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Identification of Relative Age and Depositional Environment of Gumai Formation in Carbonaceous Sandstone, Keban Agung Area, Lahat Regency, South Sumatra

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ABSTRACT

This study aims to determine the relative age and depositional environment of the Gumai Formation in the Keban Agung area, Lahat Regency, South Sumatra, through micropaleontological analysis of foraminiferal assemblages. Fieldwork and laboratory analyses identified five species of planktonic foraminifera and five species of benthonic foraminifera from carbonate sandstone outcrops. Relative age determination, using the Blow (1969) biozonation framework and the method of earliest appearance and latest extinction, indicates that the formation dates from the Early to Middle Miocene. The depositional environment was inferred using the Planktonic/Benthonic (P/B) ratio, which yielded a value of 17.56%, corresponding to the Middle Neritic zone (20–100 m depth). These findings confirm that the Gumai Formation was deposited under marine transgressive conditions, providing valuable insights for regional stratigraphy and potential petroleum exploration.

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1. INTRODUCTION

The South Sumatra Basin exhibits a complex geological evolution characterized by pre-rift, syn-rift, and syn-inversion megasequences that contributed to the deposition of multiple stratigraphic formations, including the Kikim, Talang Akar, Baturaja, and Gumai Formations. Among these, the Gumai Formation, part of the Telisa Group, is known for its extensive lateral distribution and lithological composition of tuffaceous shale, marl, and carbonaceous sandstone, containing diverse foraminiferal assemblages. These foraminifera microscopic, shelled protists serve as critical bioindicators in paleoenvironmental and biostratigraphic studies due to their abundance, ecological sensitivity, and rapid evolutionary rates (Barefoot et al., 2023; Neuharth et al., 2022). Their ecological adaptability and fine-scale environmental responsiveness make them invaluable for reconstructing marine depositional settings and determining their relative geological ages.

Despite the significance of the Gumai Formation in the South Sumatra Basin, detailed micropalaeontological analyses, particularly in the Keban Agung area, have not been conducted extensively. This area, with its prominent carbonaceous sandstone outcrops, presents an

opportunity to extract critical biostratigraphic and palaeoenvironmental data that remain underexplored. To address this research gap, this study employed quantitative micropalaeontologicalmicropaleontological techniques, notably the identification of planktonic foraminifera to determine the relative age, and the application of the Planktonic/Benthonic (P/B) ratio method to interpret depositional environments (Brink, 2023; Vahidinia et al., 2016). These approaches enable a more refined paleoenvironmental reconstruction based on microfossil distributions.

The use of foraminifera as paleoenvironmental proxies is well supported in the scientific literature, where numerous studies have demonstrated their sensitivity to ecological variables such as salinity, temperature, dissolved oxygen, and sediment texture (Jurnaliah et al., 2019; Li et al., 2023). Benthonic foraminifera, in particular, have proven effective in reconstructing depositional settings because of their habitat specificity and diverse morphology (Gooday et al., 2021; Ismail et al., 2024). Foraminifera serve as dependable bioindicators for monitoring coral reef health and conducting assessments of marine ecosystems. Moreover, the application of the P/B ratio has become a standard method for inferring bathymetric zones of sediment deposition, providing quantitative support for paleoenvironmental interpretation (Campos-Soto et al., 2022). Collectively, these methodologies offer robust tools for geological reconstruction.

Previous studies have employed integrated microfossil and macrofossil analyses to reconstruct depositional settings in various formations across Java (Hibatullah et al., 2024; Rahmadani et al., 2024). However, no comprehensive micropalaeontological study has specifically focused on the carbonaceous sandstones of the Gumai Formation in the Keban Agung area. The lack of site-specific microfossil data and P/B ratio analyses highlights a critical research gap. Furthermore, while existing studies offer foundational methods, their direct application to Keban Agung remains untested, especially concerning the integration of biozonation with quantitative paleoenvironmental indicators. Consequently, this study seeks to fill this gap by implementing a focused and data-driven micropalaeontological approach.

This study aimed to determine the relative age and depositional environment of the Gumai Formation in the Keban Agung area based on planktonic and benthonic foraminiferal analysis. Its novelty lies in the application of the P/B ratio method in this specific geological setting, an approach not previously utilised in this locality, and in the detailed identification of foraminiferal species from carbonate sandstones. This study included a literature review, field observations, sample preparation, micropalaeontological identification, relative age determination, and bathymetric interpretation. These findings are expected to enhance the stratigraphic resolution and contribute valuable insights into the paleoenvironmental history of the South Sumatra Basin.

2. METHOD

2.1. Materials

The materials used in this study included carbonate sandstone samples from the Gumai Formation, collected from the Keban Agung area, Lahat Regency, South Sumatra (the research location can be seen on the map in Figure 1). The primary analytical tools included a geological hammer for outcrop sampling, 100 mesh sieves (150 µm) for granulometric separation, an oven for drying samples at 100°C, and a binocular microscope for species identification. Additionally, distilled water (H_2O) and hydrogen peroxide (H_2O_2) were employed for sample disaggregation and cleaning during micropalaeontological preparation.

2.2. Sample Preparation

Field samples were initially selected from fresh, nonweathered carbonate sandstone outcrops. Each sample was crushed with a geological hammer and then soaked in a mixture of H_2O and H_2O_2 for 24 h to facilitate disaggregation. After soaking, the samples were oven-dried for two hours at 100°C. The dried samples were then sieved using 100 mesh sieves for 3 min in three consecutive repetitions. The sieved fractions were separated by mesh size, and micropalaeontological analyses were conducted on the appropriate fractions. Species identification was conducted under a binocular microscope to determine planktonic and benthonic foraminiferal assemblages.

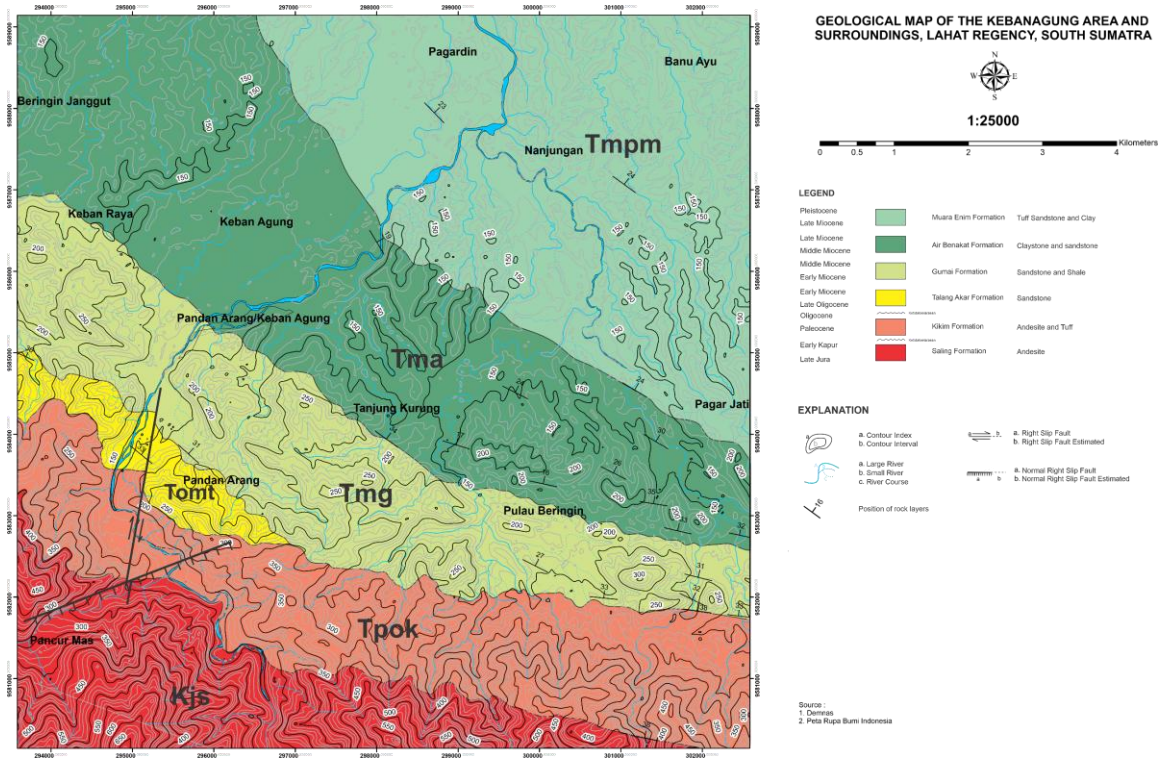

Figure 1. Map of the research location.

2.3. Experimental Set-up

Micropalaeontological analysis was performed on the processed samples to identify foraminiferal species. The identification enabled the determination of relative ages using the Blow biozonation chart (Vahidinia et al., 2016). Relative age was inferred using the "earliest appearance and latest extinction" approach. Furthermore, the P/B ratio (planktonic/benthic) was calculated based on the fossil counts in each sample using the following formula:

$$PB\ Ratio = \frac{P}{P+B} x100\% \quad (1)$$

where is the number of planktonic foraminifera and is the number of benthonic foraminifera in each mesh sample.

The primary parameters analysed in this study included (1) the abundance and diversity of planktonic and benthonic foraminifera, (2) relative age estimation of the stratigraphic unit, and (3) the depositional environment inferred from P/B ratios. Depth interpretation was further refined using bathymetric classifications from Barker and Grimsdale, which align specific P/B percentages with marine depositional zones (Barker, 1960; Vahidinia et al., 2016).

2.4. Statistical Analysis

Descriptive statistical methods were used to calculate the mean values of foraminiferal abundance and P/B ratios across the three mesh quadrants. The average abundance for planktonic and benthonic groups was computed per mesh and used in the P/B ratio determination. The resulting percentages were matched against standard depositional environment classifications to infer the paleoenvironmental conditions of the Gumai Formation in the study area.

3. RESULTS AND DISCUSSION

3.1. RESULTS

Field observations revealed that the Gumai Formation in the study area is predominantly composed of carbonate sandstone and mudstone lithologies. The outcrops were fresh, with brown weathered and beige fresh colours, fine sand grain size (1/8–1/4 mm), moderate sorting, and a

grain-supported fabric. Micropalaeontological analysis of these carbonate sandstone samples identified five planktonic foraminifera species: Orbulina universa, Globigerina praebulloides, Globigerina seminulina, Catapsydrax dissimilis, and Globigerinoides obliquus. In addition, five benthonic foraminiferal species were identified: Tubinella inornata, Astrononion stelligerum, Hoglundina elegans, Quinqueloculina lamarckiana, and Cibicides robertsonianus.

Table 1. Identified Foraminiferal Species

Type	Species
Planktonic	Orbulina universa
	Globigerina praebulloides
	Globigerina seminulina
	Catapsydrax dissimilis
	Globigerinoides obliquus
Benthonic	Tubinella inornata
	Astrononion stelligerum
	Hoglundina elegans
	Quinqueloculina lamarckiana
	Cibicides robertsonianus

Figure 2 illustrates the lithological appearance of the carbonate sandstone unit exposed at the surface of the study area. This provides context for the rock types sampled and analysed in the micropalaeontological study.

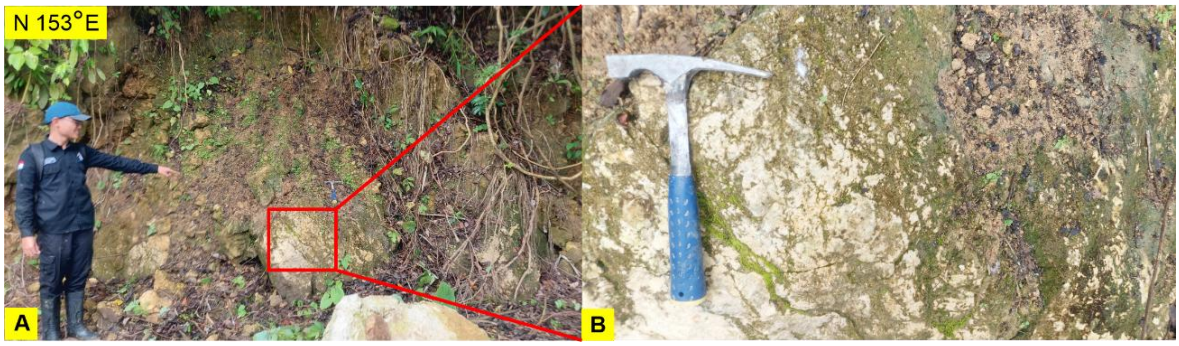

Figure 2. Fresh Carbonate Sandstone Outcrop.

Figure 2 displays the morphological characteristics of the planktonic foraminifera identified in the Gumai Formation. Their structures and chamber arrangements assist in relative age determinations.

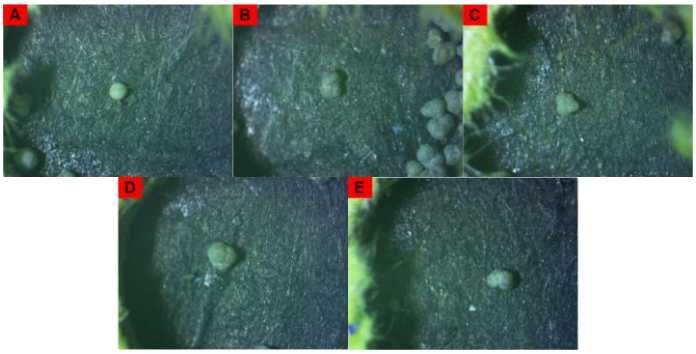

Figure 3. a) Orbulina universa, b) Globigerina praebulloides, c) Globigerina seminulina, d) Catapsydrax dissimilis, e) Globigerinoides obliquus.

Figure 4 shows the diagnostic features of the benthonic foraminifera species used to infer paleobathymetric conditions. Their ecological distribution supports the depositional environment analysis and can be seen in Figure 4.

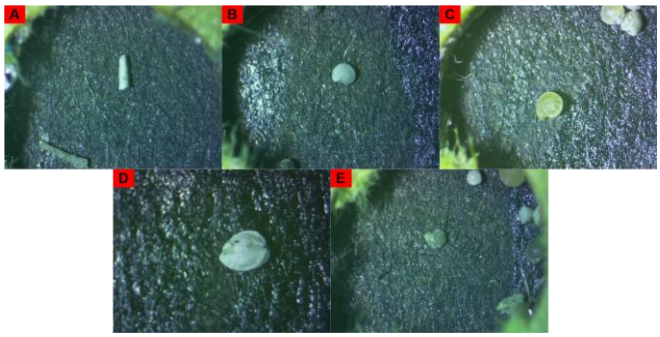

Figure 4. a) Tubinella inornata, b) Astrononion stelligerum, c) Hoglundina elegans, d) Quinqueloculina lamarckiana, e) Cibicides robertsonianus.

Using Blow's (1969) biozonation and the principle of earliest appearance and latest extinction, the planktonic foraminifera assemblage suggests a relative age of the Early Miocene to Middle Miocene for the studied section. The key species determining this age include the long-ranging Orbulina universa and Globigerina seminulina, as well as the extinct Catapsydrax dissimilis.

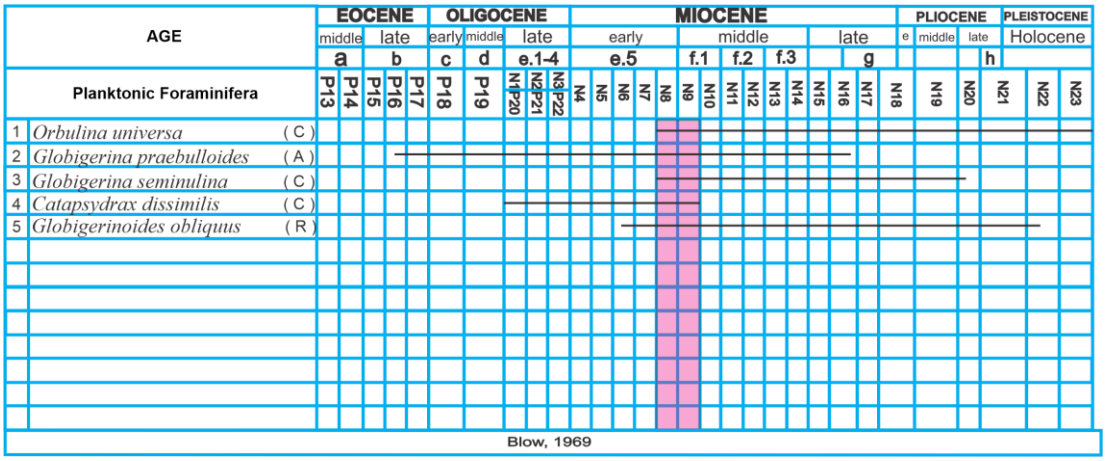

Figure 5. Relative Age Zonation based on Blow.

The calculation of the P/B ratio from all mesh quadrants resulted in a value of 17.56%, based on the mean abundances of 3.91 planktonic and 2.67 benthonic foraminifera.

Table 2. P/B Ratio Calculation

Parameter	Value
Average Planktonic (P)	3.91
Average Benthonic (B)	2.67
P/B Ratio (%)	17.56%

Species-specific bathymetric interpretations based on the depths associated with individual benthonic foraminifera confirmed the Middle Neritic to Neritic Edge environments.

Table 3. Deposition environment Benthonic Foraminifera

Species	Depth (m)
Astrononion stelligerum	20.1
Quinqueloculina lamarckiana	27.4
Tubinella inornata	36.5 - 109.7
Hoglundina elegans	128
Cibicides robertsonianus	67.6

Figure 6 presents a graphical summary of the bathymetric interpretation derived from the benthic foraminiferal species identified in the study area. This illustrates the corresponding depositional depths based on species-specific ecological preferences, thereby reinforcing the paleoenvironmental analysis discussed.

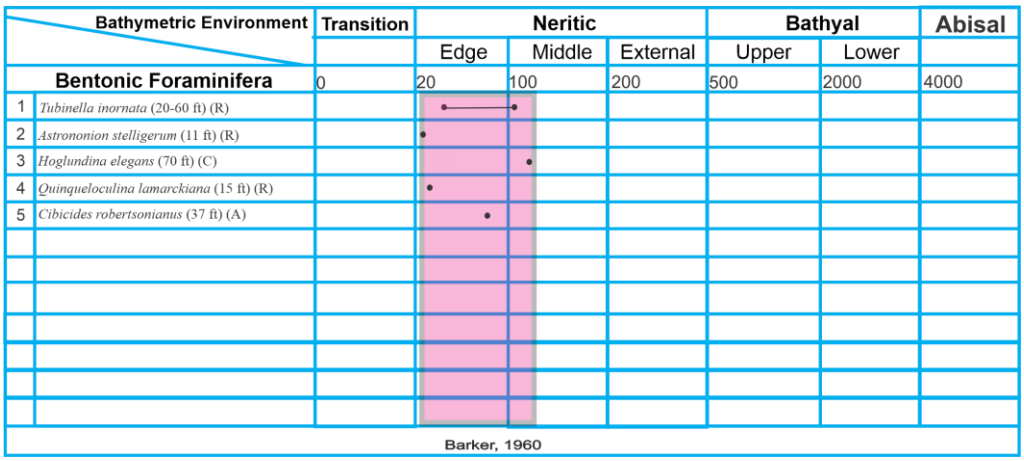

Figure 6. Depth Classification by Foraminiferal Species.

The synthesis of micropalaeontological data, including faunal composition, age zoning, and P/B ratios, indicates that the Gumai Formation in the Keban Agung area was deposited during the maximum marine transgression. This interpretation is visually supported by the palaeontological and bathymetric evidence presented in Figures 1 through 4, especially the relative age zonation illustrated in Figure 2 based on Blow (1969) and the depositional environment inferred from benthonic foraminiferal depth associations in Figure 4. These figures collectively demonstrate a transition into deeper marine conditions characteristic of a transgressive system tract.

3.2. Discussion

The findings align with similar studies on the paleoenvironmental applications of foraminifera, which have consistently demonstrated their value as bioindicators due to their abundance and sensitivity to environmental changes (Hallock et al., 2003; Jurnaliah et al., 2019). The identification of Globigerina praebulloides and Orbulina universa in this study confirms comparable biostratigraphic trends observed in other Miocene marine sequences across Southeast Asia (Hallock et al., 2003). The assemblage's composition closely resembles previously documented communities from equivalent depths and time periods (Jurnaliah et al., 2017). Furthermore, the diversity among benthic foraminifera supports the interpretation of dynamic ecological gradients (Brink, 2023). This aligns with microfaunal ecological frameworks applied to Neogene formations (Jurnaliah et al., 2019).

The integration of foraminiferal assemblages confirms their utility as proxies in stratigraphic and paleoenvironmental reconstructions. The distinct occurrence of environmentally responsive taxa enables high-resolution interpretation of depositional settings and age estimation. These findings are critical for refining the biostratigraphic zonation across the Gumai Formation. In practical terms, the micropalaeontological results provide valuable data for hydrocarbon reservoir assessments. This confirms the relevance of fossil-based indicators in applied geological investigations.

This age assignment corresponds with regional geological studies that place the Gumai Formation within the Early to Middle Miocene transgressive sequence (Fan et al., 2023; Sagar et al., 2024). The planktonic foraminiferal species documented in this study validated the age interpretation under the Blow scheme (Vahidinia et al., 2016). This biostratigraphic consistency strengthens the chronostratigraphic framework of the South Sumatra Basin. These findings mirror the age assessments derived from lithostratigraphic and tectonic markers in similar basins. These comparisons confirm the reliability of micropalaeontological dating in regional stratigraphy.

Recognising the Miocene age of the Gumai Formation consolidates its position within the stratigraphic architecture of Southeast Asia. Age determination underpins the correlation with major transgressive-regressive cycles. These insights support subsurface stratigraphic modelling and resource exploration. For petroleum geologists, this age control facilitates the delineation of stratigraphic traps. Thus, biostratigraphic resolution has both academic and industrial significance.

The interpretation of depositional environments based on P/B ratios is consistent with the established marine zonation derived from ecological distribution patterns. This is further supported by the study's classification of a mid-shelf setting, which aligns with the findings from previous bathymetric analyses using P/B ratios. As such, foraminiferal ratios remain a reliable metric for inferring bathymetric conditions, and the consistency observed in this study, along with other regional investigations, reinforces confidence in the use of ecological proxies (Barker, 1960).

Establishing a Middle Neritic setting for the Gumai Formation provides a crucial environmental context. This interpretation complements age-based findings, creating a coherent geological narrative. For resource assessments, knowledge of the depositional zone provides porosity and permeability expectations. This outcome also supports sediment transport modelling in paleoceanographic studies. Integrating stratigraphy and paleoecology increases the predictive power of geological analysis.

The species depth patterns identified in this study correspond well with previous ecological findings, reinforcing the reliability of benthic foraminifera as indicators of water depth. The consistency of their bathymetric distribution across different geological formations underscores their effectiveness in paleoenvironmental reconstruction. In particular, the foraminiferal assemblages observed within the Gumai Formation reflect broader biogeographic trends, thereby supporting both the methodology and interpretive framework applied in this study (BouDagher-Fadel & Price, 2013; Mohanty et al., 2023).

The bathymetric data drawn from the foraminiferal assemblages reinforce previous depositional interpretations. These depth associations, derived from species occurrence, confirmed a neritic environment. Combined with the relative age and P/B ratio data, the conclusions become more robust. Stratigraphic correlation was enhanced using such multi-proxy approaches. These interpretations improve exploration planning and geological risk assessment.

The depositional interpretation in this study reflects transgressive models in which diverse fossil assemblages are indicative of maximum flooding surfaces. The dominance of planktonic species further supports this interpretation. Comparable fossil distribution patterns identified by previous researchers have provided additional validation for these results. Overall, these findings are consistent with widely recognized stratigraphic markers of transgression, reinforcing the credibility of the proposed depositional model (Magalhães et al., 2023; Rahmadani et al., 2024).

Integrating all the micropalaeontological indicators yielded a consistent interpretation of the depositional environment. The data collectively confirm a middle neritic setting during marine transgression. These insights are critical for stratigraphic synthesis and petroleum system analysis. High-resolution biochronology and palaeoecology have enriched subsurface mapping. Ultimately, these findings bridge academic research with exploration geoscience.

4. CONCLUSIONS

The micropalaeontological investigation conducted in the Keban Agung area of South Sumatra has confirmed that the Gumai Formation was deposited during the Early to Middle Miocene, as indicated by the presence of diagnostic planktonic foraminiferal species, such as Orbulina universa, Globigerina seminulina, and Catapsydrax dissimilis. The calculated P/B ratio of 17.56%, combined with the depth associations of benthonic foraminifera, supports a depositional environment within the Neritic Edge to Middle Neritic zones. These findings suggest that the Gumai Formation represents sedimentation during the maximum transgressive phase. The integration of biozonation, faunal assemblages, and quantitative ratios provides a comprehensive reconstruction of the age and depositional environment. This study contributes to refining regional stratigraphic correlations and enhances paleoenvironmental interpretations that are essential for hydrocarbon exploration. Future research should expand the spatial coverage of sampling to improve the resolution and validate these initial interpretations.

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