

PETROPHYSICAL ANALYSIS AND SEISMIC STRATIGRAPHY INTERPRETATION TO DETERMINE HYDROCARBON RESERVOIR IN TARAKAN BASIN, BUNYU ISLAND WATERS

ANALISIS PETROFISIKA DAN INTERPRETASI SEISMIK STRATIGRAFI UNTUK MENENTUKAN RESERVOAR HIDROKARBON DI CEKUNGAN TARAKAN, PERAIRAN PULAU BUNYU

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ABSTRACT : Tarakan Basin area of Bunyu Island Waters is known to have hydrocarbon potential with complex geological structures. This study aims to determine reservoir characterization and to obtain prospect of hydrocarbon reservoir zones based on petrophysical and seismic stratigraphy analysis with reference to Well DDS-1 and 2D seismic Line S88. Petrophysical analysis results 3 zones that have potential as hydrocarbon reservoirs. Based on petrophysical quantitative analysis, Zone 1 has values of 52.25% for shale volume, 18.48% for effective porosity, 39.84% for water saturation and 13.03 mD for permeability. Zone 2 has values of 54.66% for shale volume, 10.27% for effective porosity, 40.9% for water saturation and 1.14 mD for permeability. Zone 3 has values of 49.22% for shale volume, 9.33% for effective porosity, 56.33% for water saturation and 0.22 mD for permeability. Out of these three reservoir zones in Well DDS-1, Zone 1 has the prospect of hydrocarbons which is supported by the net pay value. Based on seismic stratigraphy interpretation, the reservoir zone is correlated to the Tabul Formation, which comprises calcareous clay and limestone.

Keywords: hydrocarbon reservoir, petrophysical analysis, seismic stratigraphy, Tabul Formation, Tarakan Basin

ABSTRAK: Wilayah Cekungan Tarakan pada Perairan Pulau Bunyu dikenal memiliki potensi hidrokarbon dengan struktur geologi yang kompleks. Studi ini bertujuan untuk mengetahui karakteristik reservoir dan mendapatkan prospek zona reservoir hidrokarbon berdasarkan analisis petrofisika dan seismik stratigrafi. Dalam analisis petrofisika dan seismik stratigrafi, digunakan data sumur DDS-1 dan seismik 2D lintasan S88. Pada hasil analisis petrofisika, ditunjukkan adanya 3 zona yang berpotensi sebagai zona reservoir hidrokarbon. Berdasarkan perhitungan petrofisika, Zona 1 memiliki nilai volume shale 52.25%, porositas efektif 18.48%, saturasi air 39.84% dan permeabilitas 13.03 mD. Zona 2 memiliki nilai volume shale 54.66%, porositas efektif 10.27%, saturasi air 40.9% dan permeabilitas 1.14 mD. Zona 3 memiliki nilai volume shale 49.22%, porositas efektif 9.33%, saturasi air 56.33% dan permeabilitas 0.22 mD. Dari ketiga zona reservoir pada sumur DDS-1, Zona 1 memiliki prospek adanya hidrokarbon yang didukung oleh nilai net pay. Berdasarkan interpretasi seismik stratigrafi, zona reservoir sebanding dengan Formasi Tabul yang menunjukkan keterdapatan batulempung karbonatan dan batugamping.

Kata Kunci: reservoir hidrokarbon, analisis petrofisika, seismik stratigrafi, Formasi Tabul, Cekungan Tarakan

INTRODUCTION

To measure hydrocarbon reserves in Bunyu Island Waters, an integrated method is needed to detect the presence of hydrocarbons in reservoir rocks to obtain and produce hydrocarbons. The objective of this research is to determine hydrocarbon potential in reservoir rocks based on petrophysical and seismic stratigraphy analysis. Petrophysical analysis is used to determine the ability of rocks to store and release fluids based on the parameters of shale volume, porosity, water saturation, permeability, net reservoir and net pay of reservoir rocks (Darling, 2005). Seismic stratigraphy analysis is used to analyze the

sandstones and several calcareous deposits (Setyowiyoto et al., 2019). Tarakan Basin is bordered by Sekatak Berau Ridge to the west, Suikerbrood Ridge and Mangkalihat Peninsula to the south, Sempurna Peninsula to the north, and Sulawesi Sea to the east. Tarakan Basin is located in the middle of the estuary of the Sajau River (Figure 2).

Stratigraphically, the Tarakan Basin is divided into two sedimentary systems, i.e., the older (non-deltaic) main sediments and the younger deltaic sediments. The non-deltaic sedimentary systems occurs during the Eocene to Early Miocene. This sedimentary system contains volcanic material, distributed from the deep sea to the

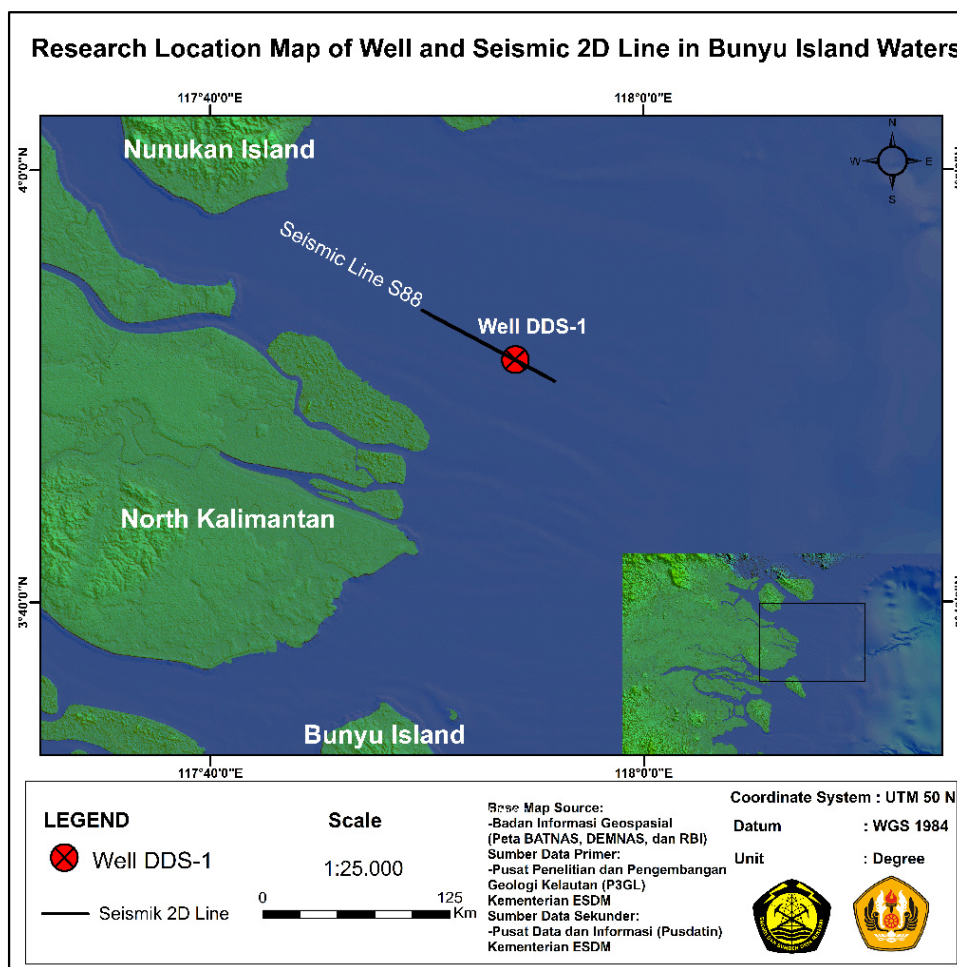


Figure 1. Map of Research Location in Bunyu Island Waters

presence of reservoir rocks based on rock lithology and stratigraphy obtained from seismic and well log data (Veeken, 2007).

GEOLOGICAL SETTINGS

Tarakan Basin is one of the three main Tertiary basins in the eastern part of Kalimantan Island, which is characterized by the presence of clastic sedimentary rocks as the dominant constituent with fine to coarse grained

mainland. This sediment is detected above the basement complex of metamorphic-igneous rock which was deformed by faults. The lithostratigraphy of the non-deltaic sedimentary systems can be identified as the Sembakung, Sajau, Seilor, Mangkabua, Tempilan, Tabalar, Mesaloi, and Naintupo Formations. Meanwhile, the delta sedimentary system occurs during the Middle Miocene to the Quaternary. This system consists of

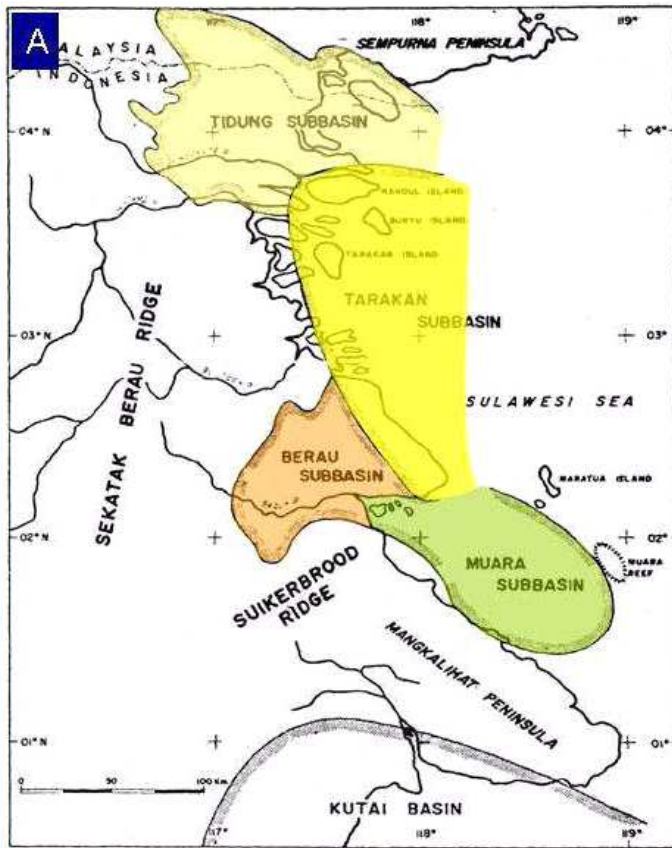


Figure 2. Regional Geology of Tarakan Basin (modified from Achmad and Samuel, 1984)

interfingering between deltaic deposits and prodelta deposits of the Naintupo Formation. The clastic material of the delta was originated from the western part of the Tarakan Basin, which is known as the Central Kalimantan Mountains or the Kuching Plateau. The general stratigraphy of the Tarakan Basin can be seen in Figure 3.

DATA AND METHODS

The study uses one well data (Well DDS-1) and one post-stack time migration 2D seismic line data (Line S88). Well data is used for quantitative petrophysical analysis and lithological identification, while post-stack time migration 2D seismic data is used for seismic stratigraphy interpretation to provide lithological and stratigraphic information on the subsurface area. The flow chart of this research can be seen in Figure 4.

Reservoir Zone Identification

Reservoir zone identification is conducted by analyzing the lithology logs of gamma ray and spontaneous potential, the resistivity logs of Lateralog Deep (LLD), Lateralog Shallow (LLS), Micro Spherically Focused Log (MSFL) which provides fluid information, and the porosity logs of density, neutron and sonic (Nopiayanti et al., 2020). The identification of the reservoir zone is derived from the curve pattern of lithology logs which shows the depth of sandstone or carbonate rocks. The

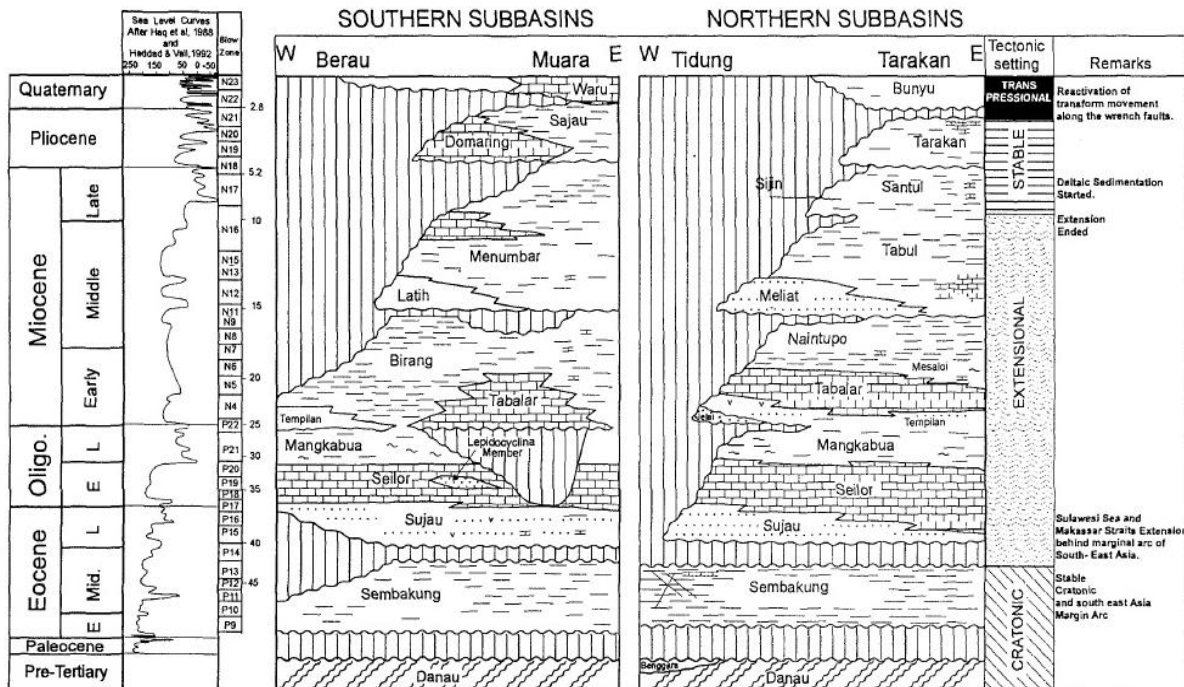


Figure 3. Regional Stratigraphy of Tarakan Basin (Lentini and Darman, 1996)

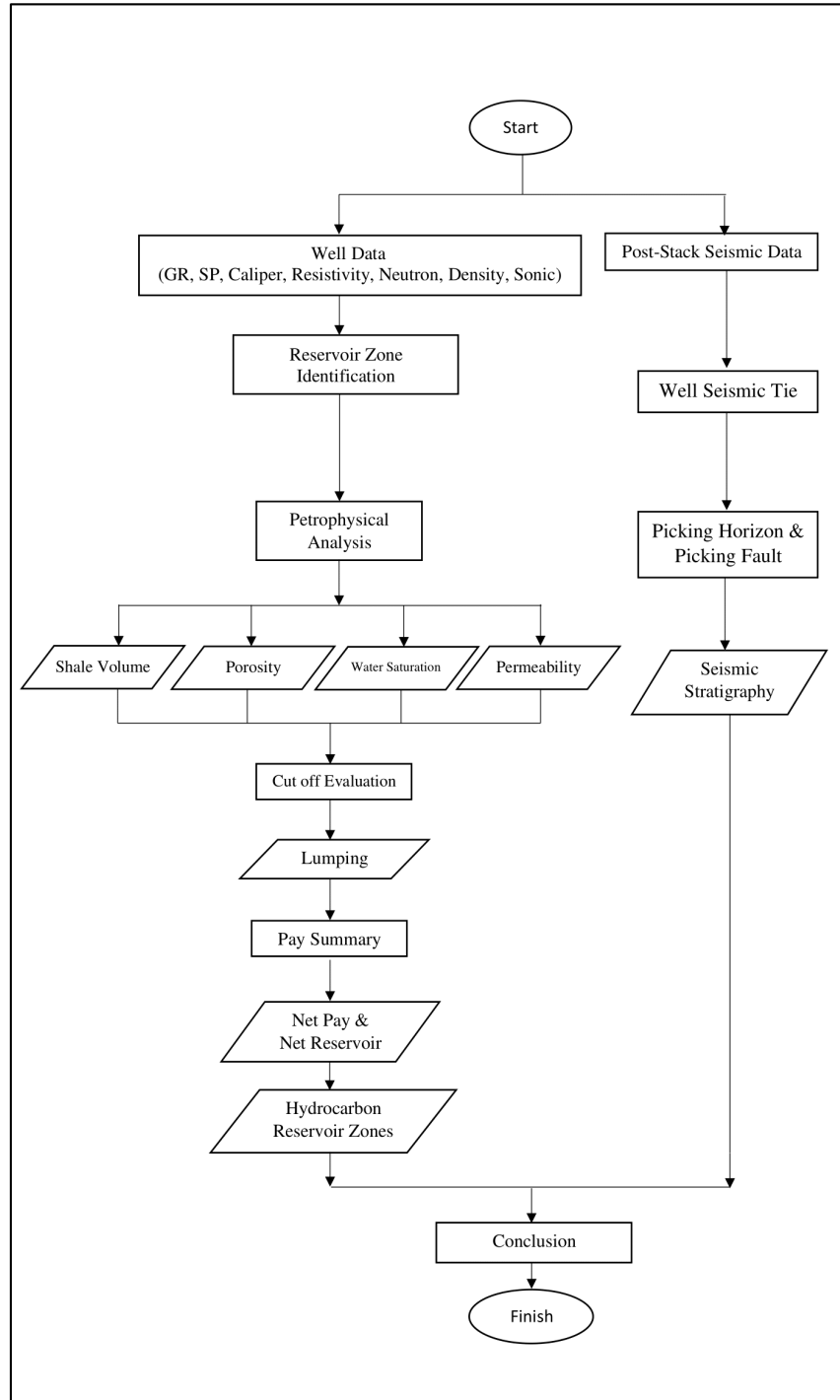


Figure 4. The flowchart of petrophysical and seismic stratigraphy analysis

resistivity log shows a fairly high resistivity value indicated by its hydrocarbons and fresh water contents. The porosity log shows the porosity of the rock formation (Purba et al., 2020).

Shale Volume

Shale volume is the volume of shale fraction in the formation determined by the volume of clay content over the total volume of the formation. Shale volume calculation which is based on gamma-ray log uses a linear

method (Asquith & Krygowski, 2004) with the following equation:

$$V_{sh} = IGR = \frac{GR_{log} - GR_{clean}}{GR_{shale} - GR_{clean}} \quad (1)$$

where:

- V_{sh} = Shale Volume (%)
- IGR = Gamma Ray Index (%)
- $GRlog$ = Gamma ray log reading (API)
- GR_{clean} = Log response in shale-free zone
- GR_{shale} = Log response in the shale zone

Porosity

Porosity is the size of the pore space in the rock which functions as a storage area for fluids (water, oil, and gas). The porosity intended to obtain from this research is effective porosity because it shows the properties of rock pores that are interconnected, allowing the fluid to flow. Rock pores that are unable to transmit fluid are not included in the type of effective porosity (Asquith & Krygowski, 2004). In this study area, the Wyllie Sonic Porosity equation is used because the time acoustic parameters, lithology of rock type (Δt_{ma}), and fluid type of pore filler (Δt_f) are known to show lithology and fluid content in the zoning area. According to Wyllie (1958), the porosity equation can be written as follow:

$$(\Phi) = \frac{\Delta t_{sh} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}} \quad (2)$$

where:

- (Φ) = Porosity (%)
- Δt_{ma} = Interval transit time in the rock matrix (msec/ft)
- Δt_{sh} = Interval transit time in the shale zone (msec/ft)
- Δt_{fl} = Interval transit time in the fluid in formation (msec/ft)

The porosity value in equation (2) is the value of total porosity, while the porosity value used in this research is the effective porosity. Krygowski (2003) used the following equations to obtain the value of effective porosity:

$$\Phi_e = \Phi_t - (V_{sh} * \Phi_{sh}) \quad (3)$$

$$\Phi_{sh} = \frac{(\rho_{Dsh} - \rho_{sh})}{(\rho_{Dsh} - \rho_{fl})} \quad (4)$$

Where:

- Φ_e = Effective porosity (%)
- ρ_{sh} = Shale density (g/cc)
- V_{sh} = Shale Volume (%)
- Φ_t = Total porosity (%)
- ρ_{fl} = Fluids density (g/cc)
- Φ_{sh} = Total porosity in the shale zone (%)
- ρ_{Dsh} = Dry shale density (g/cc)

Water Saturation

Water saturation (S_w) is the part of the pore space filled with water, while the part filled with hydrocarbons is called hydrocarbon saturation (S_h) which has a value of (1

- S_w) (Harsono, 1997). In this study area, the Indonesia equation is applied to acquire the value of water saturation because this equation considers the shale effect on the basis of shale volume (V_{sh}), as well as the resistivity of shale (R_{sh}) to reduce the effect of the shale (Dwiyono and Winardi, 2014). The Indonesia equation can be written with the following equation:

$$\frac{1}{\sqrt{R_t}} = \frac{\Phi^{m/2}}{\sqrt{\alpha \times R_w}} + \frac{V_{sh}^{1-0.5V_{sh}}}{\sqrt{R_{sh}}} \times S_w^n \quad (5)$$

Where:

- S_w = Water saturation (%)
- R_w = Formation water resistivity (ohm.m)
- R_t = Formation true resistivity value (ohm.m)
- Φ = Porosity (%)
- V_{sh} = Shale Volume (%)
- R_{sh} = Resistivity of shale
- a = Tortuosity factor (1)
- m = Cementation exponent (2)
- n = Saturation exponent (2)

Permeability

Permeability is the ability of rocks to be passed by fluids. In this study, the Coates Free Fluid Index equation was used. The Coates Free Fluid Index equation can be written with the following equation:

$$K = \left(C * (\Phi)_e^2 \frac{(1 - S_{wirr})}{(S_{wirr})} \right)^2 \quad (6)$$

Where:

- K = Permeability (mD)
- $(\Phi)_e$ = Effective porosity (%)
- S_{wirr} = Irreducible water saturation (%)
- C = The coates constant (70)

Cut-off Evaluation

Cut-off value is calculated to determine the reservoir zone with high prospect of hydrocarbon. This calculation is based on the crossplots on porosity-permeability, shale-porosity volume and water-porosity saturation (Worthington and Cosentino, 2005). Indriyani et al. (2020) proposed Western Culture method to determine the cut-off value for porosity, shale volume, and water saturation; whereas the cut-off value of permeability is assumed as the minimum absolute permeability value (Worthington and Cosentino, 2005).

The assumption for the cut-off value of permeability is derived from the assumption of the fluid type in the reservoir zone. If the type of fluid is gas, the minimum absolute permeability is 0.1 mD; while oil has the minimum absolute permeability of 1 mD (Worthington and Cosentino, 2005). The well report of the study area reveals that the type of its reservoir fluid is gas, thus the

minimum absolute permeability is 0.1 mD. This cut-off permeability value is used to determine the effective porosity value from the porosity-permeability crossplot and then applying the western culture method, the cut-off value of porosity is used to determine the cut-off value of shale volume which was obtained from the shale volume versus porosity crossplot. The same porosity value is also used to determine the cut-off value of water saturation deriving from the water saturation versus porosity crossplot.

Net Reservoir and Net Pay

Net Reservoir represents the total value of the formation thickness which has the quality of reservoir rock. Net Pay shows the value of the reservoir rock interval of hydrocarbon reservoir. Net Reservoir and Net Pay can be obtained from the petrophysical parameters by determining the cut-off value.

Based on Figure 6, it shows the presence of gross rock which determines all reservoir rock intervals that being evaluated. Gross reservoir is a part of the gross rock that meets the shale volume cut-off value. Net Reservoir is a fraction of the gross reservoir that fits the cut-off of

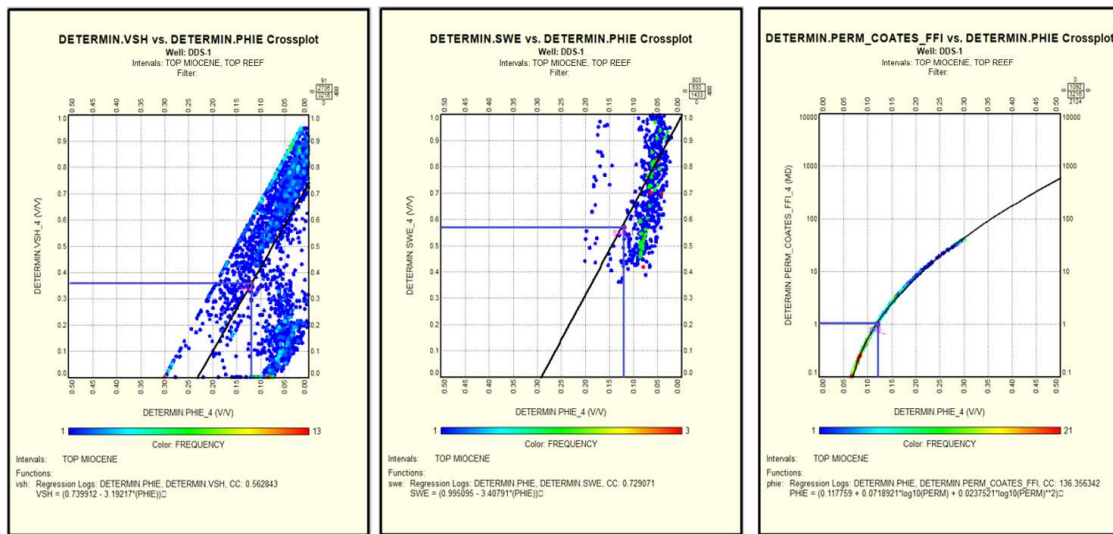


Figure 5. Crossplots of petrophysical parameters in Well DDS-1

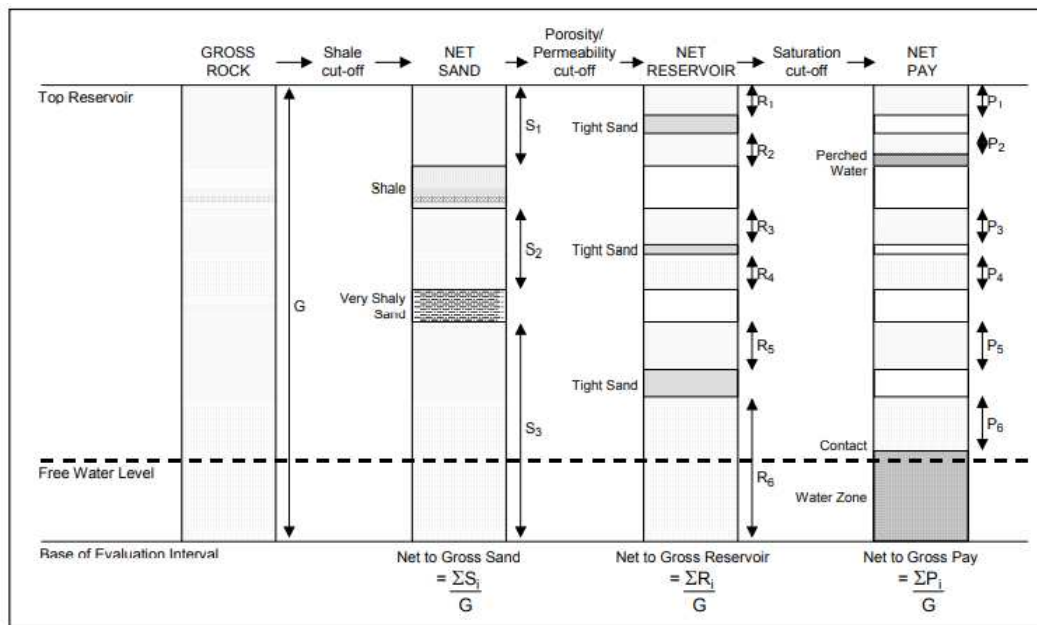


Figure 6. Schematic of net parameters (Worthington and Cosentino, 2005)

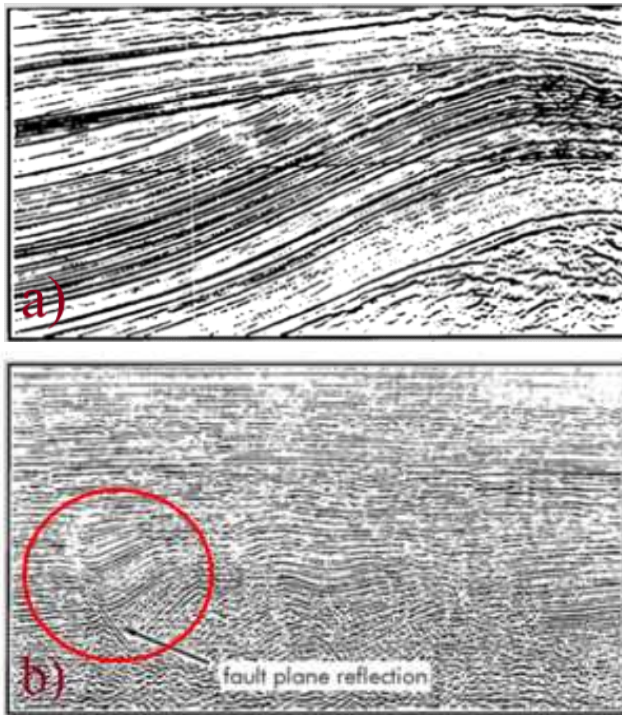


Figure 7. Sedimentary reflections (a) and non-sedimentary reflections (b) (Veeken, 2007)

porosity and permeability value. Net Pay denotes a portion of the Net Reservoir that fulfills the cut-off of water saturation value (Worthington and Cosentino, 2005).

Seismic Stratigraphy Analysis

Seismic stratigraphy analysis is conducted to determine the order of the subsurface rock types containing stratigraphic information based on the interpretation of the 2D seismic data (Veeken, 2007). One of the basic concepts of seismic stratigraphy is that sedimentary reflections can respond as a single timeline. These reflections represent time intervals of continuous sedimentation conditions. Each reflector coincides with a period of time of a similar depositional state in a geological sense (Setiady et al., 2017).

In seismic stratigraphy, there are two types of subsurface seismic reflections. The first is sedimentary reflections which represent the area of the bedding, showing conformity changes in the depositional regime (Figure 7a). The second, non-sedimentary reflections which indicate the presence of a fault plane characterized by prominent seismic reflections. It is usually observed when a high impedance acoustic contrast exists between two different lithologies on either side of the fault plane (Figure 7b). The coherence of the fault plane energy is normally attenuated in seismic processing because of its high dip. Fluid contact between porous bodies, such as fluid (oil-gas-water) contact or water presence in the hydrocarbon-bearing reservoir, also shows its reflection (Veeken, 2007).

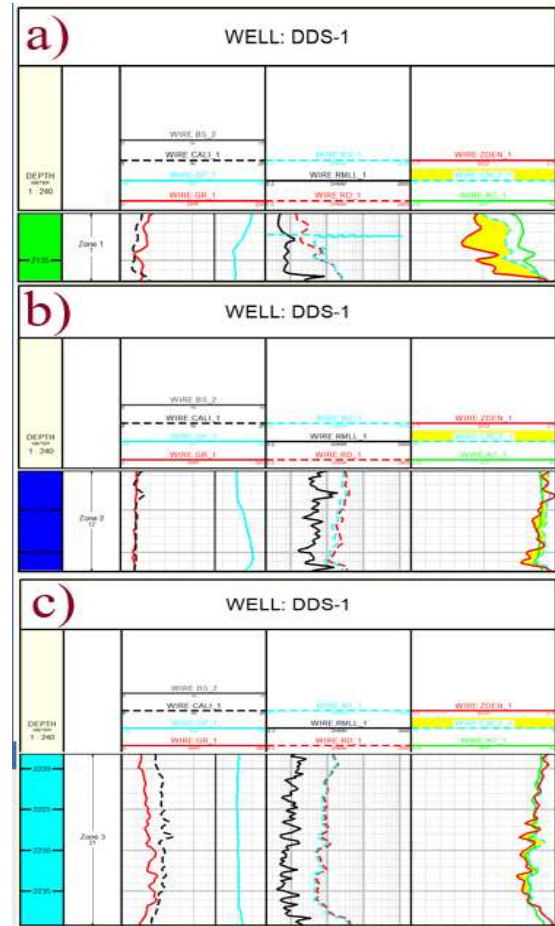


Figure 8. Reservoir zone 1 (a), zone 2 (b) and zone 3 (c) of Well DDS-1

RESULTS

Purba et al. (2020) argued that Well DDS-1 has good porosity based on the overlay of its density and neutron logs along with the acoustic value of slow-wave propagation time of its sonic log. Analyzing log curve patterns of Well DDS-1 lithology to identify the characteristic of the reservoir zone results in three reservoir zones, namely Zone 1 at the depth of 2130 - 2137 meters, Zone 2 at the depth of 2190 - 2202 meters, and Zone 3 at the depth of 2218 - 2239 meters. (Figure 8).

Shale volume calculation gives the average value of 52.25% for Zone 1, 54.66% for Zone 2 and 49.22% for Zone 3. Based on these results, all of the three zones have clay or shale content, but they can potentially become hydrocarbon reservoir rocks after correcting the calculation of the effective porosity and water saturation as proposed by Kamel and Mabrouk (2003).

The calculation of effective porosity yields the average value of 18.48% for Zone 1, 10.27% for Zone 2, and 9.33% for Zone 3. The porosity classification of Koesoemadinata (1980) shows that Zone 1 has good porosity, Zone 2 has fair porosity, and Zone 3 has poor porosity.

Calculating water saturation results in the average value of 39.84% for Zone 1, 40.9% for Zone 2 and 56.33% for Zone 3. The water saturation values in these three zones reveal that each value is considered as low (<60%), which means that the saturation value of the hydrocarbons is high, thus indicating the presence of hydrocarbon fluids.

outside the cut-off value to define the net reservoir and net pay zones.

The lumping processing on the results of the cut-off values obtains Net Reservoir and Net Pay and determines whether the reservoir zone has good reservoir characteristics or not. Applying it, table 3 shows that Zone

Table 1. Petrophysic Calculation of Reservoir Zone in Well DDS-1

Well	Zone	Depth (m)	Shale Volume (%)	Effective Porosity (%)	Water Saturation (%)	Permeability (mD)
DDS-1	1	2130 - 2137	52.25	18.48	39.84	13.03
	2	2190 - 2202	54.66	10.27	40.9	1.14
	3	2218 - 2239	49.22	9.33	56.33	0.22

Table 2. Cut-off Values of Reservoir Zones in Well DDS-1

Cut-off Parameters	Cut-off Value
Permeability (mD)	≥ 0.1
Porosity (%)	≥ 12
Shale Volume (%)	≤ 36
Water Saturation (%)	≤ 57

1 has Net Reservoir value of 2.14 meters at the intervals of 2130.93 - 2133 meters and of 2133.37 - 2153.53 meters; Zone 2 has values of 0.3048 meters at the interval of 2197.23 - 2197.46 meters and 0.92 meters at the intervals of 2200.58 - 2201.42 meters; whereas Zone 3 does not have Net Reservoir value. Consequently, reservoir zones that are good for passing fluid are Zone 1 and Zone 2.

Table 4 shows that Net Pay found in Zone 1 has

Table 3. Net Reservoir Values of Reservoir Zones of Well DDS-1

Zone	DEPTH TOP (METER)	DEPTH BASE (METER)	GROSS (METER)	NET RESERVOIR (METER)	NET TO GROSS
1	2130.93	2133	3.96	2.14	0.54
	2133.37	2135.53	2.44	2.14	0.88
2	2197.23	2197.46	33.38	0.3048	0.01
	2200.58	2201.42	3.96	0.92	0.23
3	2218	2239	20.88	0	0

Table 4. Net Pay Values of Reservoir Zones of Well DDS-1

Zone	DEPTH TOP (METER)	DEPTH BASE (METER)	GROSS (METER)	NET PAY (METER)	NET TO GROSS
1	2133.6	2134.06	359.13	0.61	0
	2134.82	2135.53	1.37	0.76	0.56
2	2197.3	2197.46	33.38	0.3048	0.01
	2200.65	2201.42	3.96	0.91	0.23
3	2218	2239	20.88	0	0

The potential for hydrocarbon reservoirs in the three zones is confirmed by the permeability parameter as the final result of petrophysical calculations, providing the information on the ability of rocks to pass the fluid. With reference to the parameter of permeability, the average value is 13.03 mD for Zone 1, 1.4 mD for Zone 2 and 0.22 mD for Zone 3.

All the petrophysic calculation results of Well DDS-1 analysis are listed in Table 1 below.

Determining the petrophysical cut-off values derived from the cross-plot results, the permeability cut-off value is ≥ 0.1 , the porosity cut-off is $\geq 12\%$, the shale volume cut-off is $\leq 36\%$, and the water saturation cut-off is $\leq 57\%$ (Table 2). These results can be used to eliminate intervals

values of 0.61 meters at the intervals of 2133.6 - 2134.06 meters and of 0.76 meters at the intervals of 2134.82 - 2135.53 meters; Zone 2 has values of 0.3048 meters at the intervals of 2197.3 - 2197.46 meters and 0.91 meters at the intervals of 2200.65 - 2201.42 meters. The existence of Net Pay values indicate that reservoir rocks found in Zone 1 and Zone 2 have the potential to store and release hydrocarbon fluids.

Analyzing the 2D seismic data of Line S88, some formations are adjusted referring to the marker data in the well report and the horizon picking, as well as depiction of the fracture structures seen during the fault picking (Figure 9).

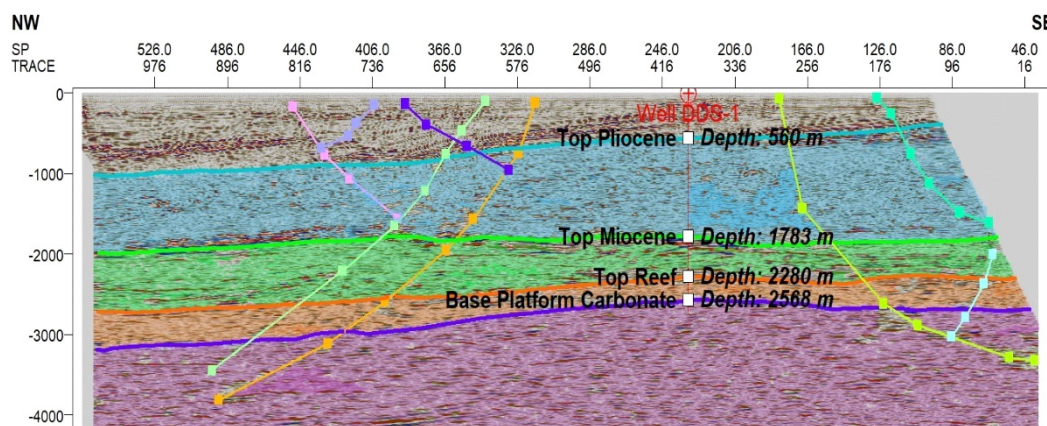


Figure 9. Results of horizon and fault picking interpreted from 2D seismic data of Line S88

DISCUSSION

The interpretation of gamma ray log of Well DDS-1 and 2D seismic section Line S88 in the Bunyu Island waters shows the presence of a petroleum system (Figure 9). The potential for source rock is between the Top Reef and Base Platform Carbonate boundaries, indicated by a high gamma-ray value. Based on the information in the well report, the source rock is in the Middle Miocene area and is comparable to the carbonate shale rock of Meliat Formation. This rock type of Meliat Formation is capable of being a place for the hydrocarbon maturation process (Setyowiyoto et al., 2019). We refer this source rock as Top Reef-Base Platform Carbonate Formation.

The hydrocarbon in the source rock moves towards the surface and migrates to the reservoir rock through reverse faults (Figure 10). The potential for reservoir rocks

is between the Top Miocene and Top Reef boundaries at the depth range of 2130 to 2280 meters. As reported in the well report, the reservoir rock is in the Late to Middle Miocene area which is comparable to the carbonate claystone and limestone of Tabul Formation. According to Setyowiyoto et al. (2019), the Top Miocene-Top Reef Formation can store gaseous hydrocarbons. Based on the gamma-ray log in Figure 10, the three reservoir zones of Well DDS-1 shows low gamma-ray values. Further analysis of these reservoir zones disclose that reservoir zone 1 and reservoir zone 2 have low shale contents, hence the potential to become reservoir rocks for storing hydrocarbon (Figure 11).

Overlying the Top Miocene-Top Reef Formation is the potential caprock, indicated by high value in the gamma-ray log. The well report reveals the caprock is in the Late Miocene area which is comparable to the deltaic

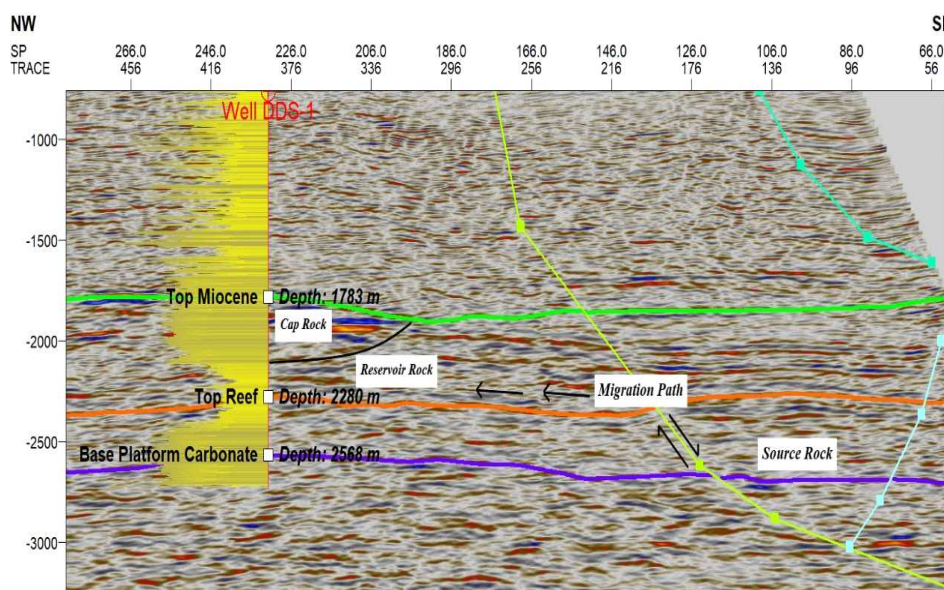


Figure 10. Seismic stratigraphy interpretation of Line S88

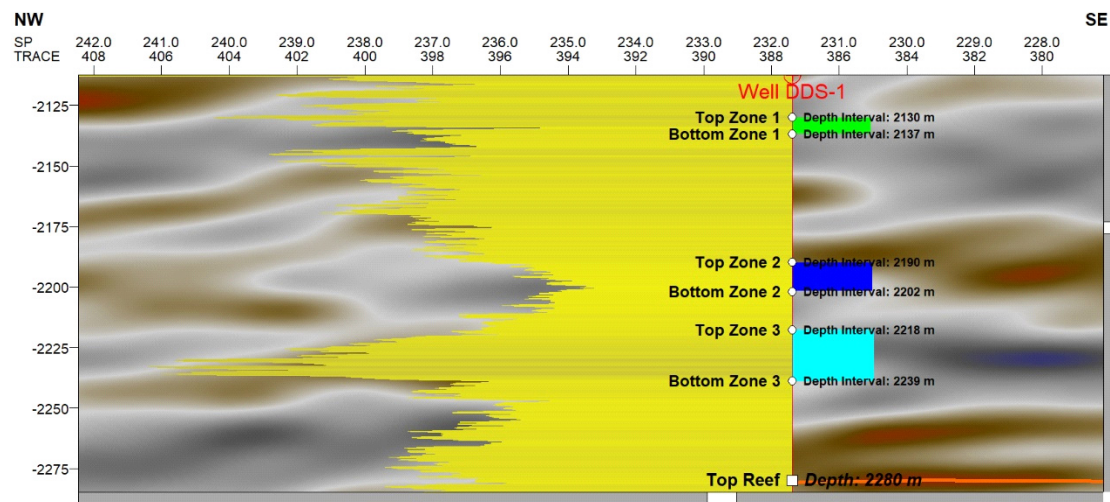


Figure 11. Reservoir zonations in Well DDS-1

claystone of Santul Formation (Setyowiyoto et al., 2019). At the upper boundary of the Top Miocene-Top Reef Formation, reflection misalignments can be seen and interpreted as a hydrocarbon trap system. Setyowiyoto et al. (2019) classified this trap type in Bunyu Islands waters as an unconformity stratigraphic trap, formed by structural processes followed by the deposition of fine sedimentary rock associated with the deltaic depositional environment.

In terms of reservoir zone determined from the Well DDS-1, the calculation of shale volume shows the highest shale content at 54.66% in Zone 2 which has the most inhibiting properties of rock in flowing fluid, compared to Zone 1 and Zone 3. Among the three zones, Zone 3 has the lowest porosity and permeability values. Therefore, Zone 3 is categorized as a bad reservoir zone.

Valuing the potential reservoirs of Zone 1 and Zone 2, their net pay parameters indicate the presence of hydrocarbon in the reservoir rock. However, based on the permeability classification of Koesoemadinata (1980), Zone 2 has a poor permeability at 1.14 mD, suggesting the zone cannot properly store fluid in the reservoir rock.

CONCLUSIONS

The petrophysical and seismic stratigraphy analysis assess the ability of reservoir rocks to store fluid based on their rock lithology. In this study, the calculation of petrophysical parameters in the Well DDS-1 shows three zones of reservoir rocks but only Zone 1 (2130 – 2137 meters) has reservoir characteristics that can store hydrocarbons, while Zone 2 (2190 – 2202 meters) and Zone 3 (2218 – 2239 meters) are not. The hydrocarbon prospects of Zone 1 indicates gas-typed hydrocarbon. Seismic stratigraphy interpretation of Line S88 determines the three reservoir zones are in the same formation, i.e., the

Top Miocene-Top Reef Formation, comparable to the carbonate claystone and limestone of Tabul Formation.

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