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IDENTIFICATION OF MIOCENE LIMESTONE AND LARGE BENTHIC FORAMINIFERA ASSEMBLAGES FROM CIBODAS FORMATION IN SURADE AREA, WEST JAVA, INDONESIA

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ABSTRACT

UNESCO Global Geoparks preserve outstanding geological records that are essential for reconstructing regional paleoenvironmental histories and evolution. Among these records, large benthic foraminifera and limestone facies are widely recognized as reliable indicators of shallow-marine depositional environments. This research aims to analyze limestone facies distribution and large benthic foraminifera assemblages within the Cibodas Formation in the Surade area, West Java, which forms part of the Ciletuh Palabuhanratu UNESCO Global Geopark. The limestone of the Cibodas Formation was examined through petrographic analysis to determine lithofacies characteristics and fossil content. The results show that the limestone is composed of boundstone, grainstone, packestone, and wackestone facies. Boundstone is characterized by interlocking skeletal components, indicating in-situ framework construction, with micritization processes commonly observed. Grainstone consists of abundant grain composition, grain supported, plagioclase and quartz minerals are present. Packestone is dominated by skeletal grains, particularly large benthic foraminifera, including *Lepidocyclina stratifera*, *Lepidocyclina (Nephrolepidia) subradiata*, *Amphistegina bowdenensis*, *Amphistegina* sp., *Heterostegina* sp., *Cycloclypeus* sp., and *Austrotrilina howchini*. Wackestone shows a micrite-supported fabric locally overlain by sparite cement and contains *Lepidocyclina stratifera*, *Amphistegina* sp., and *Austrotrilina howchini*, reflecting relatively lower-energy conditions. The results of this study provide insights into the diversity of limestone facies and large benthic foraminifera assemblages in the study area, which are essential for interpreting the paleoenvironmental conditions and depositional setting of the Cibodas Formation in Ciletuh Palabuhanratu.

Keywords: Benthic Foraminifera, Cibodas Formation, Limestone, Petrography, Surade

ABSTRAK

UNESCO Global Geoparks melestarikan rekaman geologi yang penting sebagai sumber utama untuk merekonstruksi sejarah dan evolusi paleoenvironmental regional. Di antara rekaman-rekaman tersebut, Foraminifera bentonik besar dan fasies batugamping secara luas dijadikan indikator yang reliabel untuk lingkungan pengendapan laut dangkal. Penelitian ini bertujuan untuk menganalisis distribusi fasies batugamping dan asosiasi foraminifera bentonik besar pada Formasi Cibodas di daerah Surade, Jawa Barat, yang merupakan bagian dari UNESCO Global Geopark Ciletuh–Palabuhanratu. Batugamping Formasi Cibodas dianalisis melalui kajian petrografi untuk menentukan karakteristik litofasies dan kandungan fosilnya. Hasil penelitian menunjukkan bahwa batugamping tersusun atas fasies boundstone, grainstone, packestone, dan wackestone. Boundstone memiliki karakteristik komponen skeletal yang interlocking, yang menunjukkan struktur in-situ, dengan proses mikritisasi yang sangat umum dijumpai. Grainstone terdiri dari komposisi butiran yang melimpah, grain supported, dan mengandung mineral plagioklas dan kuarsa. Packestone didominasi oleh butiran skeletal, khususnya foraminifera bentonik besar, antara lain *Lepidocyclina stratifera*, *Lepidocyclina (Nephrolepidia) subradiata*, *Amphistegina bowdenensis*, *Amphistegina* sp., *Heterostegina* sp., *Cycloclypeus* sp., dan *Austrotrilina howchini*. Wackestone menunjukkan struktur yang tersusun dari mikrit, setempat ditutupi oleh semen sparite, dan terdapat *Lepidocyclina stratifera*, *Amphistegina* sp., serta *Austrotrilina howchini*, yang mencerminkan kondisi pengendapan berenergi relatif rendah. Hasil penelitian ini memberikan pemahaman mengenai keragaman fasies batugamping dan asosiasi foraminifera bentonik besar di daerah penelitian, yang penting untuk menafsirkan kondisi lingkungan purba dan pengendapan Formasi Cibodas di Ciletuh Palabuhanratu.

Kata Kunci : Foraminifera Bentonik, Formasi Cibodas, Batu Kapur, Petrografi, Surade

INTRODUCTION

Limestone is a type of sedimentary rock with the primary component being carbonate minerals with limestone >or=90% calcite or aragonite (Mackenzie, 2003). In particular, it can be divided into limestone with carbonate mineral content ($CaCO_3$) and dolomite limestone with chemical composition ($CaMg(Co_3)_2$) (Maryanto, 2017). The warm marine conditions and stable shallow-water settings in this region provide an optimal environment for the development of carbonate-producing organisms, particularly corals and large benthic foraminifera. Ecological studies indicate that living foraminifera require specific environmental conditions, including minimum seawater temperatures of around 18°C and relatively shallow water depths, typically less than 35 m (BouDagher-Fadel, 2008). These constraints emphasize the strong control of temperature and water depth on carbonate production and foraminiferal distribution, reinforcing the interpretation of warm, shallow-marine depositional environments within the Indo-Pacific carbonate systems. Studies on Indonesian carbonate successions have shown that foraminiferal assemblages are effective proxies for interpreting depositional environments, paleobathymetry and paleoclimatic conditions (Farida et al., 2022; Fauzielly et al., 2015; Farida et al., 2017; Wilson et al., 1997). The distribution of limestone in West Java can be found in the coastal area of the southern coast of Java until it is exposed in some areas away from the marine area, such as the Rajamandala Formation, Parigi Formation, Cibodas Formation (Sukamto, 1975).

The study area belongs to the Cibodas Formation in the Ciletuh Palabuhanratu UNESCO Global Geopark, which exhibits exceptionally complex geological characteristics. The area exposes rock units ranging from pre-Tertiary to Middle–pre-Eocene age, including mélange complexes, ophiolite rocks, deep-sea sedimentary rocks, and continental sedimentary successions (Rosana, 2006; Sarmili et al., 2015). The Cibodas formation is made up of limestone, tuffaceous and partly passivated with interbeds of silty sandstone and tuffaceous sandstone. The limestone contains foraminifera of the species *Lepidocyclina verbeeki*, *Cycloclpeus* sp., *Operculina* sp., *Textularia* sp., *Bolivina* sp., *Globigerina* sp., *Orbulina* sp., *Cibicides* sp., *Ouinqueluculina* sp., *Rotalia* sp. (Sukamto, 1975). The fossils signify an Upper Miocene age and the depositional environment indicated a Neritic to Littoral environment (Sukamto, 1975). Within the area of the Cibodas Formation, a shark tooth fossil record was found in the Gunung Sungging region (Winarto, 2022). The southern part of the Cibodas Formation transforms gradually into the Upper Bentang Formation while the northern part of this formation horizontally transforms into the Lower Bentang Formation. This rock formation shows unconformity stratigraphy with the upper Bentang Formation and interfingers with the Cikarang Member of the Jampang Formation (Sukamto, 1975; Pratiwi et al., 2023). Examination of the lithologic characteristics both petrologically and in thin section (petrography) can reveal further information about the composition of the rocks, such as the presence of skeletal fragments in the form of large benthic foraminifera, carbonate mud, and carbonate cement (Farrokhad et al., 2022). It can be associated with the determination of limestone type based on rock composition, depositional texture, abundance of grain size uniformity (sorting) and relationship between rock constituents (packing).

Research focusing on detailed analyses of limestone distribution in the Surade area is still limited. This information is crucial for evaluating limestone resources, developing biostratigraphic interpretations for paleoenvironmental and geological history reconstructions, and enhancing the role of the Ciletuh Palabuhanratu UNESCO Global Geopark as a site for scientific and field-based activities.

This research aims to investigate the distribution of limestone and analysis of large benthic foraminifera assemblages in the study area. The findings are expected to enhance understanding of limestone facies characteristics and associated fossil assemblages, with specific relevance to the study area.

MATERIAL AND METHOD

Administratively, the research area is located in Surade Area, Pasiripis District, Sukabumi Regency, West Java Province with coordinates between 7°20'46''-7°23'29'' S and 106°29'50''- 106°32'33'' E (Figure 1).

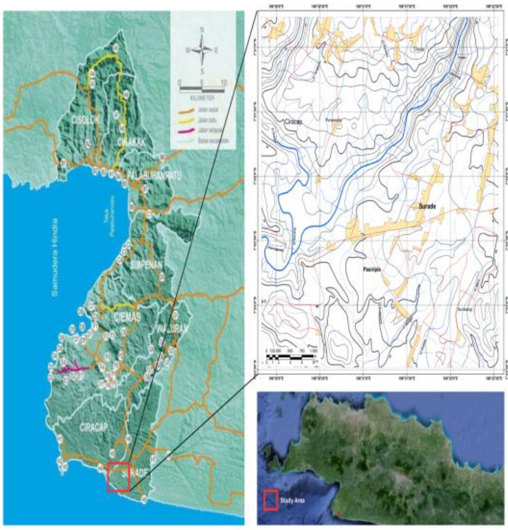

Figure 1. Location of Study area

The research method begins with field observation and sampling in Surade area, Sukabumi, West Java. Petrographic analysis was conducted at the Petrology and Mineralogy Laboratory, Faculty of Geological Engineering, Universitas Padjadjaran to determine the type of limestone based on Dunham's classification (Dunham, 1962). The identification of large benthic foraminifera types was based on the comparability of previous references (Van Der Vlerk, 1931; Postuma, 1966) and in a large benthic foraminifera catalogue.

RESULT AND DISCUSSION

The sampling of rock was carried out at each location in the Surade area, Ciletuh Palabuhanratu (Table 1). Seven samples from limestone outcrops were selected for further analysis, namely D-10, D-14, D-21, D-22, D-36, D-37, D-52. The observation locations were around Surade road, Sindang, Ci beledug river, Ci kutamara river, Pasiripis beach, and Cikarang river. Based on petrographic observations, the limestone of the Cibodas Formation is classified into boundstone, grainstone, packestone, and wackestone facies. Megascopic observations indicate that the rocks exhibit a fresh yellowish-white color and a grayish-black weathered surface. The limestone is characterized by a medium grain size (<2 mm), with preserved depositional textures, predominantly unbound components, and moderate sorting. Biogenic structures, trace fossil bodies, fossil shells of gastropod and other skeletal fragments. Rock composition is composed of minerals (calcite, quartz), and weathered material. Rock hardness is compact, carbonate and the weathering color is grayish black to grey.

Table 1. Sampling location from 7 Surade area

No	Location	Code	Longitude	Latitude
1	Surade road	D-10	7°22'27.7" S	106°30'03.3" E
2	Surade road	D-14	7°22'45.1" S	106°30'15.5" E
3	Ci beledug river	D-21	7°21'27.9" S	106°31'58.2" E
4	Sindang	D-22	7°21'55.1" S	106°31'53.9" E
5	Ci Kutamara River	D-36	7°22'41.1" S	106°31'39.1" E
6	Pasiripis Beach	D-37	7°23'27.6" S	106°30'09.0" E
7	Ci Karang River	D-52	7°22'22.1" S	106°30'12.4" E

Boundstone

The boundstone outcrops (D-14, D-21) were found in a cave near the Surade road, close to the Ci Karang River. The outcrop structure reflects a binding framework derived from the remnants of reef-building organisms, indicative of a reef structure.he rock structure consists of biogenic structures, in the form of fossil body traces (molds), skeletal fossils in the form of a gastropod shell, and other skeletal fragments. Based on microscopic observation, it shows brownish ash color (PPL). The appearance of bound components, medium sorting, matrix supported. The rock composition consists of skeletal fragments, mineral, and dominated by allochem fragments (Figure 2). It can be interpreted that micritization occurred initially, followed by uplift and subsequent dissolution processes, as indicated by the presence of skeletal fragments and secondary porosity (Carpentier, et al., 2015) (Figure 3). Appearance of unsorted components, medium sorting, grain supported. The rock components are composed of skeletal fragments (40%), non-skeletal fragments (15%), mineral (10%), cement (20%), and mud (15%). Both skeletal fragments and carbonate minerals, quartz, and plagioclase are widely distributed in the rock. The genesis of this rock can be interpreted as allochtonous with a diversity of skeletal grains that have been replaced by carbonate minerals originating from a transport process prior to deposition. The presence of terrigenous sedimentary clastic material, such as quartz and plagioclase mineral fragments.

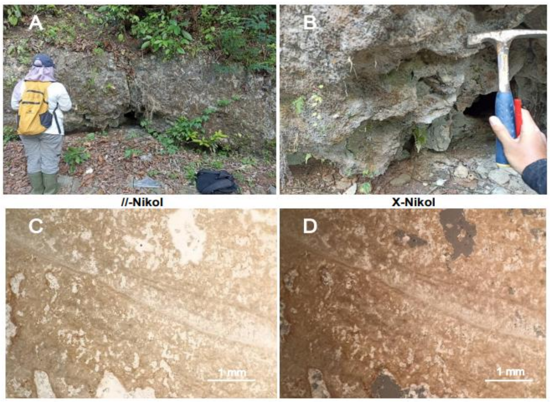

Figure 2. A and B: boundstone outcrops found in the cave around Surade road (D-14), C: planar polarized light, D: crossed polarized light, showing the appearance of trace skeletal fragments of benthic foraminifera.

Grainstone

The grainstone outcrop (D-37) was found on the Pasiripis coast. Based on microscopic observation, it shows a yellowish white color (PPL). The component appearance is unbound, medium sorting, grain supported. The rock is composed of skeletal and non-skeletal grains, minor terrigenous minerals, and sparry calcite cement. The rock genesis can be interpreted as allochthonous, as indicated by the diverse skeletal grain assemblage that has been transported prior to deposition and locally altered or replaced by carbonate material. The presence of minor composition of quartz and plagioclase fragments, further supports sediment input from siliciclastic sources during deposition. (Figure 4).

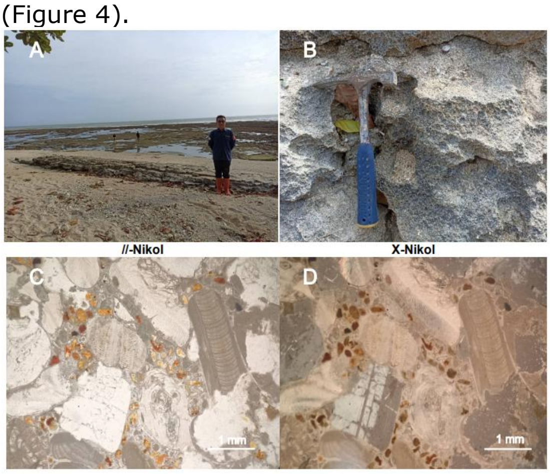

Figure 4. A and B: grainstone outcrops (D-37), C: planar polarized light, D: crossed polarized light, showing grain supported material, trace fossils, skeletal fragments.

Packstone

Packestone outcrops were found around Cikarang river (D-52), Surade road (D-10), Sindang (D-22). Shows brownish white color (PPL). The component appearance is unbound, medium sorting, grain supported. Rock components consist of skeletal fragments, minerals, sparite and micrite. Skeletal fragments are notably abundant, with large benthic foraminifera such as *Lepidocyclina stratifera*, *Lepidocyclina subradiata*, and *Amphistegina bowdenensis* representing the dominant components. (Figure 5). It can be interpreted that the genesis of this rock is allochthonous with a diversity of skeletal grains that have been micritized by carbonate muds (Chaerul, et al., 2017) (Figure 6).

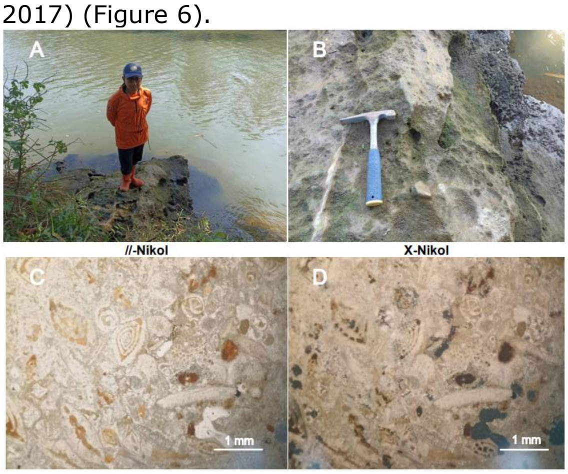

Figure 5 A: packestone outcrop in Ci Karang river (D-52), B: rock showing massive structure - coral reef, C: planar polarized light, D: crossed polarized light, shwoing the dominance of skeletal fragment material.

Figure 6 A: packestone outcrop in Sindang area (D-22), B: rock showing massive structure, C: planar polarized light, D: crossed polarized light, showing dominance of skeletal fragment material.

The rock structure consists of biogenic structures in the form of fossil body traces (molds), fossil shells in the form of gastropod shells, and other skeletal fragments.

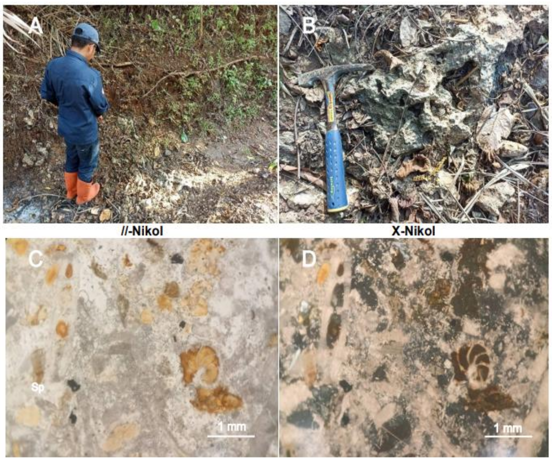

Figure 7. A: packestone outcrop in Surade road (D-10), B: rock showing massive-reef structure, C: planar polarized light, D: crossed polarized light.

Wackstone

Wackestone outcrops found in Ci Kutamara river (D-36). Shows gray-white color (PPL). The component appearance is unbound, medium sorting, matrix supported. The rock component consists of skeletal fragments, minerals, micrites, and is dominated by carbonate material (sparite) which forms the groundmass. Large benthic foraminifera are present, such as *Lepidocyclina stratifera*, *Austrotrlina howchini*.

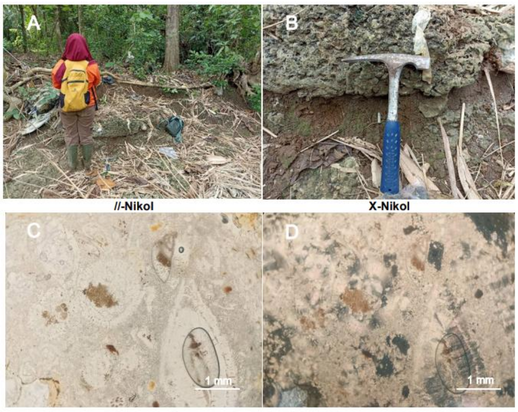

Fig. 8 A: outcrop of wackestone in Ci Kutamara river (D-36), B: rock showing massive reef structure, C: planar polarized light, D: crossed polarized light, showing the appearance of large benthic foraminifera.

The presence of significantly large benthic foraminifera in limestone can provide a guide to past marine environments, ecological conditions including salinity, temperature and sedimentary process (Murray, 2006). These foraminifera are unicellular creatures, with soft shells, in a warm, shallow temperature environment (Romano, et al., 2022). analysis was conducted by examining the shape, size, distribution of each large benthic foraminifera group and comparing with previous references (Natsir, 2022).

In the research area, large benthic foraminifera are present abundantly in packestone and wackestone. In packestone outcrops, Cikarang river (D-52), around Surade road (D-10), Sindang (D-22) there are occurrences of *Lepidocyclina stratifera*, *Lepidocyclina (Nephrolepidia) subradiata*, *Amphistegina bowdenensis, Amphistegina* sp , *Heterostegina* sp., *Cycloclypeus* sp., and *Austrotrilina howchini*. And the large foraminiferafrom wackstone sample (D-36) are consist of *Austrotrilina howchini*, *Lepidocyclina stratifera*, *Amphistegina* sp., (Figure 8). Lepidocyclina is the most common species in this rock sample. In thin section, a genus of large, robust foraminifera, exhibits distinctive features that are crucial for identifying and interpreting ancient marine environments (figure 9). The presence of these foraminifera is widely spread in some environments, such as the forereef shelf (Rachman, 2021).

The abundance of limestone in the southern part of West Java, especially in the Surade area, proves that the past depositional environment was a marine environment. The South Sukabumi was influenced by the process of transgression of sea level that occurred since the Oligocene and deposited reef sediments (Alif, 2011). The formation of reef limestone is due to the accumulation of organic materials and sediments in the transgression process, the uplift process plays a role for the appearance of limestone on land.

Limestone is formed in a marine environment rich in organic sediments and calcium carbonate accumulation. In particular, it is formed during the accumulation of organic materials, such as shells and body parts of living organisms that accumulate at the seafloor, even coral reefs, corals that will later form limestone (Boggs, 2012; Flügel, 2010). In addition, chemical processes, such as water solutions in caves will form limestone stalactites and stalagmites. The formation of limestone can be evidence of the environment and climate of the past.

The variety in limestone types reflects the diverse conditions under which they form, including water depth, temperature, and biological activity, making limestone a valuable indicator of past marine environments and the ecological conditions that prevailed during its formation.

The study identified four types of limestone based on Dunham's classification (1962), namely boundstone, grainstone, packestone and wackestone. Each type of limestone shows its own characteristics, in terms of rock composition, such as skeletal grain, mud and cement. Boundstone is interpreted to have formed in a high-energy environment, where the bodies of organisms, such as coral reefs, algae will be bound and cemented together (Fang, 2021). Similarly, grainstone can be found at medium-low energy levels, such as coastal areas, with grain forms that show supported grains, such as shells, foraminifera, rock fragments and even minerals and less matrix content (Dunham, 1962).

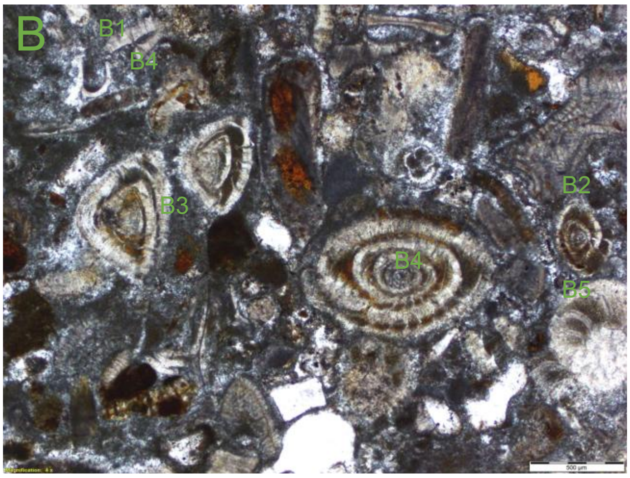

Figure 9. *Lepidocyclina* sp.(B1), *Operculina* sp. (B-2), *Amphistegina* sp. (B3), *Amphistegina bowdenensis (B4), Heterostegina* sp. *(B5)*

Packestone and wackestone is common in slightly quieter marine settings, such as lagoons or shallow marine areas, where the sediment is packed together with a significant amount of matrix filling the spaces between grains. Therefore, the accumulation of organic material will be more, such as large benthic foraminifera will be found in these rocks.

CONCLUSIONS

The distribution of limestone facies in the study area includes boundstone, grainstone, packestone, and wackestone, which are differentiated according to their skeletal grain content, matrix (mud) proportion, rock composition, and the presence of terrigenous minerals. The presence of large benthic foraminifera is observed in packestone and wackestone. The packestone contains *Lepidocyclina stratifera, Lepidocyclina (Nephrolepidia) subradiata, Amphistegina bowdenensis, Amphistegina* sp., *Heterostegina* sp., *Cycloclypeus* sp., and *Austrotrilina howchini*. Wackestone showing *Lepidocyclina stratifera*, *Amphistegina* sp., and *Austrotrilina howchini*. The presence of various types of limestones can indicate the past depositional environment condition.

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