Identifying and evaluating thin-bedded reservoirs using well logging data: A case study in Well X, Field YT, Cuu Long Basin, Vietnam

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. With Well X at Field YT in Cuu Long basin, the combination of 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, the presence of thin-bedded reservoirs will be recognized. In this study, the sand percentage ranges from 40% - 60% (equivalent to the shale percentage ranges from 60% - 40%), showing 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.
Keywords: *Cuu Long basin, reservoir, well logging, thin-bedded reservoir*

1 INTRODUCTION

Oil and gas exploration and production activities in the CuuLong basin began in the 1970s of the twentieth century [1]. The fields in the Cuu Long basin that contribute significantly to oil and gas reserves [2], which have been produced for a period of 15 to 36 years, typically Bach Ho field, which is currently in the final stage of production of the field. These field are also facing high water cut that is increasing over time. 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 and necessary in finding solutions to increase enhanced oil recovery, improve productivity as well as discover other potential reservoirs besides the basement rock. Lower Miocene sediments of the Bach Ho formation and Oligocene are the large production targets after basement rocks that are focused on research and development because they have the best permeability properties in the Cuu Long basin [3-5]. However, part of the reservoirs belonging to the Field YT, Hai Su Trang Field, Rong Field, etc. Cuu Long basin is characterized by thinly layered reservoirs. 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, has been proven with a production flowrate of 20-25 thousand barrels per day and night, with some periods up to 55 thousand barrels per day and night at two main formations included Upper Oligocene (C, D) and Lower Miocene. From production data and studies on thin-bedded reservoirs, new directions have been opened for evaluating the potential of thin-bedded shale sand reservoirs.[6]

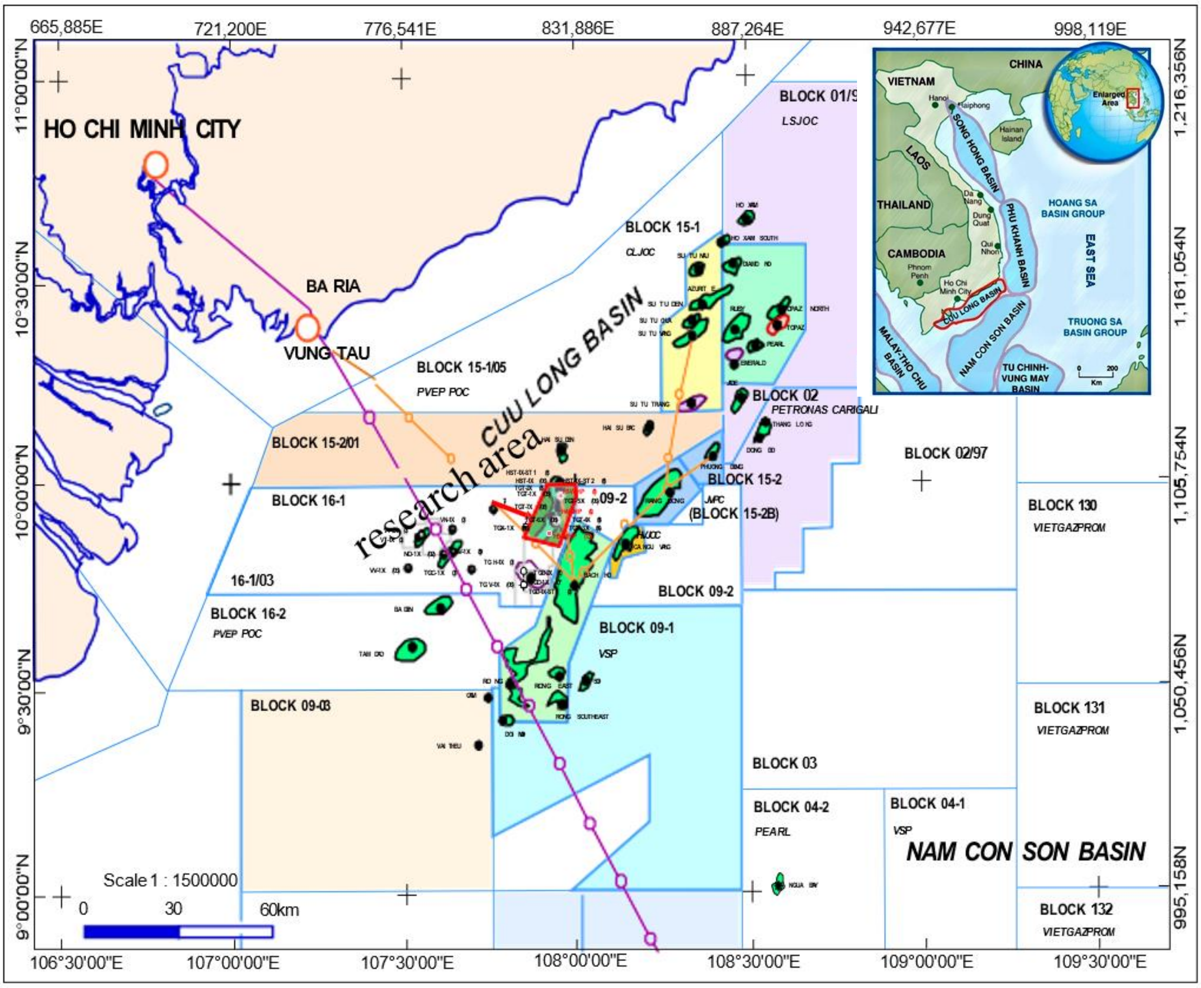

Fig 1. The map shows location of research area [6]

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 Northeast - Southwest direction [3]. The Oligocene and early Miocene periods were a period of strong tectonic activity of faults, most of which were 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 mainly deposited in continental and shallow marine continental sedimentary environments.[2, 6]

Through analyzing the history, geological formation, 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 and sand layers thinning towards the south of the reservoir with permeability and porosity ranging from good to very good.

٢ METHODOLOGY

٢,١ 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 accurately characterize individual sand and shale beds. 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 solve these problems for geologists, geophysicists in identification and evaluation of thin-bed reservoirs, this study has proposed a method to identify thin-bed reservoirs through statistical probability.

٢,٢ 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 the changing trend of lithological characteristics in thin-bed reservoirs. Percentiles (P10, P50 and P90) are imperative statistical tools for describing variations in data distribution among facies [13].

P10: represents equal to or less than 10% of the value of the data set, P10 represents 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 equal 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 remaining values in the data, P90 reflects the high GR value segment in the study area. Often considered the "upper edge" of GR

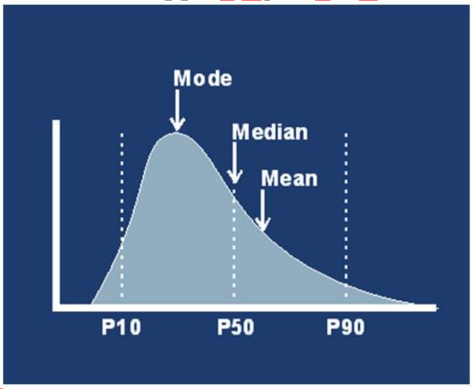

Fig 2. Statistical probability [14]

The quantiles, (P10 and P90), allow thresholds to distinguish notable features of the data, namely clean sand areas and shale areas. They have an important role in identifying changing trends in the data and setting thresholds to determine 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 reservoir determination from the statistical probability analysis method is compared with the results of the interpretation of well logging data, core, geological and other data. As a result, localizing thin-bed reservoirs creates a premise for more accurate interpretation.

٢,٣ Workflow

٢,٣,١ *Choose valuable range for clean sand zone and shale zone*

Based on well logging data, the Gamma Ray value is preferred to be used to identify a clean sand reservoir and a shale reservoir. The Histogram of each Zone needs to be built to serve the purpose of determining the proportion of sand and shale during the calculation process. At the clean sand reservoir, we take 2 points S_1 (API) and S_2 (API) corresponding to 2 points with cumulative frequency equal to 10% (P10) and 90% (P90). At the shale reservoir, we take 2 points G_1 (API) and G_2 (API) corresponding to 2 points with cumulative frequencies of 10% (P10) and 90% (P90). Clean sand reservoir is characterized by low Gamma Ray values and fluctuates relatively stable with large thickness. For shale reservoir, Gamma Ray values are quite high. To select two continuous intervals of clean sand and clean shale, we apply the formula:

$$S_{average} = \frac{S_{٢} + G_{١}}{٢} \text{ (Eq. 1)}$$

With:

- $S_{average}$: This is 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.

Savg 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 Savg value, the reservoir will be assumed to be sand and if it is larger, it will be assumed to be clay reservoir. From this formula, we will have 2 ranges of standard clean sand and shale values as follows: from S_1 to $S_{average}$ and from $S_{average}$ to G_2 [13,14,15].

٢,٣,٢ *Apply standard value ranges for other zones*

To identify the presence of thin-bed in other zones, we need to determine the percentage of sand and shale through the Gamma Ray data set. First of all, we determine the cumulative frequencies (%) at locations with Gamma Ray values equal to S_1, $S_{average}$ and G_2. Let A is the percentage of sand in the range $S_{average} – S_1$ and B is the percentage of shale in the range $G_2 – S_{average}$. So, we can find A (% sand) and B (% shale) in the other zones.

٢,٣,٣ *Standardize the percentage of sand and shale in zone*

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

$$\% \, Sand = \frac{A}{A+B} \text{ (Eq. 2)}$$

$$\% \, Shale = \frac{B}{A+B} \text{ (Eq. 3)}$$

With:

A (%): Cumulative frequency of clean sand interval

B (%): Cumulative frequency of shale interval

٢,٣,٤ *Identify thin bed based on the percentages of sand and shale*

The statistical method identifies the presence of thin bed when the percentage between sand and shale in the zone does not have too much difference [14]. However, this ratio needs to be compared with actual data such as well logging data, core data, and production data to prove the reliability and correctness of the method. From there, it serves as a basis for interpretation of other reservoirs and identification of thin-bedded reservoirs is easily carried out.

The statistical method uses Zone 1 and Zone 7 as 2 standard Zones for determining the value range of clean sand and shale. After that, the method's effectiveness will be tested and proven with other documents in Zones 3, 4, 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..

٣ RESULTS

٣,١ Zone division

The reservoir boundary division is determined based on the natural Gamma Ray log curve combined with 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 showed 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

٣,٢ 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].

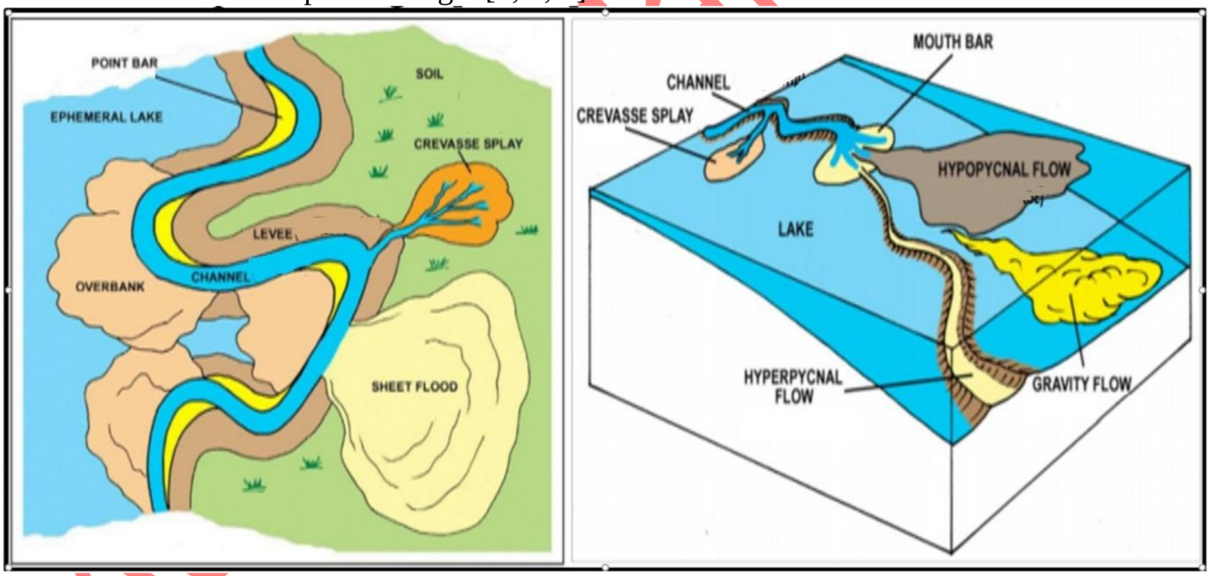

Fig 3. Lacustrine (left) and alluvial plain (right) sedimentary environment [6]

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, 16] and exhibit pay thicknesses ranging on average from 1 to 2 m..

٣,٣ 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 2 Zones containing 100% clean sand and 100% shale with Gamma Ray values fluctuating in 2 ranges including 41-93 (API) and 93-133 (API) as Fig 4 and Fig 5, respectively. The choice of value range is based on analyzing the cumulative frequency according to the probability P10 and P90 of the data set.

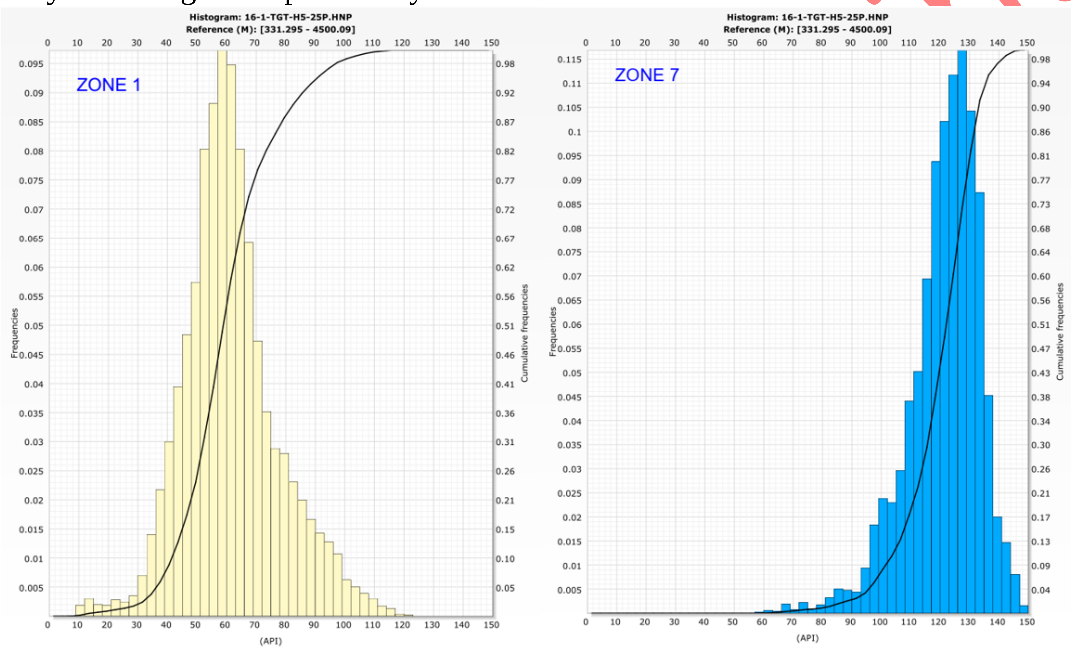

Fig 4. Gamma Ray histogram of ZONE 1 and 7

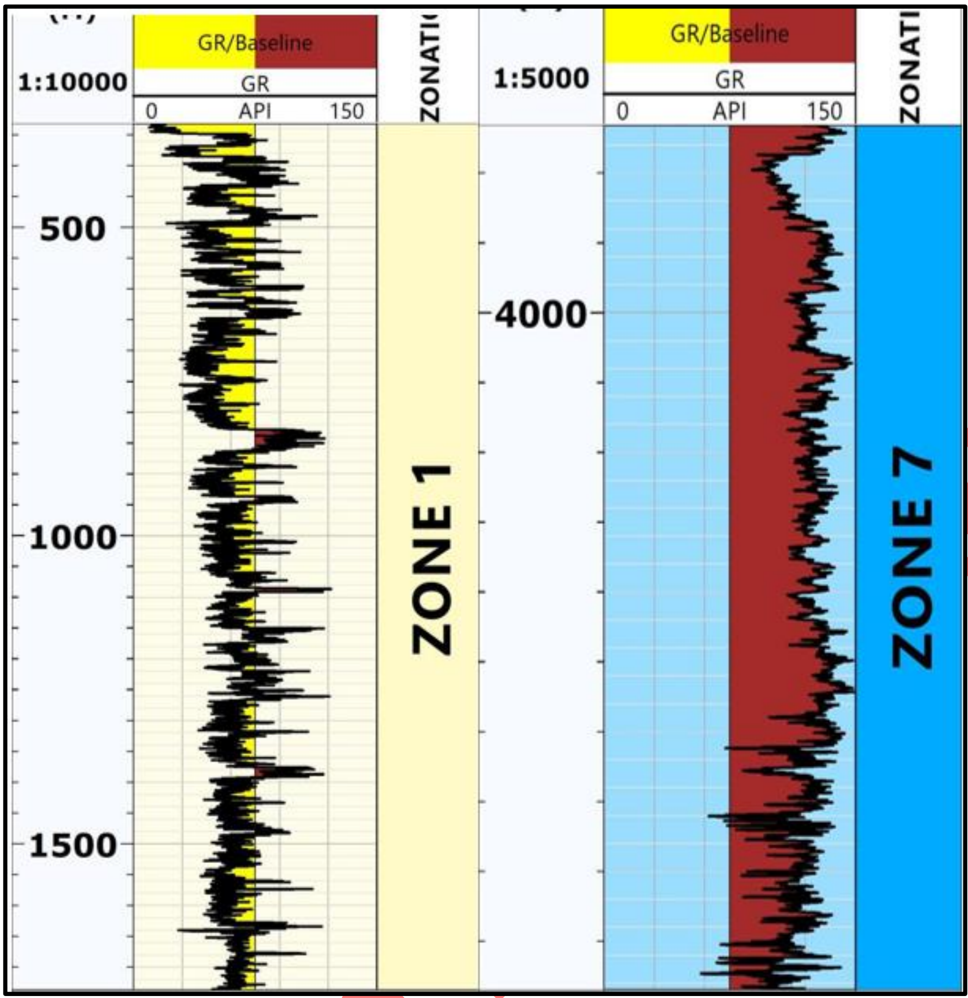

Fig 5. Gamma Ray Log of ZONE 1 and 7

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 layer being produced by 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 Fig 6 [14]. The combination between histogram and GR log curve, upper part of ZONE 3 mainly is shale, but lower part has sand layers laminated with thin shale layers.

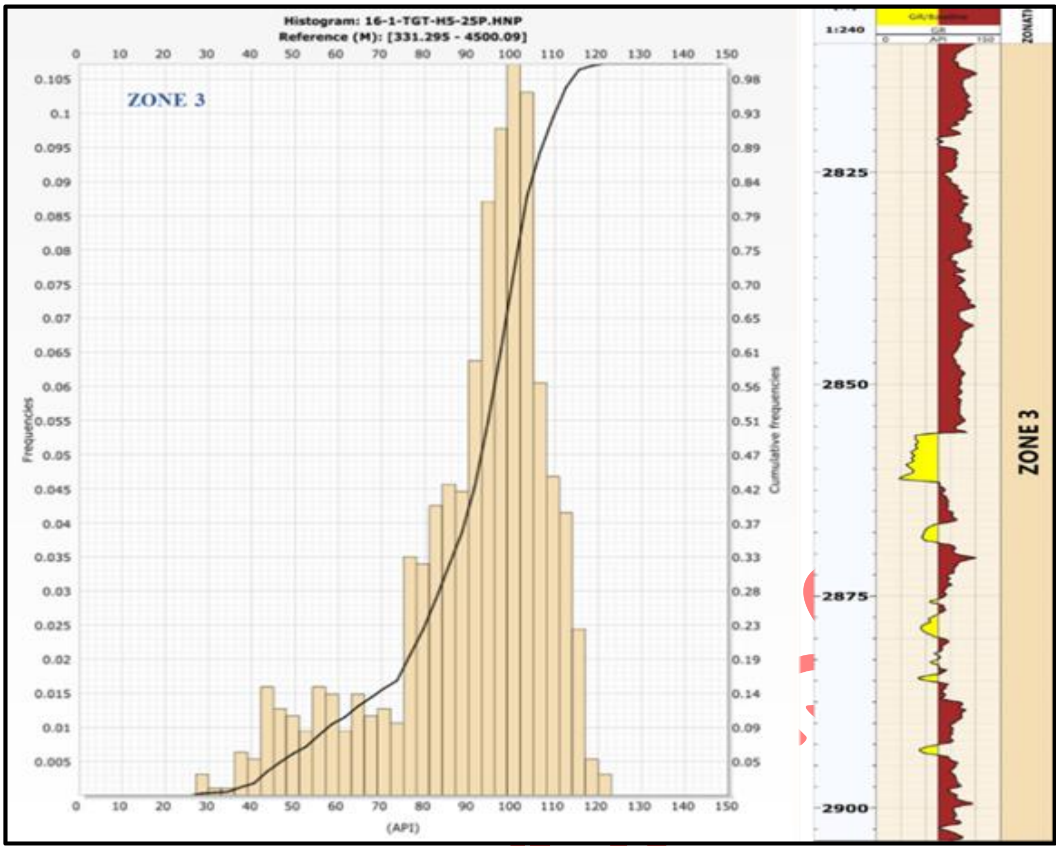

Fig 6. GammRay histogram and Log of Zone 3

Following that, ZONE 4 was also identified with about 45% sand and 55% shale in Fig 7. With almost equivalent proportions, the presence of thin bed is predicted. With a normal distribution [14], the values are concentrated mainly around the peak value 93 API. Although GR values are quite high, but there are also a several thin sand layers

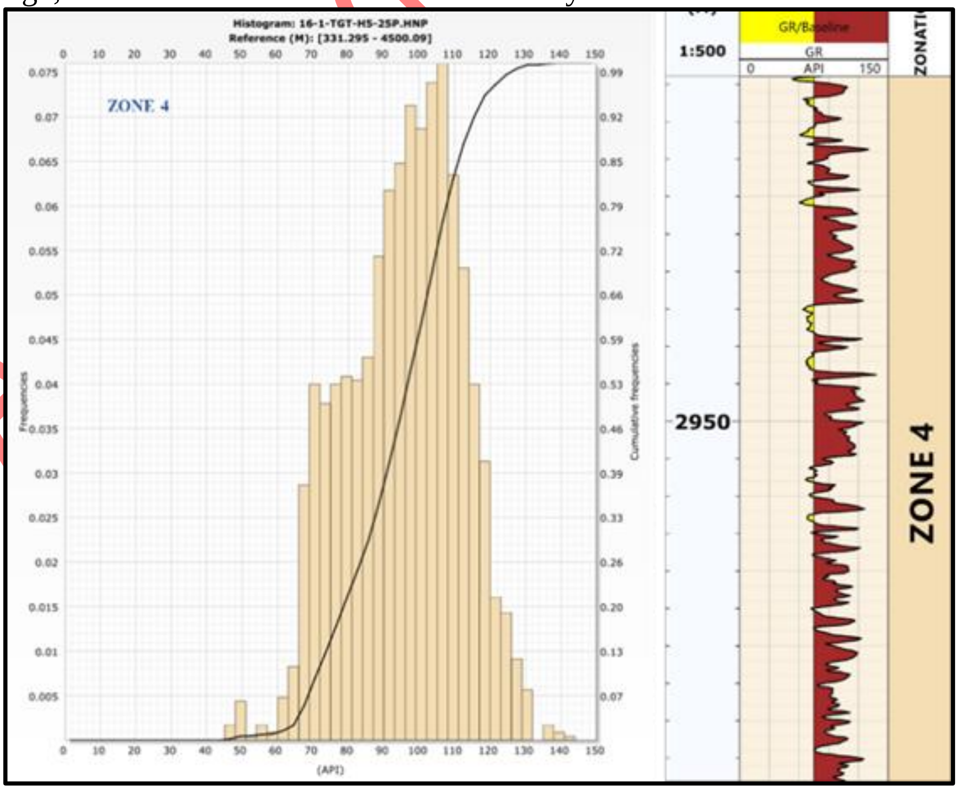

Fig 7. GammRay histogram and Log of Zone 4

ZONE 5 is also predicted to have the presence of thin bed when the percentages of sand and shale are nearly equal at 51.5% and 48.5%, as Fig 8 respectively. Distributed in the form of a bimodal distribution [14], the Gamma Ray values are high concentrated around 100 API, and the next peak is distributed around the low Gamma Ray values, about 65 API. When the percentage of sand and clay in the reservoir is nearly equal, combined with looking GR log curve, it prove the presence of many thin layers.

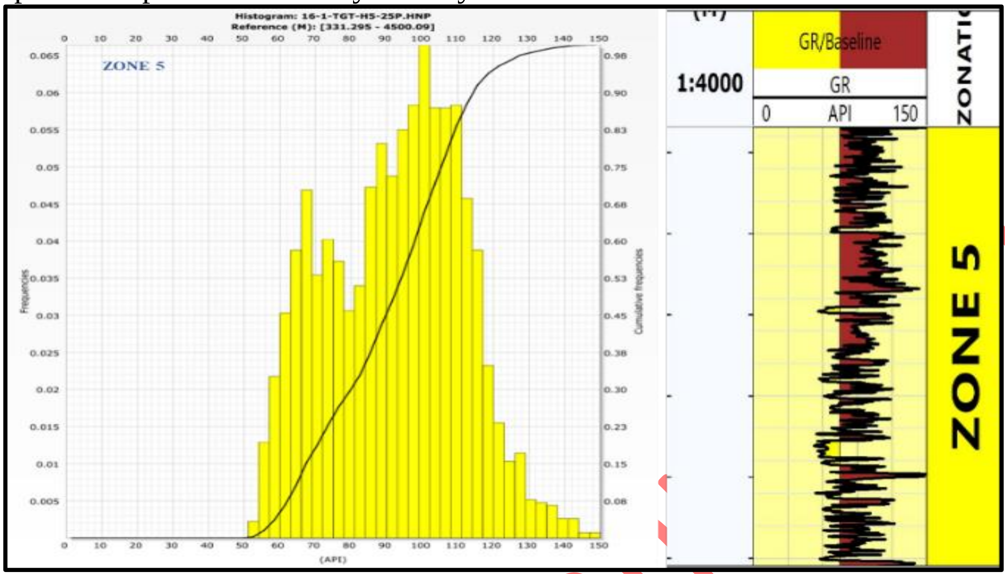

Fig 8. GammRay histogram and Log of Zone 5

In summary, the statistical analysis of Gamma Ray values in Zones including Zones 3, 4, 5 has good signal on the presence of thin-bed reservoirs. The data set has a normal distribution and bimodal distribution [14], with nearly equal percentages of sand and shale in the 3 Zones. Gamma Ray values are evenly distributed and typically range from 70-120API, demonstrating the presence of both sand and shale in the reservoir.

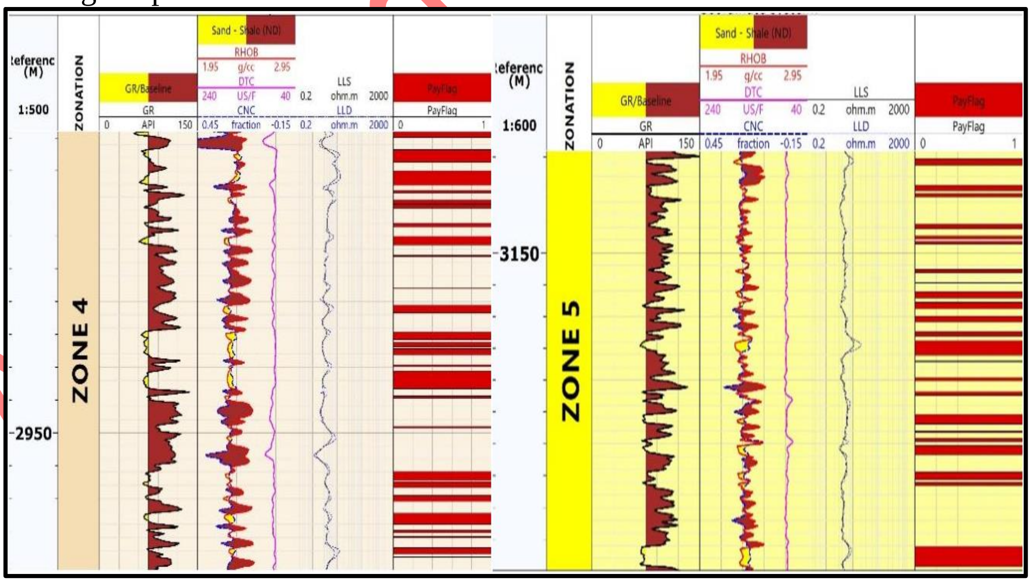

Fig 9. Well logging interpretation of Zone 4 and Zone 5

Through the interpretation of well logging, in Fig 9, including basic log curves such as GR, resistivity, density, neutrons, sonics, the typical reservoirs in this area are thin bed layers [17]. The Gamma Ray value fluctuates quite continuously over a large range, the separation between the density and neutron curves changes continuously and the actual measured resistivity value ranges from 1.9 Ohm.m to 8 Ohm.m [6]. The presence of thin layers of shale sand reservoirs is also the cause of low resistivity measurement values. The Pay Flag in red is calculated from traditional well-log interpretation method and after applying Cut-off values (Shale volume, Effective Porosity and Water Saturation). The Pay Flag is also showed by many thin layers and pay thickness is about 1-2m.

Parameters such as porosity and permeability of the 3 produced zones including 3, 4 and 5 are also calculated through well logging data combined with 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 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 day and night although the reservoirs in Field YT are mostly thin-bed reservoirs [6].

٣,٤ 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 in finding the presence of thin layers of interbedded shale sand. Therefore, the method will be applied to predict the percentage of shale sand in ZONE 2 and ZONE 6 that has not yet been put into actual exploitation, helping to shorten exploration and production costs and better control the remaining reserves contained in the reservoir.

With bimodal distribution, GR values of 2 Zones are mainly concentrated in two peaks representing sand and shale layers. Zone 2 in Fig 10 shows that Gamma Ray values are fairly evenly distributed and the distribution are mainly high GR values. In contrast, Zone 6 in Fig **11 with the highest GR frequencies are approximately 65 API. Combined with quick-look** technique on log scale, it proves that the percentage of sand is higher than the percentage of shale. When compared with the GR value shown on the log curve, zone 2 is still predicted to have the presence of thin bed with the calculated percentage of sand and shale being about 65% and 35%, respectively. However, when evaluating on the log curves by 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 completely identify that Zone 6 is mainly sand reservoirs, thin shale layers are insignificant. Therefore, ZONE 6 is considered a normal reservoir with high effective thickness.

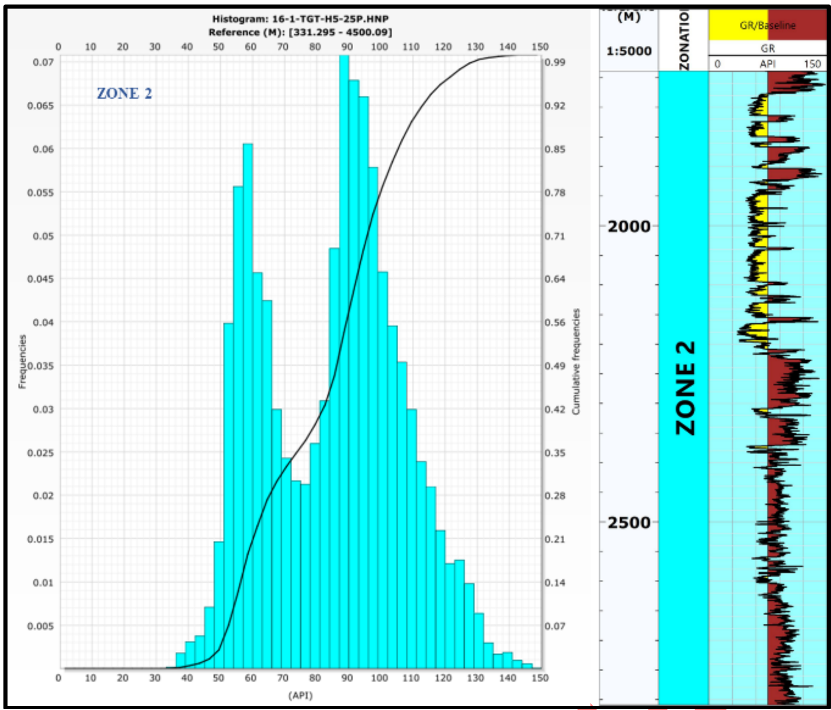

Fig 10. GammRay histogram and Log of Zone 2

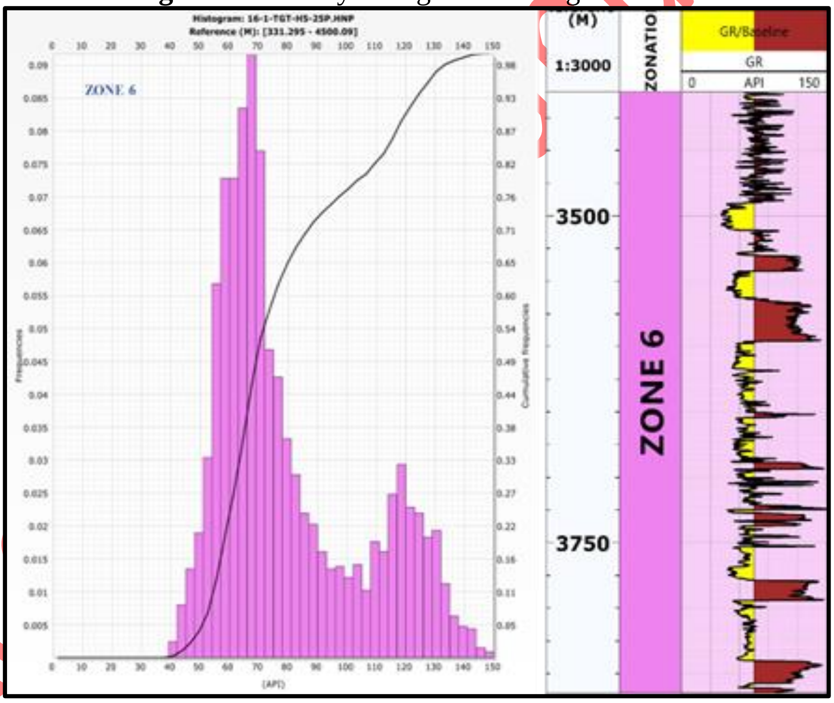

Fig 11. GammRay histogram and Log of Zone 6

4 CONCLUSION

There are some conclusions:

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

- The reservoir model in the study area is mainly thin-bedded shaly sand reservoir, this is also one of the reasons for the low resistivity value. True resistivity value of Well X is quite low, approximately 8 Ohm.m for 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 are 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% - 60% (equivalent to the shale percentage ranges from 60% - 40%), showing 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 satisfy 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**)**, MDT (Modular Formation Dynamics Tester), etc. in research area to make the results more accurate.

٥ ACKNOWLEDGEMENT

The authors would like to thank PetroVietnam and VietSovPetro for their support to publish this study. This research is funded by Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number B2024-20-22. Authors thank to unknown reviewers for improving the submission.

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Appendix

Parameters	Calculation formulas	Nomenclatures
Average API (gamma ray units) value ($S_{average}$)	$S_{average} = \frac{S_2 + G_1}{2}$	- $S_{average}$: This is 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.
The percentage of Sand (%)	$\% \, Sand = \frac{A}{A+B}$	A (%): Cumulative frequency of clean sand interval B (%): Cumulative frequency of shale interval
The percentage of Shale (%)	$\% \, Shale = \frac{B}{A+B}$	A (%): Cumulative frequency of clean sand interval B (%): Cumulative frequency of shale interval