Microfacies and paleoenvironmental study of the Peneta Limestone Formation from Tebing Tinggi, Kerinci Area

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Abstract

The research location is the Tebing Tinggi Village, Kerinci region - Jambi, part of the Barisan Zone. This study focuses on the limestone of the Peneta Formation, which is part of the Pre-Tertiary age. The research will investigate the characteristics of carbonate rocks in the Peneta Formation, including the developed facies, fossil content, and the diagenesis process in the Peneta Formation using field data, petrography, and XRD. Our research has succeeded in dividing the Limestone of the Peneta Formation into 3 lithofacies in the study area, including dismicrite, dolomitic limestone, and meta-mudstone. The lack of marine organisms and the dominance of the mudstone facies indicate that the limestone of the Peneta Formation was deposited in an evaporite or brackish zone environment. The limestone diagenesis process was also confirmed in this study. The research location is included in the mesogenesis stage due to the presence of foliation structures, decussate texture, and dolomite minerals until the telogenesis stage, which is characterized by sparite calcite blocky. Furthermore, forsterite and diaspore minerals were also identified through petrographic and XRD analysis, indicating the occurrence of metamorphic processes at our research location.

Keywords: Limestone, Microfacies, Peneta Formation, Kerinci

INTRODUCTION

Limestone is a sedimentary rock containing more than 90% calcium carbonate (CaCO3), formed in shallow marine environments, such as continental shelves or platforms. However, smaller amounts were formed in many other environments (Boggs, 2006). Limestone forms when these minerals precipitate out of water containing dissolved calcium, which can be formed by biological and nonbiological processes, such as the accumulation of corals and shells in the sea (Scholle and Ulmer-Scholle, 2005; Boggs, 2006). Limestone often contains fossils as a skeletal fragment and aggregated carbonate mud, such as pellet or peloid, as a non-skeletal fragment (Scholle and Ulmer-Scholle, 2005), which can provide information on ancient marine environments. Some applications of limestone composition study (especially fossil content) for interpreting paleo-marine conditions include identifying the age of limestone formation, the geometry of paleo-marine (paleo-environment) (Gischler et al., 2003; Sierra et al., 2023), paleo-salinity (Kammer, 1979), and also paleotemperature and paleo-oceanography (Montanez, 2002; Akmaluddin et al., 2010).

This study focuses on the limestone of the Peneta Formation in the Tebing Tinggi, Kerinci, Jambi. Limestone is a type of lithology or rock containing many marine biota types. This limestone of Peneta Formation in the Tebing Tinggi, Kerinci, is older than the Tertiary (older than 66 million years ago). Geologically, the Kerinci region is part of the Barisan Zone and Bengkulu Zone (Kusnama et al., 1992), located on the edge of the Bukit Barisan (Figure 1). The Peneta Formation is composed of shale, sandstone, and limestone of the Cretaceous age (66 to 145 million years ago). The discovery of ammonite fossils of the Early Cretaceous age was the first research on the Peneta Formation carried out by Baumberger (1925) in the Sungi Pobungo area, and Silvestri (1925) found *Choffatella cyclamminoides* fossils from the Late Jurassic to Early Cretaceous in the Sungi Tuo area, Jambi. Furthermore, Jannah and Hastuti (2022) and Lakon and Hastuti (2024) also examined the characteristics and provenance of Peneta Formation sandstone in Sarolangun Regency, Jambi. No detailed studies or publications discuss the limestone of Peneta Formation, such as limestone

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composition and characteristic fossils; hence, studying in the Jambi area or other locations is interesting.

Then, there is still minimal knowledge regarding the existence of the limestone of the Peneta Formation in Kerinci Region, where the regional geological Map from Kusnama et al. (1972) and Suwarna et al. (1992) does not even mention the presence of limestone of the Peneta Formation in this area, and this study will revise this. Therefore, the research aims to identify limestone in the Goa Kelelawar area to interpret the marine environment conditions when the limestone was formed. This research will focus on studying the characteristics of carbonate rocks in the Peneta Formation, including the evolving facies, fossil content, and diagenetic of the Peneta Formation.

MATERIAL AND METHOD

This research has collected 20 samples of Peneta Formation limestone from 20 observation locations using the purposive sampling method. The limestone rock was previously formed in a shallow marine environment. The sampling location was around Goa Kelelawar in the Tebing Tinggi area, Kerinci, Jambi (Figure 1). Rock samples were taken by considering the stratigraphic position, representing the rock's old and young ages. All samples had physical descriptions of the rocks directly while in the field.

A total of 6 selected samples measuring 10x10 cm were used for petrographic analysis. The petrographic method involves preparing a thin section of a rock sample on a mica plate measuring 2 x 6 cm and a section thickness of ±0.2 mm. Thin section analysis can observe rock characteristics such as texture, structure, mineral composition, and fossil content. Folk's (1962) classification will be used as a reference in determining rock names based on matrix content. The Flugel's (2010) classification is used to interpret depositional environments based on the dominance of lithological characteristics. The thin section samples were then observed in the paleontology laboratory, geological engineering UGM, using a polarizing microscope with 40x magnification and taking representative photos of each sample. Meanwhile, paleontological analysis was carried out by identifying the types of fossils found in the rocks to determine the age and paleoenvironment of the limestone in the Peneta formation.

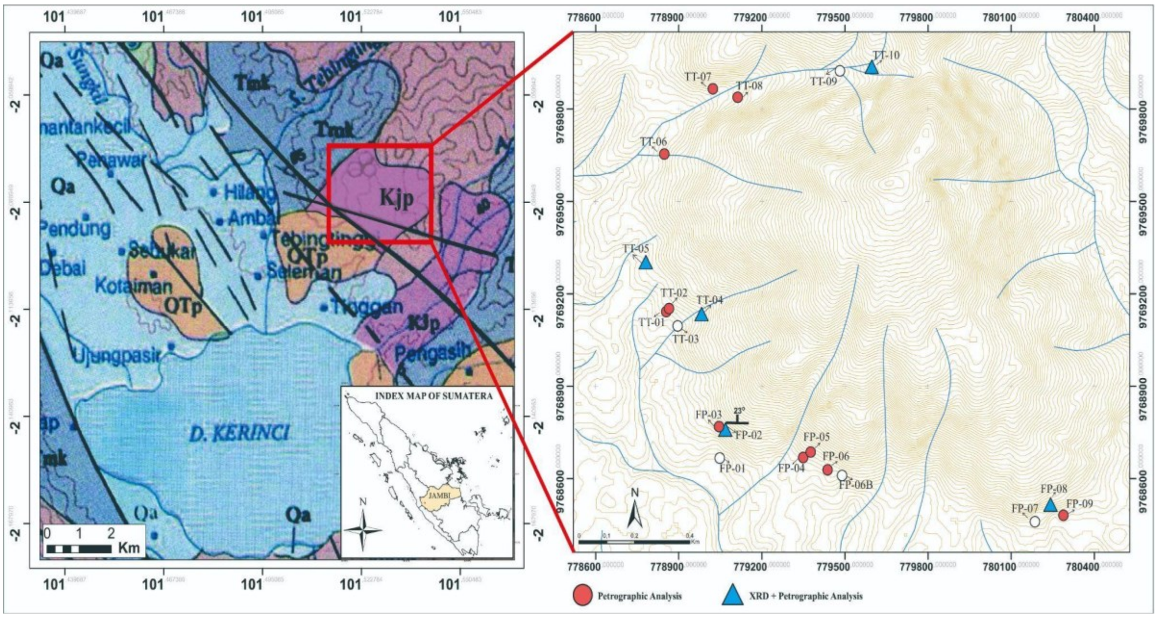

Figure 1. The research area of the Peneta Formation (KJp) on the Geological Map (Kusnama et al., 1992) and sample position on the topographic map (Badan Informasi Geospasial, 2017).

Additionally, the X-ray diffraction (XRD) Method is applied through testing at the Geochemical Laboratory in the Geological Engineering UGM and is used to support our petrographic analysis. The concept of the XRD method is to calculate the diffraction angle of the material emitted by X-ray transmission. This XRD method can provide precise and quantitative mineral information on samples. Determination of rock mineral composition using references from Chen (1977). The lithology, petrography, and XRD analysis results will be a reference for facies division in the Peneta Formation at the research location.

RESULT DAN DISCUSSION

Based on the fieldwork in the Goa Kelelawar area, analysis and sampling were conducted on the lithology found. All the lithology found is limestone (carbonate rock, in general). This is quite different from the regional geological Map from Kusnama et al. (1992), where it is considered that the Peneta Formation in this area is composed of sandstone (non-carbonate rock) lithology. Therefore, this study evaluates previously existing regional geological maps. The Peneta Formation is also composed of sandstone lithology, but it developed in the Tambang Tinggi and Slango areas, Sarolangun Regency, as mentioned by Jannah and Hastuti (2022) and Lokon and Sutriyono (2024).

A total of 20 samples, including sedimentary carbonate rocks and meta-carbonate rocks, were collected and analyzed (Table 1). The samples were collected from the research area's northern, western, southern, and southeastern parts. Some samples were selected for petrography and XRD analysis. The lithofacies were interpreted based on the integration between field observation and petrography. Calcite and dolomite minerals were identified as present in all rock samples. The lithofacies of the Peneta Formation in the research area can be divided into three lithofacies:

This facies is developed in the western part of the research area, as indicated by the lithology and petrography observed in the FP-02, FP-03, TT-01, TT-02, TT-04, and TT-05 samples. Macroscopically (Figure 2a), this facies is crystalline and has a light gray color, very fine to fine grain/crystal size. Microscopically (Figure 2b), this facies is composed of lithology dominated by very fine micrite (<0.1 mm) and present locally at sparite calcite blocky, mud supported, presence of calcite vein, and fossils not found. The limestone is generally unaffected by metamorphism. All these characteristics are the basis for determining these facies.

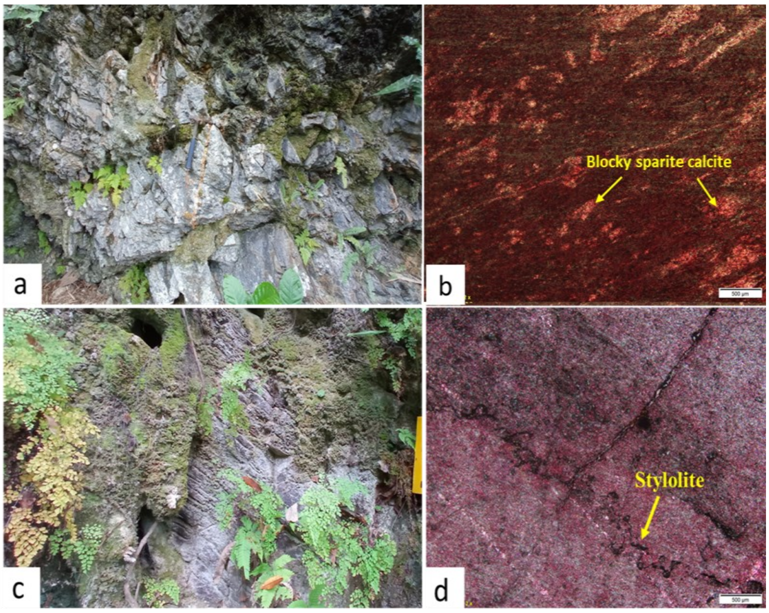

Figure 2. Photograph of a rock outcrop (a) and a thin section showing blocky sparite calcite (b) from FP-02 and rock outcrop (c) and thin section showing stylolite structure (d) from TT-10 sample.

Table 1. Macroscopic feature of the Peneta Formation sample

Sample	Macroscopic Features			
	Color	Vein	Foliation/ Alignment	Sylolite
TT-01	Gray	white	-	-
TT-02	Light gray	white	-	-
TT-03	Light gray		-	-
TT-04	Gray	white	-	-
TT-05	Light gray	white	low	-
TT-06	Light to dark gray	white	moderate	-
TT-07	Dark gray	Dark	high	-
TT-08	Dark gray	White, greenish	high	-
TT-09	Dark gray		moderate	-
TT-10	Gray	Dark	high	low
FP-01	Light gray		-	-
FP-02	Light gray		-	-
FP-03	Gray		-	-
FP-04	Gray		-	-
FP-05	Gray		low	-
FP-06	Light gray	White	-	-
FP-06B	Gray	White	-	-
FP-07	Dark gray	Dark	moderate	-
FP-08	Light to dark gray	White, greenish	moderate	-
FP-09	Dark gray	White, greenish	high	-

This facies is developed in the southern part of the research area, as indicated by the lithology and petrography observed in the FP-04, FP-05, and FP-06 samples. Macroscopically, this facies has a light gray color, very fine grain/crystal size, and is often characterized by calcite veins. Microscopically, these facies consist of lithology dominated by micrite and a small amount of medium-sized (0.25-0.5 mm) dolomite crystals, mud-supported. The limestone is generally unaffected (none to minor evidence) by metamorphism. The dominant presence of dolomite is the basis for determining these facies.

This facies develops in the northwest and southeast parts of the research area, as indicated by the lithology observed and petrography in the TT-06, TT-07, TT-08, TT-09, TT-10, FP-07, FP-08, and FP-09 samples. Macroscopically (Figure 2c), this facies has a dark gray color, fine to medium grain/crystal size with a mosaic foliated structure, and is often characterized by calcite vein. Microscopically (Figure 2b), these facies dominate fine to medium-sized calcite and dolomite crystals (0.1 – 0.2 mm). The presence of foliated, decussate, and stylolite structures in macroscopic and microscopic samples is based on determining these facies. In mineralogy, these facies also contain accessory minerals such as feldspar, forsterite, muscovite, diaspore, and phlogopite (Table 2) (figure 3). The limestone is generally low to moderate, affected by metamorphism. Petrographic identification results, especially on sample FP-09, show indications of large foraminifera fossils and some appearances of small, round-shaped large corals that are difficult to identify due to transformation into calcite cement.

The lithofacies of dismicrite and dolomitic mudstone are generally developed in the western to southwestern part of the research area. In contrast, the metamorphism-affected lithofacies (meta-mudstone) are developed in the northern and southeastern part of the research area. In general, the three facies identified in this study align with the evaporitic or brackish zone (Flugel, 2010) (Figure 4), characterized by the dominance of mudstone, the occurrence of dolomitic mudstone, and a few marine organisms.

Table 2. Mineral composition based on petrography analysis of meta-mudstone facies. In column Mineralogical assemblage: Cal (calcite), Dol (dolomite), Fsp (feldspar), Fo (Forsterite), Ms (muscovite), Di (diaspore), Phl (phlogopite)

Sample Code	Mineralogical Occurrence							Name
	Carbonate Minerals		Accessory Minerals					
	Cal	Dol	Fsp	Fo	Ms	Di	Phl	
FP 08	Main	Sub		x		x		Meta-Mudstone
FP 09	Sub	Main			x			Meta-Mudstone
TT 06	Sub	Main			x		x	Meta-Mudstone
TT 07	Main	Sub	x		x		x	Meta-Mudstone
TT 08	Sub	Main	x	x	x	x		Meta-Mudstone
TT 10	Main	Sub	x					Meta-Mudstone

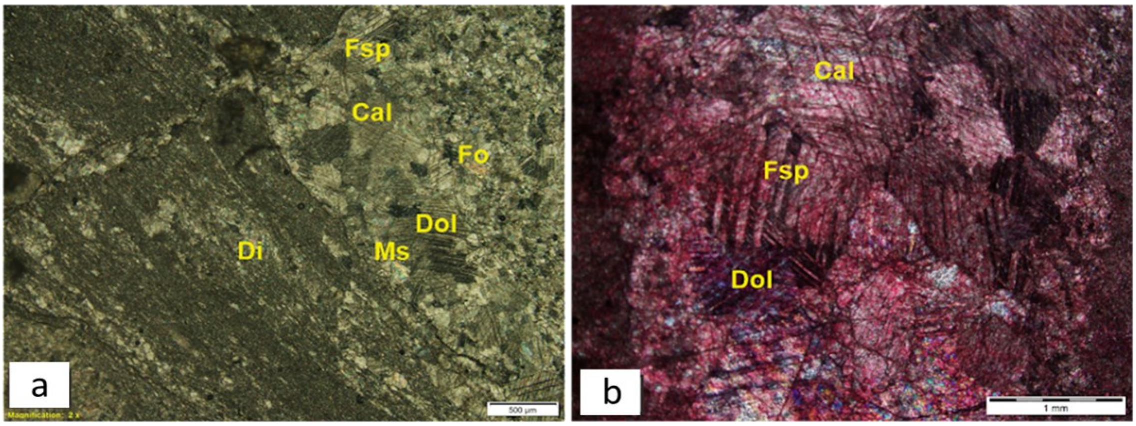

Figure 3. Photomicrographs from meta-mudstone facies on TT-08 (a) and TT-10 (b) samples show mudstone lithology. There are foliated structural features in sample TT-08 (a) and decussate texture in sample TT-10 (b). The mineral composition present includes carbonate minerals such as calcite (Ca) and dolomite (Dol) and accessory minerals such as muscovite (Ms), phlogopite (Phl), feldspar (Fsp), diaspore (Di), and forsterite (Fo).

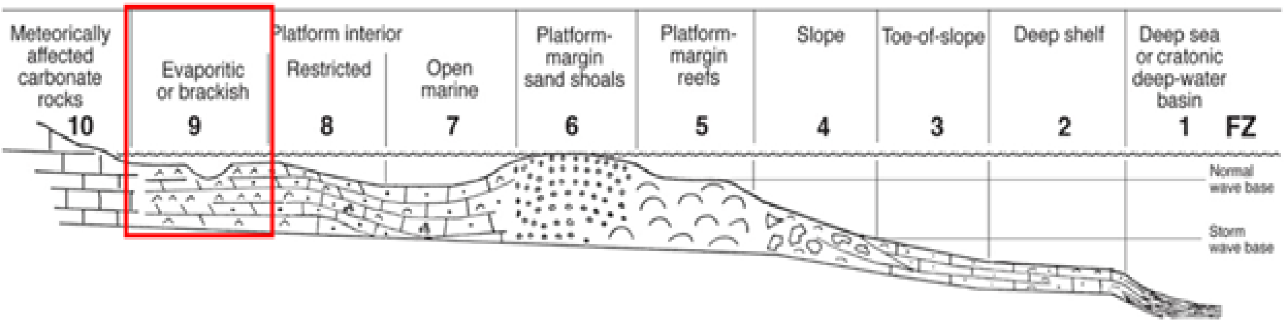

Figure 4. Facies and paleoenvironmental analysis of the Peneta Limestone Formation from Tebing Tinggi indicates an evaporite or brackish zone (Flugel, 2010)

XRD analysis is carried out to determine the mineral composition of the rocks of each sample at the research location. The mineral data from XRD analysis was obtained from the highest peak read, using the references from Chen (1977). The mineral results from processing the graphic patterns for each sample can be seen in Table 3 below. Dolomite, Forsterite, Calcite, Corondum, Talc, and Diaspore were detected in almost all of the samples (Figure 5).

Based on the results of field data analysis and petrography of the limestone from the Peneta Formation, it is challenging to identify fossil species due to their intensive metamorphism and replacement into calcite cement. Therefore, identifying this study's age and paleoenvironment is quite challenging. However, in FP-09 samples from this Peneta formation, *Choffatella* cf. *cyclamminoides*, large foraminifera, and mollusca shell fossils are present (Figure 6). Provides a general picture that the Peneta Formation was formed in a paleoenvironment around the reef, which tends more toward the back reef lagoon. Thus, in this study, the age of the rocks refers to Silvestri (1925) researcher, who found *Choffatella cyclamminoides* fossils from the Late Jurassic to Early Cretaceous. The result has the same concepts as a previous study by Kusnama et al. (1992) and Silvestri (1925), suggesting that the Peneta Formation is from the Jurassic to Cretaceous age range. It is equivalent to the Pre-Tertiary carbonate from Aceh studied by Adhari et al. (2023), which is interpreted as a rock constituent of the Woyla Group (Barber and Crow, 2003).

Table 3. Geochemical composition based on XRD analysis

Mineral	Sample Code				
	FP-03	FP-08	TT-04	TT-05	TT-10
Calcite	x	x	x	x	x
Dolomite	x		x	x	x
Diaspore	x	x	x	x	x
Forsterite	x	x	x	x	x
Talc	x	x	x	x	x
Corundum	x	x	x	x	x

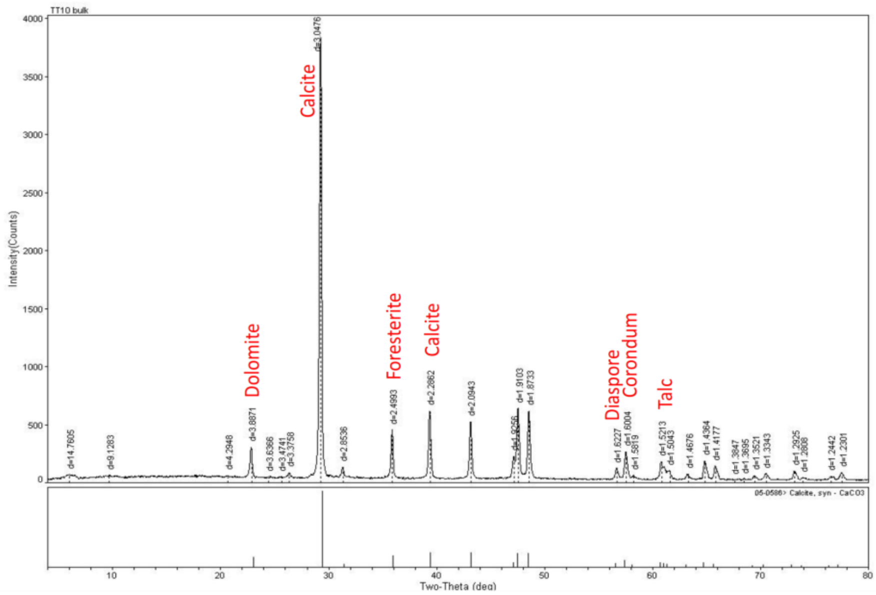

Figure 5. Selected XRD pattern (sample TT-10) showing the presence of diagenetic minerals (Dolomite) and metamorphic minerals (Forsterite and Diaspore) in the Limestone of Peneta Formation.

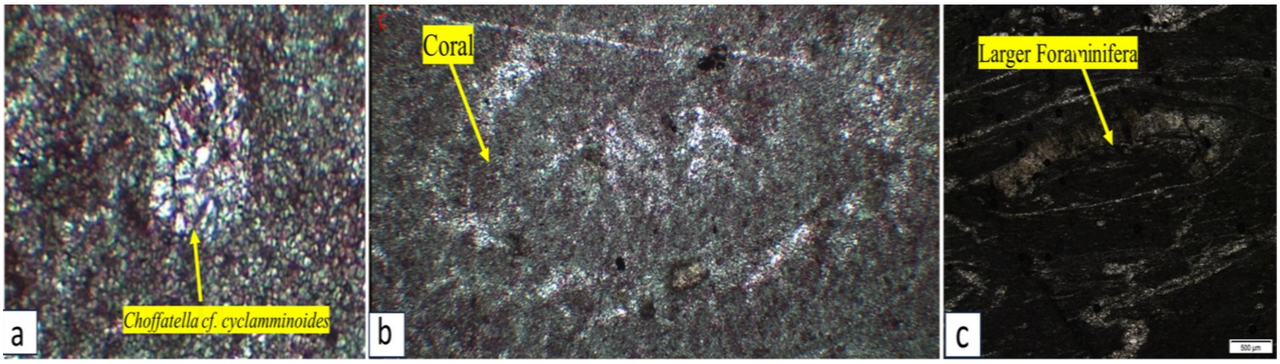

Figure 6. Photomicrographs of an identified skeletal fragment in Peneta Formation, (a) *Choffatella cf. cyclamminoides, (b) coral fragment,* and (c) large foraminifera in FP-09 sample.

The changes in the facies indicate a diagenetic process, and further north, the limestone changes to meta-mudstone (Figure 3). Outcrop and petrographic analysis also confirmed the diagenetic process that foliation and stylolite structures were found locally in the northern area. The petrographic and XRD analysis results show the presence of dolomite minerals. Early diagenetic or eogenetic stages in this study could not be observed. Meanwhile, the diagenetic process at the mesogenetic stage is characterized by a stylolite structure (Figure 2d), which shows the process of compaction diagenesis and pressure solution refer to mechanical and chemical processes that are triggered by increasing overburden of sediment during burial and increasing temperature and pressure conditions (Flugel, 2010). However, the more specific environment of the burial could not be determined in this study. The next stage is telogenetic, which occurs in a meteoric phreatic environment and is characterized by the presence of sparite calcite blocky (Figure 2a) and when rocks continue to rise to the surface in a vadose meteoric environment and come into contact with rainwater, causing dissolution to occur more intensely.

Then, indications of the metamorphism process were also found, which were visible from alteration minerals such as forsterite and diaspora originating from the metamorphism process of dolomite limestone or high Mg calcite limestone (Tormmsdof, 1996; Strauss et al., 2015). Furthermore, minerals like marcasite, diaspore, and pyrophyllite indicate hydrothermal alteration's influence on the Peneta Formation's limestone (Klein & Hurlbut, 1985). Based on the presence of these minerals, and also considering the distribution of facies with grain alignment and the presence of regional faults in the research area, it can be concluded that there is an influence of regional shear faults leading to both metamorphic and hydrothermal alteration processes in the Peneta Formation limestone in the study area.

CONCLUSION

The limestone of the Peneta Formation in the research area consists of three facies: dismicrite facies, dolomitic limestone facies, and meta-mudstone facies. The depositional environment is based on the dominance of mudstone and a few marine organisms, which concluded that the limestone of the Peneta Formation was deposited in an evaporitic or brackish zone environment. The diagenetic processes include mesogenesis in burial environments and telogenesis in meteoric phreatic and vadose environments.

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REFERENCES

Adhari, M. R., & Hidayat, R. (2023). A geological overview of the limestone members of the Woyla Group of Sumatra, Indonesia. *Journal of Geoscience, Engineering, Environment, and Technology*, 8(3), 189-195, doi: 10.25299/jgeet.2023.8.3.12190

Akmaluddin, Watanabe, K., Kano, A., & Rahardjo, W. (2010). Miocene warm tropical climate: Evidence based on oxygen isotope in central Java, Indonesia. *World Academy of Science, Engineering, and Technology*, 71, 66-70.

Badan Informasi Geospasial. (2017). Peta Per Wilayah RBI Kerinci. Retrieved February 20, 2024, from https://tanahair.indonesia.go.id/unduh-rbi/#/

Barber, A. J., & Crow, M. J. (2003). An evaluation of plate tectonic models for the development of Sumatra. *Gondwana Research*, 6(1), 1-28, doi: 10.1016/S1342-937X(05)70642-0

Baumberger, E. (1925). Die Kreidefossilien von Dusun Pobungo, Batu Kapur-Menkadai und Sungi Pobungo (Djambi, Sumatra), *Verhandelingen Geologisch-Mijnbouwkundig Genootschap, Kol., Geol,* Serie 8 (Verbeek volume), p. 17-47, Nederland.

Boggs, S. (2006). Principles of sedimentology and stratigraphy (4th ed.). Upper Saddle River, N.J.: Pearson Prentice Hall. pp. 177.

Chen, P.Y., (1977), Table of Key by Lines in X-Ray Power Diffraction Patterns of Minerals in Clays and Associated Rocks. Occasional Paper 21, Department of Natural Resources, Geological Survey, Bloomington, 67 p.

Flügel, E., & Munnecke, A. (2010). Microfacies of carbonate rocks: analysis, interpretation and application, Vol. 976, p. 2004. Berlin: Springer.

Folk, R.L., (1962), Spectral subdivision of Limestone Types. In: Classification of Carbonate Rocks, *American Association Petroleum Geologist*, Telsa.

Gischler, E., Hauser, I., Heinrich, K. & Scheitel, U. (2003): Characterization of depositional environments in carbonate platforms based on benthic foraminifera, Belize, Central America. *Palaios*, 18: 236-255.

Jannah, S.M., & Hastuti, E.W.D. (2022). Karakteristik Batupasir dan Provenance Formasi Peneta Daerah Tambang Tinggi dan Sekitarnya, Kabupaten Sarolangun, Jambi. *Jurnal Penelitian Sains Teknologi,* 13(1), 9-19.

Kammer, T.W. (1979). Paleosalinity, paleotemperature, and isotopic fractionation records of Neogene foraminifera from DSDP site 173 and the Centerville Beach Section, California. *Marine Micropaleontology,* 4, 45–60.

Kusnama, R. Pardede, S., Mangga, A. & Sidarto. (1992). Peta Geologi Lembar Sungai Penuh dan Ketaun, Sumatra, Skala 1:250.000, *Pusat Penelitian dan Pengembangan Geologi*, Bandung.

Lokon, B., & Sutriyono, E. (2024). Studi Provenance Batupasir Formasi Peneta Desa Slango, Kabupaten Sarolangun, Jambi. *Jurnal Universal Technic,* 3(1), 91-100.

Montanez, I.P. (2002). Biological skeletal carbonate records change in major-ion chemistry of paleo-oceans. Proceedings of the National Academy of Sciences, 99(25)

Scholle, P.A., Ulmer-Scholle, D.S. (2003) A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, Diagenesis. AAPG Memoir 77. The American Association of Petroleum Geologists

Silvestri, A. (1925). Sur quelques foraminiferes et pseudoforaminiferes de Sumatra. Verhandelingen Geologisch-Mijnbouwkundig Genootschap Kol., Geol. Serie 8 (Verbeek volume), p. 449-458, Nederland

Suwarna, N., Suharsono, & Gafur, S. (1992). Geological Map of the Sarolangun quadrangle, Sumatera. Bandung: Pusat Penelitian dan Pengembangan Geologi.