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Characterization of Overpressure in Well Al, North Sumatra Basin: Evaluation of Pore Pressure Using the Eaton Method and Sonic-Density Crossplot

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Abstract: The North Sumatra Basin is one of the major sedimentary basins in Indonesia with significant hydrocarbon potential. However, exploration in this region faces challenges due to overpressure, which can increase operational risks such as blowouts. This study aims to analyze pore pressure and overpressure formation mechanisms in Well Al using the Eaton method and a crossplot approach between sonic and density data. The analysis results indicate that the top overpressure is identified at a depth of 8,500 ft in the Keutapang Formation and continues into the Baong, Bampo, and Parapat Formations. Wireline log evaluation indicates anomalies in the sonic, neutron, and density logs, which are consistent with disequilibrium compaction patterns. The Dutta crossplot results also confirm the dominance of smectite minerals without transformation into illite, reinforcing that the primary overpressure mechanism is loading due to disequilibrium compaction. Accurate pore pressure modeling is necessary to improve drilling safety and efficiency in this area.

Keywords: Disequilibrium compaction; Eaton method; Overpressure; Pore pressure

Introduction

Exploration strategies in the North Sumatra Basin must consider abnormal subsurface pressures to mitigate operational risks. Abnormal pressures can manifest as underpressure or overpressure, each affecting well stability and drilling design. One of the biggest challenges in this basin is overpressure, where fluid pressure within rock pores exceeds hydrostatic pressure, increasing the risk of blowouts, drilling accidents, and operational costs (Umorem, 2011; Haris, et al., 2017).

Previous research by Irawan (2014) identified the Keutapang and Baong Formations as primary overpressure zones dominated by shale and claystone with low permeability. This condition traps fluids, causing pressure accumulation beyond hydrostatic limits. Therefore, this study focuses on pore pressure analysis and identifying overpressure formation mechanisms to understand the factors contributing to pressure accumulation in these formations.

Method

Understanding pore pressure is crucial in identifying overpressure formation mechanisms, which is the main focus of this study. Pore pressure is a key parameter influencing well stability and drilling design, requiring accurate estimation. Therefore, pore pressure estimation was conducted using the Eaton method (Eaton, 1975), with the equation:

$$P = \sigma_v - (\sigma_v - P_n)\left(\frac{\Delta t_n}{\Delta t}\right)^n \quad (1)$$

Description:
P = pore pressure
σ_v = overburden pressure
P_n = normal pressure

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Δt_n = normal travel time
Δt = actual travel time
n = Eaton exponent

The data used in this study were obtained from Well Al, including mud weight data, Leak-Off Test (LOT), and drilling reports. Additionally, wireline log analysis was conducted, covering sonic, density, neutron, resistivity, and gamma-ray logs. All data were converted into psi/ft units to ensure consistency in analysis. This comprehensive data usage enables more accurate and representative pore pressure estimation. Understanding pore pressure estimation is not only essential for identifying overpressure formation mechanisms but also significantly impacts well stability and drilling design. Overpressure can form through two main mechanisms: loading and unloading.

As illustrated in Figure 1, the loading mechanism occurs when effective stress in the rock remains constant while overburden increases due to rapid sedimentation, preventing effective fluid escape from pores. This condition typically occurs in low-permeability rocks, such as shale, which hinder fluid release (Swarbrick & Osborne, 1998). As a result, pressure accumulation leads to disequilibrium compaction, where rocks fail to compact normally (Haris et al., 2017).

Figure 2 shows the ideal pattern of overpressure characteristics formed through disequilibrium compaction. Normally, porosity decreases with increasing depth; however, in overpressure conditions, porosity remains constant. Similarly, sonic wave velocity remains constant because, under overpressure conditions, the rock does not experience further compaction that would otherwise increase wave velocity and reduce travel time. Consequently, travel time, which typically decreases with depth, remains unchanged. Rock density also does not significantly increase since pore space is maintained due to high fluid pressure, keeping density values constant instead of increasing with depth (Bowers, 2002).

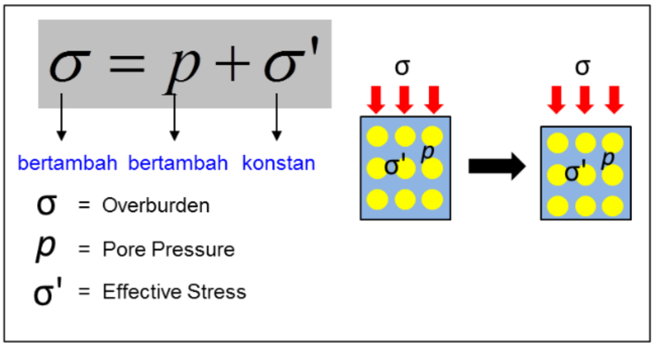

Figure 1. Overpressure in rock under disequilibrium compaction conditions (Swarbrick & Osborne, 1998)

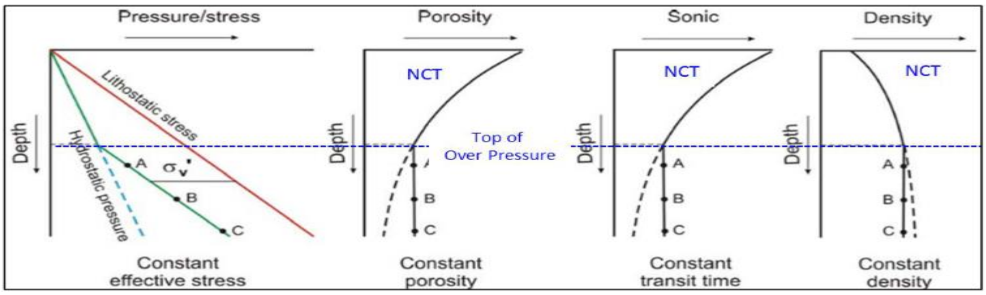

Figure 2. Ideal pattern of overpressure characteristics with the disequilibrium compaction mechanism (Bowers, 2002)

Meanwhile, Figure 3 illustrates the unloading mechanism, which occurs due to reduced effective stress and increased fluid volume in pores caused by decompaction or mineralogical reactions, such as mineral transformations that release additional fluids (Bowers, 2002). This process differs significantly from the loading mechanism, as overpressure is no longer controlled by compaction but rather by factors such as fluid expansion or pore volume changes. Figure 4 shows the ideal overpressure characteristics formed through the unloading mechanism.

Under normal conditions, porosity decreases with depth. However, during unloading, porosity increases due to reduced effective stress, resulting in larger pore spaces. Sonic wave velocity, which should decrease with depth due to rock compaction, instead increases under unloading conditions. This is due to increased pore volume filled with fluid, prolonging travel time. Similarly, rock density, which normally increases with depth, decreases under the unloading mechanism due to increased porosity reducing overall rock mass density.

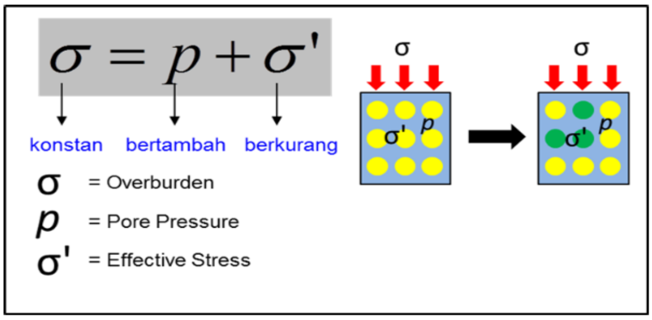

Figure 3. Cartoon illustration of overpressure due to the unloading mechanism (Bowers, 2002)

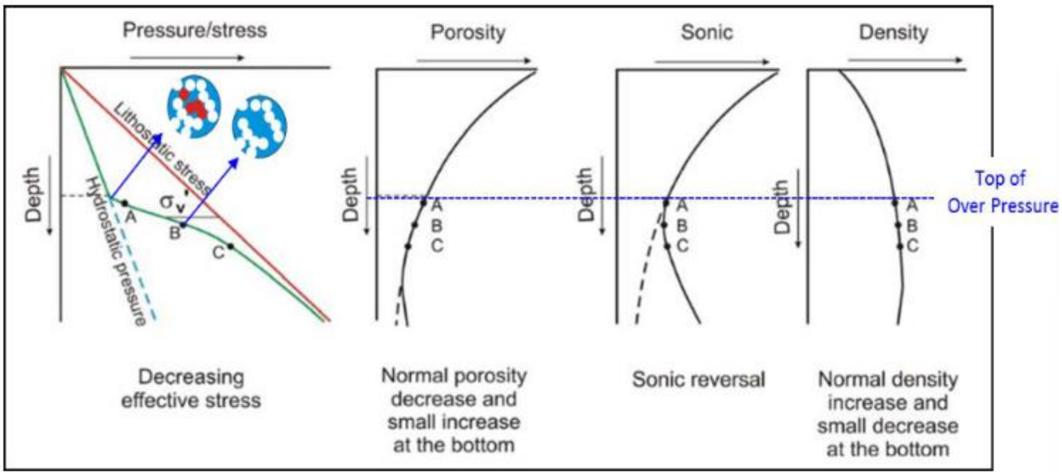

Figure 4. Ideal pattern of overpressure characteristics with the unloading mechanism (Bowers, 2002)

Results and Discussion

Figure 5 shows that the top overpressure is at a depth of 8,500 ft in the Keutapang Formation. It also indicates that high and constant sonic travel time suggests a lack of compaction, signifying that the rock retains high pore pressure. This is further supported by rock density that does not significantly increase, indicating that compaction due to overburden load is not fully effective. Additionally, decreasing resistivity may be associated with high-conductivity formation water filling rock pores. Higher porosity than normal trends suggests that the rock still has good fluid storage capacity, potentially supporting hydrocarbon accumulation in the petroleum system.

This overpressure condition is not limited to the Keutapang Formation but also extends into deeper formations such as Baong, Bampo, and Parapat, indicating a stacked reservoir system. The presence of multiple hydrocarbon accumulation zones at varying depths reflects a complex petroleum system, where hydrocarbons are trapped in multiple layers with different pressure levels.

Leak-Off Test (LOT) results in Figure 5, used as fracture pressure indicators, show higher formation pressures than expected, further confirming overpressure in this area. The high Leak-Off Test (LOT) suggests that formation pressure is beyond normal limits, potentially affecting borehole stability and determining the maximum allowable drilling mud density. Low resistivity anomalies in the overpressure zone may indicate high-conductivity fluids, such as formation water, filling rock pores. However, when combined with increasing mud weight trends, this phenomenon may also suggest free gas presence in the petroleum system.

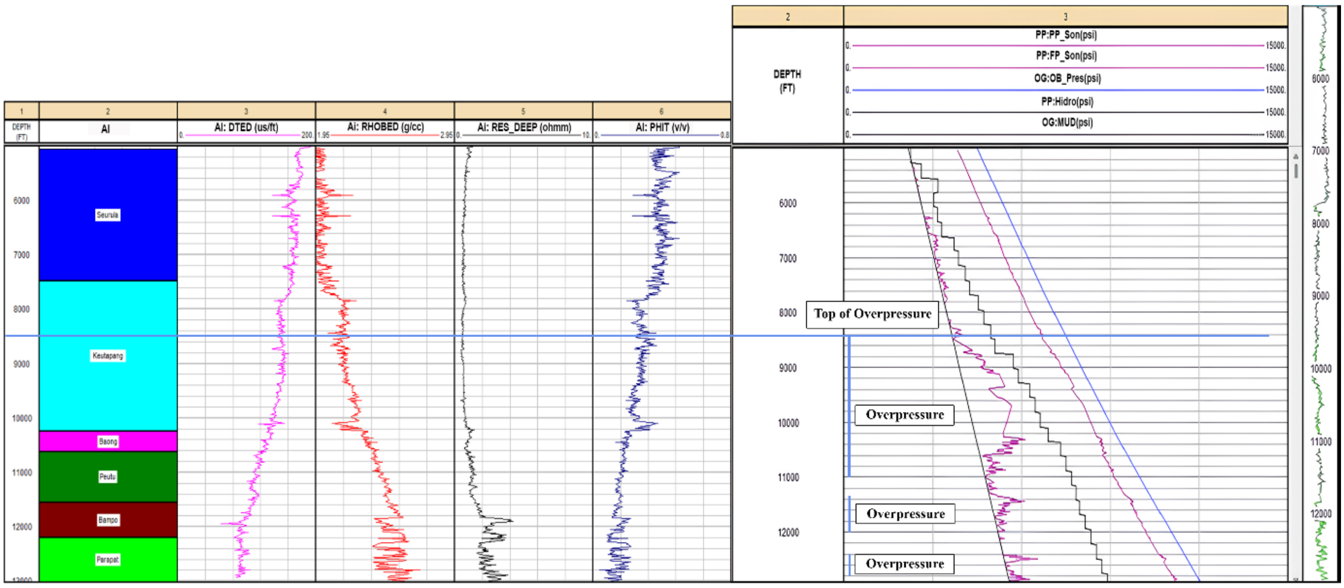

Figure 5. Depth-pressure curve and top overpressure determination

For wireline log anomalies found in the overpressure zone in Figure 6, distinctive characteristics are observed due to the inability of the rock to undergo complete compaction. The sonic log shows a consistently high and constant travel time despite increasing depth, indicating that high fluid pressure prevents rock compaction. This is consistent with the neutron log results, which show an increase in values due to the high fluid content in the rock pores, particularly in low-permeability formations that hinder fluid release. Additionally, the density log does not show a significant increase with depth, further reinforcing the indication that rocks in the overpressure zone have not undergone complete compaction.

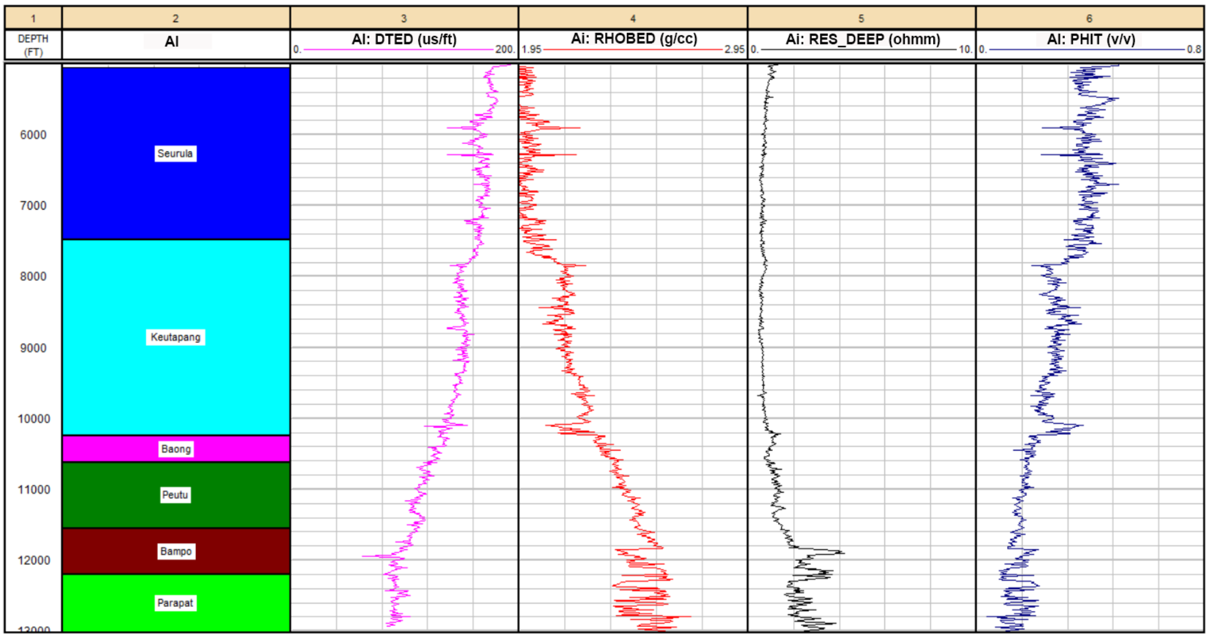

Figure 6. Sonic log, density, resistivity, and porosity data

Meanwhile, Figure 7 presents a crossplot between sonic and density data, showing the dominance of smectite minerals in the Seurula, Keutapang, and Baong formations (Dutta, 2002). Smectite has a high-water retention capacity within rock pores, which hinders fluid release and maintains high pore pressure. In contrast, data points in the Parapat Formation tend to approach the Illite Line, indicating that rocks in this zone have undergone further diagenesis and have better mineralogical stability. More mature illite minerals generally have higher permeability than smectite, thus supporting better hydrocarbon accumulation and production.

In Figure 7, the Keutapang Formation, characterized by high sonic travel time and low density (positioned between the smectite line and illite line), exhibits low resistivity, indicating a significant presence of formation water. However, a different pattern is observed in the Baong, Bampo, and Parapat Formations, where zones with similar characteristics show higher resistivity. This increase in resistivity may indicate the presence of gas-bearing zones, as reported by Haris et al. (2017) in the Bintuni Basin, where gas trapped in rock pores replaces conductive fluids such as formation water, thereby increasing resistivity values and reinforcing the indication of hydrocarbons.

Furthermore, analysis results also indicate that overpressure in Well AI is predominantly caused by loading due to disequilibrium compaction. This process occurs when the addition of overburden load progresses faster than the release of fluid from rock pores, causing pore pressure to remain high and impeding fluid migration. This condition not only impacts formation pressure but also affects reservoir properties.

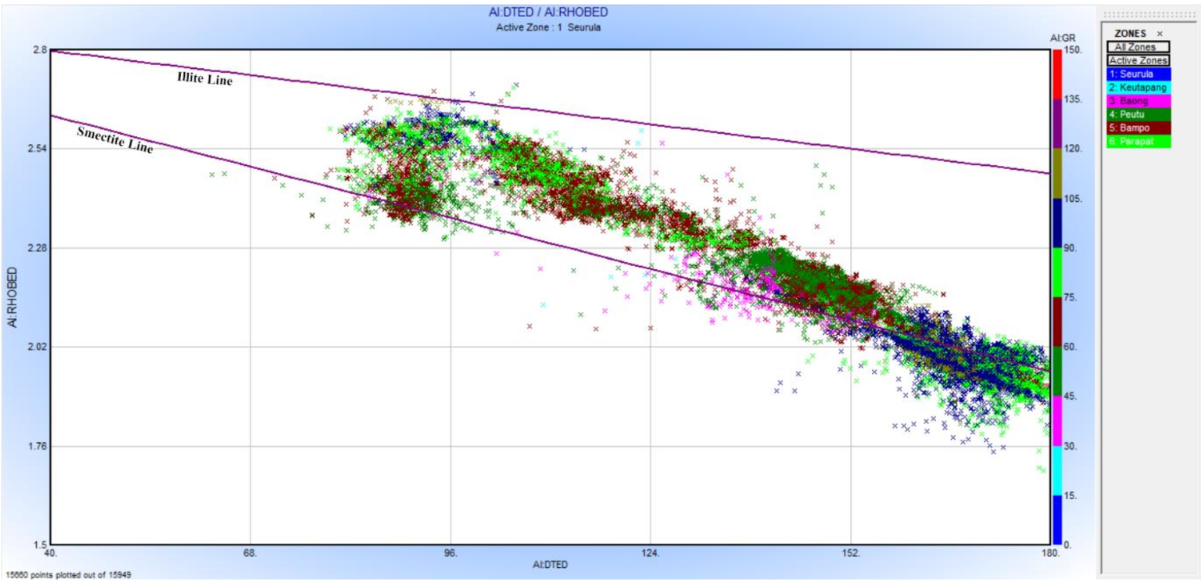

Figure 7. Dutta crossplot between sonic and density

Conclusion

Based on pore pressure analysis and overpressure mechanisms in Well Al, the overpressure zone was identified with a top overpressure at 8,500 ft in the Keutapang Formation, extending into the Baong, Bampo, and Parapat Formations. The significant increase in mud weight indicates a high overpressure risk in the study area. Additionally, wireline log anomalies observed in sonic, neutron, and density logs indicate that pore pressure remains high, consistent with disequilibrium compaction as the primary overpressure mechanism. The Dutta crossplot results confirm that overpressure in Well Al is primarily caused by loading due to disequilibrium compaction rather than the unloading mechanism.

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Author Contributions

Conceptualization, A.H.; methodology, A.H.; R.; formal analysis, R.; writing – original draft preparation, R.; writing – review and editing, A.H.; R.; supervision, A.H. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

No conflict of interest.

References

Bowers, G. L. (2002). Detecting High Overpressure. *Leading Edge*, *21*, 174-177. https://doi.org/10.1190/1.1452608

Dutta, N. C. (2002). Geopressure Prediction Using Seismic Data: Current Status and the Road Ahead. *Geophysics*, *67*(6), 2012–2041. https://doi.org/10.1190/1.1527101

Eaton, B. A. (1975). The Equation for Geopressure Prediction from Well Logs. *Society of Petroleum Engineers*, *SPE Paper*. https://doi.org/10.2118/5544-MS

Haris, A., Parlindungan, E., & Riyanto, A. (2017). Pore Pressure Prediction in Laminated Shaly Sand Reservoir: A Case Study of Bintuni Basin. *AIP Conference Proceedings*, *1862*, 030161. https://doi.org/10.1063/1.4991265

Irawan, B. (2014). Geomechanics Analysis of North Sumatra Basin. *Indonesian Petroleum Association Proceedings*, *38*(1), 45–56.

Swarbrick, R. E., & Osborne, M. J. (1998). Mechanisms that Generate Overpressure. *APPG Bulletin*, *82*(1), 51–74.

Umorem, U. E. (2011). Overpressure and Its Implication for Drilling Safety. *Journal of Petroleum Science and Engineering*, *77*(2), 215–223.