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Research Article

Planktonic Foraminifera Biostratigraphy of the Pliocene Kintom and Bongka Formations, Central Sulawesi, Indonesia

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ABSTRACT
The Pliocene sediments exposed in the Eastern Arm of Southern Sulawesi consist of Kintom and Bongka Formations, thought to be the result of collisions in the Middle Miocene. The research area is located along the Matindok – Ondoondolu road, Banggai Regency, Central Sulawesi Province. The aims of the research is to determine the rock units that developed in the Kintom and Bongka Formations and determine the chronological time frame based on planktonic foraminifera biostratigraphy. This research used stratigraphic measurement on a scale of 1:100 and Plio-Pleistocene planktonic foraminifera biostratigraphy. A lithological column along 315 meters divided into three rock units. The marl unit and calcareous sandstone unit show characteristics similar to flysch deposits from the collision and are part of the Kintom Formation. Intergrade conglomerate gravelly sandstone deposited unconformably on top of the previous unit is part of the Bongka Formation. This last unit shows characteristics similar to molasse deposits. In total of 46 rock samples were analyzed for foraminifera biostratigraphy. Seven foraminifera biozones showing the age of rock deposition from the Early Pliocene to the Late Pleistocene. The order of the foraminifera biozone is *Globorotalia tumida* Brady LOZ (PL1a; 5.59 - 4.45 Ma), *Globoturborotalita nepenthes* Todd CRZ (PL1b; 4.45 - 4.39 Ma), *Globotalia acostaensis* Blow PRZ (PL2a; 4.39 – 4.31 Ma), *Globotalia margaritae* Bolli HOZ (PL2b; 4.31 - 3.85 Ma), *Sphaeroidinellopsis seminulina* Schwager HOZ (PL 3-4; 3.85 – 3.20 Ma), *Globorotalia* (M) *miocenica* Palmer/ *Globorotalia miocenica* Palmer HOZ (PL5–6; 3.20 – 2.30 Ma), and *Pulleniatina praecursor* Banner & Blow HOZ (PL6–PT1a; 2.30 – 2.26 Ma).

INTRODUCTION
The collision between the Eastern Arm of Sulawesi and the Banggai Sula microcontinent led to the formation of post-orogenic clastic sediments included in the Kintom and Bongka Formations. Both formations are widely exposed in the southern part and, to a lesser extent, in the northwest of the eastern arm of Sulawesi. This collision event is estimated to have occurred during the Middle Miocene (Simandjuntak 1986), while the post-orogenic sediments are interpreted to have formed during the Middle Miocene or later.

The Kintom and Bongka Formations in the eastern section of the study area display a slightly distinct rock configuration compared to those found in the western region. In the west, the Kintom Formation consists of fine-grained rocks such as sandy marl and sandstone, while in the east, it consists of conglomerate, sandstone, and limestone. The Bongka Formation, both in the western and eastern parts, consists of relatively similar rocks in the form of conglomerate, sandstone, marl, siltstone, and lignite. According to Simandjuntak (1986), Rusmana et al. (1993) and Surono et al. (1993), these two formations were deposited during the Late Miocene to Middle Pliocene. Recent research on post-orogenic sediments in Sulawesi (Nugraha et al. 2022) suggests that the Kintom Formation formed during the Early Pliocene and is unconformably overlained by the Bongka Formation, which ranges in age from the Late Pliocene to the Pleistocene.

The Matindok section is located along the Matindok - Ondo Ondolu road, Batui District, Banggai Regency, Central Sulawesi Province, displays rock layers known as the Kintom and Bongka Formations, according to the Regional Geological Map of the Batui Sheet (Surono et al. 1993). The Kintom Formation is present in the northwest part of the Matindok section, while the Bongka Formation is found in the southeast. Based on the dip of the rocks sloping towards the southeast, it is assumed that the Kintom Formation is younger than the Bongka Formation. The type and sequence of sedimentary rocks in the Matindok section slightly differed from other Kintom and Bongka Formation outcrops in various areas.

The differences in the rocks that make up the Kintom and Bongka Formations as well as the age of deposition of the rocks as well as the existence of the Matindok Section, which reveals the Kintom-Bongka Formation rocks well-encouraged researchers to carry out this research. This research has two objectives; the first is to determine the rock units that developed in the Kintom and Bongka Formations, and the second is to build a chronological time frame for the rock units that make up the Kintom and Bongka Formations through biostratigraphy of planktonic foraminifera. The location of the Matindok Section is illustrated in Figure 1.

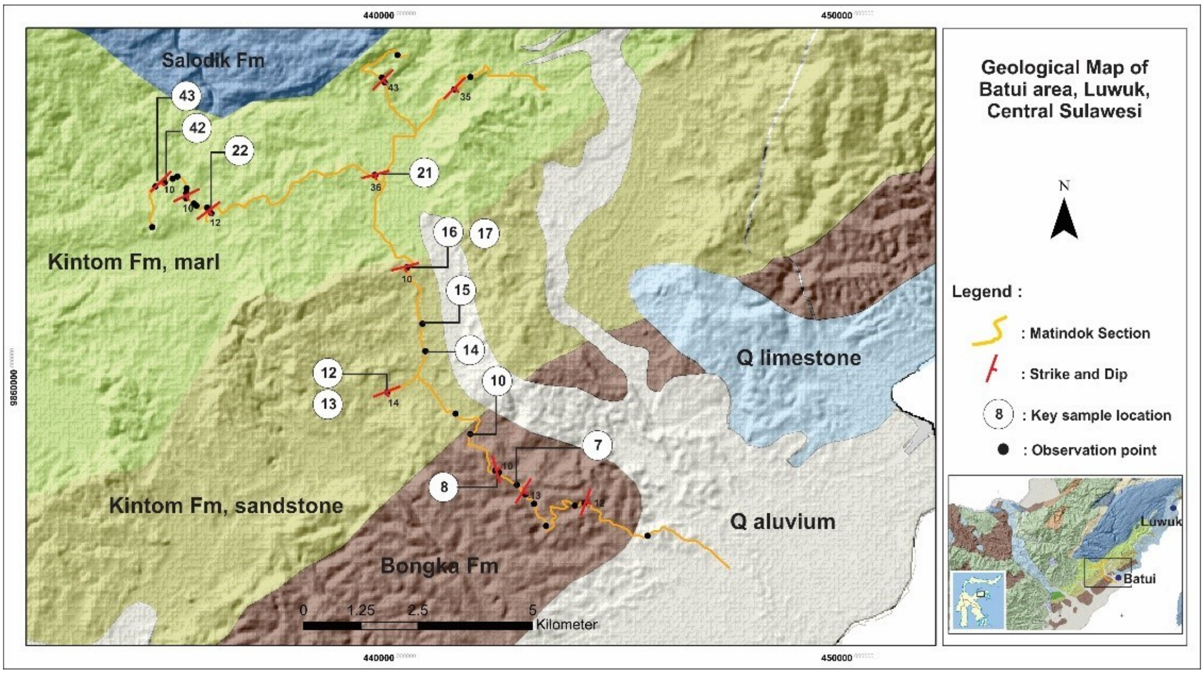

Figure 1. Geological Map of the research location (Surono et al. 1993) located in the southwest of the Eastern Arm of Sulawesi. The orange lines indicate the sections for collecting stratigraphic data, and the black dots indicate the observation locations with several sample numbers that are key to this study's division of foraminifera biozones.

Sedimentary rocks in the East Arm of Sulawesi are mostly distributed on the southern side, with a range of rock ages from the Mesozoic to the Quaternary. A small number of sedimentary rocks can be found in the western part (Martosuwito 2012). The outcrop of Pliocene sedimentary rocks at the surface forms the Kintom, Bongka, and Lonsio Formations (Rusmana et al. 1993; Surono et al. 1993). Rocks from the Bongka and Kintom Formations are considered as the result of the collision between the Eastern Arm of Sulawesi and the Banggai Sula Microcontinent, which has been occurring since the Middle Miocene (Simandjuntak 1986), with sedimentary material originating from the collision complex. This differs from the Lonsio Formation, which has sediment origins from volcanic highs. The Kintom and Bongka Formations are distributed in the southern and western parts of the Eastern Arm of Sulawesi, while the Lonsio Formation is spread in the northern part of Balantak Head and the Togian Islands.

GEOLOGICAL SETTING

The research is located within the Banggai Basin, a vessel-like, narrow in the north and widening towards the south. The research area in the north is bordered by Paleogene-Neogene limestone folded hills. To the south, the research area is bordered by the alluvial-coastal plain.

The northwestward movement of the Banggai Sula microcontinent in the early Miocene pushed it closer to the Asian plate, including the Sulawesi Island Arc, leading to a collision between continental plates (Garrard et al. 1988). Following the collision, rocks originating from the Bangai Sula and Sulawesi microcontinents undergo obduction towards the east, resulting in the forming of molasses deposits (Figure 2).

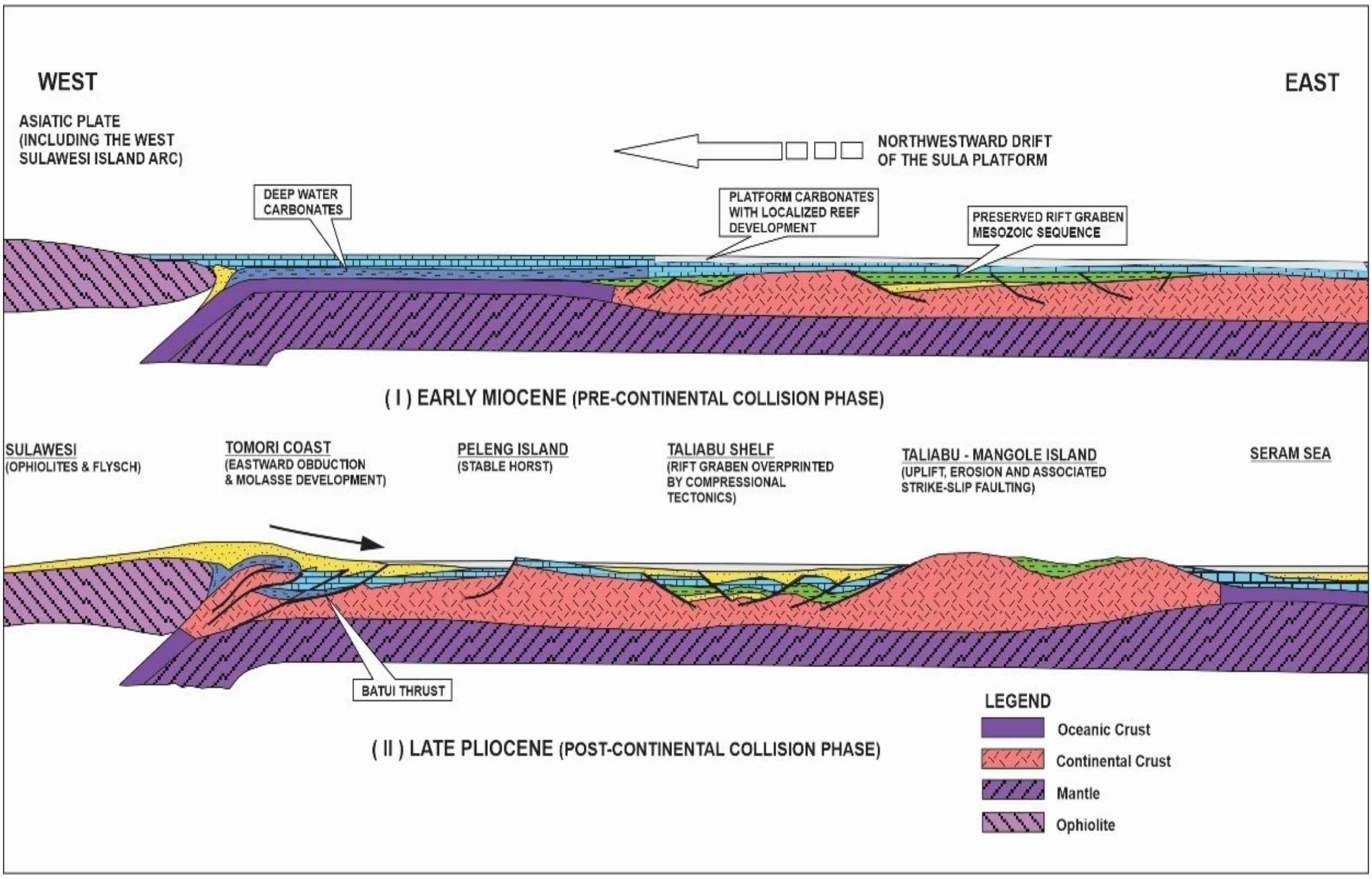

Figure 2. The movement of the Banggai Sula microcontinent towards the Asian plate (including the Sulawesi Island Arc) during the Early Miocene caused rocks formed initially on both plates to undergo eastward obduction, becoming the source material for the formation of flysch and molasse during the Late Pliocene (Garrard et al. 1988).

The rocks formed after the movement of the Banggai Sula microcontinent from the Early Miocene to the Holocene are divided into several formations, as seen in Figure 3 :

a. Bancuh Kolokolo

The "Bancuh Kolokolo" consists of of Mesozoic rock fragments; chert, schist, peridotite, gabbro, serpentinite, limestone, marl, and siltstone within a scaly clay and marl matrix. The age of the Bancuh Kolokolo, based on fossil content in limestone and marl fragments, is Oligocene to Miocene. The foraminifera fossil assemblage includes *Amphistegina* sp., *Orbulina universa* D'Orbigny, *Globigerina* sp., *Globigerinoides* sp., *Globorotalia menardii* D'Orbigny, *Globorotalia* sp., *Lepidocyclina* sp., and *Sphaeroidinellopsis subdehiscens* (Blow).

However, is based on the fossil content of planktonic foraminifera in the scaly mud and marl matrix, indicating the formation age from the Middle Miocene to Pliocene (Figure 3). The planktonic foraminifera fossils in this matrix includes *Globigerina venezuelana* Hedberg, *Globigerinoides immaturus* Broniman, *Globigerinoides obliquus* Bolli, *Globigerinoides sacculifer* Brady, *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia cultrata*, *Globorotalia menardii* D'Orbigny, *Globorotalia scitula* Brady, *Globorotalia tumida*, *Orbulina universa* D'Orbigny, *Orbulina* sp., *Sphaeroidinella subdehiscens* Blow, and *Sphaeroidinellopsis seminulina* Schwager (Surono et al. 1993).

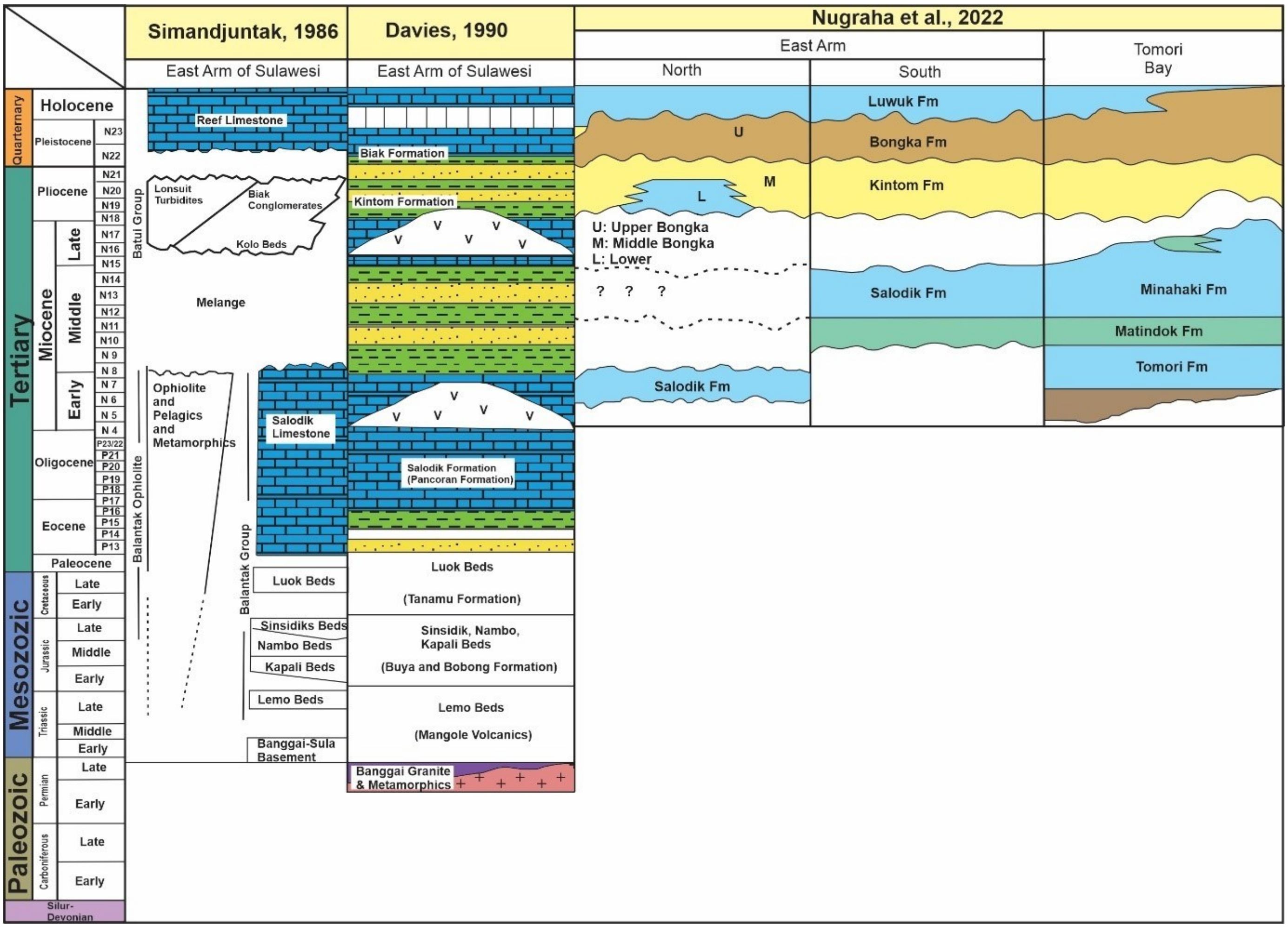

Figure 3. The stratigraphy of the study is based on several previous studies (Simandjuntak 1986; Davies 1990; Nugraha et al. 2022). Fine-grained sedimentary rocks are interpreted as part of the Kintom Formation formed during the Pliocene, while coarse-grained sedimentary rocks are included in the Bongka Formation (Nugraha et al. 2022) or Biak Formation (Simandjuntak 1986; Davies 1990). The red box represents the formation that is the focus of this study.

b. Salodik Formation

The Salodik Formation consists of bedded limestone with marl and sandstone intercalations. The abundant presence of large foraminifera indicates the age of the formation from the Middle Eocene to the Middle Miocene (Rusmana et al. 1993; Surono et al. 1993; Nugraha et al. 2022). The large foraminifera include *Amphistegina* sp., *Alveolinella* sp., *Cycloclypeus* sp., *Distichoplax biserialis* (Dietrich), *Heterostegina* sp., *Lepidocyclina* (*Eulepidina*) *ephipoides* Jones & Chapman, *Lepidocyclina* sp., *Nummulites* sp., *Operculina* sp., and *Spiroclypeus tindunganensis* Van Der Vlerk. The marl contains several species of small planktonic foraminifera, including *Globigerina boweri* Bolli, *Globigerinoides immaturus* Broniman, and *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia acostaensis* Blow, *Globorotalia aragonensis* Nuttal, *Globorotalia menardii* D'Orbigny, *Globorotalia spinulosa* Cushman, *Orbulina universa* D'Orbigny, and *Sphaeroidinellopsis seminulina* Schwager (Rusmana et al. 1993; Surono et al. 1993).

In the Poh-Pagimana area, the age of the Salodik Group is slightly different, ranging from the Early Eocene to the Middle Miocene. The age determination is based on the planktonic foraminifera content; *Morozovella aragonensis* Nuttal, *Morozovella lehneri* Cushman & Jarvis, *Morozovella subbotinae* Morozova, *Morozovella caucasica* Glaessner, *Paragloborotalia peripheroacuta* Blow & Banner, and *Paragloborotalia peripheroronda* Blow & Banner (Fakhruddin & Kurniadi 2019). This formation extends from the eastern to western parts of the Eastern Arm of Sulawesi, forming folded hills in the central part. In the sub-surface, Tomori PSC, the Salodik Formation forms three rock formations, namely Matindok, Tomori, and Minahaki (Davies 1990; Nugraha et al. 2022).

c. Poh Formation

The Poh Formation consists of interbedded limestone with marl and some carbonate sandstone intercalations at its base. Similar to the Salodik Formation, Poh limestone is rich in large foraminifera such as *Amphistegina* sp., *Alveolinella* sp., *Cycloclypeus* sp., *Gypsina* sp., *Heterostegina* sp., *Lepidocyclina* (*Eulepidina*) sp., *Lepidocyclina ferreroi* Provale, *Miogypsina* sp., *Operculina* sp., and *Spiroclypeus tindunganensis* Van Der Vlerk, indicating an age from the Oligocene to the Late Miocene. The marl in the Poh Formation is rich in small foraminifera fossils such as *Globigerina naparimaensis* Bronniman, *Globigerinoides ruber* D'Orbigny, *Globigerinoides trilobus* Reuss, *Globorotalia acostaensis* Blow, *Globorotalia plesiotumida* Banner & Blow, *Globorotalia* sp., *Sphaeroidinella subdehiscens* Blow, and *Sphaeroidinellopsis seminulina* Schwager (Rusmana et al. 1993; Surono et al. 1993). The stratigraphic relationship between the Salodik and Poh Formations is interfingering. In the sub-surface, Tomori PSC, this formation is equivalent to the Mentawa Member (Davies 1990; Nugraha et al. 2022).

d. Kintom Formation

The Kintom Formation in the western part comprises fine-grained rocks such as sandy marl and sandstone (Surono et al. 1993), while the eastern part consists of conglomerate, sandstone, and limestone (Rusmana et al. 1993). In the sub-surface, Tomori PSC, the Kintom Formation consists of mudstone with intercalations of sandstone and limestone (Figure 3). The planktonic foraminifera content in the marl consist of *Globigerinoides immaturus* Broniman, *Globigerinoides obliquus* Bolli, *Globigerinoides sacculifer* Brady, *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globoquadrina venezuelana* (Hedberg), *Globorotalia acostaensis* Blow, *Globorotalia flexuosa* (Koch), *Globorotalia menardii* D'Orbigny, *Globorotalia multicamerata* Cushman & Jarvis, *Globorotalia plesiotumida* Banner & Blow, *Globorotalia tumida* Brady, *Hastigerina siphonifera* (D'Orbigny), *Orbulina universa* D'Orbigny, *Sphaeroidinella subdehiscens* Blow, and *Sphaeroidinellopsis seminulina* Schwager (Rusmana et al. 1993; Surono et al. 1993). This fossil assemblage indicates an age from the Late Miocene to the Pliocene.

e. Bongka Formation

The rocks forming the Bongka Formation consist of repetitive sequences of conglomerates with sandstone and mudstone, along with several lenses of limestone. Occasionally, in some locations, siltstone and lignite intercalations can be found. The age of the Bongka Formation is the same as that of Kintom, which is from the Late Miocene to the Pliocene (Surono et al. 1993; Rusmana et al. 1993). However, according to other researchers (Nugraha et al. 2022), the Bongka Formation has a Late Pliocene age and unconformably overlies the Kintom Formation, which has an Early Pliocene age (Figure 3). The foraminifera fossil assemblage, including *Candeina nitida* D'Orbigny, *Globigerina naparimaensis* Bronniman, *Globigerinoides extremus* Bolli & Bermudez, *Globigerinoides immaturus* Broniman, *Globigerinoides obliquus* Bolli, *Globigerinoides ruber* D'Orbigny, *Globoquadrina venezuelana* (Hedberg), *Globorotalia acostaensis* Blow, *Globorotalia crassaformis* Galloway & Wissler, *Globorotalia crassaformis* Blow, *Globorotalia menardii* D'Orbigny, *Globorotalia multicamerata* Cushman & Jarvis, *Globorotalia tumida* Brady, *Globorotalia tosaensis* Takayanagi & Saito, *Orbulina universa* D'Orbigny, *Pulleniatina obliquiloculata* Parker & Jones, *Pulleniatina primalis* Banner & Blow, and *Sphaeroidinella dehiscens* Parker & Jones, indicates an age from the Late Miocene to the Pliocene (Rusmana et al. 1993; Surono et al. 1993).

f. Quaternary Coral Reefs

The formation consists of coralline-reefal limestone with marl (Surono et al. 1993; Rusmana et al. 1993). In some places, such as on the road cut in the village of Bunga, reefal limestone cut by conglomerate layers is found. Nugraha et al. (2022) and Rusmana et al. (1993) refer to it as the Luwuk Formation. Based on the content of planktic foraminifera such as *Globorotalia tosaensis* Takayanagi & Saito, *Globorotalia truncatulinoides* D'Orbigny, *Globorotalia tumida* Brady, *Pulleniatina obliquiloculata* Parker & Jones, and *Pulleniatina primalis* Banner & Blow, the age of this formation is Pleistocene (Surono et al. 1993). The Luwuk Formation unconformably overlies the Kintom-Bongka Formation and is still forming today (Figure 3).

Previously, Rusmana et al. (1993) and Surono et al. (1993) have categorised the Kintom, Bongka, and Luwuk Formations as molasse-type sedimentary rocks. This study will only focus on the Kintom and Bongka Formations, while the Luwuk Formation will not be the subject of this research.

MATERIALS AND METHODS

The stratigraphic column of the Matindok Section was obtained by conducting a measured section around the Matindok - Ondoondolu road with a scale of 1:100. Measurements were taken on outcrops located on cliffs, riverbanks, and road cuts (Figure 4). Some outcrops had weathered rock conditions, necessitating a shift to other locations to obtain fresh outcrops or stratigraphic measurements were not performed (Figure 1). As a result, there are several points in the stratigraphic column where the column is empty. Based on the measured stratigraphy, a 315 m thick stratigraphic column was produced (Figure 5).

A total of 46 rock samples were collected for the analysis of planktonic foraminifera content to determine the age of the rocks in this section. The prepared rocks mostly consisted of marl, but some rock samples were taken from calcareous sandstone and conglomerate matrix due to the absence of fine-grained rocks, especially in the sandstone and conglomerate units.

A 100-gram rock sample was crushed by pounding and soaked in hydrogen peroxide (H_2O_2) solution. After several hours, the hydrogen peroxide solution was discarded, and the sample is filtered under running water. The filters used employ mesh sizes of 50, 150, and 200. Before usage, the filters were soaked in a methylene blue solution to stain fossils from the previous filtration process that may have been missed on the mesh. After filtration, the samples were dried in an oven, and once dried, they were ready for observation under a binocular microscope. The identification of planktonic foraminifera was facilitated by referring to standard foraminifera identifications from Bolli et al. (1985), Ducassou et al. (2015), BouDagher-Fadel (2015), Berghuis et al. (2019), Badaro and Petri (2022), and Bown et al. (2024).

The foraminifera zonation followed the classification outlined by Wade et al. (2011) and van Gorsel et al. (2014). Wade et al. (2011) was chosen because it presented a calibration of Cenozoic planktonic foraminifera zones in low-latitude areas. The calibration has also been synthesised with the Cenozoic geomagnetic polarity time scale (GPTS) and the astronomical time scale (ATS). In general, the results of Wade et al. (2011) were in accordance with previous studies (ex. Bolli et al. 1985), but in some cases, there are several adjustments to the biochron duration. Van Gorsel et al. (2014) conducted a review of biostratigraphy and biofacies interpretation in Cenozoic basins in Indonesia and Southeast Asia. Several biodatums not found in Wade et al. (2011) can be found in van Gorsel et al. (2014).

RESULTS AND DISCUSSION

Rock Unit

From the stratigraphic measurements, three rock units were identified, from oldest to youngest, consisting of:

a. Marl unit consists of marl with intercalations of calcareous sandstone and breccia. The marl has a gray color and is massive, with grain size ranging from silt to very fine sand (Figure 4A), sub-angular grain shapes, open fabric, and the composition is lithic sedimentary and mafic igneous rocks, also rich in small foraminifera. The calcareous sandstone is light gray, generally massive (Figure 4B), but sometimes shows parallel sedimentary structures. It has fine sand grain size, sub-angular grain shapes, open fabric, and the composition is lithic fragments and small foraminifera. The breccia is gray, with a massive-channel sedimentary structure, the fragment sizes ranging from 4 mm to 6 cm, angular shapes, open fabric, with dominant fragment composition is lithic marl and calcareous sandstone fragments (Figure 4C).

b. Calcareous sandstone unit consists of calcareous sandstone with intercalations of claystone and siltstone. The calcareous sandstone is cream-colored with graded–bedded sedimentary structures, occasionally massive, fine – medium sand grain size, subangular to subrounded grain shapes, open fabric, and fragments composed of quartz, small foraminifera, serpentinite, and opaque minerals (Figure 4D). The claystone is dark gray, massive, with clay-sized grains, and a thickness of 5 cm. The siltstone is gray and massive, with sub-angular grain shapes, open fabric, and a fragment composition consisting of small foraminifera, quartz, and lithic sedimentary and igneous rocks.

c. Intergrade conglomerate- gravelly sandstone unit. The conglomerate is gray, with a graded-bedded, channel to cross-beds structures (Figure 4E), fragment sizes ranging from 4 mm to 10 cm, rounded grain shapes, open fabric, and a composition of fragments including serpentinite, gabbro, peridotite, greenschist, claystone, and limestone (Figure 4F). The conglomerate matrix is sand-sized with a composition similar to the fragments, and sometimes small foraminifera can be found. The gravelly sandstone is light brown, exhibiting graded-bedded to cross-bed sedimentary structures, with coarse sand grain size and some gravel-sized fragments. The grain shapes are subrounded to rounded, with an open fabric. The fragment composition includes lithic rocks of ultramafic origin such as serpentinite, gabbro, peridotite, and green schist; as well as sedimentary rocks like claystone and limestone.

Figure 4. Rocks outcrops in the Matindok section. A. Marl from the marl unit with intercalations of calcareous sandstone and breccia. The marl is massive and often jointed. B. Intercalation of calcareous sandstone with parallel bedding sedimentary structures. C. Breccia intercalation with fragments of calcareous sandstone and marl. D. Layer of fine calcareous sandstone from the calcareous sandstone unit with claystone and tuffaceous rock intercalations. E. Graded conglomerate transitioning into gravelly sandstone. F. Conglomerate fragments consisting of lithic gabbro, basalt, serpentinite, and limestone.

Foraminiferal Biostratigraphy

From the 46 prepared samples, one sample was barren. The other samples contained small foraminifera, both planktonic and benthonic, with varying abundances. A total of 49 species of planktic foraminifera were successfully identified from the prepared samples. The significant abundance of foraminifera from the research results provided a fairly good division of foraminifera biostratigraphy. Seven foraminifera biozones during the Pliocene could be identified. Markers delimited the biozones used the first occurrence (FO) and last occurrence (LO) of a species as datum (Figure 5). The markers generally used the biozonation employed by Wade et al. (2011) and van Gorsel et al. (2014). The names of the biozones referred to 5 types of biozones based on stratigraphic presence, namely Lowest Occurrence Zone (LOZ), Highest Occurrence Zone (HOZ), Taxon Range Zone (TRZ), Concurrent Range Zone (CRZ), and Partial Range Zone (PRZ) (Wade et al. 2011). Seven biozones generated, from the oldest to the youngest, are:

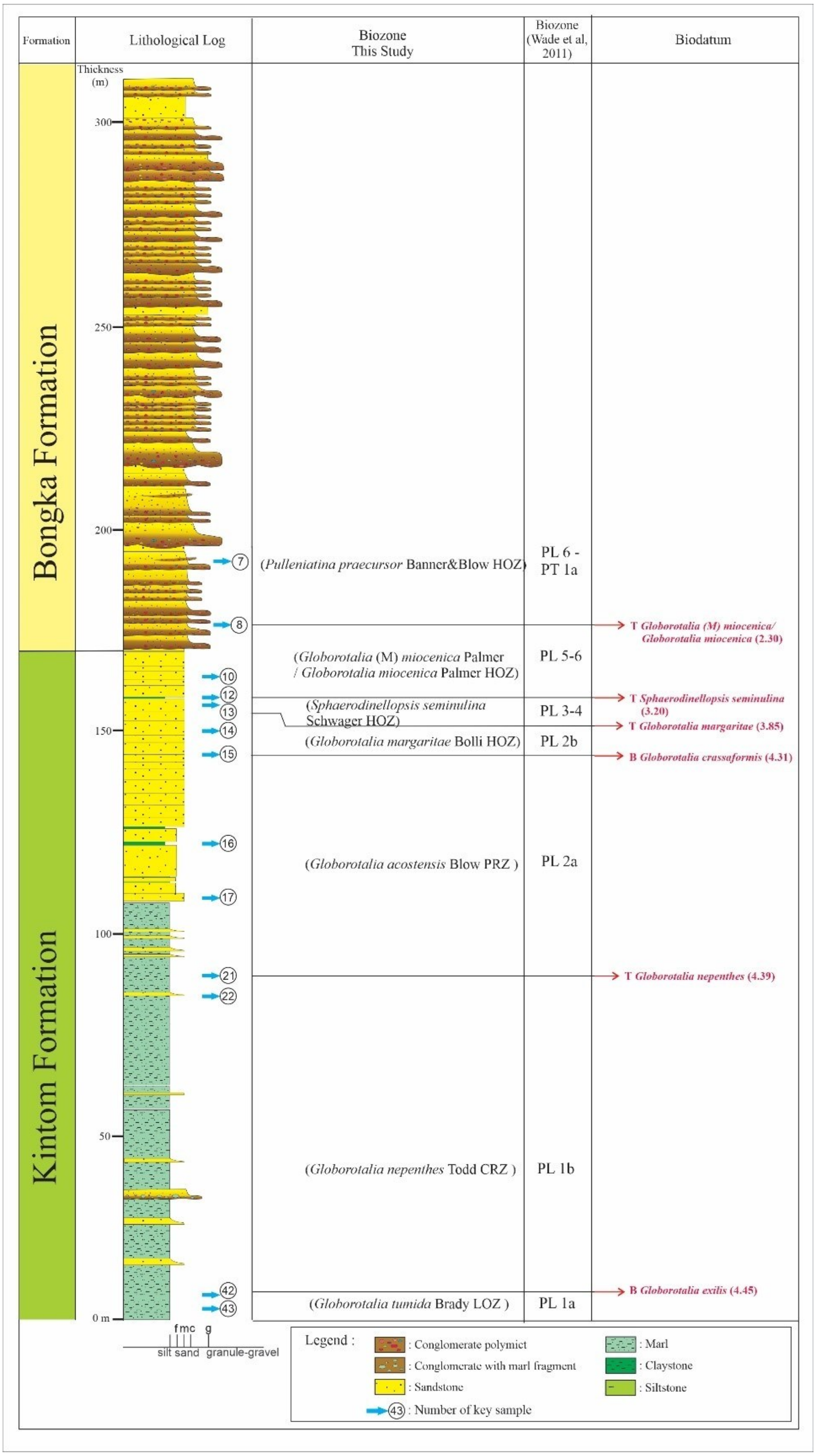

Figure 5. The biozonation position and biodatum of the Kintom and Bongka Formation. The biozonation scheme proposed by Wade et al. (2011) was utilised to compare the nomenclature and age assignment of the biozones and biodata. Please refer to Table 1 on the attached page for the distribution chart of planktonic foraminifera in the Matindok Section.

Globorotalia tumida Brady Lowest Occurrence Zone

Globorotalia tumida Brady Zone Wade et al. (2011), *Globorotalia margaritae margaritae* Bolli & Bermudez Zone Bolli et al. (1985).

Definition: This zone is *Globorotalia tumida* Brady Lowest Occurrence Zone (LOZ), marked by FO of *Globorotalia tumida* Brady to FO of *Globorotalia exilis* Blow and *Globorotalia menardii* B Bolli (Figure 5).
Sample Distribution: No.sample 45 – 43
Remarks: The biozones had a thickness of 10 m in the lithology column of the Matindok Section. The foraminifera identified in this zone are: *Globigerinoides immaturus* Broniman, *Globigerinoides obliquus extremus* Bolli & Bermudez, *Globigerinoides obliquus obliquus* Bolli , *Globigerinoides ruber* D'Orbigny, *Globigerinoides sacculiferus* Brady, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia acostaensis* Blow, *Globorotalia menardii menardii* (Parker, Jones & Brady), *Globorotalia merotumida* Blow & Banner, *Globorotalia plesiotumida* Blow & Banner, *Globorotalia pseudomiocenica* Bolli & Bermudez, *Globorotalia tumida* Brady, *Hastigerina aequilateralis* Brady, *Orbulina universa* D'Orbigny, *Pulleniatina primalis* Banner & Blow, *Sphaeroidinella dehiscens* Parker & Jones, and *Sphaeroidinellopsis seminulina* Schwager have also been identified. Other species found in these biozones include *Globigerinoides sacculiferus fistulosus* Schubert, *Globorotalia margaritae* Bolli & Bermudez, *Globorotalia menardii A* Bolli, *Globigerinoides altiaperturus* Bolli, *Globigerinoides conglobatus* Brady, *Globigerinoides extremus* Bolli & Bermudez, *Globigerinoides quadrilobatus* D'Orbigny, *Globigerinoides sicanus* de Stefani, *Globigerinoides trilobus* Reuss, *Globoquadrina dehiscens* Jenkins, *Globorotalia cibaoensis* Bermudez, *Globorotalia humerosa* Takayanagi & Saito, *Globorotalia humerosa humerosa* Takayanagi & Saito, and *Globorotalia pseudoopima* Blow.
Stratigraphic Distribution: Marl unit, Matindok section lithology column interval 0 - 10 m.
Horizon: PL 1c (Early Pliocene), B *Globorotalia tumida* Brady (5.59 Ma) – B *Globorotalia exilis* Blow (4.45 Ma) see Table 1.

Globoturborotalita nepenthes Todd Concurrent-range Zone

Globoturborotalita nepenthes Todd CRZ (Wade et al. 2011), *Globorotalia margaritae evoluta* Cita Zone (Bolli et al. 1985).
Definition: This Zone is *Globoturborotalita nepenthes* Todd Concurrent-Range Zone (CRZ), marked by FO of *Globorotalia exilis* Blow to LO of *Globoturborotalita nepenthes* Todd and LO *Globoquadrina venezuelana* Hedberg (Figure 6).
Sample Distribution: No.sample 42 – 22
Remarks: The biozones in the lithology column of the Matindok Section had a thickness of 70 m. The foraminifera identified in this zone include *Dentoglobigerina altispira* Cushman & Jarvis, *Globigerinoides conglobatus* Brady, *Globigerinoides extremus* Bolli & Bermudez, *Globigerinoides immaturus* Broniman, *Globigerinoides obliqus extremus* Bolli & Bermudez, *Globigerinoides obliquus obliquus* Bolli, *Globigerinoides ruber D'Orbigny*, *Globigerinoides sacculiferus* Brady, *Globigerinoides sicanus* de Stefani, *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globoquadrina dehiscens* Jenkins, *Globoquadrina praedehiscens* Blow & Banner, *Globoquadrina tripartita* Koch, *Globorotalia acostaensis* Blow, *Globorotalia cibaoensis* Bermudez, *Globorotalia exilis* Blow, *Globorotalia humerosa* Takayanagi & Saito, *Globorotalia humerosa humerosa* Takayanagi & Saito, *Globorotalia margaritae* Bolli & Bermudez, *Globorotalia (Menardella) miocenica* Palmer, *Globorotalia menardii A* Bolli, *Globorotalia menardii B* Bolli, *Globorotalia menardii cultrata* D'Orbigny, *Globorotalia menardii menardii* (Parker, Jones & Brady), *Globorotalia merotumida* Blow & Banner, *Globorotalia multicamerata* Cushman & Jarvis, *Globorotalia plesiotumida* Blow & Banner, *Globorotalia pseudomiocenica* Bolli & Bermudez, *Globorotalia pseudoopima* Blow, *Globorotalia tumida* Brady,

Hastigerina aequilateralis Brady, *Orbulina bilobata* D'Orbigny, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow, *Pulleniatina primalis* Banner & Blow, *Sphaeroidinella dehiscens* Parker & Jones, *Sphaeroidinellopsis seminulina* Schwager, and *Sphaeroidinellopsis seminulina seminulina* Schwager.
Stratigraphic Distribution: Marl unit, Matindok section lithology column interval 10 - 80 m.
Horizon: PL 1b (Early Pliocene), B *Globorotalia exilis* Blow (4.45 Ma) – T *Globoturborotalita nepenthes* Todd (4.39 Ma) see Table 1.

Globorotalia acostaensis Blow Partial Range Zone
Globorotalia margaritae Bolli HOZ (Wade et al. 2011), *Globorotalia margaritae evoluta* Cita Zone (Bolli et al. 1985).
Definition: This Zone is *Globorotalia acostaensis* Blow Partial Range Zone (PRZ), marked by LO of *Globoturborotalita nepenthes* Todd and *Globoquadrina venezuelana* Hedberg to FO of *Globorotalia crassaformis crassaformis* Galloway & Wissler (Figure 6).
Sample Distribution: No.sample 21 - 16
Remarks: The biozones in the lithology column of the Matindok Section have a thickness of 65 m. The foraminifera identified in this zone include *Globigerinoides altiaperturus* Bolli, *Globigerinoides conglobatus* Brady, *Globigerinoides immaturus* Broniman, *Globigerinoides obliqus extremus* Bolli & Bermudez, *Globigerinoides obliquus obliquus* Bolli, *Globigerinoides ruber* D'Orbigny, *Globigerinoides sacculiferus* Brady, *Globoquadrina altispira* Cushman & Jarvis, *Globoquadrina dehiscens* Jenkins, *Globorotalia acostaensis* Blow, *Globorotalia exilis* Blow, *Globorotalia humerosa* Takayanagi & Saito *Globorotalia humerosa humerosa* Takayanagi & Saito, *Globorotalia margaritae* Bolli, *Globorotalia (Menardella) miocenica* Palmer, *Globorotalia menardii cultrata* D'Orbigny, *Globorotalia menardii menardii* (Parker, Jones & Brady), *Globorotalia merotumida* Blow & Banner, *Globorotalia plesiotumida* Blow & Banner , *Globorotalia pseudomiocenica* Bolli & Bermudez, *Globorotalia pseudoopima* Blow, *Globorotalia tumida* Brady, *Hastigerina aequilateralis* Brady, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow, *Pulleniatina primalis* Banner & Blow, *Sphaeroidinella dehiscens* Schwager, and *Sphaeroidinellopsis seminulina* Schwager.
Stratigraphic Distribution: Upper marl – lower calcareous sandstone unit, Matindok section lithology column interval 80 - 145 m.
Horizon: PL 2a (Early – Late Pliocene), T *Globoturborotalita nepenthes* Todd (4.39 Ma) – B *Globorotalia crassaformis crassaformis*(4.31 Ma) see Table 1.

Globorotalia margaritae Bolli Highest Occurrence Zone
Globorotalia margaritae Bolli HOZ (Wade et al. 2011), *Globorotalia margaritae evoluta* Cita Zone (Bolli et al. 1985)
Definition: Interval from FO *Globorotalia crassaformis crassaformis* Galloway & Wissler to LO *Globorotalia margaritae* Bolli (Figure 6).
Sample Distribution: No.sample 15 – 14
Remarks: The biozones in the lithology column of the Matindok Section had a thickness of 9 m. The foraminifera identified in this zone include *Dentoglobigerina altispira* Cushman & Jarvis , *Globigerinoides conglobatus* Brady, *Globigerinoides immaturus* Broniman, *Globigerinoides obliqus extremus* Bolli & Bermudez, *Globigerinoides obliquus obliquus* Bolli, *Globigerinoides quadrilobatus* D'Orbigny, *Globigerinoides ruber* D'Orbigny, *Globigerinoides sacculiferus fistulosus* Schubert, *Globigerinoides tosaensis* Takayanagi & Saito, *Globigerinoides trilobus* Reuss, *Globoquadrina dehiscens*

Jenkins, *Globorotalia crassaformis crassaformis* Galloway & Wissler, *Globorotalia dutertrei blowi* Rogl & Bolli, *Globorotalia exilis* Blow, *Globorotalia margaritae* Bolli, *Globorotalia menardii A* Boll*i*, *Globorotalia menardii B* Bolli, *Globorotalia menardii menardii* (Parker, Jones & Brady), *Globorotalia merotumida* Blow & Banner, *Globorotalia multicamerata* Cushman & Jarvis, *Globorotalia plesiotumida* Blow & Banner, *Globorotalia pseudomiocenica* Bolli & Bermudez, *Globorotalia pseudoopima* Blow, *Globorotalia tumida* Brady, *Hastigerina aequilateralis* Brady, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow, *Pulleniatina* primalis Banner & Blow, *Sphaeroidinella dehiscens* Schwager, and *Sphaeroidinellopsis seminulina* Schwager.
Stratigraphic Distribution: Calcareous sandstone unit, Matindok section lithology column interval 145 - 154 m.
Horizon: PL 2b (Early Pliocene), B *Globorotalia crassaformis crassaformis* (4.31 Ma) – T *Globorotalia margaritae* Bolli (3.85 Ma) see Table 1.

Sphaeroidinellopsis seminulina Schwager Highest Occurrence Zone

Sphaeroidinellopsis seminulina Schwager HOZ (Wade et al. 2011), *Globorotalia margaritae evoluta* Cita Zone (Bolli et al. 1985).
Definition: This Zone is *Sphaeroidinellopsis seminulina* Schwager Highest Occurrence Zone (HOZ), marked by LO of *Globorotalia margaritae* Bolli & Bermudez to LO of *Sphaeroidinellopsis seminulina* Schwager (Figure 6).
Sample Distribution: No.sample 13
Remarks: The biozones in the lithology column of the Matindok Section had a thickness of 2.5 m. The foraminifera identified in this zone include *Globigerinoides extremus* Bolli & Bermudez, *Globigerinoides immaturus* Broniman, *Globigerinoides obliquus obliquus* Bolli, *Globigerinoides ruber* D'Orbigny, *Globigerinoides sacculiferus* Brady, *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia humerosa humerosa* Takayanagi & Saito, *Globorotalia (Menardella) miocenica* Palmer, *Globorotalia miocenica* Palmer, *Globorotalia plesiotumida* Blow & Banner, *Globorotalia pseudoopima* Blow, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow, *Sphaeroidinella dehiscens* Schwager, and *Sphaeroidinellopsis seminulina* Schwager.
Stratigraphic Distribution: Calcareous sandstone unit, Matindok section lithology column interval 154 – 156,5 m.
Horizon: PL 3 - 4 (Early – Late Pliocene), T *Globorotalia margaritae* Bolli (3.85 Ma) – T *Sphaeroidinellopsis seminulina* Schwager (3.20 Ma) see Table 1.

Globorotalia (M) miocenica Palmer / *Globorotalia miocenica* Palmer Highest Occurrence Zone

Globorotalia miocenica Palmer HOZ (Wade et al. 2011), *Globorotalia miocenica* Palmer / *Globorotalia trilobus fistulosus* Schubert Zone (Bolli et al. 1985).
Definition: This Zone is *Globorotalia (M) miocenica* Palmer / *Globorotalia miocenica* Palmer Highest Occurrence Zone (HOZ), marked by LO of *Sphaeroidinellopsis seminulina* Schwager to LO of *Globorotalia (M) miocenica* Palmer / *Globorotalia miocenica* Palmer (Figure 6).
Sample Distribution: No.sample 12 - 8
Remarks: The biozones in the lithology column of the Matindok Section had a thickness of 18.5 m. The foraminifera identified in this zone include *Globigerinoides conglobatus* Brady, *Globigerinoides immaturus* Broniman, *Globigerinoides obliqus extremus* Bolli & Bermudez, *Globigerinoides ruber* D'Orbigny, *Globigerinoides trilobus* Reuss, *Globoquadrina altispira* Cushman & Jarvis, *Globorotalia crassaformis*

crassaformis Gallowas & Wissler, *Globorotalia dutertrei blowi* Rogl & Bolli, *Globorotalia dutertrei dutertrei* D'Orbigny, *Globorotalia exilis* Blow, *Globorotalia (Menardella) miocenica* Palmer, *Globorotalia menardii cultrate*, *Globorotalia miocenica* Palmer, *Globorotalia merotumida* Blow & Banner, *Globorotalia plesiotumida* Blow & Banner, *Globorotalia pseudoopima* Blow, *Globorotalia tumida* Brady, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow, and *Pulleniatina primalis* Banner & Blow.

Stratigraphic Distribution: Upper calcareous sandstone – lower gravelly sandstone unit Matindok section lithology column interval 156,5 - 175 m.

Horizon: PL 5 - 6 (Late Pliocene), T *Sphaeroidinellopsis seminulina* Schwager (3.20 Ma) – T *Globorotalia miocenica* Palmer (2.30 Ma) see Table 1.

Figure 6. Examples of several species of planktonic foraminifera that can be found in rocks in the Matindok Section are as follows: 1a-b: *Globogerinoides nepenthes* Todd 2a-b: *Globorotalia tumida* Brady 3a-b: *Globorotalia acostaensis* Blow 4a-b: *Globorotalia scitula-margaritae* Bolli & Bermudez 5a-b: *Sphaeroidinellopsis seminulina* Schwager 6a-b: *Globorotalia (M) miocenica* Palmer 7a-b: *Globorotalia miocenica* Palmer 8a-c: *Dentoglobigerina altispira* Cushman & Jarvis 9a-b: *Globorotalia multicamerata* Cushman & Jarvis 10a-b: *Globorotalia menardii* Bolli 11a-c: *Globoquadrina altisipra* Cushman & Jarvis 12a-b: *Pulleniatina praecursor* Banner & Blow.

Pulleniatina praecursor Banner & Blow Highest Occurrence Zone

Pulleniatina praecursor Banner & Blow HOZ from (Wade et al. 2011), *Globorotalia miocenica* Palmer / *Globorotalia tosaensis tosaensis* Takayanagi & Saito Zone (Bolli et al. 1985).

Definition: This Zone is *Pulleniatina praecursor* Banner & Blow Highest Occurrence Zone (HOZ), marked by LO of *Globorotalia (M) miocenica* Palmer / *Globorotalia miocenica* Palmer to LO *Pulleniatina praecursor* Banner & Blow (Figure 6).
Sample Distribution: No.sample 7 - 1
Remarks: Biozones had a thickness of 140 m in the lithology column of the Matindok Section. The foraminifera identified in this zone are: *Globoquadrina* altispira Cushman & Jarvis, *Globorotalia tumida* Brady, *Orbulina universa* D'Orbigny, *Pulleniatina praecursor* Banner & Blow and *Pulleniatina primalis* Banner & Blow.
Stratigraphic Distribution: Gravelly sandstone unit, Matindok section lithology column interval 175 - 315 m.
Horizon: PL 6 – PT1a (Late Pliocene), T *Globorotalia miocenica* Palmer (2.30) – T *Pulleniatina praecursor* Banner & Blow (2.26 Ma) see Table 1.

Discussion

Lithology can be grouped based on different categories with clearly distinguishable characteristics (Darman et al. 2023). This research divided the rocks exposed in the Matindok Section into lithostratigraphic and biostratigraphic units. Lithostratigraphic units divided rock bodies based on lithological characteristics with the official basic unit called formation. Biostratigraphic units were based on the division of rock bodies based on the fossil content in the rock with the basic unit being biozones or zones.

The stratigraphic development in the research area started with marl units with intercalations of sandstone and breccia. Subsequently, it gradually transitioned into sandstone with intercalations of claystone-siltstone and concluded with repetitive conglomerate-sandstone gradations. The stratigraphic development indicated a pattern of coarsening upward in rock changes. This pattern generally signified changes in the depositional environment becoming shallower upwards.

In the marl units, the rock character was poor in sedimentary structure and had an open fabric. This suggests a deposition mechanism involving turbidity currents. The fine grains present in the rock, along with the abundant content of planktic foraminifera and a diverse range of species, particularly within the *Globorotalia* genus, imply a deeper marine depositional environment. It is highly probable that the depositional setting is situated in the distal part of the submarine fan.

The calcareous sandstone units showed an increase in rock grain size. Additionally, sedimentary structures such as graded bedding and parallel bedding were becoming appear frequently, although the subangular grain shape and open fabric suggested a relatively similar depositional mechanism in turbidity currents. The amount of planktic foraminifera slightly decreased with a relatively high variety of species, particularly within the genus *Globorotalia*. The depositional environment was a proximal submarine fan.

The intergrade conglomerate-gravelly sandstone units had a very coarse grain size with a channel, graded bedding, parallel-cross bedding sediment structure, and a rounded grain shape. The deposition mechanism involved the movement of traction current, with a shallowing upward depositional environment in the delta front-prodelta slope of a fan delta. In contrast to the two previous units, which were rich in planktic foraminifera, this unit has a low occurrence of planktic foraminifera. The large depositional energy required for this unit implied that planktic foraminifera would face challenges in being deposited in the same environment. Consequently, there will be only a small amount of planktic foraminifera in this unit.

Table 1. Distribution chart of planktonic foraminifera from the Matindok Section with biodatum, age, biozanation from Wade et al. (2011) and biozonation from this study. R: Rare = 1 – 2 specimens, F: Few = 3 – 5 specimens, C: Common = 6 – 10 specimens, A: Abundant = > 10 specimens.

SECTION	FORMATION	NO SAMPLE	FORAMINIFERA PLANKTONIK: *Dentoglobigerina altispira*	*Globigerinoides altiaperturus*	*Globigerinoides conglobatus*	*Globigerinoides extremus*	*Globigerinoides immaturus*	*Globigerinoides obliqus extremus*	*Globigerinoides obliquus obliquus*	*Globigerinoides quadrilobatus*	*Globigerinoides ruber*	*Globigerinoides sacculiferus*	*Globigerinoides sacculiferus fistulosus*	*Globigerinoides sicanus*	*Globigerinoides tosaensis*	*Globigerinoides trilobus*	*Globoquadrina altispira*	*Globoquadrina dehiscens*	*Globoturborotalita nepenthes*
MATINDOK	BONGKA	1															R		
		2																	
		3																	
		4																	
		5																	
		6																	
		7															R		
		8									R					F	F		
		9					R												
	KINTOM	10			R			R			R						R		
		11					F										R		
		12					R												
		13				R	A		R		F	C				C	C		
		14	R		R		R		R		F				R		R	F	
		15					R			R	R		R		R		R		
		16		R				R	R		F	F						R	
		17		R	R		R	R	R		R							R	
		18			R		R				R								
		19			R		R	R									R		
		20							R		R							R	
		21			R			R											
		22	R			F	C		C			A				A	A		R
		23			R				R										
		24			R	C	C	R	C		R	C		A		A	R	R	R
		25				C	A	R	C		F	A		C		A	C		
		26			R		R	R									R		
		27				R	C					C				A	C		
		28					R												
		29			R	A	A	R	A		R	A		C		C	A		
		30				C	C		C			A				C	A	R	
		31				R	C	R	C			C				C	C		
		32			R			R											
		33			R		R		R		R							R	
		34			R			R									R		
		35				A	C		C			C		F		C	C		
		36				C	C		C			C		C		C	A		
		37	R		R		R										R		
		38				A	C		C		F	A		F		A	A	C	R
		39					R		R		F	F					R	F	
		40				F	C		C		F	C		C		C	C	R	
		41																	
		42					R	R	R										
		43		R	R	A	C	F	C	R		C		C		C	C	R	
		44					F		F				R				F		
		45					F	F	F		F	F					F		
		46																	

NO SAMPLE	*Globoquadrina praedehiscens*	*Globoquadrina tripartita*	*Globoquadrina venezuelana*	*Globorotalia acostaensis*	*Globorotalia cibaoensis*	*Globorotalia crassaformis crassaformis*	*Globorotalia dutertrei blowi*	*Globorotalia dutertrei dutertrei*	*Globorotalia exilis*	*Globorotalia humerosa*	*Globorotalia humerosa humerosa*	*Globorotalia margaritae*	*Globorotalia (Menardella) miocenica*	*Globorotalia menardii A*	*Globorotalia menardii B*	*Globorotalia menardii cultrata*	*Globorotalia menardii menardii*
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8													R				
9							R	R	R								
10								F	R							R	
11						R											
12																	
13											A		R				
14						F		F	F			F		R	R		R
15						R			R			F		R			R
16				F					F								
17				R							R	R		R			
18				R							R	R		R			
19									R								R
20											R			R			
21				R							R			R			
22		R	C	F					R			R		C			R
23											R			R			
24		R	C	R							A	R		C			
25		C	C	F	A				F	C			A	C			
26									R			R					R
27		R	R										C	A			
28																	
29		C	R	R	F					F	R		A	R			
30		F	R							C	R			C			
31			R						R					A			R
32											R	R		R			
33				R							R			R			
34												R					R
35		C	F										F	C			
36	R		C		F					R			R	F			
37									F			F					
38		R	F	F						C	F			R	R		
39				C							F			R	R		
40			R	R						C	R		F	C	R		
41																	
42									F					R	R		
43				C	F					A	F			R			R
44												F		F			
45				F													F
46																	

NO SAMPLE	*Globorotalia miocenica*	*Globorotalia merotumida*	*Globorotalia multicamerata*	*Globorotalia plesiotumida*	*Globorotalia pseudomiocenica*	*Globorotalia pseudoopima*	*Globorotalia tumida*	*Hastigerina aequilateralis*	*Orbulina bilobata*	*Orbulina universa*	*Pulleniatina praecursor*	*Pulleniatina primalis*	*Sphaerodinella dehiscens*	*Sphaerodinellopsis seminulina*	*Sphaerodinellopsis seminulina seminulina*
1															
2															
3							R			A	R				
4															
5															
6															
7										F	R	R			
8	R									R					
9	R					R	R			R					
10	R	R				F	F			F		F			
11				R						C	F	F			
12										R					
13	F			C		R	R			F	C	R		R	
14				R	R	F	C	R		A	R	R	R	R	
15		R	R	R		R	C	R		A	R	R	R		
16		R				F		R		A					
17				R	R		R			R					
18				R	R		R			R					
19						R				R	R	R	R	R	
20							R			R		R			
21										R		R			
22				A	R	R		R		C	R	R	R	R	F
23				R			R			C					
24				A	R	C	C			C		C	R	F	
25		R		A		C	C	C	C	A	A				C
26				R	R	R				R	R	R	R	R	
27				A			A			C	A		F		
28				R									R		
29				A		C	A	A		A		A			
30				C		C	C	C		C		A			
31				A		R	A			C	R	C	R	R	
32				R						C		R			
33				R			R			C					
34				R	R	R				R	R	R	R	R	
35				C		A	A	F		C	C				A
36				R		R	C	C	A	C		C		C	
37			R	C	R					F		F	R	R	
38				F		A	A	F	R	A		A		F	
39				R						A			R		
40				C		C	C	C		C		A	C		
41															
42					F		F			F			R		
43		R		A	F	C	C	C		C		C		F	
44					F		F			A					
45		F		F	F		F	F		A		F	F	F	
46															

NO SAMPLE	BIODATUM		Wade et al. (2011)	BIOZONES
1–8			PL6 - PT1a	*Pulleniatina praecursor* Banner & Blow HOZ
8	T *Globorotalia (M) miocenica* / T *Globorotalia miocenica*	2.30 mya		
9–12			PL5-6	*Globorotalia* (*M*) *miocenica* Palmer HOZ/ *Globorotalia miocenica* Palmer HOZ
13	T *Sphaerodinellopsis seminulina*	3.20mya	PL 3 - 4	*Sphaerodinellopsis seminulina* Schwager HOZ
14	T *Globorotalia margaritae*	3.85 mya		
14–16			PL2b	*Globorotalia margaritae* Bolli HOZ
16	B *Globorotalia crassaformis crassaformis*	4.31 mya		
17–21			PL2b	*Globorotalia acostaensis* Blow PRZ
22	T *Globoturborotalita nepenthes*	4.39 mya		
22–42			PL1b	*Globoturborotalita nepenthes* Todd CRZ
43	B *Globorotalia exilis*	4.45 mya		
43–46			PL1b	*Globorotalia tumida* Brady LOZ

The characteristics of the first and second rock units can be classified as flysch deposits resulting from a collision, while the characteristics of the third unit can be classified as molasses deposits from a collision (Kurniawan et al 2018; Kotlia et al. 2018; Martín-Martín et al. 2020; Milli et al. 2021; Zhang et al. 2020). Reworked rock fragments, including ultramafic igneous rocks such as serpentinite, gabbro, basalt, and sedimentary rocks such as marl, along with reworked foraminifera fossils such as *Globoquadrina dehiscens* Chapman, Parr & Collins, provide indications of the uplift of the ultramafic rocks of the Sulawesi Plate and the formation of newly generated flysch sediments. This phenomenon is common in collision areas as the two colliding plates approach each other.

Grouping rocks into a formation must refer to the locality type for each formation. Based on the locality type, the grouping of rocks in the Matindok Section will follow the definition of the Kintom and Bongka Formations according to Surono et al. (1993). The rock characteristics, mechanisms, and depositional environment are interconnected, allowing marl units with calcareous sandstone-breccia intercalations and sandstones with claystone-siltstone intercalations to be grouped into a distinct formation. When compared with Surono et al. (1993), these two rock units are classified within the Kintom Formation.

In contrast to the two previous units, the third unit shows distinct characteristics, mechanisms, and depositional environments, allowing its classification within a different formation. The repeating units of conglomerate and sandstone gradation are included in the Bongka Formation.

Wade et al. (2011) determined Zone PL1 to be between FO *Globorotalia tumida* Brady and LO *Globoturborotalita nepenthes* Todd and divided Zone PL1 into 2 based on the extinction of LO *Globorotalia ciboensis* Bermudez. Zone PL1 in the research area is divided into two parts, namely Zone PL1a and 1b. Zone PL 1a is *Globorotalia tumida* Brady LOZ, while PL1b is *Globoturborotalita nepenthes* Todd CRZ. This zone is slightly different from the zone proposed by Wade et al. (2011). The boundaries of Zone PL 1a and 1b are determined based on FO *Globorotalia exilis* Blow. LO *Globorotalia ciboensis* Bermudez was found in the study area but its stratigraphic position is above FO *Globorotalia exilis* Blow so it is considered to be reworked from older rocks.

Zone PL2 according to Wade et al. (2011) is the *Globorotalia margaritae* Bolli HOZ with a biostratigraphic interval between LO *Globoturborotalita nepenthes* Todd and LO *Globorotalia margaritae* Bolli. In this study PL2 can be divided into 2 zones: PL2a and 2b based on FO *Globorotalia crassaformis crassaformis* Galloway & Wissler. PL 2a is *Globorotalia acostaensis* Blow PRZ while PL 2b is *Globorotalia margaritae* Bolli HOZ. *Globorotalia acostaensis* Blow PRZ bordered by LO *Globoturborotalita nepenthes* Todd with FO *Globorotalia crassaformis crassaformis* Galloway & Wissler. *Globorotalia margaritae* Bolli HOZ is bordered by FO *Globorotalia crassaformis crassaformis* Galloway & Wissler with LO *Globorotalia margaritae* Bolli.

The next zone of the research area is PL3-4 with the boundary being LO *Globorotalia margaritae* Bolli and *Sphaeroidinellopsis seminulina* Schwager. PL3 zone according to Wade et al. (2011) is *Sphaeroidinellopsis seminulina* Schwager HOZ while PL4 is *Dentoglobigerina altispira* Cushman & Jarvis HOZ. The PL3-4 zone is only found in one rock sample, namely sample no. 13. This indicates the existence of unconformity after rock formation in PL3 and 4, resulting in stacked biostratigraphic zones. This unconformity can occur due to nondeposition or erosion.

Zone PL5 - 6 in the research area is *Globorotalia (M) miocenica* Palmer/ *Globorotalia miocenica* Palmer HOZ while Zones PL5 and 6 Wade et al. (2011) in the form of *Globorotalia pseudomiocenica* Bolli & Bermudez HOZ and *Globigerinoides fistulosus* Scubert HOZ. PL5 in the study area used LO *Sphaeroidinellopsis seminulina* Schwager with LO *Globorotalia (M) miocenica* Palmer/ *Globorotalia miocenica* Palmer while Wade et al. (2011) used LO *Dentoglobigerina altispira* Cushman & Jarvis with LO *Globorotalia pseudomiocenica* Bolli & Bermudez. The use of the biodatum LO *Sphaeroidinellopsis seminulina* Schwager, as the lower limit of PL5 for the study area, is due to the relatively consistent and continuous presence of this species compared to *Dentoglobigerina altispira* Cushman & Jarvis. Meanwhile, the use of the biodatum LO *Globorotalia (M) miocenica* Palmer/ *Globorotalia miocenica* Palmer in the research area for PL6 is due to the fact that *Globorotalia pseudomiocenica* Bolli & Bermudez has not been found since PL2b and *Globigerinoides fistulosus* Scubert has not been found in the research area since the beginning.

The last zone that developed in the PL6 – PT1a research area was *Pulleniatina praecursor* Banner & Blow HOZ while Zone PL6 and PT1a Wade et al. (2011) are *Globigerinoides fistulosus* Scubert HOZ and *Globorotalia tosaensis* Takayanagi & Saito HOZ. Determination of Zone PL6 – PT1a based on the biodatum LO *Globorotalia (M) miocenica* Palmer/ *Globorotalia miocenica* Palmer and the presence of *Pulleniatina praecursor* Banner & Blow. *Globigerinoides fistulosus* Scubert and *Globorotalia tosaensis* Takayanagi & Saito were used to divide PL6 and PT1a by Wade et al. (2011) not found. The presence of *Pulleniatina praecursor* Banner & Blow in this zone is considered to be the re-presence of the *Pulleniatina* genus in Zone PT1a according to Wade et al. (2011). Based on this, the youngest zone of the research area is included in Zone PL6 – PT1a.

The correlation of lithological units with biostratigraphic units in the research area produces several interesting things. The marl rock unit as the first lithological unit formed in the research area, with a thickness of 115 m contains three biostratigraphic units, namely Zones 1a, 1b and lower part 2a with. The time range for the formation of this unit is approximately 2 My. With a predominantly fine-grained lithology, it takes quite a long time to form this unit.

The calcareous sandstone unit, as the second unit, has a thickness of 55 m containing four biostratigraphic units, namely Upper Zone 2a, 2b, 3 -4 and 5-6. The formation time range is approximately the same as the formation of the first unit, approximately 2 My. The lithology in this second unit has a larger grain size of the constituent material compared to the first unit. Generally, with the same deposition time, coarse-grained lithology will have a greater thickness than fine-grained lithology. The thinner lithology of the second unit compared to the first unit could be due to erosion or non-deposition during the formation of this unit. Erosion can reduce the thickness of the lithology that was originally formed, while non-deposition results in thinner lithology that forms. Nondeposition in submarine fan areas due to lobe/channel displacement is common.

Zones PL3-4 and PL5-6 indicate possible erosion and nondeposition in the second unit. PL3-4 has a measured lithological thickness of 2.2 m. The time required to deposit the lithology is 0.65 My. There are 2 biozonations contained in coarser-grained lithology with a thickness of 2.2 m and over a relatively long time. There were no areas of erosion at the boundaries of the lithological layers, so it is thought that there was a long deposition lag during the displacement of the submarine channel. PL5-6 has a lithological thickness of 25 m. The upper limit of the second unit is at PL5-6 and is eroded by the last unit. Therefore, the lithology thickness at PL5-6 has decreased.

The intergrade conglomerate-gravelly unit, sandstone as the third and final unit, has a lithological thickness of 145 m and contains 1 biostratigraphic unit, namely Zone PL6-PT1a. The formation time range is short, ranging from 0.2 – 0.4 My. The coarse-grained lithologies that make up this unit require high depositional energies. Generally, high deposition energy will produce thick deposits in a relatively short time as seen in this last unit.

CONCLUSION

The lithology exposed along the Matindok Section can be categorized into three lithology units: marl units consist of marl with interbedded sandstone-breccia, calcareous sandstone unit consists of calcareous sandstone with interbedded claystone-siltstone, and intergrade conglomerate-gravelly sandstone *gradations.* The first two units belonged to the Kintom Formation and had appropriate characteristics with flysch deposits in the collision area, while the last unit was part of the Bongka Formation and had similarities with molasses deposits. The Kintom Formation was deposited from the Early Pliocene to early Late Pliocene, as indicated by the biozonation of foraminifera, including *Globorotalia tumida* Brady LOZ (PL1a; 5.59 - 4.45 Ma), *Globoturborotalita nepenthes* ToddCRZ (PL1b; 4.45 - 4.39 Ma), *Globotalia acostaensis* Blow PRZ (PL2a; 4.39 – 4.31 Ma), *Globotalia margaritae* Bolli HOZ (PL2b; 4.31 - 3.85 Ma), *Sphaeroidinellopsis seminulina* Schwager HOZ (PL 3-4; 3.85 – 3.20 Ma), and *Globorotalia (M) miocenica* Palmer / *Globorotalia miocenica* Palmer HOZ (PL5 – 6; 3.20 – 2.30 Ma). Above the Kintom Formation, the Bongka Formation was deposited unconformably during the Late Pliocene, based on the biozonation of foraminifera including *Globorotalia (M) miocenica* Palmer / *Globorotalia miocenica* Palmer HOZ (PL5 – 6; 3.20 – 2.30 Ma) and *Pulleniatina praecursor Banner & Blow* HOZ (PL6 – PT1a; 2.30 – 2.26 Ma).

AUTHORS CONTRIBUTION

Moch. Indra Novian designed the research, analyzed the paleontology, stratigraphy data and wrote the manuscript; Didit Hadi Barianto collected the data; Salahuddin Husein analysed the sedimentology data; Akmaluddin analysed the paleontology data and Sugeng Sapto Surjono supervised the process.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest in preparing this article.

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