



Identification of the Capabilities of the Kerek Sandstone Unit as a Hydrocarbon Reservoir in the Karangkepoh Area and Surrounding Areas, Boyolali, Central Java

Dwi Wahyu Hardiyanto^{1*}, Adelia Saras Nugraheni¹

¹Study Program of Mining Engineering, Faculty of Engineering, Tridianti University.

²Study Program of Geology Engineering, Faculty of Engineering, Sriwijaya University.

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Correspondence:

Dwi Wahyu Hardiyanto

Phone : +6282329074611

Abstract: Karanggede is part of the Kendeng Zone physiography, which was formed by compressional tectonics since the Middle Oligocene. This zone consists of deep marine to transitional sedimentary deposits with hydrocarbon reservoir potential. The Kerek Formation in the study area is dominated by layered carbonate sandstone and carbonate mudstone. The study site is located in Karangkepoh Village, Karanggede District, Boyolali Regency, Central Java. Geologically, this unit has undergone structural deformation that affects the physical properties of the reservoir rock. This study aims to evaluate the quantity and quality characteristics of the Kerek Formation carbonate sandstone as a hydrocarbon reservoir. The research methods include field observations and laboratory analysis of porosity and permeability parameters. The test results show very low porosity values, ranging from 1.53% to 1.78%. These porosity values indicate the rock's limited ability to store fluids. In contrast, the permeability values range from 98.53 mD to 906.74 mD. These permeability values are classified as good to very good. This condition indicates the presence of fluid flow paths that develop despite limited effective pore space. The relatively high permeability is controlled by grain size and inter-pore connectivity. The rock texture relationship plays a significant role in determining reservoir characteristics. Overall, the carbonate sandstone of the Kerek Formation in the study area acts primarily as a fluid-flow medium rather than a storage medium.

Keywords: Reservoir; sandstone; porosity; permeability; Kerek

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Introduction

Hydrocarbon reservoirs are important components of petroleum systems, serving as sites of accumulation and pathways for hydrocarbon fluid flow. Identification of an oil reservoir basin can be seen in the form of oil seeps. The presence of oil seeps on the surface indicates that the source rock has undergone thermal maturity and that the hydrocarbons produced have migrated to the surface of the petroleum system (Abrams, 2005; Purwasatriya & Waluyo, 2012; Ilmi et al, 2024). As in the Kerek Formation, oil seeps indicate the activity of source rocks that produce petroleum (Praptisih, 2016). This phenomenon provides insight

into the characteristics of petroleum systems. One of the petroleum systems is the reservoirs. Halliburton (2001) states that reservoir rocks have porous and permeable surfaces, so the two are closely related. According to Knebel and Rodriguez (1956), as cited in Koesoemadinata (1980), 59% of oil and gas fields are located in sandstone reservoirs, while 40% are located in carbonate reservoirs. The size of the reserves stored in the reservoir is determined by the reservoir rock's ability to hold and flow hydrocarbons, which are influenced by porosity and permeability. Based on this concept, evaluating porosity and permeability characteristics is important for understanding the quality of hydrocarbon

Email: dwiwahyu@univ-tridianti.ac.id

reservoirs, particularly in layered carbonate sandstones of the Kerek Formation in the Karangkepoh Boyolali area (Figure 1), which are geologically controlled by sedimentation processes and structural deformation.

This study aims to examine the characteristics of the layered carbonate sandstone reservoir of the Kerek Formation using a multidisciplinary approach. The analysis is based on measured stratigraphic data, petrographic analysis, and testing of rock physical properties, including porosity and permeability. This approach is used to gain a comprehensive understanding of the relationships among lithological characteristics, rock texture, and fluid-flow properties within the reservoir unit under study.

The main objective of this study is to evaluate the quantitative and qualitative characteristics of the layered carbonate sandstone of the Kerek Formation as a hydrocarbon reservoir and to relate them to the rock's ability to store and transport fluids. This evaluation is expected to assess the feasibility of this rock unit as a hydrocarbon reservoir, particularly in the context of the study area's structural geology and sedimentology. The benefit of this study is to provide scientific data and interpretations regarding the potential of hydrocarbon reservoirs in the study area, particularly in the Kerek Formation.

The results of this study are expected to serve as a reference for subsequent studies on reservoir characterization and to support the development of conceptual reservoir models based on field and

laboratory data obtained using various analytical instruments.

Geology of the Study Area

The complex tectonic evolution involving compressional and strike-slip deformation is linked to broader tectonic shifts that affect the stability of the basin structure in Central Java and its surroundings (Prasetyadi et al., 2011). One example is the development of the Kerek Formation. The Kerek Formation is a flysch-type sedimentary rock consisting of alternating layers of mudstone, claystone, sandy sandstone, and sandy limestone, with intercalated volcanic rocks (Sukardi & Budhitrisna, 1992).

Hidayat and Fatimah (2007) confirmed that the Kerek Formation has abundant organic material originating from a marine environment. Based on its physiography, the Kendeng Zone is sandwiched between the present-day Volcanic Arc and the Rembang Zone, within which various formations have developed, including the Kerek Formation (van Bemmelen, 1949). The Kendeng Zone has developed into an anticlinorium unit that formed as part of the back-arc basin, forming a horst-graben pattern under compressive forces during the Neogene–Pliocene–Pleistocene deformation (Novianto et al., 2020). One form of geological structural control is that the clastic rocks scattered throughout the study area exhibit several manifestations, including oil seepage that emerges from the rock body or, in this case, the carbonate sandstone.

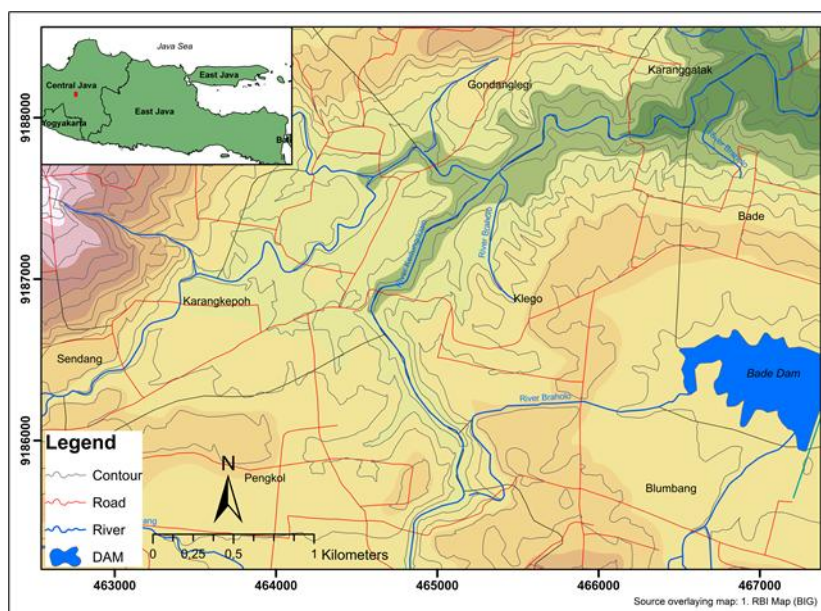


Figure 1. The research location map

Method

The research method used in this study was designed to examine the geological conditions of the

study area through field geological studies, laboratory analysis, and integrated data interpretation. The field geological study included mapping and description

based on the classification of carbonate rock grain size components (Folk, 1962). Porosity analysis used blue day petrography and the fluid saturation porosity method based on (Koesoemadinata, 1980) (a) (b) (Table 1). The determination of the dominant pore diameter was indicated by the average pore diameter (Choquette & Pray, 1970).

$$(a) \ \emptyset \ Total = \frac{Vol \ Pore}{Vol \ Total \ BAT} \times 100\%$$

$$(b) \ \emptyset \ Efektif = \frac{Vol \ Interconnected \ Pores}{Vol \ Total \ BAT} \times 100\%$$

Where: \emptyset Total (ratio between pore volume and total rock volume), \emptyset Effective: (ratio of interconnected pore spaces)

Permeability analysis is a property of reservoir rock that allows fluid to pass through interconnected pores without damaging the interconnected particles (Koesoemadinata, 1980). Permeability analysis uses a measured-sample-density approach that can be divided into several types, as shown in (Table 2).

Table 1. Porosity values based on classification (Koesoemadinata, 1980)

Percentage of Porosity	Notes
0% - 5%	Dapat Diabaikan (<i>Negligible</i>)
5% - 10%	Buruk (<i>Poor</i>)
10% - 15%	Cukup (<i>Fair</i>)
15% - 20%	Baik (<i>Good</i>)
20% - 25%	Sangat Baik (<i>Very Good</i>)
>25 %	Istimewa (<i>Excellent</i>)

Table 2. Quantitative permeability scheme for reservoirs (Koesoemadinata, 1980).

Type	In (millidarcy)
Ketat (Tight)	< 5
Cukup (Sufficiet)	5 - 10
Baik (Good)	10-100
Baik sekali (Very Good)	100-1000
Sangat baik (Excellent)	>1000

Result and Discussion

The study area is part of the Kerek Formation, characterized by the development of layered carbonate sandstone lithology. Based on porosity-permeability correlation tests, reservoir analogies show that the porosity values obtained from density testing on all samples are very low. The porosity values for samples

BPK1, BPK2, BPK3, and BPK4 were 1.65% (Figure. 2a), 1.77% (Figure. 3a), 1.78% (Figure. 4a), and 1.53% (Figure. 5a), respectively, all of which fall into the negligible category. The weighted results based on the porosity classification scheme indicate that the carbonate sandstone units in the study area have limited reservoir potential. The dominant internal structure controlling porosity is interpreted as fabric selective porosity. Based on its form, porosity develops as interparticle to intercrystalline pores. Pore size classification shows considerable variation, but in general, it is dominated by pores ranging from 0.5 to 4 mm, which are classified as mesopores.



Figure 2. a) Medium calcarenite sample with negligible porosity using the density analysis method b). Negligible porosity using the petrographic observation method (PPL).



Figure 3. a). Fine calcarenite sample with negligible porosity using the density analysis method b). Negligible porosity using the petrographic observation method (PPL)

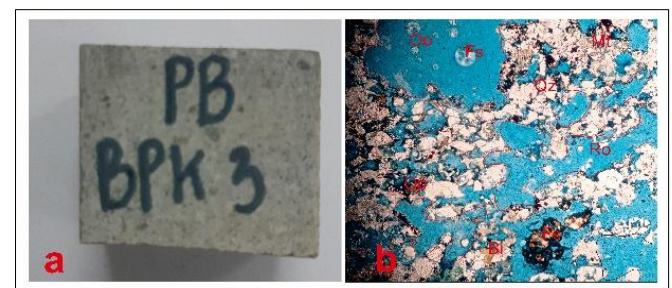


Figure 4. a). Medium calcarenite sample with negligible porosity using the density analysis method b). Negligible porosity using the petrographic observation method (PPL)



Figure 5. a). Medium calcarenite sample with negligible porosity using the density analysis method b). Negligible porosity using the petrographic observation method (PPL)

The permeability test results show variations in values for each sample. Sample BPK1 had a permeability value of 598.95 mD, which is classified as very good (Figure. 2b); BPK2 had a value of 134.49 mD, which is also classified as very good (Figure 3b); BPK3 had a value of 906.74 mD, which is also classified as very good (Figure. 4b), and BPK4 had a value of 98.53 mD, which is classified as good (Figure. 5b). The permeability values were weighted based on the quantitative

reservoir permeability classification scheme. The dynamics of the genesis process influence the variation in porosity values between samples during the deposition of clastic rocks, which are generally associated with unconsolidated rock conditions. Therefore, the magnitude of porosity values is more influenced by grain size distribution than by absolute grain size. In the study area, the primary porosity that developed was dominated by intergranular porosity (d-porosity) with a very small (negligible) average value. This condition was caused by diagenetic processes, such as recrystallization and replacement, which occurred to a limited extent, as well as by dissolution processes that did not develop intensively.

As a result, the test results show that the variation in porosity between samples is relatively small and does not significantly affect each sample's porosity. In addition, when reviewing the factors influencing decreases in porosity across the study area, the dominant factors are the degree of intergranular compaction and cementation. These two processes cause particle interlocking, thereby reducing pore space and decreasing porosity (Figure 6).

Table 3. Relationship between D-porosity (%), permeability (mD), and pore size (mm)

No	Sample	D.Porosity %	Permeability mD	Pore Size mm
1	P-BPK1	1,65 (<i>negligible</i>)	598,95 mD	1-2 mm (<i>mesopori</i>)
2	P-BPK2	1,77 (<i>negligible</i>)	134,49 mD	3-2 mm (<i>mesopori</i>)
3	P-BPK3	1,78 (<i>negligible</i>)	906,74 mD	4-3 mm (<i>mesopori</i>)
4	P-BPK4	1,53 (<i>negligible</i>)	98,53 mD	1-1/2 mm (<i>mesopori</i>)

The permeability test results for layered carbonate sandstone show a strong relationship, with average permeability values predominantly in the good-to-very-good range. This indicates that the rock samples at the study site have sufficient fluid-flow capacity, thus potentially supporting their function as reservoir rocks (Table 3).

Microscopic observations show that the pore spaces between fragments do not interlock, with the pore type dominated by interparticle-intercrystal pores.

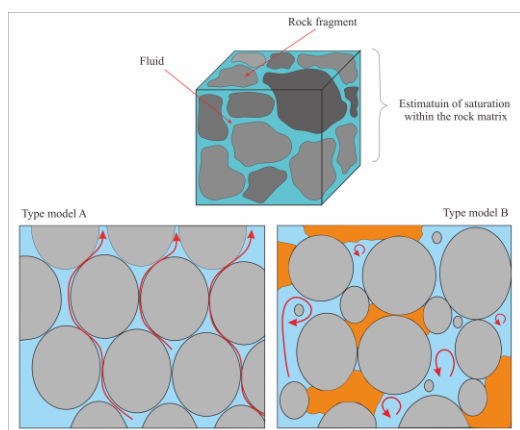


Figure 6. A simplified model of the mechanism controlling rock porosity and permeability was developed in the study area

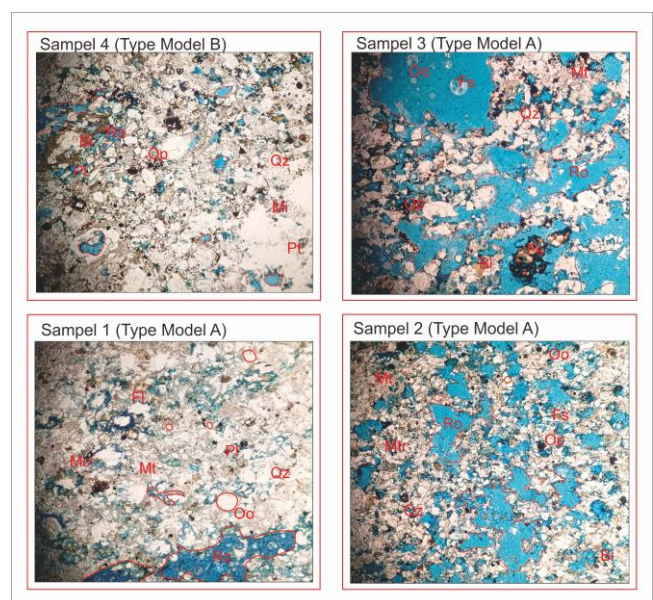


Figure 7. The relationship between porosity and permeability that dominates the research location

This condition contributes to the high permeability values in several samples. In addition, reservoir analogy tests on four-layered carbonate sandstone samples indicate porous and permeable reservoir characteristics, suggesting that the study area can store and transport fluids or hydrocarbons (Figure 7). These variations are influenced by several factors, including the process of increased porosity associated with the recrystallization of minerals in rocks, such as magnesium, calcite, and aragonite, which undergo changes and dissolution due to interaction with meteoric water. On the other hand, decreases in porosity are also influenced by several processes, such as rock compaction and the replacement of carbonate minerals by silica, anhydrite, and sulfide, which act as pore-filling materials between fragments. These processes can occur both during rock deposition and after deposition.

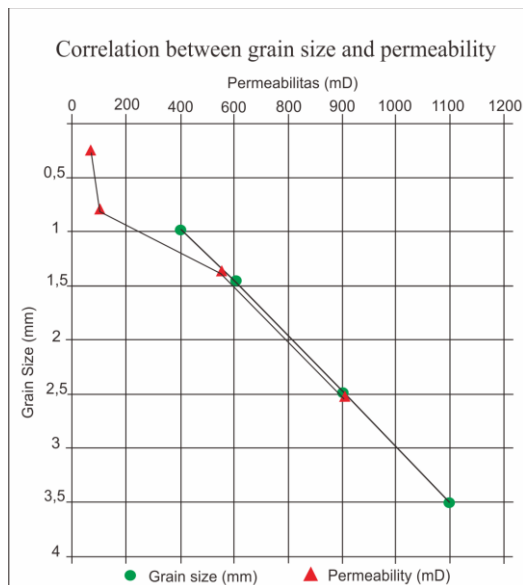


Figure 8. Graph of the linear relationship between grain size and permeability in the research area

Cementation plays an important role in pore formation by producing blocky intergranular relationships. The relationship between porosity values and grain geometric characteristics at the study site is influenced by several factors, including relatively diverse grain-size distributions, angular to moderately angular grain shapes, and sorting levels that are generally moderate to poor at the time of deposition. In addition, petrographic section observations show that the cementation that developed after the sedimentation process of fragments was quite dominant. Meanwhile, the compaction process had a relatively small effect on the variation in porosity values in each sample. The correlation between grain size, porosity, and permeability was used to explain their relationship. The relationship between grain size and permeability shows

a random or inverse pattern, indicating that larger grain size is associated with lower permeability (Figure. 8). Meanwhile, the correlation between grain size and porosity is linear, with larger grain sizes associated with lower porosity (Figure. 9)

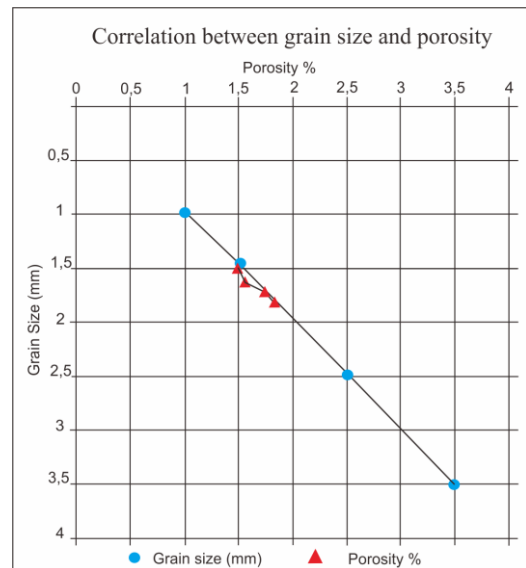


Figure 9. Graph of the linear relationship between grain size and permeability in the research area

Conclusion

The evaluation of rocks in the study area indicates porous, permeable reservoirs with fairly good fluid storage and flow properties. This interpretation is supported by relatively favorable permeability, porosity, and grain size characteristics. However, the porosity percentage based on the D-porosity value shows a relatively low trend. This condition does not significantly affect fluid flow capacity, as the permeability values of each sample remain fairly well classified.

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