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Evaluation of Mud Logging and Wellsite Geology Data for Geothermal Feed Zone Identification In Well DUG-L6, Gea Field, South Sumatera

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Abstract

This study evaluates the integration of mud logging and wellsite geological data for feed zone identification during the drilling of Well DUG-L6 in the Gea Field, South. Real-time drilling parameters datasets, such as ROP, WOB, SPP, and torque were analyzed alongside mud logging indicators and cuttings description, were integrated to identify anomalies including drilling breaks, circulation losses, temperature variations, and hydrothermal alteration that collectively serve as proxies for reservoir permeability.Weel DUG L-6 indicate three significant drilling breaks at 1388–1389.7 mMD, 1667–1669 mMD, and 2495.7–2497 mMD, each marked by abrupt increases in ROP, reductions in WOB, and thermal responses at surface level. Total loss circulation (TLC) occurred continuously from 1355 to 2593 mMD, confirming extensive fracture-related permeability in the deeper section. Cutting evaluation revealed lithology dominated by dacitic lithic tuff and andesitic volcanic units. These features are consistent with fluid–rock interaction and indicate the presence of active geothermal up-flow pathways. Two primary productive intervals 1300–1355 mMD and 2300–2593 mMD were delineated by the concurrence of significant drilling breaks, the onset and persistence of total loss circulation (1355 mMD to TD), BHCT anomalies exceeding 55 °C (peaks of 63.4°C and 60.6°C), and the presence of hydrothermal alteration minerals. These findings underscore the operational value of mud logging and wellsite geology as reliable, cost-effective tools for reservoir early characterization, enabling informed decision-making during drilling and supporting the sustainable development of geothermal resources in Indonesia.

Keywords: *mud-logging, feed zone, drilling breaks*

Abstrak

Studi ini mengevaluasi integrasi data mud logging dan geologi lokasi sumur untuk identifikasi zona umpan selama pengeboran Sumur DUG-L6 di Lapangan Gea, Selatan. Parameter pengeboran seperti ROP, WOB, SPP, dan torsi dianalisis bersama dengan indikator mud logging dan *drilling breaks*, diintegrasikan untuk mengidentifikasi anomali termasuk interval pengeboran, kehilangan sirkulasi, variasi suhu, dan alterasi hidrotermal yang secara kolektif berfungsi sebagai proksi untuk permeabilitas reservoir. Sumur DUG L-6 menunjukkan tiga interval pengeboran yang signifikan pada 1388–1389,7 mMD, 1667–1669 mMD, dan 2495,7–2497 mMD, masing-masing ditandai dengan peningkatan mendadak dalam ROP, penurunan WOB, dan respons termal di permukaan. Sirkulasi kehilangan total (TLC) terjadi terus menerus dari 1355 hingga 2593 mMD, yang mengonfirmasi permeabilitas terkait rekahan yang luas di bagian yang lebih dalam. Evaluasi pemotongan menunjukkan litologi yang didominasi oleh tuf litik dasit dan satuan vulkanik andesit. Fitur-fitur ini konsisten dengan interaksi fluida-batuan dan menunjukkan keberadaan jalur aliran naik panas bumi yang aktif. Dua interval produktif utama, 1300–1355 mMD dan 2300–2593 mMD, digambarkan oleh kebetulan patahan pengeboran yang signifikan, permulaan dan persistensi sirkulasi kehilangan total (1355 mMD hingga TD), anomali BHCT di atas 55 °C (puncak 63,4°C dan 60,6°C), dan keberadaan mineral alterasi hidrotermal. Temuan ini menggarisbawahi nilai operasional pencatatan lumpur dan geologi lokasi sumur sebagai alat yang andal dan hemat biaya untuk karakterisasi awal reservoir, memungkinkan pengambilan keputusan yang terinformasi selama pengeboran, dan mendukung pengembangan berkelanjutan sumber daya panas bumi di Indonesia.

Kata kunci: *mud-logging, feed zone, drilling breaks*

I. INTRODUCTION

During drilling is vital for optimizing liner placement, reservoir targeting, and flow testing. Traditional Geothermal energy is increasingly recognized as a cornerstone of sustainable energy development because it provides clean, renewable, and reliable base-load power. Unlike solar or wind energy, which are intermittent and heavily dependent on climatic conditions, geothermal resources deliver continuous electricity generation with minimal fluctuations. Globally, geothermal power plants supply more than 16 GW of installed capacity, with significant contributions from countries such as the United States, the Philippines, Iceland, Kenya, and Indonesia (International Renewable Energy Agency, 2023). Among these, Indonesia possesses the largest geothermal potential after the United States, with an estimated 28,000 MW of resources distributed along its volcanic arcs (Hochstein & Sudarman, 2008). This potential is directly linked to the nation's tectonic position on the Pacific Ring of Fire, where active subduction zones create abundant heat flow and hydrothermal systems.

Despite this vast potential, geothermal development in Indonesia faces considerable technical and economic challenges. One of the primary obstacles is the high cost and risk of drilling, which can constitute 40–60% of total project investment (Purwanto et al., 2018). Unlike hydrocarbon wells, geothermal wells must penetrate fractured volcanic terrains, unstable lithology, and high-temperature environments. These conditions often lead to drilling hazards such as severe loss of circulation, well-bore instability, stuck pipe, and equipment failure (Ikinya & Ng'ang'a, 2018). Moreover, the productivity of a geothermal well is not guaranteed even after successful drilling, as it depends largely on intersecting permeable intervals known as feed zones. Feed zones are natural conduits that allow hydrothermal fluids to flow from the reservoir into the wellbore and are therefore critical in determining the commercial viability of a geothermal well (Castaneda, 1981).

Conventional approaches to reservoir evaluation include wireline logging and post-drilling pressure–temperature–spinner (PTS) surveys, which provide valuable data on reservoir conditions (Tsuchiya, 2010). However, their application in geothermal settings is frequently constrained by operational risks. High temperatures, unstable formations, and severe circulation losses often prevent the acquisition of high-quality log data, while tool failures are common in extreme geothermal environments (Moos & Ronne, 2010). In addition, these methods are conducted only after drilling, delaying decision-making regarding well completion and reservoir targeting. For these reasons, increasing emphasis has been placed on the integration of real-time data from mud logging units (MLU) and well-site geological observations. These approaches can provide continuous monitoring and immediate feedback during drilling, allowing for the early detection of productive zones and the mitigation of operational risks (Reynolds, 2002; Witter et al., 2018).

Mud logging units play a vital role in geothermal drilling by recording drilling parameters, gas compositions, cuttings, and fluid returns. These datasets enable the recognition of anomalies such as drilling breaks, mud losses, and gas peaks, which may indicate permeability pathways (Molua et al., 2022). When combined with systematic cutting descriptions by well-site geologists—including lithology, texture, and hydrothermal alteration—mud logging provides a powerful tool for subsurface evaluation. Previous studies in geothermal fields worldwide have demonstrated that drilling breaks, when correlated with mud gas anomalies and mineralogical indicators, are reliable proxies for productive feed zones (Dreesen et al., 1987; Gonfalini et al., 1987). Similar methods have been successfully applied in geothermal systems in the Philippines, New Mexico, and Iceland, where real-time mud logging allowed operators to identify fractures and optimize well completion strategies (Aragón-Aguilar & Hernández, 2023; Bostanci et al., 2023).

The Gea Field in South Sumatra represents one of Indonesia's major geothermal prospects, situated along the Sumatra volcanic arc. The field is characterized by complex volcanic stratigraphy, fault-controlled permeability, and active hydrothermal alteration, which create both opportunities and challenges for resource development (Arifin et al., 2023). Well DUG-L6 was drilled in this field as a directional production well, targeting structural features such as NE-3 and Caldera Rim. The well trajectory reached a measured depth of 2593 m, with a true vertical depth of approximately 2201 m, and intersected volcanic clastics, lavas, and intrusive bodies. Drilling operations encountered multiple circulation loss events and drilling breaks, underscoring the dynamic nature of the geothermal system (Gea Saka et al., 2024).

This study evaluates Well DUG-L6 using integrated drilling and geological datasets. Drilling parameters, circulation losses, gas anomalies, and cutting analyses were combined to identify productive feed zones. Three major drilling breaks were recorded at 1388–1389.7 mMD, 1667–1669 mMD, and 2495.7–2497 mMD, while total loss circulation extended from 1355 to 2593 mMD. Lithological analyses identified dacitic tuffs and andesitic volcanics with hydrothermal alteration dominated by chlorite and illite, suggesting active geothermal fluid pathways. The integration of drilling anomalies with geological observations provided strong evidence for productive feed zones, correlating with subsurface targets predicted in the field prognosis.

By emphasizing real-time integration of drilling and geological data, this research addresses a critical gap in geothermal drilling operations: the identification of feed zones during drilling rather than after completion. The findings demonstrate that mud logging and well-site geology are not supplementary but essential for reservoir evaluation. Moreover, the results provide broader insights into how operational data can reduce uncertainty, optimize drilling performance, and enhance the sustainability of geothermal development in Indonesia. The objectives of this paper are therefore threefold: (1) to analyze drilling parameter anomalies and circulation events in Well DUG-L6; (2) to evaluate mud logging and cuttings data as indicators of reservoir permeability; and (3) to integrate these findings to delineate productive feed zones. Through this case study, the paper illustrates the broader applicability of real-time data integration as a model for geothermal drilling in high-risk, high-cost environments worldwide

II. METHODOLOGY

The methodology employed in this study is designed to integrate engineering and geological datasets acquired during the drilling of Well DUG-L6 in the Gea geothermal field, South Sumatra. The approach emphasizes the use of real-time data from drilling operations and mud logging units (MLU), complemented by systematic cuttings description conducted by the well-site geologist. This integration provides a framework for identifying permeable intervals and feed zones during drilling without relying on post-completion surveys. The methodology is divided into four major stages: (1) acquisition of drilling data, (2) mud logging analysis, (3) cuttings and alteration mineralogy description, and (4) correlation and feed zone interpretation.

2.1 Drilling Data Acquisition and Evaluation

Drilling data were sourced from daily drilling reports (DDR) and the final well report (FWR) of Well DUG-L6 (Gea Saka et al., 2024). Parameters including rate of penetration (ROP), weight on bit (WOB), standpipe pressure (SPP), torque, and drilling fluid circulation volumes were systematically reviewed. Particular emphasis was placed on identifying anomalies such as drilling breaks, where sudden increases in ROP occur without proportional changes in WOB, and circulation losses, which are indicative of open fracture networks. Total loss circulation (TLC) intervals were carefully recorded to delineate permeable formations intersected by the wellbore. These data served as the primary engineering indicators for potential feed zones, consistent with practices outlined in geothermal drilling studies worldwide (Moos & Ronne, 2010; Purwanto et al., 2018).

2.2 Mud Logging Analysis

The mud logging unit (MLU) provided continuous monitoring of drilling parameters, return flow, and gas compositions throughout the drilling process. Gas measurements included total hydrocarbon gas and chromatographic composition, which were correlated with depth to identify anomalies. Gas peaks were evaluated alongside drilling breaks and circulation losses, as these often coincide with permeable zones and reservoir fluid pathways (Molua et al., 2022; Aragón-Aguilar & Hernández, 2023). The MLU also documented temperature variations in drilling fluids, which served as supplementary evidence for thermal anomalies associated with fluid entry. By integrating gas anomalies with drilling parameter changes, mud logging data offered direct evidence of subsurface permeability features during real-time operations.

2.3 Cuttings and Alteration Mineralogy Description

Drill cuttings were collected at regular depth intervals and systematically described by the well-site geologist. Lithological classification included recognition of volcaniclastics, lavas, and intrusive units, with emphasis on texture, grain size, and primary mineralogy. Hydrothermal alteration minerals were also identified under binocular and petrographic microscope analysis, with key assemblages including chlorite, epidote, illite, and quartz. The presence and intensity of alteration minerals were used as indicators of sustained fluid–rock interaction, consistent with methodologies applied in other geothermal fields (Tsuchiya, 2010; Arifin et al., 2023). Cuttings analysis was particularly important in intervals affected by TLC, where direct fluid evidence of permeability was observed.

2.4 Correlation and Feed Zone Identification

The final stage of the methodology involved the integration of drilling, mud logging, and cuttings datasets to delineate feed zones. Depth intervals were evaluated against four main criteria: (1) drilling breaks, (2) circulation loss events, (3) gas anomalies, and (4) hydrothermal alteration mineral indicators. Intervals that met at least three of these criteria were classified as productive feed zones. This approach aligns with geothermal well evaluation frameworks that emphasize multi-parameter validation to reduce uncertainty in feed zone interpretation (Dreesen et al., 1987; Witter et al., 2018). The identified feed zones were then correlated with subsurface targets defined in the well prognosis, including NE-3 and Caldera Rim structures, to confirm their geological significance.

The detailed research methodology flowchart is presented in Figure 1, which illustrates the systematic sequence beginning from problem identification and literature review, followed by data integration and interpretation for feed zone determination, and concluding with the formulation of key findings as previously described:

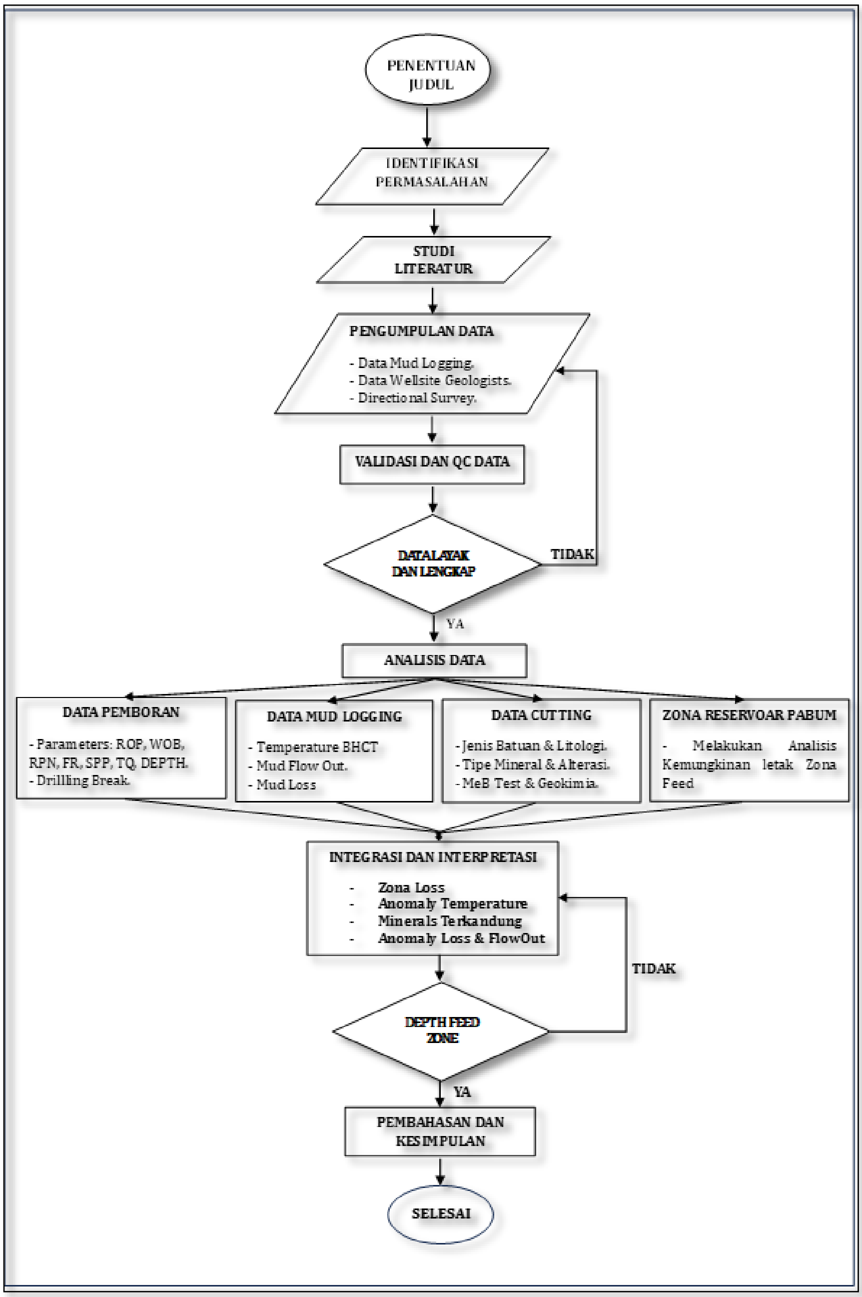


Figure 1 Methodological Workflow.

III. RESULT AND DISCUSSION

3.1 Drilling Parameters and Anomalies

The drilling of Well DUG-L6 was conducted through the 12¼" and 9⅞" hole sections between 1300 mMD and 2593 mMD, penetrating a sequence of volcaniclastics, lava flows, and intrusive rocks. Drilling parameters, including ROP, WOB, SPP, and torque, exhibited significant variations that reflect changes in formation strength and permeability.

Three distinct drilling breaks were observed at depths of 1388–1389.7 mMD, 1667–1669 mMD, and 2495.7–2497 mMD. Each break was characterized by a sharp increase in ROP and a simultaneous reduction in WOB, consistent with drilling into fractured or weakened rock intervals. These breaks coincide with intervals of significant circulation loss, suggesting the intersection of open fracture networks. The anomalies were further supported by torque fluctuations and minor pressure drops in SPP. These findings are consistent with global geothermal drilling studies, where drilling breaks serve as primary indicators of permeable feed zones (Dreesen et al., 1987; Molua et al., 2022).

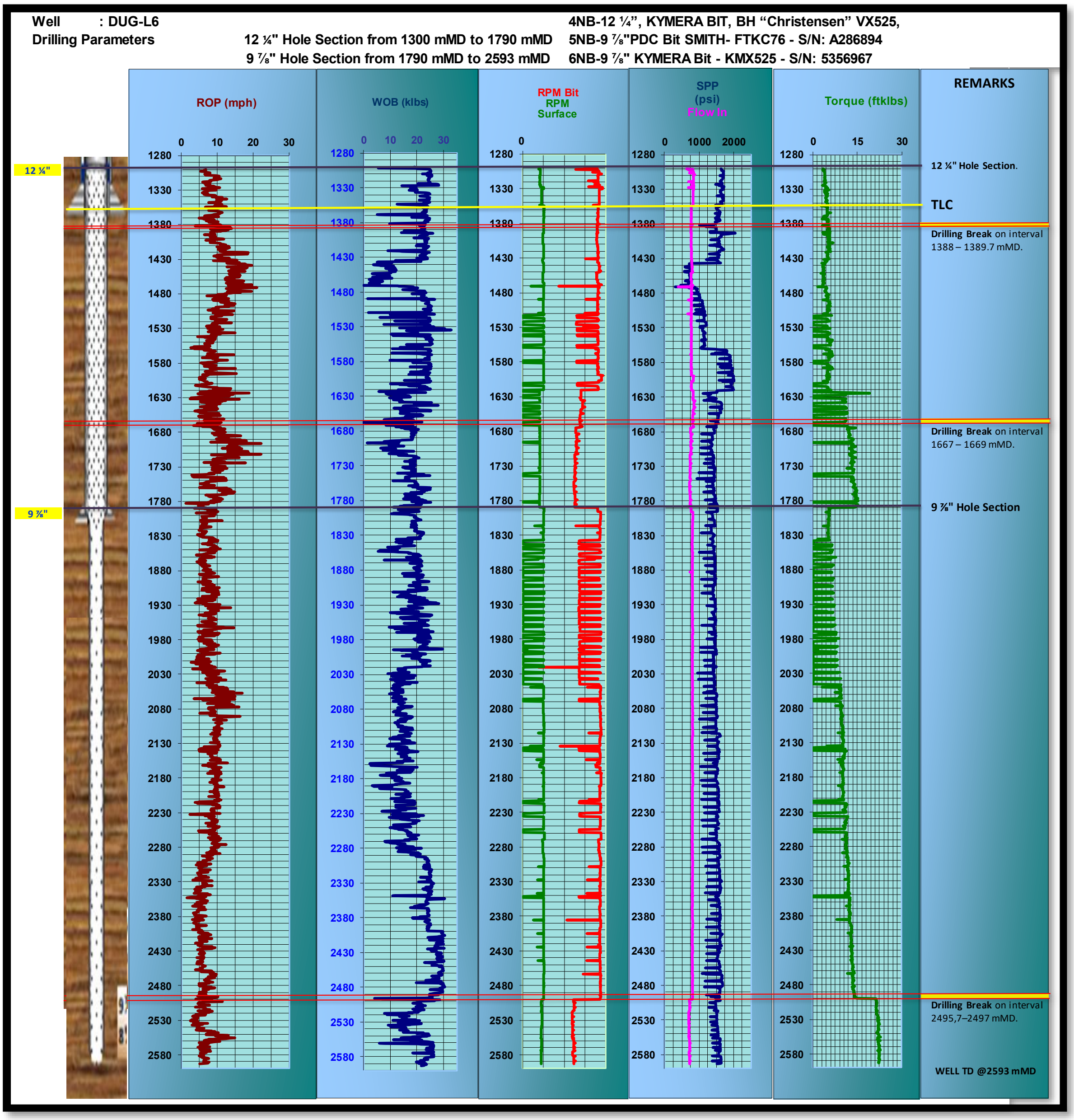
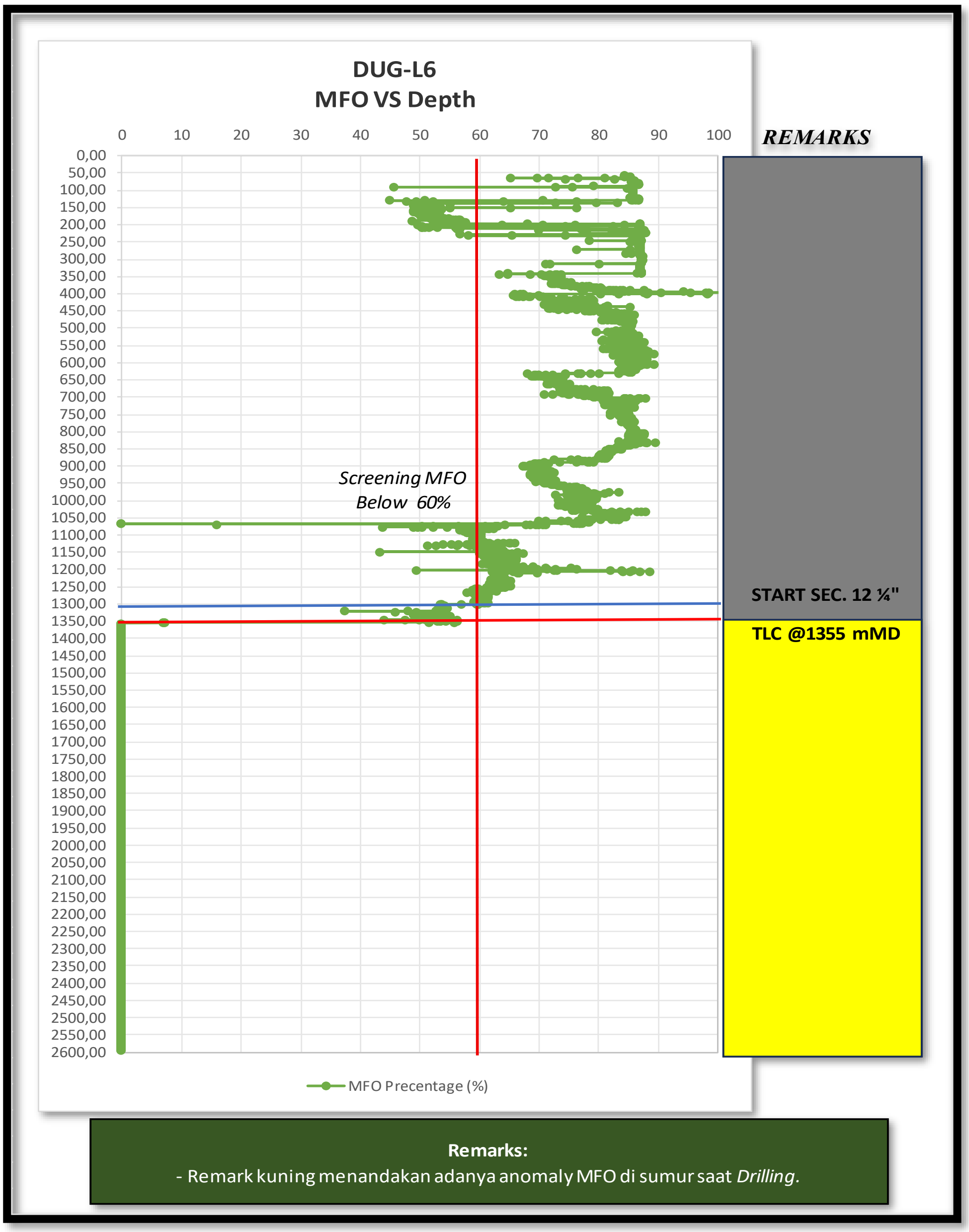


Figure 2. Drilling Parameters Plot.

3.2 Circulation Losses and TLC Intervals

Circulation losses were a dominant feature of drilling operations, beginning at 1355 mMD and continuing to the final depth of 2593 mMD. The losses escalated into total loss circulation (TLC), where no return flow was observed at surface despite continuous pumping. The persistence of TLC over more than 1200 m of drilling highlights the extensive development of fracture systems in the deeper part of the well. The visualization of the MFO trend with respect to depth can be observed in Figure 3. below.



Gambar 3. *Plot MFO VS Depth of DUG-L6.*

Losses were most severe in the intervals overlapping the drilling breaks, confirming the hydraulic connectivity of fractured volcanic units. Globally, such TLC events are regarded as one of the most direct indicators of feed zone presence, as they demonstrate active pathways for fluid movement into or out of the wellbore (Aragón-Aguilar & Hernández, 2023; Bostanci et al., 2023). The anomaly is illustrated in Figure 4, which shows a consistent decrease in Mud Flow Out (MFO) until it reached 0% at a depth of 1355 mMD.

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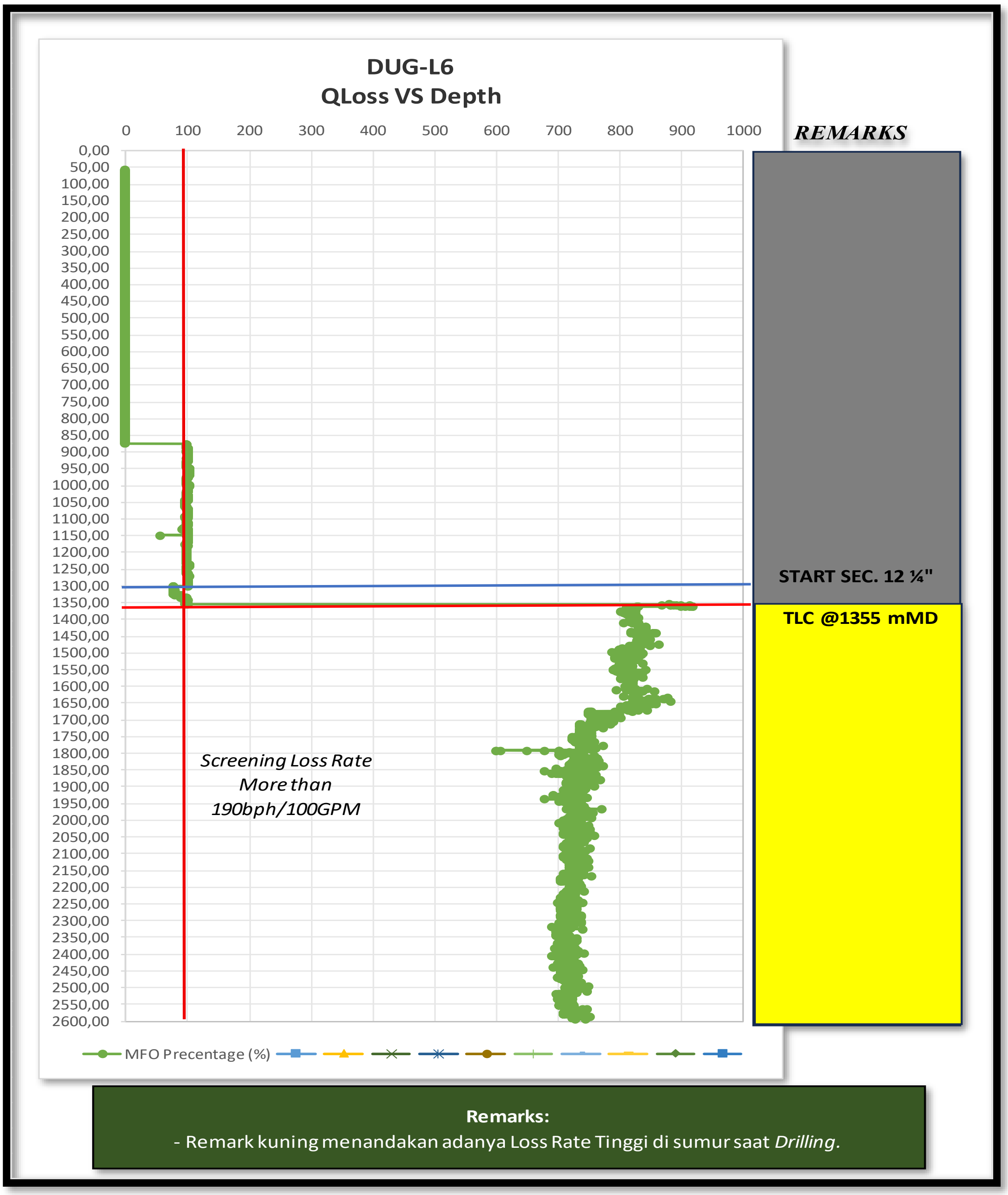

Figure 4. Plot of QLoss versus Depth in Well DUG-L6.

Based on actual drilling data, a significant decrease in the Mud Flow Out (MFO) parameter was observed within the depth interval of 1300 mMD to 1355 mMD. The MFO, which had previously been recorded at approximately 60%, declined drastically to 0%, providing strong evidence of the occurrence of total loss circulation (TLC). Using an industry-standard screening rate method, a mud loss exceeding 190 bph/100 GPM in this interval is classified as TLC. This indicates that the formation at this depth possesses extremely high permeability, capable of absorbing the entire volume of circulating drilling fluid. The TLC event at 1300–1355 mMD therefore represents a key drilling anomaly and provides critical information regarding the presence of natural fluid pathways within the formation, which is one of the primary criteria in identifying geothermal feed zones.

3.3 Cuttings and Alteration Mineralogy

Lithological analysis of cuttings revealed a stratigraphic succession dominated by dacitic tuffs, andesitic lavas, and intrusive rocks. The upper interval (1300–1500 mMD) consisted of altered volcaniclastic rocks with abundant feldspar and lithic fragments. Deeper intervals (1500–2500 mMD) were dominated by massive andesitic lavas, intersected by fractured and brecciated zones. At depths below 2400 mMD, intrusive dacitic bodies were encountered, often associated with intensive fracturing and alteration.

Hydrothermal alteration minerals identified in cuttings included chlorite, illite, and epidote, which are indicative of sustained fluid–rock interaction at elevated temperatures. Chlorite and illite were most abundant between 1600–2000 mMD, corresponding to a major zone of circulation loss, while epidote was detected in deeper intervals (>2400 mMD), suggesting higher temperature alteration. These assemblages are consistent with productive geothermal zones documented in other volcanic-hosted systems worldwide (Tsuchiya, 2010; Arifin et al., 2023). As shown in Figure 5 the Dacite Lithic Tuff formation appears consistently from 1302 to 1353 mMD, reinforcing the indication that this zone is relatively stable in terms of lithological facies, as illustrated in the figure below

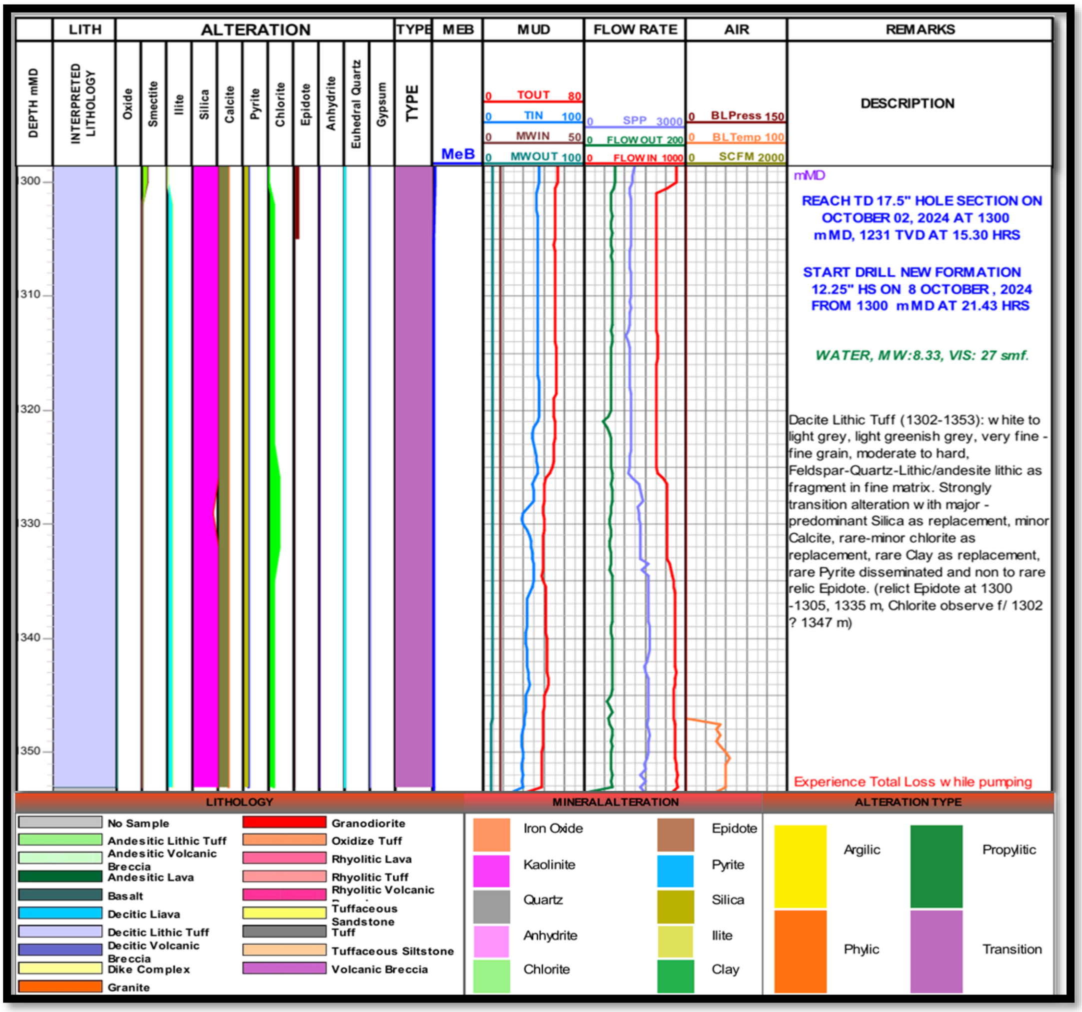

Figure 5. Alteration Mineral Distribution by Mud Log.

Also, based on the measurement results presented in Figure 6 below.

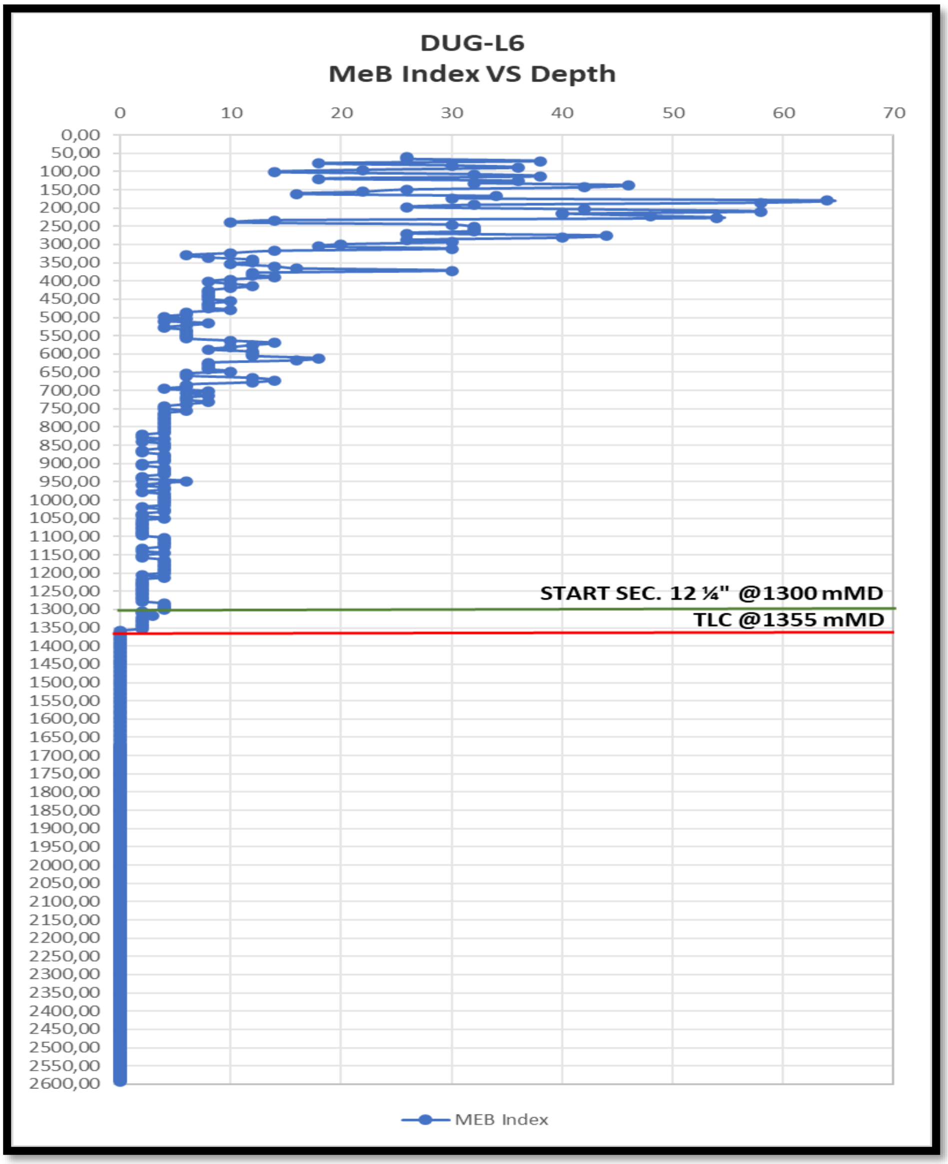

Figure 6 *MeB plot DUG-L6.*

The MeB trend shows a consistent decline after passing through the shallow zone characterized by a high clay content. This correlation is also supported by the increasing intensity of silica alteration and the occurrence of hydrothermal minerals indicative of a medium-temperature system, such as chlorite and epidote. The presence of low to moderate MeB values within this interval supports the interpretation that the zone possesses improved permeability and may function as a conduit for hot fluid migration (feed zone) within the geothermal system.

Accordingly, the evaluation of cuttings and MeB analysis suggests that the interval between 1300–1355 mMD can be classified as part of a transition zone where the sealing influence of clay diminishes and features of an open hydrothermal system begin to emerge.

3.4 Integrated Feed Zone Interpretation

The identification of geothermal reservoir zones in Well DUG-L6 was carried out by integrating three complementary datasets: drilling breaks, circulation loss events (Partial Loss Circulation/TLC), and borehole temperature anomalies recorded from BHCT (MWD). These three parameters serve as the primary basis for feed zone evaluation, as each represents the formation's response to fluid pressure, rock permeability, and hot fluid migration pathways.

For a zone to be classified as a strong candidate for permeability (feed zone), it must satisfy at least three key criteria:

1. The occurrence of a significant drilling break, which serves as the initial determinant of classification.
2. The presence of fluid loss (PLC/TLC) with a loss rate greater than 50% of the total pumped volume.
3. The occurrence of a borehole circulation temperature (BHCT) anomaly with values exceeding 55°C during active drilling.
4. Based on the integration of these three datasets, two main intervals were interpreted as geothermal reservoir zones (feed zones) in Well DUG-L6.

The first zone is located in the interval of 1300–1355 mMD, at the lower part of the 12¼" hole section. In this interval, the first significant drilling break was observed, with ROP increasing sharply from 3 to 49 m/hr and WOB decreasing from 6 to 1–2 klbs. In addition, a Total Loss Circulation occurred as the flow out dropped from 60% to 0%, indicating penetration into an open permeable zone. BHCT data in this interval recorded a maximum circulation temperature of 63.4°C, which is well above the 55°C threshold. These three indicators collectively confirm that the interval 1300–1355 mMD represents a highly productive feed zone.

The second zone is located in the interval of 2300–2593 mMD, within the final section of the 9⅞" hole. BHCT data show that circulation temperature increased again, reaching a peak of 60.6°C, accompanied by gradually worsening loss circulation conditions up to total depth (TD). Although less pronounced than the first zone, a moderate drilling break was also recorded at 2495.7–2497 mMD, with ROP increasing from 5.8 to 10.2 m/hr and WOB decreasing significantly from 22 to 4 klbs. The formation responses recorded in these parameters indicate that this zone also possesses relatively high permeability and may serve as an additional conduit for reservoir fluid inflow.

IV. CONCLUSION

analysis from Well DUG-L6, several key conclusions can be drawn regarding the identification of geothermal feed zones and their implications for reservoir characterization: Evaluation of Mud Logging Unit (MLU) data revealed two borehole circulation temperature (BHCT) anomalies exceeding 55°C during active circulation: the first in the interval 1300–1355 mMD with a maximum of 63.4°C, and the second in the interval 2300–2593 mMD with a maximum of 60.6°C. In addition, total loss circulation (TLC) was recorded beginning at 1355 mMD, together with significant variations in Mud Flow Out (MFO) and QLoss, further supporting the presence of active fluid pathways. Cuttings analysis from the 1300–1355 mMD interval indicated a dominance of Dacite Lithic Tuff, supported by the presence of hydrothermal alteration minerals such as chlorite, illite, epidote and claystone. The alteration mineralogy suggests equilibrium within a temperature range of 180–230°C. Complementary MeB testing yielded values between 4 and 5, pointing to the presence of active clays that support the interpretation of this interval as a productive flow zone.. Based on the integration of technical and geological datasets, two intervals fulfilled at least three out of four feed zone validation criteria: 1300–1355 mMD and 2300–2593 mMD. Both intervals combine indicators of drilling breaks, total loss circulation, elevated borehole temperature, and the presence of hydrothermal alteration minerals. These findings demonstrate that reservoir feed zone identification can be accurately achieved using only real-time mud logging and wellsite geological data, without requiring post-drilling surveys.

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