CARBON CAPTURE AND STORAGE (CCS) POTENTIAL AT LOW-RESISTIVITY RESERVOIR USING PETROPHYSICAL ANALYSIS AT "SOKA JINGGA" FIELD, TALANG AKAR FORMATION, ASRI BASIN

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ABSTRACT

Carbon Capture and Storage (CCS) is an emerging technology that reduces carbon dioxide emissions by utilizing subsurface reservoirs to store CO_2 beneath the Earth's surface. PT XYX conducted a comprehensive exploration of the CCS potential in Indonesia. The "Soka Jingga" Field, located at Talang Akar Formation, Asri Basin, is a potential candidate for CCS. The "Soka Jingga" Field has low resistivity reservoirs. There are five wells at "Soka Jingga" Field, namely DZ-1, DZ-2, DZ-3, DZ-4, and DZ-5. The objective of this study is to assess the CCS potential in the laminated sand interval of the "Soka Jingga" Field. The research method used is petrophysical analysis. The petrophysical data processing results show porosity values ranging from 23% to 35.5% with a net reservoir thickness ranging from 5.25 ft to 65 ft. The highest capacity was found in DZ-4 in the Zelda Member Zone 3, amounting to 37,923,654,924.52 kg or 37,923,654.92 tonnes. Summing the total capacity at "Soka Jingga" Field, the total CO_2 storage capacity in the research area is 125,169,497,575.91 kg or 125,169,497.58 tonnes.

Keyword: Carbon Capture and Storage, Talang Akar, CO_2 Storage Capacity, Low-Resistivity Reservoir, Petrophysics

INTRODUCTION

Growing global concerns about climate change and greenhouse gas emissions have generated considerable interest in Carbon Capture and Storage (CCS) technologies. PT XYX, a leading oil and gas company, has been actively supporting this program by conducting studies on the potential for CCS in various regions. This research, supported by PT XYX, focuses on the laminated sand interval within the "Soka Jingga" field at Talang Akar Formation of the Asri Basin, a region which offers a unique geological setting to study low-resistivity reservoirs.

The interval characterized by thin layers of sand and shale which gave challenges for conventional reservoir evaluation methods due to their heterogeneous nature and variable fluid saturations. However, it also provides significant storage capacity for CO_2 due to their extensive lateral continuity and effective porosity. This research aims to evaluate the physical properties of low-resistivity reservoirs using petrophysical methods, providing insights into the reservoir characteristics that influence CO_2 storage potential.

LITERATURE REVIEW

Geology of Research Area

The Asri Basin is located in the northwestern part of the Java Sea and has been the focus of oil and gas exploration and production since the 1970s. The study area, Talang Akar Formation, is one of many geological formation that formed in The Asri Basin. The Talang Akar Formation consists of two members, the Zelda Member and the Gita Member. The Zelda Member was deposited unconformably on top of the Banuwati Formation, while the Gita Member was deposited in the post-rift period of the Early Miocene. The Talang Akar Formation consists of various rock types, including sandstones, shales and carbonates, indicating a deltaic to shallow marine depositional environment.

Low-Resistivity Reservoir

Low-resistivity reservoirs are reservoirs that have petrophysical properties that do not support optimal hydrocarbon production. These reservoirs usually have low permeability and porosity, as well as high water saturation, which makes them difficult to exploit using conventional methods.

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Laminated Sand

Laminated sand is a type of sedimentary rock that consists of thin layers of sand and shale. These layers can affect reservoir quality due to the difference in physical properties between sand and shale. Laminated sand often exhibits low resistivity due to high shale content and variable water saturation. This makes it challenging for reservoir evaluation using conventional methods.

Petrophysics

Petrophysics is a branch of geology that studies the physical and chemical properties of reservoir rocks and fluid interactions within them. Petrophysical analysis involves various methods to determine important parameters such as shale volume, water saturation and porosity.

Shale Volume

Shale volume is the percentage of shale content in the reservoir rock. The linear method is one of the methods used to calculate shale volume based on gamma-ray logs.

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Equation 1 Linear Method (*Darwin V. Ellis and Julian M. Singer in Well Logging for Earth Scientists*)

Description

GR_{log} : Gamma ray log reading at formation depth (API)

GR_{max} : Maximum reading of the gamma ray log at formation depth (API)

GR_{min} : Minimum reading of the gamma ray log at formation depth (API)

Porosity

Porosity is the fraction of pore space in rocks or the ability of reservoir rocks to store fluid. Rock porosity can be influenced by several factors, namely grain size, grain shape, sorting, and fabrics. The Neutron-Density method is one of the methods used to calculate porosity.

$$\Phi\ (\%) = \frac{\text{Pore Volume}}{\text{Bulk Volume}}$$

Equation 2 Porosity Calculation

Calculation of neutron-density porosity based on Bateman-Konen:

$$\Phi e = \frac{\Phi D \times \Phi Nsh - \Phi N \times \Phi Dsh}{\Phi Nsh - \Phi Dsh}$$

Equation 3 Neutron-Density Method *(Raymond M. Bateman and Louis J. Konen, 2007)*

Description

Φe : Effective porosity

ΦD : Porosity density

ΦNsh : Neutron porosity in shale

ΦDsh : Density porosity in shale

Koesomadinata (1978) made a classification related to reservoir quality based on pore value in units of percent as follows.

Table 1 Classification of Rock Porosity Quality Level (Koesomadinata, 1978)

Porosity	Description
0 – 5 %	Negligible
2.5 – 10 %	Poor
10 – 15 %	Fair
15 – 20 %	Good
20 – 25 %	Very Good
> 25 %	Excellent

Water Saturation

Water saturation is the percentage of water volume contained in the pores of the reservoir rock compared to the total volume of fluid filling the pores of the reservoir rock. The Indonesia method is one of the methods used to calculate water saturation.

$$SW = 1 - Sh$$

Equation 4 Water Saturation Calculation

Description

SW : Water saturation (%)

Sh : Hydrocarbon saturation (%)

The Indonesian method of water saturation calculation is based on Poupon-Leveaux, 1971:

$$SW = \left(\sqrt{\frac{\sqrt{\frac{1}{RT}}}{\left(\frac{Vsh^{(1-0.5)}}{\sqrt{Rsh}}\right) + \frac{\Phi^{\frac{m}{2}}}{\sqrt{a\ x\ Rw}}}} \right)^{\frac{2}{n}}$$

Equation 5 Indonesian Method (Poupon-Leveaux, 1971)

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Description

SW : Water saturation

Rw : Resistivity of formation water

Rt : Actual formation resistivity

Rsh : Shale resistivity

a : Tortuosity constant

m : Cementation factor

n : Saturation constant

Φ : Effective porosity

Vsh : Shale volume

Carbon Capture Storage

Carbon Capture and Storage (CCS) is a technology crucial for decreasing carbon dioxide (CO_2) emissions into the atmosphere. This process entails capturing CO_2 from emission sources like factories or power plants and then securely storing it underground to prevent its release back into the atmosphere.

CO_2 Storage Capacity Estimates

CO_2 storage capacity estimates reflect the potential for geological storage when considering current economic and regulatory factors. For the development of specific commercial-scale geological storage sites, economic and regulatory constraints must be taken into account to determine the portion of the estimated CO2 storage resources that can be utilized under various development scenarios (Bachu, 2008).

The equation for calculating the CO_2 storage resource (G_{CO2}) in geological storage within saline formations is:

Description

$$G_{CO2} = A_t h_g \, \Phi_{tot} \, \rho \, E_{saline}$$

Equation 6 CO2 Storage Resource Calculation (Goodman, et al, 2011)

A_t : Total area

h_g : Gross formation thickness

Φ_{tot} : Total porosity

ρ : CO_2 density

E_{saline} : Storage efficiency factor

$$E_{saline} = E_{An/At} E_{hn/hg} E_{\Phi e/\Phi tot} E_A E_L E_g E_d$$

Equation 7 Saline Calculation (Goodman, et al, 2011)

Description

$E_{An/At}$: Net to total area

$E_{hn/hg}$: Net to gross thickness

$E_{\Phi e/\Phi tot}$: Effective to total porosity

Table 2 Saline Formation Efficiency Factors (Goodman, et al., 2011)

Lithology	P10	P50	P90
Clastics	0.51%	2.0%	5.4%
Dolomite	0.64%	2.2%	5.5%
Limestone	0.40%	1.5%	4.1%

RESEARCH METHOD

The research method involves the application of petrophysical methods to analyze the physical properties of the reservoir rocks. Specifically, the methods used include Shale Volume (Vsh) estimation using the linear method, Water Saturation (SW) calculation using the Indonesian method, and Porosity (PHIE) estimation using the neutron-density method. These three methods are the best methods to use in the research area because they are the most suitable for its characteristics which contain clastic lithology.

The data used in this research include core data, well log data, and laboratory data. Core data includes Side Wall Core (SWC), mud log, and X-ray diffraction (XRD) data. Well log data includes gamma ray (GR), resistivity, and neutron-density log.

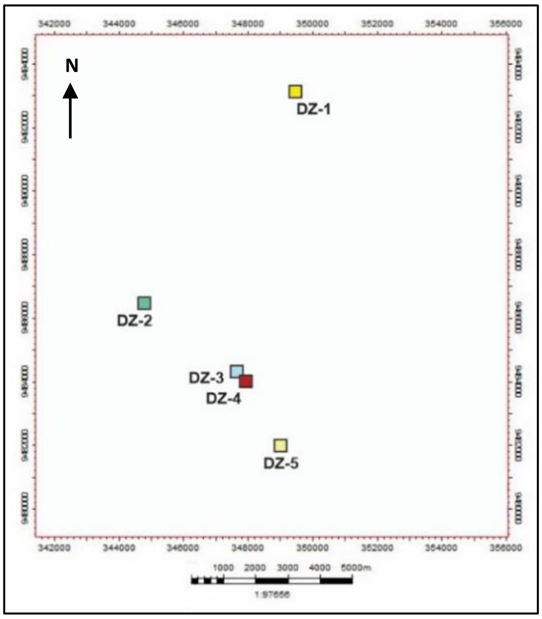

Figure 1 Well Distribution Map at "Soka Jingga" Field

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RESULTS AND DISCUSSION

Data processing was carried out on five wells, namely DZ-1, DZ-2, DZ-3, DZ-4, and DZ-5, which are scattered throughout the research location. The base map used for this study provides a detailed representation of the area. The locations of each "DZ" well are precisely plotted on this map, allowing for easy identification and reference. The distribution of the wells is shown in Figure 1, which illustrates their spatial arrangement across the research site.

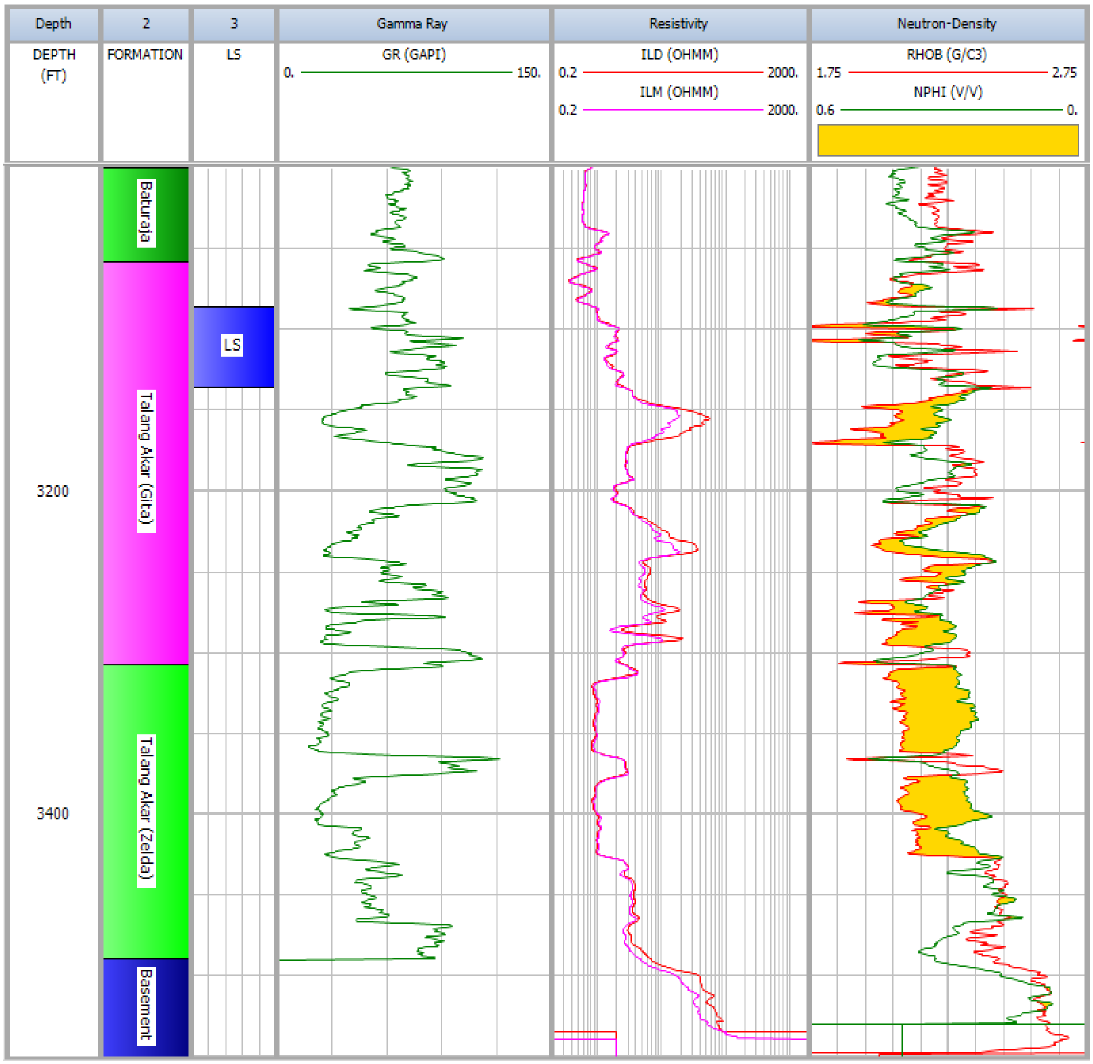

Figure 2 Triple Combo DZ-1

Key Well

In this research, the method of each petrophysical parameter will be determined from the DZ-1 well which is the key well of the "Soka Jingga" field. The gamma ray, resistivity, and neutron-density log in Figure 2 shows the laminated sand interval zone symbolized in dark blue with the label "LS". In this interval, the GR log shows sand-shale lamination. This interval has low resistivity and a cross over between the neutron-density log.

Based on the characteristics of the research area, the linear method for shale volume determination is used because it produces the highest shale results compared to the other method, so that the most pessimistic shale results are obtained. For water saturation parameters, the Indonesian method is used because it is in accordance with the conditions of the formation which has shaly sand characteristics and has a low salinity. Meanwhile, the neutron-density method was used to determine porosity. The method was chosen because it is able to calculate PHIT and

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PHIE simultaneously, with correction for the shale value.

Shale Volume (Vsh)

The shale volume in a formation affects the quality of the reservoir rock in the formation, because shale will affect the porosity value. The calculation of Vshale is done using a single indicator which is the gamma ray log. In determining the shale volume, the ideal method used is the linear method where the Vshale content value is equal to the gamma ray index value. The determination of the shale volume is determined from the maximum and minimum gamma ray values.

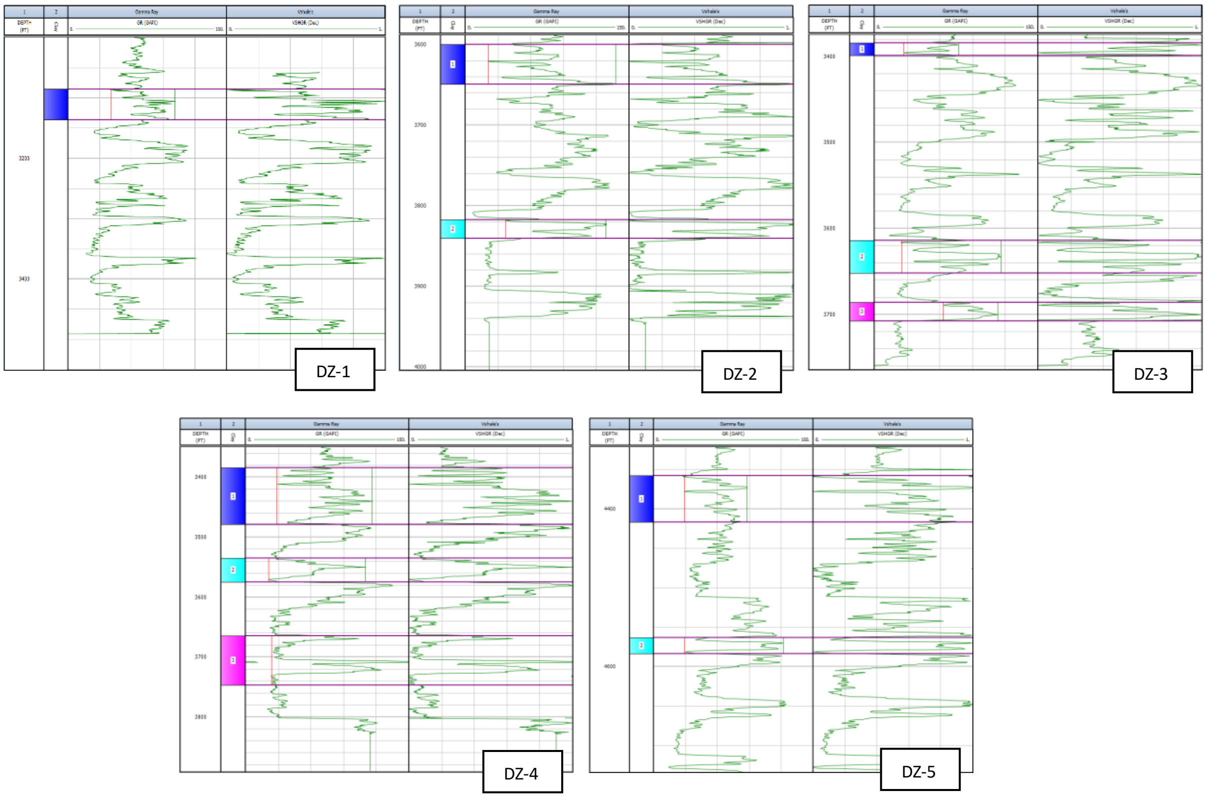

Figure 3 Shale Volume Calculation from GR Log

From Figure 3, the results of Vshale with the linear method using the Asquith equation (1982) are obtained, the results for all wells are shown in Table 2.

Table 3 Shale Volume Result

Well Code	Zone	Depth (ft)	Av Vsh
DZ-1	1	3086 - 3137	0.286
DZ-2	1	3599 - 3651	0.231
	2	3817 - 3841	0.19
DZ-3	1	3382 - 3398	0.201
	2	3614 - 3652	0.176
	3	3686 - 3708	0.202
DZ-4	1	3384 - 3479	0.22
	2	3533 - 3575	0.172
	3	3663 - 3748	0.081
DZ-5	1	4358 - 4418	0.202
	2	4563 - 4584	0.099

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Table 2 shows variations in shale volume across different zones from five wells analyzed. In DZ-1, the first zone at a depth of 3086-3137 ft has a Vsh of 0.286 or 28.6%, indicating significant shale volume. The second zone at 3599-3651 ft has a Vsh of 0.231 or 23.1%, also reflecting considerable shale volume. In DZ-2, the second zone at a depth of 3817-3841 ft has a Vsh of 0.19 or 19%, indicating a moderate amount of shale, which is lower compared to DZ-1. DZ-3 shows variation in shale volume across its zones, with the first zone (3382-3398 ft) having a Vsh of 0.201 or 20.1%, the second zone (3614-3652 ft) with a Vsh of 0.176 or 17.6%, and the third zone (3686-3708 ft) with a Vsh of 0.202 or 20.2%. This moderate shale volume indicates a mixture of shale and sand. DZ-4 shows a clearer variation, with the first zone (3384-3479 ft) having a Vsh of 0.22 or 22%, the second zone (3533-3575 ft) with a Vsh of 0.172 or 17.2%, and the third zone (3663-3748 ft) with a Vsh of 0.081 or 8.1%, indicating a higher dominance of sand in the third zone. Lastly, Well DZ-5 has the first zone (4358-4418 ft) with a Vsh of 0.202 or 20.2%, and the second zone (4563-4584 ft) with a Vsh of 0.099 or 9.9%, showing lower shale volume.

Porosity (PHIE)

The porosity calculation in this research uses the neutron-density method. To determine the porosity of a rock using this method, several porosity parameters (Rho) for wet clay (matrix), dry shale, and fluid are required. These values are obtained from picking the NPHI, RHOB, and GR parameters. After picking the parameters, the calculation is performed using the Bateman-Konen neutron-density porosity equation, which yields total porosity (PHIT) and effective porosity (PHIE). The porosity calculation is performed simultaneously with the water saturation calculation, as shown in Figure 4.

Table 4 Porosity Result

Well Code	Zone	Depth (ft)	Av Phi
DZ-1	1	3086 - 3137	0.23
DZ-2	1	3599 - 3651	0.291
	2	3817 - 3841	0.3
DZ-3	1	3382 - 3398	0.355
	2	3614 - 3652	0.341
	3	3686 - 3708	0.338
DZ-4	1	3384 - 3479	0.307
	2	3533 - 3575	0.263
	3	3663 - 3748	0.313
DZ-5	1	4358 - 4418	0.285
	2	4563 - 4584	0.304

Table 3 shows the results of the porosity calculation. Based on the classification conducted by Koesomadinata (1978), all zones across all wells exhibit porosity values that fall into the "Excellent" category, with the exception of DZ-1 (3086-3137 ft) which is classified as "Very Good". This indicates that the rock quality in terms of porosity is very high

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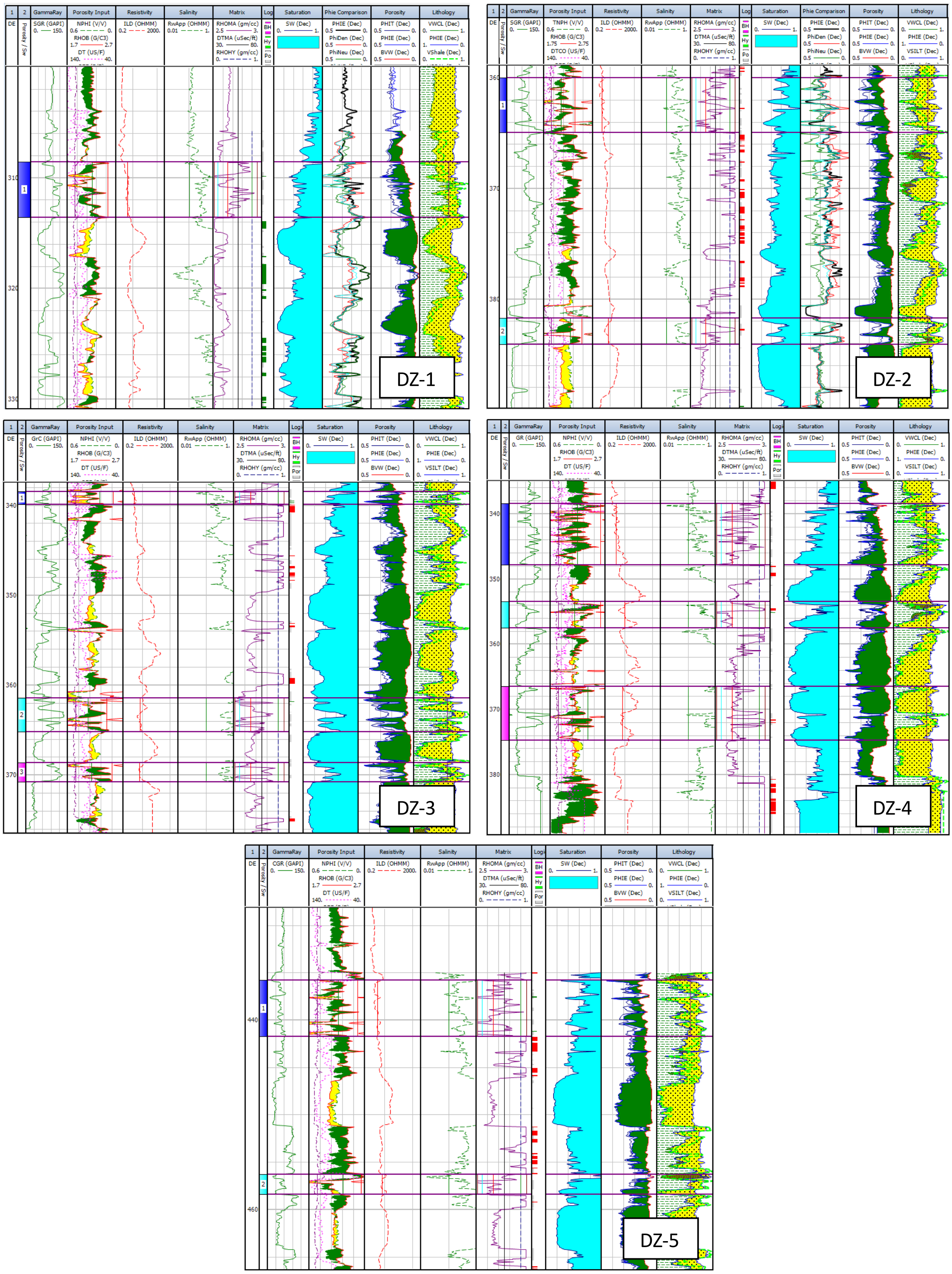

Figure 4 Porosity and Water Saturation Calculation

Water Saturation (SW)

In calculating water saturation, it is first necessary to determine the coefficients a, m, and n. These values are obtained from core sample analysis, which is part of a formation evaluation series. The tortuosity coefficient (a) is 1, the cementation factor (m) is 1.88, and the saturation exponent (n) is 1.87.

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The water saturation calculation in this research uses the Indonesian equation. This equation is suitable for shaly sand formations such as the Talang Akar Formation, which involves shale correction in its calculations.

To determine the water saturation value, calculation parameters such as formation water resistivity (Rw) are required. The Rw value is obtained from a picket plot between the NPHI log and the RT log, then determining the water-bearing zone as the boundary for water saturation value (Figure 5). The calculation is shown in Figure 4 and the results for each well are obtained and shown in Table 4.

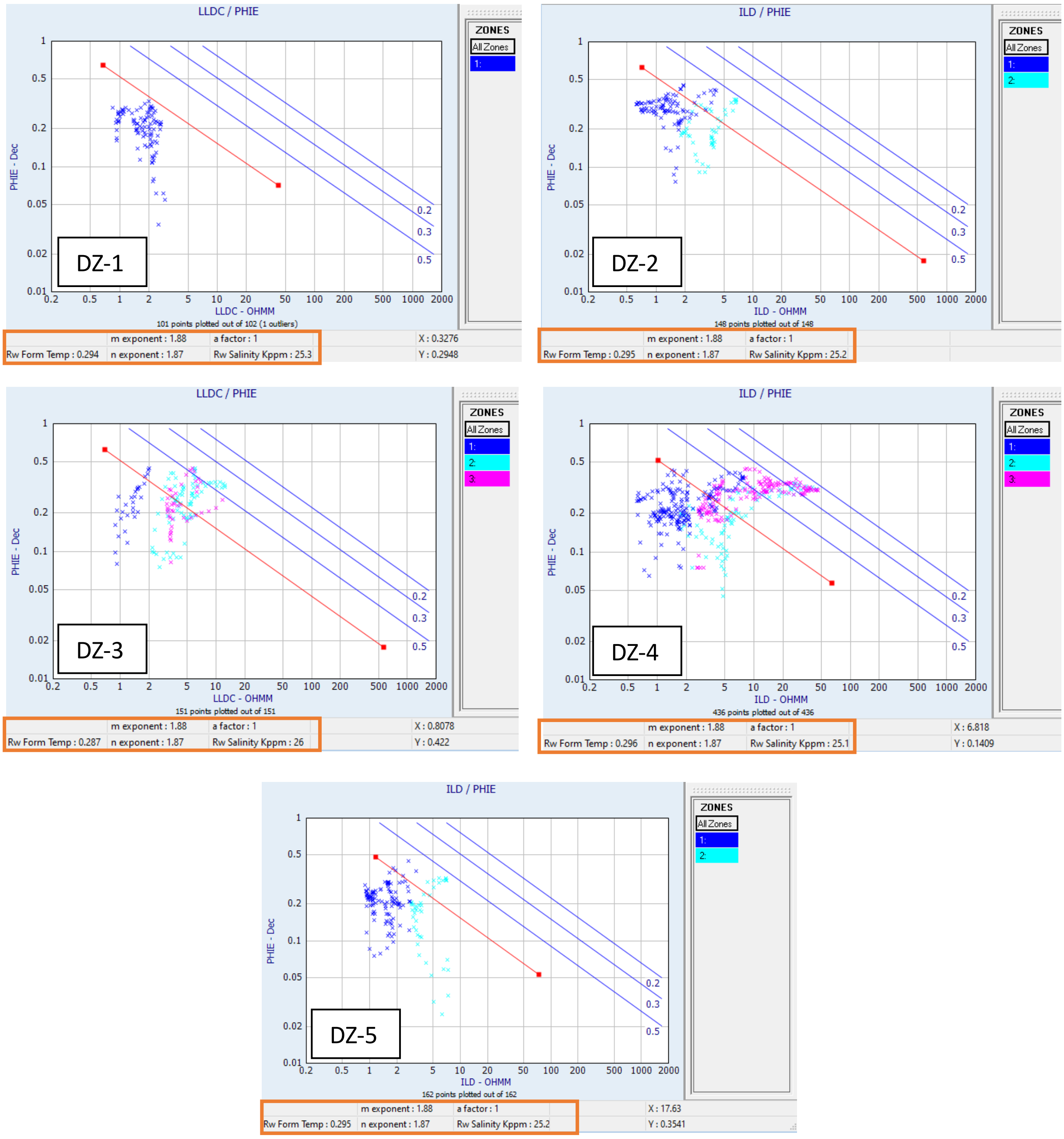

Figure 5 Picket Plot NPHI Log - RT Log

Table 5 Water Saturation Result

Well Code	Zone	Depth (ft)	Av SW
DZ-1	1	3086 - 3137	0.496
DZ-2	1	3599 - 3651	0.522

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	2	3817 - 3841	0.298
DZ-3	1	3382 - 3398	0.41
	2	3614 - 3652	0.232
	3	3686 - 3708	0.236
DZ-4	1	3384 - 3479	0.388
	2	3533 - 3575	0.202
	3	3663 - 3748	0.18
DZ-5	1	4358 - 4418	0.521
	2	4563 - 4584	0.259

From Figure 5, the values for Rw can be concluded. The Rw values vary between 0.287 and 0.296, with salinity levels ranging from 25,100 to 26,000 ppm. From Rw and salinity values, water saturation results are obtained. DZ-1 has relatively high water saturation in both zones, with average values of 0.496 and 0.522. DZ-2 shows a significant difference between its zones, where the first zone has a lower water saturation (0.298) compared to the second zone (0.41). DZ-3 consistently has lower water saturation in both zones, with average values of 0.232 and 0.236. DZ-4 also shows variation, with the first zone having higher water saturation (0.388) compared to the second zone (0.202). DZ-5 has highly variable water saturation between its zones, with the highest value in the first zone (0.521) and the lowest in the second zone (0.18), while an additional zone has a value of 0.259.

Cut-off and Lumping

Determining the cut-off values for shale volume and porosity can be done using a cross plot between shale volume and effective porosity. Meanwhile, the determination of cut-off value for water saturation is using a cross plot between water saturation and effective porosity.

The cut-off values obtained for this research is shale volume ≤ 35%, porosity ≥ 15%, and water saturation ≤ 65%. The lumping result is shown in Table 5.

Table 6 Lumping Result

Well Code	Member - Zone	Depth (ft)	Gross (ft)	Net Res (ft)	N/G	Av Vsh	Av SW	Av Phi
DZ-1	Gita - 1	3086 - 3137	51	6.25	0.123	0.286	0.496	0.23
DZ-2	Gita - 1	3599 - 3651	52	33.75	0.649	0.231	0.522	0.291
	Gita - 2	3817 - 3841	24.5	9	0.367	0.19	0.298	0.3
DZ-3	Gita - 1	3382 - 3398	15	6.25	0.417	0.201	0.41	0.355
	Gita - 2	3614 - 3652	38	14.5	0.382	0.176	0.232	0.341
	Zelda - 3	3686 - 3708	22	7	0.318	0.202	0.236	0.338
DZ-4	Gita - 1	3384 - 3479	94.5	33.75	0.357	0.22	0.388	0.307
	Gita - 2	3533 - 3575	42	24.5	0.583	0.172	0.202	0.263
	Zelda - 3	3663 - 3748	85	65	0.765	0.081	0.18	0.313
DZ-5	Gita - 1	4358 - 4418	59.5	17.25	0.29	0.202	0.521	0.285
	Gita - 2	4563 - 4584	21	5.25	0.25	0.099	0.259	0.304

Based on Table 5, the highest porosity value is found in DZ-2 Zone 2, which is 35.5%. Conversely, the lowest porosity value is found in DZ-1, which is 23%. The largest reservoir zone is found in DZ-4 Zone 3 in the Zelda Member, which is 65 ft. Based on these porosity value, the CCS can be estimated.

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Table 7 CCS Estimation Parameters

Well Code	Member - Zone	Depth (ft)	A_t (m^2)	h_g (m)	Phi	ρ CO_2 (kg/m3)	E_{saline}
DZ-1	Gita - 1	3086 - 3137	436,827,019.77	1.905	0.23	700	0.02
DZ-2	Gita - 1	3599 - 3651		10.287	0.291		
	Gita - 2	3817 - 3841		2.7432	0.3		
DZ-3	Gita - 1	3382 - 3398		1.905	0.355		
	Gita - 2	3614 - 3652		4.4196	0.341		
	Zelda - 3	3686 - 3708		2.1336	0.338		
DZ-4	Gita - 1	3384 - 3479		10.287	0.307		
	Gita - 2	3533 - 3575		7.4676	0.263		
	Zelda - 3	3663 - 3748		19.812	0.313		
DZ-5	Gita - 1	4358 - 4418		5.2578	0.285		
	Gita - 2	4563 - 4584		1.6002	0.304		

Carbon Capture Storage Estimation

The A_t values denote the areal extent of the research area considered suitable for CO_2 storage, with larger areas capable of storing more CO_2. The net reservoir thickness (h_g) values represent the suitable portions of geological formations for CO_2 storage, with thicker reservoirs holding more CO_2. A subsurface CO_2 density assumption of 700 kg/m^3 was used for reliable storage capacity predictions under typical high-pressure and moderate-temperature conditions. High porosity values in the wells indicate substantial pore spaces, making them ideal for CO_2 storage. Finally, the study used an E saline value of 2%, representing the P50, to provide a balanced and realistic estimate of the saline formation's effectiveness in carbon capture and storage (CCS). This comprehensive assessment aids in identifying and quantifying the potential of the site for effective long-term CO_2 storage.

Table 8 G_{CO2} Accumulation Result

Well Code	Member - Zone	Depth (ft)	G_{CO2} (kg)	G_{CO2} (tonnes)
DZ-1	Gita - 1	3086 - 3137	2,679,540,621.97	2,679,540.62
DZ-2	Gita - 1	3599 - 3651	18,307,087,536.37	18,307,087.54
	Gita - 2	3817 - 3841	5,032,876,298.66	5,032,876.30
DZ-3	Gita - 1	3382 - 3398	4,135,812,699.13	4,135,812.70
	Gita - 2	3614 - 3652	9,216,687,725.45	9,216,687.73
	Zelda - 3	3686 - 3708	4,410,290,860.23	4,410,290.86
DZ-4	Gita - 1	3384 - 3479	19,313,662,796.10	19,313,662.80
	Gita - 2	3533 - 3575	12,010,866,085.34	12,010,866.09
	Zelda - 3	3663 - 3748	37,923,654,924.52	37,923,654.92
DZ-5	Gita - 1	4358 - 4418	9,164,028,927.14	9,164,028.93
	Gita - 2	4563 - 4584	2,974,989,100.99	2,974,989.10
Total			125,169,497,575.91	125,169,497.58

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Based on the data from the Table 8, the highest G_{CO2} is found in DZ-4, specifically in the Zelda-3 zone, with values of 37,923,654,924.52 kg or 37,923,654.92 tonnes. The lowest G_{CO2} is observed in DZ-1, specifically in the Gita-1 zone, with values of 2,679,540,621.97 kg or 2,679,540.62 tonnes. These results provide a comprehensive overview of the CO_2 storage potential across the various wells and zones, highlighting both the extremes and the cumulative storage capacity. Additionally, it is evident that a larger porosity in the geological formations results in a greater capacity for CO_2 storage, as larger pore spaces allow for more CO_2 to be accommodated. Therefore, the CO_2 storage capacity in "Soka Jingga" Field is 125,169,497,575.91 kg or 125,169,497.58 tonnes.

CONCLUSION

The research location is in the laminated sand interval of the Talang Akar Formation in the Asri Basin. The study was conducted at "Soka Jingga" Field with five research wells: DZ-1, DZ-2, DZ-3, DZ-4, and DZ-5. This research utilizes petrophysical methods. Based on the calculations, the porosity values range from 23% to 35.5% with the net reservoir thickness ranges from 5.25 ft to 65 ft. These two parameters are used to determine the capacity for carbon capture storage. The highest capacity was found in DZ-4 in the Zelda Member Zone 3, amounting to 37,923,654,924.52 kg or 37,923,654.92 tonnes. Summing the total capacity at "Soka Jingga" Field, the total CO_2 storage capacity in the research area is 125,169,497,575.91 kg or 125,169,497.58 tonnes. This research indicates that the laminated sand interval at the low-resistivity reservoir have the potential to be a CO_2 storage.

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