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Cover Letter

June 18, 2022

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Dear Editor of News of the National Academy of Sciences of the Republic of Kazakhstan-Series of Geology and Technical Sciences,

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The method and results of our research the level of novelty are high.

These informations are very interesting for the development of stratigraphy, microfasies and petrology of carbonate rocks in the field for scientists, researchers, and lecturers who read our journals.

This manuscript has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere.

Thank you for receiving our manuscript and considering it for review. We value the time of the Board of Editor and we await your response from the Board of Editor.

Thank you very much for your consideration.

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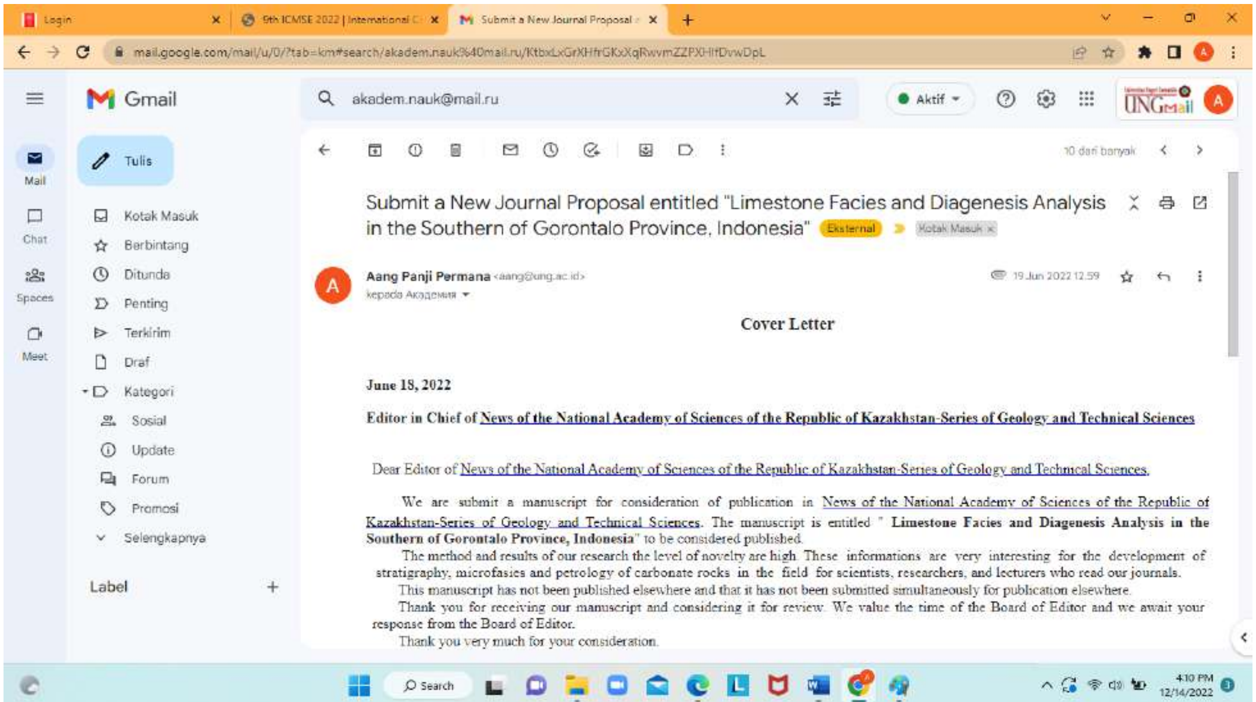
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Limestone Facies and Diagenesis Analysis in the Southern of Gorontalo Province, Indonesia

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Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province. The raising of limestone into hills, as seen today, is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Limestone research in the proposed research area is done on a regional scale, therefore more in-depth research is required to gather the most up-to-date geological data. For this reason, the goal of this research was to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys, including megascopic study of limestone and rock samples, and petrographic analysis in the laboratory, will be used to achieve the research objectives. The results revealed that the limestone facies in Gorontalo Province's southern part is coralline floatstone. Based on petrographic analysis, there are six different types of diagenesis processes that occur in coralline floatstone. The six processes of diagenesis include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises of three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end with the diagenesis process in the meteoric vadose zone.

Keywords: Diagenesis, Facies, Gorontalo, Limestone

1. Introduction

Diagenesis refers to the physical and chemical changes that occur after a sediment or sedimentary rock is deposited. It does not, however, contain metamorphism [1], a process involving high temperatures and pressures. Diagenesis has the ability to preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the sediments in relation to burial, uplift and sea level change, the influx of pore fluids and climatic differences [2].

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved in order to determine the sequence of diagenesis [3]. Changes can occur in three main diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history [4,5,6].

Carbonate rock diagenesis is comprised of six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, rate of water influx, time, and structural control [2]. Complex characteristics influence diagenesis processes in carbonate deposits such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development [7,8,9,10,11]. The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties. The chemistry of the pore water in particular, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis takes place in marine, meteoric, brackish, and hypersaline brines [8,12,13,14].

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 [15] composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of: basalt lava, andesitic lava, volcanic breccia, with intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, which is estimated to be of Pliocene-Plistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian [16]. The Reef Limestone Unit, which was formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid. This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift [16,17,18]. Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

2. Research Method

The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25"-0° 30' 05" N and 123° 2' 25" 123° 03' 00" E) (Figure 1).

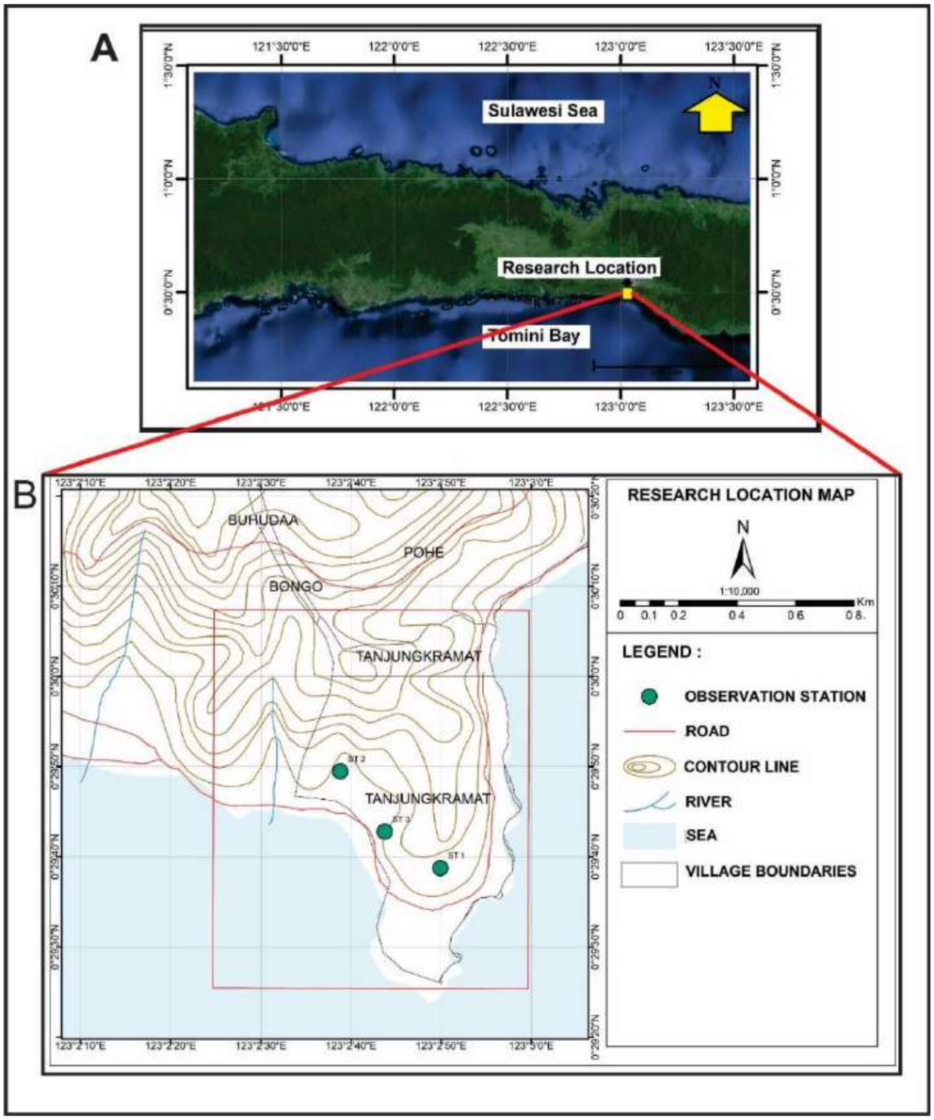

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

There are two research methods: field survey and laboratory analysis. There are two research approaches: qualitative analysis and quantitative analysis. The description and interpretation of limestone types, as well as suitable sampling for laboratory analysis, are the focus of field surveys. Laboratory analysis is petrographic analysis performed in the Geo Optics laboratory. The petrographic analysis stage begins with the formation of a thin section using the blocking method, which serves to infiltrate the blue dye into the pores in order to distinguish the original rock pores from the pores formed during preparation [19,20]. Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera [21,22,23]. Petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited [24,25].

3 Research Results and Discussion

A. Facies

The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, open packed, floating grains in the matrix and a massive structure. It is composed of coral fragments, quartz minerals, micrite, and sparite. The limestone is known as Coralline floatstone based on petrological analysis [26].

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone [26].

Detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The interference color varies in order II in the appearance of crossed nickel (X). The fragments are generally replaced by sparite (calcite) and the pores are filled with micrite as a result of micritization.

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X) the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains considered to be of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//) it is colorless brownish, on the appearance of nickel crossed (X) it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18^o. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, short prismatic shape, translucent, low relief, no pleochroism, no fracture observed. The appearance of crossed nickel (X) has an orange interference color of order 2, the darkening angle is 20-22^o.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, fracture is not observed, bladed – equant shape, blocky structure and meniscus. In the appearance of crossed nickel (X), it varies by the order of two. It is composed of calcite. It is the result of pore filling, micrite recrystallization, or changing the composition of the shell or coral.

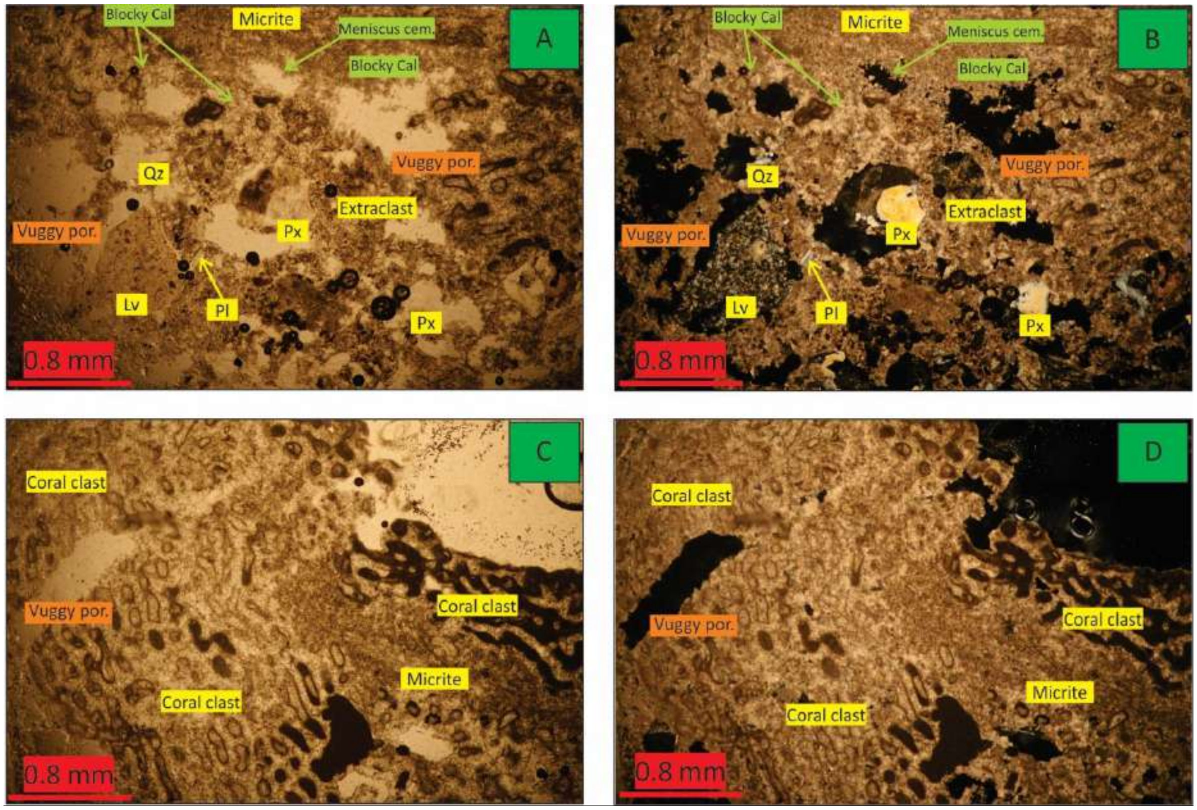

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

B. Diagenesis

Based on petrographic study, there are six different types of diagenesis processes that can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification [3], which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the chronology or stages of limestone diagenesis in the research area.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

Stages of the Diagenesis Process		Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
Relative Time				
1	Microbial Micritization			
2	Initial Calcite Cementation			
3	Cementation			
4	Dissolution			
5	Neomorphism (Inversion)			
6	Neomorphism (Recrystallization)			
7	Cement Structure Dominated by Blocky Structure			
8	Cement Structure Dominated by Meniscus Structure			
9	Vuggy Porosity			

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

A. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage. The major dissolving product in the matrix is cementation.
B. In the meteoric phreatic zone, the diagenesis process progresses to the second stage. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.
C. In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance, as well as the presence of porosity due to extensive dissolution (Figure 4).

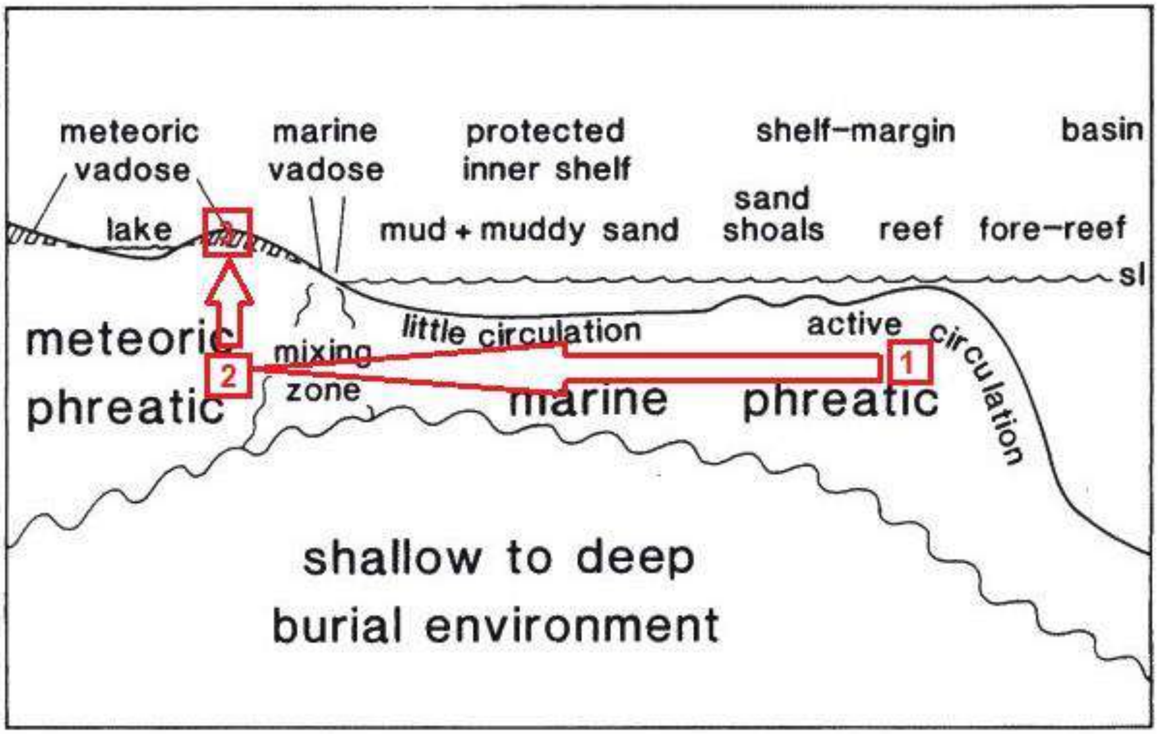

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province [2]

4. Conclusion

Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.
2. Based on petrographic analysis, there are six different types of diagenesis processes that occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).
3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

ACKNOWLEDGMENTS

We thank Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology and Institute for Research and Community Service (or LPPM) of Gorontalo State University. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.

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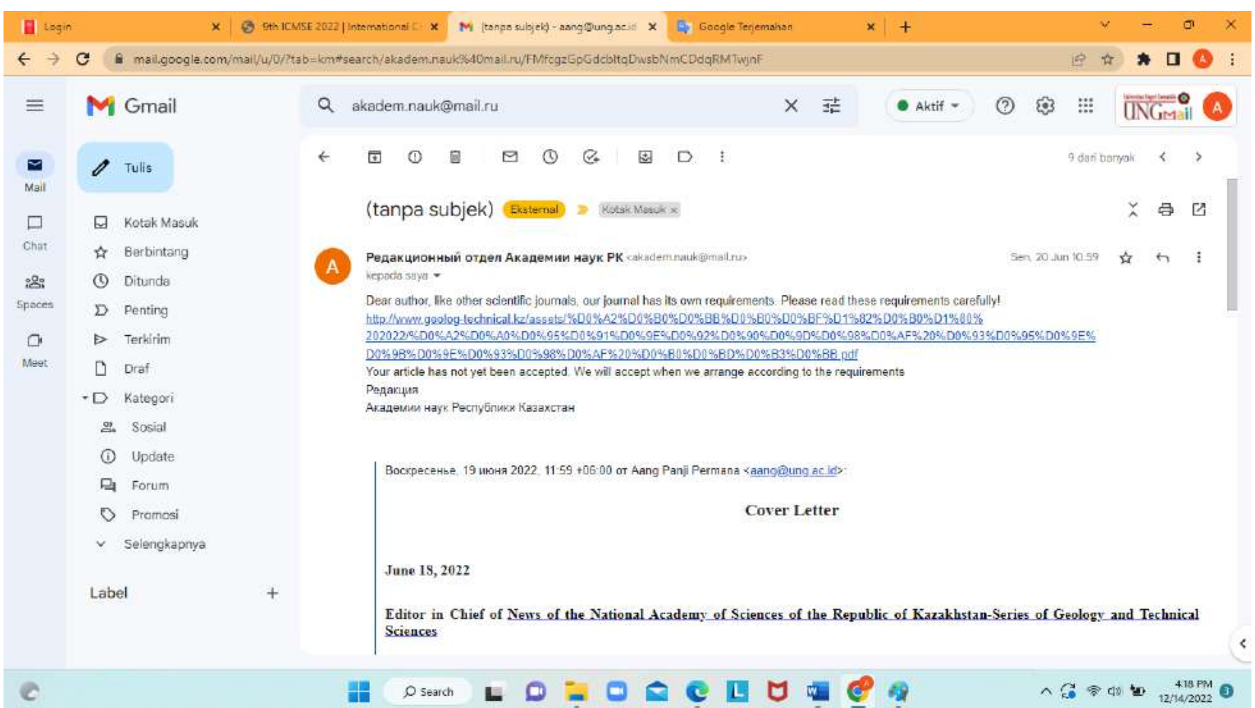

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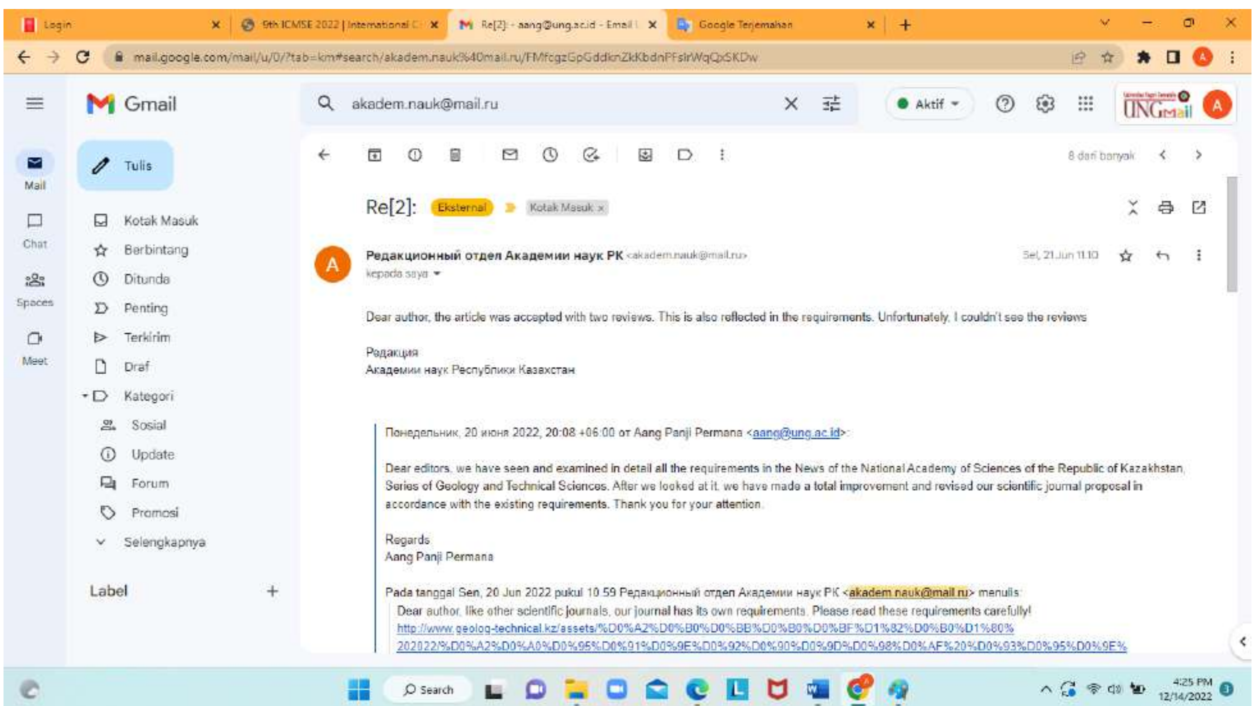

REVIEW NOTES

Manuscript Title : LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Manuscript ID :

1. Impact on science and technology:

[ ] Give a new theory base
[V] Give new information
[ ] Is a confirmation
[ ] Nothing new

2. Priority for publication in Journal :

[V] High
[ ] Moderate
[ ] Low

3. Comments

No.	Object	Comments
1.	***Title***	Revision
2.	***Abstract***	Revision
3.	***Introduction***	Revision
4.	***Methodology***	Revision
5.	***Results and Discussion***	Revision
6.	***Conclusion***	Revision
7.	***References***	Ok
8.	***Special Notes***	Minor Revision

*SUBMISSION DECISION**

☐	***Accepted***
☐	***Accepted with some revision by editorial board***
■	***Accepted with some revision by authors***
☐	***Rejected***

* *Please fill/mark the form*

Dr. Eng. Ir. Wahyu Wilopo., S.T., M.T., IPM (Candidate Profesor)

August 17, 2022

REVIEW NOTES

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No.	Object	Comments
1.	***Title***	good
2.	***Abstract***	Need revision
3.	***Introduction***	Need more new references, no more than 10 years
4.	***Methodology***	good
5.	***Results and Discussion***	good
6.	***Conclusion***	good
7.	***References***	good
8.	***Special Notes***	

No.	Object	Comments
		it would be better if the carbonate facies was reviewed before diagenesis either in the introduction, research results and discussion.

SUBMISSION DECISION*

- [ ] ***Accepted***
- [v] ***Accepted with some revision by editorial board***
- [ ] ***Accepted with some revision by authors***
- [ ] ***Rejected***

* *Please fill/mark the form*

(Dr. Ir. Asmoro Widagdo., S.T., M.T., IPM)

(17 August 2022)

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LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province, Indonesia. The raising of limestone into hills, as seen today,As seen today, the raising of limestone into hills is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Most of the research related to Llimestone research in the proposed research area was conducted on ais done on a regional scale, therefore, a more in-depth research analysis is required to gather the most up-to-date geological data. For this reason, the goal of this research wasis research aimed to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys, including megascopic study of limestone and rock samples, and petrographic analysis in the laboratory, will be used to achieve the research objectives will be used to achieve the research objectives, including a megascopic study of limestone and petrographic analysis in the laboratory. The results revealed that the limestone facies in Gorontalo Province's southern part isGorontalo Province's southern part's limestone facies are coralline floatstone. Based on the petrographic analysis, there are six different types of diagenesis processes thatsix different diagenesis processes occur in coralline floatstone. The six processes of diagenesidiagenesis processes include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises of three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and endthree diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turns into the meteoric phreatic zone, and ends with the diagenesis process in the meteoric vadose zone.

Key-words: Diagenesis, Facies, Gorontalo, Limestone

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ИНДОНЕЗИЯ, ГОРОНТАЛО ПРАВИНЦИЯСЫНЫҢ ОҢТҮСТІГІНДЕГІ ӘКТАСТЫ ФАСИЯЛАР ЖӘНЕ ДИАГЕНЕЗІЗДІ ТАЛДАУ

Аннотация. Күшті тектоникалық әсерлер Горонтало провинциясының оңтүстік жартысындағы геологиялық жағдайлардың күрделілігіне әсер етті. Әктастың төбеге көтерілуі бүгінгі күннің бір мысалы. Сонымен қатар, ол негізгі жанартаулық және плутондық тау жыныстары арасында орналасқандықтан, зерттелетін аймақта әктастың таралуы айтарлықтай ерекшеленеді. Ұсынылған зерттеу аймағында әктастарды зерттеу аймақтық ауқымда жүргізіледі, сондықтан ең өзекті геологиялық деректерді жинау үшін тереңірек зерттеулер қажет. Осы себепті бұл зерттеудің мақсаты Индонезияның Горонтало провинциясының оңтүстік бөлігіндегі әктастардың фациялары мен диагенезін қарау болды. Зерттеу мақсаттарына қол жеткізу үшін далалық зерттеулер, соның ішінде әктас пен тау жыныстарының үлгілерін мегаскопиялық зерттеу және зертханада петрографиялық талдау қолданылады. Нәтижелер Горонтало провинциясының оңтүстік бөлігіндегі әктас фациялары маржанды флоттас екенін анықтады. Петрографиялық талдауға сүйене отырып, кораллдық флотта пайда болатын диагенез процестерінің алты түрі бар. Диагенездің алты процесіне микробтық микротизация, кальциттің бастапқы цементтелуі, цементтелуі, еруі, неоморфизм (инверсия) және неоморфизм (қайта кристалдану) жатады. Зерттеу аймағының әктас диагенетикалық ортасы үш диагенез ортасынан тұрады: ол теңіз фреатикалық аймағында диагенез процесінен басталып, кейін метеорлық фреатикалық аймаққа айналады және метеорлық вадоза аймағында диагенез процесімен аяқталады.

Негізгі сөздер : Диагенез, Фация, Горонтало, Әктас

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ИЗВЕСТНЯКОВЫЕ ФАЦИИ И ДИАГЕНЕЗИЧЕСКИЙ АНАЛИЗ НА ЮГЕ ПРОВИНЦИИ ГОРОНТАЛО, ИНДОНЕЗИЯ

Абстрактный. Сильные тектонические воздействия повлияли на сложность геологических условий в южной половине провинции Горонтало. Поднятие известняка в холмы, как мы видим сегодня, является одним из примеров. Кроме того, поскольку он расположен между основными вулканическими и плутоническими породами, распределение известняка на исследуемой территории весьма своеобразно. Исследования известняка в предлагаемом районе исследований проводятся в региональном масштабе, поэтому необходимы более глубокие исследования для сбора самых современных геологических данных. По этой причине целью данного исследования было изучение фаций и диагенеза известняков в южной части провинции Горонтало в Индонезии. Полевые исследования, включая микроскопическое исследование образцов известняка и горных пород, а также петрографический анализ в лаборатории, будут использоваться для достижения целей исследования. Результаты показали, что фация известняка в южной части провинции Горонтало представляет собой плавучий коралловый камень. Основываясь на петрографическом анализе, существует шесть различных типов процессов диагенеза, происходящих в коралловом флоатстоуне. Шесть процессов диагенеза включают микробную микритизацию, начальную цементацию кальцита, цементацию, растворение, неоморфизм (инверсию) и неоморфизм (перекристаллизацию). Диагенетическая обстановка известняков района исследований состоит из трех диагенетических сред: она начинается с процесса диагенеза в морской фреатической зоне, затем переходит в метеоритно-фреатический пояс и заканчивается процессом диагенеза в метеоритном аэрационном поясе.

Ключевые слова: диагенез, фация, горонтало, известняк.

Introduction. Diagenesis refers to the physical and chemical changes ~~that occur~~ after ~~a~~ sediment, or sedimentary rock is deposited. It does not~~, however,~~ contain metamorphism (Scholle & Ulmer-Scholle, 2003), a process involving high temperatures and pressures. Diagenesis ~~has the ability to~~can preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the ~~sediments~~ deposits ~~in relation to~~concerning burial, uplift and sea level change, the influx of pore fluids and climatic differences (Tucker & Wright, 1990).

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved ~~in order~~

to determine the sequence of diagenesis (Longman, 1980). Changes can occur in three main diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history (Wright et al., 2003; James et al., 2005; Wright & Cherns, 2008).

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Carbonate rock diagenesis ~~is comprised of~~comprises six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, ~~rate of water influx~~water influx rate, time, and structural control (Tucker & Wright, 1990). Complex characteristics influence diagenesis processes in carbonate deposits, such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development (Machent et al., 2007; Morad et al., 2012; Armelenti et al., 2016; Li et al., 2017; Seibel & James, 2017).

The c~~omplexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties. The chemistry of the pore water in particular, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis takes place in marine, meteoric, brackish, and hypersaline brines (Morad et al, 2012: 2019; James & Jones, 2015; Swart, 2015)~~hemistry of the pore water, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis occurs in marine, meteoric, brackish, and hypersaline brines (Morad et al., 2012: 2019; James & Jones, 2015; Swart, 2015). The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties.

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 (Bachri et al., 1997) composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of~~:~~ basalt lava, andesitic lava, volcanic breccia, ~~with~~ intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, ~~which is~~ estimated to be of Pliocene-Pleistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian (Apandi & Bachri, 1997). The Reef Limestone Unit, ~~which was~~ formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid. This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift (Apandi & Bachri, 1997; Permana et al., 2019; 2021). Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

Research materials and methods. The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25''-0° 30' 05'' N and 123° 2' 25'' 123° 03' 00'' E) (Figure 1).

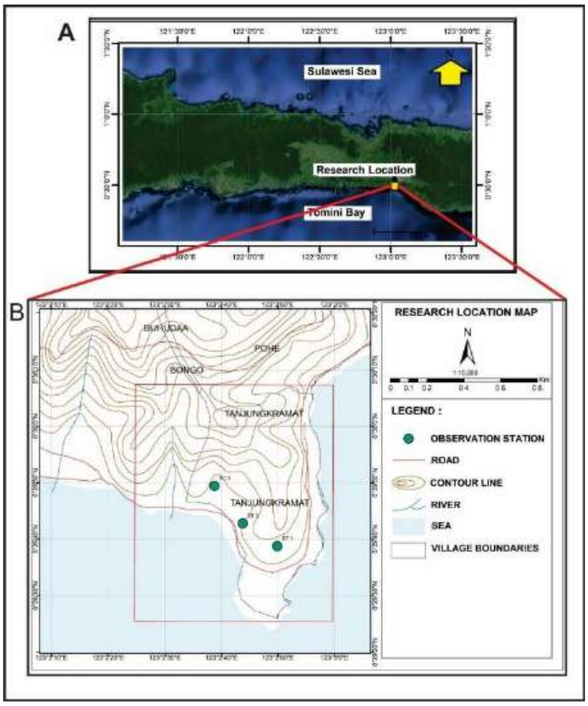

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

~~There are two research methods:~~ ~~f~~A field survey and laboratory analysis was performed in this study. ~~There are two research approaches: qualitative analysis and quantitative analysis.~~ The ~~description and interpretation of limestone types, as well as suitable sampling for laboratory analysis, are the focus of field survey~~focus of field surveys is the description and interpretation of limestone types and suitable sampling for laboratory analysis. The petrographic analysis ~~Laboratory analysis~~ is ~~petrographic analysis~~ performed in the Geo Optics laboratory. The petrographic analysis stage begins with ~~the formation of a thin section using the blocking method, which serves to infiltrate the blue dye into the pores in order~~forming a thin section using the blocking method, which infiltrates the blue dye into the pores to distinguish the original rock pores from th~~e pores~~ose formed during preparation (Dickson, 1966; Crabtree et al., 1984). Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera (Tetley & Daczko, 2013; Serge & Senthilkumar, 2017; Ofulume et al., 2018). ~~Petrographic~~ A petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited (Maryanto, 2012; Arosi & Wilson, 2015).

Results. The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, ~~open~~ open-packed, floating grains in the matrix and a massive structure. ~~It is composed of coral fragments, quartz minerals, micrite, and sparite. The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971)~~The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971). It contains coral fragments, quartz minerals, micrite, and sparite.

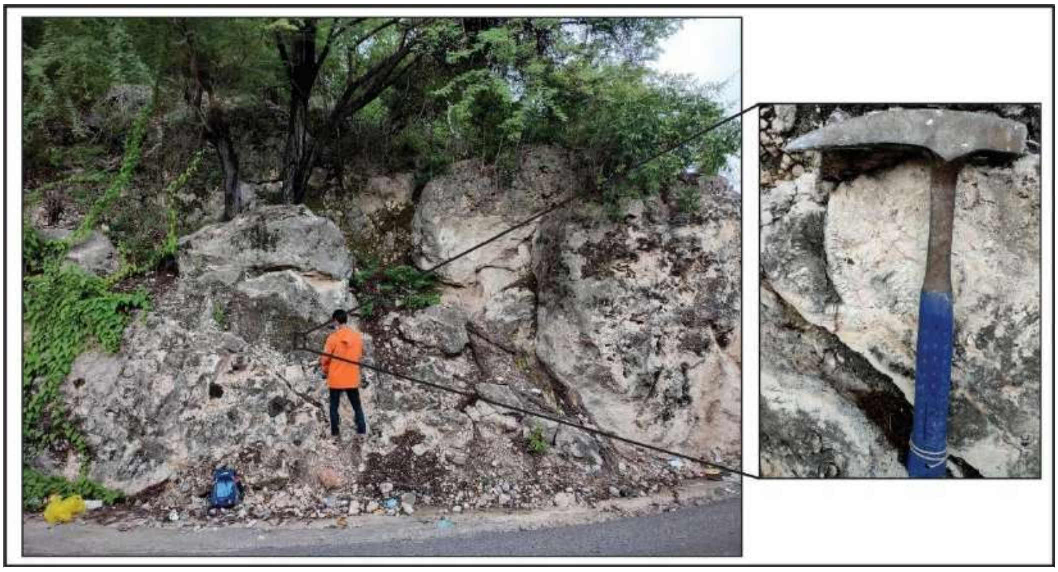

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone (Embry & Klovan, 1971).

~~Detailed~~ A detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The ~~interference color varies in order II in the appearance of crossed nickel (X). The fragments are generally replaced by sparite (calcite) and the pores are filled with micrite as a result of micritization~~fragments are generally replaced by sparite (calcite), and the pores are filled with micrite due to micritization. The interference color varies in order II in the appearance of crossed nickel (X).

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X), the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains ~~considered to be~~ of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//), it is colorless brownish, on the appearance of nickel crossed (X), it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, and no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, a long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18^{o}. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, a short prismatic shape, translucent, low relief, no pleochroism, and no fracture observed. The ~~appearance of crossed nickel (X)~~crossed nickel (X) appearance has an orange interference color of order 2, and the darkening angle is 20-22^{o}.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, a fracture is not observed, bladed – equant shape, blocky structure, and meniscus. ~~In t~~The appearance of crossed nickel (X)~~, it~~ varies by~~ the~~ order of two. It is composed of calcite. It ~~is the result of~~results from pore filling, micrite recrystallization, or changing the composition of the shell or coral.

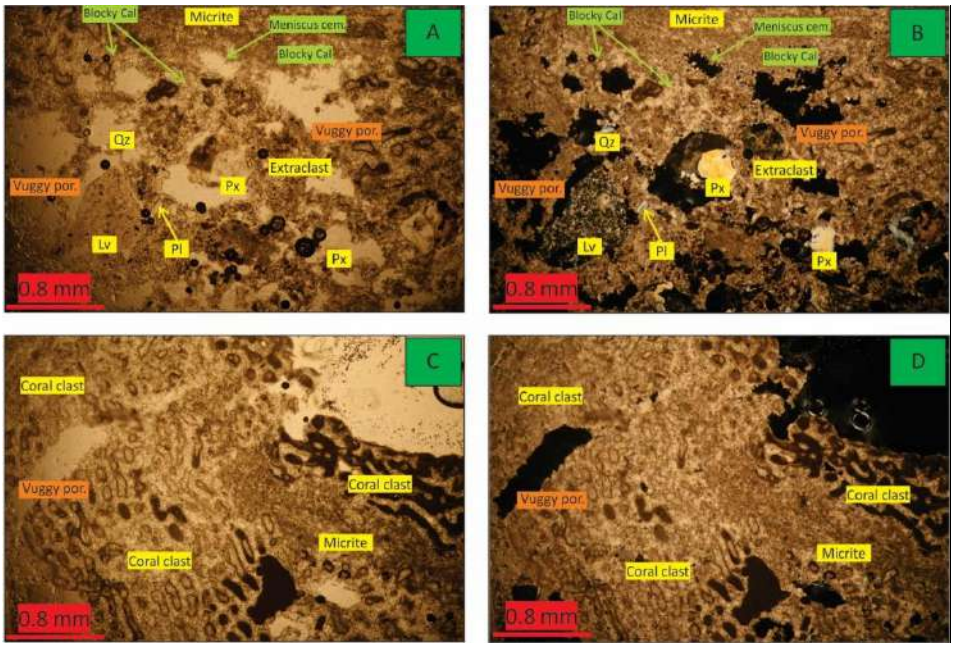

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

Discussion. Based on the petrographic study, ~~there are six different types of diagenesis processes that~~six different diagenesis processes can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

Microbial micritization is this process that occurs in the marine environment, and drilling activity can be carried out by organisms such as endolithic fungi, bacteria, and green algae or possibly red algae. The grain micritization process is indicated by ~~the process of replacing a number of skeleton grains by~~replacing several skeleton grains with cloudy brown micrite that coats the granules. The cementation process in carbonate sediments is the main diagenetic process~~ and~~. It occurs when the pore-fluid is supersaturated with the cement phase, and there are no kinetic factors that hinder cement precipitation. The dissolving process requires a large volume of supersaturated water and is influenced by the selectivity of the matrix, grain shape, grain size, and skeleton properties. The neomorphism process consists of inverse, recrystallization, and coalescive neomorphism (aggrading/degrading neomorphism). Inversion is the change of one mineral to a polymorph, for example, the polymorphic transformation of aragonite to calcite~~,~~ and alteration of Mg calcite to calcite. While recrystallization is a change in crystal size without a change in mineralogy, for example, increasing/reducing the size of calcite crystals or the replacement (replacement) of ~~small~~ tiny calcite crystals by larger calcite crystals (Folk, 1965).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification (Longman, 1980), which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the ~~chronology or stages of limestone diagenesis in the research area~~research area's chronology or stages of limestone diagenesis.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

	Stages of the Diagenesis Process	Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
	Relative Time →			
1	Microbial Micritization	■		
2	Initial Calcite Cementation	■		
3	Cementation		■	■
4	Dissolution		■	■
5	Neomorphism (Inversion)		■	
6	Neomorphism (Recrystallization)		■	
7	Cement Structure Dominated by Blocky Structure		■	
8	Cement Structure Dominated by Meniscus Structure			■
9	Vuggy Porosity			■

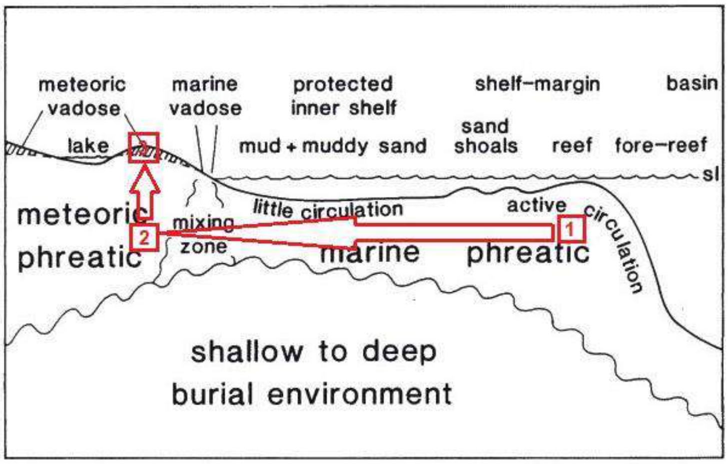

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province (Tucker & Wright, 1990)

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

A. The ~~early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage. The major dissolving product in the matrix is cementation~~major dissolving product in the matrix is cementation. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage.

B. ~~In the meteoric phreatic zone, the diagenesis process progresses to the second stag~~The diagenesis process progresses to the second stage in the meteoric phreatic zone. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate an inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.

C. In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of a calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance~~, as well as~~ and the presence of porosity due to extensive dissolution (Figure 4).

Conclusion.

Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.
2. Based on the petrographic analysis, ~~there are six different types of diagenesis processes that~~six different types of diagenesis processes occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).
3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

Acknowledgments. We thank the Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology, and Institute for Research and Community Service (or LPPM) of Gorontalo State University. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.

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LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province. The raising of limestone into hills, as seen today, is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Limestone research in the proposed research area is done on a regional scale, therefore more in-depth research is required to gather the most up-to-date geological data. For this reason, the goal of this research was to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys, including megascopic study of limestone and rock samples, and petrographic analysis in the laboratory, will be used to achieve the research objectives. The results revealed that the limestone facies in Gorontalo Province's southern part is coralline floatstone. Based on petrographic analysis, there are six different types of diagenesis processes that occur in coralline floatstone. The six processes of diagenesis include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises of three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end with the diagenesis process in the meteoric vadose zone.

Key words: Diagenesis, Facies, Gorontalo, Limestone

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ИНДОНЕЗИЯ, ГОРОНТАЛО ПРАВИНЦИЯСЫНЫҢ ОҢТҮСТІГІНДЕГІ ӘКТАСТЫ ФАСИЯЛАР ЖӘНЕ ДИАГЕНЕЗІЗДІ ТАЛДАУ

Аннотация. Күшті тектоникалық әсерлер Горонтало провинциясының оңтүстік жартысындағы геологиялық жағдайлардың күрделілігіне әсер етті. Әктастың төбеге көтерілуі бүгінгі күннің бір мысалы. Сонымен қатар, ол негізгі жанартаулық және плутондық тау жыныстары арасында орналасқандықтан, зерттелетін аймақта әктастың таралуы айтарлықтай ерекшеленеді. Ұсынылған зерттеу аймағында әктастарды зерттеу аймақтық ауқымда жүргізіледі, сондықтан ең өзекті геологиялық деректерді жинау үшін тереңірек зерттеулер қажет. Осы себепті бұл зерттеудің мақсаты Индонезияның Горонтало провинциясының оңтүстік бөлігіндегі әктастардың фациялары мен диагенезін қарау болды. Зерттеу мақсаттарына қол жеткізу үшін далалық зерттеулер, соның ішінде әктас пен тау жыныстарының үлгілерін мегаскопиялық зерттеу және зертханада петрографиялық талдау қолданылады. Нәтижелер Горонтало провинциясының оңтүстік бөлігіндегі әктас фациялары маржанды флоттас екенін анықтады. Петрографиялық талдауға сүйене отырып, кораллдық флотта пайда болатын диагенез процестерінің алты түрі бар. Диагенездің алты процесіне микробтық микротизация, кальциттің бастапқы цементтелуі, цементтелуі, еруі, неоморфизм (инверсия) және неоморфизм (қайта кристалдану) жатады. Зерттеу аймағының әктас диагенетикалық ортасы үш диагенез ортасынан тұрады: ол теңіз фреатикалық аймағында диагенез процесінен басталып, кейін метеорлық фреатикалық аймаққа айналады және метеорлық вадоза аймағында диагенез процесімен аяқталады.

Негізгі сөздер : Диагенез, Фация, Горонтало, Әктас

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ИЗВЕСТНЯКОВЫЕ ФАЦИИ И ДИАГЕНЕЗИЧЕСКИЙ АНАЛИЗ НА ЮГЕ ПРОВИНЦИИ ГОРОНТАЛО, ИНДОНЕЗИЯ

Абстрактный. Сильные тектонические воздействия повлияли на сложность геологических условий в южной половине провинции Горонтало. Поднятие известняка в холмы, как мы видим сегодня, является одним из примеров. Кроме того, поскольку он расположен между основными вулканическими и плутоническими породами, распределение известняка на исследуемой территории весьма своеобразно. Исследования известняка в предлагаемом районе исследований проводятся в региональном масштабе, поэтому необходимы более глубокие исследования для сбора самых современных геологических данных. По этой причине целью данного исследования было изучение фаций и диагенеза известняков в южной части провинции Горонтало в Индонезии. Полевые исследования, включая микроскопическое исследование образцов известняка и горных пород, а также петрографический анализ в лаборатории, будут использоваться для достижения целей исследования. Результаты показали, что фация известняка в южной части провинции Горонтало представляет собой плавучий коралловый камень. Основываясь на петрографическом анализе, существует шесть различных типов процессов диагенеза, происходящих в коралловом флоатстоуне. Шесть процессов диагенеза включают микробную микритизацию, начальную цементацию кальцита, цементацию, растворение, неоморфизм (инверсию) и неоморфизм (перекристаллизацию). Диагенетическая обстановка известняков района исследований состоит из трех диагенетических сред: она начинается с процесса диагенеза в морской фреатической зоне, затем переходит в метеоритно-фреатический пояс и заканчивается процессом диагенеза в метеоритном аэрационном поясе.
Ключевые слова: диагенез, фация, горонтало, известняк.

Introduction. Diagenesis refers to the physical and chemical changes that occur after a sediment or sedimentary rock is deposited. It does not, however, contain metamorphism (Scholle & Ulmer-Scholle, 2003), a process involving high temperatures and pressures. Diagenesis has the ability to preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the sediments in relation to burial, uplift and sea level change, the influx of pore fluids and climatic differences (Tucker & Wright, 1990).

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved in order to determine the sequence of diagenesis (Longman, 1980). Changes can occur in three main diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history (Wright et al, 2003; James et al, 2005; Wright & Cherns, 2008).

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Carbonate rock diagenesis is comprised of six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, rate of water influx, time, and structural control (Tucker & Wright, 1990). Complex characteristics influence diagenesis processes in carbonate deposits such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development (Machent et al, 2007; Morad et al, 2012; Armelenti et al, 2016; Li et al, 2017; Seibel & James, 2017).

The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties. The chemistry of the pore water in particular, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis takes place in marine, meteoric, brackish, and hypersaline brines (Morad et al, 2012: 2019; James & Jones, 2015; Swart, 2015).

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 (Bachri et al, 1997) composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of: basalt lava, andesitic lava, volcanic breccia, with intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, which is estimated to be of Pliocene-Plistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian (Apandi & Bachri, 1997). The Reef Limestone Unit, which was formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid. This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift (Apandi & Bachri, 1997; Permana et al, 2019; 2021). Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

Research materials and methods. The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25"-0° 30' 05" N and 123° 2' 25" 123° 03' 00" E) (Figure 1).

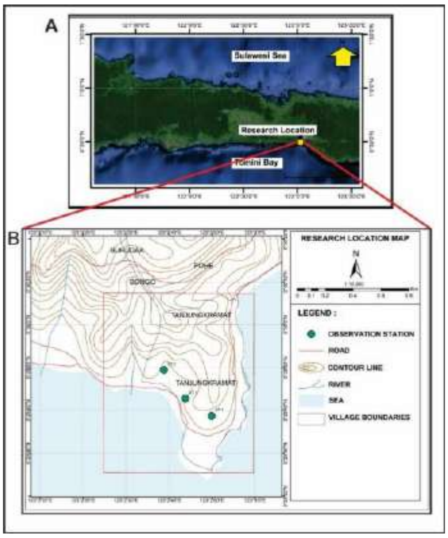

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

There are two research methods: field survey and laboratory analysis. There are two research approaches: qualitative analysis and quantitative analysis. The description and interpretation of limestone types, as well as suitable sampling for laboratory analysis, are the focus of field surveys. Laboratory analysis is petrographic analysis performed in the Geo Optics laboratory. The petrographic analysis stage begins with the formation of a thin section using the blocking method, which serves to infiltrate the blue dye into the pores in order to distinguish the original rock pores from the pores formed during preparation (Dickson, 1966; Crabtree et al, 1984). Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera (Tetley & Daczko, 2013; Serge & Senthilkumar, 2017; Ofulume et al, 2018). Petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited (Maryanto, 2012; Arosi & Wilson, 2015).

Results. The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, open packed, floating grains in the matrix and a massive structure. It is composed of coral fragments, quartz minerals, micrite, and sparite. The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971).

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone (Embry & Klovan, 1971).

Detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The interference color varies in order II in the appearance of crossed nickel (X). The fragments are generally replaced by sparite (calcite) and the pores are filled with micrite as a result of micritization.

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X) the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains considered to be of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//) it is colorless brownish, on the appearance of nickel crossed (X) it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18^{o}. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, short prismatic shape, translucent, low relief, no pleochroism, no fracture observed. The appearance of crossed nickel (X) has an orange interference color of order 2, the darkening angle is 20-22^{o}.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, fracture is not observed, bladed – equant shape, blocky structure and meniscus. In the appearance of crossed nickel (X), it varies by the order of two. It is composed of calcite. It is the result of pore filling, micrite recrystallization, or changing the composition of the shell or coral.

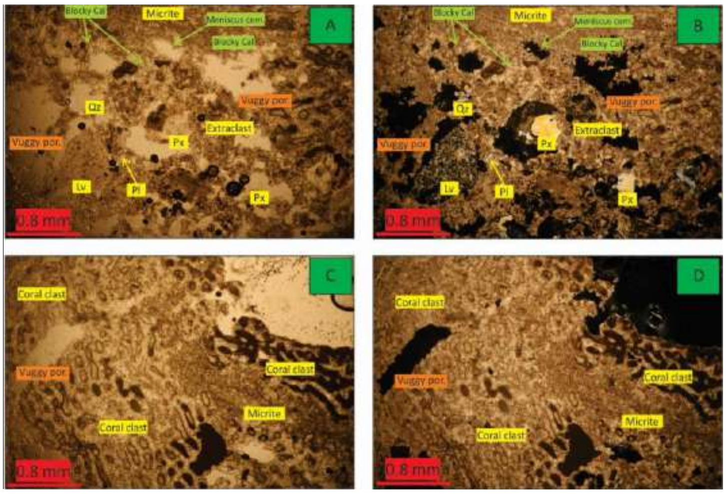

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

Discussion. Based on petrographic study, there are six different types of diagenesis processes that can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

Microbial micritization is this process that occurs in the marine environment, drilling activity can be carried out by organisms such as endolithic fungi, bacteria and green algae or possibly red algae. The grain micritization process is indicated by the process of replacing a number of skeleton grains by cloudy brown micrite that coats the granules. The cementation process in carbonate sediments is the main diagenetic process and occurs when the pore-fluid is supersaturated with the cement phase and there are no kinetic factors that hinder cement precipitation. The dissolving process requires a large volume of supersaturated water and is influenced by the selectivity of the matrix, grain shape, grain size and skeleton properties. The neomorphism process consists of inverse, recrystallization and coalescive neomorphism (aggrading/degrading neomorphism). Inversion is the change of one mineral to a polymorph, for example polymorphic transformation of aragonite to calcite, alteration of Mg calcite to calcite. While recrystallization is a change in crystal size without a change in mineralogy, for example increasing/reducing the size of calcite crystals or the replacement (replacement) of small calcite crystals by larger calcite crystals (Folk, 1965).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification (Longman, 1980), which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the chronology or stages of limestone diagenesis in the research area.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

	Stages of the Diagenesis Process	Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
	Relative Time →			
1	Microbial Micritization	■		
2	Initial Calcite Cementation	■		
3	Cementation		■	■
4	Dissolution		■	■
5	Neomorphism (Inversion)		■	
6	Neomorphism (Recrystallization)		■	
7	Cement Structure Dominated by Blocky Structure		■	
8	Cement Structure Dominated by Meniscus Structure			■
9	Vuggy Porosity			■

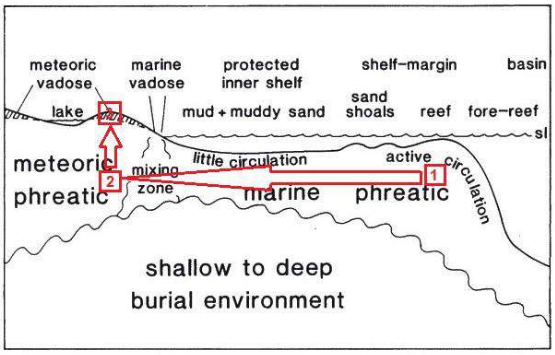

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province (Tucker & Wright, 1990)

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

A. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage. The major dissolving product in the matrix is cementation.
B. In the meteoric phreatic zone, the diagenesis process progresses to the second stage. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.
C. In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance, as well as the presence of porosity due to extensive dissolution (Figure 4).

Conclusion. Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.
2. Based on petrographic analysis, there are six different types of diagenesis processes that occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).
3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

Acknowledgments. We thank Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology and Institute for Research and Community Service (or LPPM) of Gorontalo State University. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.

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Revised Results/Authors Response

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20 Jun 2022
21.08

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Dear editors, we have seen and examined in detail all the requirements in the News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. After we looked at it, we have made a total improvement and revised our scientific journal proposal in accordance with the existing requirements. Thank you for your attention.

Regards
Aang Panji Permana

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LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province. The raising of limestone into hills, as seen today, is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Limestone research in the proposed research area is done on a regional scale, therefore more in-depth research is required to gather the most up-to-date geological data. For this reason, the goal of this research was to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys, including megascopic study of limestone and rock samples, and petrographic analysis in the laboratory, will be used to achieve the research objectives. The results revealed that the limestone facies in Gorontalo Province's southern part is coralline floatstone. Based on petrographic analysis, there are six different types of diagenesis processes that occur in coralline floatstone. The six processes of diagenesis include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises of three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end with the diagenesis process in the meteoric vadose zone.

Key words: Diagenesis, Facies, Gorontalo, Limestone

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ИНДОНЕЗИЯ, ГОРОНТАЛО ПРАВИНЦИЯСЫНЫҢ ОҢТҮСТІГІНДЕГІ ӘКТАСТЫ ФАСИЯЛАР ЖӘНЕ ДИАГЕНЕЗІЗДІ ТАЛДАУ

Аннотация. Күшті тектоникалық әсерлер Горонтало провинциясының оңтүстік жартысындағы геологиялық жағдайлардың күрделілігіне әсер етті. Әктастың төбеге көтерілуі бүгінгі күннің бір мысалы. Сонымен қатар, ол негізгі жанартаулық және плутондық тау жыныстары арасында орналасқандықтан, зерттелетін аймақта әктастың таралуы айтарлықтай ерекшеленеді. Ұсынылған зерттеу аймағында әктастарды зерттеу аймақтық ауқымда жүргізіледі, сондықтан ең өзекті геологиялық деректерді жинау үшін тереңірек зерттеулер қажет. Осы себепті бұл зерттеудің мақсаты Индонезияның Горонтало провинциясының оңтүстік бөлігіндегі әктастардың фациялары мен диагенезін қарау болды. Зерттеу мақсаттарына қол жеткізу үшін далалық зерттеулер, соның ішінде әктас пен тау жыныстарының үлгілерін мегаскопиялық зерттеу және зертханада петрографиялық талдау қолданылады. Нәтижелер Горонтало провинциясының оңтүстік бөлігіндегі әктас фациялары маржанды флоттас екенін анықтады. Петрографиялық талдауға сүйене отырып, коралльдық флотта пайда болатын диагенез процестерінің алты түрі бар. Диагенездің алты процесіне микробтық микротизация, кальциттің бастапқы цементтелуі, цементтелуі, еруі, неоморфизм (инверсия) және неоморфизм (қайта кристалдану) жатады. Зерттеу аймағының әктас диагенетикалық ортасы үш диагенез ортасынан тұрады: ол теңіз фреатикалық аймағында диагенез процесінен басталып, кейін метеорлық фреатикалық аймаққа айналады және метеорлық вадоза аймағында диагенез процесімен аяқталады.

Негізгі сөздер : Диагенез, Фация, Горонтало, Әктас

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ИЗВЕСТНЯКОВЫЕ ФАЦИИ И ДИАГЕНЕЗИЧЕСКИЙ АНАЛИЗ НА ЮГЕ ПРОВИНЦИИ ГОРОНТАЛО, ИНДОНЕЗИЯ

Абстрактный. Сильные тектонические воздействия повлияли на сложность геологических условий в южной половине провинции Горонтало. Поднятие известняка в холмы, как мы видим сегодня, является одним из примеров. Кроме того, поскольку он расположен между основными вулканическими и плутоническими породами, распределение известняка на исследуемой территории весьма своеобразно. Исследования известняка в предлагаемом районе исследований проводятся в региональном масштабе, поэтому необходимы более глубокие исследования для сбора самых современных геологических данных. По этой причине целью данного исследования было изучение фаций и диагенеза известняков в южной части провинции Горонтало в Индонезии. Полевые исследования, включая микроскопическое исследование образцов известняка и горных пород, а также петрографический анализ в лаборатории, будут использоваться для достижения целей исследования. Результаты показали, что фация известняка в южной части провинции Горонтало представляет собой плавучий коралловый камень. Основываясь на петрографическом анализе, существует шесть различных типов процессов диагенеза, происходящих в коралловом флоатстоуне. Шесть процессов диагенеза включают микробную микритизацию, начальную цементацию кальцита, цементацию, растворение, неоморфизм (инверсию) и неоморфизм (перекристаллизацию). Диагенетическая обстановка известняков района исследований состоит из трех диагенетических сред: она начинается с процесса диагенеза в морской фреатической зоне, затем переходит в метеоритно-фреатический пояс и заканчивается процессом диагенеза в метеоритном аэрационном поясе.

Ключевые слова: диагенез, фация, горонтало, известняк.

Introduction. Diagenesis refers to the physical and chemical changes that occur after a sediment or sedimentary rock is deposited. It does not, however, contain metamorphism (Scholle & Ulmer-Scholle, 2003), a process involving high temperatures and pressures. Diagenesis has the ability to preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the sediments in relation to burial, uplift and sea level change, the influx of pore fluids and climatic differences (Tucker & Wright, 1990).

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved in order to determine the sequence of diagenesis (Longman, 1980). Changes can occur in three main diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history (Wright et al, 2003; James et al, 2005; Wright & Cherns, 2008).

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Carbonate rock diagenesis is comprised of six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, rate of water influx, time, and structural control (Tucker & Wright, 1990). Complex characteristics influence diagenesis processes in carbonate deposits such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development (Machent et al, 2007; Morad et al, 2012; Armelenti et al, 2016; Li et al, 2017; Seibel & James, 2017).

The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties. The chemistry of the pore water in particular, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis takes place in marine, meteoric, brackish, and hypersaline brines (Morad et al, 2012: 2019; James & Jones, 2015; Swart, 2015).

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 (Bachri et al, 1997) composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of: basalt lava, andesitic lava, volcanic breccia, with intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, which is estimated to be of Pliocene-Plistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian (Apandi & Bachri, 1997). The

Reef Limestone Unit, which was formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid. This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift (Apandi & Bachri, 1997; Permana et al, 2019; 2021). Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

Research materials and methods. The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25"- 0° 30' 05" N and 123° 2' 25" 123° 03' 00" E) (Figure 1).

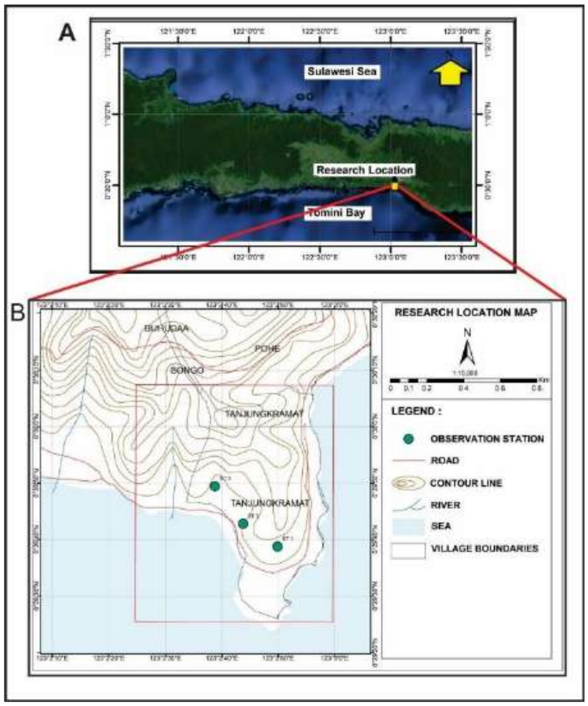

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

There are two research methods: field survey and laboratory analysis. There are two research approaches: qualitative analysis and quantitative analysis. The description and interpretation of limestone types, as well as suitable sampling for laboratory analysis, are the focus of field surveys. Laboratory analysis is petrographic analysis performed in the Geo Optics laboratory. The petrographic analysis stage begins with the formation of a thin section using the blocking method, which serves to infiltrate the blue dye into the pores in order to distinguish the original rock pores from the pores formed during preparation (Dickson, 1966; Crabtree et al, 1984). Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera (Tetley & Daczko, 2013; Serge & Senthilkumar, 2017; Ofulume et al, 2018). Petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited (Maryanto, 2012; Arosi & Wilson, 2015).

Results. The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, open packed, floating grains in the matrix and a massive structure. It is composed of coral fragments, quartz minerals, micrite, and sparite. The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971).

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone (Embry & Klovan, 1971).

Detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The interference color varies in order II in the appearance of crossed nickel (X). The fragments are generally replaced by sparite (calcite) and the pores are filled with micrite as a result of micritization.

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X) the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains considered to be of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//) it is colorless brownish, on the appearance of nickel crossed (X) it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18^{o}. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, short prismatic shape, translucent, low relief, no pleochroism, no fracture observed. The appearance of crossed nickel (X) has an orange interference color of order 2, the darkening angle is 20-22^{o}.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, fracture is not observed, bladed – equant shape, blocky structure and meniscus. In the appearance of crossed nickel (X), it varies by the order of two. It is composed of calcite. It is the result of pore filling, micrite recrystallization, or changing the composition of the shell or coral.

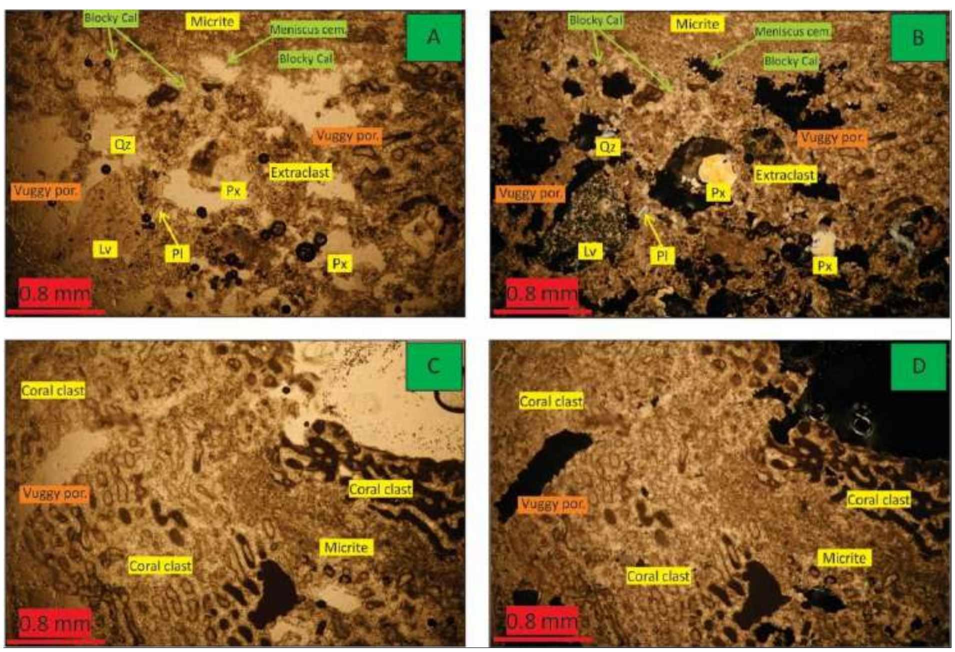

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

Discussion. Based on petrographic study, there are six different types of diagenesis processes that can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation,

cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

Microbial micritization is this process that occurs in the marine environment, drilling activity can be carried out by organisms such as endolithic fungi, bacteria and green algae or possibly red algae. The grain micritization process is indicated by the process of replacing a number of skeleton grains by cloudy brown micrite that coats the granules. The cementation process in carbonate sediments is the main diagenetic process and occurs when the pore-fluid is supersaturated with the cement phase and there are no kinetic factors that hinder cement precipitation. The dissolving process requires a large volume of supersaturated water and is influenced by the selectivity of the matrix, grain shape, grain size and skeleton properties. The neomorphism process consists of inverse, recrystallization and coalescive neomorphism (aggrading/degrading neomorphism). Inversion is the change of one mineral to a polymorph, for example polymorphic transformation of aragonite to calcite, alteration of Mg calcite to calcite. While recrystallization is a change in crystal size without a change in mineralogy, for example increasing/reducing the size of calcite crystals or the replacement (replacement) of small calcite crystals by larger calcite crystals (Folk, 1965).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification (Longman, 1980), which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the chronology or stages of limestone diagenesis in the research area.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

Stages of the Diagenesis Process		Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
Relative Time →				
1	Microbial Micritization	■		
2	Initial Calcite Cementation	■		
3	Cementation		■	■
4	Dissolution		■	■
5	Neomorphism (Inversion)		■	
6	Neomorphism (Recrystallization)		■	
7	Cement Structure Dominated by Blocky Structure		■	
8	Cement Structure Dominated by Meniscus Structure			■
9	Vuggy Porosity			■

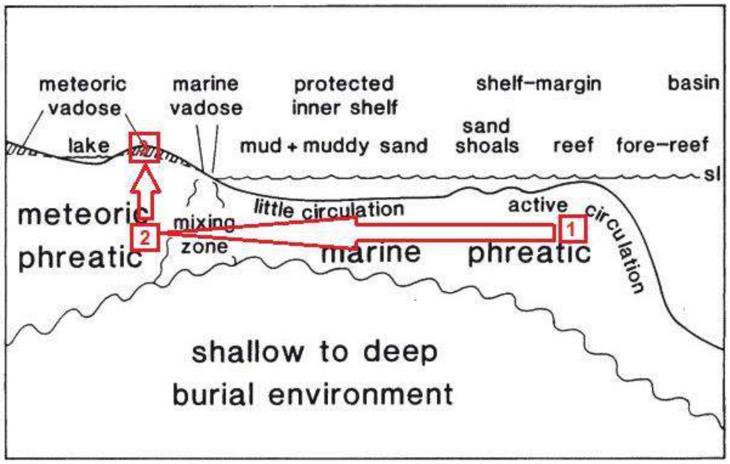

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province (Tucker & Wright, 1990)

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

A. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage. The major dissolving product in the matrix is cementation.
B. In the meteoric phreatic zone, the diagenesis process progresses to the second stage. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.
C. In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance, as well as the presence of porosity due to extensive dissolution (Figure 4).

Conclusion. Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.
2. Based on petrographic analysis, there are six different types of diagenesis processes that occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).
3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then

turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

Acknowledgments. We thank Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology and Institute for Research and Community Service (or LPPM) of Gorontalo State University. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.

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LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province, Indonesia. As seen today, the raising of limestone into hills is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Most of the research related to limestone in the research area have only been conducted on a regional scale, therefore, a more in-depth analysis is required to gather the most up-to-date geological data. For this reason, this research aimed to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys will be used to achieve the research objectives, including a megascopic study of limestone and petrographic analysis in the laboratory. The results revealed that Gorontalo Province's southern part's limestone facies are coralline floatstone. Based on the petrographic analysis, six different diagenesis processes occur in coralline floatstone. The six diagenesis processes include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turns into the meteoric phreatic zone, and ends with the diagenesis process in the meteoric vadose zone.
Keywords: Diagenesis, Facies, Gorontalo, Limestone

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ИНДОНЕЗИЯ, ГОРОНТАЛО ПРАВИНЦИЯСЫНЫҢ ОҢТҮСТІГІНДЕГІ ӘКТАСТЫ ФАСИЯЛАР ЖӘНЕ ДИАГЕНЕЗІЗДІ ТАЛДАУ

Аннотация. Күшті тектоникалық әсерлер Индонезияның Горонтало провинциясының оңтүстік жартысындағы геологиялық жағдайлардың күрделілігіне әсер етті. Бүгінгі күні көрініп тұрғандай, әктастың төбеге көтерілуі бір мысал. Сонымен қатар, ол негізгі жанартаулық және плутондық жыныстардың арасында орналасқандықтан, зерттелетін аймақтағы әктастың таралуы айтарлықтай ерекшеленеді. Зерттеу аймағындағы әктасқа қатысты зерттеулердің көпшілігі тек аймақтық ауқымда жүргізілді, сондықтан ең өзекті геологиялық деректерді жинау үшін тереңірек талдау қажет. Осы себепті бұл зерттеу Индонезияның Горонтало провинциясының оңтүстік бөлігіндегі әктастардың фациялары мен диагенезін зерттеуді мақсат етті. Зертханада әктастарды мегаскопиялық зерттеу және петрографиялық талдауды қоса алғанда, зерттеу мақсаттарына қол жеткізу үшін далалық зерттеулер қолданылады. Нәтижелер Горонтало провинциясының оңтүстік бөлігіндегі әктас фациялары маржанды флотта екенін анықтады. Петрографиялық талдау негізінде кораллин флоатста алты түрлі диагенез процесі жүреді. Алты диагенез процестеріне микробтық микротизация, кальциттің бастапқы цементтелуі, цементтелуі, еруі, неоморфизм (инверсия) және неоморфизм (қайта кристалдану) жатады. Зерттеу аймағының әктас диагенетикалық ортасы үш диагенез ортасынан тұрады: ол теңіз фреатикалық аймағында диагенез процесінен басталып, кейін метеорлық фреатикалық аймаққа айналады және метеорлық вадоза аймағында диагенез процесімен аяқталады.

Негізгі сөздер : Диагенез, Фация, Горонтало, Әктас

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ИЗВЕСТНЯКОВЫЕ ФАЦИИ И ДИАГЕНЕЗИЧЕСКИЙ АНАЛИЗ НА ЮГЕ ПРОВИНЦИИ ГОРОНТАЛО, ИНДОНЕЗИЯ

Абстрактный. Сильные тектонические эффекты повлияли на сложность геологических условий в южной половине провинции Горонтало, Индонезия. Как видно сегодня, поднятие известняка в холмы является одним из примеров. Кроме того, поскольку он расположен между основными вулканическими и плутоническими породами, распределение известняка на исследуемой территории весьма своеобразно. Большинство исследований, связанных с известняком в районе исследований, проводились только в региональном масштабе, поэтому для сбора самых современных геологических данных требуется более глубокий анализ. По этой причине это исследование было направлено на изучение фаций и диагенеза известняков в южной части провинции Горонтало в Индонезии. Для достижения целей исследования будут использованы полевые исследования, в том числе мегаскопическое изучение известняка и петрографический анализ в лаборатории. Результаты показали, что известняковые фации южной части провинции Горонтало представляют собой плавучий коралловый камень. На основании петрографического анализа в коралловом флоатстоуне происходят шесть различных процессов диагенеза. Шесть процессов диагенеза включают микробную микритизацию, начальную цементацию кальцита, цементацию, растворение, неоморфизм (инверсию) и неоморфизм (перекристаллизацию). Диагенетическая обстановка известняков района исследований включает три диагенетические обстановки: она начинается с процесса диагенеза в морской фреатической зоне, затем переходит в метеоритно-фреатический пояс и заканчивается процессом диагенеза в метеоритном аэрационном поясе.

Ключевые слова: диагенез, фация, горонтало, известняк.

Introduction. Diagenesis refers to the physical and chemical changes after sediment, or sedimentary rock is deposited. It does not contain metamorphism (Scholle & Ulmer-Scholle, 2003), a process involving high temperatures and pressures. Diagenesis can preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the deposits concerning burial, uplift and sea level change, the influx of pore fluids and climatic differences (Tucker & Wright, 1990).

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved to determine the sequence of diagenesis (Longman, 1980). Changes can occur in three main

diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history (Wright et al., 2003; James et al., 2005; Wright & Cherns, 2008).
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Carbonate rock diagenesis comprises six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, water influx rate, time, and structural control (Tucker & Wright, 1990). Complex characteristics influence diagenesis processes in carbonate deposits, such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development (Machent et al., 2007; Morad et al., 2012; Armelenti et al., 2016; Li et al., 2017; Seibel & James, 2017).

The chemistry of the pore water, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis occurs in marine, meteoric, brackish, and hypersaline brines (Morad et al., 2012: 2019; James & Jones, 2015; Swart, 2015). The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties.

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 (Bachri et al., 1997) composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of basalt lava, andesitic lava, volcanic breccia, intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, estimated to be of Pliocene-Pleistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian (Apandi & Bachri, 1997). The Reef Limestone Unit, formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid. This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift (Apandi & Bachri, 1997; Permana et al., 2019; 2021). Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

Research materials and methods. The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25''-0° 30' 05'' N and 123° 2' 25'' 123° 03' 00'' E) (Figure 1).

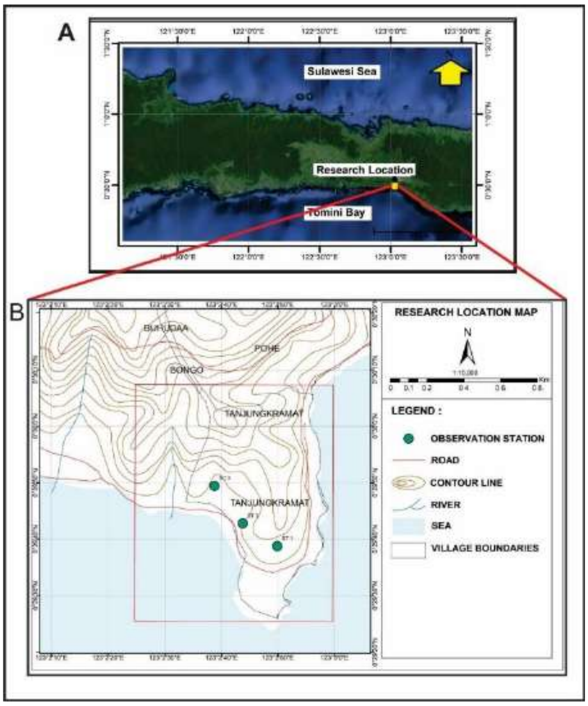

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

A field survey and laboratory analysis was performed in this study. The focus of field surveys is the description and interpretation of limestone types and suitable sampling for laboratory analysis. The petrographic analysis is performed in the Geo Optics laboratory. The petrographic analysis stage begins with forming a thin section using the blocking method, which infiltrates the blue dye into the pores to distinguish the original rock pores from those formed during preparation (Dickson, 1966; Crabtree et al., 1984). Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera (Tetley & Daczko, 2013; Serge & Senthilkumar, 2017; Ofulume et al., 2018). A petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited (Maryanto, 2012; Arosi & Wilson, 2015).

Results and Discussion. A. Facies. The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, open-packed, floating grains in the matrix and a massive structure. The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971). It contains coral fragments, quartz minerals, micrite, and sparite.

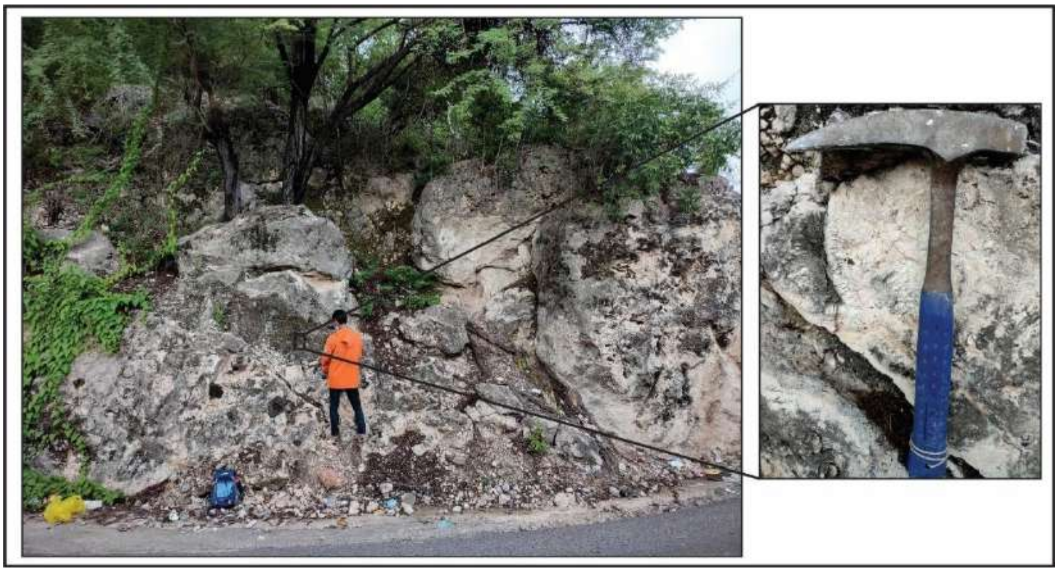

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone (Embry & Klovan, 1971).

A detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The fragments are generally replaced by sparite (calcite), and the pores are filled with micrite due to micritization. The interference color varies in order II in the appearance of crossed nickel (X).

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X), the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//), it is colorless brownish, on the appearance of nickel crossed (X), it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, and no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, a long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18^{o}. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, a short prismatic shape, translucent, low relief, no pleochroism, and no fracture observed. The crossed nickel (X) appearance has an orange interference color of order 2, and the darkening angle is 20-22^{o}.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, a fracture is not observed, bladed – equant shape, blocky structure, and meniscus. The appearance of crossed nickel (X) varies by order of two. It is composed of calcite. It results from pore filling, micrite recrystallization, or changing the composition of the shell or coral.

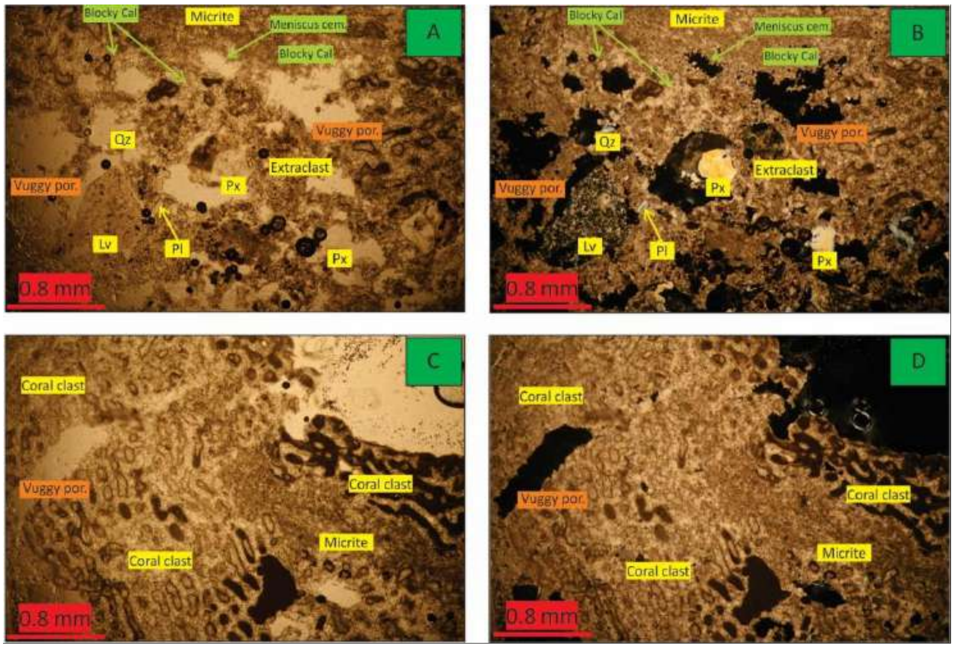

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

B. Diagenesis. Based on the petrographic study, six different diagenesis processes can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

Microbial micritization is this process that occurs in the marine environment, and drilling activity can be carried out by organisms such as endolithic fungi, bacteria, and green algae or possibly red algae. The grain micritization process is indicated by replacing several skeleton grains with cloudy brown micrite that coats the granules. The cementation process in carbonate sediments is the main diagenetic process. It occurs when the pore-fluid is supersaturated with the cement phase, and there are no kinetic factors that hinder cement precipitation. The dissolving process requires a large volume of supersaturated water and is influenced by the selectivity of the matrix, grain shape, grain size, and skeleton properties. The neomorphism process consists of inverse, recrystallization, and coalescive neomorphism (aggrading/degrading neomorphism). Inversion is the change of one mineral to a polymorph, for example, the polymorphic transformation of aragonite to calcite and alteration of Mg calcite to calcite. While recrystallization is a change in crystal size without a change in mineralogy, for example, increasing/reducing the size of calcite crystals or the replacement (replacement) of tiny calcite crystals by larger calcite crystals (Folk, 1965).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification (Longman, 1980), which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the research area's chronology or stages of limestone diagenesis.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

	Stages of the Diagenesis Process	Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
	Relative Time			
1	Microbial Micritization			
2	Initial Calcite Cementation			
3	Cementation			
4	Dissolution			
5	Neomorphism (Inversion)			
6	Neomorphism (Recrystallization)			
7	Cement Structure Dominated by Blocky Structure			
8	Cement Structure Dominated by Meniscus Structure			
9	Vuggy Porosity			

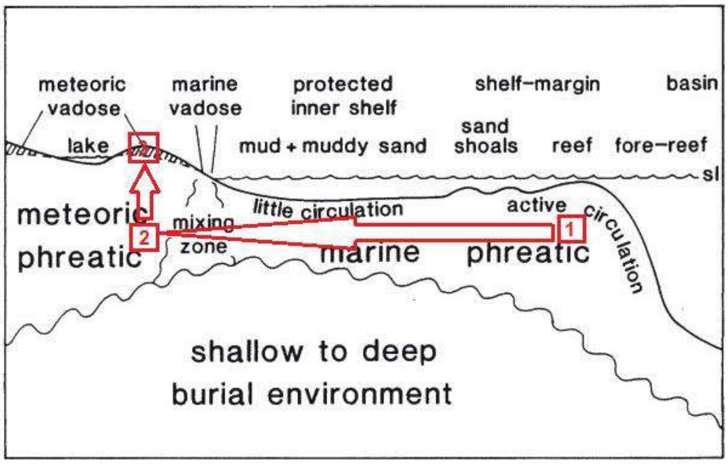

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province (Tucker & Wright, 1990)

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

A. The major dissolving product in the matrix is cementation. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage.
B. The diagenesis process progresses to the second stage in the meteoric phreatic zone. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate an inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.
C. In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of a calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance and the presence of porosity due to extensive dissolution (Figure 4).

Conclusion.

Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.
2. Based on the petrographic analysis, six different types of diagenesis processes occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).
3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

Acknowledgments. We thank the Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology, and Institute for Research and Community Service (or LPPM) of Universitas Negeri Gorontalo. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.

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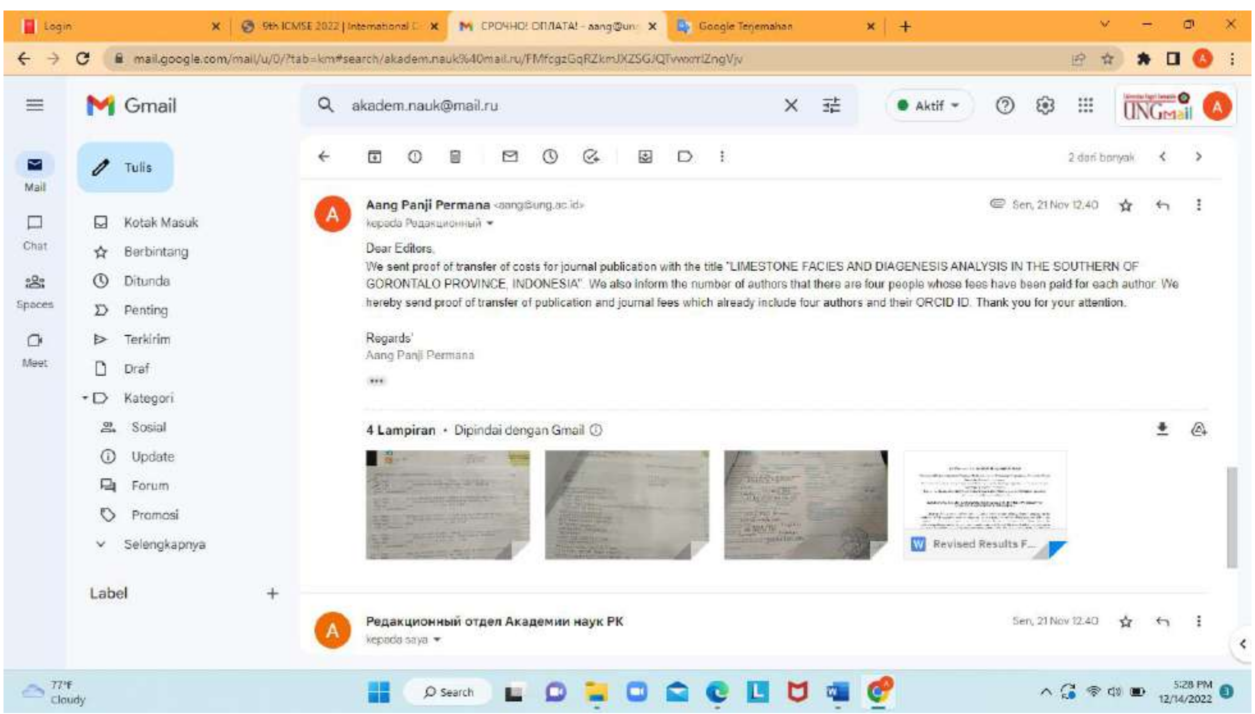

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
НАУК РЕСПУБЛИКИ
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N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
Satbayev University

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

6 (456)
NOVEMBER – DECEMBER 2022

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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«ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).

Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*

Мерзімділігі: жылына 6 рет.

Тиражы: 300 дана.

Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Типографияның мекен-жайы: «Аруна» ЖК, Алматы қ., Мұратбаев көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соединений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

Address of printing house: ST «Aruna», 75, Muratbayev str, Almaty.

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 456 (2022), 185-195
https://doi.org/10.32014/2022.2518-170X.248

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LIMESTONE FACIES AND DIAGENESIS ANALYSIS IN THE SOUTHERN OF GORONTALO PROVINCE, INDONESIA

Abstract. Strong tectonic effects have influenced the complexity of the geological conditions in the southern half of Gorontalo Province, Indonesia. As seen today, the raising of limestone into hills is one example. Furthermore, because it is located between the major volcanic and plutonic rocks, the distribution of limestone in the study area is quite distinctive. Most of the research related to limestone in the research area have only been conducted on a regional scale, therefore, a more in-depth analysis is required to gather the most up-to-date geological data. For this reason, this research aimed to look at the facies and diagenesis of limestones in the southern section of Indonesia's Gorontalo Province. Field surveys will be used to achieve the research objectives, including a megascopic study of limestone and petrographic analysis in the laboratory. The results revealed that Gorontalo Province's southern part's limestone facies are coralline floatstone. Based on the petrographic analysis, six different diagenesis processes occur in coralline floatstone. The six diagenesis processes include microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization). The research area's limestone diagenetic environment comprises three diagenesis environments: it begins with the diagenesis process in the marine phreatic zone, then turns into the meteoric phreatic zone, and ends with the diagenesis process in the meteoric vadose zone.

Key words: Diagenesis, Facies, Gorontalo, Limestone.

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ИНДОНЕЗИЯ, ГОРОНТАЛО ПРАВИНЦИЯСЫНЫҢ ОҢТҮСТІГІНДЕГІ ӘКТАСТЫ ФАСИЯЛАР ЖӘНЕ ДИАГЕНЕЗІСТІ ТАЛДАУ

Аннотация. Күшті тектоникалық әсерлер Индонезияның Горонтало провинциясының оңтүстік жартысындағы геологиялық жағдайлардың күрделілігіне әсер етті. Оның бір мысалы әктастың төбеге көтерілуі. Олар жанартаулық және плутондық жыныстардың арасында орналасқандықтан, зерттелетін аймақтағы әктастың таралуы айтарлықтай ерекшеленеді. Зерттеу аймағындағы әктасқа қатысты зерттеулердің көпшілігі тек аймақтық ауқымда жүргізілді, сондықтан ең өзекті геологиялық деректерді жинау үшін тереңірек талдау қажет. Осы себепті бұл зерттеу Индонезияның Горонтало провинциясының оңтүстік бөлігіндегі әктастардың фациялары мен диагенезін зерттеуді мақсат етті. Зертханада әктастарды мегаскопиялық зерттеу және петрографиялық талдауды қоса алғанда, зерттеу мақсаттарына қол жеткізу үшін далалық зерттеулер қолданылады. Нәтижесінде Горонтало провинциясының оңтүстік бөлігіндегі әктас фациялары маржанды флотта екенін анықталды. Петрографиялық талдау негізінде кораллин флоатста алты түрлі диагенез процесі жүреді. Алты диагенез процестеріне микробтық микротизация, кальциттің бастапқы цементтелуі, еруі, инверсия және қайта кристалдану жатады. Зерттеу аймағының әктас диагенетикалық ортасы үш диагенез ортасынан тұрады: ол теңіз фреатикалық аймағында диагенез процесінен басталып, кейін метеорлық фреатикалық аймаққа айналады және метеорлық вадоза аймағында диагенез процесімен аяқталады.

Түйін сөздер: диагенез, фация, горонтало, әктас.

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ИЗВЕСТНЯКОВЫЕ ФАЦИИ И ДИАГЕНЕЗИЧЕСКИЙ АНАЛИЗ НА ЮГЕ ПРОВИНЦИИ ГОРОНТАЛО, ИНДОНЕЗИЯ

Аннотация. Сильные тектонические эффекты повлияли на сложность геологических условий в южной половине провинции Горонтало, Индонезия. Как видно сегодня, поднятие известняка в холмы является одним из примеров. Кроме того, поскольку он расположен между основными вулканическими и плутоническими породами, распределение известняка на исследуемой территории весьма своеобразно. Большинство исследований, связанных с известняком в районе исследований, проводились только в региональном масштабе, поэтому для сбора самых современных геологических данных требуется более глубокий анализ. По этой причине это исследование было направлено на изучение фаций и диагенеза известняков в южной части провинции Горонтало в Индонезии. Для достижения целей исследования будут использованы полевые исследования, в том числе мегаскопическое изучение известняка и петрографический анализ в лаборатории. Результаты показали, что известняковые фации южной части провинции Горонтало представляют собой плавучий коралловый камень. На основании петрографического анализа в коралловом флоатстоуне происходят шесть различных процессов диагенеза. Шесть процессов диагенеза включают микробную микритизацию, начальную цементацию кальцита, цементацию, растворение, неоморфизм (инверсию) и неоморфизм (перекристаллизацию). Диагенетическая обстановка известняков района исследований включает три диагенетические обстановки: она начинается с процесса диагенеза в морской фреатической зоне, затем переходит в метеоритно-фреатический пояс и заканчивается процессом диагенеза в метеоритном аэрационном поясе.

Ключевые слова: диагенез, фация, горонтало, известняк.

Introduction. Diagenesis refers to the physical and chemical changes after sediment, or sedimentary rock is deposited. It does not contain metamorphism (Scholle & Ulmer-Scholle, 2003), a process involving high temperatures and pressures. Diagenesis can preserve information on the primary appearance, post-deposition history, pore water composition, and temperature. The key controllers of diagenesis are the composition and mineralogy of the sediments, the chemical composition of the pore fluids and the rate of fluid flow, the geological history of the deposits concerning burial, uplift and sea level change, the influx of pore fluids and climatic differences (Tucker & Wright, 1990).

Changes from one diagenesis environment to another may occur multiple times in the history of carbonate diagenesis. This can be determined using texture data that has been preserved to determine the sequence of diagenesis (Longman, 1980). Changes can occur in three main diagenesis environments: marine, meteoric, and burial, all of which have predictable processes throughout geological history (Wright et al., 2003; James et al., 2005; Wright & Cherns, 2008).

Carbonate rock diagenesis comprises six major processes: dissolution, cementation, neomorphism, dolomitization, microbial micritization, and compaction. In this case, the contributing variables are pressure, temperature, mineral stability, equilibrium conditions, water influx rate, time, and structural control (Tucker & Wright, 1990). Complex characteristics influence diagenesis processes in carbonate deposits, such as micritization, dissolution, compaction, cementation, dolomitization, and recrystallization. These criteria include primary mineralogy, depositional texture, porosity and permeability, pore water chemistry, oil saturation, and sedimentary basin tectonic development (Machent et al., 2007; Morad et al., 2012; Armelenti et al., 2016; Li et al., 2017; Seibel & James, 2017).

The chemistry of the pore water, which has the primary control over the diagenesis reaction, may vary widely. In near-surface conditions, diagenesis occurs in marine, meteoric, brackish, and hypersaline brines (Morad et al., 2012: 2019; James & Jones, 2015; Swart, 2015). The complexity of these controlling parameters makes perfect modeling of the role of diagenesis on the distribution and evolutionary pathways of reservoir quality in carbonate succession fraught with difficulties.

The regional stratigraphy of Gorontalo Province's southern part refers to a geological map of Tilamuta sheets on a scale of 1: 250,000 (Bachri et al., 1997) composed of several rock formations. In regional stratigraphic order, the oldest formation is the Tinombo Formation consisting of basalt lava, andesitic lava, volcanic breccia, intercalated sandstone, green sandstone, siltstone, red limestone, gray limestone, and a small amount of thermally recovered rock. The age of this rock unit is estimated to be between the Eocene and the Early Miocene. Above it, the Middle Miocene Bilungala Volcano Formation was created, consisting of volcanic breccia, tuff, and lava. The color of this lithology ranges from gray to dark gray. The Diorite Bone Formation, which includes diorite, quartz diorite, granodiorite, and adamelite, is estimated to be Middle Miocene in age. The Tinombo and Bilungala Volcano Formations were both cut through by this unit. Aside from that, there are variations in the composition of quartz diorite, granodiorite, and adamelite, with the main components being andesine, quartz, and hornblende. The Pinogu Volcano Formation, estimated to be of Pliocene-Pleistocene age, is not aligned. This formation consists of tuff, lapilli tuff, breccia, and lava. Volcanic breccias can be found in the Bone Mountains, Mount Mongadalia, and Pusian (Apandi & Bachri, 1997). The Reef Limestone Unit, formed unconformably in the Late Pleistocene-Holocene age, is the youngest formation. It is white and solid.

This unit has been elevated into hills, while others are still developing beneath the water. The uplift of numerous limestone facies in the Limboto Basin reaches 0.0699-0.0724 mm/year, demonstrating the tectonic influence of limestone uplift (Apandi & Bachri, 1997; Permana et al., 2019; 2021). Based on the preceding, the primary goal of this research is to investigate the facies and diagenesis of limestones in the southern region of Gorontalo Province.

Research materials and methods. The research material is a limestone outcrop in Gorontalo Province's southern part. The study area is a plateau (hills) has coordinates (0° 29' 25»-0° 30' 05» N and 123° 2' 25» 123° 03' 00» E) (Figure 1).

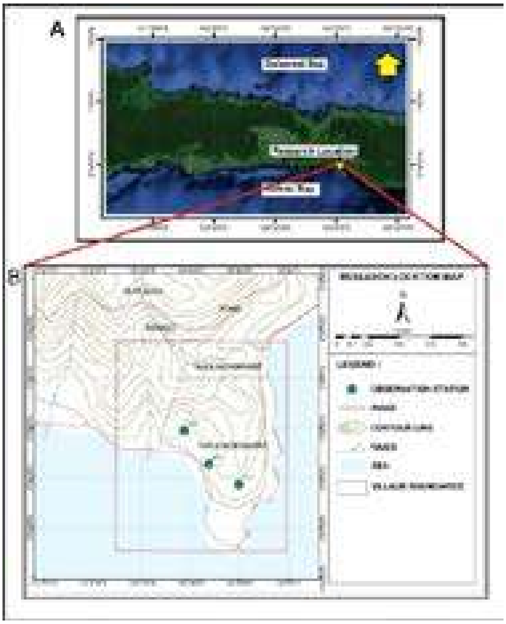

Figure 1. (A) The research location on the map of Gorontalo Province, (B) The research location is in the Tanjung Kramat area, Gorontalo City

A field survey and laboratory analysis was performed in this study. The focus of field surveys is the description and interpretation of limestone types and suitable sampling for laboratory analysis. The petrographic analysis is performed in the Geo Optics laboratory. The petrographic analysis stage begins with forming a thin section using the blocking method, which infiltrates the blue dye into the pores to distinguish the original rock pores from those formed during preparation (Dickson, 1966; Crabtree et al., 1984). Petrographic analysis was conducted with a Euromex 1053 binocular polarizing microscope equipped with a computer-connected camera (Tetley & Daczko, 2013; Serge & Senthilkumar, 2017; Ofulume et al., 2018). A petrographic analysis is very useful in determining the mineral composition of the rock and the kind of porosity, which allows the type of diagenesis to be determined. The interpretation of this type of diagenesis will assist in determining the diagenesis environment of the limestone after it has been formed or deposited (Maryanto, 2012; Arosi & Wilson, 2015).

Results and Discussion. A. Facies. The results of a field survey conducted at the research site in the southern portion of Gorontalo Province demonstrate the study's morphology in the form of limestone hills (Figure 2). Petrological analysis of limestone samples reveals white rock with poorly sorted, open-packed, floating grains in the matrix and a massive structure. The limestone is known as Coralline floatstone based on petrological analysis (Embry & Klovan, 1971). It contains coral fragments, quartz minerals, micrite, and sparite.

Figure 2. Coral limestone outcrops located in the hills of the southern part of Gorontalo Province

The petrological analysis results were then compared to the petrographic analysis using a polarizing microscope (Figure 3). The petrographic analysis revealed that the carbonate rock incision was brown, the interference color was dark brown, with a particle size of 0.1 - > 4 mm, an abundance of material measuring > 2 mm, up to 11%, and the rock texture was based on the relationship between the matrix's supported grains. There is a vuggy porosity with a 12 % abundance. There are skeletal fragments in the form of coral fragments, non-skeletal grains in the form of extraclase, non-carbonate grains in the form of volcanic lithic, quartz, plagioclase, and pyroxene minerals, as well as micrite and sparite, according to its composition. The limestone facies is known as Coralline floatstone (Embry & Klovan, 1971).

A detailed description of the rock composition, namely skeletal grain in the form of coral fragments (11 percent): on the parallel nickel appearance (//) it is brown, has a porous shape, > 4 mm in size, high relief, no pleocroism is visible, and has a sort of translucent transparency. The fragments are generally replaced by sparite (calcite), and the pores are filled with micrite due to micritization. The interference color varies in order II in the appearance of crossed nickel (X).

Non-skeletal grain in the form of extraclase (3%): on the appearance of parallel nickel (//) is colorless brownish, size 0.6 mm, high relief. In the appearance of cross-linked nickel (X), the interference color varies in order of 2. Because it has been heavily crystalline, the texture cannot be determined. It is considered an extraclase because it is more diegenic than other grains of rock origin.

Non-carbonate grains consist of 1. Andesite lithic (2%): on the appearance of parallel nickel (//), it is colorless brownish, on the appearance of nickel crossed (X), it has an interference color of yellowish black, size 0.8 mm, porphyroafanitic texture, the composition in the form of plagioclase, quartz with a base mass of glass material. 2. Quartz (2%): on the appearance of parallel nickel (//), it is colorless, 0.1 mm in size, conchoidal shape, translucent, low relief, no pleochroism, and no fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, wavy dark. 3. Plagioclase (2%): on the appearance of parallel nickel (//) colorless, 0.1 mm in size, a long prismatic shape, translucent, low relief, no pleochroism, one-way fracture. On the appearance of crossed nickel (X), it has an interference color of order 1 gray, Carlsbad twinning, and the darkening angle is 14-18°. 4. Clino-Pyroxene (2%): on the appearance of parallel nickel (//), it is colorless brownish, 0.2 mm in size, a short prismatic shape, translucent, low relief, no pleochroism, and no fracture observed. The crossed nickel (X) appearance has an orange interference color of order 2, and the darkening angle is 20-22°.

The matrix consists of 1. Micrite (63%): on the appearance of parallel nickel (//), it is dark brown-yellowish brown, mineral size < 0.1 mm, moderate relief, cleavage is not observed, no pleocroism is visible, and has a type of translucent transparency. On the appearance of nickel crossed (X), it has a golden brown color. 2. Sparite (15%): on the appearance of parallel nickel (//), it is colorless, size 0.1 - 0.4 mm, moderate relief, a fracture is not observed, bladed – equant shape, blocky structure, and meniscus. The appearance of crossed nickel (X) varies by order of two. It is composed of calcite. It results from pore filling, micrite recrystallization, or changing the composition of the shell or coral.

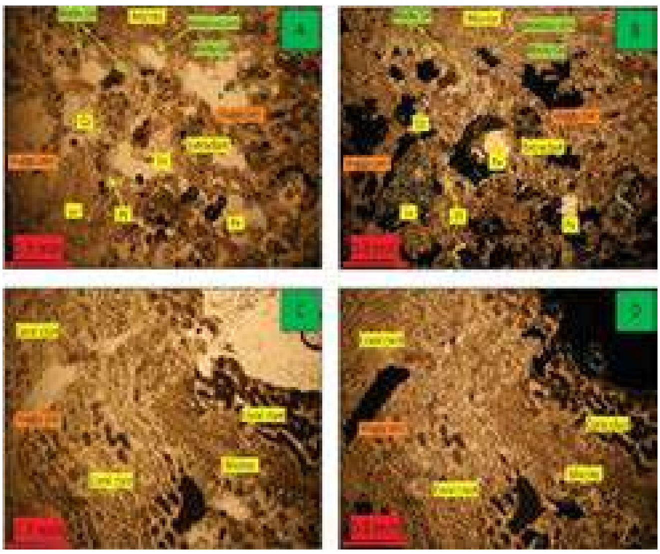

Figure 3. Petrographic analysis of rock samples showing the Coralline floatstone facies. Various types of diagenesis occur in the Coralline floatstone facies. (A) and (C) parallel nikol, (B) and (D) cross nikol

B. Diagenesis. Based on the petrographic study, six different diagenesis processes can occur in Coralline floatstone samples. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (recrystallization) are the six processes that occur during diagenesis (Figure 3).

Microbial micritization is this process that occurs in the marine environment, and drilling activity can be carried out by organisms such as endolithic fungi, bacteria, and green algae or possibly red algae. The grain micritization process is indicated by replacing several skeleton grains with cloudy brown micrite that coats the granules. The cementation process in carbonate sediments is the main diagenetic process. It occurs when the pore-fluid is supersaturated with the cement phase, and there are no kinetic factors that hinder cement precipitation. The dissolving process requires a large volume of supersaturated water and is influenced by the selectivity of the matrix, grain shape, grain size, and skeleton properties. The neomorphism process consists of inverse, recrystallization, and coalescive neomorphism (aggrading/degrading neomorphism). Inversion is the change of one mineral to a polymorph, for example, the polymorphic transformation of aragonite to calcite and alteration of Mg calcite to calcite. While recrystallization is a change in crystal size without a change in mineralogy, for example, increasing/reducing the size of calcite crystals or the replacement (replacement) of tiny calcite crystals by larger calcite crystals (Folk, 1965).

It is possible to determine the diagenetic environment of the limestone in the study area based on petrographic analysis and diagenesis type determination using the classification (Longman, 1980), which includes three diagenesis environments: marine phreatic zone, meteoric phreatic zone, and meteoric vadose zone. The reconstruction of the history of limestone diagenesis in the southern part of Gorontalo Province is helped by the analysis of three diagenesis environments based on diagenesis type. Table 1 shows the research area's chronology or stages of limestone diagenesis.

Table 1. Stages of the diagenesis process that occurred based on relative time in limestones in the southern region of Gorontalo Province

Stages of the Diagenesis Process		Marine Phreatic Zone	Meteoric Phreatic Zone	Meteoric Vadose Zone
Relative Time				
1	Microbial Micritization			
2	Initial Calcite Cementation			
3	Cementation			
4	Dissolution			
5	Neomorphism (Inversion)			
6	Neomorphism (Recrystallization)			
7	Cement Structure Dominated by Blocky Structure			
8	Cement Structure Dominated by Meniscus Structure			
9	Vuggy Porosity			

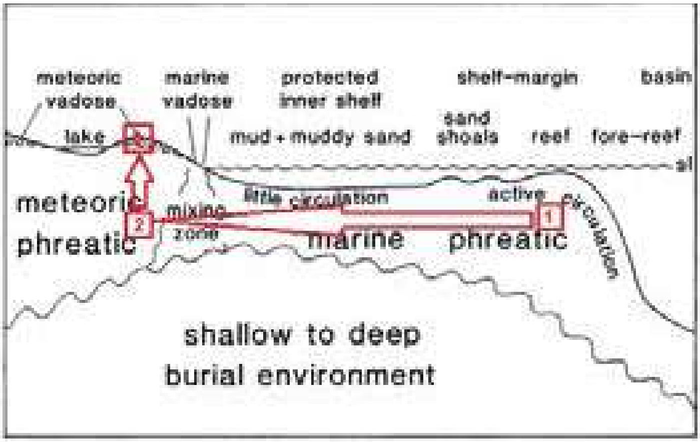

Figure 4. Environmental scheme of carbonate diagenesis in the Coralline floatstone facies in the southern area of Gorontalo Province (Tucker & Wright, 1990)

According to Table 1, the study area's chronology or stages of limestone diagenesis can be divided into three categories:

The major dissolving product in the matrix is cementation. The early steps of the diagenesis process take place in the marine phreatic zone. The process of microbial micritization and early calcite cementation characterize this stage.

The diagenesis process progresses to the second stage in the meteoric phreatic zone. The presence of a substantial dissolving process in the matrix and shell, with the matrix dominating, characterizes this stage. There is also a neomorphism process that involves inversion and recrystallization. Changes in shell composition or coral fragments into blocky calcite indicate an inversion. The process of nemorphism takes the form of recrystallization, as seen by the transformation of micrite to blocky calcite. The bladed equant form dominates the cement's morphology.

In the meteoric vadose zone, the diagenesis process reaches its third stage. The occurrence of a disintegrating process characterizes this stage. Vuggy porosity is formed as a result of this minor dissolving process. There was also a cementation process, as evidenced by the existence of a calcite cement pore filling with a meniscus structure. This is supported by the rock's cementation dominance and the presence of porosity due to extensive dissolution (Figure 4).

Conclusion. Several important conclusions can be taken from the results and discussion of facies analysis and limestone diagnosis studies in the southern portion of Gorontalo Province, including:

1. Coralline floatstone is the limestone facies found in the southern half of Gorontalo Province.

2. Based on the petrographic analysis, six different types of diagenesis processes occur in Coralline floatstone. Microbial micritization, initial calcite cementation, cementation, dissolution, neomorphism (inversion), and neomorphism (inversion) are the six diagenesis processes (recrystallization).

3. The limestone diagenetic environment in the study area consists of three diagenesis environments, which begin with the diagenesis process in the marine phreatic zone, then turn into the meteoric phreatic zone, and end in the diagenesis process in the meteoric vadose zone.

Acknowledgments. *We thank the Directorate of Technology Research and Community Service. Directorate General of Higher Education, Ministry of Education, Culture, Research and Technology, and Institute for Research and Community Service (or LPPM) of Universitas Negeri Gorontalo. Support is provided in the form of financial or legality to this research through the Decentralization Program Research in Higher Education for the Fiscal Year 2022.*

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ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Директор отдела издания научных журналов НАН РК *А. Ботанқызы*
Заместитель директор отдела издания научных журналов НАН РК *Р. Жәлиқызы*
Редакторы: *М.С. Ахметова, Д.С. Аленов*
Верстка на компьютере *Г.Д. Жадыранова*

Подписано в печать 06.12.2022.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
20,0 п.л. Тираж 300. Заказ 6.

Национальная академия наук РК
050010, Алматы, ул. Шевченко, 28, т. 272-13-19