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Analysis Diagenesis and Porosity Values of Carbonate Rocks of the Wonosari Formation in Krakitan Village, Bayat.

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Abstract

Diagenesis is a process that are common in sedimentary rocks especially in carbonates. The process may cause an increase or decrease in the porosity of rocks depending on their types. The types of diagenesis varies, depends on the environment of where they happened. This variation of the environment will affecting the type of the diagenesis that will affecting the pore types and certain diagenesis characteristics of the rocks. The purpose of this research is to understand the type and the role of diagenesis to the porosity of rocks from Wonosari Formation. The study site is located at 458119 South, 9143867 West, at the northern part of Jiwo Barat hills in Bayat, Central Java. We implement field investigation methods by conducting a measured stratigraphy of the rock layers, describe the rock layers in hand specimen, and also laboratory analysis including petrographic analysis to estimate the porosity value of the samples. In general, samples taken at Wonosari Formation of Jiwo Barat experienced intensive leaching diagenesis processes and calcite cementation. The type of porosity observed in the samples are channel and vuggy. The porosity value is increase in the samples with leaching diagenesis and decrease in the samples with cementation diagenesis.

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1. Introduction

The Bayat Hills are composed of Pre-Tertiary and Tertiary rocks surrounded by Quaternary deposits, primarily Merapi fluvio-volcanic sediments. The hills are classified as low-lying, with elevations not exceeding 400 meters above sea level. The oldest exposed rocks in the Jiwo Hills area are a Pre-Tertiary metamorphic complex, forming the basement of the Paleogene sedimentary basin. Paleogene deposits consist of sandstone with limestone intercalations containing larger foraminifera, intruded by Late Paleogene microdiorite igneous bodies. Neogene carbonate rocks, deposited in deep-marine and shallow-marine facies, unconformably overlie the Paleogene rocks. Quaternary sediments, including volcanic breccia and alluvial deposits, were deposited after Late Neogene erosion.

The Structurally, the Bayat area is part of the Southern Mountain Zone of Central Java, characterized by folded Eocene and younger rocks. The area features an anticline with an Eocene limestone core and homoclinal structures dipping southward. Fault orientations in the Jiwo Hills area trend northeast-southwest, north-south, northwest-southeast, and east-west.

Carbonate rocks are crucial in hydrocarbon exploration, hosting over 50% of global oil and gas reserves. Their reservoir quality is controlled by porosity and permeability, which vary spatially and temporally. Diagenesis, the physical, chemical, and biological processes altering sediments after deposition, significantly impacts carbonate porosity. Dissolution processes create secondary porosity, while calcite cementation and recrystallization reduce pore spaces.

The Wonosari Formation, a Tertiary carbonate unit in Java's Southern Mountains, has potential as a hydrocarbon reservoir. Previous studies indicate intensive diagenetic processes in the Bayat area's carbonate rocks. However, the relationship between diagenesis, pore types, and porosity values in the Wonosari Formation remains understudied. This research examines the influence of diagenetic processes on the porosity of Wonosari Formation carbonate rocks through petrographic analysis and porosity measurements, aiming to contribute to carbonate diagenesis concepts and hydrocarbon exploration in Indonesia.

This study aims to comprehensively examine the influence of diagenetic processes on the porosity characteristics of carbonate rocks of the Wonosari Formation in the Bayat area, Central Java. The investigation of the relationship between diagenesis and porosity is critically important, as diagenetic processes are recognized as the primary factors controlling the quality of carbonate reservoirs after deposition (Choquette and Pray, 1970; Ahr, 2011).

Regional geology

Physiographically, the Bayat Hills constitute part of the Jiwo Hills, which belong to the Southern Mountain Zone of Central Java. This area is composed of Pre-Tertiary to Tertiary rocks surrounded by Quaternary deposits, predominantly fluvio-volcanic sediments derived from the activity of Mount Merapi. The maximum elevation of the hills generally does not exceed 400 meters above sea level; therefore, morphologically, the area is classified as low hills (Raharjo, 1997; van Bemmelen, 1949).

According to Raharjo (1997), the oldest rocks exposed in the Jiwo Hills area consist of a metamorphic rock complex that is interpreted to be of Pre-Tertiary age. This metamorphic complex serves as the basement for the development of the Paleogene sedimentary basin in central Java. The presence of this metamorphic basement has also been reported by van Bemmelen (1949) and Bothe (1929), who identified the Jiwo Hills as one of the key localities for the exposure of ancient rocks in Java.

Overlying the basement rocks are Paleogene deposits, which are generally composed of sandstone with intercalations of limestone rich in larger foraminifera, indicating deposition in shallow-marine to open-marine environments. These Paleogene deposits were subsequently intruded by igneous bodies, predominantly microdiorite, which are interpreted to have occurred during the Late Paleogene as part of regional magmatic activity (Raharjo, 1997; van Bemmelen, 1949).

Furthermore, the Paleogene sedimentary and igneous rocks are unconformably overlain by Neogene carbonate rocks. The Neogene carbonates in the Bayat area developed in two main facies, namely deep-marine and shallow-marine facies, reflecting variations in carbonate depositional environments during the Neogene. Regionally, these carbonate units are correlated with the Wonosari Formation, which is widely developed in the Southern Mountains of Java (Surono et al., 1992; Wilson, 1996).

During the Late Neogene, regional erosional activity resulted in the formation of an unconformity, followed by the deposition of Quaternary units. Quaternary deposits in the Bayat area consist of volcanic breccia, colluvial deposits, fluvio-volcanic deposits, and alluvial deposits, reflecting the strong influence of Quaternary volcanism from Mount Merapi as well as terrestrial to fluvial sedimentary processes (van Bemmelen, 1949; Prasetyadi, 2007).

From a structural geology perspective, the Bayat area belongs to the Southern Mountain Zone of Central Java and is characterized by folded and faulted structures. Paleogene and Neogene rocks in this area have undergone deformation in the form of anticlines and synclines, with one of the major structures being an anticline cored by Eocene rocks of the Wungkal–Gamping Formation, as well as homoclinal structures in younger rock units with a dominant southward dip (Raharjo, 1997; Prasetyadi, 2007).

Fault structures in the Jiwo Hills area exhibit a complex pattern and can be grouped into four principal orientations: northeast–southwest, north–south, northwest–southeast, and east–west. This structural pattern reflects the influence of repeated regional tectonic forces in the Southern Mountains from the Paleogene to the Neogene and plays an important role in controlling fracture development, fluid circulation pathways, and the evolution of diagenetic processes in carbonate rocks (Prasetyadi, 2007; Scholle and Ulmer, 2003).

The occurrence of newly exposed rock outcrops in the Bayat area has progressively revealed the true stratigraphic framework of Bayat and its surrounding regions. The results of this study indicate that the stratigraphic relationship between the Jiwo Hills and the Southern Mountains, which had not previously been clearly established, has now become evident (Figure 1). This stratigraphic relationship suggests that the metamorphic rock complex and the Wungkal Limestone Formation constitute the basement for the sedimentation of the Kebo Butak Formation, which represents the oldest formation within the Southern Mountains. Consequently, the stratigraphic contact between these units is interpreted to be an unconformity (Pandita and Sukartono, 2014).

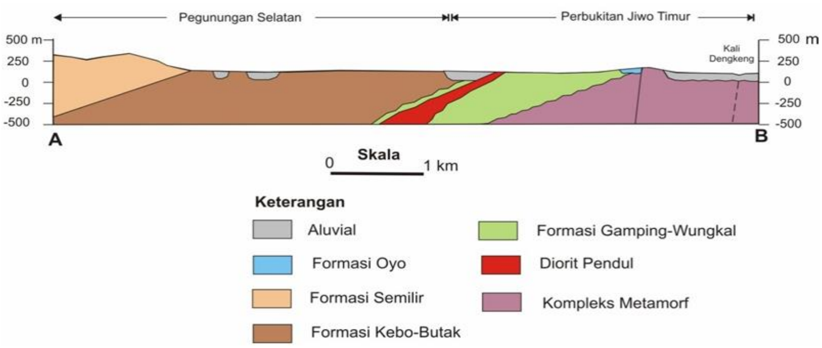

Figure 1. Reconstruction Geology stratigraphic relationship between the Jiwo Hills and the Southern Mountains

2. Materials and methods

The research methodology employed in this study includes stratigraphic measurements at a scale of 1:100 to determine the sampling positions of carbonate rocks from the lower, middle, and upper sections. Petrographic analysis was conducted on three rock samples to identify diagenetic products, while qualitative porosity analysis was carried out using the gravimetric (weighting) method. This study applies an integrated approach encompassing field investigations, laboratory analyses, and descriptive as well as analytical data interpretation. Such an approach is commonly applied in carbonate geology studies to understand the relationships between facies, diagenesis, and the physical properties of carbonate rocks (Tucker and Wright, 1990; Scholle and Ulmer, 2003).

Outline the overall design of your study. Detail the step-by-step procedures followed during the experiment. Mention any software tools or programs used for data analysis. Discuss any potential limitations or biases in your study. Cite any established methods followed.

3. Results and Discussion

3.1 Carbonate Rock Characteristics of the Research Area

Lower Packstone Facies Macroscopically, the lower packstone facies is characterized by a fresh white to grayish color and a weathered yellowish-white color. It has a medium sand grain size, subrounded grain shapes, good sorting, open packing, and a massive sedimentary structure, indicating a carbonate composition. Petrographically, this facies contains algal and foraminiferal fossils as skeletal grains, with micrite content of 35.11% and sparite content of 0.89%. Middle Grainstone Facies Macroscopically, the middle grainstone facies is characterized by a bright white to grayish color, with a weathered yellowish-brown color. It exhibits a fine sand grain size, rounded grain shapes, good sorting, open packing, and a well-bedded sedimentary structure, with a carbonate composition and shell fragments as skeletal grains. Petrographic analysis shows skeletal grains of 37.78%, micrite content of 2.57%, and sparite content of 6.33%. Upper Packstone Facies Macroscopically, the upper packstone facies is characterized by a bright white to grayish color and a reddish-white weathered color. It has a very coarse sand grain size, subrounded to subangular grain shapes, good sorting, open packing, and a massive sedimentary structure. This facies is composed of shell fragments as grains and calcite minerals. Petrographically, foraminifera are the dominant skeletal grains (40.11%), with micrite content of 29.34% and calcite content of 5.22% (Figure 2).

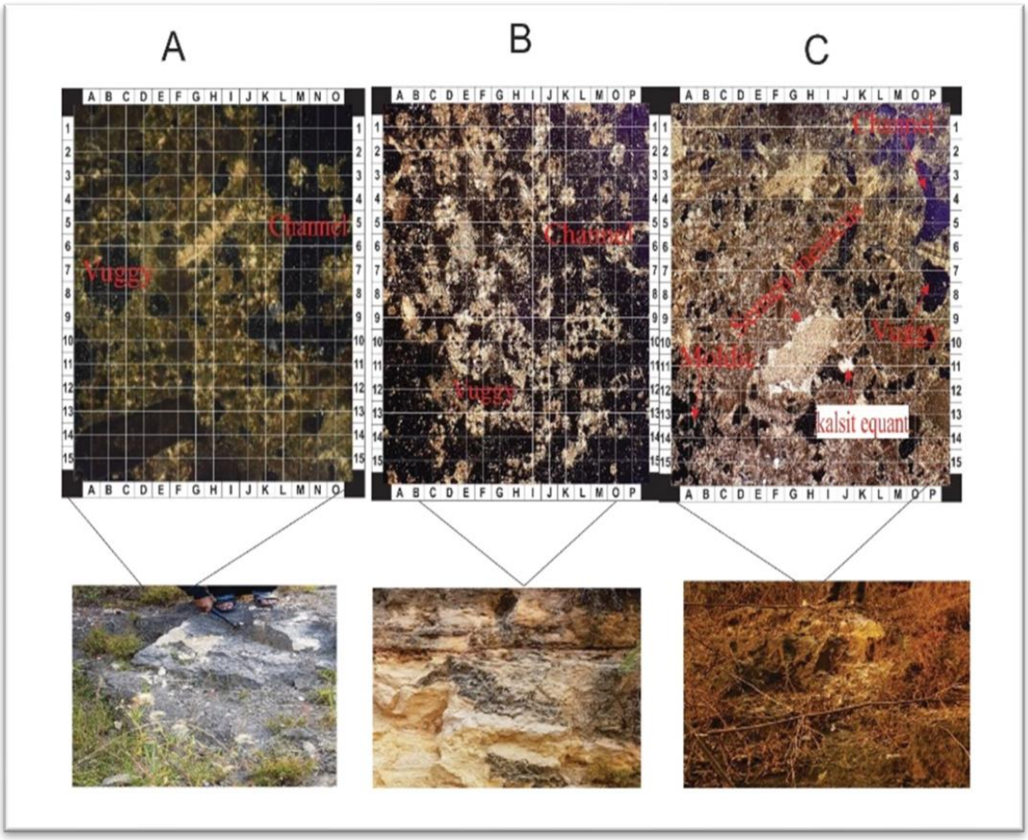

Figure 2. thin section, A(Packstone), B(Grainstone) , C (Packstone)

3.2 Diagenesis of the Research Area

Based on petrographic observations, the characteristics of the study area indicate that diagenetic processes developed in two main models. The classification of these diagenetic processes is based on the identification of diagenetic products, mineralogy, and rock textures, which allows the recognition of diagenetic processes affecting the carbonate rocks in the study area.

In the lower packstone facies and the middle grainstone facies, diagenetic products are represented by the development of vuggy and channel pore types. The formation of these pore types has resulted in a significant increase in porosity in these samples. The presence of secondary porosity indicates that these carbonate rocks have undergone dissolution diagenesis.

In the upper packstone facies, diagenetic products are characterized by the presence of secondary vuggy and channel pores, as well as the occurrence of equant calcite minerals and meniscus cement binding the grains together (Figure 3).

By identifying the diagenetic processes, it is possible to determine the stages of diagenesis based on the products formed. In the study area, the occurrence of secondary porosity, meniscus cement, and equant calcite suggests that the carbonate rocks experienced an early diagenetic porosity stage. According to Reekmann and Friedman (1982; reprinted with permission of Elf Aquitaine, Wiley-Interscience), these diagenetic features are indicative of early-stage diagenesis.

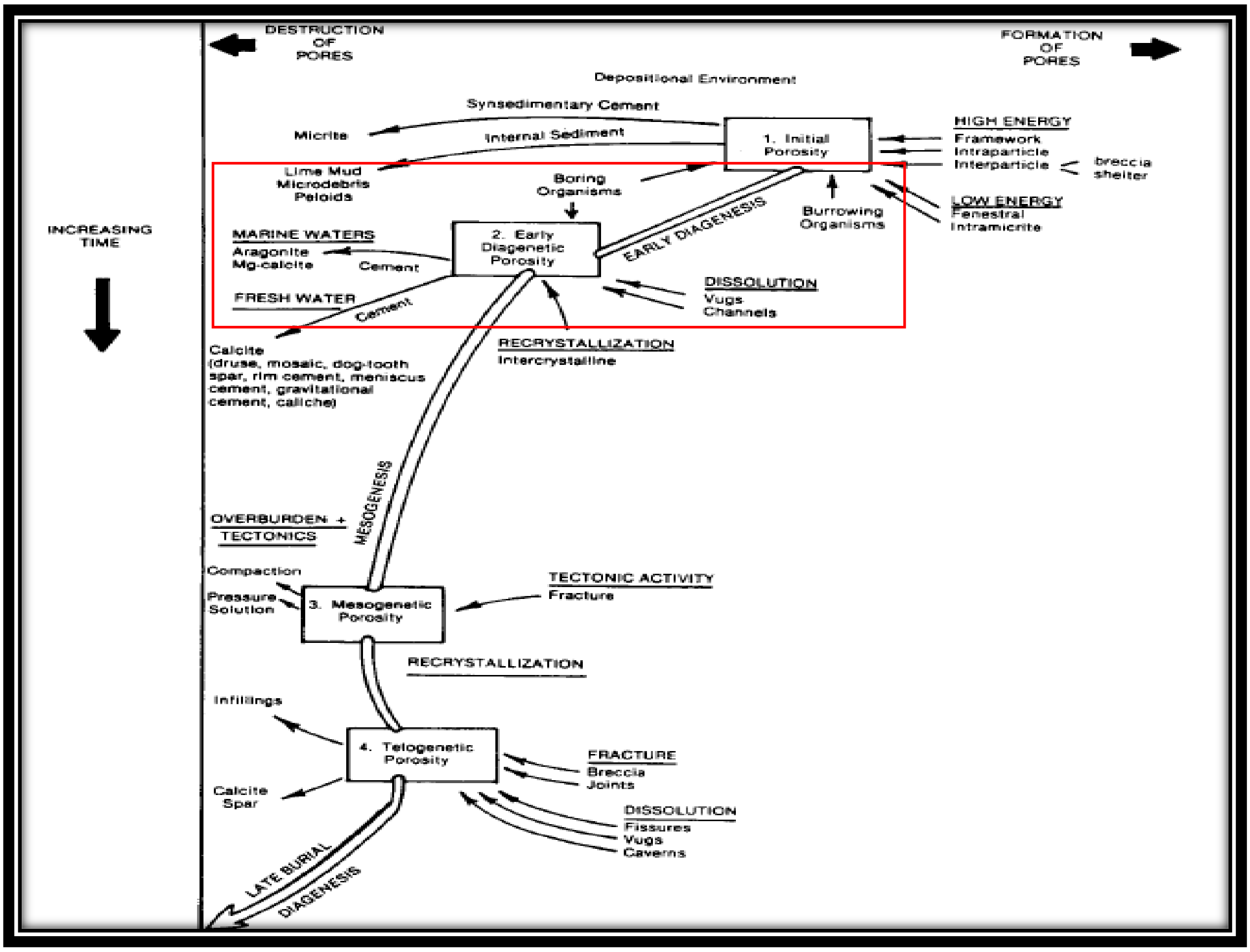

Figure 3. Showing the stages of diagenesis based on the relationship between pore type and diagenetic process by Recckman and Friedman, 1982; reprinted with permission of Elf-Aquitaine, Wiley-Interscience

3.3 Diagenetic Environment of the Study Area

Based on petrographic thin-section analysis, the diagenesis of limestone of the Wonosari Formation in the western Jiwo Hills, Bayat area, occurred within meteoric diagenetic environments, namely the meteoric phreatic zone and the meteoric vadose zone (Figure 4). The meteoric phreatic environment is characterized by dissolution diagenesis, whereas the meteoric vadose zone is indicated by calcite cementation.

Initially, the limestone experienced diagenesis within the meteoric phreatic environment, which is located below the water table. This stage is marked by the development of secondary porosity in the form of vuggy and channel pores, representing dissolution diagenesis. These processes are interpreted to be associated with tectonic uplift that exposed the carbonate rocks and facilitated fluid circulation. Subsequently, the rocks evolved into a near-surface diagenetic environment with direct interaction with meteoric water, namely the meteoric vadose zone, which is characterized by the formation of meniscus cement and equant calcite.

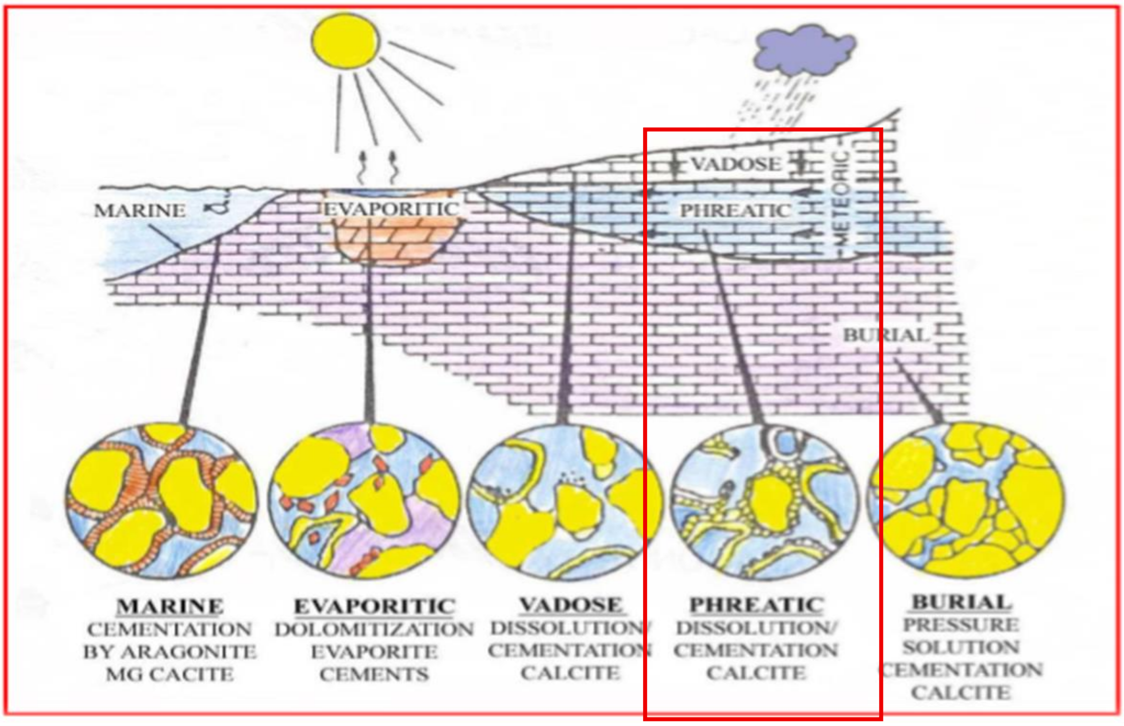

Figure 4. Showing the diagenetic environment of the research area according to Loucks and Brown (1988, vide Kaldi et al., 1992).

3.4 Porosity Value of the Research Area

Porosity determination in the study area was conducted using the gravimetric (weighting) method at the Soil Mechanics Laboratory, Faculty of Civil Engineering, Universitas Gadjah Mada. Porosity analysis was carried out on three rock samples. The lower packstone facies (Sample 1) shows an average porosity value of 36.60%, the middle grainstone facies (Sample 2) exhibits an average porosity of 43.67%, and the upper packstone facies (Sample 3) has an average porosity value of 31.60%. Based on these porosity values, the clastic limestone of the Wonosari Formation is interpreted to have good potential as a carbonate reservoir (Kosoemadinata, 1990) (Table 1).

Table 1. Calculation of porosity values using the weighting method

No Sample	Porosity I%	Porosity II %	Average Porosity Value

D.A.01.Bottom	36.42%	36.79%	36.60%
D.A. 02. Midle	44.57%	42.77%	43.67%
D.A. 03. Upper	32.35	31.61	31.98

3.5 The Relationship Between Porosity Values and Diagenetic Processes

According to Ahr (2008), porosity values may increase or decrease as a result of diagenetic processes. The study area is characterized by two main diagenetic models that significantly control porosity variations.

The Algae–Foraminifera Packstone facies (lower section) exhibits a relatively high porosity value of 36.60% based on laboratory analysis. This high porosity is primarily controlled by dissolution diagenesis, which preferentially affects fossil components that have not been filled by micrite or sparite. As a result, dissolution generates secondary vuggy and channel porosity, leading to a significant increase in overall porosity.

Similarly, the Foraminifera Grainstone facies (middle section) shows the highest porosity value of 43.67%. This porosity enhancement is also controlled by dissolution diagenesis affecting fossil shells that lack micrite and sparite infill. The limited presence of micrite and sparite allows extensive dissolution, producing abundant vuggy and channel pores and resulting in large-scale porosity development.

In contrast, the Algae Packstone facies (upper section) displays a lower porosity value of 31.60%, which is mainly controlled by cementation diagenesis. This process is indicated by the presence of meniscus calcite cement binding the grains, reducing pore space and limiting dissolution. Additionally, algal fossils filled with micrite are less susceptible to dissolution, further contributing to porosity reduction. Although minor dissolution still occurs in some fossil components, the resulting pore types are smaller due to the dominant cementation process.

Overall, the porosity characteristics of the study area are considered favorable according to Kosoemadinata (1990) and are strongly controlled by diagenetic processes. Petrographic analysis indicates that dissolution diagenesis enhances porosity in the lower and middle facies, whereas cementation diagenesis reduces porosity in the upper facies.

4. Conclusions

The Krakitan area, particularly Dukuh Nglebak Sendang, is composed of carbonate facies including algae–foraminifera packstone, foraminifera grainstone, and algae packstone. Two main diagenetic models are identified: dissolution diagenesis, which enhances porosity in the algae–foraminifera packstone and foraminifera grainstone facies, and cementation diagenesis, which reduces porosity in the algae packstone facies. Diagenetic products and pore types indicate meteoric phreatic and meteoric vadose environments corresponding to an early diagenetic porosity stage. Porosity values range from 31.98% to 43.60%, with the development of secondary vuggy, moldic, and channel porosity, indicating that the carbonate rocks in the study area exhibit good reservoir characteristics and potential for hydrocarbon accumulation. Porosity reduction in the upper algae–foraminifera packstone facies is primarily controlled by meniscus cementation, confirming the strong influence of diagenetic processes on reservoir quality.

5. Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Author’s contributions

N. Retongga conceptualized the study, conducted field investigations, performed petrographic and diagenetic analyses, and prepared the original manuscript draft. Y. Siregar contributed to data interpretation, supervised the research process, and reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript.

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