INDONESIAN JOURNAL ON GEOSCIENCE
Geological Agency
Ministry of Energy and Mineral Resources

Journal homepage: http://ijog.geologi.esdm.go.id
ISSN 2355-9314, e-ISSN 2355-9306

Calcareous Nannofossil Biostratigraphy of Tonasa Formation at Barru River Traverse, South Sulawesi, Indonesia

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Manuscript received: January, 6, 2021; revised: March, 2, 2021;
approved: August, 23, 2022; available online: October, 14, 2022

Abstract - Barru is one of the areas in South Sulawesi where the stratigraphic sequences of lithology from Mesozoic to recent are well exposed. The Tonasa Formation is quite widespread in this area, and it is interesting to find out its various aspects related to the carbonate rock development. For this reason, the distribution of nannofossils were recorded and the relative age of Tonasa Formation was determined using nannofossil collected by measuring section at Barru River. The calcareous nannofossil assemblages are moderate to poor preserved. A total of twenty-three species were identified from the bottom to the top of the interbedded marl and limestone. The nannofossil assemblage-based biostratigraphy of the studied area was shown by the First Occurrence (FO) and Last Occurrence (LO) of the marker species. As for the results, there were six data found in this study, *i.e.* FO and LO of *Reticulofenestra umbilicus,* FO of *Sphenolithus pseudoradians*, LO of *Discoaster saipanensis*, LO of *Calcidiscus formosus*, and LO *Reticulofenestra bisectus*. Based on the noted nannofossil data, the determined age of Tonasa Formation at Palakka area included NP 15 – NN 1 or CP 13 - CN 1a, and equivalent to Middle Eocene until Early Miocene. The result shows important data that will contribute significantly in age constraint of Tonasa Formation.

Keywords: biostratigraphy, carbonate rock, nannofossil, Tonasa Formation

How to cite this article:
Farida, M., Jaya, A., and Nugraha, J., 2023. Calcareous Nannofossil Biostratigraphy of Tonasa Formation at Barru River Traverse, South Sulawesi, Indonesia. *Indonesian Journal on Geoscience*, 9 (3), p.371-381. DOI: 10.17014/ijog.9.3.371-381

Introduction

Background

Tonasa Formation is the most widespread carbonate rock in South Sulawesi and partly has interesting karst topography, especially in the studied area where the alternations between limestone and marl are found. One of well outcrops is exposed in Barru River (Figure 1). The Tonasa carbonate platform is included in a Cenozoic tropical carbonate production. Several previous studies on the Tonasa Formation have conducted by many researchers, particularly regarding paleontological data which were observed by Leeuwen (1981), Sukamto (1982), Wilson and Bosence (1996), Farida *et al*. (2016), and Farida *et al*. (2019). The Tonasa *Formation* was developed in a shallow marine carbonate platform (Sukamto, 1982; Wilson and Bosence, 1996; Wilson and Bosence, 1997). It was deposited during Early Eocene to

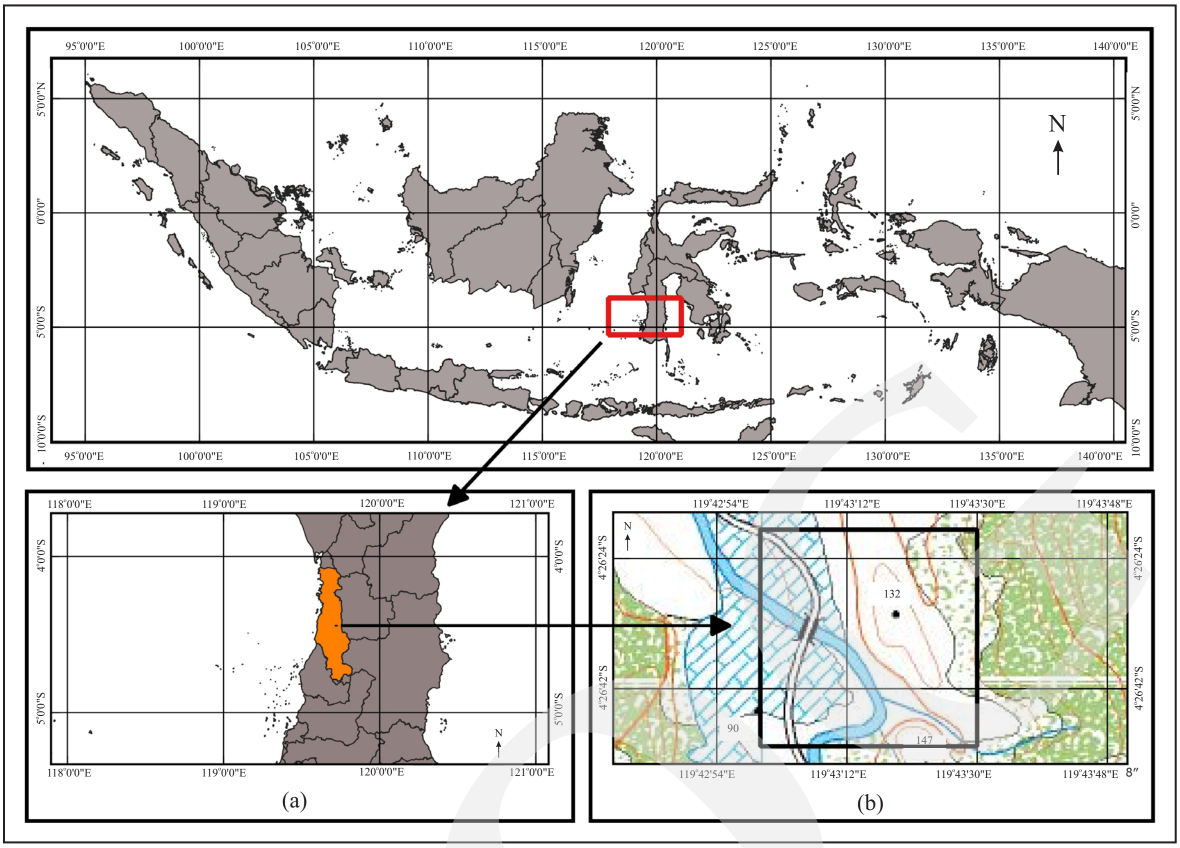


Figure 1. Maps of (a) Barru District, and (b) Barru River traverse area of South Sulawesi Province, Indonesia.

Late Miocene. On the other hand, some areas developed until the Middle Miocene (Sukamto, 1982; Wilson and Bosence, 1996). The evolution of the syntectonic of Tonasa Formation in South Sulawesi during Eocene to Middle Miocene was described in detail by Wilson *et al*. (2000). Besides, they explained that sedimentation, facies distribution, and sequence development were the main drivers of the evolution.

Nannofossils have properties, such as their abundant, planktonic, mainly cosmopolitan, high evolution, and small size (Bown and Young, 1999). They are the reason behind the suitability of nannofossil for biostratigraphic resolution (Bown and Young, 1999; Agnini *et al*., 2007), typically in marine sediments during Jurassic through present (Perch-Nielsen, 1985; Bown *et al*. 2004; Armstrong and Brasier, 2005; Adeigbe and Adeleye, 2016). Calcareous nannofossils are strongly affected rather than other marine planktonic organisms (Melinte, 2004). In this study, standard zonation was used for calcareous nannofossil proposed by Martini, 1971 (the cosmopolitan to high latitude) and scheme proposed by Okada and Bukry, 1980 (the low latitude).

The latest biostratigraphy taxonomy and nannofossils were proposed by Bown (1999). Studies on biostratigraphy of calcareous nannofossil from the Eocene - Oligocene have been carried out by previous researchers (Persico and Villa, 2004; Shamrock, 2010), and other investigations on Tertiary nannofossils biostratigraphy have been conducted in Java (Hendrizan, 2016; Choiriah et al. 2020).

As aforementioned, the paleontological data of this study, *i.e*. foraminifera, has been used by previous researchers to determine the relative age of the Tonasa Formation in the Barru area. However, a high-resolution analysis of the nannofossil is required to assign the age of rocks. Calcareous nannofossils are abundant in marine sediments well preserved in fine sediments. The Tonasa Formation in this studied area consists of interbedded marl and limestone. The investigation of calcareous nannofossil is the first work to be undertaken in this area. Therefore, in this study, calcareous nannofossil species, their distribution, as well as determining their data or zonal boundary were investigated. Finally, this study is significant to provide the distribution of calcareous nannofossil assemblages and detailed biostratigraphic data in the Tonasa Formation sequence, particularly in the studied area.

Geological Setting

Sulawesi is an island with typical shape and complex geological conditions in the world. There are three major plates that move toward Indonesia, *i.e.* Eurasian Plate which moves to the southeast, the Pacific Plate to the west, and the Indian-Australian Plate to the north. Three main tectonic events have occurred in Indonesia, *i.e.* the first one occurred between the Late Cretaceous and Middle Eocene, the second one within the Middle Miocene, and the third one occurred in the Late Pliocene (Leeuwen, 1981). These tectonic events have greatly affected the shape of Sulawesi Island and its geological setting. The Tonasa carbonate platform developed to the west of volcanic arc and is overlain by Camba Formation during the Middle to Upper Miocene (Sukamto, 1982; Wilson, 2000). Further explanation mentioned that it was influenced by many factors, such as volcanism and tectonics, either local or regional scale in SE Asia (Wilson, 2000; Wilson *et al*., 2000).

The tectonic process in the western part of the studied area lasted until the Early Miocene, while in the eastern part, volcanic activity had started again during the Early Miocene (Sukamto, 1982; Sukamto and Supriatna, 1982). The subsidence was the dominant control forming the accommodation space of the Tonasa Carbonate Platform (Wilson and Bosence, 1997). In the Barru area, redeposited carbonates of Tonasa limestone are the evidence of tectonic activity (Wilson and Bosence, 1996). The Tonasa Formation has been widely studied by researchers from various scientific disciplines due to its extensive and interesting karst topography and historical sites which are recorded in these rocks.

The geological conditions of the Sulawesi Island are controlled by the events mentioned above, including their stratigraphic sequences (Figure 2). The oldest rocks from the Mesozoic to the present day can be found in South Sulawesi. They are Mesozoic basements which are overlain angular unconformably by the Cretaceous Balangbaru Formation as a deep marine deposit, and siliciclastic Mallawa Formation deposited unconformably above during Eocene. The transgressive sequence is then upwards to become a shallow marine carbonate platform of the Eocene to Middle Miocene Tonasa Formation, and it has approximately 3,000 m thick (Sukamto, 1982; Sukamto and Supriatna, 1982).

The Camba Formation consists of volcanic and volcaniclastic rocks (deep marine deposits) overlain by the Middle Miocene - Upper Miocene rock (Leeuwen, 1981; Sukamto, 1982; Wilson and Bosence, 2000; Leeuwen *et al*., 2010).

Tonasa carbonate platform initially formed as a transgressive sequence in a probable backarc setting developed from Pangkajene to Jeneponto areas of South Sulawesi (Wilson and Bosence, 1997). Especially in the south of the Barru area from Lower/Middle Eocene to Middle Miocene, the carbonate was deposited on a relatively stable shallow-water platform (Sukamto, 1982; Wilson and Bosence, 1996; Wilson, 2000). Besides, in the western part of South Sulawesi, very thick and extensive carbonate rocks were deposited from the Late Eocene to the Early Miocene.

Methods and Materials

The smear-slide method was used for the preparation. After it was ready, all of the smear slides were identified for its number of species and the age of calcareous nannofossil content using a polarizing light microscope with an immersion oil objective at 1,000 x magnification. Detailed identification was performed for all the taxa which encountered in each slide to find out the biozonation. One of the indicators observed is preservation of nannofossils which includes good, moderate, and poor. Moderate to poor preservation is caused by dissolution or overgrowth. Therefore, it is very difficult to determine nannofossil species (Sandoval

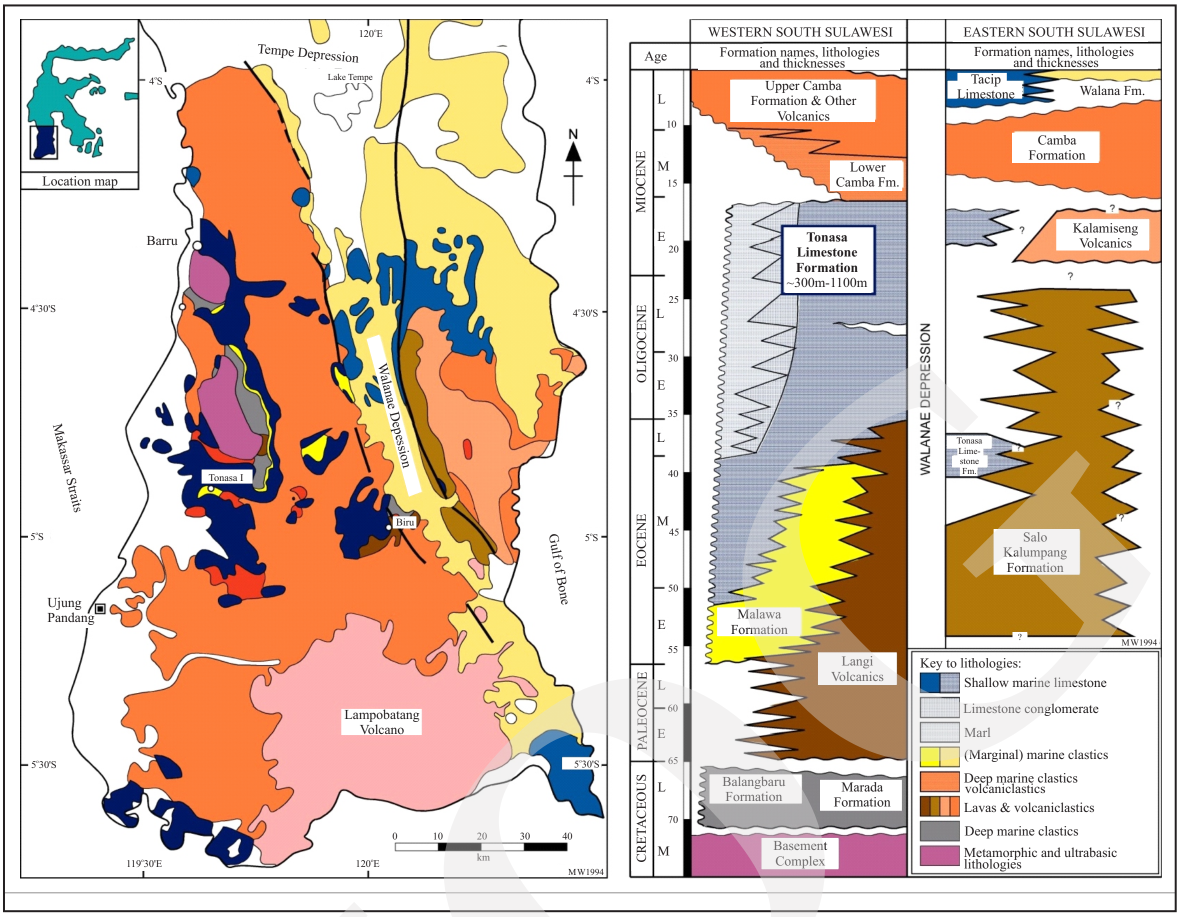


Figure 2. Simplified geological map and stratigraphic sequences of the South Sulawesi area, showing the distribution of lithological formations and comparison between western and eastern of South Sulawesi. The Tonasa Limestone Formation, known as Tonasa Formation by Sukamto, 1982), is widespread from the north to the south (Barru to Jeneponto areas) overlain by Camba Formation (volcanic and volcaniclastic rocks), and lies on the western part of Walanae depression (modified by Wilson and Bosence, 1996).

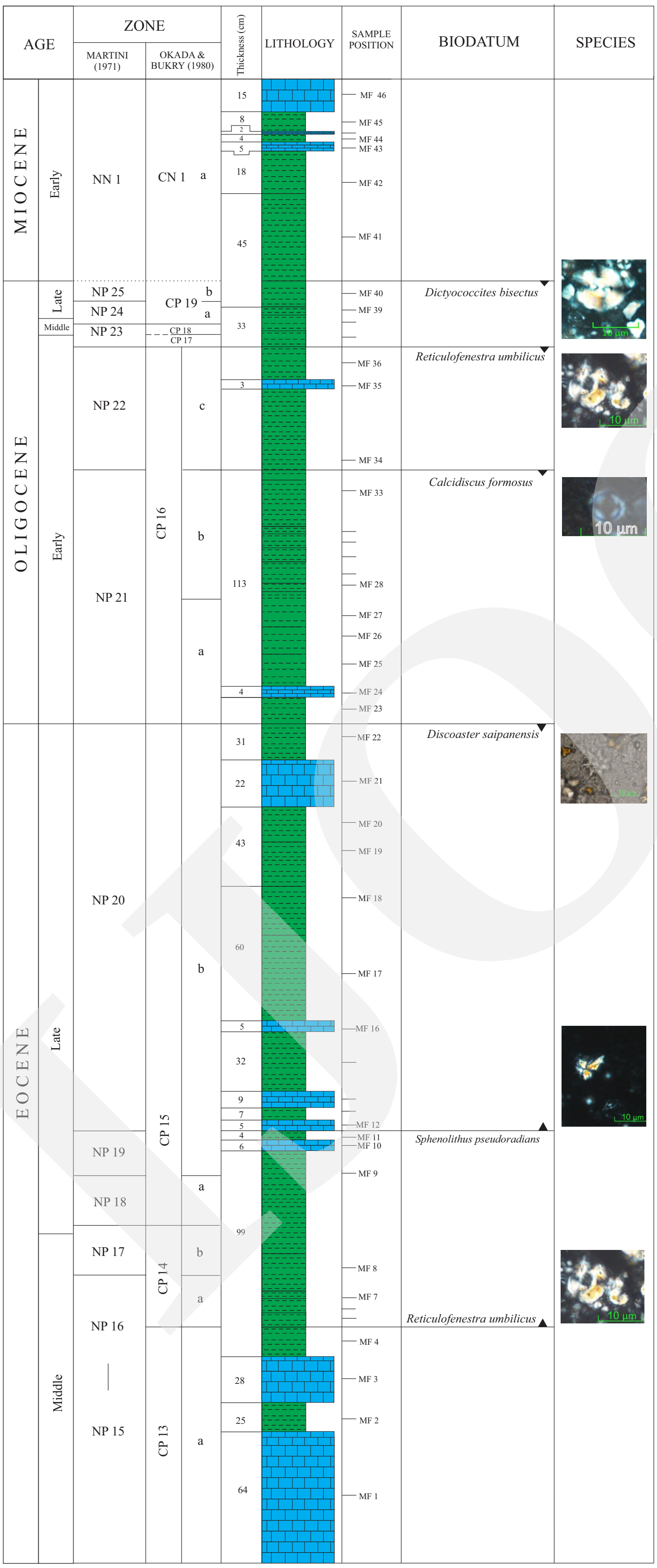
et al., 2012; Zahran, 2013). The Discoaster which is likely to have an overgrowth made it difficult to distinguish one species from another. The age determination was made according to the presence of marker species of nannofossils, whether the First Occurrence (FO) or the Last Occurrence of marker species, with reference to Martini's zonal marker (1971) as well as Okada and Bukry's (1980). Therefore, biostratigraphy and relative age analysis of the rock in the studied area could be arranged in stratigraphic sequences of Tonasa Formation.

The material used in this study was collected from the outcrop at the Barru River traverse, consisting of an intercalating marl and limestone using a measuring section method. The observed traverse has 12 m long and the total of 690 m thick with thirty collected samples.

Result And Analysis

Calcareous Nannofossil Distribution

As many as thirty-one calcareous nannofossil species (Figure 3) were identified and determined from the Barru River traverse. The preservation of calcareous nannofossils in this studied area is moderate to poor condition. Some species showed moderate preservation if there was no calcite overgrowth or dissolution. Therefore, one species could be identified and distinguished from another quickly. Otherwise, some calcareous nannofossils were difficult to determine. Their preservation depends on the diagenetic process which has developed in limestone and marl. However, diagenesis is more common in limestone.



Calcareous nannofossil species:

Braarudosphaera bigelowii (*Gran and Braarud*) Deflandre

Calcidiscus formosus (Kamptner) Loeblich and Tappan

Coccolithus eopelagicus (Bramlette and Riedel)

Coccolithus pelagicus (Wallich) J.Schiller

Coccolithus sp.

Cribrocentrum reticulatum (Gartner and Smith) Perch-Nielsen

Cyclicargolithus floridanus (Roth and Hay) Bukry

Discoaster barbadiensis Tan Sin Hok

Discoaster deflandrei Bramlette and Riedel

Discoaster gemmifer Stradner

Discoaster tanii Bramlette and Riedel

Discoaster tanii nodifer (Bramlette and Riedel)

Discoaster saipanensis Bramlette and Riedel

Discoaster sp.

Reticulofenestra bisectus (Hay, Mohler, and Wade) Bukry and Percival

Reticulofenestra spp.

Reticulofenestra umbilicus (Levin) Martini and Ritzkowski

Sphenolithus conicus Bukry

Sphenolithus moriformis

Figure 3. Biostratigraphic column of Barru River traverse.

Twenty-three calcareous nannofossil taxa were determined throughout the section (Figure 4), *i.e.* *Braarudosphaera bigelowii*, *Calcidiscus formosus*, *Cyclicargolithus floridanus*, *Coccolithus eopelagicus*, *Coccolithus pelagicus*, *Coccolithus* sp., *Cribrocentrum reticulatum, Reticulofenestra* spp., *Discoaster barbadiensis*, *Discoaster deflandrei*, *Discoaster tanii, Discoaster*

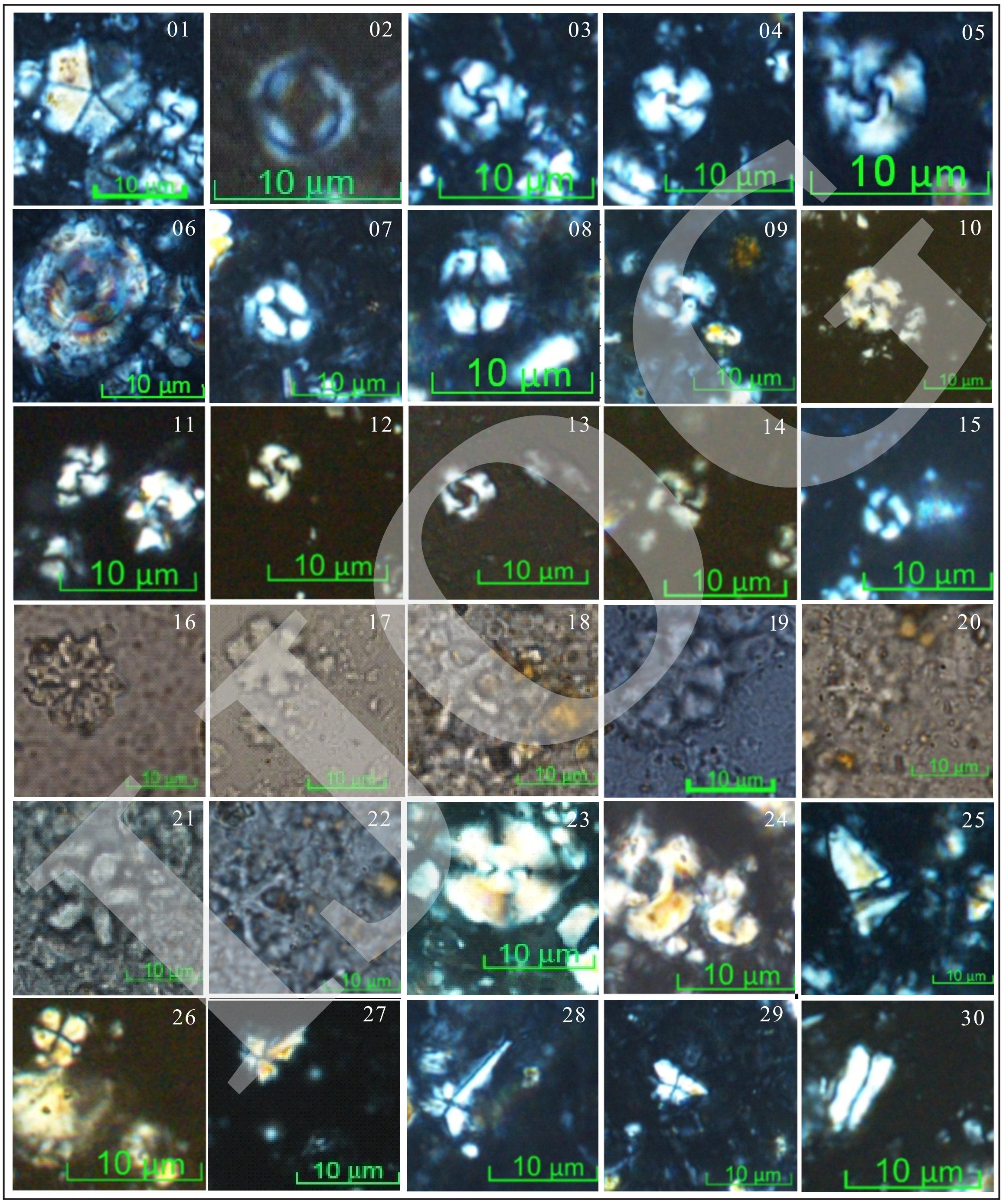


Figure 4. Photomicrographs of: (1). *Braarudosphaera bigelowi;* (2). *Calcidiscus formosus;* (3,4,5). *Cyclicargolithus floridanus;* (6). *Coccolithus eopelagicus*; (7). *Coccolithus pelagicus*; (8). *Coccolithus* sp.; (9, 10). *Cribrocentrum reticulatum;* (11, 12, 13, 14, 15). *Reticulofenestra* spp.; (16). *Discoaster barbadiensis*; (17). *Discoaster deflandrei*; (18). *Discoaster tanii;* (19). *Discoaster gemmifer*; (20). *Discoaster saipanensis*; (21). *Discoaster* sp. ; (22). *Discoaster tanii nodifer*; (23). *Reticulofenestra bisectus*; (24). *Reticulofenestra umbilicus;* (25). *Sphenolithus predictentus;* (26). *Sphenolithus moriformis* (27). *Sphenolithus pseudoradians;* (28). *Sphenolithus radians;* (29). *Sphenolithus conicus;* (30). *Zygrhabilathus bijugatus.*

gemmifer, *Discoaster saipanensis*, *Discoaster* sp., *Discoaster tanii nodifer*, *Reticulofenestra bisectus*, *Reticulofenestra umbilicus*, *Sphenolithus predistentus, Sphenolithus moriformis, Sphenolithus pseudoradians, Sphenolithus radians, Sphenolithus editus,* and *Zygrhabilathus bijugatus.*

The abundance of nannofossils from the bottom to the top of the section are described as follows:

1. *Calcareous nannofossils* is abundant in layers 1 and 4 (sample number: MF 1 and MF 4), *i.e. Coccolithus eopelagicus*, *Cribrocentrum reticulatum, Reticulofenestra spp.,* and *Reticulofenestra umbilicus*.
2. Layer 7 shows the decrease in the number of nannofossils.
3. Layer 8 (MF 8) and layer 9 (MF 9) show the number of specimen and species increase, such as *Cribrocentrum reticulatum*, *Reticulofenestra spp., Sphenolithus moriformis*, *Coccolithus eopelagicus,* and *Zygrhabilathus bijugatus.*
4. The next layer shows the decrease in the number of specimens, such as *Cribrocentrum reticulatum,* while the dominant species found in this layer are *Coccolithus eopelagicus*, *Reticulofenestra spp.* 3-4µm, *Reticulofenestra spp.* 4-5µm, and *Sphenolithus moriformis*.
5. *Coccolithus eopelagicus* is dominant in layers 11 and 17, followed by *Dictyococcites, Cyclicargolithus,* and *Sphenolithus,* as well as other common and rare species.
6. In the next layer, the number of species and specimens decrease dramatically.

However, in the nineteenth layer, the abundant dominant species are *Cribrocentrum reticulatum*, *Coccolithus eopelagicus*, *Reticulofenestra spp.* 3 - 4µm, and *Reticulofenestra spp.* 4-5µm. Furthermore, two species are recognized in seven specimens, *i.e*. *Cribrocentrum reticulatum* and *Sphenolithus predistentus*. The number of species and specimens increase sharply at layers 21 - 23. Moreover, it decreases again in layers 24 to 27. At layer 28 (MF 28), the number of species and specimens increase sharply and abundantly, but it drastically decrease at layer 34, and the number increase again at layers 35 - 46 even though the number significantly decrease at layers 39 and 43. The Discoaster have begun to appear from the first layer, but they were not found in the whole layers. Several marker species were also identified in this section, one of which is quite abundance, *Cribrocentrum reticulatum*, but in this paper the marker species proposed by Martini (1971) and Okada and Bukry (1980) are used.

Biostratigraphy

Based on the biostratigraphic analysis, the age determination was assigned on the First Occurrence (FO) or Last Occurrence (LO). The zonal boundary in this section was distinguished by referencing to the zones found by Martini (1971) and Okada and Bukry (1980). The results of the observation of calcareous nannofossil content which had been carried out on thirty samples from a total of forty-six layers showed six data, namely the First Occurrence (FO) and Last Occurrence (LO) of *Reticulofenestra umbilicus,* FO *Sphenolithus pseudoradians*, LO of *Discoaster saipanensis*, LO of *Calcidiscus formosus*, and LO of *Reticulofenestra bisectus.* The biostratigraphy of the studied area is described as follows:

The first zonal boundary CP13/CP14 (Okada and Bukry, 1980) was determined by the First Occurrence (FO) of *Reticulofenestra umbilicus* at layer 2 (MF 2). The presence of datum marker of *Reticulofenestra umbilicus* was found along with *Coccolithus eopelagicus, Sphenolithus radians, Calcidiscus formosus, Dictyococcites scrippsae, Cribrocentrum reticulatum, Reticulofenestra bisectus, Reticulofenestra* spp., and *Cribrocentrum reticulum*. The abundant species in this layer are *Coccolithus eopelagicus, Cribrocentrum reticulatum*, and *Reticulofenestra umbilicus*. Several marker species were not found. The Zonal boundary of CP13/CP14 is correlated to NP 16 by Martini (1971). Therefore, the zone boundaries from NP 16/17 to NP 18/19 were not determined.

The next zonal is NP19/NP20 zone boundary according to Martini (1971), which was signed by the First Occurrence (FO) of *Sphenolithus* *pseudoradians* in layer 11 (MF 11) or correlated with the CP15b (Okada and Bukry, 1980). The nannofossil assemblages in this layer to layer 15 are *Discoaster* sp. *Coccolithus pelagicus*, *Sphenolithus radians*, *discoaster gemmifer*, *Coccolithus eopelagicus*, *Cribrocentrum reticulatum*, *Sphenolithus pseudoradians*, *Reticulofenestra* spp., *Sphenolithus moriformis*, and *Discoaster deflandrei*. The abundant species in this layer consists of *Coccolithus eopelagicus*, *Reticulofenestra* spp, *Reticulofenestra umbilicus*, and *Sphenolithus pseudoradians*. *Sphenolithus radians* were also found as reworked fossil from the Early Eocene.

The third zonal boundary NP20/21 (Martini, 1971) and CP15/16 at layer 22 (MF 22) were marked by the Last Occurrence of *Discoaster saipanensis*. The number of specimens is relatively abundant; however, there are the diversity in few species. The species assemblages in this layer consist of *Coccolithus eopelagicus, Coccolithus sp., Reticulofenestra* spp.*, Sphenolithus moriformis,* and *Sphenolithus predistentus.*

The zonal boundary of NP21/NP22 (Martini, 1971) is marked by the Last Occurrence of *Calcidiscus formosus*, which was terminated in layer 34. This specimen was also called *Ericsonia formosa* (Perch-Nielsen, 1985). The number of species decreased and disappeared until layer 35 including Discoaster and Cyclicargolithus. Furthermore, having marked by the Last Occurrence of *Reticulofenestra umbilicus* as a feature of the zonal boundary between NP 22/23 (Martini, 1971) and CP16 / CP17 (Okada and Bukry, 1980), this marker species was terminated, last appearing in layer 36 (MF 36). The zonal boundary NP 21/22 was not determined. The species that present in this layer are *Cyclicargolithus* sp.*, Discoaster sp, Coccolithus pelagicus, Coccolithus eopelagicus, Reticulofenestra umbilicus, Reticulofenestra bisectus, Reticulofenestra* spp.*, Zygrhablithus bijugatus, Sphenolithus moriformis, Sphenolithus predictentus, Discoaster deflandrei, Discoaster tanii nodifer,* and *Braarudosphaera bigelowii.*

The last zonal boundary is NP25/NN1 (Martini, 1971), which was marked by the First Occurrence (FO) of *Reticulofenestra bisectus.* The marker species is found in layer 40 (MF 40) along with species assemblages of *Discoaster sp., Coccolithus pelagicus, Coccolithus pelagicus, Reticulofenestra* spp.*, Zygrhablithus bijugatus, Sphenolithus moriformis, Sphenolithus predictentus, Discoaster deflandrei,* and *Braarudosphaera bigelowii.* There are also the number of diversity in the increase species as well as the abundance of specimens.

Discussion

The record of Southeast Asian carbonates in equatorial marine systems, both regionally and globally during the Cenozoic has poorly been known (Wilson, 2008), thus many researches on carbonate rocks will enrich the data. The Tonasa Limestone Formation is one of the carbonate-dominated foraminifera in Southeast Asia, and its number became greater from Eocene to Oligocene (Wilson, 2000; Wilson, 2008). However, foraminifera diversity has decreased (Soták, 2010; BouDagher-Fadel, 2015) as well as calcareous nannoplankton (Bown and Young, 1999). These facts indicate that foraminifera diversity has a positive correlation with the decreased diversity of calcareous nannofossils in Barru area during that age. One of the causes of the decline in the number of marine organisms is the climate change as what has been explained in Zachos *et al.* (2001).

The abundance of calcareous nannofossils in the studied area is moderate until abundant, and moderate to poor preserved. Some of them had gone through the diagenesis process. Consequently, they were difficult to identify. The result of nannofossil biostratigraphic analysis shows a relative age of Tonasa Formation in Barru River traverse, indicating Eocene – Oligocene. Typical Eocene through Oligocene species are present in this traverse, such as *Reticulofenestra umbilicus, Cribrocentrum reticulatum, Sphenolithus pseudoradians, Reticulofenestra bisectus, Zygrhablithus bijugatus, Discoaster barbadiensis,* and *Discoaster saipanensis.* Some of marker species could not be adequately identified due to the dissolving process, diagenesis, or the fossils that were not well preserved.

The age boundary of Eocene/Oligocene and Oligocene/Miocene are determined in this section. The calcareous nannofossil assemblages were abundant during Eocene, while the diversity was declined in Oligocene. These events may be related to the Paleocene – Eocene Thermal Maximum (PETM), and caused a greenhouse effect and warmer temperature (Stoll *et al*., 2007). When the thermal was maximum, it caused marine organisms to reach high productivity, then it was cooling in the Oligocene that some species became extinct or evolved. In the Equatorial Pacific, *Coccolithus* decreased through the PETM, besides *Zygrhabilathus* increased during PETM (Stoll *et al.*, 2007). The species *Zygrhablithus bijugatus* is almost abundant in all layers. It shows that the sea water temperature was maximum. Therefore, this area had been influenced by the global climate events.

The results of the investigation will give other new insight into geological evolution of the studied area. Many key-nannofossil species are identified in this section, and the detailed age was clarified from Middle Eocene to Early Miocene of the Tonasa Formation which is a widely distributed carbonate formation in South Sulawesi.

Conclusion

A total of thirty-one species had been identified in the Barru River traverse. The species diversity was higher in the Eocene. Otherwise, it decreased in the Oligocene. The age determination was assigned on the First Occurrence (FO) or Late Occurrence (LO) marker species. There were six nannofossil data found in this studied area, i.e. the FO and LO of *Reticulofenestra umbilicus,* FO *Sphenolithus pseudoradians*, LO of *Discoaster saipanenesis*, LO of *Calcidiscus formosus*, and LO of *Reticulofenestra bisectus.* Based on the appearance of the datum marker, the age of the Tonasa Formation in this area is NP 15 – NN 1 or CP 13 – CN 1a, and it was correlated to Middle Eocene – Early Miocene. This result will give contribution for local and regional stratigraphy setting in Sulawesi.

Acknowledgments

The authors express their gratitude to the Directorate General of Higher Education, Ministry of National Education, Indonesia, for *Penelitian Dasar Perguruan Tinggi* (PDUPT) decentralization grant of Hasanuddin University in 2020, under the Research and Community Service Institute (LP2M). Special appreciation is also delivered to Akita University Japan for providing the binocular polarizing microscope. The authors also thank the Barru Regency Government for giving a permit to conduct this study, and the Paleontology Laboratory of Hasanuddin University. Thanks to Ikhwana and Afrisal for their assistance during the accomplishment of this research. Last but not least, their gratitude to reviewers who have provided corrections to improve this paper.

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