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Identifying and Evaluating Thin-Bedded Reservoirs Using Well Logging Data: A Case Study in Well X, Field YT, Cuu Long Basin, Vietnam

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ABSTRACT

During the current period of decline in oil and gas production in the Cuu Long Basin, it is necessary to evaluate a typical reservoir. One of the important geometrical reservoirs is the thin-bed reservoir. To determine the presence and evaluate the potential of thin-bedded reservoirs, well logging data are normally used. At Well X in the Cuu Long basin, the distribution of Gamma Ray values (histogram), log curves from well logging techniques, and geological analysis are used to calculate the percentages of sand and shale. Based on these results, thin-bedded reservoirs will be recognized. In this study, the sand percentage ranges from 40% to 60% (equivalent to a shale percentage range of 60% to 40%), indicating the presence of thin-bed layers. Porosity and permeability tend to decrease with increasing depth, particularly when moving from the Lower Miocene formation to the Upper Oligocene formation.

Introduction

Oil and gas exploration and production activities in the CuuLong basin began in the 1970s of the twentieth century. The fields in the Cuu Long basin that contribute significantly to oil and gas reserves and have been producing for 15 to 36 years include the Bach Ho field, which is currently in the final stage of production. These fields are also experiencing increasing water cuts [1, 2]. The target that has been and is being exploited mainly from the Granitoid fractured basement rocks.

However, after a long production process, the volume of production from the basement rock is declining. Exploration is very important for finding solutions to enhance oil recovery, improve productivity, and discover other potential reservoirs beyond the basement rock. Lower Miocene sediments of the Bach Ho formation and the Oligocene are the major production targets after basement rocks, with research and development focused on them because they have

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the best permeability properties in the Cuu Long basin [3-5]. However, part of the reservoirs belong to the Field YT, Hai Su Trang Field, Rong Field, etc. Thinly layered reservoirs characterize the Cuu Long basin. This has caused many difficulties for geologists, geophysicists, and petrophysicists in identifying and evaluating reservoir potential for development and management plans.

The hydrocarbon reserves at Field YT, Cuu Long basin, have been proven, with a production rate of 20-25 thousand barrels per day and night, and in some periods up to 55 thousand barrels per day and night, across two main formations: Upper Oligocene (C, D) and Lower Miocene (Fig. 1). From production data and studies on thin-bedded reservoirs, new avenues have been opened for evaluating the potential of thin-bedded shale-sand reservoirs [6].

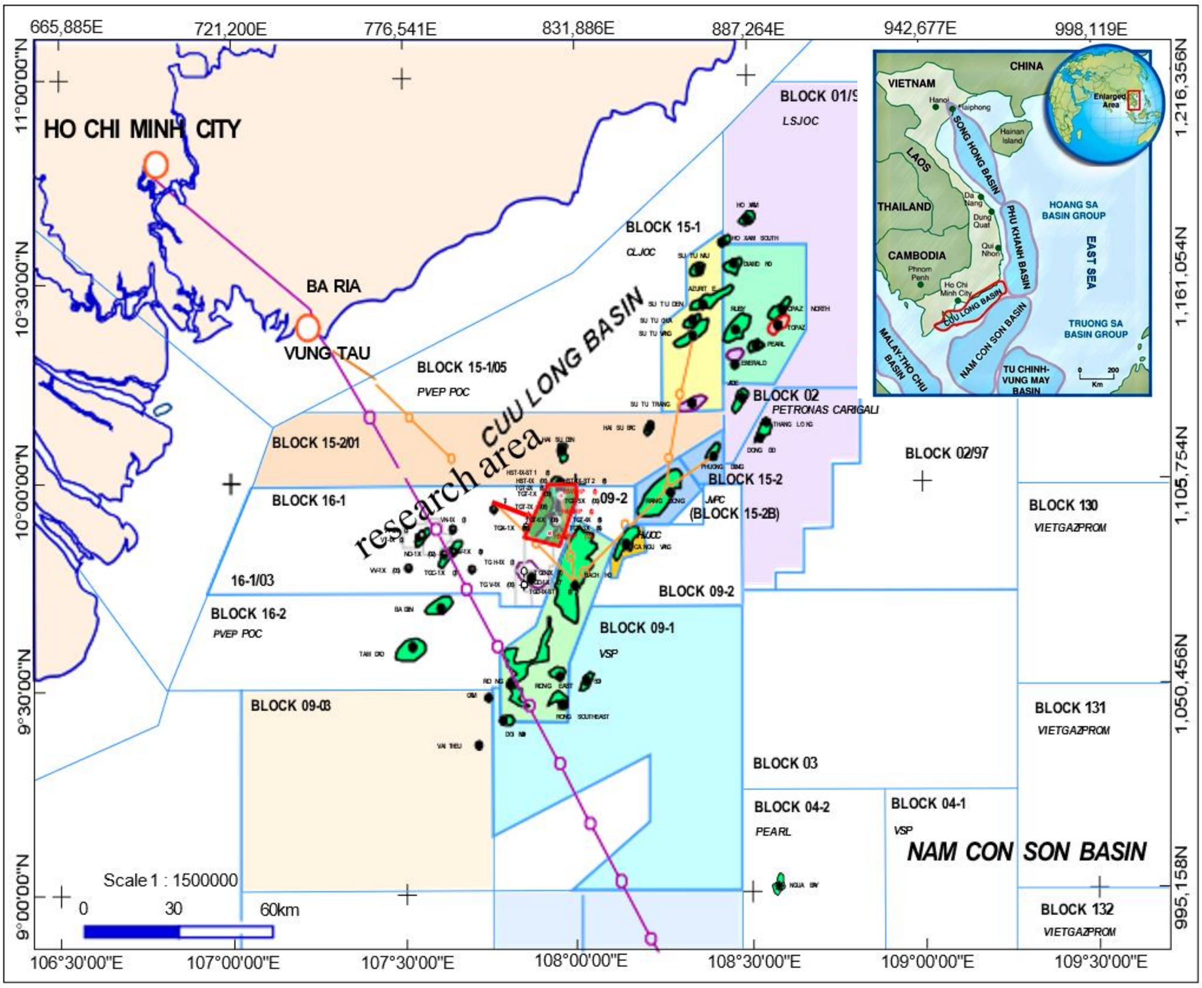

Fig. 1. The location of the research area [6]

Field YT is located in the center of the Cuu Long basin, block 16-1, at the southeastern continental shelf of Vietnam, with a sea level depth of about 40-50m. The field is divided into separate blocks, including H-1, H-2, H-3, H-4, and H-5 through the main fault system with a Northeast - Southwest direction [3]. The Oligocene and early Miocene periods were characterized by strong tectonic activity, with most faults discovered in the Tra Tan and Bach Ho sub-formations. The structure has a terraced shape with a tendency to deepen slightly to the South and shallower to the North. The sediments of the Tra Tan and Bach Ho formations were deposited mainly in continental and shallow-marine environments [2, 6].

Based on the history, geological formations, stratigraphic analysis, and well logging data of Field YT, reservoirs were mainly discovered in late Oligocene and early Miocene sediments [3, 4]. The reservoirs in the Field YT tend to gradually deepen, with sand layers thinning towards the south, and permeability and porosity ranging from good to very good.

Methodology

Thin-Bedded Reservoirs

Thin beds refer to geological layers or laminae with minimal thickness, typically less than 2 feet or just a few inches [7-10]. Unfortunately, conventional logging tools, which have limited vertical resolution, struggle to characterize individual sand and shale beds accurately. The standard interpretation methods for reservoirs with thin interbedded sand and shale often result in significant underestimation due to the following reasons: the tool's resolution is insufficient to detect thin beds, conventional logging tools provide a combined response for thin shale-sand laminae, masking the true properties of individual beds, and the dominance of high-conductivity shale layers in conventional resistivity readings [6, 7, 8, 10-12].

To address these problems for geologists and geophysicists in the identification and evaluation of thin-bed reservoirs, this study proposes a statistical approach to identify them.

Method

Gamma ray logging is a crucial technique in petroleum engineering that measures the natural radioactivity of rock formations to identify potential hydrocarbon reservoirs [11]. The tool detects gamma radiation emitted by rocks, with higher readings typically indicating the presence of shale and lower readings suggesting cleaner formations like sandstone or limestone. By analyzing these logs, geologists can infer the lithology of subsurface formations and correlate geological layers between wells, which is essential for constructing accurate geological models and evaluating hydrocarbon-bearing Zones.

Statistical probability and percentile analysis methods are used to identify trends in lithological characteristics in thin-bed reservoirs. Percentiles (P10, P50, and P90) are essential statistical tools for describing variation in data distributions across facies (Fig. 2) [12].

P10 represents equal to or less than 10% of the data set's value; it corresponds to the segment of low GR values in the study area. It can be viewed as the "lower margin" of GR.

P50: Is the center point that divides the data into two halves. In a sorted data set, P50 is the middle value. It is the point that divides the data into the lower 50% and the upper 50%, giving a view of the "characteristic" value of the data set.

P90 accounts for 10% of the remaining values in the data; it reflects the high GR-value segment in the study area. Often considered the "upper edge" of GR.

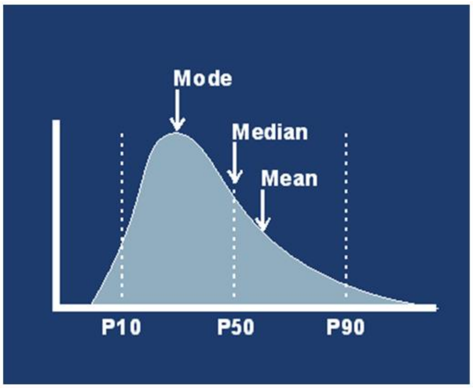

Fig. 2. Statistical probability [13]

The quantiles (P10 and P90) allow thresholds to distinguish notable features of the data, namely clean sand areas and shale areas. They play an important role in identifying trends in the data and in setting thresholds to identify thin-bed reservoirs in the GR dataset.

Input data includes petrophysical parameters measured from wellbore geophysical methods, including basic logs such as Gamma Ray, wellbore diameter, resistivity, Neutron, density, and acoustics. Other related data are also used in identifying thin-bedded reservoirs.

The percentage of thin-bed reservoirs determined using the statistical probability analysis method is compared with the results of interpreting well logging, core, geological, and other data. As a result, localizing thin-bed reservoirs creates a premise for more accurate interpretation.

Workflow

Choose Valuable Range for Clean Sand Zone and Shale Zone

Based on well logging data, the Gamma Ray value is preferred for identifying clean sand reservoirs and shale reservoirs. The Histogram for each Zone needs to be built to determine the proportions of sand and shale during the calculation process. At the clean sand reservoir, we take 2 points, S1 (API) and S2 (API), corresponding to cumulative frequencies of 10% (P10) and 90% (P90). At the shale reservoir, we take 2 points, G1 (API) and G2 (API), corresponding to cumulative frequencies of 10% (P10) and 90% (P90). Low Gamma Ray values characterize a clean sand reservoir and fluctuate relatively stably with a large thickness. For the shale reservoir, the Gamma Ray values are quite high. To select two continuous intervals of clean sand and clean shale, we apply the following formula:

$$S_{average} = \frac{S_2 + G_1}{2} \quad (1)$$

with:

- $S_{average}$: The average GR value located at the boundary between the clean sand and shale intervals.
- S_1: The GR value corresponding to the point with 10% cumulative frequency (P10) in the cumulative frequency distribution of GR for the clean sand reservoir.
- S_2: The GR value corresponding to the point with 90% cumulative frequency (P90) in the cumulative frequency distribution of GR for the clean sand reservoir.
- G_1: The GR value corresponding to the point with 10% cumulative frequency (P10) in the cumulative frequency distribution of GR for the shale reservoir.
- G_2: The GR value corresponding to the point with 90% cumulative frequency (P90) in the cumulative frequency distribution of GR for the shale reservoir.

$S_{average}$ is the average value located on the sand and clay boundary; this is the value divided into 2 distinct sandy clay intervals. If it is smaller than the $S_{average}$ value, the reservoir will be assumed to be a sand reservoir; if it is larger, it will be assumed to be a clay reservoir. From this formula, we will obtain 2 ranges of standard clean sand and shale values: from S1 to Saverage, and from $S_{average}$ to G_2 [12-14].

Apply Standard Value Ranges for Other Zones

To identify the presence of thin beds in other Zones, we need to determine the percentages of sand and shale from the Gamma Ray data set. First, we determine the cumulative frequencies (%) at locations with Gamma Ray values equal to S_1, $S_{average}$, and G_2. Let A be the percentage of sand in the range Saverage – S1, and B be the percentage of shale in the range $G_2 – S_{average}$. So, we can find A (% sand) and B (% shale) in the other Zones.

Standardize the Percentage of Sand and Shale in the Zone

Because the percentage of sand and shale in a Zone is considered 100%, the percentage value calculated from the accumulated frequency must be standardized to a common scale using the standard values of the two reservoirs, clean sand and shale. Normalization formulas:

$$\%\,Sand = \frac{A}{A+B} \tag{2}$$

$$\%\,Shale = \frac{B}{A+B} \tag{3}$$

with:

- A (%): Cumulative frequency of clean sand interval
- B (%): Cumulative frequency of shale interval

Identify Thin Bed Based on the Percentages of Sand and Shale

The statistical method identifies the presence of a thin bed when the percentage difference between sand and shale in the Zone is not too great [13]. However, this ratio needs to be compared with actual data, such as well logging, core, and production data, to demonstrate the method's reliability and accuracy. From there, it serves as a basis for interpreting other reservoirs, and the identification of thin-bedded reservoirs is easily carried out.

The statistical method uses Zones 1 and 7 as the 2 standard Zones for determining the value ranges of clean sand and shale. After that, the method's effectiveness will be tested and proven with other documents in Zones 3, 4, and 5. And then it will be applied to the remaining 2 Zones, including Zone 2 and Zone 6, to predict the presence of thin bed using statistical methods.

Results and Discussion

Zone Division

The reservoir boundary is determined based on the natural Gamma Ray log curve and actual production data. The main product beds being produced at Field YT include Zone 2 and Zone 3 [6]. The depth of each Zone is shown in Table 1.

Table 1. Zone separation

Zonation	Depth (mMD)	
	Top	Bottom
Zone 1	331.295	1738.51
Zone 2	1738.51	2809.8
Zone 3	2809.8	2903.9
Zone 4	2903.9	3133.9
Zone 5	3133.9	3405.1
Zone 6	3405.1	3865.45
Zone 7	3865.45	4485.4

Sedimentary Environment

Based on geological, geophysical and core data analysis, the research targets belong to the lower Miocene and upper Oligocene of the Field YT with two main sedimentary environments: Lacustrine and alluvial plain as Fig. 3 [1, 4, 6].

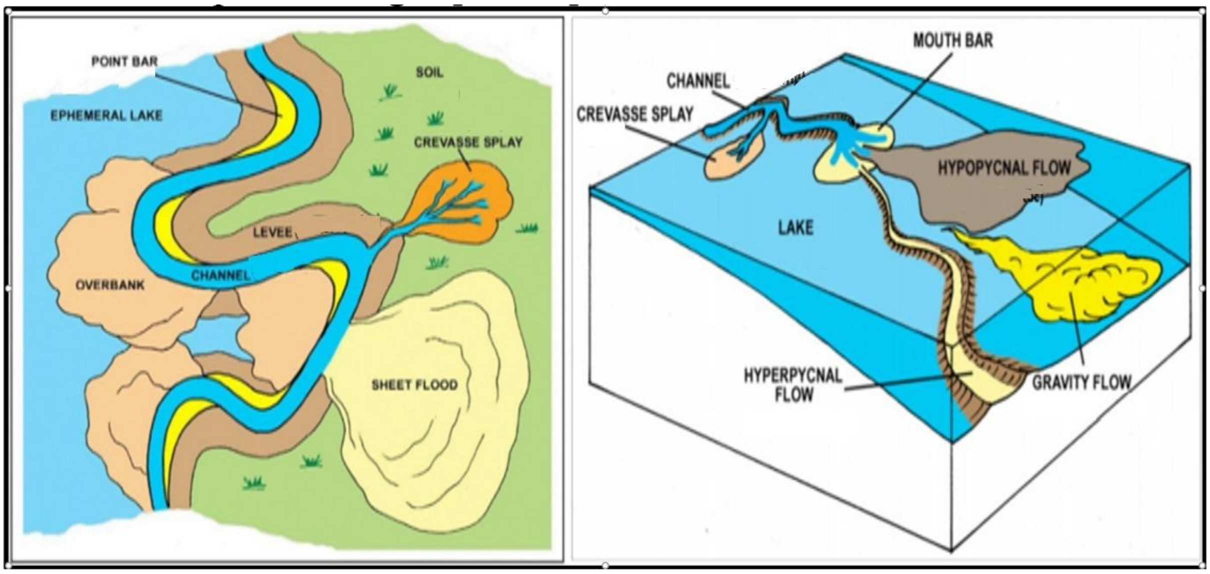

Fig. 3. Lacustrine (left) and alluvial plain (right) sedimentary environment [6]

Table 2. Sediment's thickness

Sedimentation environment	Types	Thickness (m)
Lacustrine	Gravity flow	2
	Hyperpycnal	1
	Lacustrine mud facies	1
	Mouth bar	0.01 – 0.1
Alluvial plain	Channel fill	2 – 5
	Over bank	< 0.3
	Crevasse splay	1.5
	Soil	1
	Sheet flood	0.5 - 1

Through the analysis of geology presented in Table 2 and the sedimentary environment interpreted from borehole images, it is shown that at Field YT, thin-bedded reservoirs are predominantly formed [9, 15] and exhibit pay thicknesses ranging on average from 1 to 2 m.

Histogram Chart

Based on the histogram of Gamma Ray values from well logging data, we can choose 2 Zones as the standard value range for calculating the percentage of sand and shale in the remaining Zones. Zone 1 and Zone 7 were chosen as Zones containing 100% clean sand and 100% shale, respectively, with Gamma Ray values falling into 2 ranges: 41-93 (API) and 93-133 (API), as shown in Figs. 4 & 5, respectively. The choice of the value range is based on the cumulative frequency of the P10 and P90 values in the data set.

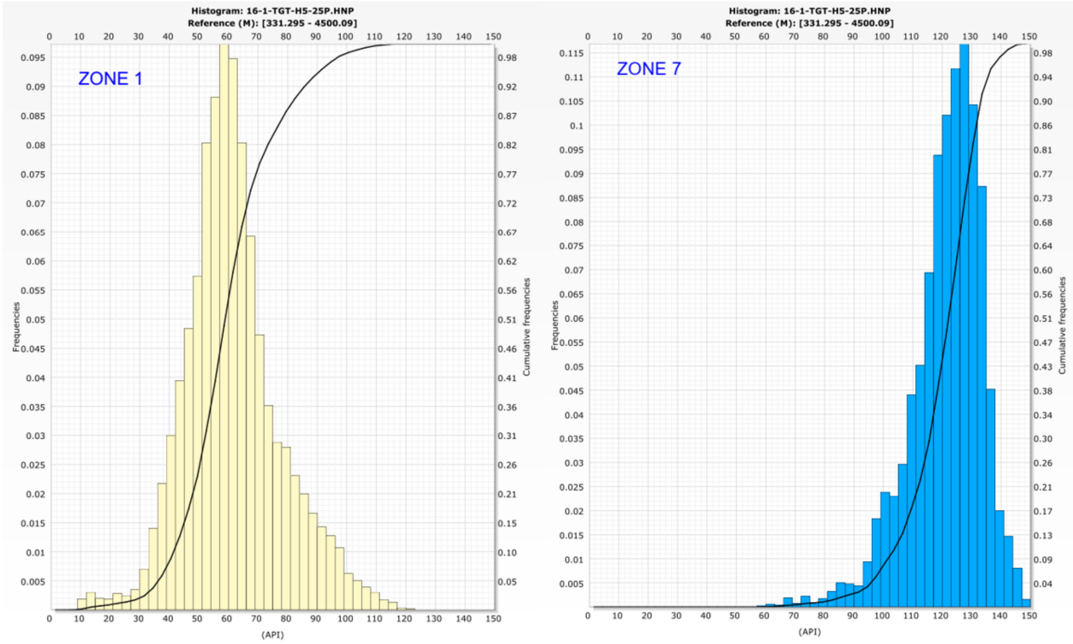

Fig. 4. Gamma Ray histogram of Zones 1 and 7 [13]

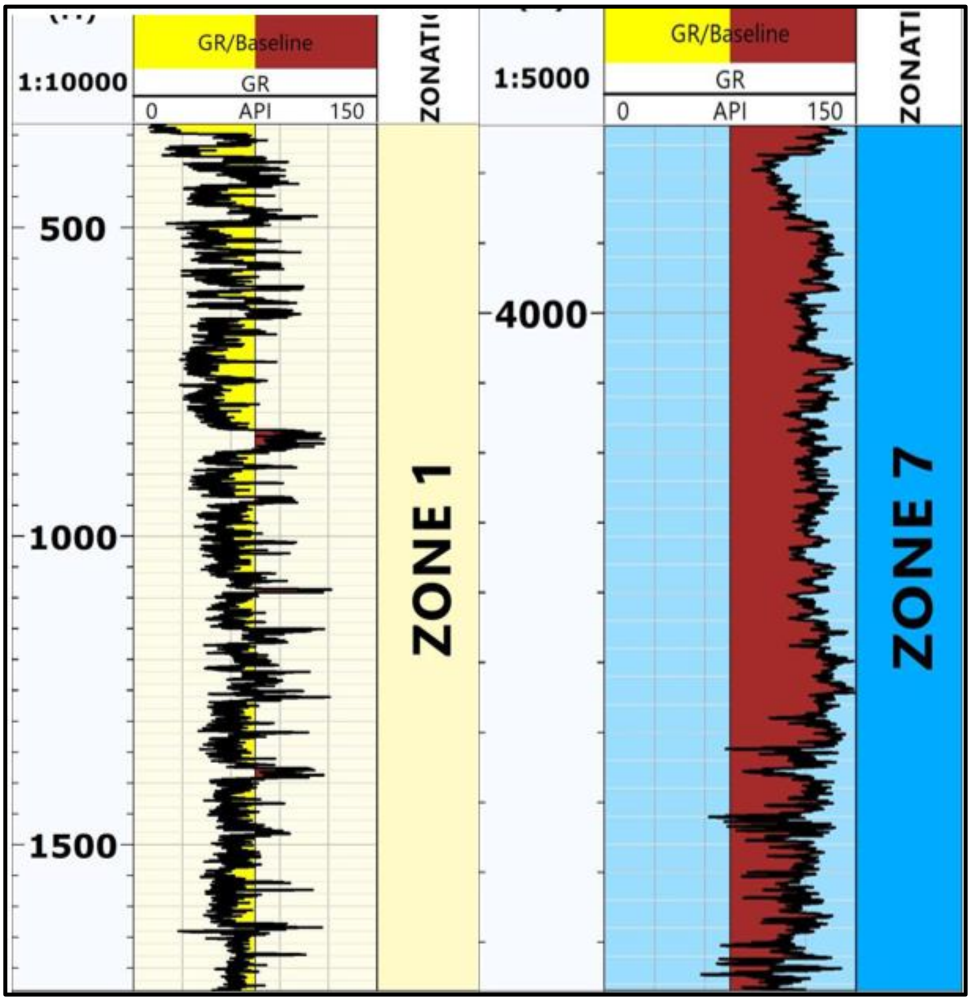

Fig. 5. Gamma Ray Log of Zones 1 and 7 [13]

Through statistical analysis and calculation, Zone 3 was determined to be about 45.46% sand and 54.54% shale. Fairly similar proportions of sand and shale are predicted for the presence of thin laminations when combined with direct observations on Gamma Ray log curves. Zone 3 is also a layer being produced by the owner company. Gamma Ray values are distributed mainly in a bimodal distribution, with high GR values concentrated mainly on the right peak and low GR values on the left peak, as shown in Fig. 6 [13]. The combination of the histogram and GR log curve shows that the upper part of Zone 3 is mainly shale, but the lower part has sand layers laminated with thin shale layers.

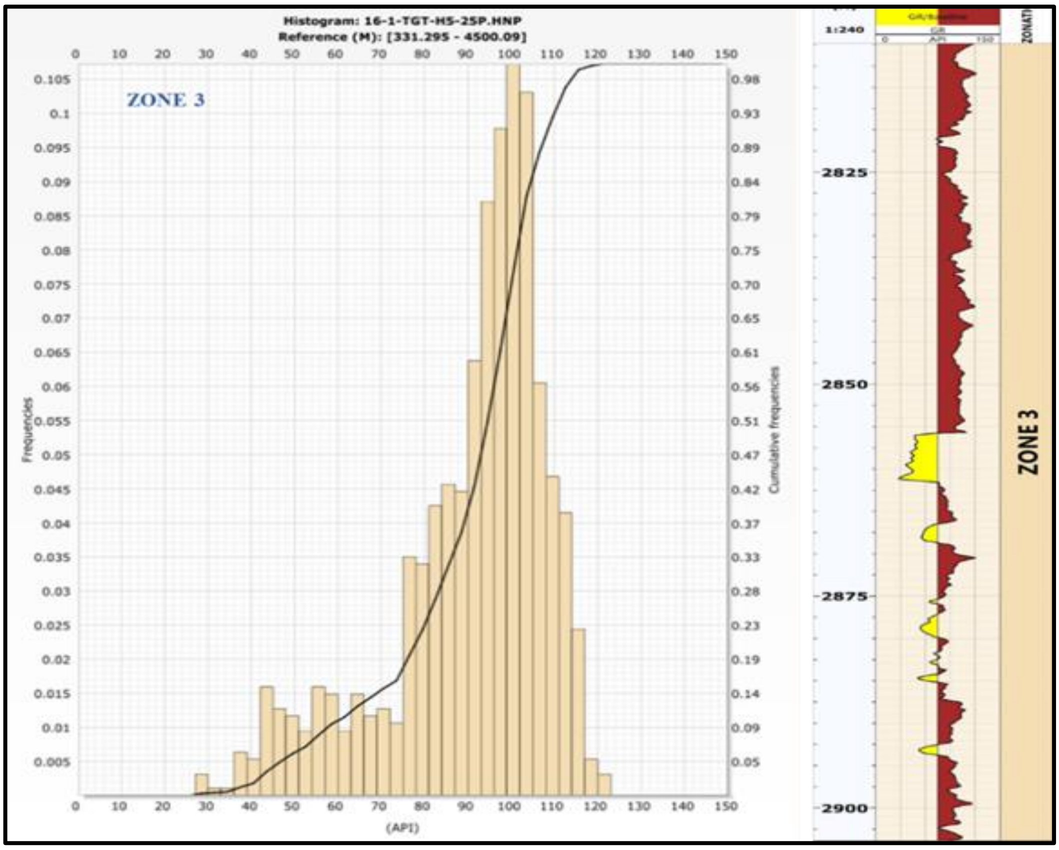

Fig. 6. Gamma Ray histogram and Log of Zone 3 [13]

Following that, Zone 4 was also identified as containing about 45% sand and 55% shale in Fig. 7, with proportions almost equivalent, suggesting a thin bed. In a normal distribution, the values are concentrated mainly around the peak at 93 API. Although GR values are quite high, several thin sand layers are also present [13].

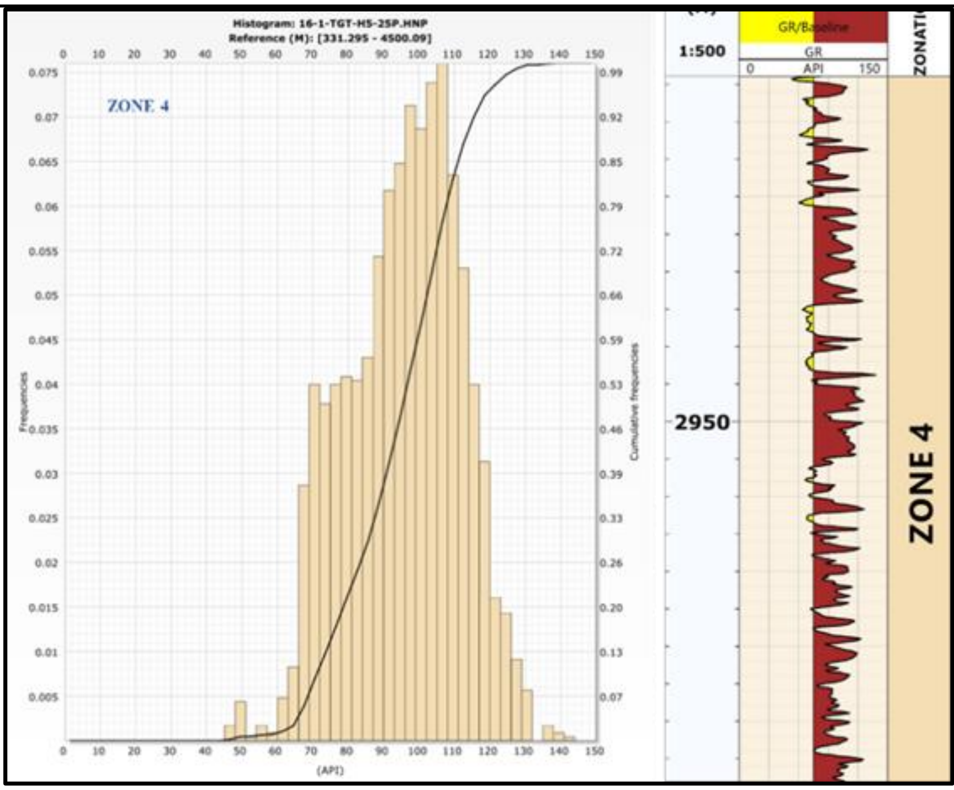

Fig. 7. Gamma Ray histogram and Log of Zone 4 [13]

Zone 5 is also predicted to have the presence of a thin bed when the percentages of sand and shale are nearly equal at 51.5% and 48.5%, as shown in Fig. 8. Distributed in the form of a bimodal distribution, the Gamma Ray values are highly concentrated around 100 API, and the next peak is distributed around the low Gamma Ray values, about 65 API. When the percentages of sand and clay in the reservoir are nearly equal, combined with the GR log curve, this indicates the presence of many thin layers [13].

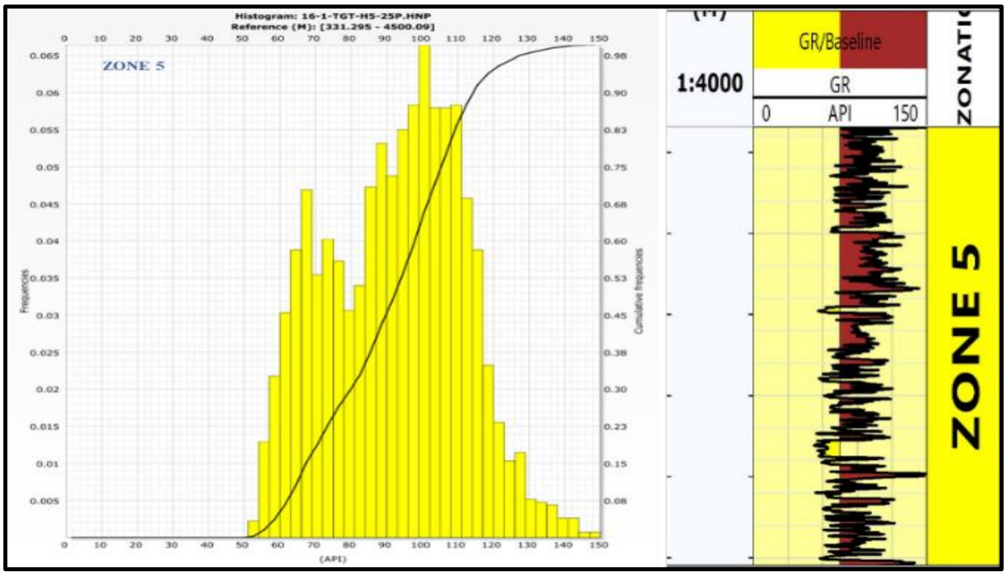

Fig. 8. Gamma Ray histogram and Log of Zone 5 [13]

In summary, the statistical analysis of Gamma Ray values in Zones 3, 4, and 5 shows a strong signal for the presence of thin-bed reservoirs. The dataset has a normal distribution and a bimodal distribution, with nearly equal percentages of sand and shale across the 3 Zones. Gamma Ray values are evenly distributed and typically range from 70 to 120 API, demonstrating the presence of both sand and shale in the reservoir [13].

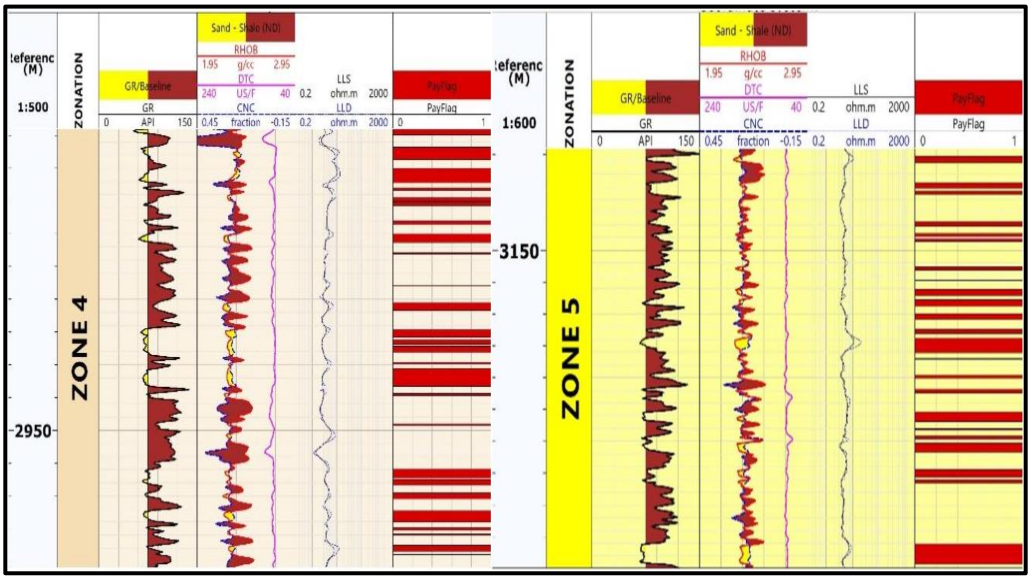

Fig. 9. Well logging interpretation of Zone 4 and Zone 5 [13]

Through well logging interpretation (Fig. 9), including basic log curves such as GR, resistivity, density, neutrons, and sonics, the typical reservoirs in this area are thin-bed layers [16]. The Gamma Ray value fluctuates widely, the separation between the density and neutron curves changes continuously, and the measured resistivity ranges from 1.9 Ohm.m to 8 Ohm.m [6]. The presence of thin layers of shale in the sand reservoirs is also the cause of low resistivity measurements. The Pay Flag in red is calculated from the traditional well-log interpretation method, and after applying Cut-off values (Shale volume, Effective Porosity, and Water Saturation). The Pay Flag is also evident in many thin layers, with a pay thickness of about 1-2 m.

Parameters such as porosity and permeability for the 3 produced Zones, including zones 3, 4, and 5, are also calculated from well logging and core data. Absolute porosity and permeability values tend to decrease when going from Zone 3 (lower Miocene formation) to Zone 5 (upper Oligocene formation), as shown in Table 3.

Table 3. Results of reservoir parameter analysis

Zonation	Depth		Porosity	Permeability (K_e), mD
	Top	Bottom		
Zone 3	2809.8	2903.9	0.192	491.6
Zone 4	2903.9	3133.9	0.181	321.2
Zone 5	3133.9	3405.1	0.161	133.3

Despite the presence of thin beds in the reservoirs, the porosity and permeability satisfy the cut-off values, meeting the technical requirements for interpretation and economic efficiency. These are also 3 Zones being produced with up to 30 wells, reserves sometimes up to 60 thousand barrels per day and night, although the reservoirs in Field YT are mostly thin-bed reservoirs [6].

Forecast the Presence of Thin-Bed in Zone 2 and Zone 6

Based on calculations, predictions, and comparisons with available actual data, the statistical probability analysis method is highly useful for detecting thin layers of interbedded shale and sand. Therefore, the method will be applied to predict the percentage of shale sand in Zones 2 and 6 that has not yet been put into actual exploitation, helping to shorten exploration and production costs and better control the remaining reserves in the reservoir.

In the bimodal distribution, GR values for the 2 Zones are concentrated in 2 peaks, representing sand and shale layers. Zone 2 in Fig. 10 shows that Gamma Ray values are fairly evenly distributed, with a predominance of high GR values. In contrast, Zone 6 in Fig. 11, with the highest GR frequencies, has an API of approximately 65. Combined with the quick-look technique on a log scale, this shows that the percentage of sand is higher than that of shale. Compared with the GR value shown on the log curve, Zone 2 is still predicted to have a thin bed, with calculated percentages of sand and shale of about 65% and 35%, respectively. However, when evaluating the log curves using the quick-look technique, high-potential product layers are concentrated mainly in the upper part of Zone 2. Zone 6 is calculated with 75% sand and 25% shale. Based on the log GR curve, we can clearly identify that Zone 6 is mainly sand reservoirs, with thin shale layers being insignificant. Therefore, Zone 6 is considered a normal reservoir with high effective thickness.

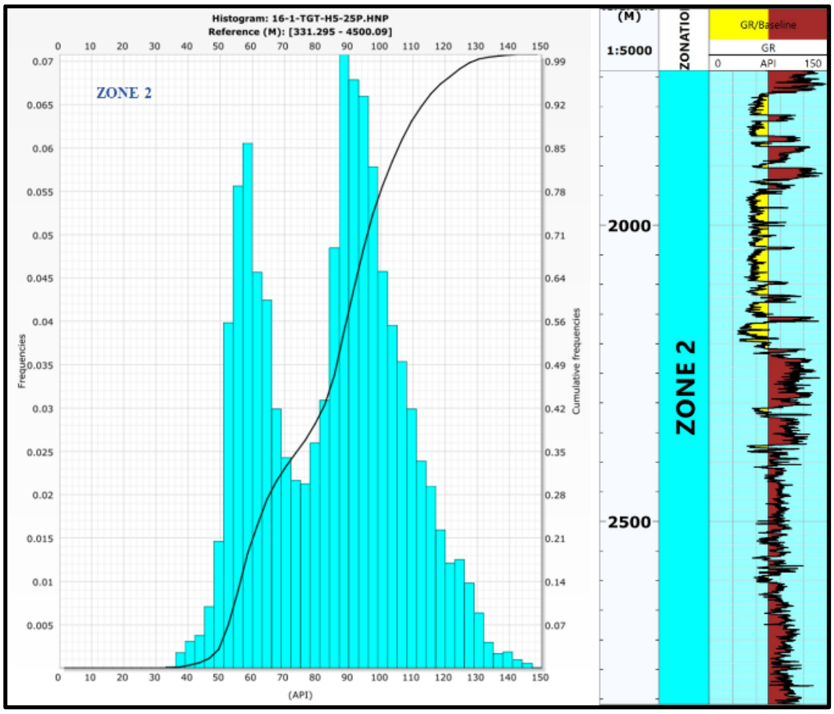

Fig. 10. Gamma Ray histogram and Log of Zone 2 [13]

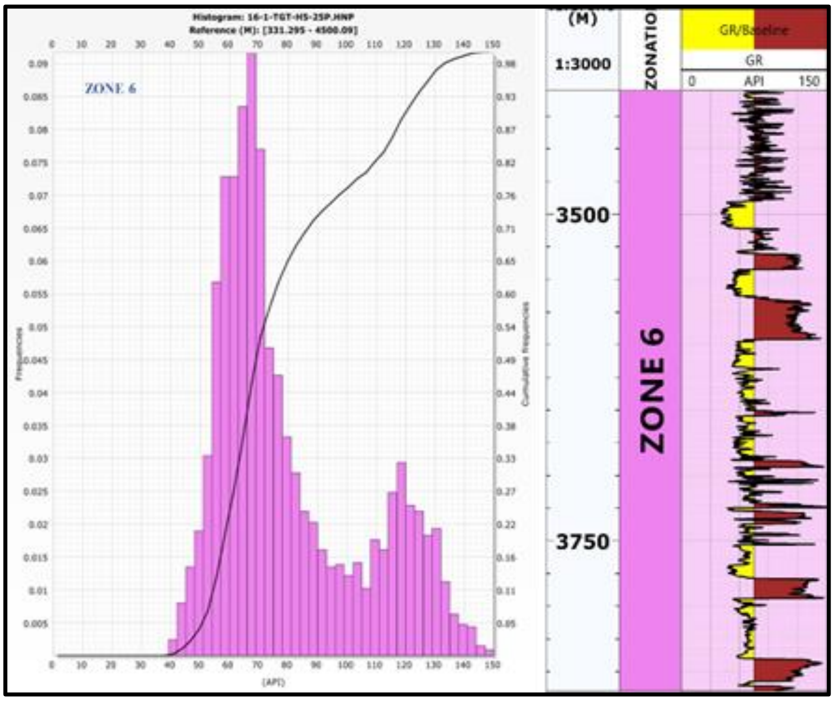

Fig. 11. Gamma Ray histogram and Log of Zone 6 [13]

Conclusion

There are some conclusions:

- Based on geological, geophysical, and core analysis, the targets being researched and actually produced include Zone 3, 4, and 5 in Field YT, deposited in 2 main environments: Lacustrine and alluvial plain

- The reservoir model in the study area is mainly a thin-bedded shaly sand reservoir, which is also one of the reasons for the low resistivity value. The true resistivity of Well X is quite low, approximately 8 Ohm.m in the oil Zones.

- The distribution of GammRay values in thinly layered Zones is mainly normal distribution and bimodal distribution, the cumulative frequency between high and low GR values is almost equivalent and symmetrical through the middle value, $S_{average}$.

- The combination of sand and shale percentage, well logging data, and geological analysis proves the presence of thin-bedded reservoirs. In this study, the sand percentage ranges from 40% to 60% (equivalent to a shale percentage ranging from 60% to 40%), indicating the presence of thin-bed layers.

- Porosity and permeability tend to decrease as depth increases, from Zone 3 (lower Miocene formation) to Zone 5 (upper Oligocene formation). However, the value of porosity and permeability satisfies the technical requirements for hydrocarbon production

- The statistical probability analysis contributes to the identification of thin-bed reservoirs. The results need to be compared with other documents, such as log curves, core samples, DST (Drill Stem Testing), and MDT (Modular Formation Dynamics Tester), in the research area to improve accuracy.

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Nomenclature

$S_{average}$	The average GR value is located at the boundary between the clean sand and shale intervals
S_1	The GR value corresponding to the point with 10% cumulative frequency (P10) in the cumulative frequency distribution of GR for the clean sand reservoir
S_2	The GR value corresponding to the point with 90% cumulative frequency (P90) in the cumulative frequency distribution of GR for the clean sand reservoir
G_1	The GR value corresponding to the point with 10% cumulative frequency (P10) in the cumulative frequency distribution of GR for the shale reservoir
G_2	The GR value corresponding to the point with 90% cumulative frequency (P90) in the cumulative frequency distribution of GR for the shale reservoir
A (%)	Cumulative frequency of clean sand interval
B (%)	Cumulative frequency of shale interval

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