Stratigraphic Sequences Analysis Based on Well Log and Petrophysical Calculations in Bunyu Tapa Field, Tarakan Basin, North Kalimantan

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Abstract. The Bunyu Tapa Field, located in the Tarakan Basin's deltaic setting, is a major gas producer with complex sedimentation patterns. To minimize future exploration risks, it is essential to interpret the reservoir stratigraphically and understand its condition. This study aims to analyze the stratigraphic framework, identify prospective hydrocarbon zones, and evaluate the petrophysical properties of reservoir. The result of this study shows that Bunyu Tapa Fields is The depositional environment in the Bunyu Tapa field exhibits a delta progradation depositional system, where the Santul Formation, deposited in a delta front setting, transitions into a lower delta plain-delta front environment in the Tarakan Formation. The Bunyu Formation is subsequently deposited within a fluvial-deltaic setting. Based on stratigraphic concepts, the research field is divided into two sequences, with each sequence boundary influenced by regional tectonic events. The overall depositional cycle in the study area is regressive, and each sequence includes a brief transgressive phase marked by Maximum Flooding Surfaces. The petrophysical calculations for the Bunyu Tapa Field reveal a lithological condition characterized by shaly-sand or a multi-layered reservoir, with an average shale volume ranging from 0.18 v/v to 0.41 v/v. The porosity is classified as good to very good, and the water saturation values range between 25% and 66%. The salinity values, based on the depositional environment, fall within the transitional zone range (5,000–20,000 ppm). The Santul Formation is identified as the most prospective zone, supported by the thickest net pay of 621.67 m, with an average shale volume of 0.21 v/v, a porosity value of 13%, and a water saturation value of 56%.
Keywords: sequence stratigraphy, petrophysics

1. Introduction

The Tarakan Basin located along the margins of Kalimantan, Indonesia, has been notable for hydrocarbon exploration. Significant discoveries include four major oil fields and one large gas field, with cumulative production exceeding 320 million barrels of oil (MMBO). The hydrocarbon reserves are located within thick deltaic sandstone reservoirs and marine sandstones. The stratigraphy of the study area, deposited from the Miocene to the Pleistocene, includes the Santul, Tarakan, and Bunyu Formation.

The aim of this study is to achieve a more accurate sequence stratigraphic framework and reservoir characterization through comprehensive petrophysical analysis. The petrophysical analysis results, including shale content, porosity, and water saturation from all wells, provide significant insights for refining reservoir models. Integrating geological concepts with petrophysical parameters is crucial for obtaining reliable outcomes within the study area.

2. Data and Methodology

2.1 Introduction

A total of 13 wireline logs of the Bunyu field were used in the petrophysical analysis. Reliable core data were available, providing lithology description, core porosity, and fluid content. Biostratigraphy data were available from three wells, which were used to optimize depositional environment interpretation.

2.2 Determination of Depositional Environment Analysis and Stratigraphic Sequences

This phase begins with analyzing electrofacies patterns based on gamma-ray logs across all wells. Following the determination of electrofacies, depositional facies analysis will be conducted with control from regional geological conditions. The analysis will be guided by models of transitional lower delta plain depositional environments in zones where coal is present (Horne et al., 1978), sedimentary log schemes of progradational deltas (Nichols, 2023), and previous studies related to the depositional facies in the research area. The sequence boundaries are identified based on erosional surfaces or unconformities, and the maximum flooding surfaces are determined based on the maximum point in the gamma-ray value.

2.3 Petrophysical Analysis

Data quality control involved log patching, normalization, pre-calculation, correction, and geological interpretation before petrophysical analysis.

2.3.1 Shale Volume

The calculation of shale volume from gamma-ray logs is performed using a linear function. The determination of shale volume from the gamma-ray log involves the identification of the minimum line (sand baseline) and maximum line (shale baseline) in each formation. Due to the absence of mudlog and XRD data, the integration of these datasets with the determination of shale volume could not be conducted.

2.3.2 Porosity

Porosity calculation was determined from Density logs. The values for neutron wet clay, neutron dry clay, density wet clay, and density dry clay were established through cross-plot analysis between corrected NPHI and RHOB logs, serving as input parameters for porosity calculations. The result of effective porosity was compared with core porosity and was found to be a good match.

2.3.3 Water Saturation

Since the reservoir is a shaly-sand based on qualitative analysis, core samples, and mud logs, the Simandoux water saturation model was used to calculate the water saturation in the reservoir. The water resistivity was determined using the pickett plot method (Figure 1), utilizing NPHI and ILD logs to identify water-bearing zones across each formation in all wells. The parameters of water saturation, such as a, m, and n, were defined from literature where special core analyses (SCAL) were absent. Tortuosity factor (a) was assumed as 0.62, Cementation factor (m) as 2.61 and Saturation exponent (n) as 2.

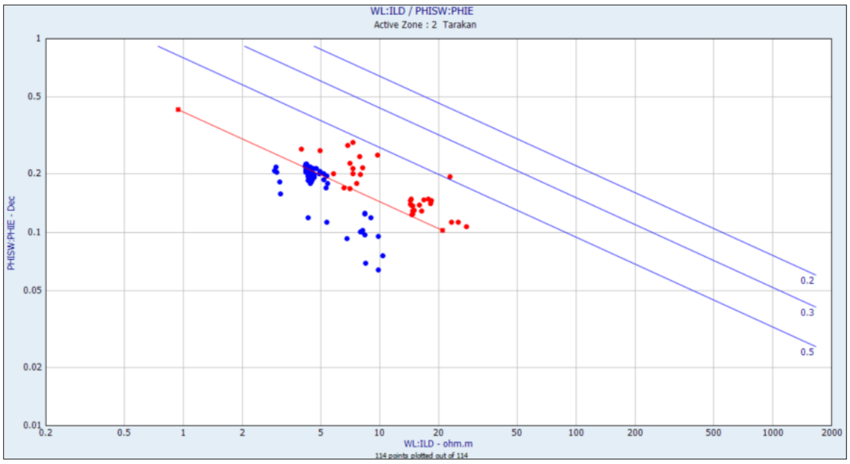


Figure 1. Pickett plot method in water saturation calculations.

2.3.4 Cut-Off Determination

After estimating the petrophysical properties, a sensitivity analysis of the cut-off values for shale volume, porosity, and water saturation was conducted to aid reserve estimation and identify productive zones. This analysis used drill stem test data to benchmark hydrocarbon-proven zones and guide cut-off determination. In zones without drill stem test data, cut-offs were determined qualitatively based on water-bearing interpretations (Figure 2). The results were compiled in the petrophysical lumping table.

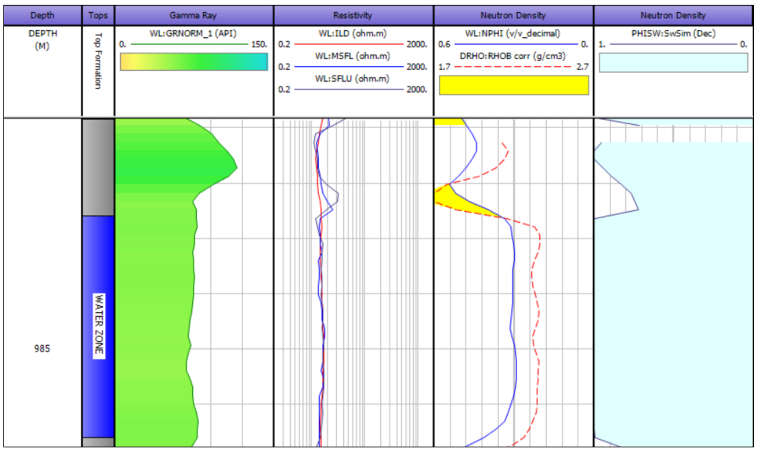


Figure 2. Water bearing zone as a reference for determining cut-off in zones where DST data is absent.

3. Results and Discussion

3.1 Depositional Environment

Based on biostratigraphic data and foraminifera zonation, the research field can be categorized into three distinct zones. The first zone, identified as Barren Zone I, is characterized by the absence of foraminifera and is interpreted to have been deposited in a fluvial-upper delta plain environment. The second zone, located in the middle, is characterized by the abundance of *Trochammina sp* (Figure 3). and *Haplophragmoides sp.* fossils and is interpreted as being deposited in a lower delta plain environment. The third zone, referred to as Barren Zone II, is associated with deposits from the delta front.

Based on the analysis of log curves, lithological informarion, and biostratigraphic data, the depositional environment in the Bunyu Tapa field can be estimated. It is found that the Santul Formation is characterized by fine to medium-grained sandstone interbedded with dark gray siltstone of fine to very fine grain size, claystone, and minor thin coal particles. A fining-upward pattern is indicated by the log curve for the Santul Formation, characteristic of delta front to prodelta deposits. The distributary mouth bar is observed to begin appearing in the upper part of the Santul Formation, as shown by a progradational pattern.

The Tarakan Formation is described as having interbedded fine-medium-grained quartz sandstone and mudstone with an increasing presence of coal beds and becoming thicker, indicating a lower delta plain environment. In the lower Tarakan, several GR curves exhibit a progradational pattern attributed to the distributary mouth bar facies. Meanwhile, a fining upward pattern with a thick sand bar is observed in the upper Tarakan, interpreted as a transition from lower delta plain to delta front deposition.

The Bunyu Formation is characterized by the dominance of thick sand bar lithology, suggesting the presence of distributary channels. Lignite, observed at several depth intervals, is interpreted as an indication of swamp depositional facies. An upward fining pattern and shale lithology within the formation are associated with overbank or fluvial deposits. Biostratigraphic analysis correlates the Bunyu Formation with a Fluvial-Upper Delta Plain depositional environment. Lithologically, core data reveal that the formation consists of white to light ash sandstone with fine to medium grains, interspersed with loose quartz and very fine sandy claystone.

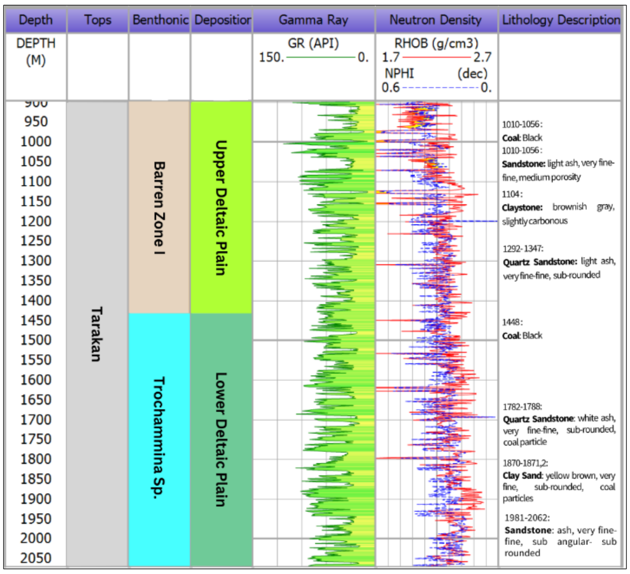


Figure 3. Integration of wireline log, core, biostratigraphy data in the Tarakan formation interval.

3.2 Sequence Stratigraphy

Sequence 1 is defined by the boundaries SB-0 and SB-1, separating the Santul Formation from the lower part of the Tarakan Formation. At the base of Sequence 1, a transgressive phase is identified by maximum gamma ray values, indicating a prodelta depositional sub-environment corresponding to the maximum flooding surface. The transition to a deltaic depositional cycle is marked by a regressive system with a prograding pattern, resulting in the formation of distributary mouth bar facies. The boundary of this sequence is characterized by a significant change in the gamma ray log, associated with an uplifting event in the Late Miocene.

Sequence 2 is bounded by SB-1 and SB-2. The initial facies above Sequence 1 is characterized by a transition from prodelta to delta front developed during a transgressive phase caused by rising sea levels that halt the regression phase at the end of Sequence 1. After a brief transgressive phase is experienced, the sequence is followed by a coarsening-upward pattern or regressive system, resulting in the formation of distributary mouth bar facies. In the upper part of the Tarakan Formation, the presence of coal indicates that deposition occurred within a lower delta plain environment. This sequence is terminated by an unconformity at the base of the Bunyu Formation, caused by tectonic folding and erosion events during the Plio-Pleistocene.

The shift in the depositional environment from lower delta plain-delta front to fluvial-upper delta plain within the Bunyu Formation indicates a regressive system. This is evidenced by the progradation pattern observed above Sequence 2. Biostratigraphic data confirm this change, as reflected by a transition from the *Trochammina Sp.* and *Haplophragmoides Sp.* fossil zones to the Barren I zone.

3.3 Petrophysical Analysis

3.3.1 Shale Volume

Based on the shale volume average, the Santul Formation exhibits the highest shale volume, ascribed to deposited in a low-energy environment, resulting in finer-grained sediments. In contrast, Tarakan and Bunyu Formation deposited in relatively higher-energy environments, display progressively lower shale volumes, consistent with the presence of coarser-grained sediments. The stratigraphic sequence from Santul to Bunyu Formation thus indicates a shallowing-upward pattern or progradational sequences as evidenced by the decreasing average shale volume. In general, well-log analysis reveals an average shale volume ranging from 0,18 v/v to 0,41 v/v.

3.3.2 Porosity

The average porosity calculated using the density method shows a decline with increasing depth. The Santul formation exhibits a lower average porosity compared to the Tarakan and Bunyu formations. This trend is primarily due to compaction, a common process in sedimentary rocks. Over time, as newer sediments accumulate, the weight of the overlying material exerts pressure on the deeper sediments, leading to a reduction in pore space.

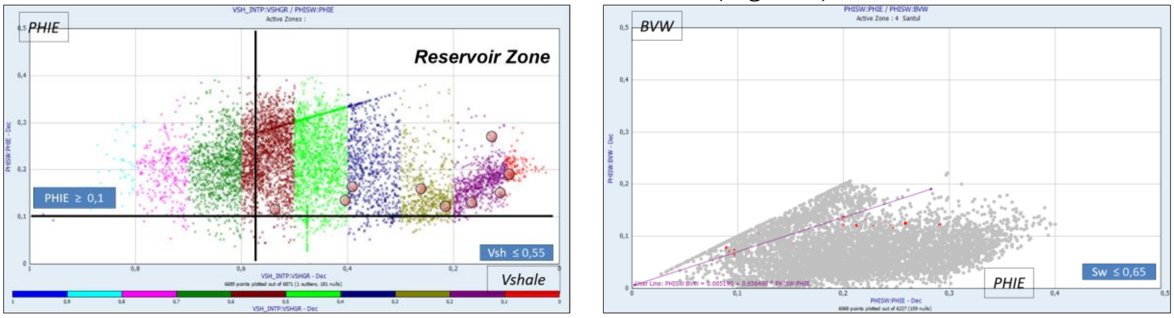
3.3.3 Water Saturation

The average water saturation calculation results are shown to be significantly impacted by the value of shale volume on the final water saturation calculation. The higher the volume of shale, the greater the water saturation is found to be. This is attributed to the ability of shale to retain water within its mineral layers, which can restrict the flow of hydrocarbons in the reservoir. Consequently, an increase in shale volume is observed to lead to higher water saturation. Salinity in this field is quite uniform, with an average salinity of 5000-18000 ppm, which corresponds to a transitional zone environment classified by Bachtiar (2010). Moreover, an increase in the salinity value affects the water resistivity and, as a result, the water saturation in the formation.

3.3.4 Petrophysical Summary

The cutoff values for shale volume and effective porosity (PHIE) are determined using a cross-plot analysis. In this plot, the effective porosity log is positioned on the x-axis, and the shale volume log is positioned on the y-axis. Similarly, for determining the water saturation cutoff parameter, another cross-plot is created with effective porosity on the x-axis and bulk volume of water on the y-axis. Drill stem test data are referenced to identify proven hydrocarbon areas or reservoir zones. Figure 4 illustrates the process of determining the cutoff values for shale volume, effective porosity, and water saturation in the Santul Formation at one of the wells.

The results from the lumping table show that the average porosity value in the Santul Formation has a range of 4% – 20% with an average water saturation value range of 25% – 59%. The Tarakan Formation has an average porosity value range of 8% – 21% and an average water saturation value of 31% – 57%. The Santul Formation has an average porosity value range of 13% – 27% and an average water saturation value of 31% – 57%. This lumping table shows that the largest net to gross is dominated by the Santul Formation and Tarakan Formation in several wells (Figure 5).



(a) (b)

Figure 4. (a) shale volume and effective porosity cut-off determination (b) water saturation cut-off determination

(a) (b)

Figure 5. (a) Final results of cut-off determination (b) Petrophysical summary illustration.

4. Conclusions

Based on processing, analysis and interpretation of data that has been carried out, there are several conclusions as follows:

1. The depositional environment and sequence stratigraphy of the Bunyu Tapa field have been effectively interpreted through the integration of core data, wireline logs, and biostratigraphy. The depositional environment in the Bunyu Tapa field exhibits a delta progradation depositional system, where the Santul Formation, deposited in a delta front setting, transitions into a lower delta plain-delta front environment in the Tarakan Formation. The Bunyu Formation is subsequently deposited within a fluvial-deltaic setting.
2. In the Bunyu Tapa Field, the Miocene-Pleistocene interval is subdivided into two sequences: Sequence 1 bounded by SB-0 and SB-1 and Sequence 2 bounded by SB-1 and SB-2. These Sequence Boundaries are defined by abrupt changes in the wireline log patterns, which are attributed to regional tectonic events that took place during the Late Miocene and Plio-Pleistocene periods. The overall depositional cycle in the study area is regressive, with each sequence containing a brief transgressive phase marked by Maximum Flooding Surfaces.
3. The results of the petrophysical calculations indicate that the average shale volume across all wells ranges from 0.18 v/v to 0.41 v/v. Based on the porosity classification for reservoir quality by Koesoemadinata (1980), the Bunyu Formation is categorized as having good to very good porosity, the Tarakan Formation ranges from poor to good porosity, and the Santul Formation is also classified as having good to very good porosity. The average water saturation values are found to range between 25% - 66%.
4. In the study area, the formation with the highest net pay is the Santul Formation in well MD-12. The net pay is recorded at 621.67 meters, with a shale volume ratio of 0.21 v/v, porosity around 13%, which is classified as good - very good, and water saturation of 56%. These findings are supported by drill stem test data from depth intervals of 2677–2754 m, showing gas fluid with a volume of 69.33 mm^3/h, and 2751–2754 m, indicating fluid with a 135.64 mm^3/h volume. The study's final outcome identifies the most prospective formation for potential production based on petrophysical analysis. The Santul Formation is determined to be the most promising zone, exhibiting the thickest net pay in the research area.

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