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Reservoir Characterization of Ngrayong Formation, Sandstone with Carbonate Intercalation, Using a Geostatistical Approach Based on Petrophysical Parameters, Northeast Java Basin, Indonesia

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ABSTRACT - Hydrocarbons have a vital role as a driver of the global economy, which causes demand to continue to increase. To achieve production targets, oil and gas companies try to conduct exploration using efficient and accurate methods to obtain optimal hydrocarbon reserves. One approach in hydrocarbon exploration is to use geostatistical analysis to understand the characteristics of petrophysical parameters of reservoir rocks (e.g. porosity, permeability, water saturation and facies). This study aims to characterize reservoirs in the NE Java Basin using a geostatistical approach that Sequential Gaussian Simulation (SGSIM) to produce random realizations that can be adjusted and validated through geostatistical analysis of data before and after the simulation. The dataset used in this study consist of well data, seismic line, and core data. The results shows the petrophysical properties distribution from the simulation reveals the dominance of carbonate sandstone reservoirs in the central part of the study area with a thinning slope towards the northwest and southeast, while sandstone reservoirs are only dominant in the southeast direction of the study area. This study provides important insights in understanding reservoir characteristics and can be a basis for efficient decision making in the exploration of hydrocarbon resources in this area.

Keywords: low-frequency extrapolation, self-supervised learning, Asri Basin, full waveform inversion, hydrocarbon, geostatistic, petrophysics, porosity, permeability, SGSIM.

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INTRODUCTION

The oil and gas industry remains an important sector in the global economy. Effective and efficient hydrocarbon development and production relies heavily on a good understanding of reservoir characteristics. Accurate reservoir characterization and hydrocarbon distribution mapping can increase productivity and optimize reservoir management. Therefore, the use of geostatistical technology in reservoir characterization and mapping can help to understand reservoir distribution more accurately. Geostatistical technique is a spatial analysis method that can be used to model and map geological phenomena in three dimensions (3D). This technique can produce estimates of variables that are not directly measurable and enable better decision making in hydrocarbon development and production (Ravalec-Dupin et al., 2011; Yang & Liu 2019).

The East Java Basin, especially in the northern part, is one of the basins that has great potential for oil and gas exploration in Indonesia. Several previous studies have been carried out to evaluate the hydrocarbon potential in this region to characterize the physical properties of reservoir rocks using log and seismic data (Lunt 2019; Sharaf et al., 2005; Bransden & Matthews 1992; Noble et al., 1997; Handoyo et al., 2024; 2025). At this location, quite a lot of log data is available, making it possible to correlate several well data for further analysis using geostatistical method.

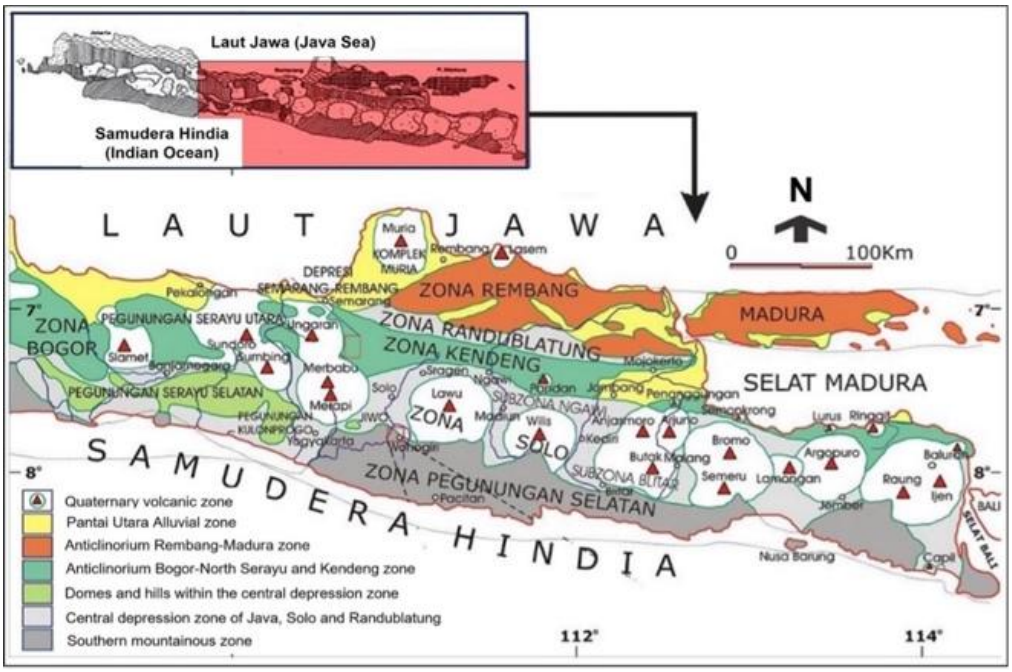

Figure 1. Physiography of The East Java Basin (modified from Smyth et al., 2005; Soeka et al., 1982).

This study aims to identify hydrocarbon field prospects using a geostatistical approach. This method does not require seismic data, so only well data is needed as in several previous studies using multi-well correlation and interpretation analysis (Grana & Della Rossa 2010; Laalam et al., 2022; Pan et al., 2023). Well information that will be used to characterize hydrocarbon potential includes porosity, water saturation, permeability and facies obtained from interpretation of gamma ray logs, resistivity, sonic, density and neutron porosity. The outcome of this study is the regional distribution along with a description of the reservoir potential in the research area. Through this research, it is hoped that we will be able to contribute to the understanding of reservoir rock characteristics using a statistical approach in oil and gas fields that have quite a lot of well data.

Geological setting

The research was carried out for the RON Field which are physiographically located in the Rembang zone, northern East Java basin (Soeka et al., 1982). The East Java Basin is a back-arc basin that trends East-West, parallel to the island of Java (Soeka et al., 1982). This basin was formed in the late Oligocene (Bemmelen 1949). The physiographic map of the East Java basin can be seen in Figure 1 (Smyth et al., 2005). Physiography of the East Java Basin consist of seven zones (from South to the North): (i) The Eastern Southern Mountains Zone; (ii) The Solo

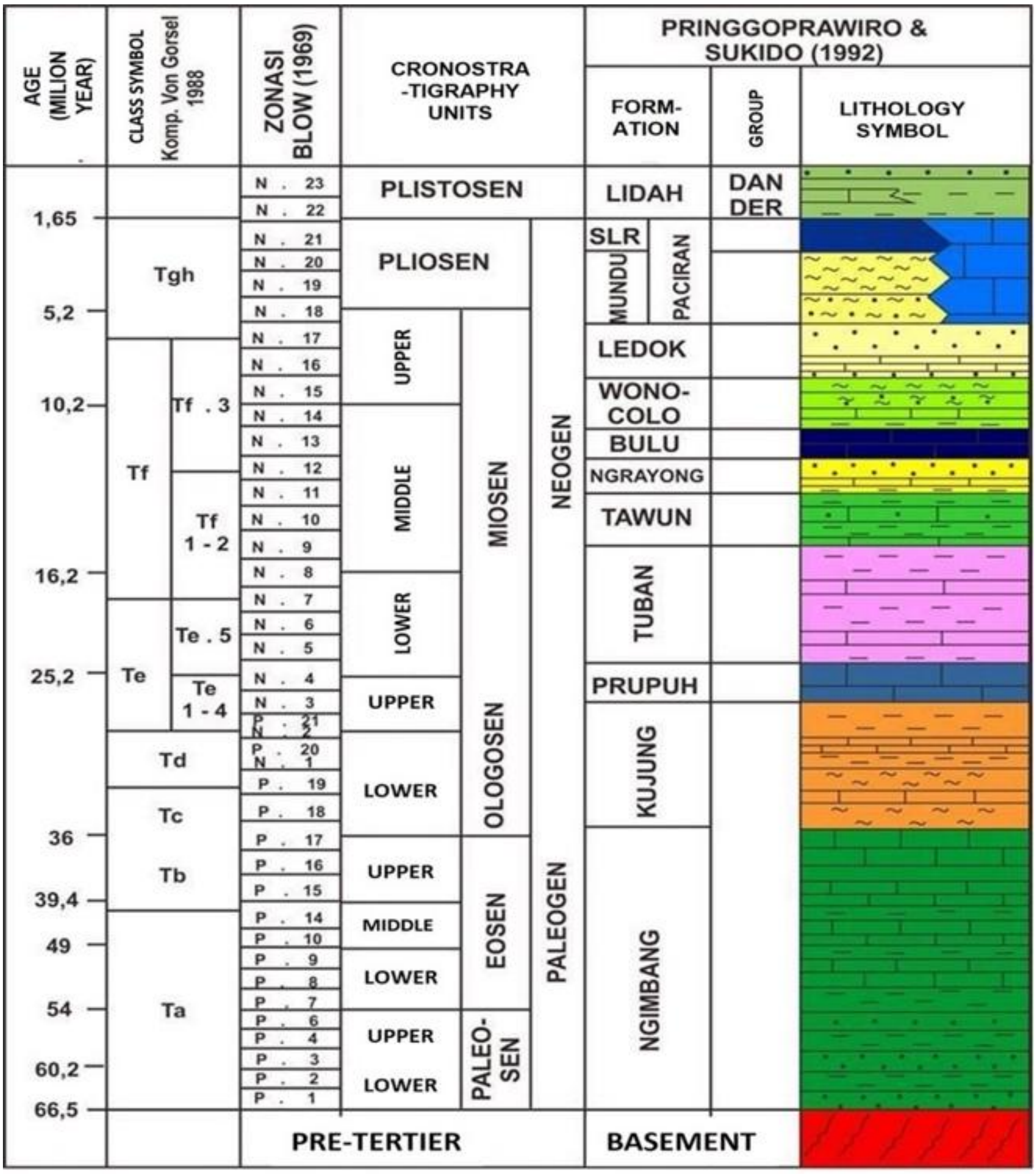

Figure 2. Stratigraphy of The East Java Basin Rembang Zone (modified from Pringgoprawiro 1983).

Zone; (iii) The Kendeng area; (iv) The Randublatung Zone; (v) The Rembang Zone; (vi) Alluvial Plains in Pantai Utara; (vii) Quaternary Volcanoes.

This study focused on the northern East Java Basin (Figure1) (modified from Pringgoprawiro 1983; Panjaitan 2010). This basin is one of the Tertiary basins in western Indonesia which is rich in oil and natural gas resources. The main hydrocarbon source rock in this basin comes from carbonate shale in the Ngimbang Formation, which was formed in marginal marine, delta and lake environments with kerogen types II and III. Deep sea shale at the bottom of the Kujung Formation also has potential as source rock (Bintarto 2020). The research location is in the Rembang Zone, an interesting and important area to study stratigraphically in uncovering a long and complex geological history. The Rembang zone has been classified into several different formation groups (Figure 2), and each formation has specific characteristic details, as recorded in previous research (Pringgoprawiro 1983).

Detailed stratigraphy in Tuban Group (Figure 2), geological formation from the Tuban Group is the Ngrayong Formation which is the main oil producer in Central Java and East Java (main interest zone in this study). The Ngrayong Formation is estimated to be of Middle Miocene age and was deposited in a delta and coastal environment at the top, to a shallow marine environment at the bottom. The upper part of the Ngrayong Formation consists of alternating calcareous sandstone and mudstone, with intercalations of limestone and thin coal intercalations, while the lower part is dominated by clay and silt with intercalations of calcareous sandstone and thin intercalations of limestone (Pringgoprawiro 1983).

METHODOLOGY

Materials

This study uses seven wells in this study, namely wells RON-1, RON-2, RON-3, LEI-1, LEI-2, LEI-3 and LEI-4 with the availability of log data described in Table 1. Parameters in well data consist of caliper, density, sonic, resistivity, neutron porosity, and spontaneous potential.

Method

Methodology of this study following eight stages: (i) Target Zone Analysis; (ii) Volume of clay determination; (iii) Porosity estimation; (iv) Water saturation estimation; (v) Permeability estimation; (vi) Interest zone selection; (vii) 3-Dimensional Grid Formation; and (viii) Geostatistical Modeling with Sequential Gaussian Simulation (SGSIM). In this study, first stage is target zone analysis. The determination of the target zone in this study was carried out by considering the depth, data availability, quick look of well data and geological conditions of the formation (Lai et al., 2022; Farfour et al., 2023). The Ngrayong Formation is the most suitable candidate to be a target zone because this formation is dominated by sandstone and carbonate. In addition, the Ngrayong Formation is also the largest formation producing hydrocarbons in the research area (Ran et al., 2020; Airlangga et al., 2024).

Second step is volume of clay determination. To determine the clay volume (Vclay) value, first it is necessary to determine the gamma-ray maximum (GRmax) and gamma-ray minimum GRmin values in the well data (Criollo et al., 2022: Zhu et al., 2023). These values are then used to find the Gamma Ray Index (IGR) value and then find the Vclay value. Step number three is porosity estimation. Determining porosity in the well is done by using the density porosity method (Ellis, 2003; Horsfall et al, 2013).

Table 1. Description of well data in this study.

Log Data Type	RON-1	RON-2	RON-3	LEI-1	LEI-2	LEI-3	LEI-4
Caliper	✓	✓	✓	✓	✓	✓	✓
Density	✓	✓	✓	✓	✓	✓	✓
Sonic (DT)	✓	✓	✓	✓	✓	✓	✓
Gamma Ray	✓	✓	✓	✓	✓	✓	✓
Resistivity ILD	✓	✓	✓	✓	✓	✓	✓
Neutron Porosity	✓	✓	✓	✓	✓	✓	✓
Spontaneous Potential	✓	✓	✓	✓	✓	✓	✓

The results of the porosity calculation require matrix density parameters, fluid density and clay density. All three are estimated based on the fitness data between the calculated porosity and the core data. Next step is water saturation estimation. Before determining water saturation, it is necessary to determine the apparent water resistivity (Rwapp) value or apparent water resistivity using the resistivity log information. Then the water saturation value can be found using the Indonesian equation (Irawan et al., 2019). Then, the step of permeability estimation. To determine the permeability value, porosity and water saturation logs are required, so that the determination of porosity and water saturation needs to be done first before determining the permeability value (Torskaya et al., 2007; Shang et al., 2003).

Next step are facies analysis and interest zone selection. Facies is a categorical unit that defines rock types based on petrophysical characteristics. Facies analysis in this study applies the quick-look principle to clay volume logs, neutron porosity, and density. The interest zone or commonly called the target zone is part of the Ngrayong Formation that is the target of the study. This zone can be identified by considering lithology, porosity and permeability values. Identification of lithology or facies is done using Vclay logs, Neutron Porosity (NPHI), and bulk density (RHOB). In this study, the reservoirs that will be considered are reservoirs with sufficient (fair) to excellent porosity, namely reservoirs with porosity values above 10%. In addition, reservoirs can also be classified based on their permeability values. The higher the permeability value, the better, because the reservoir is more capable of flowing hydrocarbons (Koesoemadinata, 1978). In this study, the reservoirs that will be considered are reservoirs with fair to excellent permeability, namely reservoirs with permeability values above 5 mD.

Step number seven is 3D grid formation. Before performing geostatistical modeling, a grid will first be formed with nodes that will be filled with interpolation values. The formation of the grid is used for the target formation only, namely the Ngrayong Formation by using depth marker data and interpolating it so that a good surface is obtained for the top of the formation (top) and the bottom of the formation (base). In forming the surface, it is better to use seismic data to obtain a more detailed structure of the formation (Kiaei et al., 2015; Amanipoor et al., 2013). In this study, seismic data will be used to form a grid based on the horizon of the top of the formation and the bottom of the formation. The last stage of this study is Geostatistical Modeling with Sequential Gaussian Simulation (SGSIM). Modeling is done using the SGSIM method which produces different realizations each time it is run, so to get the most optimum results, a comparison will be made between the data before and after the simulation. Comparing the two data can use the variogram and histogram of the property. The best results are simulation data that have minimal changes in average information, standard deviation and variogram. To compare the variogram of data before and after the simulation, the root mean square error of both equations will be used. The lower the root mean squared error (RMSE), the better the results of the simulation realization. Each property has a different histogram and variogram so that the comparison is made for all properties, namely porosity, permeability, water saturation and facies. Stochastic simulation is a way to generate multiple most likely realizations of properties such as porosity, permeability and fluid saturation, rather than simply estimating the average. Essentially, some noise is added to remove the smoothing effect of kriging (Geoff 2005; Yamamoto 2005). This method provides a better representation of the variation in the targeted property. The two most common forms of simulation used for reservoir modeling applications are Sequential Gaussian Simulation (SGSIM) for continuous variables such as porosity and sequential indicator simulation for categorical variables such as Facies (Geoff 2005; Cormen Thomas et al., 2009).

RESULT AND DISCUSSION

Petrophysical estimation and well correlation

Result of petrophysical parameters (porosity, Sw, and permeability) are calculated based on log data and core data validator. In resume, all petrophysical parameters are shown in Table 2. In general, in Well RON-1, the average porosity value of the Wonocolo Formation is 0.03 with a permeability of 168.01 mD, and Sw 0.14. Then, the average porosity value of the Ngrayong Formation is 0.06 with a permeability of 84.41 mD, and Sw 0.17. Meanwhile, the Tawun Formation has a porosity value of 0.007, a permeability of 162.70 mD, and Sw 0.2. Next well, in Well RON-2, the average porosity value of the Wonocolo Formation is 0.04, permeability of 340.22 mD, and Sw 0.10. Then, the average porosity value of the Ngrayong Formation is 0.04 with a permeability of 20.57 mD, and Sw 0.06. Meanwhile, the Tawun

Table 2. Result of petrophysical estimation.

Well	Formation	Porosity (fraction)	Permeability (mD)	S_w (fraction
RON-1	Ledok	-	-	-
	Wonocolo	0.03	168.01	0.14
	Ngrayong	0.06	84.41	0.17
	Tawun	0.07	162.70	0.20
RON-2	Ledok	-	-	-
	Wonocolo	0.04	340.22	0.10
	Ngrayong	0.04	20.57	0.06
	Tawun	0.04	33.59	0.11
RON-3	Ledok	-	-	-
	Wonocolo	0.04	275.26	0.13
	Ngrayong	0.04	35.28	0.10
	Tawun	0.04	294.69	0.11
LEI-1	Ledok	-	-	-
	Wonocolo	0.10	59.17	0.08
	Ngrayong	0.04	19.70	0.19
	Tawun	0.02	29.79	0.18
LEI-2	Ledok	-	-	-
	Wonocolo	0.04	228.60	0.22
	Ngrayong	0.03	67.94	0.15
	Tawun	0.03	25.11	0.14
LEI-3	Ledok	-	-	-
	Wonocolo	0.03	81.45	0.12
	Ngrayong	0.02	68.29	0.02
	Tawun	0.03	649.34	0.07
LEI-4	Ledok	-	-	-
	Wonocolo	-	-	-
	Ngrayong	-	-	-
	Tawun	0.09	268.70	0.20

Formation has identical porosity value of 0.04, a permeability of 33.59 mD, and Sw 0.11. In Well RON-3, average porosity in Wonocolo Formation is 0.04, permeability 275.26, and Sw 0.13. In Ngrayong Formation, average porosity is 0.04, permeability 35.28, and Sw 0.10. Then, in Tawun Formation, average porosity in Wonocolo Formation is 0.04, permeability 294.69, and Sw 0.11.

In Well LEI-1, average porosity in Wonocolo Formation is 0.10, permeability 59.17, and Sw 0.08. In Ngrayong Formation, average porosity is 0.04, permeability 19.70, and Sw 0.19. Then, in Tawun Formation, average porosity is 0.02, permeability 29.79, and Sw 0.18. In Well LEI-2, average porosity in Wonocolo Formation is 0.02, permeability 228.60, and Sw 0.22. In Ngrayong Formation, average porosity is 0.03, permeability 67.94, and Sw 0.15. Then, in Tawun Formation, average porosity is 0.03, permeability 25.11, and Sw 0.14. Next well, in Well LEI-3, average porosity in Wonocolo Formation is 0.03, permeability 81.45, and Sw 0.12. In Ngrayong Formation, average porosity is 0.02, permeability 68.29, and Sw 0.02. Then, in Tawun Formation, average porosity is 0.03, permeability 649.34, and Sw 0.02. Finally, in Well LEI-4, average porosity in Tawun Formation, average porosity is 0.09, permeability 268.70, and Sw 0.20. The result of petrophysical properties estimation and well correlation are shown in Figure 3 (i.e. porosity estimation), Figure 4 (i.e. water saturation estimation), and Figure 5 (i.e. permeability estimation). Based on petrophysical estimation that resumed in Table 2, Ngrayong Formation is the interest zone in this study.

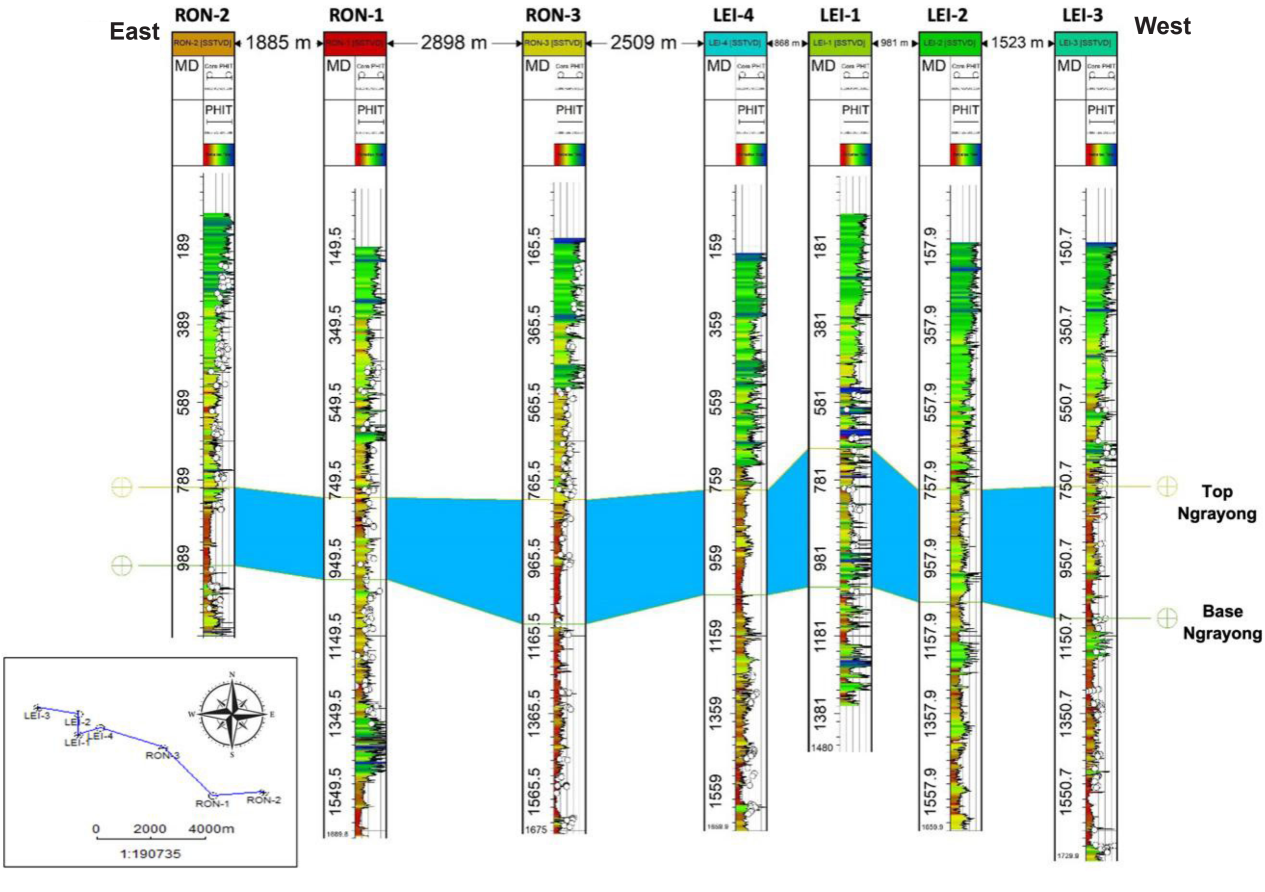

Figure 3. Correlation of well data on porosity value estimation. Ngrayong Formation is the main target zone from the selection results of the interest zone.

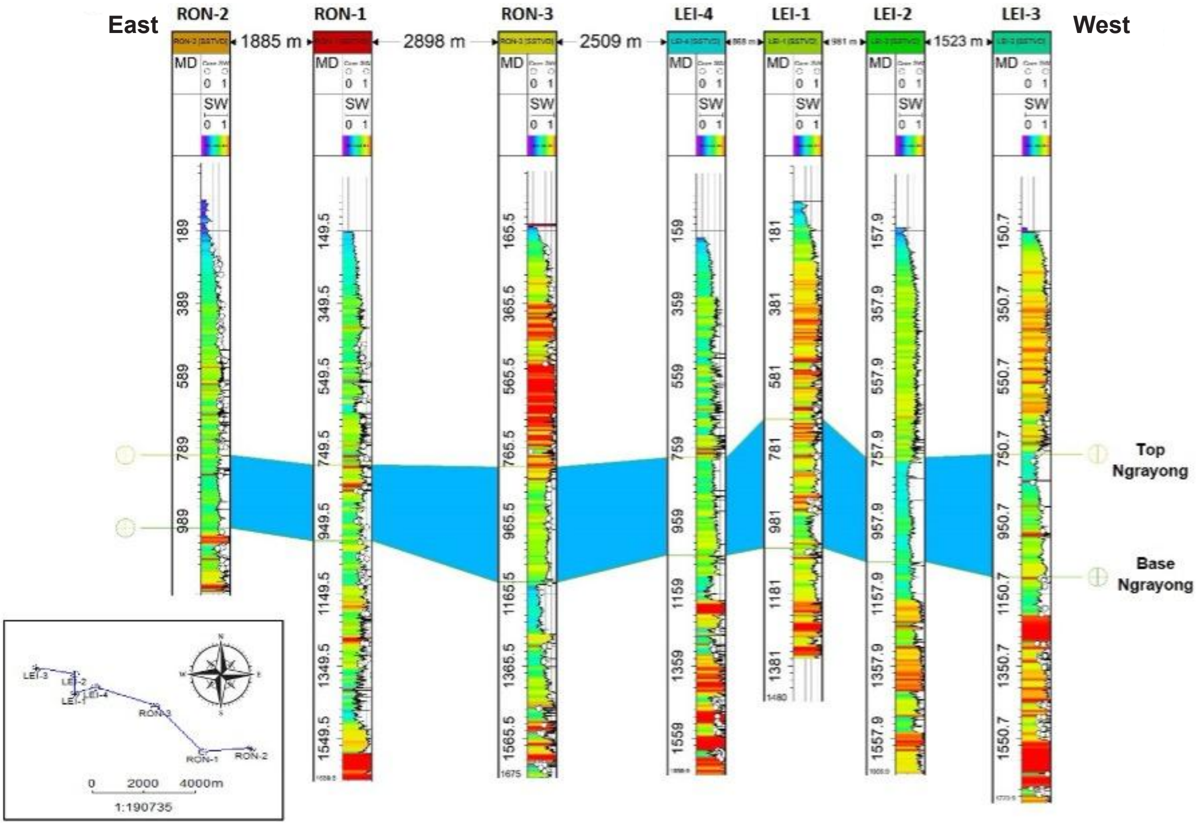

Figure 4. Correlation of well data on water saturation estimation. The Ngrayong Formation is characterized by water saturation values that are on average lower than the rock layers in other formations.

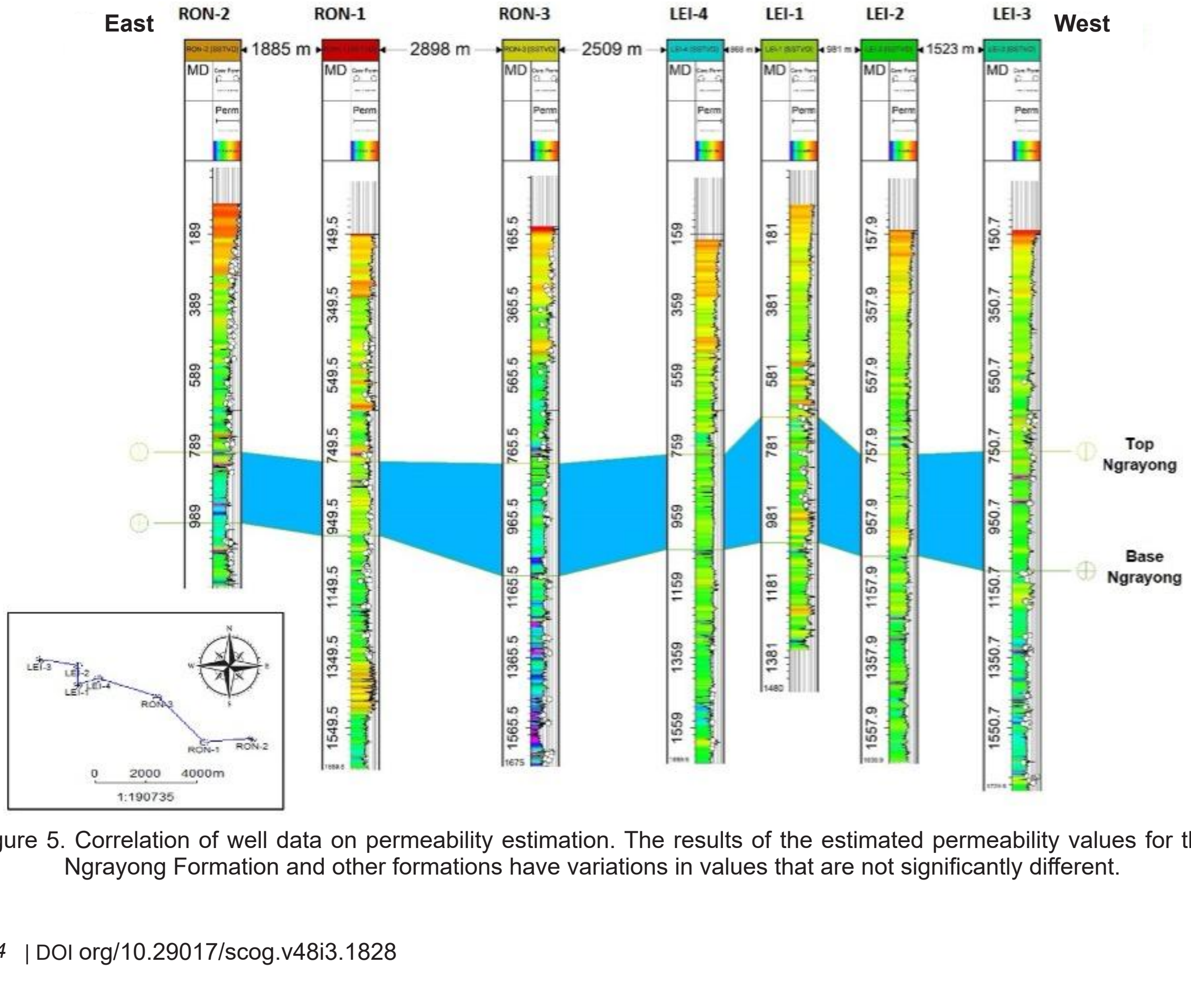

Figure 5. Correlation of well data on permeability estimation. The results of the estimated permeability values for the Ngrayong Formation and other formations have variations in values that are not significantly different.

Facies analysis of Ngrayong Formation

In facies correlation of Ngrayong Formation (Figure 6), from the RON field (i.e. wells RON-1, RON-2 and RON-3) the volume of clay increases towards the southeast. However, all three have matrix intercalations right in the middle of the formation, so it can be estimated that the reservoir in this field is quite large because it is seen from three wells. For the LEI field (e.g. wells LEI-1, LEI-2, LEI-3 and LEI-4) the volume of clay in wells LEI-2 and LEI-3 and LEI-4 is identical, with sandstone intercalations at the top, in contrast to well LEI-1, where matrix dominance occurs below the formation.

Geostatistical model

The initial step in geostatistical modeling, it is necessary to create a grid as a place to define the location of the data and its boundaries. The vertical boundaries of the grid are defined with the help of seismic data. After that, upscaling of the log data will be carried out, then modeling will be Figure out. The seismic data used is intersecting seismic data. Because there is only one well that intersects the seismic data well (well LEI-4 with seismic JNT-6 and JNT-8) and only that well has checkshot data, the well-to-seismic tie is performed on only one well, so that horizon distribution can be done optimally if the seismic data intersects each other. To do horizon picking, it is only based on two markers, namely the Top Ngrayong marker (Ngrayong marker) and Base Ngrayong (Tawun marker). The horizon that has been picked in the form of points is then spatially interpolated to form a 3D surface to get the upper limit of the grid. This is done for both Top Ngrayong and Base Ngrayong. Surface is defined as a surface with a distance between nodes of 50 m X-axis and 50 m Y-axis. The horizontal limit of the surface is 10 nodes from each well from all directions.

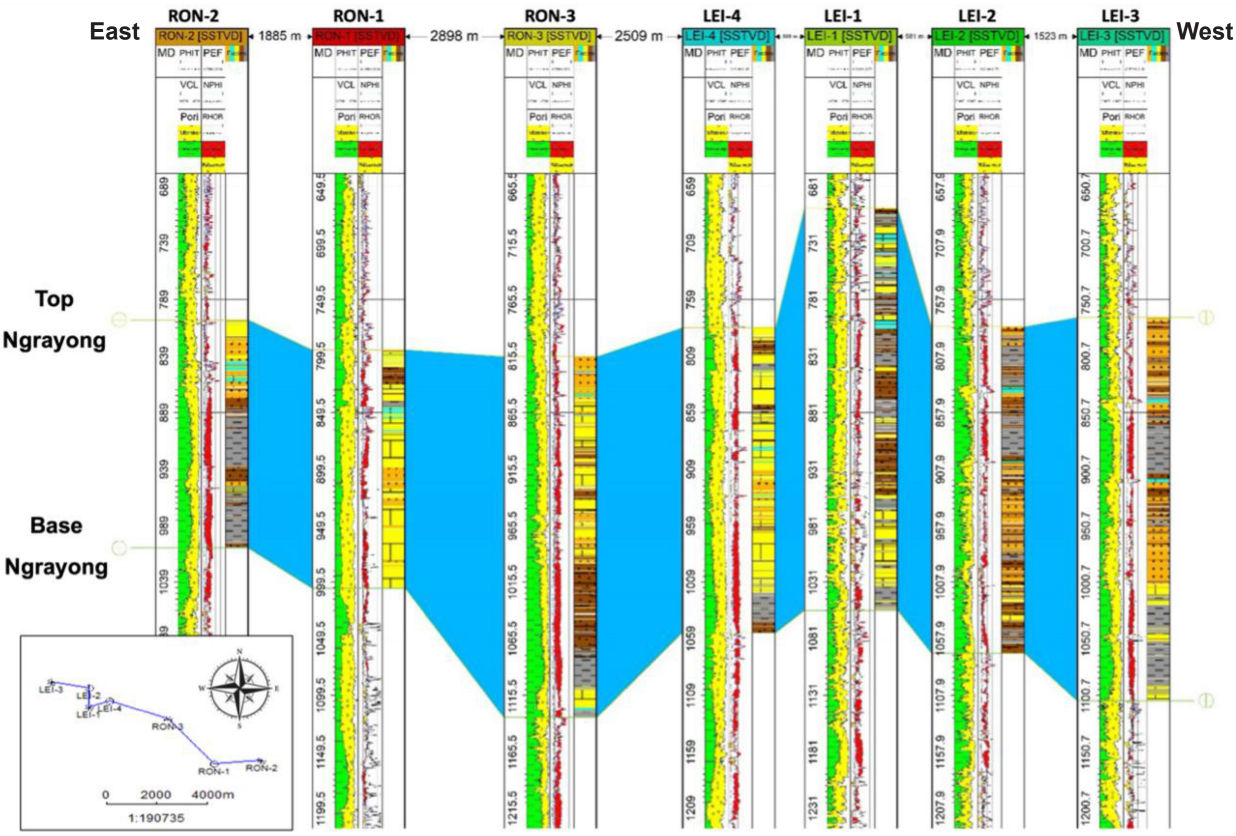

Figure 6. Facies correlation of Ngrayong Formation. In general, the thickness distribution of the Ngrayong Formation thickens in the middle of the observation line.

The layers from Top to Bottom of the Ngrayong Formation are divided based on the analysis of the thinnest zone of interest, so that layering is carried out at every depth fraction of the thickness of the zone of interest and is distributed proportionally between the two surfaces. In this study, based on fractional thickness, the second zone of the LEI-2 well is the thinnest zone against the formation thickness, which is around 0.47%, so that for the final grid it will be distributed every 0.47% vertically to form a total of 211 layers. Based on the number of layers, upscaling of the log data will be performed. However, before upscaling is performed, the data will be transformed into a normal distribution. Log upscaling is a representation of well data if the log has as many samples as the number of layers in the grid interval. Upscaling of the log uses the average of the original log data from the layer interval in the well. Upscaling can reduce computation time because the higher the sample, the modeling computation time requires a lot of resources. The result of geostatistical modeling for porosity correlation is shown in Figure 7, permeability in Figure 8, water saturation in Figure 9, and facies distribution in Figure 10.

Reservoir characterization

Qualitative analysis of well log data and facies interpretation are important initial steps in understanding the characteristics and potential of hydrocarbon reservoirs. After identifying two facies that are potential reservoirs (sandstone and sandstone with carbonate intercalation) based on the data, the next step is to perform a slice based on the cutoff values that have been set for porosity, permeability, and facies type. The cut-off value that has been set for porosity is accepted if it is above 0.1 or 10%, for permeability it is accepted if it is above 5 mD, and for facies type it is accepted if it is sandstone or sandstone with carbonate intercalation (Figure 7 and Figure 8). The result of this slice is the distribution of reservoirs with the property displayed being water saturation. This means that we can see the distribution of water saturation in the reservoir based on the properties that have been fulfilled (porosity > 10%, permeability > 5 mD, and the facies type is sandstone or carbonate sandstone).

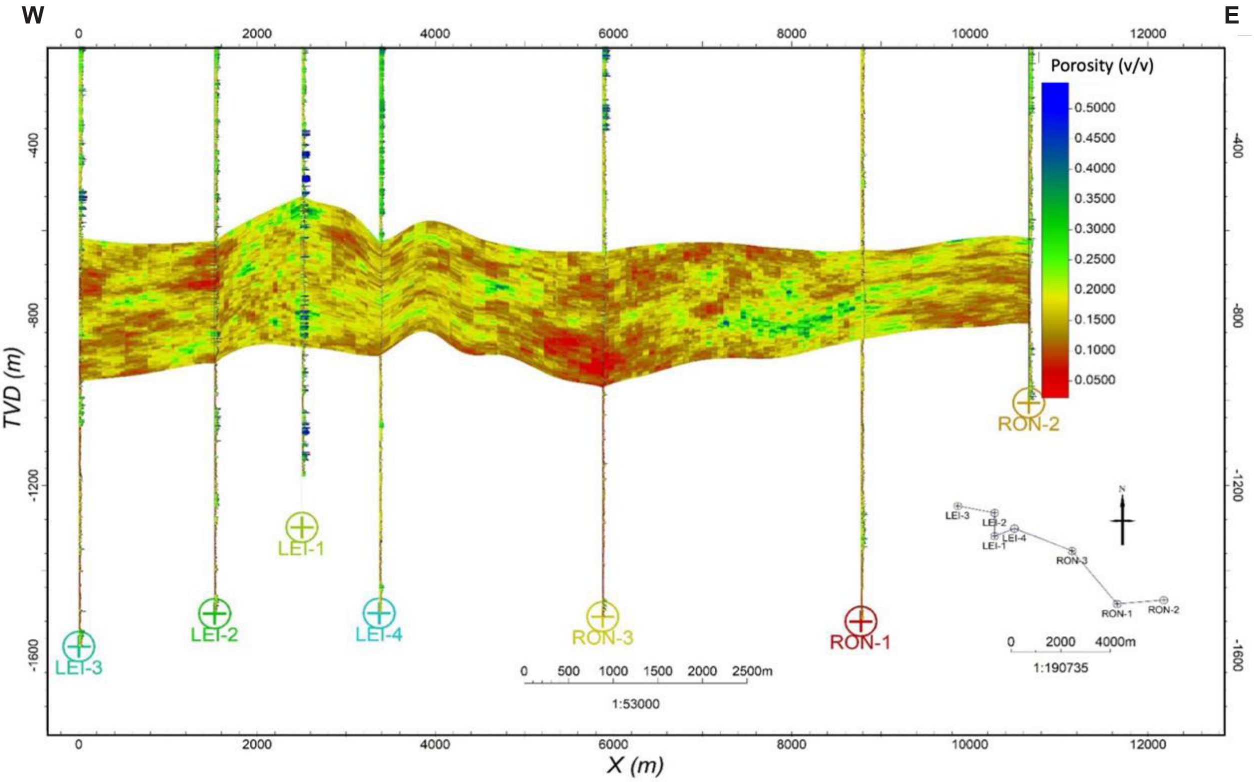

Figure 7. Porosity intersection of geostatistical modeling in Ngrayong Formation. The distribution of porosity values in the Well RON-1 and Well LEI-1 has a relatively higher value than in locations near other wells.

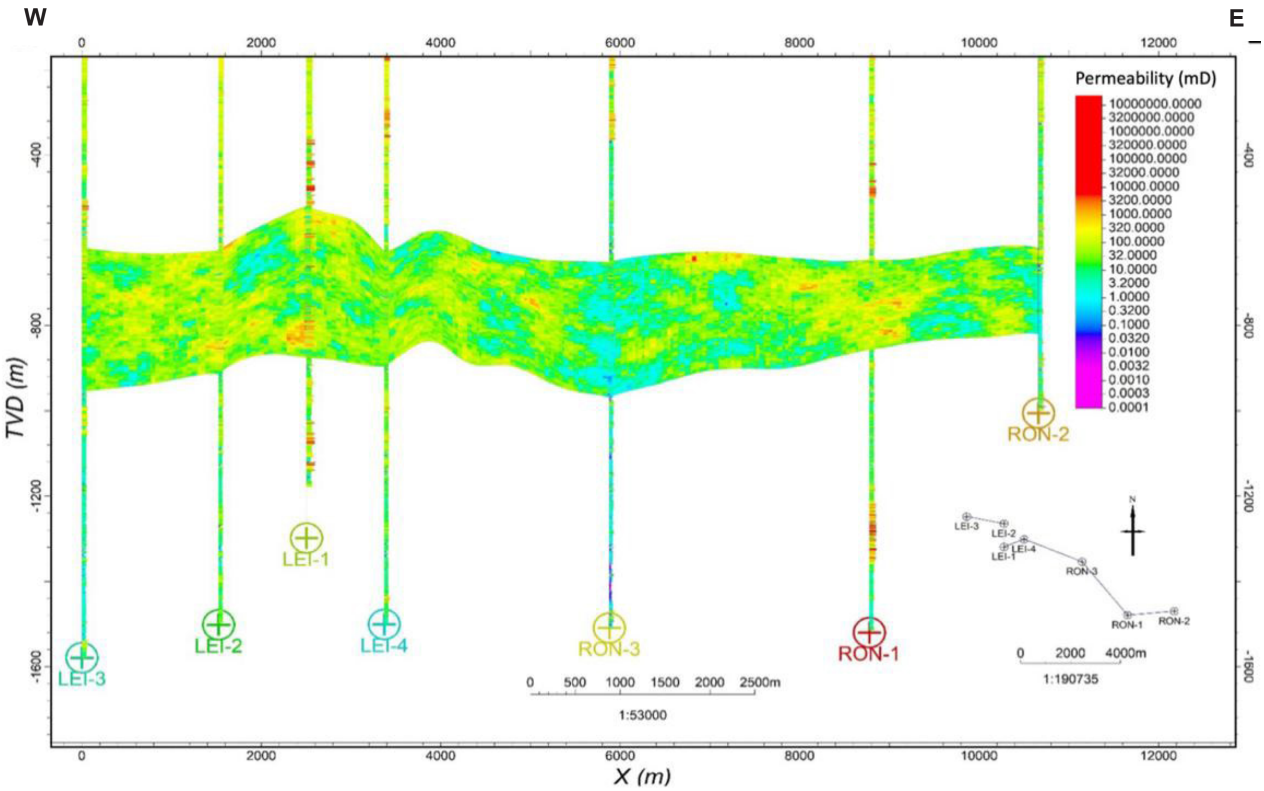

Figure 8. Permeability intersection of geostatistical modeling in Ngrayong Formation. Similar to the distribution of porosity values, the permeability near Well RON-1 and Well LEI-1 has a higher value, indicating that this location is very good as an exploitation well.

Based on the intersection analysis of each well (Figure 9), there is a thick sandstone zone at a depth of about 700 meters in the LEI-4 well with continuity to the LE-2 well. In this section, the water saturation value is in the range of 0.8 (yellow) to 0.4 (blue). In this section, the continuity is also not too thick because there could be an intercalation between carbonate rocks in the upper part. The disadvantage of this section is that this section is also cut off at the LEI-2 well and is not visible until the RON-3 well, where there is a sandstone reservoir with a relatively high saturation value from the west and low on the east. It is possible that these two parts are not connected because they are cut off at the top of the LEI-1 and LEI-4 wells which appear to be dominated by carbonate sandstone. The second zone is seen at a depth of about 800 meters from the LEI-3 well which extends to the middle between RON-1 and RON-2. This continuity thins out in the northwest of the LEI-1 and RON-3 wells. The water saturation value is high in the LEI-3 well and low in the LEI-2 well, high in the LEI-1 well and low in the LEI-4 well. Then, in the northwest of the RON-1 well there is a thickening of sandstone which has a water saturation value of 0.6 to 0.8 (green to yellow) (Figure 9). To the east of the RON-1 well there is a high-water saturation value.

In Figure 10, for sandstone with carbonate intercalation reservoirs, it is seen that these facies are much more dominant than sandstone facies. Analysis shows that the LEI-4 well shows the most reservoir dominance of all the wells in the area, with dominance covering the entire depth range of the well. Gradually, the reservoir dominance tends to thin out as it moves towards the LEI-1 well, especially in the upper part of the reservoir. However, the lower part of the reservoir remains relatively constant in thickness but has a lower water saturation value compared to the LEI-4 well. In addition, the lower part of the reservoir can also be identified up to around the LEI-2 well, but its existence becomes thinner as it approaches the LEI-3 well. At the top of the LEI-4 well reservoir, there is a fairly thick continuity that leads to the RON-3 well but pours about 400 meters before reaching the RON-3 well location. This continuity likely indicates a significant hydrocarbon migration path in geological history.

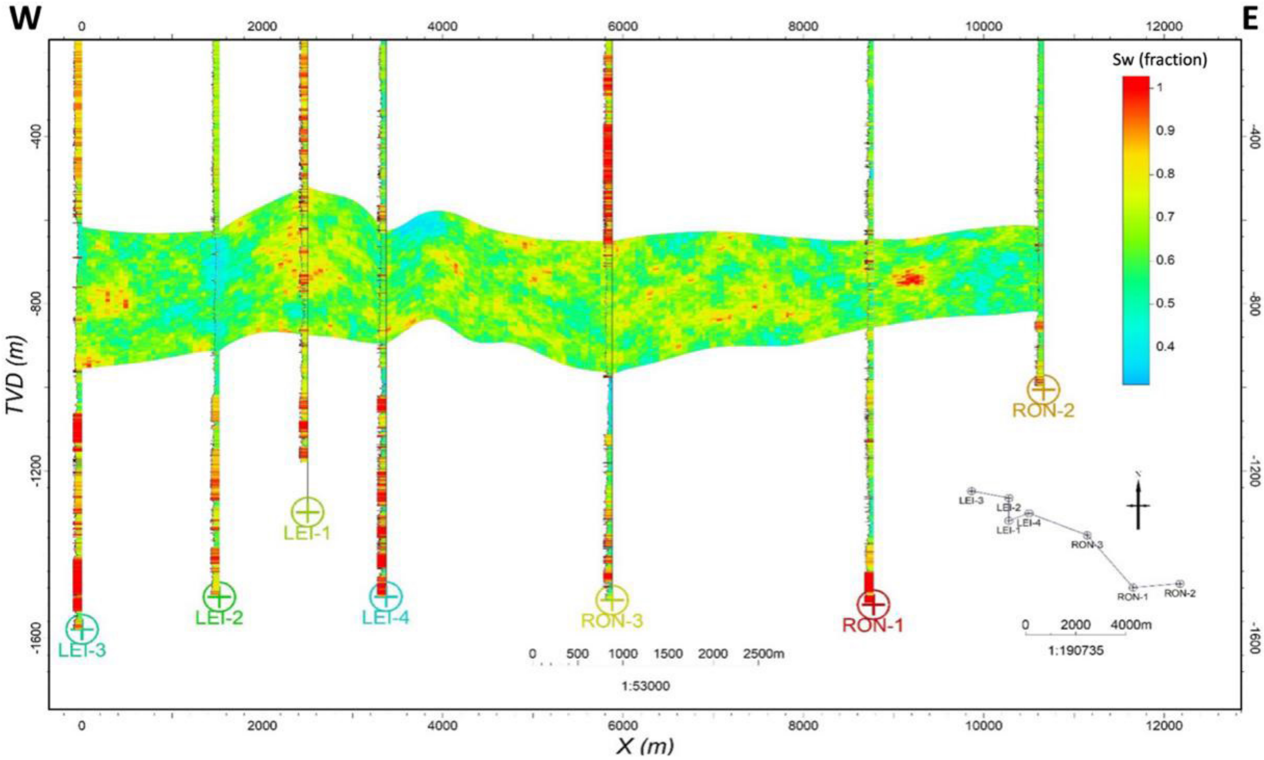

Figure 9. Water saturation intersection of geostatistical modeling in Ngrayong Formation. In the high porosity (Figure 7) and permeability (Figure 8) areas (around Well RON-1 and LEI-1), there is a high distribution of water saturation, indicating that the fluid flow around the two wells is more dynamic.

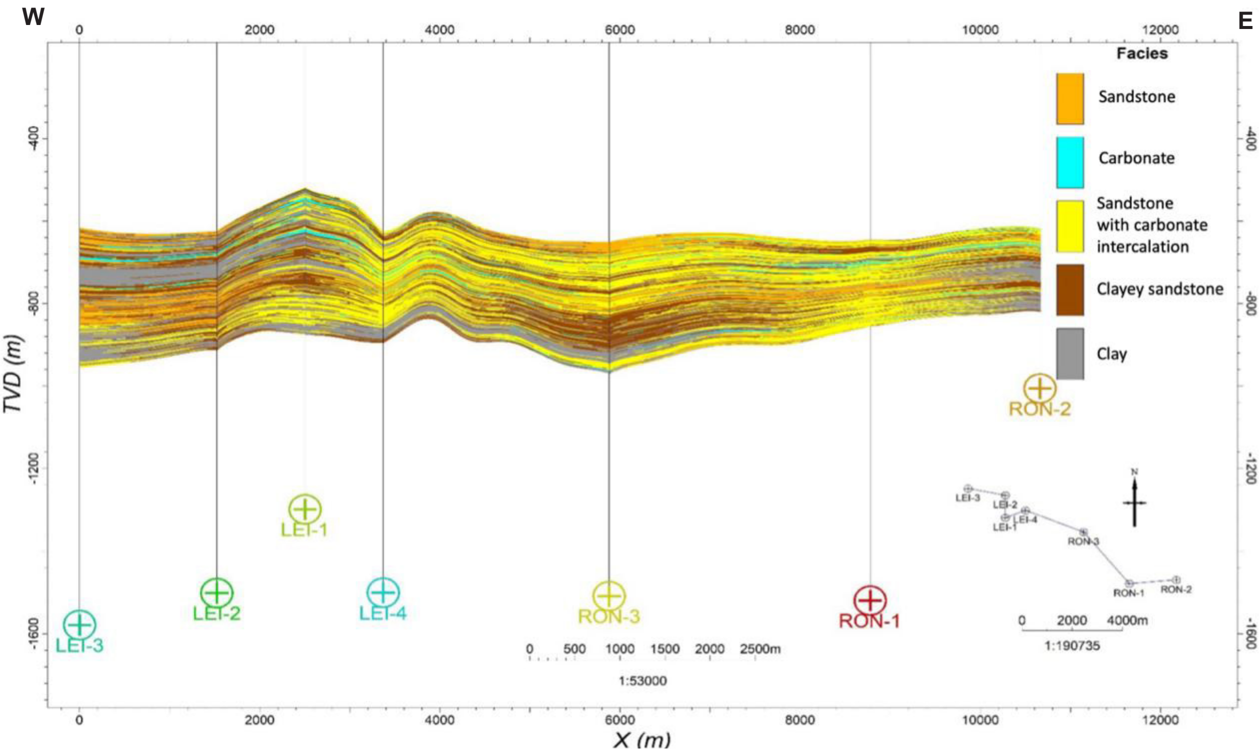

Figure 10. Facies intersection of geostatistical modeling in Ngrayong Formation. From the results of the facies cross-section, the Ngrayong Formation is dominated by the distribution of sandstone lithology with carbonate intercalation.

In addition, this continuity tends to thin out when it reaches the RON-1 well, and finally ends at the RON-2 well. In the RON-1 well, the reservoir is also dominated by carbonate sandstone facies both at the top and bottom of the reservoir. However, at the bottom of the reservoir, there is no continuity, and the reservoir connection is broken both towards the RON-3 well and towards the RON-2 well.

Finally, the results of geostatistical modeling of physical parameters (porosity, water saturation, permeability) and facies in the Ngrayong Formation provide a comprehensive picture of the characteristics of the dominant sandstone layer with carbonate interclaction which is a prospective location for hydrocarbon exploration and field development to increase national oil and gas production.

CONCLUSION

Reservoir characterization using petrophysical parameters is a routine analysis in the oil and gas industry. However, petrophysical parameters derived from well data are limited in lateral resolution. To address this limitation, this study integrates well and seismic data, supported by geostatistical analysis using Sequential Gaussian Simulation (SGSIM), to improve the accuracy of reservoir characterization.

From the results obtained in this study, several conclusions were drawn: (i) Estimation of porosity, permeability, water saturation and facies values from wells for both the "RON" and "LEI" fields can be done using well data with low errors, and it can be seen that the Ngrayong Formation is dominated by sandstone and carbonate sandstone facies which are potential reservoirs; (ii) Distribution or interpolation of porosity, permeability, water saturation and facies properties can be done using the Sequential Gaussian Simulation method by considering the characteristics of the data before and after the simulation to validate the results of the simulation realization; and (iii) Sandstone reservoirs in the research area are predominantly located in the LEI-2 and LEI-3 well areas with a water saturation range of 0.3 to 0.8 and slightly 1. Moreover, sandstone with carbonate intercalation reservoir is more dominant around the LEI-4 and RON-1 wells but are relatively lower in the LEI-2 and LEI-3 and RON-2 well areas. The water saturation value is relatively low, with a range of 0.4 to 0.8 but has a water saturation value of 1 to the east of the RON-1 well.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
GR	Gamma Ray, API	
API	American Petroleum Institute	
SGSIM	Sequential Gaussian Simulation	
NPHI	Neutron Porosity	
RHOB	Bulk Density, gram/cc	
Vclay	Volume of Clay, fraction	
Sw	Water Saturation, fraction	
Rwapp	Water Resistivity, Ohm.m	
RMSE	Root Mean Squared Error	
mD	Mili Darcy	

REFERENCES

Aguilera, R. (2006). Sandstone vs. carbonate petroleum reservoirs: A global perspective on porosity-depth and porosity-permeability relationships: Discussion. AAPG Bulletin, 90(5), 807-810. https://doi.org/10.1306/11070505163

Airlangga, F., Handoyo, H., Irawati, S. M., & Wibowo, A. S. (2024). Karakterisasi Batuan Induk Hidrokarbon dan Reservoar Nonkonvensional di Cekungan Jawa Timur Bagian Utara. Buletin Sumber Daya Geologi, 19(3), 173-185. https://10.47599/bsdg.v19i3.435.

Amanipoor, H., Ghafoori, M., & Lashkaripour, G. R. (2013). The application of géostatistical methods to prepare the 3D petrophysical model of oil reservoir. Open Journal of Geology, 3(1), 7-18.

https://10.4236/ojg.2013.31002.

Bemmelen, R. W. (1949). General Geology of Indonesia and Adjacent Archipelagoes. Goverment Printing.

Bintarto, 2020. Pemetaan Singkapan Di Indonesia Berdasarkan Pada Karakteristik Reservoar Migas Studi Kasus Cekungan Jawa Timur Utara.Yogyakarta: Fakultas Teknologi Mineral, Universitas Pembangunan Nasional "Veteran".

Bransden, P. J. E., & Matthews, S. J. (1992). Structural and stratigraphic evolution of the East Java Sea, Indonesia.

Cormen Thomas, H., Leiserson Charles, E., Rivest Ronald, L., & Stein, C. (2009). Introduction to Algorithms. MIT Press.

Criollo, D., Fam, M., Hernández, Y. F., López, A. M., & Zafra, C. (2022, December). Practical Methodology for Characterizing Unconventional Plays using Conventional Logs, Cores and Cuttings Analysis: A Case Study. In Fourth EAGE Workshop on Unconventional Resources (Vol. 2022, No. 1, pp. 1-5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.202289002.

Ellis, D. (2003). Formation porosity estimation from density logs. Petrophysics-The SPWLA Journal of Formation Evaluation and Reservoir Description, 44(05).

Farfour, M., Foster, D. J., & Gaci, S. (2023, October). A New Quick Look Interpretation for Fluid Detection: Theory and Application. In ARMA/DGS/SEG International Geomechanics Symposium (pp. ARMA-IGS). ARMA. https://10.56952/IGS-2023-0077

Geoff, B. (2005). Kriging. Lecture Notes C&PE.

Grana, D., & Della Rossa, E. (2010). Probabilistic Petrophysical-Properties Estimation Integrating Statistical Rock Physics With Seismic Inversion. Geophysics, 75(3), O21–O37. https://doi.org/10.1190/1.3386676

Handoyo, H., Ronlei, B. C., Sigalingging, A. S., Avseth, P., Triyana, E., Akin, Ö., ... & Carbonell, R. (2024). Characterization of Carbonate Reservoir Potential in Salawati Basin, West Papua: Analysis of Seismic Direct Hydrocarbon Indicator (DHI), Seismic Attributes, and Seismic Spectrum Decomposition. Indonesian Journal on Geoscience, 11(2), 173-188. https://doi.org/10.17014/ijog.11.2.173-188.

Handoyo, H., Samuel, B., & Samosir, S. (2025). Aplikasi Teknik Poro-Acoustic Impedance untuk Meningkatkan Korelasi Pengikatan Data Sumur dan Penampang Seismik. Jurnal Pendidikan, Sains, Geologi, dan Geofisika (GeoScienceEd Journal), 6(1), 335-344. https://doi.org/10.29303/goescienceed.v6i1.519.

Horsfall, O. I., Omubo-Pepple, V. B., & Tamunobereton-ari, I. (2013). Correlation analysis between sonic and density logs for porosity determination in the south-eastern part of the Niger Delta Basin of Nigeria. Asian Journal of Science and Technology, 4(1), 1-5.

Irawan, D., & Rakha, M. (2019). Integrated Initial Water Saturation Modelling. Scientific Contributions Oil and Gas, 42(3), 95-107. https://doi.org/10.29017/SCOG.42.3.396.

Kiaei, H., Sharghi, Y., Ilkhchi, A. K., & Naderi, M. (2015). 3D modeling of reservoir electrofacies using integration clustering and geostatistic method in central field of Persian Gulf. Journal of Petroleum Science and Engineering, 135, 152-160. https://10.1016/j.petrol.2015.08.019.

Koesoemadinata, R. P. (1978). Sedimentary framework of Tertiary coal basins of Indonesia. In Regional conference on geology and mineral resources of Southeast Asia. 3 (pp. 621-629).

Laalam, A., Ouadi, H., Merzoug, A., Chemmakh, A., Boualam, A., Djezzar, S., & Djoudi, M. (2022). Statistical Analysis of The Petrophysical Properties of the Bakken Petroleum System. In SPE/AAPG/SEG Unconventional Resources Technology Conference. https://10.15530/urtec-2022-3725863.

Lai, J., Wang, G., Fan, Q., Pang, X., Li, H., Zhao, F., ... & Wang, Q. (2022). Geophysical well-log evaluation in the era of unconventional hydrocarbon resources: A review on current status and prospects. Surveys in Geophysics, 43(3), 913-957. https://10.1007/s10712-022-09705-4

Lunt, P. (2019). The origin of the East Java Sea basins deduced from sequence stratigraphy. Marine and Petroleum Geology, 105, 17-31. https://doi.org/10.1016/j.marpetgeo.2019.03.038.

Nadeau, P. H., & Ehrenberg, S. N. (2006). Sandstone vs. carbonate petroleum reservoirs: A global perspective on porosity-depth and porosity-permeability relationships: Reply. AAPG bulletin, 90(5), 811-813. https://10.1306/11070505163.

Noble, R. A., Pratomo, K. H., Nugrahanto, K., Ibrahim, A. M., Prasetya, I., Mujahidin, N., ... & Howes, J. V. C. (1997). Petroleum systems of northwest Java, Indonesia.

Pan, W., Torres-Verdín, C., Duncan, I. J., & Pyrcz, M. J. (2023). Improving Multiwell Petrophysical Interpretation From Well Logs Via Machine Learning And Statistical Models. Geophysics, 88(2), D159–D175. https://doi.org/10.1190/geo2022-0151.1.

Panjaitan, S., 2010. Prospek Migas pada Cekungan Jawa Timur dengan Pengamatan Metode Gayaberat. Buletin Sumber Daya Geologi, 5(3), h.168-181. https://10.47599/bsdg.v5i3.266.

Petunin, V. V., Yin, X., & Tutuncu, A. N. (2011, November). Porosity and permeability changes in sandstones and carbonates under stress and their correlation to rock texture. In SPE Canada Unconventional Resources Conference (pp. SPE-147401). SPE. https://10.2118/147401-MS.

Pringgoprawiro, H. (1983). Biostratigraphy and Paleogeography of North East Java Basin: A New Approach. Institute of Technology Bandung.

Ran, W., Luan, X., Lu, Y., Wei, X., Zhang, H., Wang, K., ... & Islam, M. S. (2020). Seismic characteristics and strontium isotope ages of the Middle Miocene Ngrayong Formation in the Madura Strait Basin: Implications for the paleogeographic reconstruction of East Java. Journal of Asian Earth Sciences, 190, 104109. https://10.1016/j.jseaes.2019.104109.

Ravalec-Dupin, L., Enchery, G., Baroni, A., & Da Veiga, S. (2011). Preselection of reservoir models from a geostatistics-based petrophysical seismic inversion. SPE Reservoir Evaluation & Engineering, 14(05), 612-620. https://10.2118/131310-PA.

Schneider, F. N., & Owens, W. W. (1970). Sandstone and carbonate two-and three-phase relative permeability characteristics. Society of Petroleum Engineers Journal, 10(01), 75-84.

Shang, B. Z., Hamman, J. G., Chen, H. L., & Caldwell, D. H. (2003, October). A model to correlate permeability with efficient porosity and irreducible water saturation. In SPE Annual Technical Conference and Exhibition? (pp. SPE-84303). SPE. https:// 10.2118/84303-MS.

Sharaf, E., Simo, J. T., Carroll, A. R., & Shields, M. (2005). Stratigraphic evolution of Oligocene–Miocene carbonates and siliciclastics, East Java basin, Indonesia. AAPG bulletin, 89(6), 799-819. https://10.1306/01040504054.

Smyth, H., Hall, R., Hamilton, J., & Kinny, P. (2005). East Java: Cenozoic Basins, Volcanoes and Ancient Basement. Proceedings of the Indonesian Petroleum Association, 30th Annual IPA Annual Convention, 251–266. https://

Soeka, S., Suminta, S., & Siswoyo, S. (1982). The Miocene/Pliocene Boundary In The North East Java Basin, Indonesia. Scientific Contributions Oil and Gas, 5(2), 3-15. https://doi.org/10.29017/SCOG.5.2.906.

Torskaya, T., Jin, G., & Torres-Verdin, C. (2007, November). Pore-level analysis of the relationship between porosity, irreducible water saturation, and permeability of clastic rocks. In SPE Annual Technical Conference and Exhibition? (pp. SPE-109878). SPE. https://10.2118/109878-MS.

Yamamoto, J. K. (2005). Correcting the Smoothing Effect of Ordinary Kriging Estimates. Mathematical Geology, 37, 69–94. https://10.1007/s11004-005-8748-7.

Yang, B., & Liu, Z. (2019). Research on Adaptive Petrophysical Modeling Based On Machine Learning And Multivariate Geostatistics. 81st EAGE Conference and Exhibition 2019, 2019(2019), 1–5. https://10.3997/2214-4609.201900966.

Zhu, L. Q., Sun, J., Zhou, X. Q., Li, Q. P., Fan, Q., Wu, S. L., & Wu, S. G. (2023). Well logging evaluation of fine-grained hydrate-bearing sediment reservoirs: Considering the effect of clay content. Petroleum Science, 20(2), 879-892. https:// 10.1016/j.petsci.2022.09.018.