PROCEEDINGS, 48th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 6-8, 2023
SGP-TR-224

Individual Feedzone Characterization in Two Phase Geothermal Reservoir for Preliminary Indication While Drilling: A Case Study Dieng Field, Indonesia

Rizkhy Ridoh Alamsyah, Siti Olivinia Yusra, Iqbal Maratama and Maxwell Wilmarth

PT Geo Dipa Energi, Jl. Akses Tol Soroja, Blok Sumakamanah Parungserab, No.22, Parungserab, Soreang, Bandung

Jacobs Indonesia, Talavera Office Park, 15th Floor, LetJen. TB. Simatupang Street, Kav. 22-26, Jakarta, DKI Jakarta

rizkhy@geodipa.co.id

Keywords: Feedzone, drilling parameters, borehole image, PTS Injection

ABSTRACT

One of the key points for productive zone in geothermal reservoir is permeability. Permeability in most geothermal system is controlled by the presence of fractures. The result of well completion is a guidance to define feedzone location which is controlled by permeability. Feedzone characterization is important for geological and reservoir analysis. Data in this study was taken from production well in Dieng, Indonesia that has two phase reservoir system.

During drilling, the analysis of drilling parameters, loss zones and borehole image gave an early estimation of permeable zones. The determination of fluid flow contribution and feedzone location will be confirmed by the result of pressure-temperature-spinner injection during completion test. Furthermore, initial reservoir characteristic, pressure, temperature, liquid interface and top of reservoir will be confirmed by pressure-temperature data during heat up process. The objective of this study is to find out preliminary individual feedzone characteristic while drilling to determine the potential feedzone. It is also complemented for future geothermal well targeting based on drilling and subsurface aspects that potentially provide a productive zone in future.

1. INTRODUCTION

Dieng Field permeability allegedly influenced by primary permeability which is lithological contact and secondary permeability influenced by tectonic setting. Lithological contact between altered andesite unit and pyroclastic forms weak zones which acts as permeable zones and is thought to be responsible for the loss circulation zones in several places. The contact/foliation distribution is controlled by the correlation between the presence of andesite unit based on offset well data.

The structure geology of Dieng Field has been constructed utilizing the information collected from surface geology mapping and lineaments analyses, as well as subsurface information collected during drilling and well testing such as PLC/TLC zones, drilling breaks, PTS, and identification from MEQ events were also reviewed to support the interpretation.

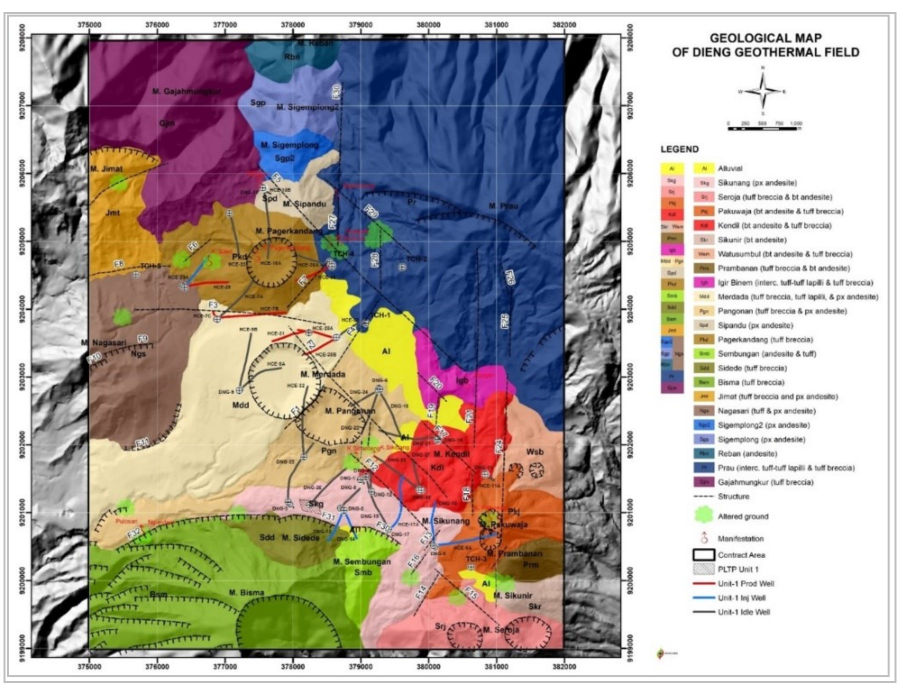


Figure 1: Geological Map of Dieng Geothermal Field

Dieng Geothermal Field is located ±110 km to the northwest of Yogyakarta City, Central Java Province, Indonesia. It is situated on the eastern part of North Serayu Gea-anticline (**Figure 2**), which is influenced by the southern Java subduction zone. The main structures that control Dieng Field are shear fractures with NW-SE trend and extensional fractures trending W-E and N-S (Detail Geological Mapping report by GDE in 2013, unpublished report). Some of the N-W and W-E extensional fractures formed normal fault. Fault which are caused by volcanic activities shows W-E trend. Dieng Geothermal Field is situated within a volcanic mountain range with a trend northwest-southeast (NW-SE), which represented by Pagarkendang, Merdada, Sikidang, and Pakuwaja Crater. This trend is inferred to control volcanic activity since the existence of Mount Sindoro and Sumbing, which located in the SE of the field, also following this trend. Pagarkendang and Merdada areas are characterized by relatively deep with high temperature zone and identified as up-flow zones. The reservoir temperature ranges from 300-335°C and production zone below 1400 mASL. Besides, the productive zone in Sikidang area is relatively shallow, low temperature and acidic.

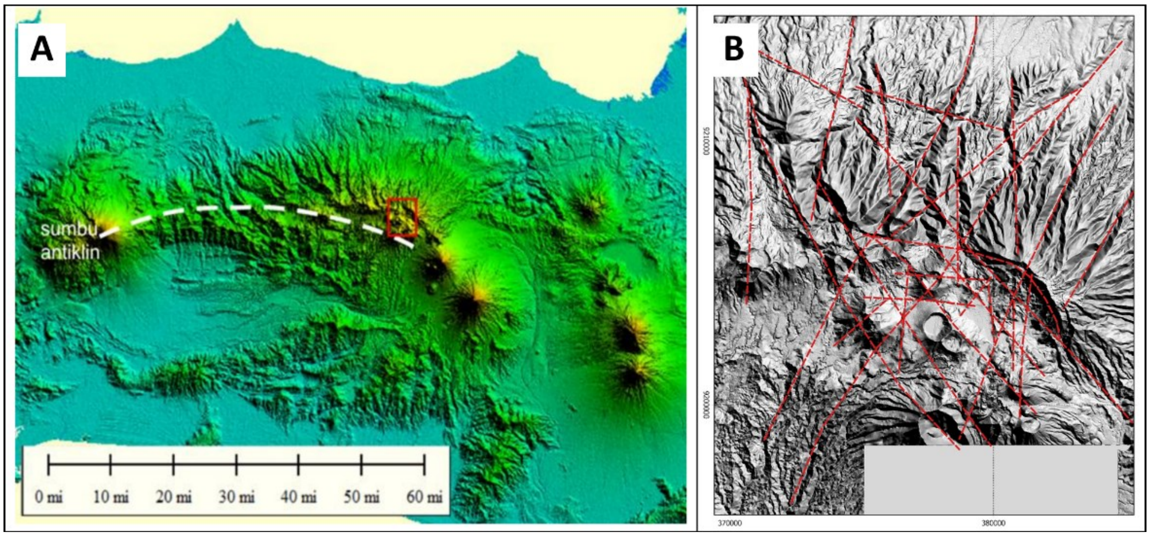


Figure 2: A) Dieng Field (red box) located on the eastern part of North Serayu Gea-anticline, B) Dieng regional lineament from image interpretation. ***Source: Detail Geological Mapping report by GDE in 2013, unpublished report.***

Interpretation regarding the existence of permeability zone in target area commonly measured by borehole image during open hole survey and PTS injection during completion test. Resistivity borehole imaging were conducted to define and analyze fracture within the borehole. Borehole image log could also help to observe lithology along the loss circulation zones. PTS injection survey is used to measure the pressure-temperature-spinner respond during injecting water to wellbore. Respond of spinner will be interpreted as velocity fluid that shows the loss or increase amount of fluid in wellbore. Those survey can show the estimation of feed zone location and its contribution. Correlating these data with drilling parameters will give an early indication of potential feed zone area while drilling.

2. BASIC THEORY

2.1 Drilling Parameter

Various data were taken during the borehole making such as rate of penetration (ROP), weight on bit (WOB), stand-pipe pressure (SPP), measure-while-drilling (MWD) temperature and loss circulation (BPM) interval are needed as preliminary assessment to identify feed zone. Sudden increase of ROP (m/h), while WOB drop significantly, sometimes followed by decreasing of SPP may well interpreted as fracture zone. Within the loss circulation zone, sudden decline of MWD temperature might interpreted as fracture zone in addition no drilling break indication.

2.2 Borehole Imaging

Modern borehole imaging logging tools provide high-resolution images of the borehole wall, in open hole, or of tubulars (casing and tubing) in cased wells. These devices create images either directly, through optical technologies (photographs or video) or indirectly, through a high density of geophysical measurements (electrical resistivity or acoustic reflectivity), Prensky (1999). Resistivity borehole imaging were conducted to define and analyze fracture within the borehole. Borehole image log could also help to observe lithology along the loss circulation zones. Dips were manually picked and further classified into fractures and linear features (**Figure 3**)

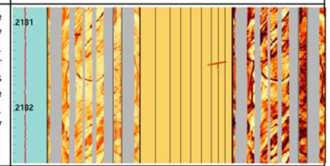
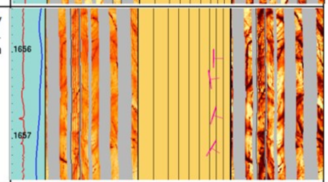
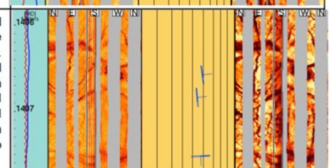
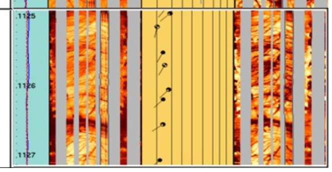
Plane type	Symbol	Description	Image Examples
Resistive fractures		Natural resistive/mineralized fractures are those that have been filled by secondary mineralization making them more resistive. Generally appear as traces that are brighter than the surrounding rock and sometimes demonstrate a "halo" appearance due to the resistivity of the secondary mineralization. Natural closed fractures are generally symmetrical and a sine wave can be fit to them.	
Partial fractures		Partially conductive fractures are not fully resolved and discontinuous around the wellbore. They appear to be partially bright and dark than the surrounding host rock.	
Conductive fractures		Natural conductive fractures are usually filled with drilling mud and appear as traces that are darker than the surrounding formation rock. Natural fractures are generally symmetrical allowing a sine wave to be fit to them. Often terminate in a single lithology, whereas induced fractures often continue through several lithologies. If the orientation is the same as an induced fracture, then it may not be possible to differentiate between the two types.	
Foliation Plane/Joint		Observed as low angle planar features or layering in the static and dynamic images typically with dip magnitude of <40 deg. Often shows consistent bedding trend across the adjacent bedding	

Figure 3 Dip classification

2.2 Completion Test

After drilling phase is completed, some test will be applied to observe the characteristic of the reservoir during injection amount of water by utilizing the drilling rig equipment. First test that immediately run was completion test. Completion test consists of series surveys **(Figure 4)** such as dummy run, pressure-temperature-spinner (PTS Injection), multiple-rate-injectivity test (II Test) and fall-off-test (FOT), Humaedi (2016). The objective of these test is to identify feed zone location/thickness, individual feed zone contribution, pressure-temperature profile during injection, well injection capacity/ injectivity index, near wellbore permeability and boundary.

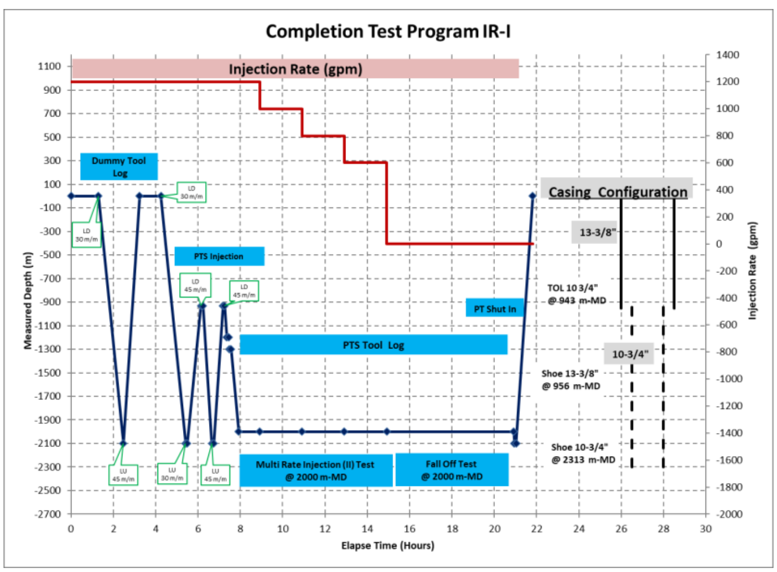


Figure 4: Completion Test program for IR-I

During PTS injection survey, PTS tool with Surface-Read-Out (SRO) measurement was used to observe the response of pressure-temperature-spinner in the well with real-time reading data. PTS injection was conducted at least with two up and down profiles that be made at different logging speed a long-perforated liner section for one stable injection rate. This procedure is carried out to obtain an accurate transformation of spinner frequency data into a fluid velocity profile. The survey should also extend into production casing by 50-100 meters for data and equipment quality check.

Pressure profile will show the depth of liquid interface and can be used as an early qualitative indication of permeability characteristic at that well. Several cases in two-phases reservoir show under pressured during cold water injection, so there are indicated inflow of hotter fluid from formation into wellbore. This condition usually can be determined by looking at characteristic of stepped temperature profile, with isothermal section between inflow zones. **Figure 5** shows such stepped temperature that representing inflows of hot fluid. When this profile found in two phase system, the value of injectivity index (II) from the completion test should be corrected by using mass heat balance equation to give more accurate value.

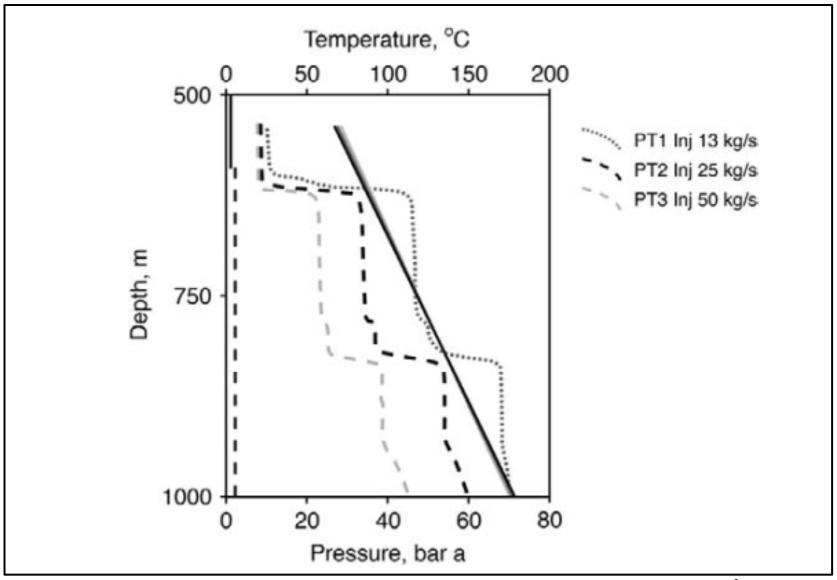


Figure 5: Stepped profile during injection in TH6. ***Source: Geothermal Reservoir Engineer 2nd Edition, Malcolm A. Grant and Paul F. Rixley.***

Spinner will give a respon of fluid flow in well. Result of spinner itself is measured in round per second on the logging tool. Before analyzing the data, several aspects should be considerate, such as schematic of well, depth correction, stable logging speed during logging up/down and type of blade use for injection condition. The data from spinner response combined with the stable logging speed will be converted to fluid velocity. Furthermore, these data analyzed to quantify mass loss or contribution to each identified feed zones.

3. CASE STUDY

IR-I and IR-6 are 2 wells that observe in this study that have two different target area. IR-I is targeting near to Pagarkendang Crater, while IR-6 is targeting to deep permeability away from crater around. Both of wells are operated by PT. Geo Dipa Energi in Indonesia.

3.1 IR-I

IR-I ground cellar sited at 2074 mASL and is a production well that drilled inside Pagarkendang Crater toward northwest with production casing sat at 981 mMD/1130 mASL and total depth at 2328 mMD/-104 mASL. Borehole image log conducted from 1020-2312 mMD and the last cutting return from 1392 mMD. Well completion test done with maximum depth at 2100 mMD, consist of pressure-temperature-spinner (PTS) logging with injection rate of 1200 GPM and multiple-rate-injectivity test (II) test with 4 injection rates (1200, 1000, 800 and 600 GPM).

First partial loss zone with 5 BPM observed at 1222 mMD/ 912 mASL during drilling. Drilling parameters showed drilling break with drop of WOB from 22 klbs to 7 klbs and SPP from 1691 psi to 1289 psi while ROP slightly increased from 9 m/h to 17 m/h. First total loss observed at 1277 mMD/862 mASL without anomaly from drilling parameters and the borehole making continued with aerated drilling and the return is intermittent (PLC 14-19 BPM). Continuous total loss observed from 1392 mMD/756 mASL to total depth.

Borehole image log conducted within 12-1/2" hole section with interval 1020-2312 mMD. The overall data quality is good except for some disturbed intervals affected by borehole breakout that pose challenges for features identification. A total of 1123 dips were manually picked and further classified into fractures and linear features **(Figure 6)**. Two major trends of foliation plane can be observed from top towards south-west and switching toward east to the bottom. Conductive fracture with dominant NNW-SSE strike were identified with total 35 fractures. The upper section exhibits two dominant directions in the N-S and ENE-WSW while the lower section exhibits NNW-SSE strike. Partial fractures with total 644 were identified shows N-S and NNE-SSW strike direction. A total of 66 resistive fractures were identified with N-S strike direction. The estimated mean for fractures aperture is 3.85-mm with maximum aperture is 10-mm. The aperture becomes bigger towards the bottom hole, which is 1-mm to 3-mm on the upper section changes to 5-mm to 10-mm on the lower section of the well.

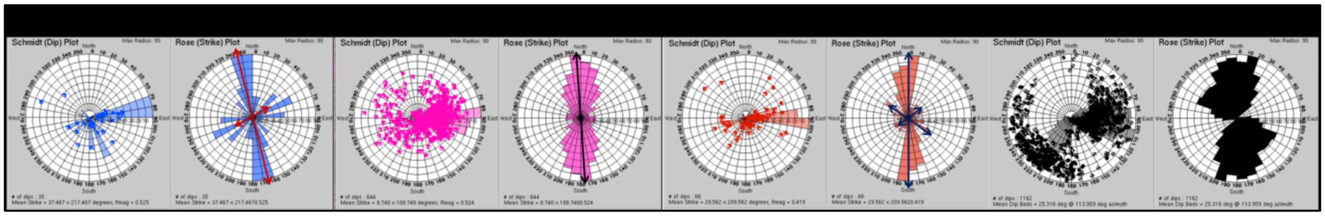


Figure 6: Partial and resistive fracture shows mainly N-S strike direction while conductive fractures exhibit NNW-SSE strike direction

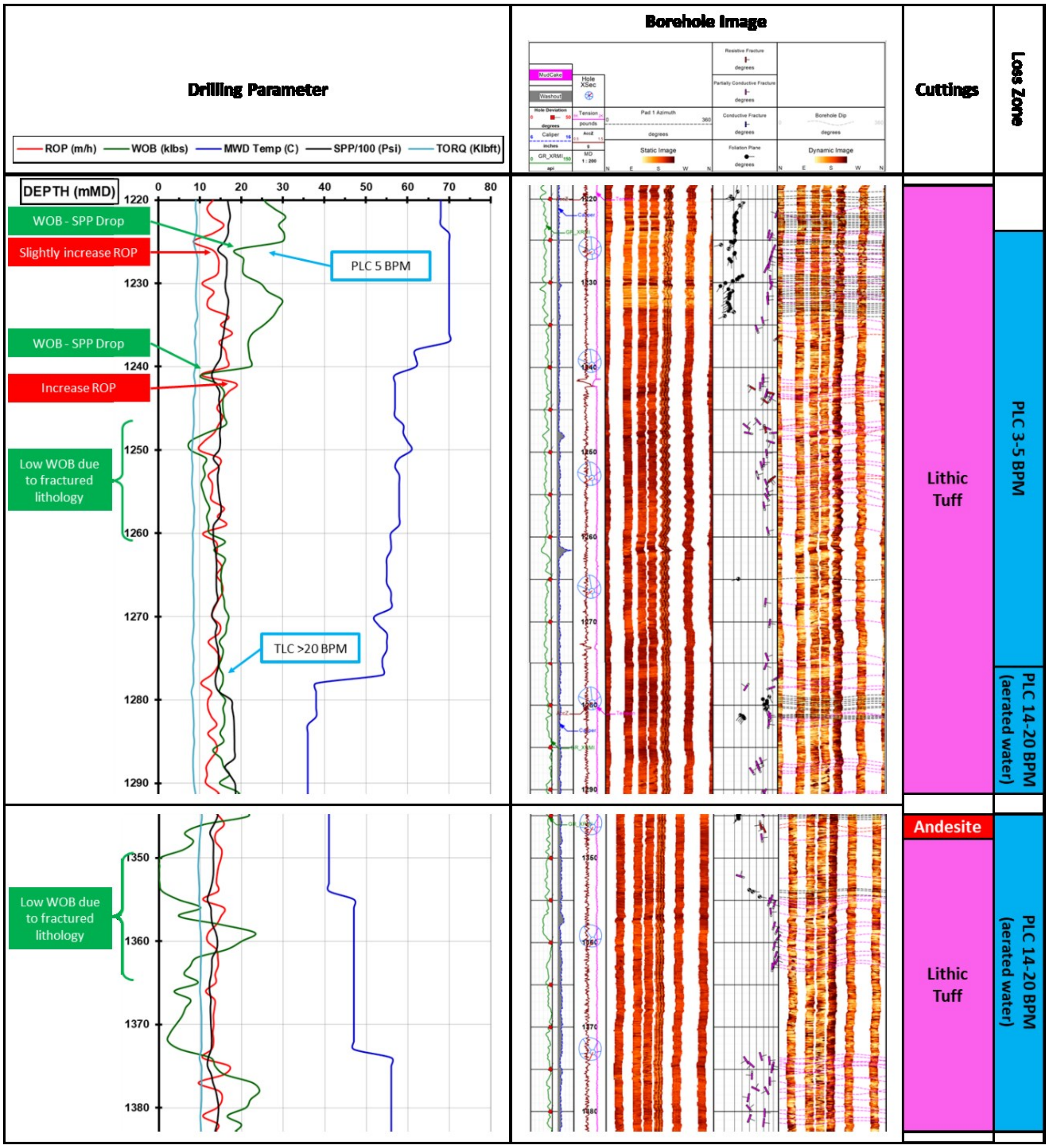


Figure 7: Drilling Parameters compared to borehole image data. Interval 1220-1290 mMD shows correlation between first loss observed correspond with high density fracture. Interval 1350-1380 mMD shows low WOB during drilling correspond with permeable zone frequently controlled by partial fractures.

Based on borehole image data, loss circulation zones during drilling correspond with high fracture density interval which are 1120-1680 mMD, 1750-1850 mMD and 2100-2250 mMD. Permeable zone frequently controlled by partial fractures with low aperture characteristic resulted the lack of significant drilling breaks existence (**Figure 7**). Several drilling breaks observed during drilling particularly related with slightly decrease of WOB and SPP. Sudden or gradually declined of MWD temperature during drilling correspond with some interval of fractures for example at 1780 mMD, 1980 mMD and 2108 mMD.

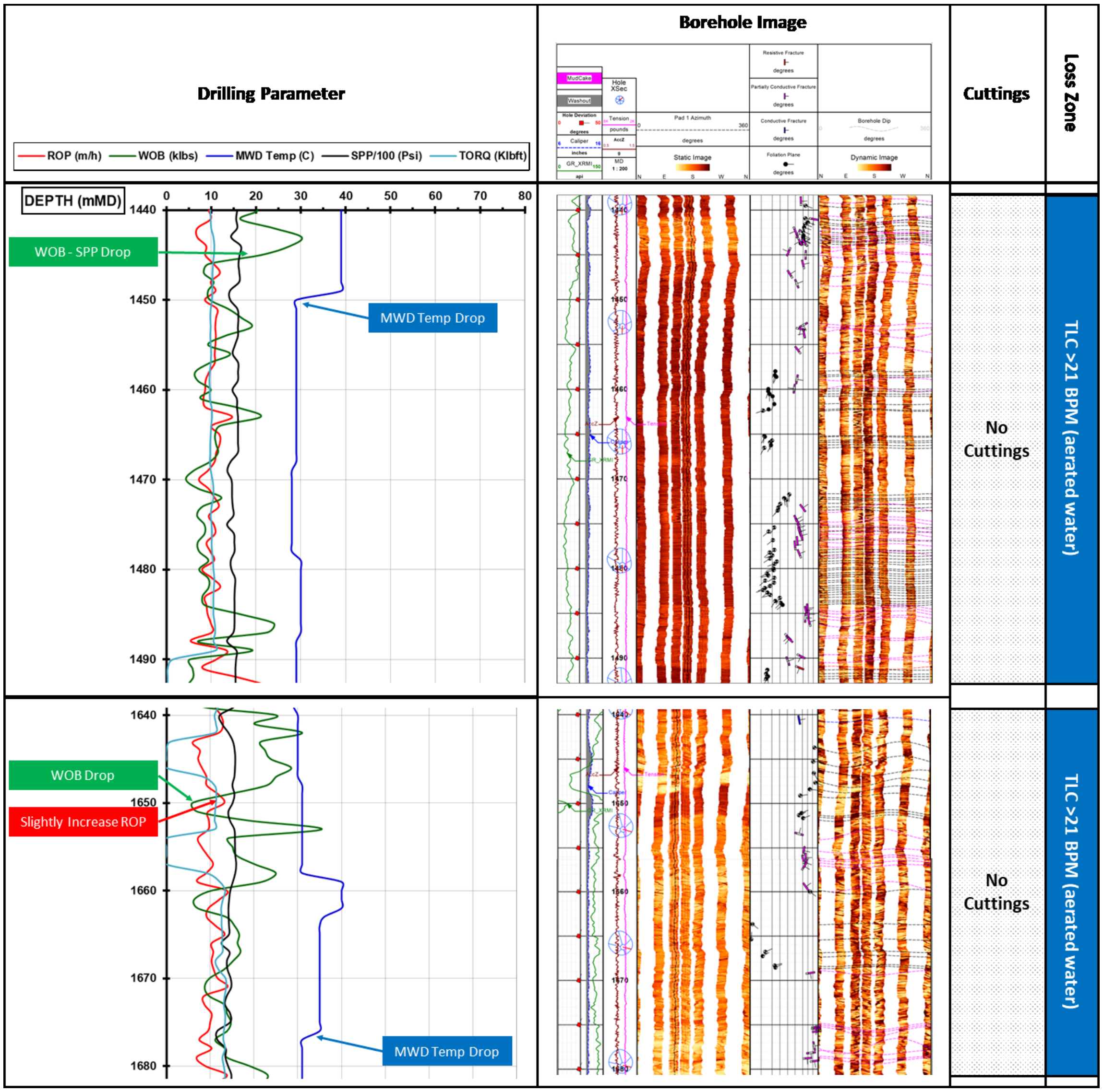


Figure 8: Interval 1440-1490 mMD and 1640-1680 mMD shows lack of drilling break during drilling correspond with permeable zone frequently controlled by partial fractures with low aperture.

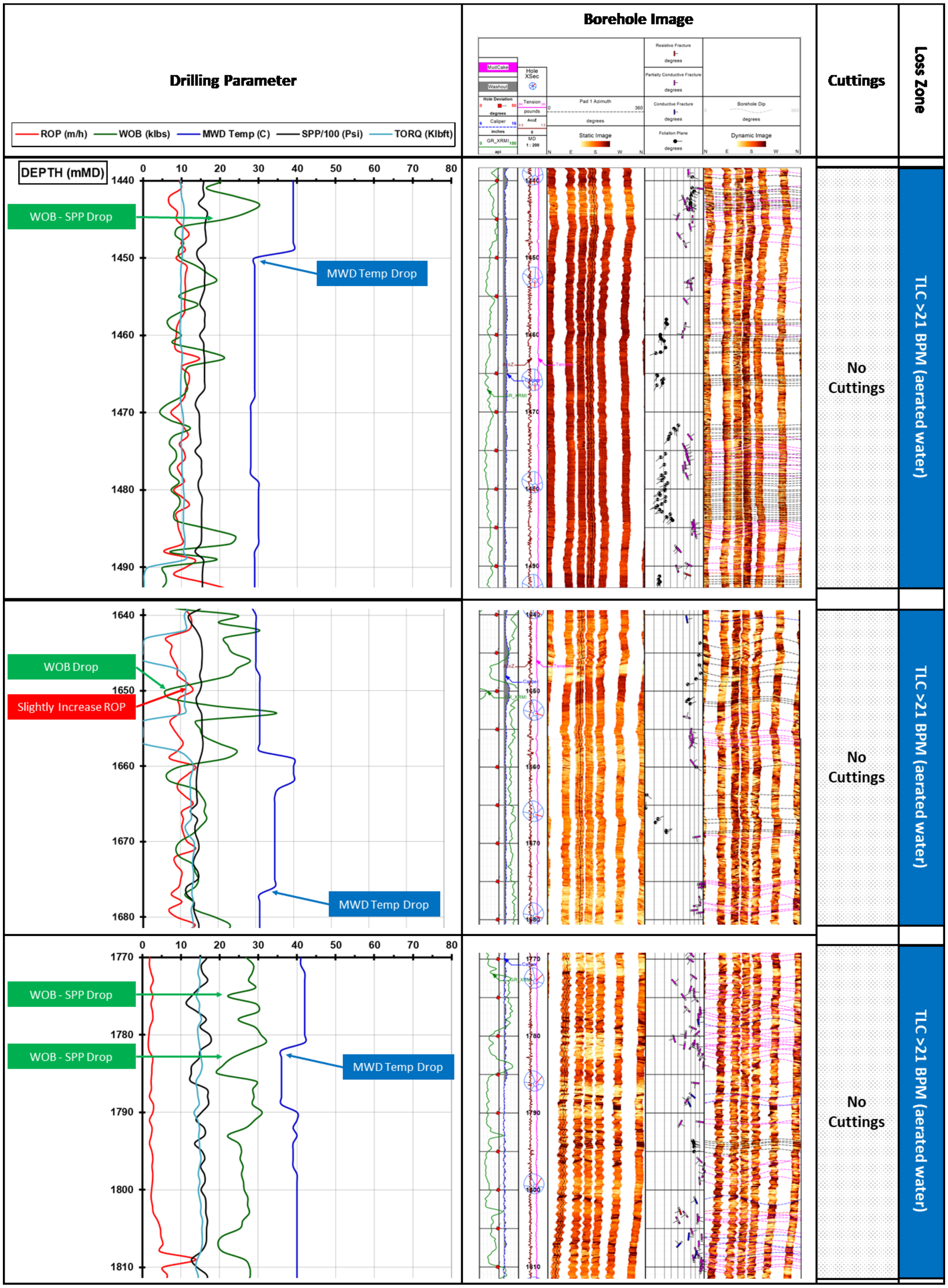


Figure 9: Fracture zones dominated by partial fractures at 1440-1490 mMD, 1640-1660 mMD and 1770-1810 mMD.

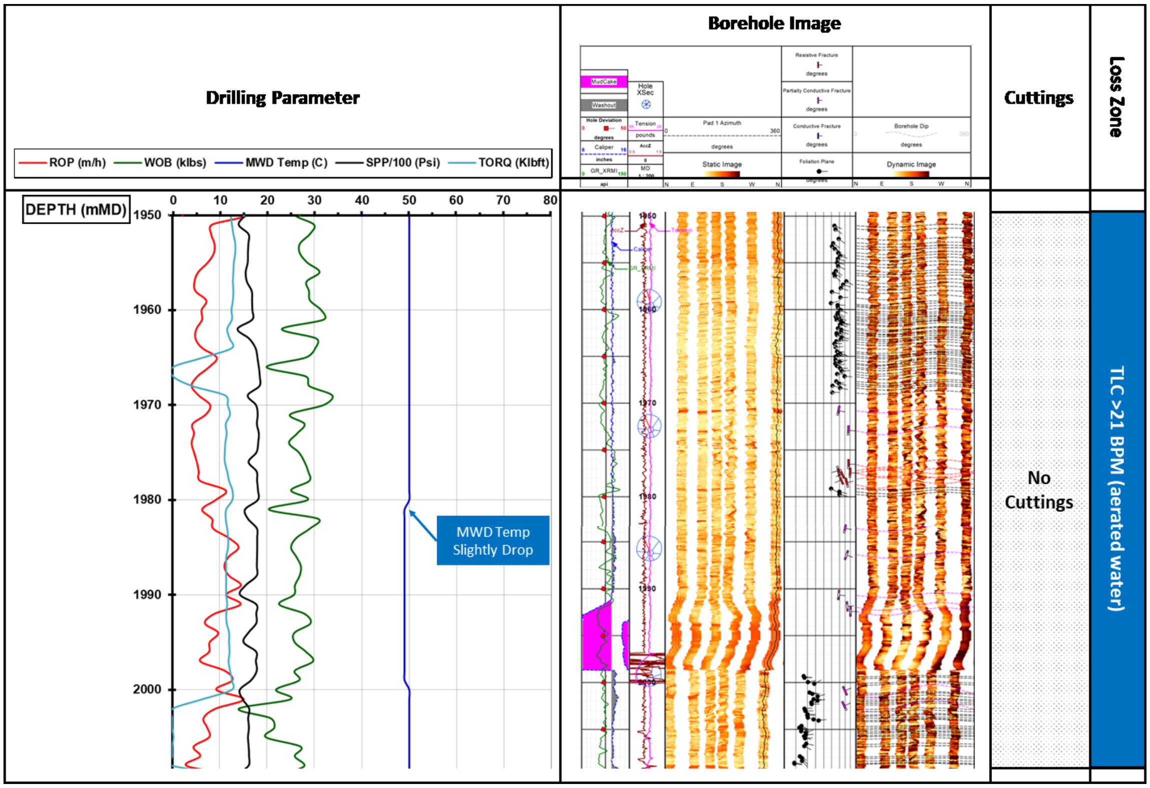


Figure 10: Interval 1950-2090 mMD shows slightly erratic WOB and gradually declined MWD Temperature correspond with feed zone from 1985 mMD which has low contribution correlated with fractures zone mainly controlled by bedding/foliation

Completion test (**Figure 11**) shows a stable pressure-temperature profiles under injection and a good spinner response. Based on pressure and temperature data, liquid level observed at 700 mMD/1392 mASL and found quite thick inflow feed zone that located between 1250 to 1650 mMD with thickness interval around 400 mMD. The inflow feed zone also confirmed by an occurrence of spinner profile around those depth. Below 1700 mMD, spinner profile shows outflow feed zones and at bottom of the well, >2100 mMD, found spinner response that means the fluid injected still flow to the beneath of that depth.

Based on PTS injection data, a comprehensive analysis including spinner interpretation and mass heat balance calculation was done and showed a good match to construct fluid flow profile inside the wellbore with simple match performed on inflow feedzone area. **Figure 12** shows fluid flow profile also mass rate chart. The result suggests 6 feed zones with 3 inflow feed zones and 3 outflow feed zones. II value from injectivity test with four difference injection rates around 14 – 27,7 kg/s/bar. The major feed zone located at the bottom (>2100 mMD) with total contribution 62% of II value. **Table 1** summarizes the contribution and location of each individual feedzone. Feed zone from 1985 mMD which has low contribution correspond with fractures zone mainly controlled by bedding/foliation at 1950-2090 mMD (**Figure 13**). Borehole image data exhibit bigger feed zone contribution corresponding with fracture zone with bigger aperture. Interval 1778-2145 mMD mostly controlled by 4-mm to 10-mm.

Table 1:Detail individual feed zones location and contribution of IR-I from completion test

No	Depth		Mass Rate	Status	Contribution
	[mMD]	*[mASL]*	*[kg/s]*		*[%]*
1	1250	887	-21,14	Inflow	
2	1465	690	-13,50	Inflow	
3	1610	557	-11,00	Inflow	
4	1790	392	35,20	Outflow	29%
5	1985	213	11,00	Outflow	9%
6	>2100	108	75,15	Outflow	62%

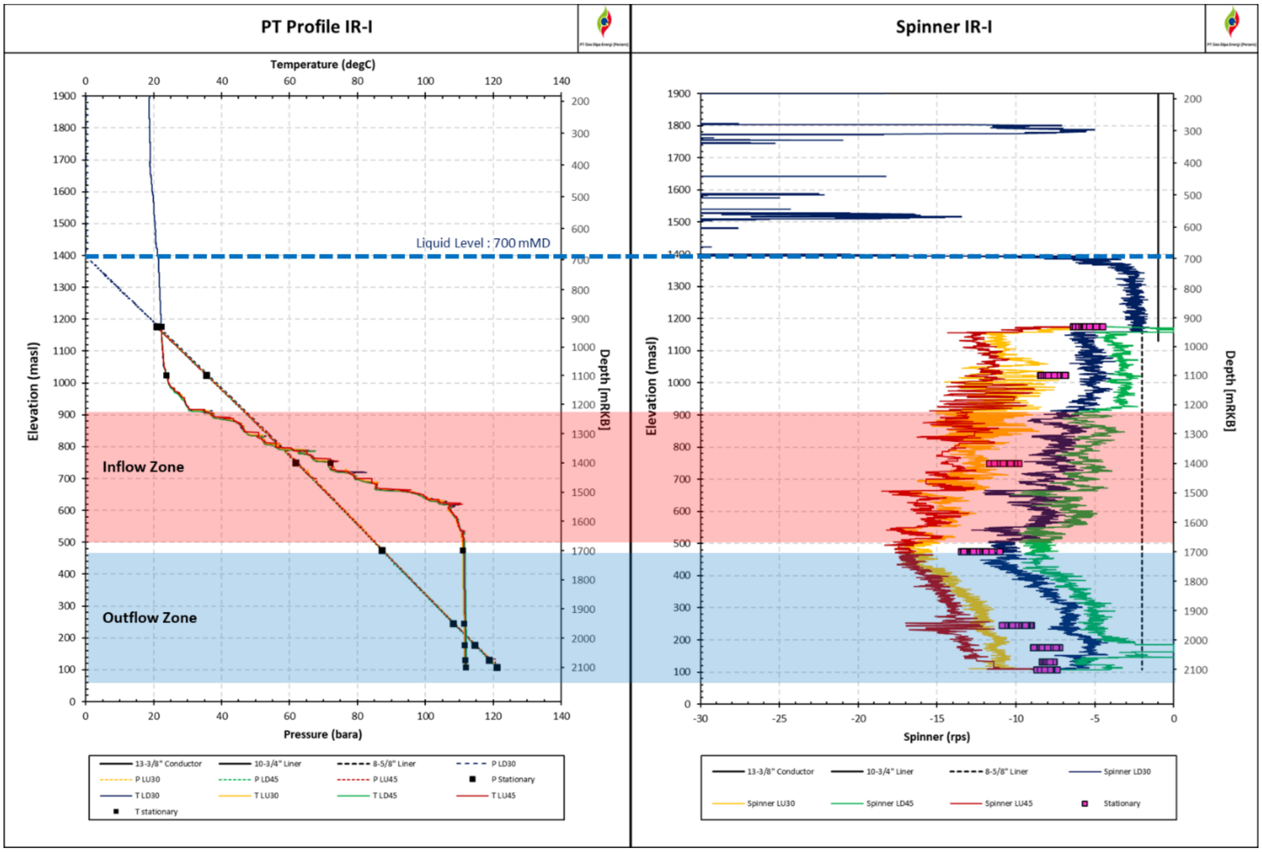


Figure 11: Pressure-Temperature-Spinner profile of IR-I during completion test

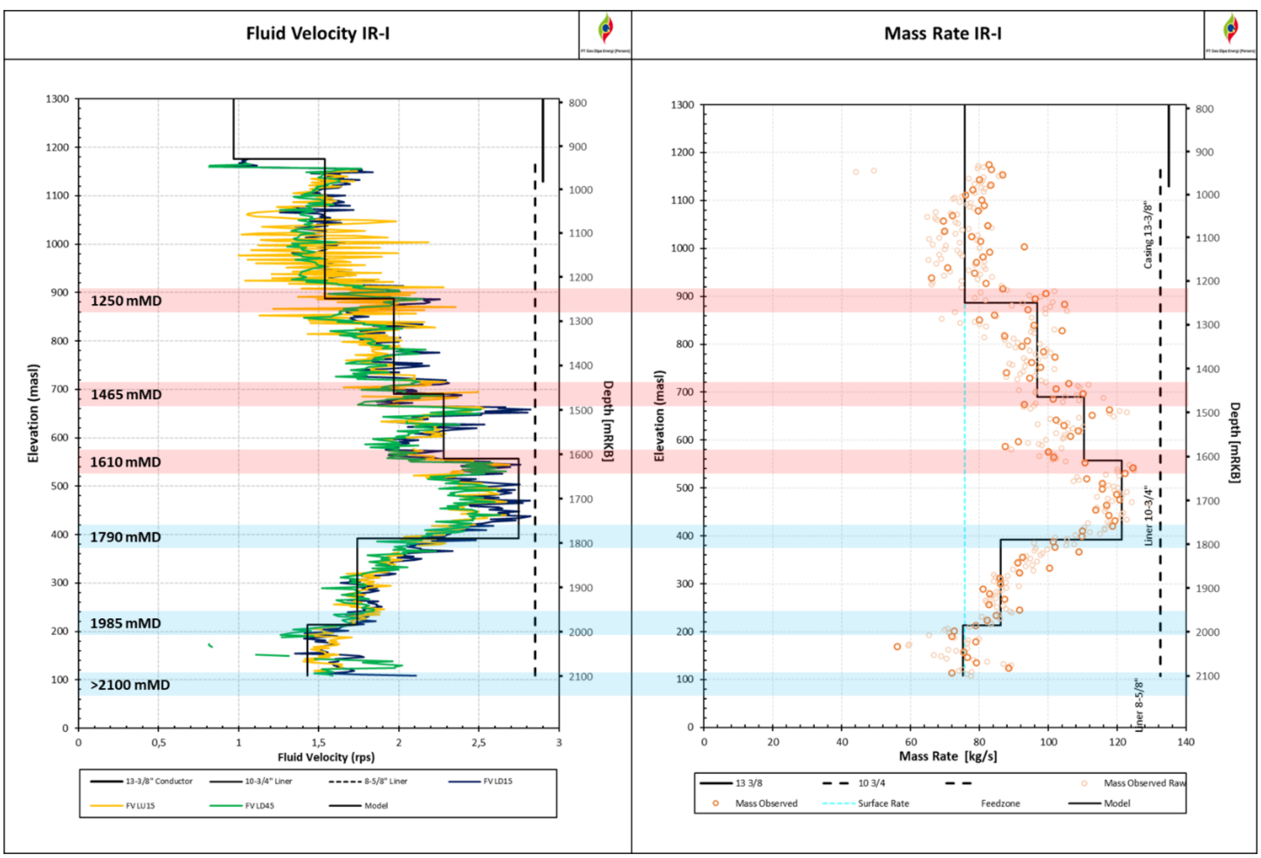


Figure 12: Fluid flow result from 800 – 2100 mMD with detail feedzone location and mass flowrate contribution

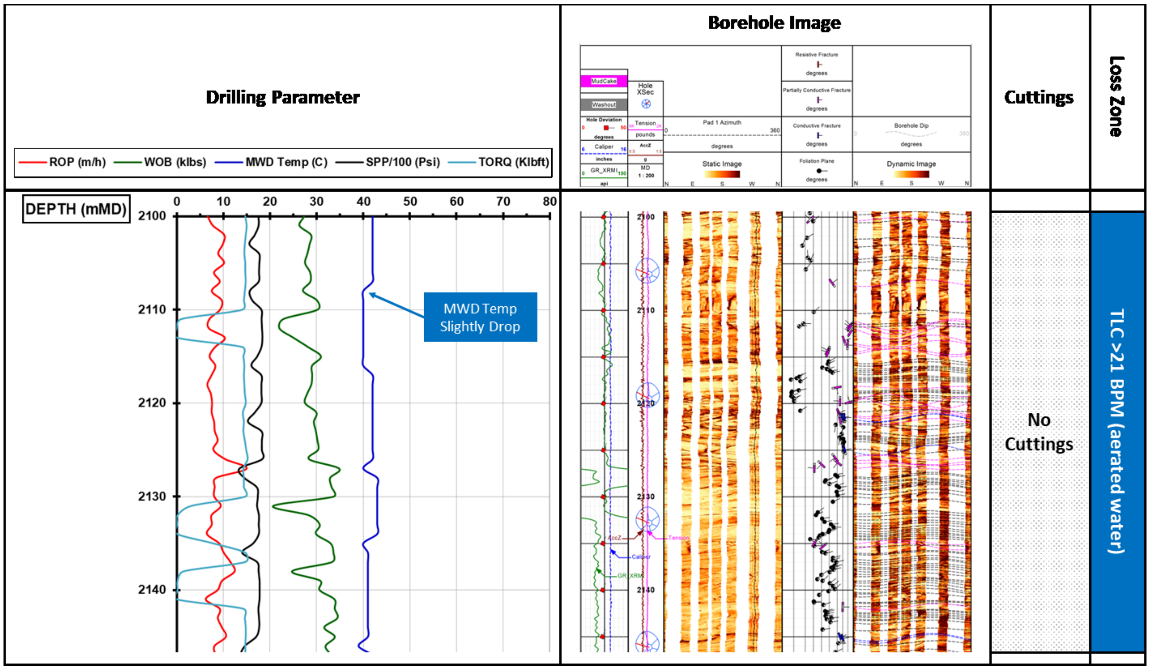


Figure 13: Interval 2100-2140 mMD shows slightly erratic WOB and gradually declined MWD Temperature correspond with feedzone from >2100 mMD which has high contribution

3.2 IR-6

IR-6 located on the western part of Pagarkendang crater while ground cellar sited at 1921.6 mASL. The well drilled toward southwest with production casing sat at 1395 mMD/621 mASL and total depth at 3004 mMD/ -766 mASL. Borehole image log conducted from 1395-2593 mMD and the last cutting return from 2536 mMD. Well completion test done with maximum depth at 2998 mMD, consist of pressure-temperature-spinner (PTS) logging with injection rate of 1200 GPM and multiple-rate-injectivity test (II) test with 4 injection rates (1200, 1000, 800 and 600 GPM).

During drilling, first total loss zone with >21 BPM observed at 2449 mMD/ -291 mASL followed by partial loss 4-5 BPM with aerated water. Drilling parameters showed drilling break with drop of WOB from 11 klbs to 1.9 klbs and SPP from 2538 psi to 2083 psi. No indication of increasing ROP due to controlled rate of penetration during drilling. Continuous total loss observed from 2530 mMD/-359 mASL to total depth. Within loss circulation zone, several drilling breaks identified by slightly decreasing of WOB and SPP, mostly perceived as erratic parameters below the average.

Borehole image log conducted within 12-1/2” hole section with interval 1395-2593 mMD. A total of 1123 dips were manually picked and further classified into fractures and linear features (**Figure 14**). Three major trends of foliation plane can be observed from top towards east, switching toward north-northwest within the middle section and towards east-north to the bottom. Conductive fracture with dominant NE-SW and NNW-SSE strike were identified with total 35 fractures. Partial fractures with total 500 were identified shows NNW-SSE strike direction. A total of 49 resistive fractures were identified with NNW-SSE strike direction. The estimated mean for fractures aperture is 0.40-mm with maximum aperture is 0.82-mm. IR-6 with range of aperture is 0.1-mm to 0.82 mm, exhibit lower value of aperture than IR-1. Unfortunately, borehole image logging not conducted in the 9-7/8” hole section.

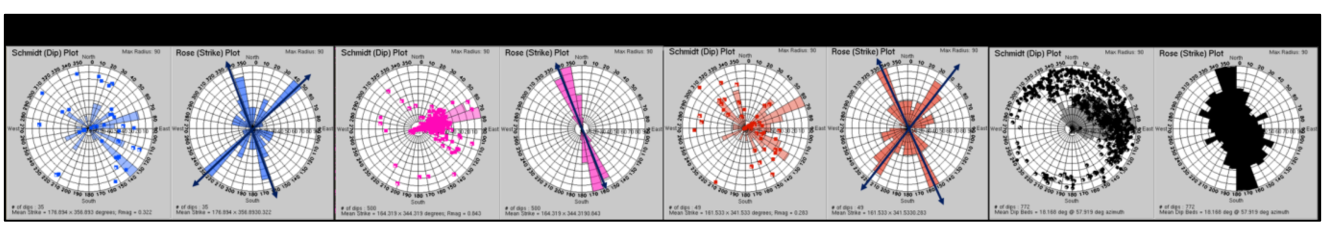


Figure 14: Conductive and resistive fracture shows mainly NE-SW and NNW-SSE strike direction while partial fractures exhibit NNW-SSE strike direction

Based on borehole image data, loss circulation zones during drilling correspond with high fracture density interval which are 2250-2500 mMD. Similar with IR-1, permeable zone frequently controlled by partial fractures with low aperture characteristic resulted the lack of significant drilling breaks existence (**Figure 15**). Fractures controlled IR-6 shows lower aperture than fractures found in IR-1, resulted with lower permeability and injectivity index.

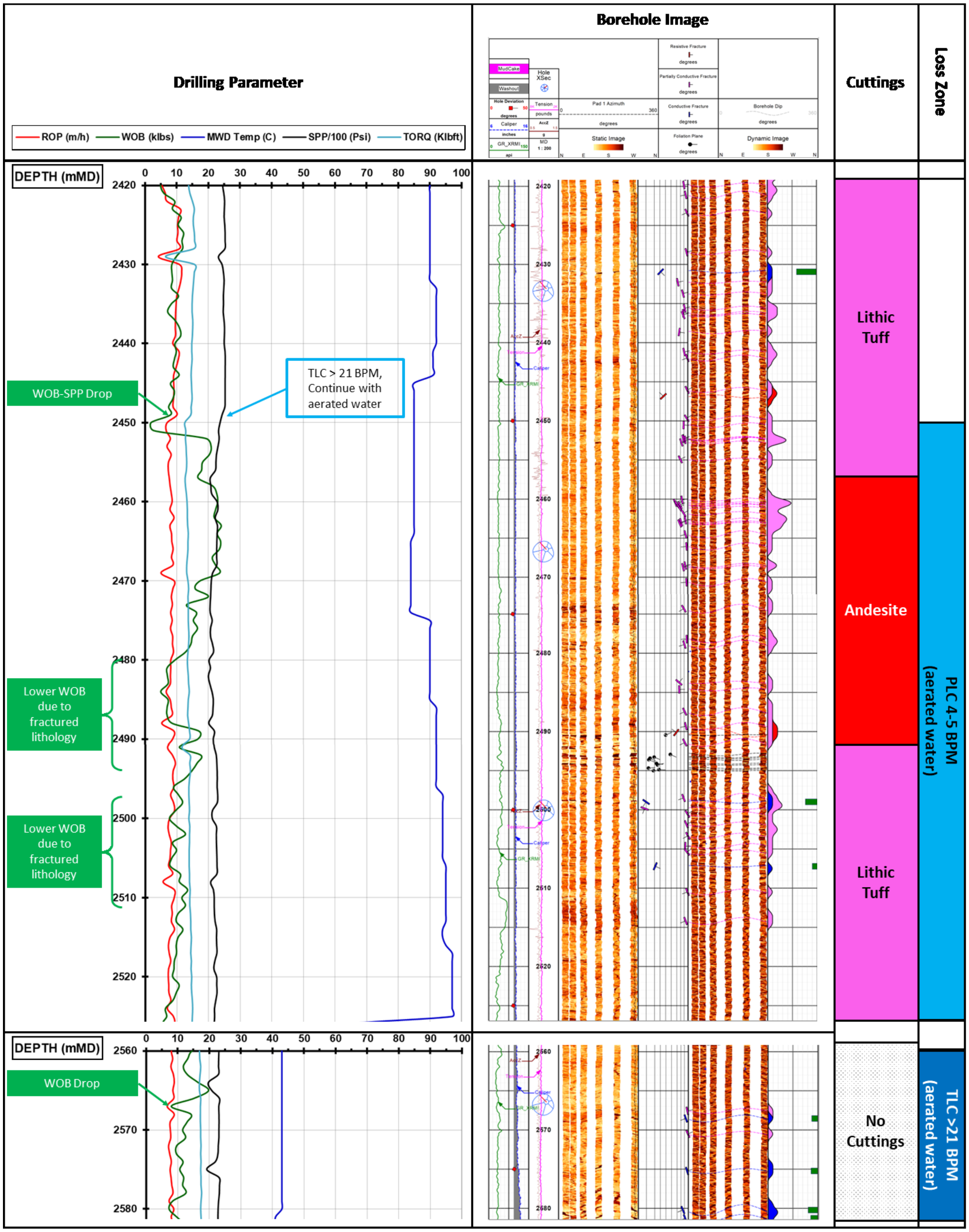


Figure 15: First loss zone observed showed decreasing of WOB and SPP while fracture zones from 2480-2510 mMD showed slightly changing of drilling parameters due to low aperture but high-density fractures zone. Drilling breaks from interval 2567 mMD shows significant decreasing of WOB correlated with conductive fractures observed.

Completion test in IR-6 was done with the same procedure as IR-I. The result (**Figure 16**) shows stabile pressure-temperature profiles and a good quality data of spinner. Based on pressure and temperature data, observed liquid level at 520 mMD/1411 mASL and possible thin inflow zone located between 2400 – 2500 mMD. Around the inflow zone found an erratic spinner response that can be an effect of the hot inflow fluid from formation to wellbore.

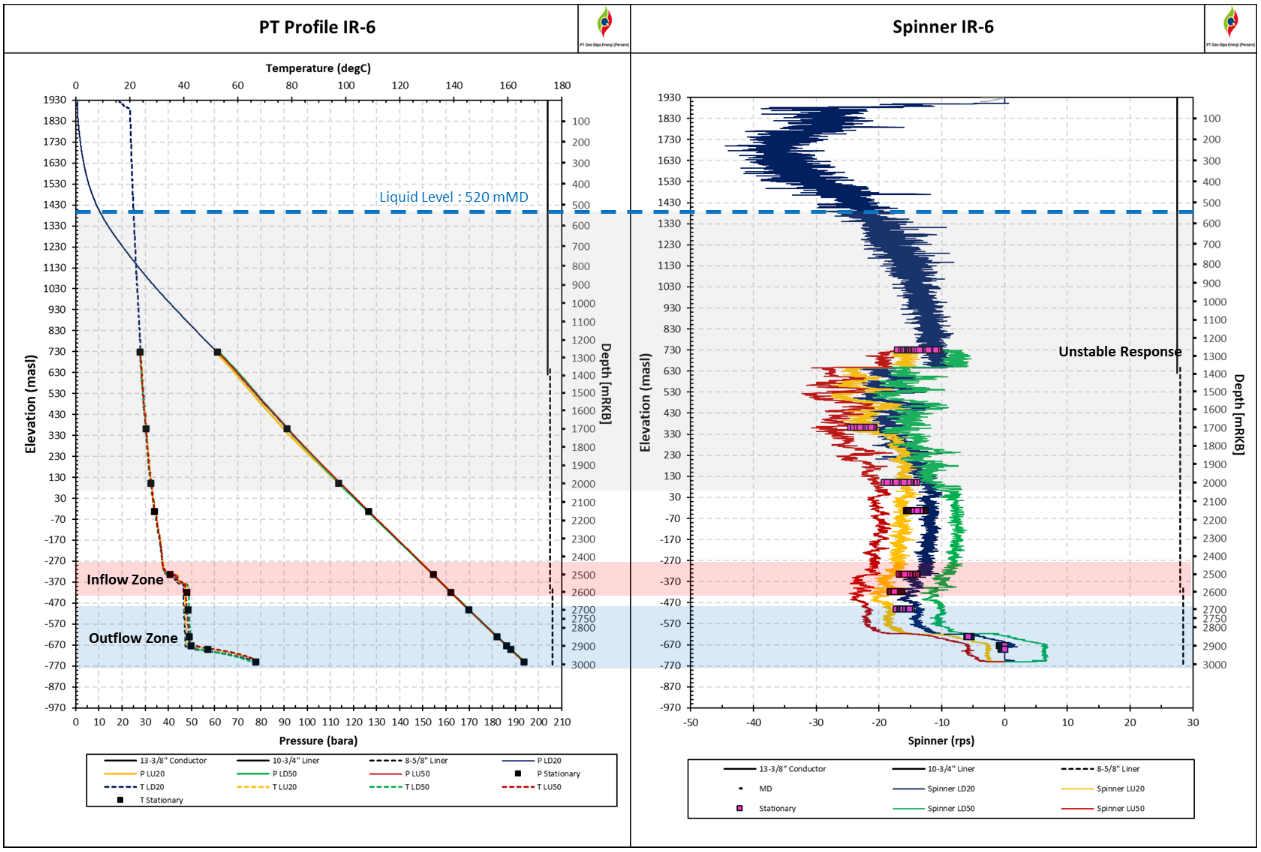


Figure 16: Pressure-Temperature-Spinner profile of IR-6 during completion test

Same analysis as IR-I was applied in IR-6. Based on spinner interpretation combined with mass heat balance calculation showed a good match to construct fluid flow profile inside the wellbore with simple match performed on inflow feedzone area. **Figure 16** shows fluid flow profile also mass rate chart. The result suggests 4 feed zones with 2 inflow (thin inflow) feed zones and 2 outflow feed zones. II value from injectivity test with four difference injection rates is 18.32 kg/s/bar. Major feed zone located at 2790 mMD / -579 mASL with total contribution 65% of II value. **Table 2** summarizes the contribution and location of each individual feedzone.

Table 2: Detail individual feed zones location and contribution of IR-6 from completion test

No	Depth		Mass Rate	Status	Contribution
	[mMD]	*[mASL]*	*[kg/s]*		*[%]*
1	2460	-300	-10,47	Inflow	
2	2495	-330	-7,53	Inflow	
3	2665	-472	33,00	Outflow	35%
4	2790 - 2920 (*)	-579	60,70	Outflow	65%

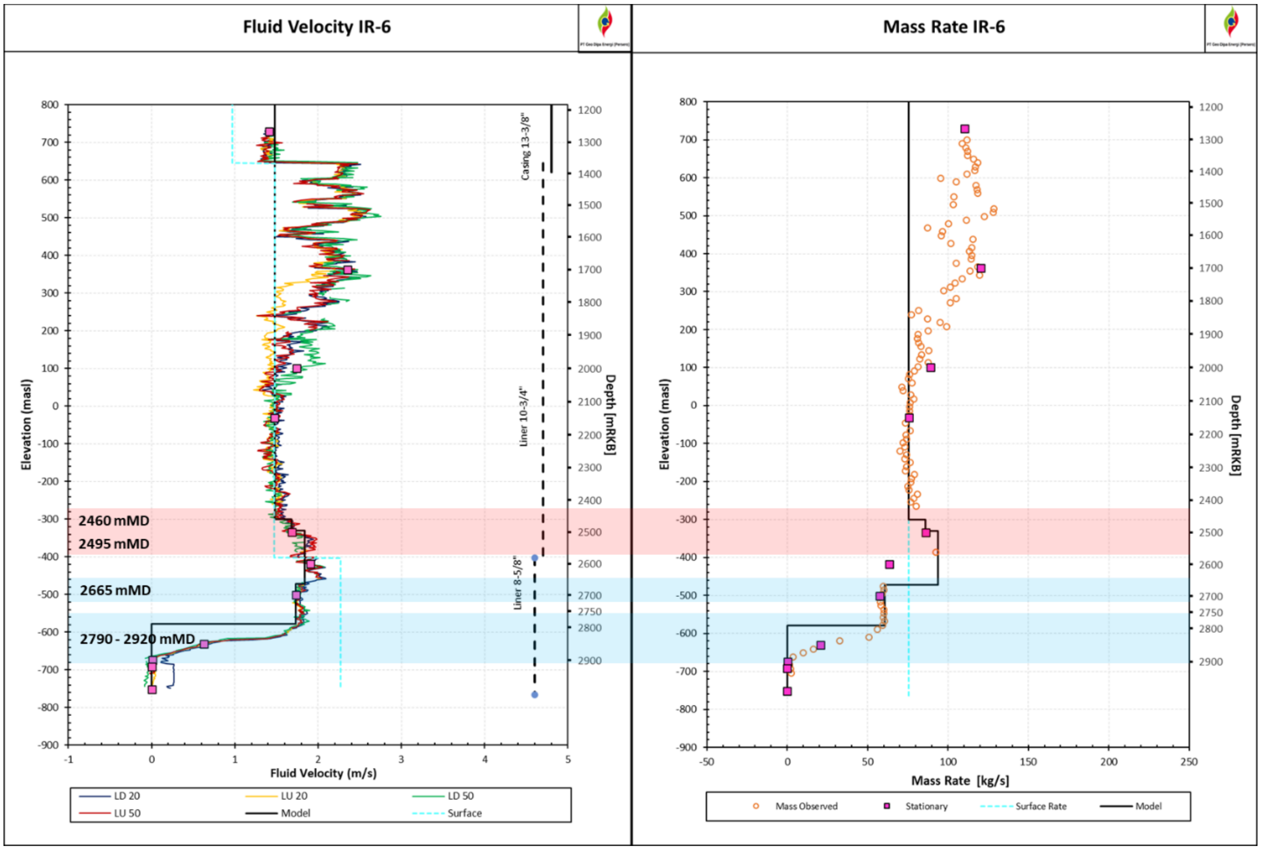


Figure 17: Fluid flow result from 1200 – 2900 mMD with detail feedzone location and mass flowrate contribution

While IR-1 have a feed zone controlled by bedding/foliation plane, IR-6 fully controlled by partial and conductive fracture from captured borehole image. Largest feed zone 65% contribution during well completion test observed from interval 2790-2920 mMD. No borehole image data collected from this interval, but during drilling, several gradually declined of MWD temperature perceived at 2783 mMD, 2818 mMD and 2878 mMD, observed corresponding with erratic WOB below the average parameter applied.

4. CONCLUSION

- IR-1 and IR-6 permeability mostly controlled by partial fractures with different strike direction and thought to be caused by the position of the well to the crater. IR-1 controlled by fractures with NNW-SSE, N-S and NNE-SSW strike direction. IR-6 show domination of fractures with NNW-SSE strike direction.
- Inflow feed zone mostly controlled by partial fractures with low aperture. First loss zone remarked by sudden drop of WOB and gradually declined of SPP with slightly increase of ROP for both wells. IR-1 inflow feed zone controlled by partial fracture dominated with N-S strike direction, conductive fracture dominated with NNW-SSE strike direction and bedding/foliation plane towards southwest, while IR-6 mostly controlled by partial and conductive fractures dominated with NNW-SSE.
- IR-1 outflow feed zone mostly controlled by partial fractures with N-S strike direction, conductive fractures with NNW-SSE strike direction and bedding/foliation plane towards East. IR-1 fifth feed zone which is controlled by bedding/foliation plane shows smaller contribution, while sixth feed zone with biggest contribution controlled by fracture with aperture ranges from 7-mm to 9-mm. Thus, perceived loss zone controlled by secondary permeability have bigger contribution than primary permeability. IR-6 outflow feed zone unfortunately not captured with borehole image logging, but possibly have similar pattern with IR-1 which is bigger aperture of fractures toward the bottom hole.
- Correlation between spinner response, borehole image and drilling parameter in IR-I and IR-6 confirmed the feed zones location and fractures that controlled the permeability. Thus, the preliminary feed zone location during drilling could be identified by drilling parameters assessment. First loss always corresponding with drilling break with sudden drop of WOB and SPP with slightly increasing of ROP. On the lower section of the bottom hole, drilling breaks are tougher to identify but sometimes fractures observed by erratic WOB below applied parameters and sudden/gradually declined of MWD temperature. The lack of significant drilling breaks existence caused by mostly fractures formed as low aperture fractures.
- Based on borehole image data and completion test result, it is recommended to drill deeper around Pagarkendang crater due to bigger aperture of fractures toward the bottom hole. Productive zone inside crater started from 800 mASL while outside crater started from -300 mASL. The orientation of strike direction is almost similar, thus it is recommended to drill towards W-E and intersect fractures zone with NNW-SSE/N-S/NNE-SSW strike direction.

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