JURNAL IPTEK
MEDIA KOMUNIKASI TEKNOLOGI
homepage URL : ejurnal.itats.ac.id/index.php/iptek

Diagenetic Controls on Porosity in Sandstones of the Talang Akar Formation: A Case Study from the Rambangnia River Track, South OKU, South Sumatra

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ARTICLE INFORMATION

Jurnal IPTEK – Volume 29 Number 1, May 2025

Page:
59–68
May 30, 2025

DOI:
10.31284/j.iptek.2025.v29i1.6746

ABSTRACT

Porosity contributes to fluid storage and determines reservoir quality. The higher the porosity, the more free space is available to store fluid. However, the porosity of reservoirs, particularly the sandstones of the Talang Akar Formation of the Rambangnia River track, is not always good. The diagenetic process in the formation of sandstones is thought to contribute to variations in porosity quality. This study aims to determine the control of diagenesis on the porosity of sandstones of the Talang Akar Formation of the Rambangnia River, South Sumatra. The research methods used were field observation, petrographic, diagenesis, and porosity analysis. Based on petrographic analysis, the study area has three types of sandstone: lithic wacke, sublitharenite, and litharenite. The study of diagenesis shows that the sandstones in the Rambangnia River's Talang Akar Formation have gone through an intense compaction phase, dissolution, cementation by silica and calcite minerals, and an authigenic phase in clay minerals. In general, the porosity of rocks in the study area ranges from fair to good.

Keywords: *Bungin Campang; Diagenesis; Petrography; Porosity; Sandstone; Talang Akar*

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ABSTRAK

Porositas memiliki kontribusi dalam menyimpan fluida dan penentu kualitas reservoir. Semakin tinggi porositas, maka semakin banyak ruang kosong yang tersedia untuk menyimpan fluida. Namun, porositas reservoir tidak selalu berada pada tingkatan yang baik, khususnya batu pasir Formasi Talang Akar lintasan sungai Rambangnia. Proses diagenesis dalam pembentukan batu pasir dirasa turut memberikan variasi kualitas porositas. Penelitian ini bertujuan untuk mengetahui kontrol diagenesis terhadap porositas batu pasir Formasi Talang Akar lintasan Sungai Rambangnia, Sumatra Selatan. Metode penelitian yang digunakan berupa observasi lapangan, analisis petrografi, analisis diagenesis, dan analisis porositas. Berdasarkan analisis petrografi, daerah penelitian memiliki tiga jenis batu pasir, yaitu *lithic wacke*, *sublitharenite*, dan *litharenite*. Hasil analisis diagenesis menunjukkan bahwa batu pasir Formasi Talang Akar lintasan Sungai Rambangnia mengalami fase kompaksi kuat, pelarutan, sementasi oleh mineral silika dan mineral kalsit serta fase *authigenesis* pada mineral-mineral lempung. Secara umum, porositas batuan pada area penelitian berkisar antara *fair* hingga *good*.

Kata Kunci: *Batu pasir; Bungin Campang; Diagenesis; Petrografi; Porositas; Talang Akar*

PUBLISHER

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INTRODUCTION

Rock porosity quantifies the voids or pores within a material based on its properties. These attributes delineate the quantity of voids or interstices present in the geological stratum [1]. Porosity can be defined as the ratio of the volume of pores or cavities inside a mass, indicating the portion of the rock volume that is unoccupied by solid matter [2]. Rocks exhibiting optimal porosity are typically very appropriate as reservoir rocks. Approximately 60% of oil and gas reservoirs are composed of sandstone, 30% of limestone, and the remainder of various other rock types [3].

The research focused on the Talang Akar Formation sandstones, specifically in the Rambangnia River track, Bungin Campang area, South OKU Regency, South Sumatra. Syn-rift and post-rift processes have influenced the formation of the Talang Akar Formation. Alluvial, river, and lacustrine sedimentation environments were established during syn-rift events. Marine and deltaic sedimentation habitats in shallow marine settings were established during post-rift processes characterized by transgression phases [4]. The Talang Akar Formation is crucial to the tectonic history of the South Sumatra Basin, having been deposited in a fluvial-deltaic environment [5], [6]. The Talang Akar Formation is recognized as a major oil and gas reservoir in the South Sumatra Basin. Seventy-five percent of the hydrocarbon content in the Talang Akar Formation, characterized by porosity values ranging from 15% to 30% and permeability above 5%, is derived from oil production in South Sumatra [7], [8].

The Talang Akar Formation's sandstones are formed through diagenetic processes that yield varied porosity in the South Sumatra Basin. Diagenetic process is a process that transforms sedimentary material into rock, so that it can increase or decrease porosity [9]. The diagenetic process includes compaction, dissolution, cementation, and authigenesis. The prior research examined the diagenesis and origin of the Talang Akar Formation sandstone in the Sukomoro region of Banyuasin Regency. In the Sukamoro area, the diagenesis process is characterized by compaction, dissolution, which alters the morphology of mineral fragments, leading to secondary porosity, cementation involving clay minerals, iron oxides, and silica minerals, and authigenesis, evidenced by the emergence of new quartz and chlorite minerals resulting from the authigenesis process [10]. The Talang Akar Formation in the Sukamoro region and its vicinity is partially sourced from magmatic arcs and recycled orogens [11]. In the Bungin Campang area, new research was conducted on the facies in the Talang Akar Formation. The facies found are *matrix-supported graded gravel* (Gmg), *matrix-supported gravel massive* (Gmm), *through cross-bedded* (St), *massive sandstone* (Sm), *horizontally bedded sandstones* (Sh), *parallel laminated siltstone and claystone* (F1), *massive siltstones, and mudstones* (Fsm). The facies associations obtained are *sedimentary gravity flow* (SG), *gravel bars* (GB), *sandy bedforms* (SB), *channels* (CH), *and overbank fine* (FF) [12]. However, research on the diagenesis of the porosity of the sandstone of the Talang Akar Formation of the Bungin Campang Area has not been conducted comprehensively. Diagenetic processes can both reduce and enhance porosity, depending on the specific mechanisms involved. While compaction and cementation tend to reduce porosity, dissolution and fracturing can increase it. So, diagenetic control is a key determinant of the evolution of porosity in sedimentary rocks, especially in the context of reservoir quality. Therefore, the results of this study are expected to provide insight into the diagenesis of Talang Akar Formation sandstones that control porosity to determine the quality of hydrocarbons that have significant reservoir potential.

LITERATURE REVIEW

Diagenesis

Diagenesis is the process by which unconsolidated sedimentary material is converted into rock via physical, biological, and chemical mechanisms. Diagenesis alters the texture and mineral composition of the rock. Physical processes entail fluid loss and material compression, which can diminish porosity and enhance permeability [9]. The aspects examined include the pattern of physical interactions among minerals (compaction), mineral dissolution, the presence of cement, and the development of authigenic minerals (authigenesis). This investigation will elucidate the diagenesis process involved in sandstone. The stages of diagenesis are divided into eogenesis, mesogenesis, or telogenesis phases.

Porosity

Porosity is a property that quantifies the volume of voids within a rock [2]. The porosity gradient is contingent upon the composition of sandstone, the nature of pore fluids, historical factors, temperature, and temporal duration [12]. This study specifically analyzes the porosity characteristics of sandstone based on its lithological composition and pore fluid properties. This aims to clarify the direct relationship between composition and porosity. Porosity is the ratio of the volume of pore spaces to the overall volume of the rock. This ratio is typically stated as a percentage and is known as porosity. Geological processes influencing the porosity properties of sandstone include those occurring during deposition (syn-depositional) and those occurring after deposition (post-depositional). The porosity value of a sedimentary rock can be classified according to [13] (Table 1).

METHOD

The research methods used are field observation, petrographic analysis, diagenesis analysis, and porosity analysis. Field observations were carried out to observe the appearance of rocks, the position of rock layers, sedimentary structures, and geological structures that developed in the research area. Field observations as well as taking field data, such as the position of sandstone layers and rock sampling, along with giving location codes TOMT-01, TOMT-02, TOMT-03, TOMT-04, TOMT-05, TOMT-06, TOMT-07, TOMT-08, TOMT-09, TOMT-10, TOMT-011, and TOMT-12 (Figure 1). Rock sampling was also carried out for laboratory analysis in the form of petrographic analysis. Studio analysis in the form of diagenesis analysis and porosity analysis of Talang Akar Formation sandstones.

Petrographic analysis was carried out on 12 sandstone samples using a polarizing microscope. The petrographic analysis uses a thin incision of rock to determine the estimated or approximate porosity value quantitatively. The petrographic analysis aims to determine the characteristics and minerals in micro-sized rocks [9]. For petrographic analysis, Pettijohn's classification of sandstones was used, which was identified based on the percentage of quartz (Q), lithic (L), and feldspar (F) minerals [14]. Petrographic analysis is used as the basis for conducting diagenesis and porosity analysis. The results of the petrographic analysis of the sandstone incision include mineral grain size, characteristics of the mineral composition of the rock, sorting, degree of sorting, and packing. These results will be useful in seeing the relationship between diagenesis and porosity of sandstones.

The studio analysis includes diagenesis analysis and porosity analysis of the Talang Akar Formation sandstones in the Rambangnia River track. The diagenesis analysis was used to determine the stages of diagenesis that occur in the Talang Akar Formation sandstones. Aspects considered during diagenesis analysis include mineral interaction patterns, mineral dissolution, cement presence, and authigenic mineral formation. The phases of diagenesis analyzed start from the compaction phase, which develops by looking at the contact between sediment grains in sandstone samples [15]. The dissolution phase is done by looking at the crushed and dissolved minerals in the sample. The cementation phase is when the cement is analyzed by looking at the cement resulting from the dissolution process, on the microscopic appearance. The authigenesis phase by looking at the primary minerals that are replaced due to weathering or precipitation.

Table 1. Classification of porosity values [13].

Porosity (%)	Quality of Porosity
0−5	Negligible
5−10	Poor
10−15	Fair
15−20	Good
20−25	Very Good
> 25	Excellent

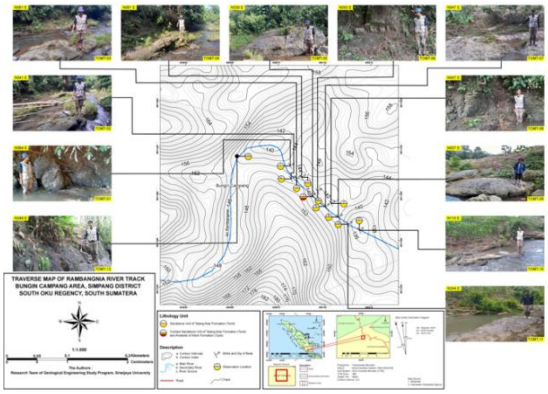

Figure 1. Traverse map of Rambangnia River Track, Bungin Campang area.

The next step is to calculate the porosity value (porosity analysis). The porosity analysis aims to obtain the percentage of rock porosity. In determining the quality of porosity of the sandstone Talang Akar Formation, porosity classification according to [13] is used. Porosity analysis on 12 Talang Akar Formation sandstone samples was carried out through thin section using ImageJ software. In this porosity analysis, the photo of the Talang Akar Formation sandstone petrographic sample was changed to 8-bit color so that it could be processed and measured, and the porosity area of 12 samples was obtained. The porosity of a rock depends on cementation, dissolution, and compaction in the diagenesis process. After obtaining all the data, we integrate the diagenesis and porosity analysis results on Talang Akar sandstone to determine the diagenetic control on the sandstone reservoir (Figure 2).

RESULTS AND DISCUSSION

Petrography Analysis

Petrographic analysis is used to determine the mineral composition of the rock and to determine the origin of the mineral composition. The mineral composition of the sandstone will later be used to determine the name of the rock (Table 2). The relationship between petrography data, diagenesis, and porosity analysis is fundamental to understanding the evolution and reservoir quality of sedimentary rocks. In the Rambangnia River, Bungin Campang area, there are three types of sandstone: lithic wacke, sublitharenite, and litharenite. Litharenite sandstones have a higher percentage of lithic fragment composition than quartz and feldspar minerals. Litharenite is typical of lower porosity due to compaction and unstable grain alteration. In the study area, litharenite is located in TOMT-03, TOMT-04, TOMT-05, TOMT-07, and TOMT-10. Lithic wacke

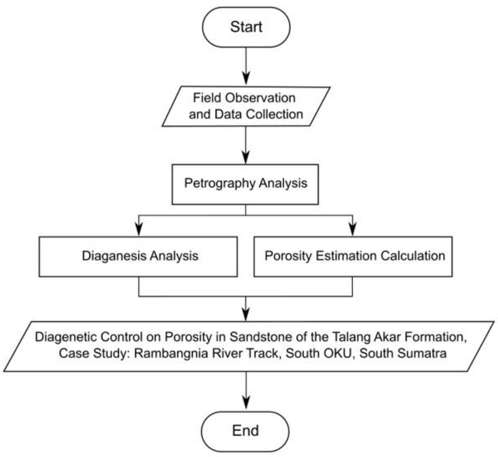

Figure 2. Research flowchart.

Table 2. Mineral composition of sandstone of Talang Akar Formation Rambangnia river track.

Sample ID	Fragment (%)												Matrix (%)			Cement (%)		Sandstone Type
	Qz	Bio	F	Calc	Ort	Op	Lit	Anh	NSG	Sg	Gl	H	L	Ma	Ml	Si	Calc	
TOMT-01	30	3	1	1	1	5	12	-	-	-	-	-	21	-	5	10	3	Lithic Wacke
TOMT-02	8	-	-	8	-	4	2	30	-	-	-	-	8	-	5	30	3	Sublitharenite
TOMT-03	7	-	-	31.5	-	3	15	8.5	0.5	-	-	-	12	-	2	5	1	Litharenite
TOMT-04	3.5	-	-	6	-	3	5	2	-	-	7	-	5.5	-	2	30	8	Litharenite
TOMT-05	4.5	-	-	10	-	7	11	-	-	-	2	-	9.5	-	2	20.5	10	Litharenite
TOMT-06	3	-	-	21	-	8	13	-	-	-	3	-	23	-	2	7.5	2	Lithic Wacke
TOMT-07	5.5	-	-	8	-	3	11	-	-	-	6	0.25	10	-	2	13	11	Litharenite
TOMT-08	3	-	-	4.5	-	10	22	0.25	-	-	7	-	9	-	10	2	5	Lithic Wacke
TOMT-09	2	-	-	30	-	4	5	-	0.5	-	3.5	-	12	-	7	19	6	Lithic Wacke
TOMT-10	6	-	-	5	-	13	36	3	-	-	8	-	10.5	-	1.5	7.25	3	Lithic Wacke
TOMT-11	-	-	-	-	-	4	6	-	-	2	3	1	-	25	1.5	35	0.5	Lithic Wacke
TOMT-12	2	-	-	-	-	4	42	-	-	-	1	1	45	-	2	20	13	Lithic Wacke

is similar in character to litharenite, but is composed of a significant clay matrix and is poorly sorted. In terms of diagenesis, later early compaction of the matrix causes severe porosity loss. The presence of a clay matrix also causes the porosity to be low and restricted. Lithic wacke sandstones are found in TOMT-01, TOMT-06, TOMT-08, TOMT-09, TOMT-11, and TOMT-12.

Diagenesis Analysis

Compaction Phase

The compaction process in the study area also shows strong compressed conditions, as seen in the calcite mineral fragments. The calcite mineral is seen to be strongly deformed, so it shows an offset in the appearance of the thin rock section (Figure 3). In addition, strong compression is also indicated by the presence of silica veins, and a *pseudo-matrix* mineral texture was also found in the rock-thin section. This texture is formed from fragments of other rocks and generally occurs in rocks that experience high pressure during deposition or advanced diagenesis (Figure 3). The sandstones of the Talang Akar Formation in the Bungin Campang area also show grain relationships between rock fragments, such as *floating contact, point contact, long contact, concavo-convex,* and *sutured contact*. This process can occur due to the loading pressure of the sediments deposited above it.

Dissolution Phase

In the Talang Akar Formation sandstones, it can be seen that all sandstone samples experienced a dissolution phase. All *dissolution* processes that occur are caused by the dissolution of silica minerals. Most of the dissolved minerals are lithic minerals, but there are also some plagioclase and calcite minerals. Dissolution of calcite minerals can be found in TOMT-03, TOMT-04, TOMT-05, TOMT-06, TOMT-07, TOMT-08, TOMT-09 and TOMT-10. Furthermore, plagioclase dissolution can be found in TOMT-08 and TOMT-10. This process also causes the formation of secondary porosity in the form of *intragranular porosity*. *Dissolution* in the samples is also partly influenced by alteration activity, as indicated by the number of *veins* found, especially in samples TOMT-2 and TOMT-7.

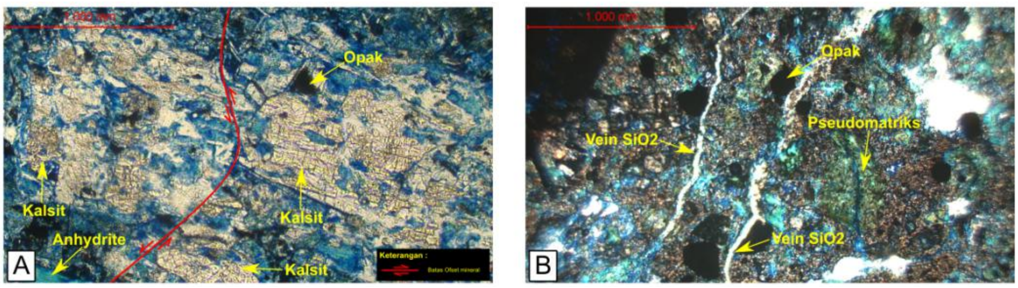

Figure 3. The appearance of strong compaction in thin sections of rock; (A) Appearance of offset on calcite mineral fragments in TOMT-03 sample with 20× magnification; (B) Appearance of silica vein and pseudomatrix texture in TOMT-04 sample with 5× magnification.

Cementation Phase

The study area is mainly cemented by silica (SiO_2) and calcite ($CaCO_3$) minerals (Figure 4).

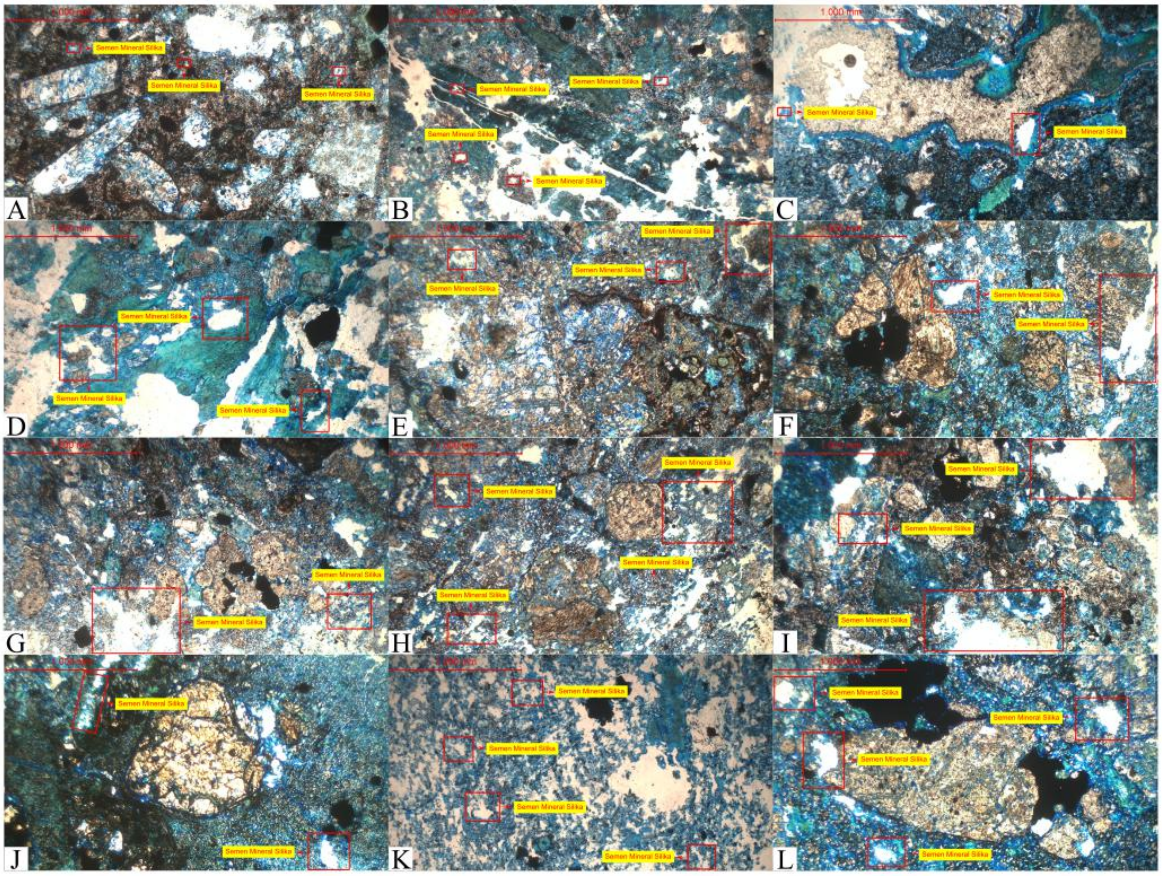

Figure 4. Appearance of cementation process in sandstone samples of Talang Akar Formation; (A) TOMT–01; (B) TOMT–02; (C) TOMT–03; (D) TOMT–04; (E) TOMT–05; (F) TOMT–06; (G) TOMT–07; (H) TOMT–08; (I) TOMT–09; (J) TOMT–10; (K) TOMT–11; (L) TOMT–12.

Authigenic Mineral Forming Phase

Authigenic minerals are seen in TOMT-01 in the form of opaque minerals above silica and calcite minerals, but oxide minerals are also found, which are naturally occurring inorganic compounds. Oxide minerals are also present in several locations, such as TOMT-01, TOMT-02, TOMT-04, TOMT-05, TOMT-011, and TOMT-012. Glauconite minerals are also found in almost every observation location and have a yellowish-green appearance. Glauconite minerals characterize marine depositional environments [16].

Based on diagenesis analysis, the eogenesis stage (*early diagenesis*) begins with the initial compaction of sedimentary deposits, rearrangement of sedimentary materials, mineralogical changes, and initiation of cementation processes in sandstone layers. This stage begins with the occurrence of changes, as well as the rearrangement of grain and rock components. Furthermore, there is a stage of mesogenesis (*burial diagenesis*) where several factors cause the compaction process to increase. There is loading by new material on top of the sedimentary layer, so that the thickness of the sedimentary layer, which was originally very thick, is then burdened and decreases in thickness. The mesogenesis process causes the dissolution of some mineral fragments to form secondary porosity (dissolution pore). The telogenesis stage (uplift diagenesis) that occurs in the sandstone layer is caused by tectonic activity, so that it is exposed to meteoric water, which causes the process of mineral dissolution and mineral oxidation. In the sandstones of the Talang Akar Formation of the Rambangnia River, the telogenesis stage is characterized by the discovery of authigenic minerals in the form of feldspar, which undergoes weathering due to meteoric water, resulting in iron oxide content and conversion into opaque minerals.

Porosity Analysis of Talang Akar Sandstone

In general, the porosity of rocks in the study area ranges from *fair to good*, with a porosity percentage of 10.15% - 19.49% [13] (Table 3 and Figure 5). The percentage of porosity in the good category (15 - 20%) is seen in observation locations TOMT-03, TOMT-04, TOMT-08, TOMT-09, and TOMT-12. Then, samples with fair porosity category (10 - 15%) are seen in observation locations TOMT-01, TOMT-02, TOMT-05, TOMT-06, TOMT-07, TOMT-10, and TOMT-011. Minerals in the form of feldspar undergo weathering due to meteoric water, so that iron oxide content is converted into opaque minerals.

Relationship Between Detrital, Diagenesis, and Porosity

The size of the porosity value of sandstone is influenced by the percentage of detrital material and diagenetic process. The higher percentage of detrital in the rock will make the porosity value smaller. This is due to the large number of fragments and matrix that close the pore space. It can also be seen that the higher the percentage of diagenesis that occurs, the smaller the porosity value of the sandstone, but the decrease in porosity value is not as big as the decrease in porosity value if the rock has a higher number of detrital materials. This is because when the diagenesis process occurs, it will also indirectly trigger the formation of secondary porosity during dissolution and compaction. Based on Figure 6, which shows the detrital, diagenesis, and porosity percentages of the 12 samples, it can be seen that the porosity (colored green) tends to be in the low to medium range, i.e., between 10% and about 20%. Although there are small fluctuations, in general, porosity appears to increase gradually from sample TOMT-01 to TOMT-12. In most samples, the porosity values are relatively higher when the diagenesis component is low, such as in samples TOMT-09 and TOMT-10, indicating the possibility that diagenetic processes such as cementation and recrystallization have reduced the pore space. In contrast, when diagenesis values are high, as in

Table 3. Porosity analysis of Rambangnia River Track, Bungin Campang area.

Sample ID	Sandstone	Porosity (%)	Quality of Porosity	Diagenesis Stage
TOMT-01	Lithic wacke	10.15	Fair	Telogenesis
TOMT-02	Sublitharenite	12.50	Fair	Telogenesis
TOMT-03	Litharenite	18.50	Good	Telogenesis
TOMT-04	Litharenite	19.23	Good	Telogenesis
TOMT-05	Litharenite	13.76	Fair	Telogenesis
TOMT-06	Lithic wacke	13.05	Fair	Telogenesis
TOMT-07	Litharenite	10.63	Fair	Telogenesis
TOMT-08	Lithic wacke	17.41	Good	Telogenesis
TOMT-09	Lithic wacke	19.49	Good	Telogenesis
TOMT-10	Litharenite	13.78	Fair	Telogenesis
TOMT-11	Lithic wacke	14.76	Fair	Telogenesis
TOMT-12	Lithic wacke	19.21	Good	Telogenesis

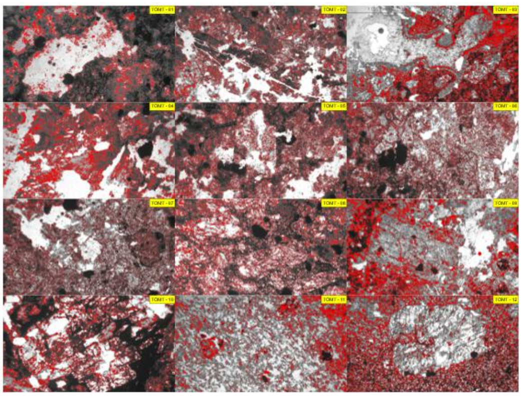

Figure 5. Porosity appearance of sandstones of Rambangnia River Track, Bungin Campang.

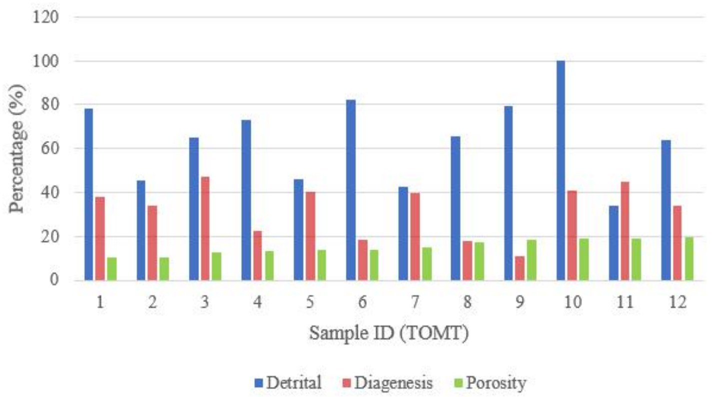

Figure 6. Percentage of detrital, diagenesis, and porosity.

TOMT-03 and TOMT-05, porosity tends to be lower, indicating a negative relationship between diagenesis intensity and pore capacity. Meanwhile, high detrital content is not directly negatively correlated with porosity; for example, samples TOMT-06 and TOMT-10 have high detrital values and still maintain good porosity. This suggests that detrital grain properties (e.g., size and roundness) also play an important role in keeping the pores open. Overall, this graph indicates that porosity is most affected by the degree of diagenesis, where the more intense the diagenetic process, the lower the porosity of the rock.

If the percentage of cement in the rock sample is greater, the porosity will be worse because the cement will close the cavity or pore of a rock, so that it cannot store fluid. Then, if there is dissolution in the sandstone sample, the porosity of the rock will be good. Furthermore, if the compaction process in a rock is stronger, the porosity of the rock will be worse, because the process will compress the sediment grains so that there is no gap or cavity for fluid to flow in the rock.

The diagenesis stage of the Talang Akar Formation sandstones of the Rambangnia River in the Bungin Campang area has reached the telogenesis stage, resulting in fair to good porosity. In addition, this is also evidenced by the presence of iron oxide minerals, which characterize the Telogenesis stage. This is different from the Talang Akar sandstone in Sukamoro, which is dominated by the eogenesis-mesogenesis stage [10]. The quality of porosity in the Rambangnia river track, South OKU regency, is fair to good, influenced by the intense compaction process. Intense compaction is one of the causes of the reduction in rock porosity value due to the closer relationship between grains that reduces the porosity value of the rock. This intense compaction is characterized by suture contact in the study area. In addition, the composition of lithic wacke-dominated sandstone also supports the porosity of the study area, which has a dominant porosity of fair value. Thus, diagenetic control influences the porosity value of sandstones of the Talang Akar Formation of the Rambangnia River Track in the Bungin Campang Area. Integration of diagenesis and reservoir analysis data was carried out to obtain potential reservoir areas in the Bungin Campang area.

In the study area, it is known that TOMT-03, TOMT-04, TOMT-08, and TOMT-09 are potential reservoir areas because they have good porosity (>15%). Although TOMT-8 and TOMT-9 are included in the lithic wacke sandstone type, due to the presence of geological structures in the form of normal faults around the position of LP-8 and LP-9, the porosity changes to high with good porosity quality. The geological structure causes secondary porosity in TOMT-08 and TOMT-09, resulting in increased pore size.

CONCLUSION

Diagenetic control affects the porosity value of sandstones of the Talang Akar Formation of the Rambangnia River Track. The Talang Akar Formation of the Rambangnia River sandstone in the Bungin Campang area consists of lithic wacke, sublitharenite, and litharenite. Based on diagenesis analysis, the research area has reached the telogenesis stage. This eogenesis occurs at a reasonably shallow depth or near the surface. Furthermore, the mesogenesis stage causes the compaction process to increase. The mesogenesis stage in the Talang Akar Formation is characterized by rock compaction, mineral dissolution, and cementation. The strong compaction can be seen from the appearance of the relationship between grains in the sample that produces grain contact in point contact, prolonged contact, concave-convex contact, and sutured contact. Rock porosity in the study area ranges from fair to good, with a porosity percentage of 10.15%–19.49%. Compaction is closely related to cementation, which continuously reduces sandstone porosity. The cementation process occurs when pores or cavities in the rock are filled by cement due to the silica dissolution of some mineral fragments. In the study area, TOMT-03, TOMT-04, TOMT-08, and TOMT-09 are potential reservoir areas because they have good porosity (>15%). Although TOMT-8 and TOMT-9 belong to the type of lithic wacke sandstone, the geological structure in the form of a descending fault around the position of LP-8 and LP-9 creates a secondary porosity that results in higher porosity quality.

ACKNOWLEDGEMENT

The research/publication of this article was funded by DIPA of Public Service Agency of Universitas Sriwijaya 2024. SP DIPA 023.17.2.677515/2022, on November 24, 2023. In accordance with the Rector’s Decree Number: 0039/UN9/SK.LP2M.PT/2024, on May 20, 2024.

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