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Petrophysical Analysis and Evaluation of Overpressure Zone as Hydrocarbon Trap in North East Java Basin

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Abstract: Errors in estimating pore pressure can cause blowouts during the drilling process, especially in overpressured zones. This study focuses on pore pressure estimation in the North East Java Basin using the approach, which is validated with field data. The well log data analyzed include resistivity, density, sonic velocity, and porosity, which are used to detect the presence of overpressure zones and identify reservoir potential. The results show that the overpressure zone begins at a depth of 4600 feet and lasts up to 9000 feet. The interval between 4800 to 7300 feet is identified as a potential reservoir, while seal rocks are found at 4000–4600 feet. The cross plot between sonic and density parameters shows the dominance of smectite minerals, indicating that perfect compaction has not occurred due to trapped fluids. This finding strengthens the suspicion that the overpressure formation mechanism is dominated by sediment loading. Precise pore pressure estimation is needed to reduce operational risks and optimize hydrocarbon exploration in this area.

Keywords: Hydrocarbon; Overpressure; Pore pressure; Reservoir; Smectite

Introduction

Failure to predict pore pressure is often the main cause of blowouts in drilling activities, especially in areas that have indications of overpressure (Bowers, 2002; Dubinya et al., 2022; Oloruntobi & Butt, 2019)). Overpressure not only poses a risk to operational safety, but can also cause environmental damage and economic losses (Pan et al., 2023; Xiu et al., 2025). Therefore, accurate pore pressure estimation is a crucial aspect in casing design planning and drilling risk mitigation (Asfha et al., 2024; Mahmoud et al., 2024). Failure to predict pore pressure: Pore pressure is the pressure of fluids (water, oil, gas) contained in the pore spaces of rocks beneath the earth's surface (Li et al., 2023; Wang et al., 2024). Accurate prediction of pore pressure is essential before and during drilling operations. Failure to predict this means that the pore pressure estimate is far from the actual condition. Often the main cause of blowouts: Blowouts are the loss of control over a drilling well, where formation fluids (oil, gas, water) erupt uncontrollably to the surface. Failure to predict pore pressure is one of the main triggers for blowouts because: Unexpected formation pressure: If the pore pressure is much higher than expected (overpressure), it can exceed the ability of the drilling mud to withstand it (Ashena et al., 2020).

The drilling mud serves to provide hydrostatic pressure to balance the formation pressure and prevent fluids from entering the well uncontrollably (Darwesh et al., 2017; Huszar et al., 2022; Wittenberger et al., 2023). Incorrect well design: Incorrect pore pressure prediction can result in inadequate casing design (the steel pipe that protects the well) and selection of well control equipment (such as a blowout preventer -BOP) to withstand the actual formation pressure. Especially in areas with indications of overpressure: Overpressure or abnormal pressure is a condition where the pore pressure exceeds the normal hydrostatic pressure at a certain depth (Nagy et al., 2021). Areas with indications of overpressure (e.g., based on seismic data, neighboring well data) have a higher risk of blowout if the pore pressure prediction is inaccurate (Bahmaei & Hosseini, 2020; Jafarizadeh et al., 2022). In these areas, the difference between the estimated and actual pore pressure can be very significant and fatal. Pore pressure prediction is a complex geotechnical challenge because it involves understanding (Amjad et al., 2023; Chen et al.,

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2025). The history of sediment loading and uplift; Rock composition and permeability; Hydrocarbon generation and migration; Tectonic activity. Various methods are used to predict pore pressure, including analysis of seismic data, well log data (measurements of the physical properties of rocks in the well), and drilling data.

However, uncertainty always exists, and failure to interpret the data or the presence of unexpected geological conditions can lead to prediction errors (Doyle et al., 2019). The North East Java Basin is an area that has geological indications of overpressure. However, there is no detailed pore pressure mapping in this area (Suryana et al., 2023). Therefore, this study aims to estimate pore pressure using the (Eaton, 1975) method by integrating well log data and validating it with actual data from the field.

Method

This study is based on the analysis of well log data that includes resistivity, density (RHOB), sonic velocity (DT), and porosity parameters. Estimation of pore pressure is carried out using the Eaton (1975) approach based on sonic velocity value anomalies correlated to hydrostatic pressure. The overpressure zone is determined by comparing the calculated pore pressure with the hydrostatic pressure, where a higher pore pressure value is an indicator of overpressure. In addition, an analysis is carried out to trace the cause of overpressure, both in terms of loading mechanisms such as imperfect compaction, and external factors such as lateral pressure or fluid expulsion. This evaluation is expected to produce accurate pore pressure mapping to support safer hydrocarbon exploration and production planning.

Results and Discussion

Interpretation of well log data shows that in general, rock porosity decreases with increasing depth due to natural compaction processes. However, at certain depths, such as 3600 ft, 6000 ft, 7200 ft, 8400 ft, 8800 ft, 9200 ft, and 10200 ft, the porosity value remains relatively high. This condition indicates that the rocks in this interval still have large enough pore space to accommodate fluids, so they have the potential to act as reservoir zones in the petroleum system. In addition, Sonic Travel Time (DT) data shows that the deeper the rock layer, the DT value generally decreases, which is a consequence of the increasing density and compactness of the rock. However, at depths between 6200 and 9000 ft, the DT value shows a stable tendency. This stability indicates a failure in the compaction process, where fluids trapped in the rock pore space inhibit further compaction. This condition can be a sign of the presence of a high-pressure zone (overpressure), which geologically can act as a hydrocarbon trap (Chen et al., 2022; Krishna et al., 2024; Tan et al., 2020).

The increasing trend of rock density (RHOB) also indicates a normal compaction process (Abbey et al., 2021; Amjad et al., 2022; Matinkia et al., 2022). However, at a depth of 6200–9000 ft, the density value does not appear to follow an increasing trend, but is relatively constant. This indicates that the presence of fluid in the rock maintains internal pressure, thereby slowing or stopping the compaction process (Hosseinzadeh et al., 2024; Jahanbakhsh et al., 2020). The presence of high Gamma Ray (GR) values at this depth interval further strengthens the suspicion that the layer consists of shale or organic-rich material, which tends to be impermeable and can store internal pressure for a long time. Analysis of the Deep Resistivity Log (LLD) also provides important information. In the depth interval of 6200–9000 ft, the resistivity values show quite large variations. Some layers show high resistivity values, while others are low. High resistivity likely reflects the presence of hydrocarbons (oil or gas), while low resistivity indicates the presence of conductive fluids such as salt water (Adeniran et al., 2024; Senger et al., 2021). This variation shows that several rock layers in the zone have been filled by different fluids, creating a complex stratigraphic potential but with high exploration value (Abd El-Hay et al., 2024; Alghamdi et al., 2024).

From the pressure aspect, top overpressure was identified at a depth of 4600 ft. The high-pressure zone was found in the interval of 4600–6000 ft and was re-detected from 6200 to 9000 ft. Most likely, this overpressure condition arose due to the presence of seal rocks that inhibited the release of fluid pressure from the layers below. In the petroleum system, seal rocks have a crucial role in maintaining hydrocarbon accumulation in the reservoir zone. Based on well log data, the main reservoir zone is located in the interval of 4800–7300 ft, which is characterized by porosity and permeability values that support fluid storage. While seal rocks were identified in the interval of 4000–4600 ft, which also corresponds to the beginning of the emergence of overpressure.

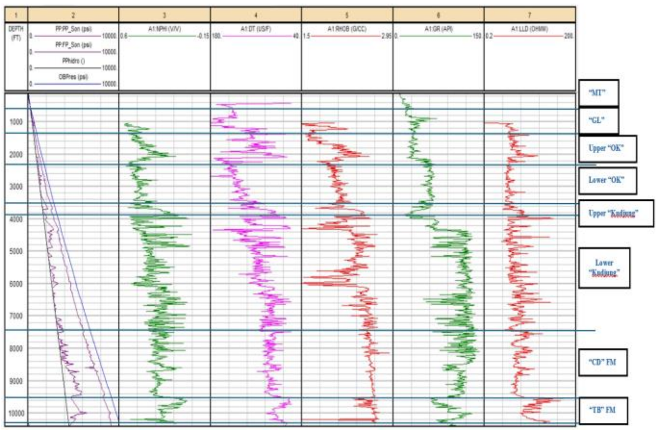

Figure 1. Sonic log, density, resistivity, and porosity data

Figure 1 shows a cross plot between Sonic (DT) and rock density (RHOB) values. In the plot, the bottom line represents the position of smectite minerals, while the top line represents the position of illite minerals. These lines are used to evaluate the level of clay mineral transformation due to diagenesis and increased temperature and pressure. Figure 2 shows the distribution of data in the cross plot across the analyzed depth intervals, the dominant mineral identified is smectite. Almost no data was found indicating transformation into illite. This indicates that the rock has not undergone advanced diagenesis, which usually occurs at higher temperatures and pressures. This means that the rock is still in the early to middle diagenetic stage.

The presence of dominant smectite strengthens the suspicion that the overpressure formation mechanism in this area is dominated by vertical loading due to sediment accumulation (loading) (Li et al., 2022). Smectite has a high water retention capacity and tends to inhibit the rock compaction process (Qin et al., 2019; Zheng & Bourg, 2023). When fluids are trapped, high pore pressure can form. This process inhibits the transformation of smectite minerals into illite and supports the formation of a stable high-pressure zone. Thus, the results of petrophysical analysis as well as pore pressure and mineralogical mapping indicate that the study area has great potential as a petroleum system (Feng et al., 2024; Hussain et al., 2022), with a combination of porous reservoirs, effective seal rocks, and overpressure zones that function as hydrocarbon traps. A thorough understanding of these physical and geological properties is essential for exploration decision making and drilling risk management (Du et al., 2024; Xu et al., 2023).

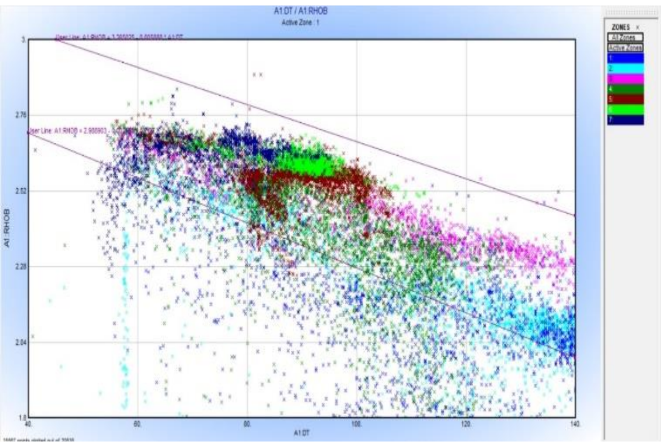

Figure 2. Dutta Crossplot between sonic and rhob

Conclusion

Petrophysical analysis of well log data indicates the presence of a reservoir zone with porosity and resistivity characteristics that support hydrocarbon accumulation at a depth of 4800–7300 ft. The seal rock zone is at 4000–4600 ft, while overpressure is identified from 4600 to 9000 ft, indicating potential hydrocarbon traps due to compaction failure. The cross plot between DT and RHOB confirms that smectite minerals are still dominant, strengthening the hypothesis that this zone is under high pressure due to sediment loading mechanisms. Thus, this area has promising hydrocarbon prospects and requires special attention in drilling planning.

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Conceptualization, M. A; methodology, A. H.; validation, R.; formal analysis, M. A.; investigation, A. H.; resources, R.; data curation, M. A.: writing—original draft preparation, A. H.; writing—review and editing, R.; visualization. All authors have read and agreed to the published version of the manuscript.

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No conflict interest.

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