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Analysis of the relationship between porosity and permeability in reservoir modeling using the petrophysical rock type approach

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Abstract

The carbonate reservoir is one of the reservoir characters found in hydrocarbon fields in Indonesia. Carbonate reservoirs have complex porosity and permeability relationships. So it is necessary to do a special reservoir character that is different from the siliciclastic reservoir. Efforts that can be made to assist the development of this hydrocarbon field are to analyze the reservoir character in more detail using the petrophysical rock type (PRT) approach. This approach is used by combining geological elements such as the depositional environment, the petrophysical properties of the rock, as well as the fluid flow in it which is reflected by capillary pressure and water saturation. Modeling with this method is expected to be a method that can increase hydrocarbon production optimally in Xena Field. The object of research from Xena Field is Zone A2 which is included in the Parigi Formation. The Parigi Formation is one of the main hydrocarbon-producing reservoirs. The data used in this study are routine core analysis (RCAL) rock data on JLB-07, JLB-08, JLB-02, JLB-23 wells, wire log data (gamma-ray log, resistivity log, density log, neutron log) of 30 wells, and 2D seismic data. The depositional facies are divided into 2 facies, namely the margin reef platform facies and the interior platform facies. Identification of rock type (RT) using the flow zone indicator (FZI) method. The rock type in this field can be divided into 4 rock types, namely RT 1, RT 2, RT 3, RT 4 with RT 1 being able to drain the best fluid and RT 4 to drain the worst fluid. Reservoir property modeling is controlled by facies and rock type (RT) models. The margin reef platform facies are associated with RT 1 and RT 2. The interior platform facies are associated with RT 2 and RT 3.

1. Introduction

Exploration activities require a basic study and research to determine areas that have hydrocarbon potential and increase oil and gas production in an area. Constraints that occur with producers, oil, and natural gas production are the decreasing production results so that a method is needed to increase the production of oil and gas. Characterization of carbonate reservoirs with high heterogeneity is more complex than siliciclastic reservoirs because the pore system in the carbonate reservoir is the effect of depositional facies and complex diagenetic processes. Therefore, understanding the geological conditions and the description of the three-dimensional model of this carbonate reservoir and the prediction of the fluid flow mechanism in it requires depositional facies analysis and rock typing analysis through more detailed petrophysical methods so that it is expected to provide better reservoir rock quality results. Geologically, the research area is included in the North West Java Basin. The research object is in the Late Miocene Parigi Formation which is a reservoir rock in Xena Field. The purpose of this study was to examine the characterization of the carbonate reservoir of the Parigi Formation which was carried out using the rock typing approach. The purpose of this study was to identify rock typing on carbonate reservoir rocks based on rock properties, to know the relationship between rock typing and depositional facies, to build a three-dimensional model, and to determine the distribution of reservoir properties A2 of the Parigi Formation in Xena Field.

2. Data and Methodology

The research methodology used in this study includes geological analysis, petrophysical analysis, and static reservoir modeling. This stage includes data collection in the form of primary data and secondary data. Primary data is in the form of well log data. Secondary data is in the form of rock core description data, base map data (Figure 1), and data from the 3D seismic interpretation which are used to create a depth structure map and literature study data. Limestone reservoir modeling in Xena Field is carried out to produce continuity and geometric distribution of reservoir in reservoir A2. Modeling using modeling software assistance approach.

Core rock data analysis includes texture, structure, mineral composition, and determination of rock names obtained from the company in the form of RCAL (Routine Core Analysis) value data so that the vertical deposition pattern can be seen. The depositional environment analysis was carried out based on core rock reviews and well log analysis. The petrophysical analysis was performed on all available wells to obtain porosity and water saturation values. In addition to the rock properties obtained, petrophysical analysis can produce the composition of the material contained in each interval. Rock Type analysis performed laboratory tests in the form of porosity and permeability used to perform rock type analysis. The Hydraulic Flow Unit (HFU) method, porosity, and permeability properties from the Routine Core Analysis are used as parameters for the Reservoir Quality Index (RQI) and Flow Zone Indicator (FZI). Static Reservoir Modeling lies in processing 3D seismic data to determine the horizon based on the results of good ties and depth structure maps.

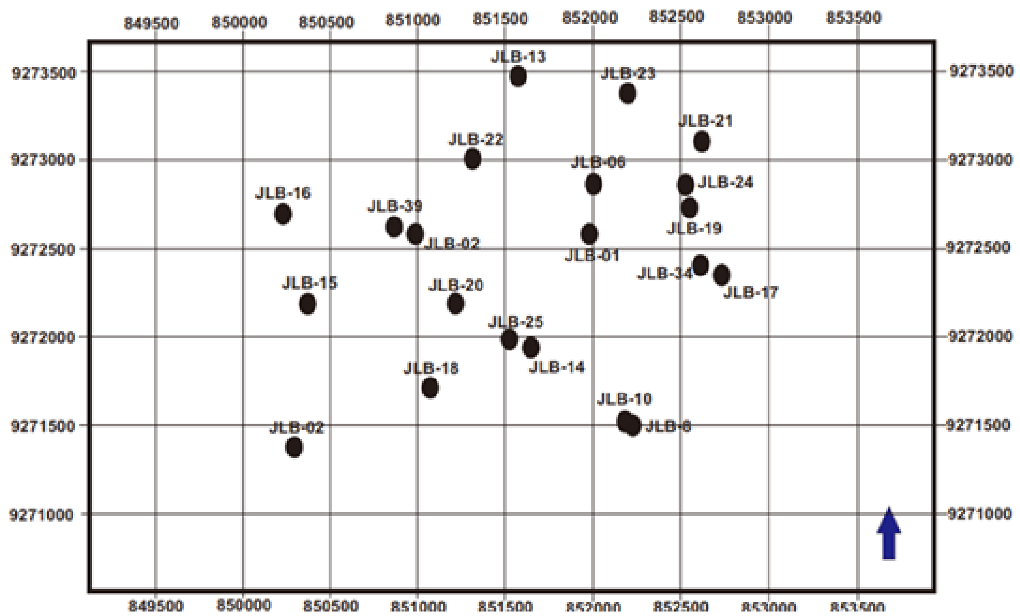

Figure 1. Basemap of Xena Field

2.1. Empirical of Petrophysical analysis

The petrophysical analysis aims to obtain the quantitative distribution of reservoir properties. This analysis uses a mathematical equation to obtain petrophysical parameter data so that the character of the formation can be known. In this study, the petrophysical analysis was carried out on thirty wells to obtain effective porosity values. The data used well log data in the form of gamma-ray log curve data, density log, and neutron log.

The parameters for calculating the porosity of the A2 carbonate reservoir using a combination of density logs and neutron logs (Figure 2). Porosity data from core rock is found in wells Jlb-23, Jlb-08, Jlb-07, Jlb-02. The results of the calibration between the porosity of the log and the porosity of the core rock can be seen in Figure 2. The calculation of porosity is divided into two stages, namely the calculation of the porosity density and the total porosity. The formula for calculating porosity with a combined log density and log neutrons according to [1], is as follows:

$Ø_{N-D} = \sqrt{(Ø_D^2 + Ø_N^2 / 2)}$ ………………………………………………...(1)

The value of density porosity is obtained from the following equation:

$Ø_D = (\rho_{bulk} – \rho_{ma}) / (\rho_{ma} – \rho_f)$ ……………………………………………...(2)

Then the density porosity is corrected for the effect of shale with the following equation:

$Ø_D$ correction = $Ø_D – (V_{sh} \times Ø_{Dsh})$ ……………………………………...(3)

The corrected neutron porosity value for the effect of shale is obtained from the following equation:

$Ø_N$ correction = $Ø_N – (V_{sh} \times Ø_{Nsh})$ ……………………………………… (4)

The calculation of effective porosity is obtained from the following equation:

$Ø_{effektive} = \sqrt{(Ø_{N\text{-}correctioni}^2 + Ø_{D\text{-}correction}^2)} / 2$ ..……...……..………….........(5)

Then the total porosity can be calculated from the following equation:

$Ø_{Total} = (Ø_D + Ø_N) / 2$ ..……………………………………………………(6)

Formula description:

ρma = Density of rock matrix, for limestone = 2,71
ρb = Rock bulk density (gr / cc), from the density log
ρf = Fluid density (gr/cc), fresh water =1; salt water =1,1
ØD = Porosity of density (%)
ØN = Porosity of neutron
Vsh = shale Volume

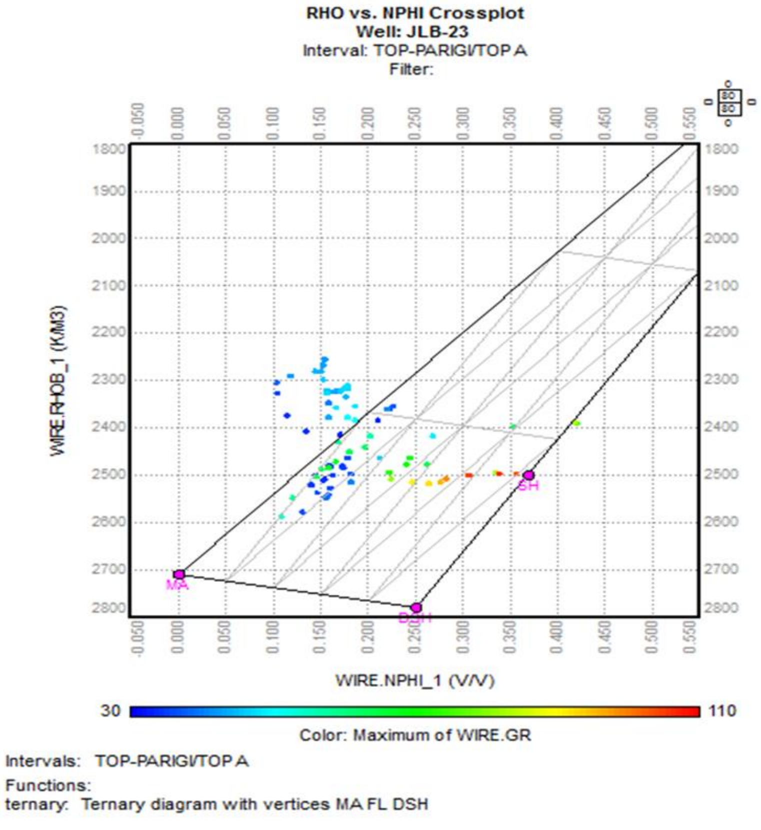

Figure 2. Cross plot of density logs and neutron logs on well J23.

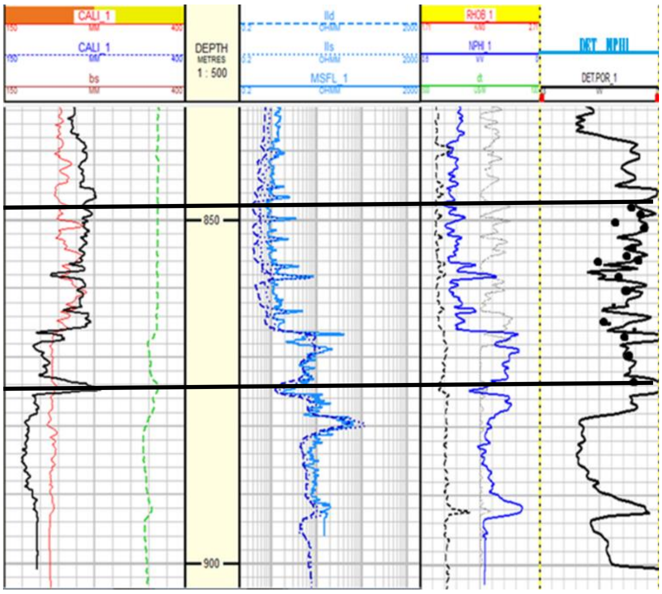

Figure 3. Calibrate core rock porosity values against calculations reservoir porosity A2.

2.2. Seismic multi-attribute method
Rock type is a method for identifying fluid flow units in the reservoir body by combining the petrophysical properties of rock [2]. The concept of petrophysical rock type is defined as a unit of rock that is deposited under the same conditions and undergoes the same diagenetic process resulting in a certain porosity and permeability relationship [3]. According to [4] rock type grouping from core rock descriptions is based on similarity in composition, texture, sedimentary structure, and stratigraphic sequences that are affected by the depositional environment.

2.2.1. Seismic multi-attribute method
Identification of the rock types in the reservoir using the Reservoir Quality Index and Flow Zone Indicator parameters [5]. RQI and FZI have the following equation functions:

$$RQI = 0{,}0314 \times \sqrt{\frac{k}{\emptyset}} \quad \ldots\ldots (7)$$

$$FZI = \frac{RQI}{\emptyset z} \quad \ldots\ldots (8)$$

$$\emptyset_z = \frac{\emptyset}{1-\emptyset} \quad \ldots\ldots (9)$$

Formula description:
K = Permeability (mD)
Ø = Porosity (%)
$\emptyset_z$ = *Normalized* porosity
RQI = *Reservoir quality index (micron)*
FZI = *Flow zone indicator(micron)*

3. Regional Geology
Xena Field carbonate reservoirs are formed on top of the horst and graben structures. The Parigi Formation was deposited in the Late Miocene based on studies of planktonic foraminifera [6],[7]. The formation in this field is dominated by limestone deposits with dolomite inserts, sandstone limestone, and limestone clay in shallow marine environments [8]. The orientation of the basin is west-east so that the thinning of the Parigi Formation to the south will be obtained, namely the Bogor zone [9].

Xena Field is located in the North West Java Basin bounded by the Sunda Shelf in the north, the Perlipatan - Bogor route in the south, the lifting area of Karimun Jawa in the east, and the Seribu Island shelf in the west [6]. The North West Java Basin is one of the Back-Arc Basin which is affected by the block faulting system that traverses North-South [7]. The North-South trending fault divides the basin into grabens or several sub-basins, namely Jatibarang Sub-Basin (research area), Ciputat Sub-Basin, Kepuh Sub-Basin, Bungur Sand Sub-Basin [10]. This sub-basin was filled with sediment and formed in the southern part of the Sunda shelf during the Tertiary age. Besides, there are several basement heights, such as Tinggian Arjawinangun, Tinggi Pamanukan, Tinggian Kandanghaur, Tinggian Rengasdengklok, and Tinggian Tangerang. Based on the stratigraphy and structural patterns, as well as its location in the bow pattern of subduction from time to time, it turns out that the West Java basin has experienced several sedimentations and tectonic phases from the Eocene to the present [11].

3.1. Regional Tectonic

The tectonic history of the North West Java Basin was formed as a result of tectonic compression and pull generated by the northward pressure force of the Indo-Australian Plate [12], [7] and rotation from Kalimantan, to form a trench-like structure whose two edges are bounded by normal faults or cracks along the southern boundary of The Sunda Shelf during the Eocene to Oligocene [13].

The offshore bedrock structural patterns formed include the Sunda Asri Basin, the Thousand Platforms, the Arjuna Basin, the Vera Basin, the Eastern Shelf, the Billiton Basin, the Karimunjawa Arc, and Bawean. The sea-level changes produce the heterogeneity of the sediment quality [14]. Some evidence suggests a combination of symmetrical curves and fault structures in the early tectonics of the formation of the basin in the North West Java area. The faults that are formed in the basin are faults trending northwest-southeast, north and northeast which form a basin in the area and an inversion structure occurs in it, and right shear faults that are east-northeast trending, while the expansion phase in Eocene-Oligocene, the main extension direction is northeast-southwest to west-east, so that this basin is not formed as a back-arc basin but a basin that occurs due to the compressional stress system.

Based on the tectonic conditions of the North West Java Basin, this research area is in the Jatibarang Sub-Basin which is controlled by two main phases that took place in the Cretaceous to Oligocene Period in Phase I and lasted from the Oligocene to Recent Periods in Phase II [15]. Tectonic phase I saw the subduction and development of the Meratus arc. During the Eocene to Oligocene Period, the Meratus subduction stopped and resulted in a tensional tectonic regime. In this regime, a horizontal shear fault occurred in the main Sundanese palace as a result of the collision of the Indian Plate with the Eurasian Plate and caused normal faults trending northwest-southeast and controlled sedimentation of syn-rift deposits in the Paleogene period, in the form of volcanic deposits at the bottom and sediments. lacustrine at the top as the Jatibarang Formation. At the end of the Oligocene, there was a change in the direction of subduction as the Java subduction pattern was trending west-east. The development of the Jatibarang Sub-Basin begins with the formation of a half-graben from the back-arc tensional system and is subsequently filled with tertiary sediment deposits. This Half-Graben development is interpreted to experience two stages of the formation period, which begins with the filling of the clastic sediment and is closed by carbonate deposition [15].

3.2. Geological research area

Xena Field carbonate reservoirs are formed on top of the horst and graben structures. The Parigi Formation was deposited in the Late Miocene based on studies of planktonic foraminifera. The formation in this field is dominated by limestone deposits with dolomite inserts, sandstone limestone, and limestone clay in shallow marine environments. The orientation of the basin is west-east so that the thinning of the Parigi Formation to the south will be obtained, namely the Bogor zone.

4. Result and Discussion

Based on the rock type analysis of core rock using the FZI method, the results of the FZI calculation can be seen in Table 1 below:

Table 1. Calculation of the FZI method.

Depth (m)	Well	Sample N	Permeabilitas (r	Poro	Fraksi Poro	RQI	Φ	FZ	DF	Cummulativ		HF
872,7	J-23	24	116	17,9	0,179	0,7993411	0,218	3,6663	13	116	0,121	RT 1
873,9	J-23	28	60	15,1	0,151	0,6259171	0,1779	3,5192	13	176	0,1836	RT 1
864,3	J-23	9	49	18,4	0,184	0,5124114	0,2255	2,2724	12	225	0,2347	RT 1
873,6	J-23	27	7,2	10,9	0,109	0,2552012	0,1223	2,0861	12	232,2	0,2422	RT 1
930,46	J-02	3	0,1	3,2	0,032	0,0555079	0,0331	1,6791	12	232,3	0,2423	RT 1
929,8	J-02	1	0,1	3,3	0,033	0,0546604	0,0341	1,6017	12	232,4	0,2424	RT 1
875,7	J-23	34	277	36,7	0,367	0,8626537	0,5798	1,4879	11	509,4	0,5313	RT 2
874,2	J-23	29	2,1	10,6	0,106	0,1397611	0,1186	1,1787	11	511,5	0,5335	RT 2
874,8	J-23	31	5,5	15	0,15	0,1901364	0,1765	1,0774	11	517	0,5392	RT 2
875,1	J-23	32	49	28,1	0,281	0,4146432	0,3908	1,061	11	566	0,5903	RT 2
930,13	J-02	2	0,1	4,5	0,045	0,0468084	0,0471	0,9934	11	566,1	0,5905	RT 2
875,4	J-23	33	140	38,98	0,3898	0,5950764	0,6388	0,9315	10	706,1	0,7365	RT 2
932,13	J-02	8	15	22,6	0,226	0,2558121	0,292	0,8761	10	721,1	0,7521	RT 2
865	J-23	11	0,06	4,3	0,043	0,0370912	0,0449	0,8255	10	721,16	0,7522	RT 2
932,46	J-02	9	18	24,6	0,246	0,2685953	0,3263	0,8233	10	739,16	0,771	RT 2
999,81	J-07	2	18	24,7	0,247	0,268051	0,328	0,8172	10	757,16	0,7897	RT 2
900	J-08	5	63	35	0,35	0,4212752	0,5385	0,7824	10	820,16	0,8554	RT 2
891	J-08	1	28	29,4	0,294	0,3064326	0,4164	0,7359	10	848,16	0,8846	RT 2
873,3	J-23	26	3	15,8	0,158	0,1368238	0,1876	0,7291	10	851,16	0,8878	RT 2
864,7	J-23	10	0,02	3,3	0,033	0,0244449	0,0341	0,7163	10	851,18	0,8878	RT 2
930,8	J-02	4	0,1	5,7	0,057	0,0415903	0,0604	0,6881	10	851,28	0,8879	RT 2
933,8	J-02	13	30	31,6	0,316	0,3059474	0,462	0,6622	10	881,28	0,9192	RT 2
	J-08	3	18	28,5	0,285	0,2495419	0,3986	0,626	10	899,28	0,938	RT 2
934,13	J-02	14	15	28,4	0,284	0,2282002	0,3966	0,5753	9	914,28	0,9536	RT 3
933,46	J-02	12	29	34,5	0,345	0,287885	0,5267	0,5466	9	943,28	0,9839	RT 3
934,46	J-02	15	5,8	22,7	0,227	0,1587197	0,2937	0,5405	9	949,08	0,9899	RT 3
874,5	J-23	30	0,23	9,2	0,092	0,0496478	0,1013	0,49	9	949,31	0,9901	RT 3
870,3	J-23	16	0,03	5,7	0,057	0,02278	0,0604	0,3769	9	949,34	0,9902	RT 3
891,3	J-08	2	0,1	8,4	0,084	0,0342602	0,0917	0,3736	9	949,44	0,9903	RT 3
899,7	J-08	4	0,1	8,7	0,087	0,0336643	0,0953	0,3533	9	949,54	0,9904	RT 3
873	J-23	25	0,65	15,6	0,156	0,064095	0,1848	0,3468	8	950,19	0,9911	RT 3
900,3	J-08	6	1,6	21	0,21	0,0866722	0,2658	0,3261	8	951,79	0,9927	RT 3
900,9	J-08	8	0,4	14,3	0,143	0,052516	0,1669	0,3147	8	952,19	0,9931	RT 3
932,8	J-02	10	0,1	10	0,1	0,0314	0,1111	0,2826	8	952,29	0,9933	RT 3
865,3	J-23	12	0,05	8,4	0,084	0,0242256	0,0917	0,2642	8	952,34	0,9933	RT 3
872,1	J-23	22	0,05	8,5	0,085	0,0240827	0,0929	0,2592	8	952,39	0,9934	RT 3
931,46	J-02	6	1,7	26,5	0,265	0,07953	0,3605	0,2206	8	954,09	0,9951	RT 3
872,4	J-23	23	0,02	7,1	0,071	0,0166654	0,0764	0,2181	8	954,11	0,9951	RT 3
870	J-23	15	0,02	7,2	0,072	0,0165493	0,0776	0,2133	8	954,13	0,9952	RT 3
900,6	J-08	7	0,1	12,8	0,128	0,0277539	0,1468	0,1891	7	954,23	0,9953	RT 4
931,13	J-02	5	2	30,8	0,308	0,0800146	0,4451	0,1798	7	956,23	0,9974	RT 4
1000,41	J-07	4	0,5	22,5	0,225	0,0468084	0,2903	0,1612	7	956,73	0,9979	RT 4

4.1. Rock type validation

Rock type in Xena Field can be divided into RT 1, RT 2, RT 3, RT 4 based on the relationship of porosity and permeability. The plot between Øz and RQI can be seen in Figure 4. Distribution of RT data on the Øz and Rock Quality Index is grouped based on clusters following a trend pattern. Samples that are located on the same straight line have the same pore throat attribute and show one hydraulic unit (Amaefule, 1993).

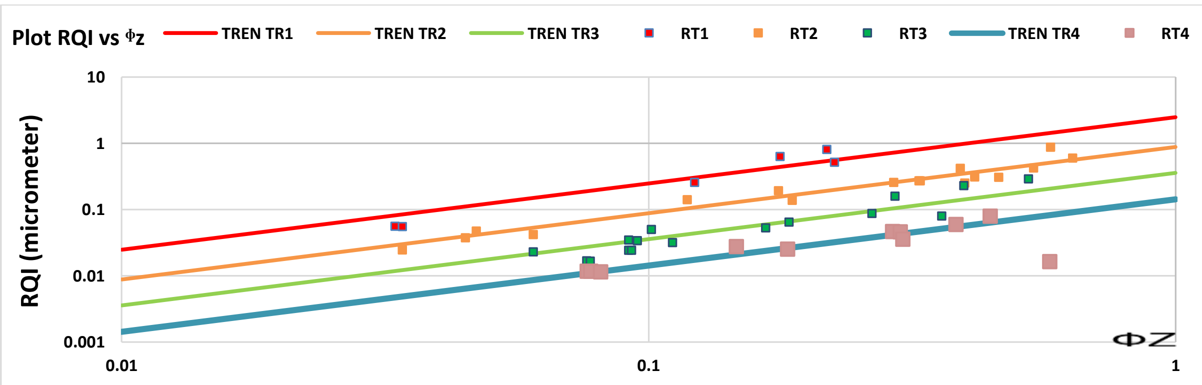

Figure 4. the Øz and RQI plot as validation of Rock Type

The Multi-Resolution Graph-Based Clustering method is a geostatistical method that can be used to predict rock type in wells that do not have core rock. The parameters used are the log curve of porosity, density, and Gamma-Ray which has been corrected first. MRGC can group electrifies which are calibrated against rock type in the form of clustering. The initial stage of using this method is by propagating wire rope logs, then associating with predetermined rock type data by selecting data clusters.

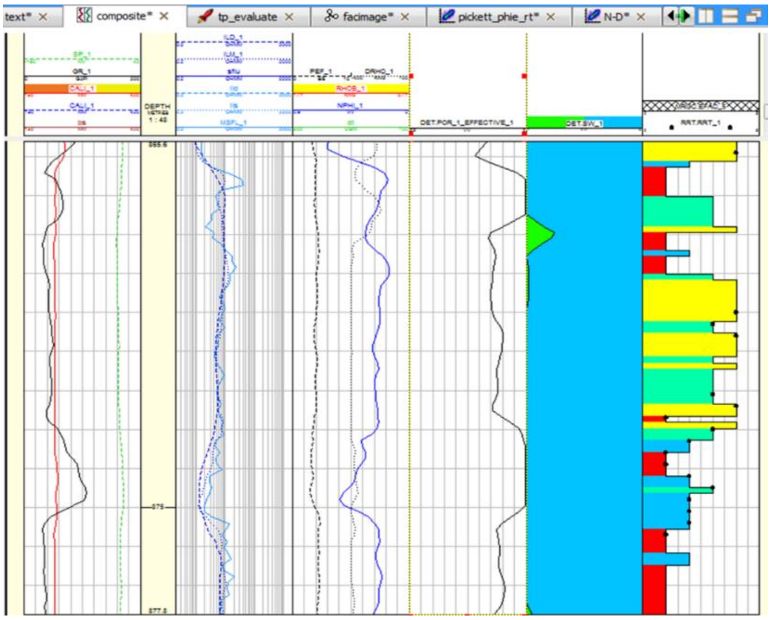

Figure 5. The MRGC method of the core rock RT values is displayed in the form of clusters.

4.2. The model of rock type distribution

Based on rock type analysis it can be shown the distribution of properties in the form of a rock type distribution map (Figure 6). The distribution of rock types is divided into four flow units, namely RT 1, RT 2, RT 3, RT 4. The distribution of rock types uses the Flow Zone Indicator method based on developing facies associations. The method used in this modeling is Sequential Gaussian Simulation.

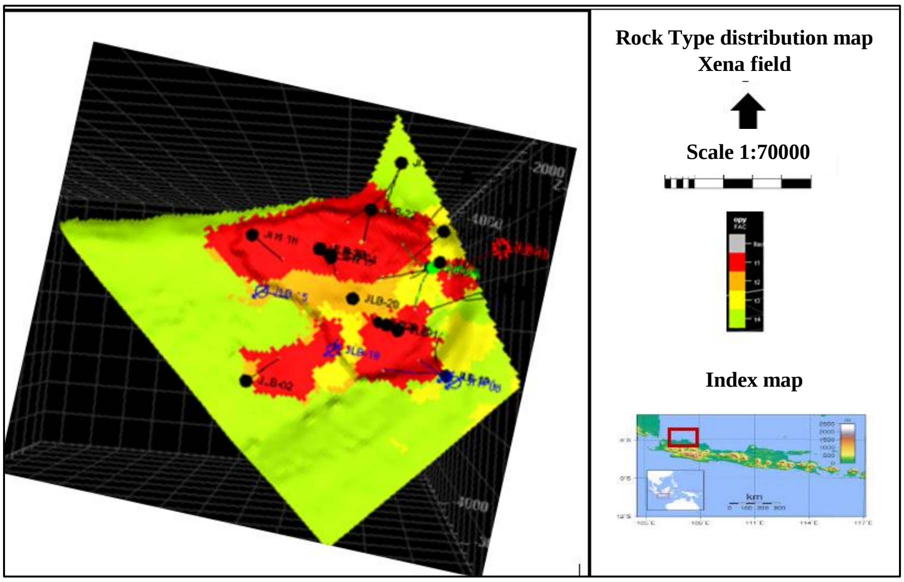

Figure 6. Xena field type rock distribution map.

5. Conclusion

Based on the identification of the rock type in the A2 carbonate reservoir, Rock-type 1 was identified as the rock type with the best reservoir quality with a porosity distribution of 18.4 and permeability at 24 mD (Table 2). This rock type consists of calcarenite limestone lithofacies. Rock type 2 is identified as a rock type with good reservoir quality with a porosity distribution of 28.5% and a permeability at 18 mD. This rock type consists of Calcilutite limestone lithofacies. Rock type 3 is identified as the rock type with the worst reservoir quality. The distribution of porosity was 21% with a permeability of 88 mD.

Rock type 4 is identified as the rock type with the worst reservoir quality. The porosity distribution is 15.5% with the smallest permeability range of 1 mD.

Table 2. The rock type relationship is based on the lithofacies of the Xena field.

No	*Rock type*	Properties	Lithofacies	Facies Association	*Depositional environment*
1	I	Porosity: 18,4 % Permeability: 24 mD	Calcarenite Limestone	*Sandshoal*	*Shelf-Edge Reef*
2	II	Porosity: 28, 5 % Permeability: 18 mD	Calsilutite Limestone	*Platform Interior*	*Shelf-Edge Reef*
3	III	Porosity: 21 % Permeability: 88 mD	Calsilutite Limestone	*Platform Interior*	*Shelf-Edge Reef*
4	IV	Porosity: 15,5 % Permeability: 1 mD	Calsilutite Limestone	*Platform Interior*	*Shelf-Edge Reef*

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