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The Characteristics of The Overpressured Sedimentary Formation in The Ulubelu Geothermal Field

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ABSTRACT

Sedimentary rock is a common lithology we can encounter in geothermal reservoir drilling activity in Sumatra, Indonesia. This formation often challenges the drilling operation due to its mechanical behaviour, especially in the Ulubelu field, which often causes the wellbore stability issue. Based on the logs data in the UBL-M well, we discuss the characteristics of this sedimentary formation encountered during drilling. The sedimentary formation is a part of the extensive Tertiary Hulusimpang formation as a compacted siltstone unit deposited interlayered with volcanic products. Due to the overburden and the lithostatic pressure gradient, the sedimentary becomes overpressure, as the permeability and porosity are extremely low, where the pore pressure significantly exceeds the hydrostatic pressure. This conclusion is revealed through the compaction analysis derived from the available drilling parameter, geophysics log and mechanical failure evidence from the image log data. The normal compaction trendline (NCT) analysis from the sonic log indicates an abnormal pressure profile along the sedimentary interval up to 7000 psi. The image log shows a prominent borehole breakout feature which indicates that the formation was drilled in underbalanced conditions. The loading curve analysis results that the overpressures were generated by fluid expansion or transfer processes, which are controlled by fractures and high-temperature geothermal fluid in the reservoir. Using this information, we managed to penetrate the thick sedimentary formation interval safely by increasing the bottom hole pressure to balance the overpressure in this formation. This study is critical to addressing the optimum drilling parameter once the well has to deal with the compacted sedimentary formation in geothermal reservoirs, especially in production or loss circulation zones, where the drilling parameter becomes more constrained to adjust. Moreover, the sedimentary unit can also contribute to the feedzone and become advantageous to drill.

1. Introduction

Natural overpressured and compacted shale formations formerly the oil and gas industry term for a shale formation in depth that store substantial hydrocarbon. These formations are characterized by higher-than-normal pore pressures, meaning that the pressure exerted by the fluids within the shale exceeds the typical pressure expected based on the weight of the overlying rock layers. One notable feature of overpressured compacted shale formations is their relatively low permeability. The fine-grained nature of shale makes it inherently impermeable but still contains some porosity, so the fluid will tend to be trapped whenever the pressure is elevated at some point which also increases the pore pressure within the fluid significantly.

Oil and gas industry activity, especially in South Sumatra, has resulting studies that characterize the overpressured shale formation in well-known formations. Ramdhan et al. (2018) identified two distinct overpressure zones: a low–-medium overpressure zone at intermediate depths characterized by disequilibrium compaction and clay diagenesis, and a deeper high overpressure zone primarily attributed to gas generation, with contributions from disequilibrium compaction and clay diagenesis. Syukri et al. (2019) suggest the overpressure regime occurs in the deep Tertiary basement due to disequilibrium compaction due to rapid burial and hydrocarbon generation. Sumarsono (2020) specifically studied the overpressure shale formation in the Gumai formation due to the dismantling factor of clay minerals.

Under typical burial conditions, sediments undergo compaction following a loading curve, resulting in decreased porosity as effective stress increases. However, when overpressures arise from disequilibrium compaction, the compaction process is hindered, leading to deposits with unusually high porosities. Disequilibrium compaction is linked to a lithostatic stress parallel pore pressure increase, maintaining a constant effective stress during burial. Consequently, sediments undergoing disequilibrium compaction remain on the loading curve on a porosity-vertical effective stress plot (Bowers, 2002). In contrast, sediments initially compacting under normal hydrostatic pressure conditions may experience overpressure due to fluid expansion or vertical transfer, following an unloading curve. The subsequent increase in pore pressure causes a decrease in vertical effective stress. Although compaction is generally irreversible, the unloading mechanism results in a slight elastic contraction of sediment grains, leading to a small change in porosity. Thus, overpressures generated by the unloading process follow a porosity-vertical effective stress path divergent from the loading curve (Bowers, 2002).

Direct pressure measurement in sedimentary formation is challenging due to its low permeability, prompting the widespread adoption of indirect methods for pressure assessment. Geophysical measurements, such as sonic velocity and bulk density, serve as valuable proxies for overpressure-related petrophysical properties in sedimentary sequences. Log data, being readily available and reliable, are commonly utilized in pressure research and prediction. The distinct petrophysical characteristics of overpressured sequences are contingent on the prevailing overpressure mechanisms, leading to varied responses to effective stress. Consequently, differentiating pressure generation mechanisms often relies on analyzing loading-unloading curves, which have proven to be effective tools in this context

Overpressured sedimentary reservoirs can be found in various geological settings, including in a geothermal field. This paper discusses the characteristics of overpressured sedimentary formation encountered in the Ulubelu reservoir during drilling. Ulubelu is a geothermal field that is shaped in a basin-like geological setting due to the depression on the tip of one of the Sumatra Fault System segments (Arifin et al., 2021). One of the sedimentary-rich formations that fill the basin is the Hulusimpang formation which lies extensively from central to southern Sumatra area and consists of interlayered sedimentary and volcanic rocks (Ikhwan et al., 2023). This sedimentary formation is encountered all over the Ulubelu reservoir, with thick intervals in the northern part, distributed extensively over 6 km from northwest to southeast. However, drilling from overpressured shale formations pose technical and operational challenges. The elevated pore pressures can lead to wellbore stability issues, including kicks, blowouts, and formation collapse if not properly managed. The geomechanical complexities associated with overpressured shale necessitate careful consideration of mud weight, drilling techniques, and casing design to ensure safe and efficient operations.

In this paper, the authors discusses the characteristics of the overpressured sedimentary unit in the Ulubelu geothermal reservoir using the available drilling parameter and logs data and successfully solves the wellbore-instability issue of this formation in the drilling activity by applying the drilling parameter that considers the results of the pore-pressure analysis in the sedimentary unit. The results could be important and valuable information to lower the risk in geothermal drilling that intersects the overpressured sedimentary unit, especially in the Sumatra geothermal field.

2. Geological Setting

Ulubelu geothermal field is located about 100 km west of Bandar Lampung, Lampung Province, southern Sumatra. It lays as a half-graben structure related to tensional stress from SFS inside the post-caldera depression of Mt. Sula. Nusantara et al. (2020) have summarized the subsurface stratigraphy of the Ulubelu field which is composed of lava and pyroclastic products of Mt.Rendingan, mixed volcaniclastics breccia associated with carbonates lenses, ignimbrite as the reservoir facies of the system, and carbonaceous rocks as the deepest layer penetrated by numerous wells at an elevation around -1100 masl. As a sequence of graben filling formation inside of a depression system, the formation lateral distribution is spread evenly aligned with the basin topography. It is proven by borehole data in every well inside the depression that the dipping of this sequence of lithology is tilted to the east.

The sedimentary unit found in the Ulubelu field is a part of the regional Hulusimpang formation (Tomh) or is equal to the Seblat formation (Toms) which is referred to regional geological map by Amin et al. (1993) (Figure 1a). The Hulusimpang formation (Tomh), was deposited during the late Oligocene to early Miocene. It is characterized by various volcanic-sedimentary products, including andesite lava, volcanic breccia, lahar deposit, tuffs, and lapilli. Seblat formation (Toms) comprises tuffaceous and volcanic-sedimentary material. Another younger volcanic-sedimentary unit mapped regionally is the Bal formation (Tmba). These volcanic-sedimentary-related formations are believed as a massive volcanic product during the Paleogene and Neogene, extensively distributed in central and southern Sumatra. They are part of the proto-Barisan mountain which marks a major tectonic event in Sumatra (Barber et al., 2005). The proto-Barisan mountain represents a volcanic arc that separated the forearc and backarc basins. During this period, maximum transgression occurred in the forearc, resulting in a major sedimentary influence on the Hulusimpang, Seblat and Bal formations (Kusnama et al., 1993) (Figure 1b). Hulusimpang formation was affected by tectonism as the Sumatra Fault System initiated in the late Miocene and tectonically sliced the these formations along NW-SE strike-slip faults, some of which may have localised on inherited rift faults (Barber et al., 2005).On the surface, they are extensively deposited in Ulubelu and mostly covered by the Quaternary volcanic deposit (Qhv). Geothermal drilling activities in several fields in Sumatra encountered this formation and found its significant role in the permeability and well's productivity (Ikhwan et al., 2023).

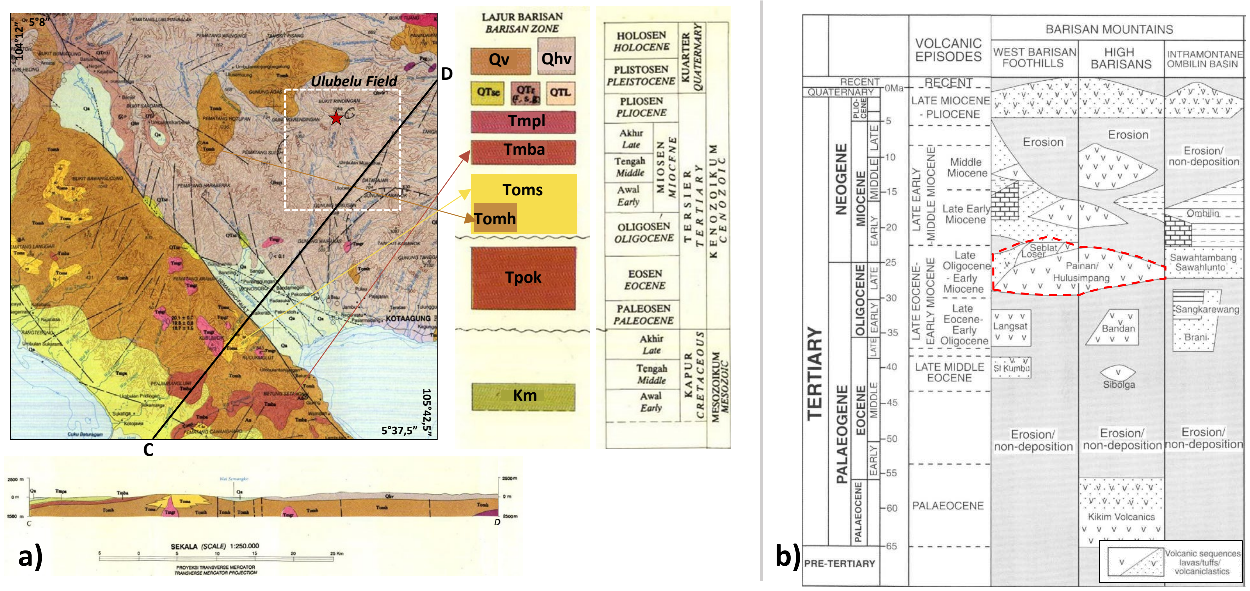

Figure 1: The regional of Hulusimpang Formation. A) The location of Ulubelu field in South Sumatra regional geological map, remarked by the white dashed line. The red star is the location of UBL-M. B) The stratigraphy of the South Sumatra formation. The Hulusimpang formation is remarked by the red dashed line.

3. Data and Method

This study is based on well data in Ulubelu called UBL-M, located in the northern part of this field. As the pressure while drilling (PWD) is not used in this well, we are using the available open-hole geophysics logs and drilling parameters to identify the overpressure sedimentary formation. The logs data available in this study included gamma-ray, sonic, density and borehole image logs. The logs data are filtered to fulfil the ideal compaction analysis environment. Overall, the quality of available logs data is good and reliable to use. All of the logs are only available in the production interval, ranging from 1200 to 2100 mMD. However, some feedzones in this well are steam zones which makes the anomaly in logs reading, especially sonic. Thus, the optimal interval to do the compaction analysis in terms of pore pressure prediction ranges from 1450 to 2100 mMD which better represents rock properties.

The normal compaction trendline (NCT) is a fundamental concept in geology used to represent the expected decrease in porosity with increasing depth during sediment burial. The NCT is constructed based on the assumption of normal compaction under hydrostatic conditions, where sediments experience progressive compaction due to the overlying weight of the overburden (Syukri et al., 2019). This trendline serves as a reference to understand the natural evolution of porosity with burial depth in the absence of abnormal pressures.

In the study of overpressure formation, the compaction curve method becomes invaluable. This method involves comparing the actual porosity of a formation, as obtained from well logs or core data, with the expected porosity predicted by the NCT at the corresponding depth. Deviations from the NCT indicate abnormal pressure conditions. Specifically, higher-than-expected porosities suggest overpressure, as the normal compaction under hydrostatic conditions would have resulted in lower porosity.

When overpressures are generated by disequilibrium compaction, the compaction curve method aids in recognizing these anomalies. Disequilibrium compaction occurs when the sediments experience overpressure due to changes in stress conditions, hindering the normal compaction trend. In such cases, the observed porosity values deviate from the NCT, and the compaction curve method helps identify the magnitude of the overpressure. Understanding the compaction curve facilitates the differentiation between normal compaction and abnormal conditions associated with overpressures

In oil and gas practice, the normal compaction trendline (NCT) is often constructed using shale, including siltstone, because shale is a common sedimentary rock with distinctive characteristics that make it a suitable reference for understanding the expected compaction behaviour of sediments during burial. It is fine-grained nature, the tendency to compact under hydrostatic conditions, sensitivity to stress and pore fluids, and the availability of well-log data make it a suitable material for constructing the normal compaction trendline. The NCT using shale provides a valuable reference for interpreting porosity-depth relationships in sedimentary basins and identifying deviations indicative of abnormal pressures. In this study, the fine-grained lithology like shale, is assumed homogeneous with the altered pyroclastic rocks such as tuff as the Ulubelu is a volcanic-hosted geothermal field that is mostly composed of volcanic products than sediment. The geological setting of Ulubelu as a depression or basin-like reservoir also comply the burial loading along the depth of the pyroclastic which make it reliable to do the NCT analysis relatively.

4. Characteristics of The Sedimentary Formation

4.1 Geology

Lithological prediction from the gamma-ray log is less effective in volcanic-dominated reservoirs as the radioactive mineral abundantly occurs in several volcanic rock types. Therefore, the geology of this interval is mostly derived from the image log data which is supported by spotted coring data from the sidewall core tool as the cutting sample tends to give uncertain lithological information and loss circulation zone also happened in this well. Figure 2b shows the lithology on the production interval which is dominated by pyroclastic rocks as the well-known reservoir host rocks in Ulubelu that are called Rhyolitic Tuff formation (Nusantara et al., 2021). The rhyolitic term used as the tuff is mostly dominated by secondary quartz that changes the parent rock colour into bright white as shown by cuttings data.

However, the image log shows a layered formation ~400 meters thick along 1750 mMD to the bottom of the well that also has significantly different drilling parameters. The sidewall core data at 1815 mMD and 2100 mMD confirms the layered formation is the sedimentary rock that is composed of siltstone which is fine-grained sedimentary rock characterized by its dark colour, typically ranging from deep grey to black (Figure 2d,e). It is composed predominantly of silt-sized particles, with a grain size finer than sand but coarser than clay. The smooth, fine texture of black siltstone results from the deposition and compaction of fine-grained sediments over geological time. This rock often exhibits a distinct, non-reflective lustre due to its fine-grained nature. In terms of hardness, the siltstone sample falls within the range of medium to hard on the Mohs scale and the physical behaviour of this sedimentary sample is brittle making it prone to cause hole problems in drilling activity. The mineralogy of this sample is composed of plagioclase, opaque and quartz fragments with glass matrix (Figure 2f). The groundmass mostly consists of very fine-grained siliciclastic sedimentary material with a size of less than 0.1 mm. Some alteration minerals also fill the vein or replace the primary minerals including secondary quartz, calcite, chlorite and iron-oxide. This sedimentary sample also contains varying amounts of organic matter, which might contribute to its dark colour. The presence of organic material is pronounced in its depositional environments, as discussed by Ikhwan et al. (2023) indicates the age range of the sedimentary samples matches the suggested Hulusimpang formation age where it was found (late Oligocene to early Miocene). This sedimentary formation occurs interlayered with the pyroclastic deposit, which agrees with the characteristics and mechanism of the volcanic-sedimentary rocks that compose the geology of this field regionally (Kusnama et al., 1993).

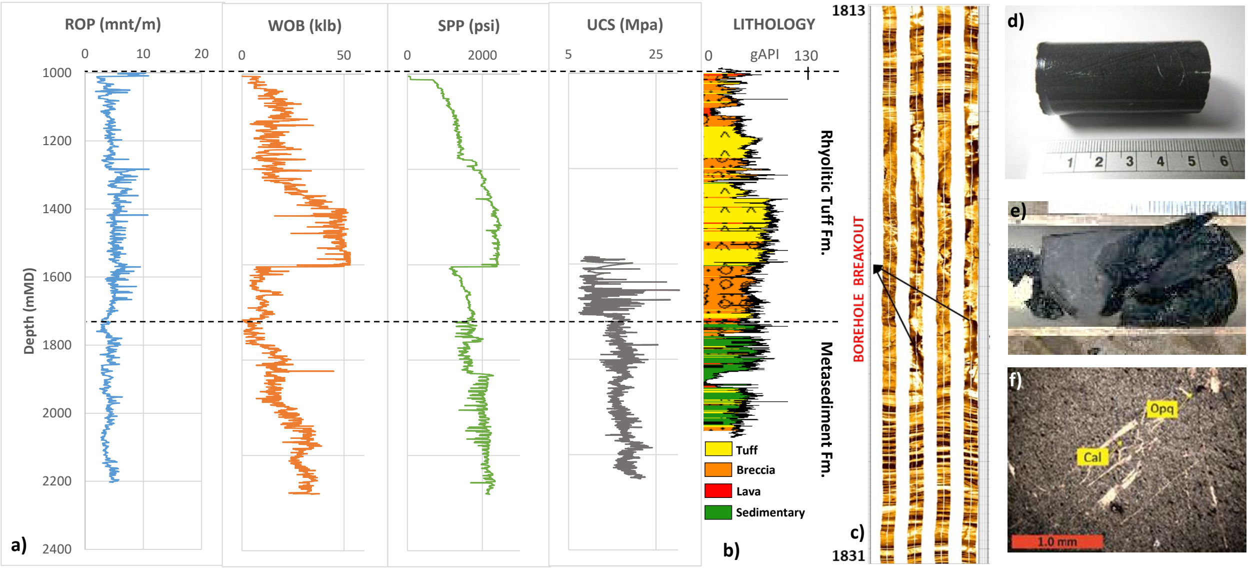

Figure 2: The measurement and lithology characteristics in UBL-M production interval. A) The drilling parameters in UBL-M. The sedimentary formation interval started by the dashed line. B) The lithology along the production interval with gamma-ray reading. C) The example of borehole breakout detected from the image log in sedimentary formation interval. D&E) The sidewall core sample of sedimentary formation. F) The thin section image of sedimentary formation.

4.2 Drilling Parameters

The sedimentary formation gives distinguished parameters during drilling which is shown by Figure 2a. To maintain the drilling rate of penetration (ROP) range between 2 – 4 minutes/meter, the weight on bit (WOB) needs to be increased gradually from 4 klb up to 30 klb, starting at 1750 mMD to the bottom of the well. The consequence is the pressure also needs to be justified by the weight to ensure the borehole wall safe from damage. In this case, due to the total loss zone, the pressure that increased is the pressure to maintain the desired ROP. These parameter changes need to be applied in the UBL-M drilling due to the hardness of the compacted sedimentary rocks is significantly harder than the overlying pyroclastic rocks. To estimate the sedimentary rock strength, we used a formula to calculate the uniaxial comprehensive strength (UCS) by the sonic and density logs. The result shows that the UCS of the sedimentary formation is higher up to three times than the pyroclastic above that range from 15 to 21 Mpa while the pyroclastic only 7 Mpa average. Therefore it needs more energy to drill this formation comparing the earlier section which impacts the drilling parameters.

4.3 Log Responses

The fractures in this well are less intense and the alteration intensity is assumed homogenous along the logged production interval which is dominated by prophylitic alteration, therefore the effect of the secondary minerals on the log's reading is assumed negligible. Gamma-ray, sonic and density logs are reliable on 1450 to 2100 mmD intervals. The gamma-ray ranges from approximately 60 to 80 API (Figure 2b), which indicates that the grains-size of this formation is bigger than the claystone which usually has a higher API up to 150 but smaller than sandstone grain size. The density of the sedimentary interval in general is also higher than overall lithology in this well, ranging from 2.6 to 2.85 g/cm3 which also indicates the lower permeability of this sedimentary interval. The compressional sonic log in the sedimentary interval decreases significantly from 80 to 60 µs/ft compared to the shallower formation.

5. Pressure Characteristics and The Origin of Overpressure

5.1 Pressure in Reservoir

In a geothermal reservoir, the pore pressure typically closely approximates hydrostatic conditions, as highlighted by Fournier (1991). While overpressure, characterized by pore pressures exceeding hydrostatic levels, can be generated in isolated pore spaces due to geological processes such as compaction or tectonic compression (Zoback, 2007), high-temperature geothermal reservoirs, operating as convection cells with interconnected porosity, generally maintain conditions close to hydrostatic. It's noteworthy that a steam cap may appear overpressured when compared to the regional hydrostatic, as it conveys pressure at the interface between liquid and steam, known as isobaric pressure. The concept of a pressure pivot point is pivotal in understanding geothermal well pressure profiles, as established by Grant and Bixley (2011). This pressure pivot point is a fixed location on the pressure profile that corresponds to the reservoir pressure. The rest of the pressure profile is contingent on the temperature and, consequently, the density of the fluid within the well. Pressure profiles for a connected liquid reservoir are determined by employing linear interpolation of pivot points obtained from multiple wells, as depicted in the provided figure. Calculating the pressure within a steam zone (above the liquid level but below the clay cap) involves determining the steam saturation pressure.

The Ulubelu reservoir has gained recognition as a liquid-dominated geothermal reservoir, as highlighted in the study by Arifin et al. in 2021. A specific interval in the well, ranging from 1200 to 2100 meters measured depth (mMD), has been subject to detailed investigation. Within this depth range, the utilization of a pressure measurement tool has provided valuable insights into the reservoir's characteristics.

The recorded linear pressure gradient within the 1450 to 2100 mMD interval indicates that the reservoir is situated below the water level. This observation is crucial for estimating hydrostatic pressure directly from the pressure measurements obtained from the well. The recorded linear pressure gradient depicts a gradual increase in pressure, starting at approximately 1900 pounds per square inch (psi) and reaching a value of around 3200 psi. This incremental rise in pressure is indicative of the subsurface conditions and the potential for hydrothermal fluids within the reservoir.

The ability to estimate hydrostatic pressure directly from pressure measurements is significant for understanding the pressure regime within the Ulubelu reservoir. The gradual increase in pressure observed in the specified depth interval suggests dynamic subsurface processes, possibly related to the movement of geothermal fluids and the reservoir's response to these changes. Such insights into pressure variations are crucial for the comprehensive characterization of the Ulubelu geothermal reservoir, contributing to the broader understanding of its reservoir pore pressure behaviour.

5.2 Pressure in Sedimentary Formation

Available sonic and density log data from the UBL-M well were used to draw comprehensive compaction curves. Figure 3 shows the compaction curves in the well: the volcanic rock units are normally compacted above 1750 mMD, and the sonic decreases with depth, whereas the density increases. Both logs exhibit no anomalies with depth. The compaction curve of well UBL-M deviates from the normal compaction trend below approximately 1750 mMD, which illustrates that the sonic and density log values are lower than the values for the normal compaction trend (NCT). The uniformly deviating well log curves reflect the pronounced overpressure in the sedimentary formation interval. This phenomenon leads to the interpretation of the overpressure zone in the well where the top of the overpressured zone can be interpreted at 1750 mMD, which is consistent with the compaction curves.

The overpressure in fine-grained sedimentary can be estimated by standard porosity-based pore pressure prediction techniques, such as the equivalent depth method, which mainly represents the overpressure generated by disequilibrium compaction. Figure 3 presents the pressures in the sedimentary formation interval on the profiles corresponding to the UBL-M well. As predicted by the sonic and density log curve anomaly, the estimated pressures show that the top of the overpressured zone is at a depth of approximately 1750 mMD right at the end of the Rhyolitic Tuff formation, where the pore pressure significantly increases from the gradual changes. The overpressures then increase with depth, and the excess pressures vary from 500 to 3900 psi from the normal compaction pressure.

The high pressure of sedimentary formation is also suspected from the occurrence of borehole breakout recorded on the borehole image log data. In general, the drilling activity of geothermal reservoirs in Indonesia is always overbalanced which means the drilling pressure is much higher than the pore pressure and the fracture gradient pressure. This can be seen from the drilling-induced fractures that mostly occur in the geothermal borehole which is the drilling-induced tensile fractures (DITF). In the case of the drilling pressure lower than the pore pressure or called underbalance drilling, the borehole breakout will appear. These two features are distinguishable from the image log. Instead of DITF, borehole breakouts appear at some depth on the sedimentary formation interval at UBL-M which indicates that the pore pressure is higher than the drilling pressure (Figure 2C). This is can be seen in Figure 4 at 1750 mMD, where the bottom hole pressure lower than the pore pressure and the borehole breakout likely to occur. Breakout commonly resulting a borehole enlargement of the borehole wall and triggered overpulled in drilling activity that can be evidence of the wellbore stability impact. This analysis supports the overpressure prediction in the sedimentary formation interval.

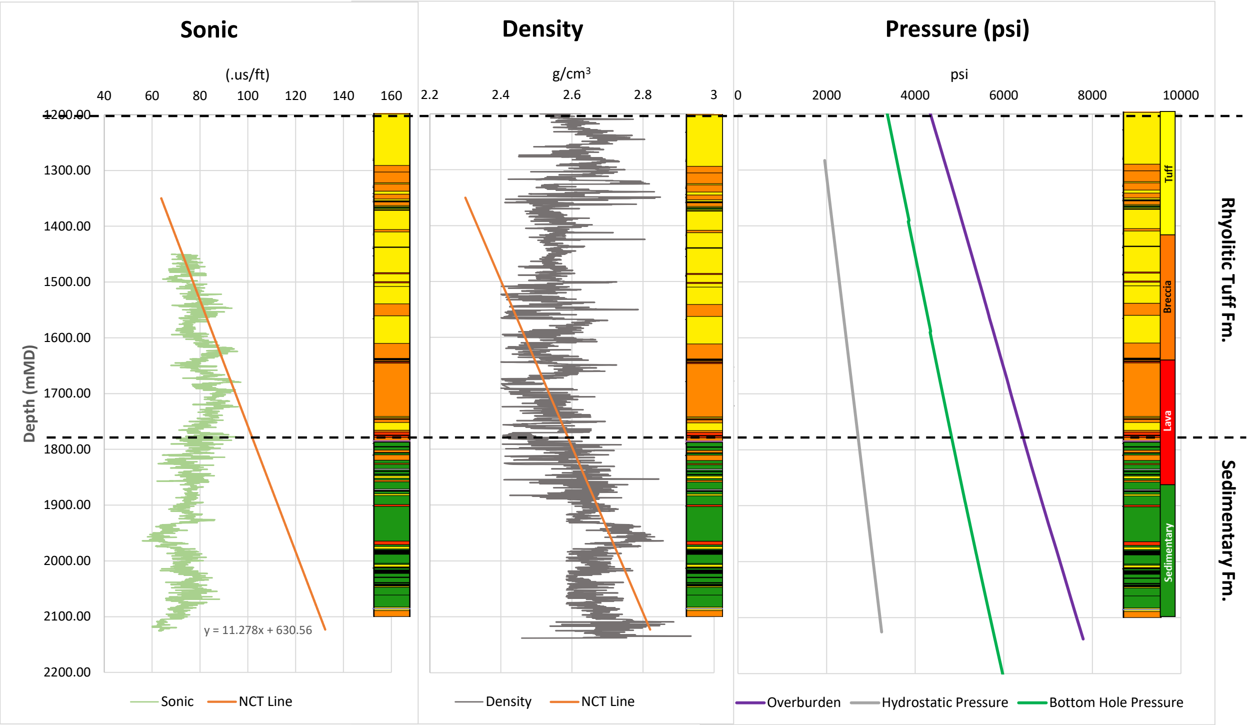

Figure 3: The logs and pressures measurements in UBL-M. The black dashed line is the top of sedimentary formation interval.

5.3 Identifying the Overpressuring Mechanisms

Overpressure in geological formations can arise from various mechanisms, two of which are disequilibrium compaction and fluid expansion or vertical transfer. These processes can lead to elevated pore pressures within the subsurface, deviating from the expected hydrostatic conditions. Here's an overview of each mechanism. Disequilibrium compaction occurs when sediments undergo compaction at a rate that does not match the rate of pore fluid expulsion. This disequilibrium arises due to factors such as rapid sedimentation or changes in sedimentation rates. Overpressure can also result from the expansion of fluids within the pore spaces or from the vertical migration of fluids from deeper sources. In fluid expansion, an increase in temperature or changes in fluid properties can cause fluids to expand, leading to higher pore pressures. This is common in geothermal reservoirs, where elevated temperatures may cause pore fluids to expand. In vertical transfer, fluids can migrate vertically from deeper formations to shallower ones. This may occur due to tectonic processes, faults, or the intrusion of new fluids. As fluids migrate, they can accumulate and create overpressure. The overpressure generated by fluid expansion or vertical transfer can manifest in various geological settings, including fault zones, areas of active tectonics, or regions with fluid-rich formations.

Loading-unloading curves, represented by plots of sonic velocity against vertical effective stress, are widely employed to differentiate the origins of overpressure (Ruth et al., 2004). The source of overpressure can be identified as disequilibrium compaction if the overpressured points align with the loading curve. Conversely, if the overpressured points deviate from the loading curve, it suggests fluid expansion or transfer processes. The vertical effective stress in the region was determined by calculating the vertical stress using density logs and incorporating pore pressures measured from the sonic log. The pore pressure from the interval before depth 1750 mMD indicated normal pressure and was utilized to establish the loading curve. By concentrating the loading curve, the impact of factors that might disrupt the similarity of sedimentary properties was eliminated, providing a robust basis for further discerning the underlying mechanisms of the unloading process.

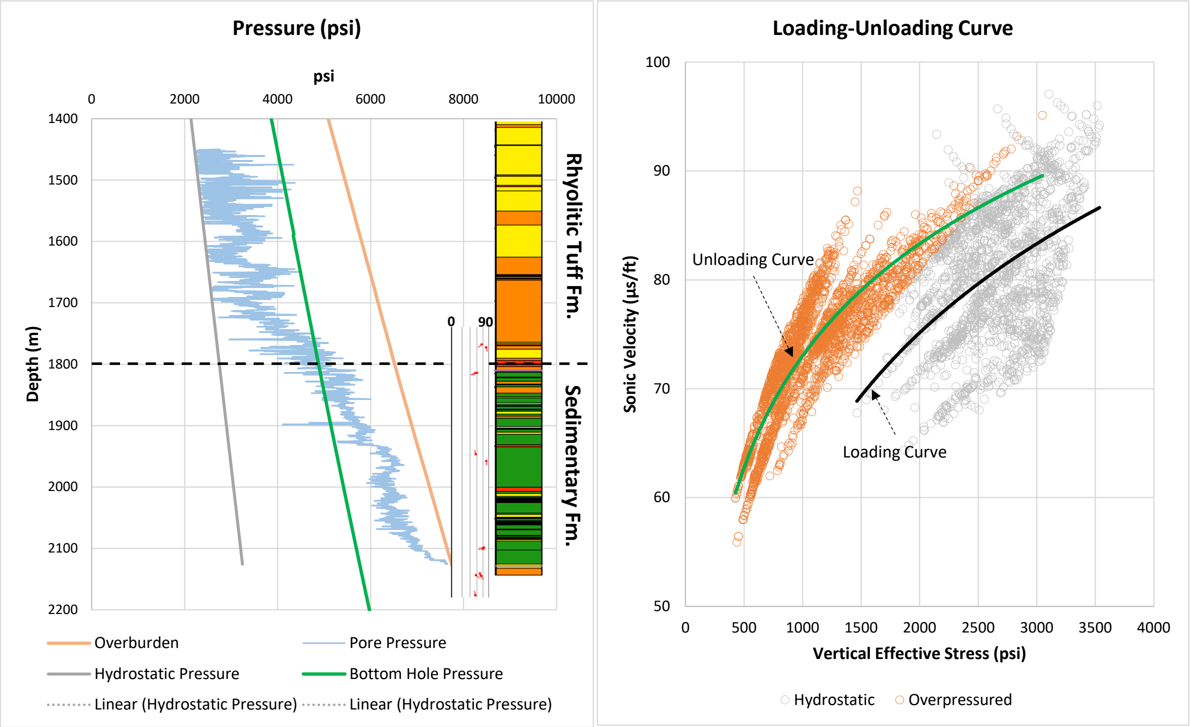

Figure 4: (Left) The pore pressure indicates the overpressure zone in the sedimentary formation. The pore pressures (blue line) overcrossing the bottom hole pressure (green line) which indicates the underbalance condition during drilling. The red tadpoles are the detected fault from the image log data which indicates near vertical dip. Right) Acoustic velocity–vertical effective stress crossplots for the UBL-M. The points are on or near the loading curve (above the sedimentary formation interval), indicating normal compaction, or disequilibrium compaction (grey points), whereas the overpressured data lie on an unloading curve, suggesting that the overpressure is generated by fluid expansion or transfer processes (orange points).

The loading curve was used as a datum baseline, which was used to identify possible overpressure generating mechanisms. It can be seen that overpressured velocity–vertical effective stress offsetting or deviating the scatter of the normal pressure points that define the loading curve. Therefore, the overpressures were generated by fluid expansion or transfer processes, which is consistent with the trend of the unloading curve. It is clear that the pressure gradient of the data that lie on the unloading curve is greater than 152 psi/km (Figure 4) as the normal hydrostatic pressure gradient in the UBL-M, and the depths of these points vary from 1750 m to the bottom of the well. The mechanism of non-disequilibrium compaction overpressure in the sedimentary formation interval might occur as the combination of vertical transfer and fluid expansion process. Two possibilities make this happen; first, from the image log data, there are several possible near vertical faults identified that could accommodate the vertical permeability in this interval. The possible fault appears as a conductive sinusoid that creates a geological displacement and can act as the conduit for the fluid to flow (Figure 4). Second, the sedimentary formation is a part of the geothermal reservoir with a high-temperature fluid up to 270°C which makes the fluid become more buoyant due to the temperature differential. The vertical permeability might accommodate the migration of the hot fluid from the deeper part to the sedimentary formation interval. This hot fluid will convectively and conductively heat the fluid within the formation and cause the fluid expansion due to the increase in temperature or change in fluid properties, resulting in higher pore pressure.

The observed overpressure within this sedimentary formation can be explained by the thermo-poroelasticity theory proposed by Cheng (2016). This theory posits that rocks are not merely solid materials but have significant porosity that allows fluid infiltration. The thermal expansion coefficient of these fluids, particularly water, is typically higher than that of the minerals constituting the rock. Consequently, when a water-saturated rock is heated, the fluid within the pores expands more significantly than the rock itself. In scenarios where the rock exhibits extremely low permeability or is effectively sealed, preventing fluid escape, the expanding fluid induces an increase in internal pore pressure. This heightened internal pore pressure can lead to the fracturing of the rock from within.

6. Conclusion

The study on the overpressured sedimentary formation in the Ulubelu geothermal field reveals crucial insights into the challenges and characteristics of drilling in such environments. The overpressure is primarily attributed to fluid expansion and vertical transfer processes, influenced by fractures and high-temperature geothermal fluids. These mechanisms lead to elevated pore pressures, which significantly exceed the hydrostatic pressure due to the extremely low permeability and porosity of the formation.

By analyzing drilling parameters, geophysical logs, and mechanical failure evidence, the study establishes that the sedimentary formation exhibits an abnormal pressure profile with pore pressures reaching up to 7000 psi. The use of image logs highlights borehole breakout features, indicating underbalanced drilling conditions. The compaction analysis and loading curve suggest that the overpressures align with fluid expansion or transfer processes rather than disequilibrium compaction.

To manage drilling in such overpressured formations, it is essential to increase bottom hole pressure to balance the formation pressure, ensuring wellbore stability and safe penetration of the thick sedimentary intervals. This study underscores the importance of understanding the geomechanical behavior of overpressured formations in optimizing drilling parameters and addressing wellbore stability issues, particularly in geothermal reservoirs where such challenges are prevalent

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