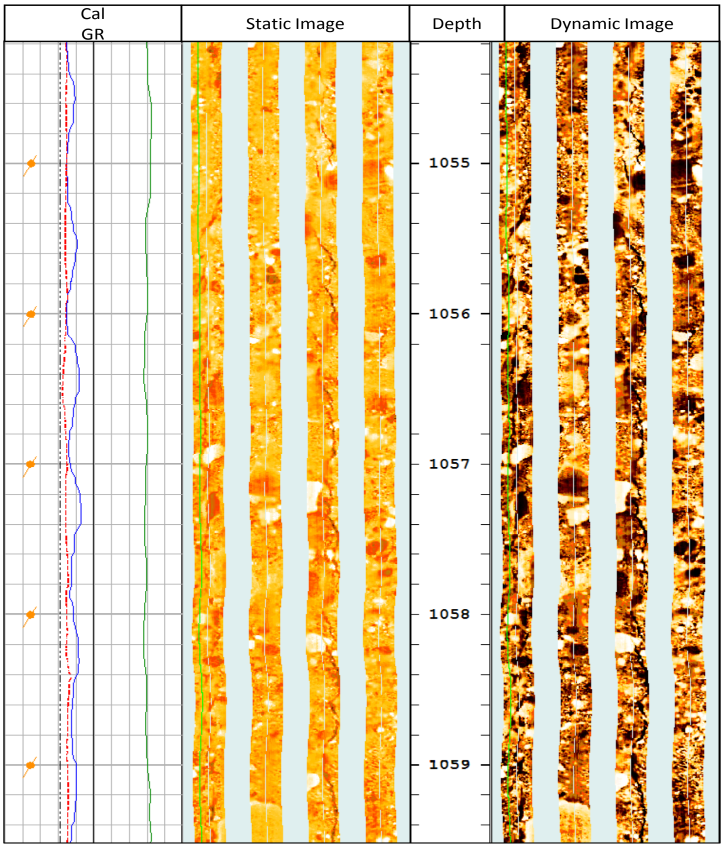


Figure 14: Borehole image data at interval 1054 – 1059 mD in LMB – 3.1. Matrix permeability of breccia might be responsible to the spinner response.

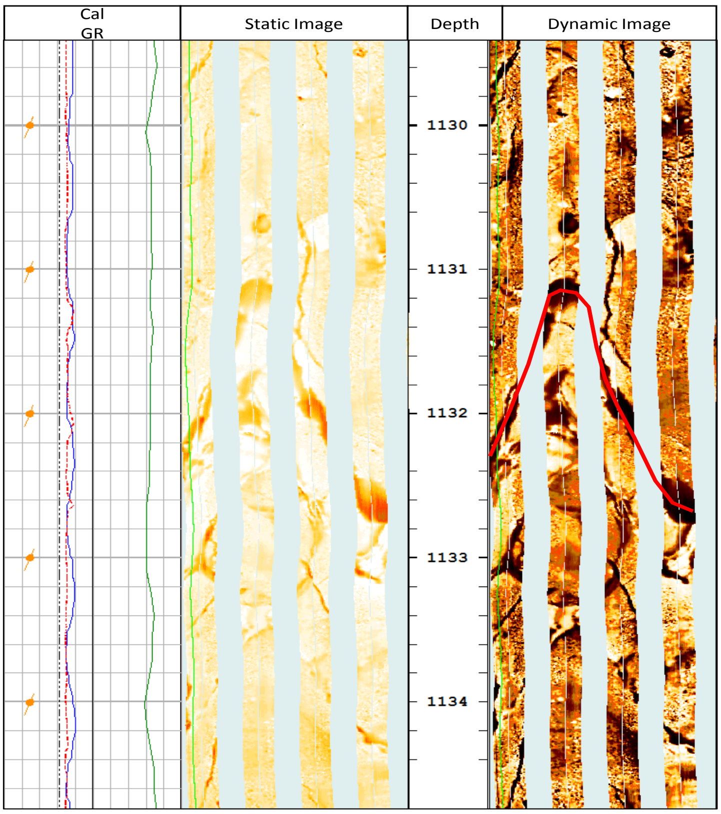


Figure 15: Borehole image data with dominant orientation at interval 1129 – 1134 mD in LMB – 3.1. Fault zone (lithological contact?) might be responsible to the spinner response.

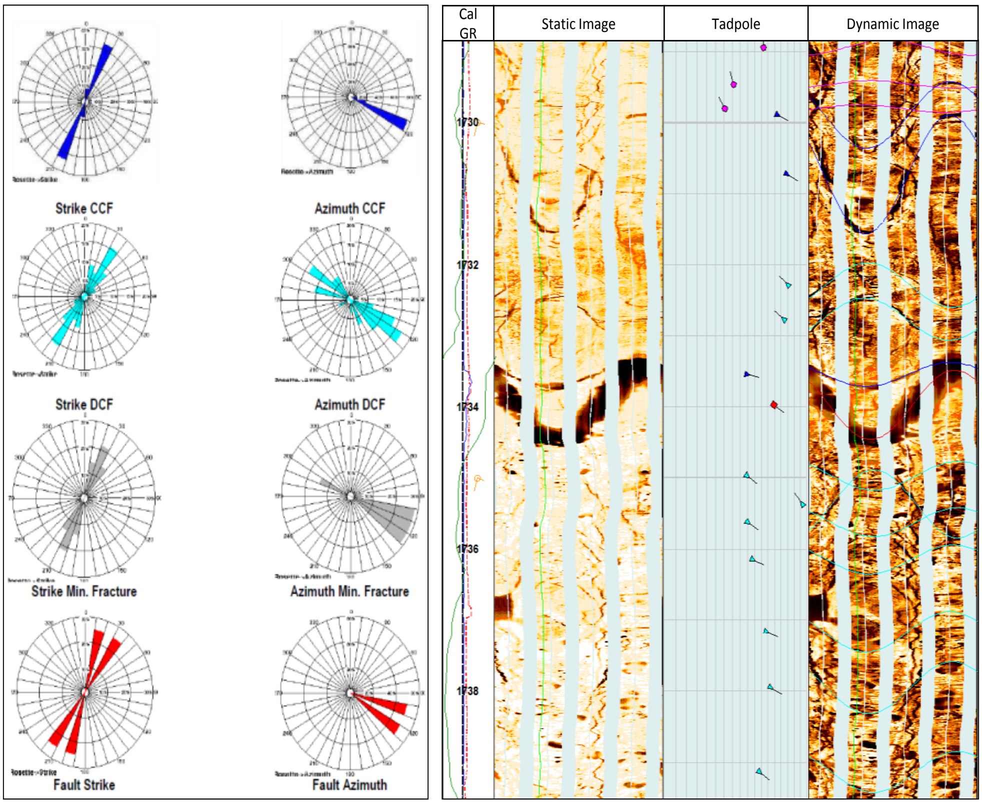


Figure 16: Borehole image data with dominant orientation at interval 1730 – 1738 mD in LMB – 3.1. Fault zone might be responsible to the spinner response.

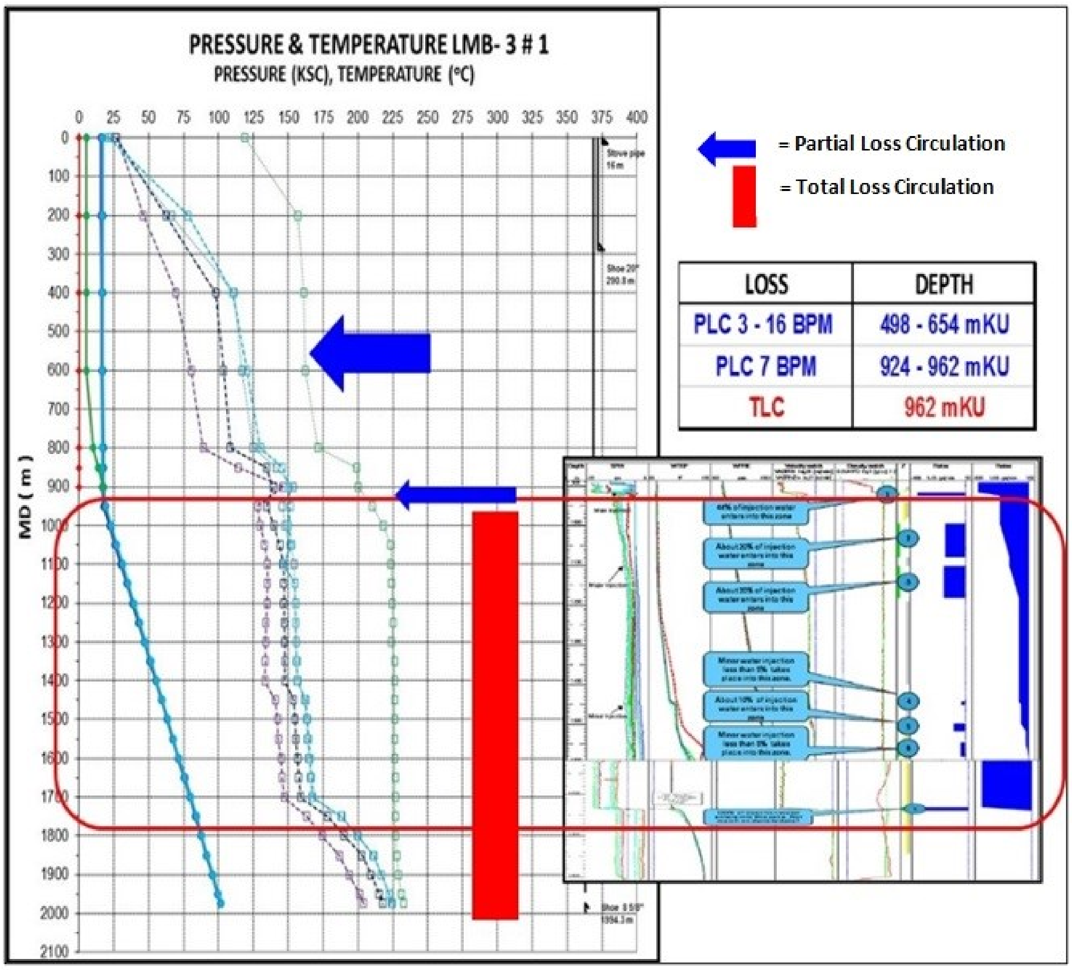


Figure 17. Correlation between loss zone and spinner data in LMB – 3.1

4. CONCLUSION

Spinner response in well KRH-4.3 and KRH-5.2 is controlled by two types permeability, primary and secondary permeability. The role of primary permeability zones indicated by the PLT 2 well KRH-4.3 and PLT 4 zones in well KRH - 5.2 where the permeability of the rock matrix of possibilities generated by the volcanic breccia lithology. While in the PLT 1 Zones in the KRH-5.2, primary permeability also play a role in generating the response spinner with open lithological contact zones are clearly visible between the volcanic tuff breccia. Secondary permeability zones to control most of the PLT which appears on both the wells. From the data FMI known that open fractures and faults are the trending NE - SW fractures. The intensity of fractures in KRH - 4.3 larger than the KRH - 5.2.

Spinner response in well LMB-5.2 is dominantly controlled by secondary permeability and LMB-3.1 is controlled by two types permeability, primary and secondary permeability . The role of primary permeability zones indicated by the PLT zone 1, 2 and 3 in well LMB-3.1 where the permeability of the rock matrix of possibilities generated by the volcanic breccia and tuff breccia lithology. Secondary permeability zones to control most of the PLT which appears on the LMB-5.2 wells. From the data FMI known that open fractures and faults are the trending NE - SW fractures. The intensity of fractures in LMB-5.2 is larger than the LMB-3.1.

From this condition it can be recommended that the target of reservoir can be structures (fractures and fault) , lithological contacts and the rock matrix.

The FMI and spinner logging data is very useful to determine the subsurface conditions. With use the datas are very helpful to interprete structures and lithology through which the wellbore. This is especially useful considering logging is the only tool that can give a real image along the wellbore.

• To determine the permeable zones and permeability controls in the subsurface

• To identify productive zones that can contribute to the production wells

• To estimate the target in the future wells

REFERENCES

Schlumberger PetroTechnical Services, 2009, Study of Well LMB-3.1 based on Formation Micro Imager (FMI*) and Production Log (PSP*) Data : Jakarta, Schlumberger.

Schlumberger Data & Consulting Services, 2012, Fracture Study of Well KRH 4-3 based on Formation Micro Imager (FMI*) Report : Jakarta, Schlumberger.

Schlumberger Data & Consulting Services, 2012, Fracture Study of Well LMB 5-2 based on Formation Micro Imager (FMI*) Report : Jakarta, Schlumberger.

Schlumberger PetroTechnical Services, 2013, Fracture Study of Well KRH 5-2 based on Formation Micro Imager (FMI*) Report : Jakarta, Schlumberger.

Asquith G.,and Krygowski D.,2004, Basic Well Log Analysis Second Edition : Tulsa, Oklahoma, AAPG Methods in Exploration Series, No. 16 p.151.