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Petrographic Characteristics and Preliminary Depositional Interpretation of the Bojongmanik Formation Limestone Member, Nayagati, Banten, Indonesia

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Abstract:
The limestone member of the Middle–Late Miocene Bojongmanik Formation crops out near Nayagati Village, Lebak Regency, Banten, Indonesia. This study describes its petrographic constituents, evaluates its depositional texture, and assesses the implications for depositional setting. Three limestone outcrops were examined in the field, and one thin section from Research Location 2 was selected for detailed microscopy under plane- and cross-polarized light. The reported component estimates are skeletal grains (34%), glauconite (24%), opaque minerals (6%), orthoclase (4%), quartz (2%), micrite (18%), and carbonate cement (12%). The observed mud-supported, bioclastic fabric is consistent with a wackestone texture, subject to verification of the relative abundance and origin of the non-carbonate grains. The substantial glauconite fraction is a distinctive feature that requires further mineralogical confirmation and sedimentological discussion. The reported benthic foraminifera and micritic fabric are compatible with a relatively low-energy marine environment, but they do not uniquely identify a back-reef setting. A sheltered shallow-marine setting is therefore proposed as a working interpretation, with a back-reef position remaining tentative. Because only one thin section was examined, the conclusions apply primarily to the analyzed sample and require testing through additional petrographic and stratigraphic observations.

Keywords: Bojongmanik Formation; carbonate petrography; glauconite; wackestone; depositional environment
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1. Introduction

Carbonate rocks preserve information on sediment production, transport, deposition, and subsequent diagenesis. Petrographic examination of constituent grains, micritic matrix, cement, and depositional fabric provides a basis for describing limestone and evaluating depositional conditions [1]–[3], [6]. Folk's classification emphasizes allochem types and the proportions of micrite and sparry cement [1], whereas Dunham's classification relies primarily on original depositional texture [2]; Embry and Klovan extended the latter framework for certain coarse-grained and organically bound carbonates [3]. These schemes are complementary but should not be applied without considering the origin and abundance of non-carbonate components. Quantitative point counting can improve the reproducibility of component estimates when the procedure and counting effort are reported [4].

Petrographic and microfacies studies have been applied to carbonate successions in Indonesia to characterize grain types, depositional fabrics, fossil assemblages, diagenetic features, and environmental variation [8]–[17]. Regional comparison is useful, but a facies interpretation should be supported by diagnostic observations rather than inferred solely from general carbonate models [6], [21], [22]. In particular, mud-supported skeletal limestone may accumulate in several relatively low-energy marine settings; environmental assignments become more robust when thin-section observations are combined with measured stratigraphic sections, fossil associations, and lateral facies relationships.

The Bojongmanik Formation is a characteristic deposit of the Banten Block, distributed across Lebak Regency, Banten Province, and extending eastward to the Leuwiliang area [18]. The formation is Miocene in age and consists of alternating sandstone, claystone, and limestone. It is divided into the Claystone Member, Sandstone Member, and Limestone Member [18]. This subdivision provides the basis for interpreting the limestone outcrops in the study area as part of the Limestone Member of the Bojongmanik Formation. Previous studies of the Bojongmanik Formation in Banten have focused mainly on stratigraphy and sedimentation. The sedimentation mechanism of the formation has been investigated using 55 samples and both planktonic and benthic foraminiferal analyses [19]. The results indicate that the formation was deposited in a marine setting from the Middle to the Late Miocene (N9–N17). Toward the end of the Middle Miocene (N13–N14), a regression caused most of the shallow-water succession to be deposited on land, whereas the deeper parts remained largely marine [19]. Lithostratigraphic changes in the formation have also been examined in the Sajira area, Lebak Regency. That study separated a claystone unit with sandstone and limestone

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interbeds (N9–N12), deposited in a neritic environment, from a sandstone unit with claystone and limestone interbeds (N13–N14) [18]. It also proposed that the sandstone and limestone units be separated and given a distinct formation name [18], so the stratigraphic status of the formation remains open to discussion. In the Leuwidamar area, the geological history has been reconstructed through stratigraphic analysis, which provides a stratigraphic and geological framework for the area [20].

Previous work on the Bojongmanik Formation has focused principally on regional stratigraphy, sedimentation, and foraminiferal evidence [18]–[20]. Detailed published petrographic descriptions from the studied Nayagati outcrops remain limited. This study therefore (1) documents the observable constituents and depositional fabric of a limestone sample from the Bojongmanik Formation Limestone Member, (2) evaluates its carbonate classification, and (3) discusses the depositional interpretations permitted by the petrographic and fossil evidence. The study is exploratory: one thin section from Research Location 2 was analyzed, and its composition cannot be assumed to represent the entire limestone member.

2. Methodology

Geological reconnaissance and outcrop description were conducted at three localities around Nayagati Village. Field observations included lithology, color, visible grain size, sedimentary structures, fossil content, weathering, and stratigraphic relationships. Outcrop positions and photographs were documented (Figure 1). The limestone was assigned provisionally to the Bojongmanik Formation Limestone Member by comparison with the regional lithostratigraphic framework [18]–[20]. The original sampling description states that material was selected from relatively fresh rock, with one sample per identified bed; however, the number of collected hand specimens and the precise stratigraphic sampling intervals should be reported explicitly by the authors.

A petrographic thin section approximately 30 µm thick was prepared from the sample at Research Location 2. It was examined under plane-polarized light (PPL) and cross-polarized light (XPL), with attention to skeletal and non-skeletal grains, micrite, carbonate cement, pore types, and grain-support relationships. This sample was chosen because the outcrop was well exposed and appeared comparatively fresh. The reported component percentages are reproduced in Table 1, but the original manuscript does not specify the number of counted points, traverse spacing, counting protocol, or whether the values reflect visual area estimates; they must therefore be treated as approximate estimates, not validated point-count results. Lithological similarities among the three exposures support sample selection for reconnaissance purposes but do not establish compositional equivalence across the formation.

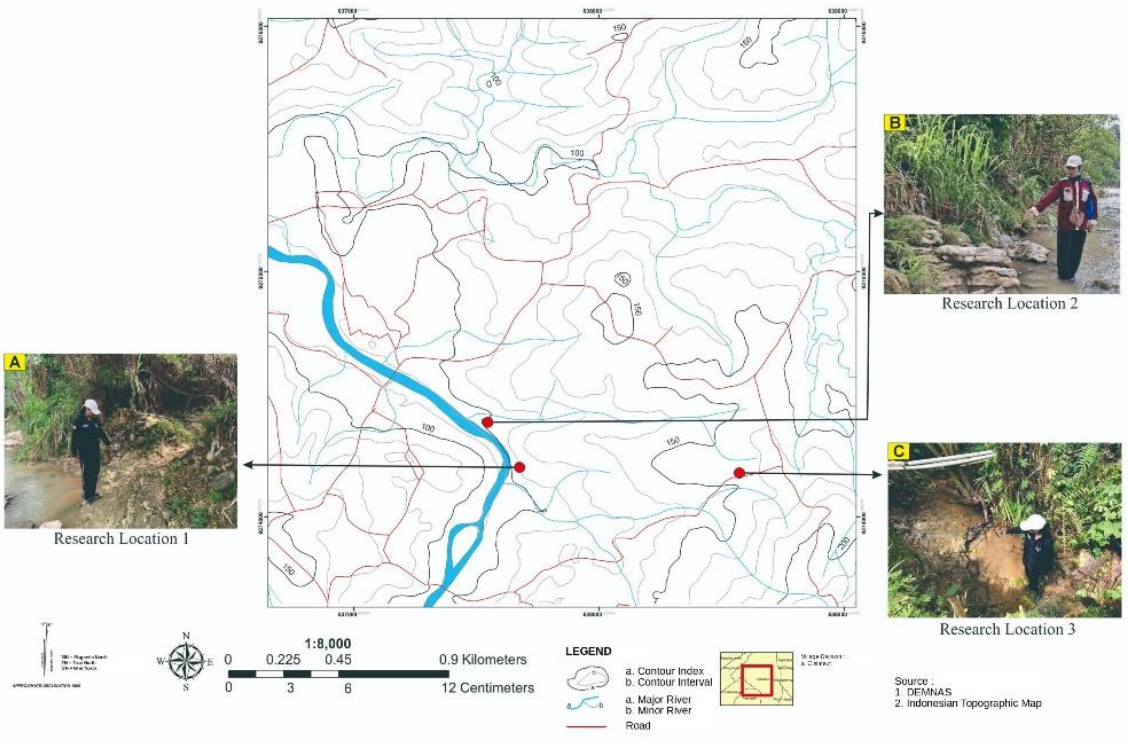


Figure 1. Locations and field photographs of the three investigated limestone outcrops in the Nayagati area: (A) Research Location 1, (B) Research Location 2, and (C) Research Location 3. Authors should verify map coordinates, legend readability, and map source.

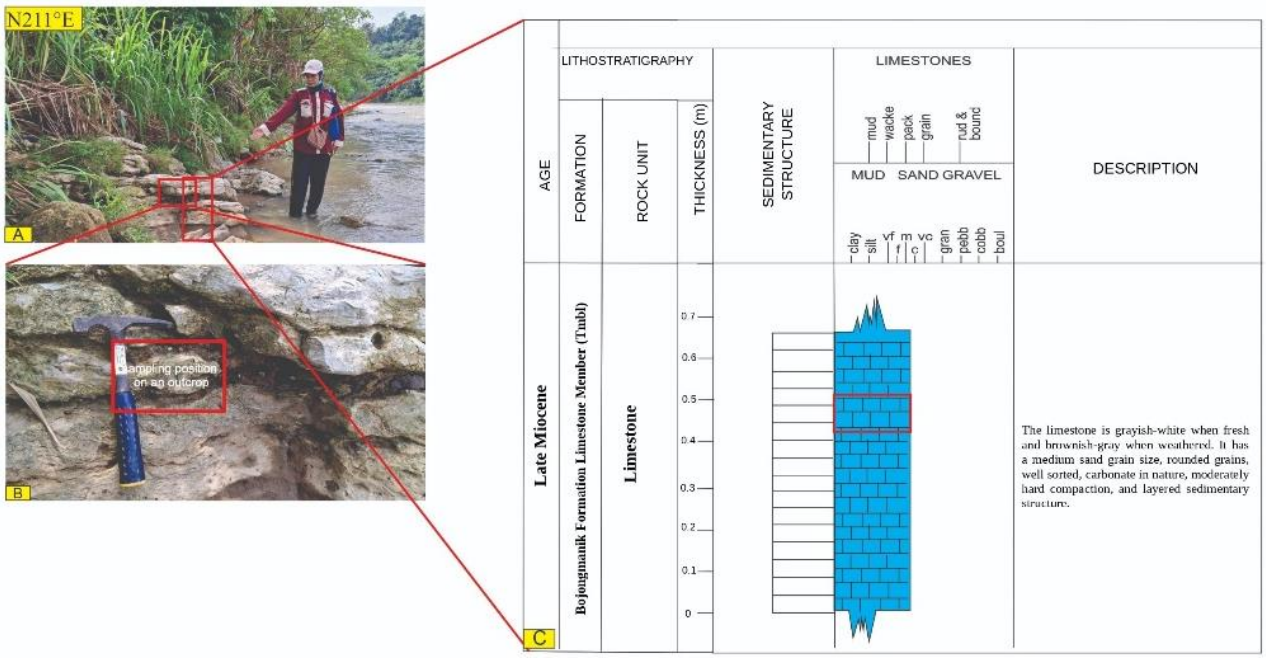


Figure 2. (A) Distant view of the lithology of the Limestone Member of the Bojongmanik Formation exposed in Nayagati Village at the Observation Location (Research Location 2) ; (B) Close-up view of the lithology of the limestone (Research Location 2) ; (C) Outcrop profile (scale 1:10).

3. Results and Discussion

3.1 Bojongmanik Formation Limestone Member (Tmbl)

Limestone outcrops attributed to the Bojongmanik Formation Limestone Member occur near Nayagati Village (Figure 1). At Research Location 2, the fresh rock is described as grayish white, whereas weathered surfaces are brownish gray. The exposure displays bedding (Figure 2). Statements that the limestone occupies approximately 6% of the mapped area and that individual grains are medium-sand sized require a mapped-area calculation and a clearly defined field or microscopic measurement method, respectively. In thin section (Figure 3), the authors report skeletal fragments, glauconite, quartz, orthoclase, opaque minerals, micritic matrix, carbonate cement, and minor intragranular porosity. The reported proportions are summarized in Table 1. The visually inferred depositional fabric is described as mud-supported; this interpretation should be checked against the spatial distribution of grains and micrite throughout the slide.

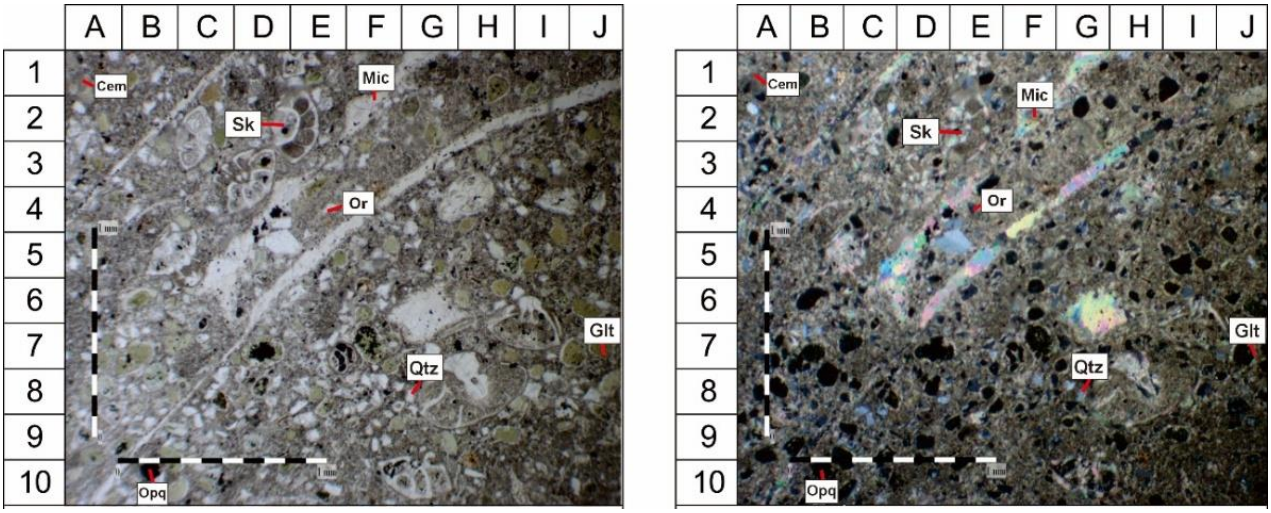


Figure 3. Thin section with 10x ocular lens and 4x objective lens of the lithology of limestone from the limestone member of the Bojongmanik Formation Research Location , PPL (left) and XPL (right) ; Scale bar = 1 mm. Indicates the locations of components referenced in the text: Cem = cement; Mic = micrite; Sk = skeletal grains (bioclasts); Qtz = quartz; Glt = glauconite; Or = orthoclase; and Opq = opaque minerals.

Table 1. Reported approximate proportions and optical descriptions of constituents in the thin section from Research Location 2. The percentage-estimation method and mineral identifications require verification.

Component	Proportion (%)	Position point	Description
Skeletal grains (bioclast)	34%	D3	Foraminiferal fossils, brown in PPL with a bluish-brown, sixth-order interference color in XPL, 0.2-0.8 mm in size, unevenly distributed.
Quartz (Qtz)	2%	G8	Colorless in PPL with a first-order gray interference color in XPL, 0.01-0.06 mm in size, angular to subrounded, low sphericity, no cleavage, no fracture, low relief, no pleochroism, parallel extinction (0°), no twinning, evenly distributed.
Orthoclase (Or)	4%	E5	Colorless in PPL, with a blackish-gray first-order interference color in XPL. Grain size is 0.06-0.19 mm, roundness is angular to subangular, and sphericity is low. Cleavage is absent, fracture is present, relief is low, and pleochroism is absent. The extinction angle is parallel (3°), twinning is absent, and the grains are unevenly distributed.
Opaque (Opq)	6%	B10	Opaque in both PPL and XPL; reported grain size 0.01–0.05 mm. Mineral species not established by transmitted-light microscopy alone; optical interference color, birefringence, and extinction angle are not applicable to opaque grains.
Glauconite (Glt)	24%	J7	Moss green in PPL, with a first-order yellow interference color in XPL and a birefringence of 0.040. Grain size is 0.01-0.3 mm, roundness is angular to subrounded, and sphericity is high. Cleavage is absent, fracture is absent, relief is high, and pleochroism is absent. The extinction angle is parallel (0°), twinning is absent, and the grains are unevenly distributed.
Micrite Matrix (Mic)	18%	F2 and F3	Yellowish-brown in PPL, with a first-order gray interference color in XPL. Grain size is <0.04 mm.
Carbonate Cement (Cem)	12%	A1	Colorless in PPL, with a first-order gray interference color in XPL. Grain size is <0.01 mm, crystal form is anhedral, and habit is equant. Cleavage is absent, fracture is absent, relief is low, and pleochroism is absent. The extinction angle is parallel (0°), twinning is absent, and the grains are evenly distributed.
Total	100%		

The reported composition totals 100%: skeletal grains 34%, glauconite 24%, opaque minerals 6%, orthoclase 4%, quartz 2%, micrite 18%, and carbonate cement 12% (Table 1). These categories should be checked for mutual exclusivity, particularly whether some opaque or glauconitic material represents replacement of skeletal grains or pore fillings. The 24% glauconite estimate is noteworthy. Before using it to infer sedimentation rate or water depth, the authors should confirm its identification, describe grain morphology and occurrence, and distinguish possible glauconite pellets from alteration or replacement products.



Figure 4. Benthic foraminiferal specimens attributed by the authors to (A) Peneroplis carinatus, (B) Tubinella funalis, (C) Quinqueloculina lamarckiana, (D) Tubinella inornata, and (E) Streblus gaimardii. Taxonomic identifications, specimen scale bars, and image documentation should be independently verified.

Table 2. Reported benthic foraminiferal taxa and inferred bathymetric ranges from Research Location 2. Depth units, species-level identifications, and supporting ecological references require verification.

Sample / Formation	: Research Location 2/ Tmbl	Rock Type	: Sedimentary Rock
Location	: Nayagati Village	Bathymetric Env.	: Transitional – Middle Neritic
Rock Name	: Limestone	Analyzed by	: Ruth Octavia Rika Sianturi

Bathymetric Environment,	Transitional	Neritic			Bathyal		Abyssal
feet depth ->		Inner	Middle	Outer	Upper	Lower	
Benthic Foraminifera (Barker, 1960)	0	20	100	200	500	2000	4000
Peneroplis carinatus (C) 20-60 fathoms		*					
Tubinella funalis (R) 15-20 fathoms			*	*			
Quinqueloculina *lamarckiana (A) 28 fathoms*		*	*				
Tubinella inornata (R) 20-60 fathoms			*	*			
Streblus gaimardii (R) 16- 25 fathoms		*					

In Dunham's scheme [2], a limestone retaining its original texture, containing carbonate mud, and supported by that mud with more than 10% grains can be called wackestone. The reported texture is therefore consistent with a bioclastic wackestone, provided that the apparent support and carbonate character are confirmed. The Folk name "sparse biomicrite" is less secure: although the skeletal fraction alone is 34%, the specimen also contains abundant glauconite and other non-carbonate grains, and the relationship between allochems, micrite, and sparry cement has not been resolved according to the complete classification criteria [1]. This label should remain provisional pending reassessment of the thin section. A descriptive term such as "glauconite-bearing bioclastic limestone with a mud-supported fabric" communicates the observations without overstating the classification.

3.2 Depositional-environment interpretation

The mud-supported fabric and micritic material are consistent with deposition or preservation of carbonate mud under relatively low-energy conditions. Bioclastic grains and the reported benthic foraminiferal taxa (Figure 4; Table 2) support a marine influence. However, the bathymetric categories assigned to the listed taxa require re-examination because individual species may have broad ecological ranges, and the depth conventions in Table 2 mix values expressed in feet and fathoms. Species identifications, sample processing, assemblage abundance, and the primary reference used to assign depth ranges should be documented before a specific "transitional to middle neritic" depth interpretation is retained.

A sheltered shallow-marine setting, potentially including lagoonal, protected platform, or inner-shelf environments, is a reasonable preliminary interpretation of the available petrographic observations. The existing data do not establish a back-reef position: no adjacent reef framework, reef crest, lateral facies transition, or reef-building association has been documented. Moreover, the unusually abundant reported glauconite should be considered in evaluating alternative shelf settings and sedimentary condensation, although glauconite abundance alone is not diagnostic. Regional evidence of Miocene marine deposition in the Bojongmanik Formation [18]–[20] is broadly consistent with a marine interpretation. More defensible environmental discrimination will require additional thin sections across beds and sites, systematic fossil counts, measured sedimentological sections, and verification of glauconite and foraminiferal identifications. Consequently, a back-reef assignment should be described as a hypothesis rather than a demonstrated depositional environment.

4. Conclusion

Petrographic examination of one thin section from Research Location 2 documents a bioclastic limestone with reported skeletal grains (34%), glauconite (24%), opaque minerals (6%), orthoclase (4%), quartz (2%), micrite (18%), and carbonate cement (12%). Its described mud-supported fabric is compatible with a wackestone texture, whereas assignment to Folk's "sparse biomicrite" category requires reconsideration of the full constituent inventory and the micrite–cement relationship. The substantial reported glauconite fraction is an important observation requiring mineralogical confirmation and sedimentological interpretation. The micritic fabric and reported foraminifera are consistent with marine deposition under relatively sheltered conditions, but the available evidence does not uniquely support a back-reef setting or a precise bathymetric interval. These findings constitute a preliminary characterization of

one analyzed sample and should be tested against additional petrographic, paleontological, and stratigraphic data before being extended to the wider Limestone Member.

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Author Contributions

Author 1: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Visualization, Writing Original Draft. **Author 2**: Validation, Writing and Review. **Author 3**: Supervision, Validation, Writing and Review. All authors have read and approved the final manuscript.

Data Availability

Field data and rock samples were collected by the authors. Thin-section preparation was carried out by a laboratory service provider, whereas petrographic observation, identification, and data processing and analysis were performed by the authors. All data generated and analyzed in this study are included in this article, comprising field photographs, thin-section images, and component estimates.

All data generated and analyzed in this study were collected and processed by the authors and are presented within this article (field photographs, thin-section images, and component estimates in Table 1).

Conflict of Interest

The authors declare no financial or non-financial interests that could constitute a conflict of interest in relation to this manuscript.

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