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The Foraminifera Fossil Record of the Sedimentary Rock at Kotadjawa, Lampung, Indonesia: The Significance of Marine Paleontological Insight

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ABSTRACT

Kotadjawa, located on the west coast of Lampung, directly faces the Indian Ocean. Lithified calcareous sedimentary beds are prevalently outcropped along this coastline. These beds likely belong to the Simpangaur Formation, which may be associated with the paleocoastal depositional environment and tectonic uplift of the Indian Ocean. Therefore, we investigated the paleontological record, focusing on foraminifera as potential indicators of the paleoenvironment. This study aimed to identify, record, and calculate the relative abundance of benthic foraminifera in the sedimentary beds of Kotadjawa, Lampung. The samples were prepared via chemical treatment of 10% H_2O_2 for 48 hours. Our results revealed a diversity of benthic foraminiferal fossils within the sedimentary rock. Notably, 11 benthic foraminifera genera were fossilized in the observed outcrop: Textularia (18.4%), Sigmoilopsis (16.5%), Rectobolivina (15.4%), Uvigerina (15.5%), Nodosaria (14.5%), Elphidium (11.5%), Lenticulina (7.7%), Hormosina (6.8%), Bolivina (6.8%), and Globobulimina (5.8%). These results suggested that the sedimentary beds exposed in our study area ranging from the foreshore to the deep ocean floor ecosystem. This suggests that a sediment mixing event, possibly triggered by a paleocatastrophic event, influenced the deposition of these beds. This study provides new insights into marine paleoenvironmental conditions and paleocatastrophic events along the west coast of Lampung, Sumatra.

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INTRODUCTION

Throughout the exploration along the west coast of Lampung, lithified calcareous sedimentary rock layers are often encountered and outcropped along the coastline. These rock sequences frequently outcropped on hilly cliffs or along the shore. Generally, these sediment layers have a strike direction of Northwest to Southeast and a dip direction of Northeast. These layers were classified within the Simpangaur Formation based on the geological map of the Kotaagung Sheet (Amin et al., 1994; Ogara, 2021). The Simpangaur Formation is a Mio-Pliocene sedimentary rock consisting of tuffaceous sandstone, tuffaceous mudstone, tuff, conglomerate, and thin lignin intercalations. It is interpreted as a fore-arc basin deposit associated with marine sedimentary rock (Amin et al., 1994; Heryanto, 2006). However, further investigation is needed to clarify the possible presence of fossils in these rock sequences, including marine organism fossils such as foraminifera.

Foraminifera are a group of amoeboid protists, each with a single-celled body. Some of these protists have calcareous shells composed of one or more tests (shell chambers). Fossils of Foraminifera are often found in the fine-grains of sedimentary rocks that originate from marine environments (Harbowo et al., 2023; Kranner et al., 2022; Lewandowska et al., 2020). Their outer shells are composed of calcium carbonate ($CaCO_3$), which enhances their chances of natural preservation and fossilization during geological processes (Weber & Jutson, 2022). Furthermore, the study of marine paleontology can provide deeper insights into the intersection of paleobiology with Earth's processes that occurred in geological history.

In our study, we observed that various calcareous foraminiferal fossils can be found in the sedimentary beds of Kotadjawa, Lampung, Indonesia. This study aimed to identify, record, and calculate the relative abundance of benthic foraminifera in the sedimentary beds of Kotadjawa, Lampung (Figure 1). Benthic foraminifera are known to inhabit specific environments that reflect the paleoecological conditions of the depositional environment (Cappelli et al., 2019). The results of this study will enhance our understanding of marine paleoecology based on the specific ecological habitats of foraminifera, particularly from a paleontological perspective. Furthermore, this study also uncovers the depositional setting that plays a role in the Simpangaur Formation, as evidenced by the taxonomic variations discovered within.

MATERIALS AND METHODS

Field data collection. Samples were collected from rock outcrops of the Sedimentary rock along the coast of Kotadjawa, Lampung (see Figure 1). This outcrop has been re-explored since 2017. Several sample collections were conducted and reviewed in 2019, before finally being documented and further analyzed in the Paleontology Laboratory of the Sumatra Institute of Technology. Strike-dip measurements using a geological compass and lithological descriptions were performed in every bed, including texture and bed thickness. Outcrop descriptions followed the methodology outlined by Nichols (2009). For each bed, about 2 kg of rock samples were collected and put in sealed bags for further treatment in the laboratory.

Fossil recovery. A 1 kg dried sample was gently ground using a mortar and pestle, then sieved through a 150 – 200 mesh sieve. Subsequently, a 100 g of the sample was obtained by performing coning and quartering sub-sampling. The sample was chemically treated by soaking it in a 10% hydrogen peroxide (H_2O_2) solution () for 48 hours. The sample was then washed in distilled water, dried in an oven at 35°C for six hours, and then stabilized at room temperature (following the procedure of Hendrizan et al. 2019; Honarmand et al. 2020).

The dried samples were observed under a stereomicroscope at magnifications ranging from 5x to 50x. Subsequently, the fossil foraminifera were carefully separated from other grains and grouped based on the morphology of their tests. The morphological observations of foraminifera fossils included test size and shape, chamber shape, size, arrangement, coiling pattern, wall composition, texture, ornamentation, aperture shape, position, as well as other iconic features observed. Similar genus morphologies were grouped for abundance calculations (as a percentage of the total recovered samples). Each selected foraminiferal genus was identified and counted.

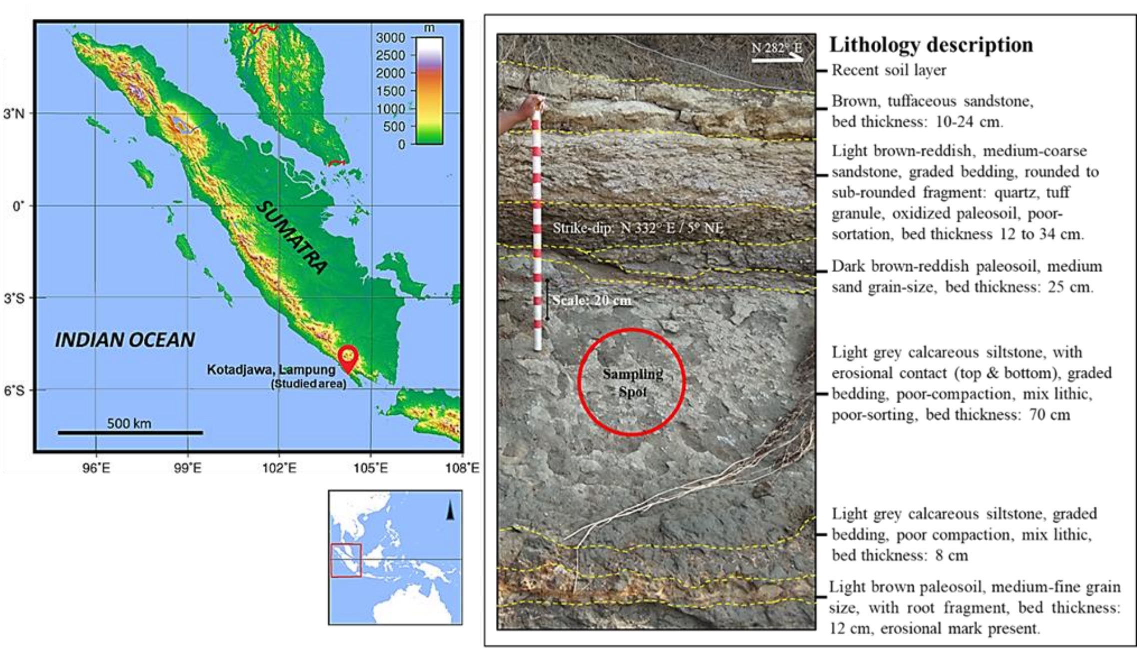

Figure 1. Location of Kotadjawa (left) and the lithological description of sedimentary rock beds outcrop, the sampling spot shown as the red circle (right)

RESULTS AND DISCUSSION

Based on the sedimentary beds analyzed in this study, foraminifera fossils were found only in the calcareous siltstone layer (**Figure 1**). The same procedure was applied to other sedimentary beds (different layers) but no foraminiferal fossils were found. These results confirm that foraminiferal fossils are only occasionally encountered in the Simpangaur Formation and are specifically associated with calcareous layers (rich in $CaCO_3$), indicative of marine deposits. In contrast, based on our observation, foraminiferal fossils were absent in the paleosoils, which are rock layers derived from lithified soil buried concurrently with the overlying depositional sediment. Similar conditions have been observed in paleontological studies of foraminifera in environments associated with terrestrial areas (Prasetyo et al., 2023; Sarkar et al., 2013).

In this study, the preparation process successfully yielded 54 specimens of benthic foraminifera fossils (n = 54). These specimens were differentiated into 11 genera within five orders. A detailed description of each taxon is provided in the following section. The morphological appearance of the benthic foraminifera fossils is illustrated in **Figure 2** and **Figure 3**.

Genera taxonomy and morphological description of specimens

Genus: *Lenticulina* Lamarck, 1804; Family: Vaginulinidae; Order: Vaginulinida. Morphological Description: The wall material is hyaline. The form is a coiled spiral with a planispiral coiling pattern and is keeled. The chamber shape ranges from triangular to trapezoidal. The aperture is positioned terminally and takes a radiate form. The sutures are raised, curved, and thickened (**Figure 2A-B**).

Genus: *Elphidium* Linnaeus, 1758; Family: Elphidiinae; Order: Rotaliida. Morphological Description: The wall material is hyaline. The form is a coiled spiral with a planispiral coiling pattern. The chamber shape ranges from triangular to trapezoidal. Multiple apertures are present, taking the form of pores. The sutures are depressed, curved, and punctuated by ponticuli. The ornamentation is characterized by a hispid-pustulose texture (**Figure 2C-E**).

Genus: *Nodosaria* Lamarck, 1816; Family: Nodosariidae; Order: Nodosariida. Morphological Description: The wall material is hyaline. The form is elongate and uniserial. The chamber shape is spherical. The terminal aperture takes the form of a round oval reniform; some specimens have features such as a neck and lips. The sutures are depressed and straight, while the ornamentation features a hispid-pustulose texture (**Figure 2F-I**).

Genus: *Hormosina* Brady, 1879; Family: Hormosinidae; Order: Hormosinida. Morphological Description: The form is elongated and uniserial. The chamber shape ranges from spherical to globular. The aperture is located terminally, taking the form of a round oval reniform. The sutures are depressed and straight (**Figure 2J**).

Genus: *Laevidentalina* Loeblich & Tappan, 1986; Family: Nodosariidae; Order: Nodosariida. Morphological Description: The wall material is hyaline. The form is elongated and uniserial. The chamber shape is pyriform. The aperture is located terminally and takes a radiate form. The sutures are depressed and straight (**Figure 2K**).

Genus: *Rectobolivina* Cushman, 1927; Family: Bolivinitidae; Order: Rotaliida. The wall material is hyaline. The form is elongated, with a variation of tri-/bi- to uni-/biserial coiling pattern. The chamber shape is brick-shaped. The aperture is located terminally and takes the form of a round oval reniform. The sutures are depressed and straight (**Figure 3A-D**).

Genus: *Bolivina* d'Orbigny 1839; Family: Bolivinitidae; Order: Rotaliida. Morphological Description: The wall material is hyaline. The form is elongated and biserial. The chamber shape is brick-shaped. The basal aperture takes the form of a round oval reniform (**Figure 3E**).

Genus: *Uvigerina* d'Orbigny, 1826; Family: Uvigerinidae; Order: Rotaliida. Morphological Description: The wall material is hyaline. The form is elongated and triserial. The chamber shape is pyriform. The terminal aperture takes the form of a round oval reniform and features a neck. The sutures are depressed and curved. The ornamentation exhibits a costate texture (**Figure 3F-H**).

Genus: *Textularia* Defrance, 1824; Family: Textulariidae; Order: Textulariida. Morphology Description: The wall material is agglutinated. The form is elongate biserial. The chamber shape resembles a brick with a basal aperture. The sutures are raised and straight (**Figure 3I-L**).

Genus *Sigmoilopsis* Finlay, 1947; Family Spiroloculinidae; Ordo Miliolida. The wall material is porcelaneous. It has a leaf-like appearance with a miliolid

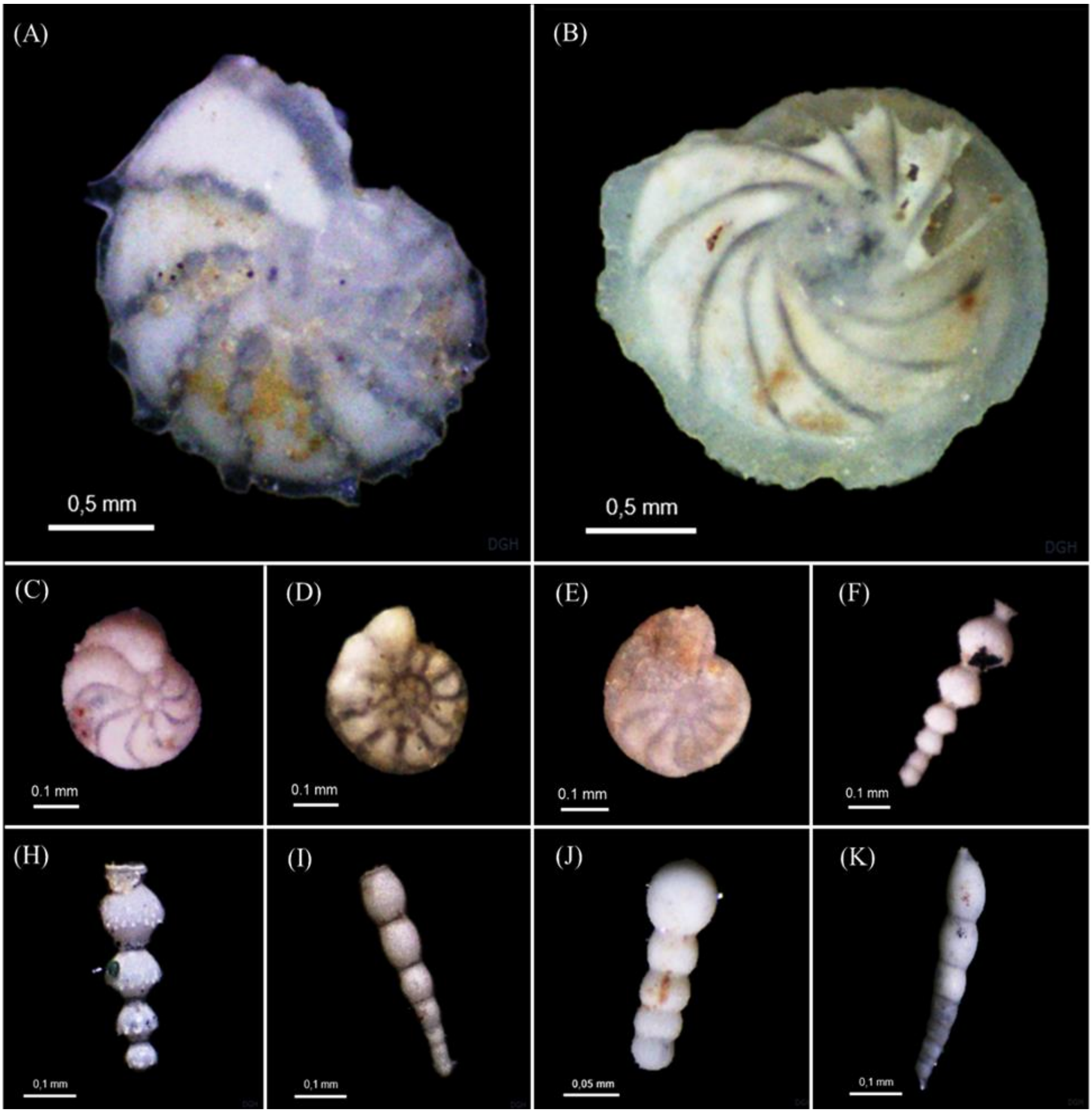

Figure 2. Documented benthic foraminiferal fossil of genus *Lenticulina* (A-B), *Elphidium* (C-E), *Nodosaria* (F-I), *Hormosina* (J), and *Laevidentalina* (K)

coiling pattern and tubular chamber shape. The terminal aperture is shaped like around oval reniform with neck features. Sutures are depressed and curved (**Figure 3M-O**).

Genus: *Globobulimina* Cushman, 1927; Family: Globobuliminidae; Order: Rotaliida. The wall material is hyaline. The form is globose to ovate triserial, with a pyriform chamber shape. The basal aperture forms an arcuate arch, featuring a tooth and lip. The sutures are curved (**Figure 3P**).

The significance of its paleoenvironment and the depositional setting

Notably, 11 benthic foraminifera genera were fossilized in the observed outcrop: Textularia (18.4%), Sigmoilopsis (16.5%), Rectobolivina (15.4%), Uvigerina (15.5%), Nodosaria (14.5%), Elphidium (11.5%), Lenticulina (7.7%), Hormosina (6.8%), Bolivina (6.8%), and Globobulimina (5.8%). From the results of the relative abundance calculations, six genera were found to be dominant (more than 15%): *Textularia*, *Elphidium*, *Sigmoilopsis*,

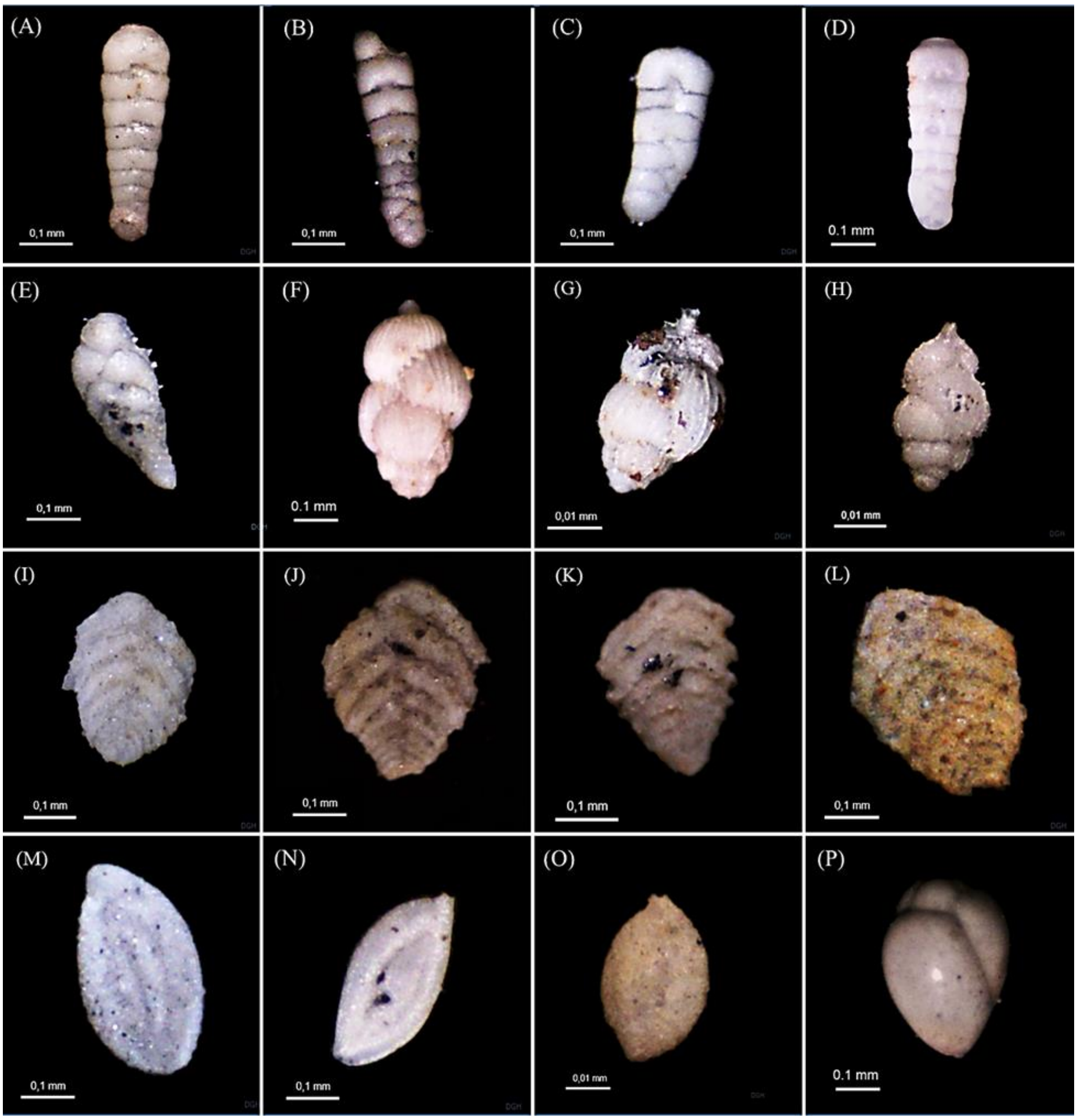

Figure 3. Another documented benthic foraminiferal fossil of genus *Rectobolivina* (A-D), *Bolivina* (E), *Uvigerina* (F-H), *Textularia* (I-L), *Sigmoilopsis* (M-O), and *Globobulimina* (P).

Rectobolivina, *Nodosaria*, and *Uvigerina*. All other genera had relative abundances of less than 8.0%. Interestingly, *Textularia* and *Elphidium*, which are coastal to shallow marine foraminifera (Boudaugher-Fadel, 2018; Haunold, 1999), and *Uvigerina* and *Nodosaria*, which are deep-sea foraminifera (El-Kahawy et al., 2022; Fiorini, 2004), were found in the same beds. This finding suggests an unusual depositional setting that may have occurred in its geological history, considering the significant differences in their original ecological habitats.

Unlike planktonic foraminifera fossils, which live in the water column, benthic foraminifera thrive in specific seabed habitats at certain bathymetric depths (Boudaugher-Fadel, 2018; Fiorini, 2004; Haunold, 1999; Lewandowska et al., 2020). Fossil foraminifera can be identified and differentiated between specimens based on their morphology, which is a key feature of their environmental adaptations (Harbowo & Muliawati, 2024). Under living conditions, each genus of benthic foraminifera or other benthic fauna cannot disperse to environments at different depths. Inappropriate temperatures and pressures can directly disrupt foraminiferal cell metabolism, leading to fatal shell damage (Danovaro et al., 2014; Thomas, 2006; Wijayanti et al., 2020). The distribution of benthic foraminifera tends to occur laterally and is limited to the same depth. Therefore, by identifying taxa from the discovered

Table 1. The Foraminifera taxa of the sample (n=54) and its origin ecological habitat

Ordo	Genus	RA* %	Ecological Habitat							Ref**
			Brackish Lagoon		Fore shore	Back reef	Coral reef	Fore reef	Deep water	
Textulariida	*Textularia*	18.4	■	■	■					1, 2
Rotaliida	*Elphidium*	11.5		■	■	■				3, 4
Vaginulinida	*Lenticulina*	7.7				■				5
Miliolida	*Sigmoilopsis*	16.5					■			3
Rotaliida	*Rectobolivina*	15.4				■	■	■		6, 7
Rotaliida	*Globobulimina*	5.8						■	■	4
Hormosinida	*Hormosina*	6.8						■	■	8, 9
Nodosariida	*Nodosaria*	14.5							■	3
Nodosariida	*Laevidentalina*	4.8							■	10, 11
Rotaliida	*Bolivina*	6.8							■	3
Rotaliida	*Uvigerina*	15.5							■	4

Note:
*RA: Calculated relative abundance of each taxa in sedimentary rock (of this study)
**References:[1]Haunold 1999; [2]Fiorini 2004, [3]Boudaugher-Fadel 2018; [4]El-Kahawy et al. 2022, [5]Haller 2018, [6]Rositasari et al. 2023; [7]Sarkar et al. 2013, [8]Saalim et al. 2022; [9]Hannah & Campbell 1996), [10]Pezelj & Drobnjak 2019; [11]Klein & Mutterlose 2001
■ Taxa ecological indicator

benthic foraminifera fossils, we can also estimate the depositional setting that occurred during the formation of these sedimentary beds. Based on their original ecological habitats, the taxa in these sedimentary beds originate from environments with different bathymetric locations (**Table 1**). This study confirmed the presence of unusual sedimentary mixing during its geological history, which is related to catastrophic events.

While observing its lithostratigraphic profile, the sedimentary beds analyzed in this study were found between two paleosol layers, also known as paleosoil (Figure 1). Paleosol refers to a layer of ancient soil preserved in the geologic record. These soils formed on the Earth's surface in the past and were later buried, preserving the characteristics of the environment at the time of their formation (Harbowo & Zahra, 2021). These paleosoils are typically light brown to reddish, with medium-to-coarse grains. Stratigraphically, this segment revealed sequences of depositional events throughout its geological history. The paleosol of this sequence indicates that before the deposition of the calcareous siltstone sedimentary beds (which are under consideration in this study), the depositional setting primarily consisted of a terrestrial environment covered by soil layers (as observed in the lower paleosol layer). Subsequently, a catastrophic event occurred, bringing marine sediments along with benthic foraminifera. These marine sediments originate from diverse environments with varying bathymetry, ranging from foreshore to deep water/abyssal sediments. Sediment mixing occurred during this process, depositing sediments in the same observed layer of our main sedimentary beds (calcareous siltstone). This catastrophic event allowed the deposition of benthic foraminiferal fossils from different environments in the same rock layer. Subsequently, the upper sedimentary beds were gradually covered by soil, which is recently observed as an upper paleosoil.

Catastrophic events, such as coastal storms or tsunamis, may have occurred in this region (Chaudhuri et al., 2019; Haque et al., 2021; Harbowo, 2023; Prasetyo et al., 2023). Since the Mio-Pliocene, this region has been directly exposed to the Indian Ocean and the western part of the Sunda Megathrust (Hall, 2002). Significant weather dynamics can trigger massive storms, generating upwelling sediments and large waves, which carry substantial volumes of marine sediments onshore. Moreover, tsunamis may have occurred due to tectonic activity. The tectonic subduction between the Indo-Australian Ocean Plate and the Eurasia Plate can generate a tremendous displacement of the water column and large waves with high-energy currents. These waves can simultaneously transport significant sediments from the deep sea to shallower areas. The forces and currents of the generated waves simultaneously erode and transport the depositional sediments, depositing them on the coast in significant volumes. At least in the observed sedimentary beds, the thickness was 70 cm (compacted), with a clear erosional sediment boundary.

This study not only revealed a diverse range of benthic foraminifera taxa in the Mio-Pliocene sedimentary beds of the Simpangaur Formation but also identified a catastrophic event responsible for the deposition of sediments. This findings enchance our understanding of geological history of the region and provide a foundation for further exploration in future research.

CONCLUSION

In the observed outcrop of calcareous sedimentary rocks of the Simpangaur Formation, a diverse array of benthic foraminifera fossil genera can be found. These include *Textularia* (18.4%), *Sigmoilopsis* (16.5%), *Uvigerina* (15.5%), *Rectobolivina* (15.4%), *Nodosaria* (14.5%), *Elphidium* (11.5%), *Lenticulina* (7.7%), *Hormosina* (6.8%), *Bolivina* (6.8%), *Globobulimina* (5.8%), and *Laevidentalina* (4.8%). Furthermore, significant differences in the original ecological habitats of each foraminifera suggest a catastrophic sediment-mixing event during its geological history.

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