Journal of Tropical Biodiversity and Biotechnology
Volume 09, Issue 01 (2024): jtbb85308
DOI: 10.22146/jtbb.85308

Research Article

Nannoplankton Biostratigraphy from Banggai-Sula Basin, Central Sulawesi

Efrilia Mahdilah Nurhidayah[1], Akmaluddin[1]*, Didit Hadi Barianto[1], Salahuddin Husein[1], Asep Saripudin[2]

1)Geological Engineering Department, Faculty of Engineering, Universitas Gadjah Mada, Jl. Grafika No. 2, Yogyakarta, 55281, Indonesia.
2)JOB Pertamina-Medco E&P Tomori Sulawesi, Jl. Jend. Gatot Subroto Kav 71-73. Jakarta, 12870, Indonesia.
* Corresponding author, email: akmaluddin@ugm.ac.id

Keywords:
Biostratigraphy
Banggai-Sula Basin
Miocene
Nannoplankton
Unconformity
Submitted:
06 June 2023
Accepted:
06 October 2023
Published:
11 March 2024
Editor:
Ardaning Nuriliani

ABSTRACT
The nannoplankton research was conducted in the MH-2 well, Banggai-Sula Basin, Central Sulawesi. Thirty-four ditch-cutting samples were utilized to observe the Minahaki, Kintom, and Biak Formations. Age determination was carried out using biostratigraphy method and standard procedure for first and last occurrence of nannoplankton biodatum and had an absolute age, widely known as a zone indicator. This study aims to determine the age and nannoplankton biozonation of each geological formation in Banggai-Sula Basin. Based on the biostratigraphic analysis, 39 species from 14 genera with abundance frequencies ranging from rare to abundant were found in the MH-2 well. In this study, new results of the age of Banggai-Sula Basin areMiddle Miocene – Early Middle Pliocene (13,706 – 3,727 Ma), and can identify into six calcareous nannoplankton zones that are more detailed than previous researchers, *Discoaster signus* zone (NN5), *Discoaster exilis* zone (NN6-NN7), *Discoaster berggrenii* zone (NN11), *Ceratolithus acustus* zone (NN12), *Helicosphaera sellii* zone (NN13-NN15), and the *Discoaster tamalis* zone (NN16). Biostratigraphic data also shows new information for the first time, the absence of three zones from zone NN8 to zone NN10. This result indicates an unconformity in the Late Miocene age (10.606–8.20 Ma).

INTRODUCTION
Calcareous nannoplankton are one of the major components of oceanic phytoplankton and are unicellular and autotrophic organisms. Nannoplankton is a group of microfossils with a size of 0.25 to 30 μm, including coccoliths, discoasters, and nannoconids that live in marine. Nannoplankton comes from Coccolithophore (Figure 1), which is generally round or oval in shape and this group is an important constituent of oceanic phytoplankton, providing a major food source for herbivorous plankton. Nannoplankton live by alternating motile and non-motile planktonic or benthic stages (Flores & Sierro 2013). The motile stage has a flexible skeleton with the coccolith embedded in a flexible cell membrane, but in the non-motile phase, the membrane calcifies and forms a rigid shell. Cenozoic calcareous nannoplanktons consistently have higher and more varied species, extinction, and evolution rates than the Mesozoic (Armstrong & Brasier 2005).

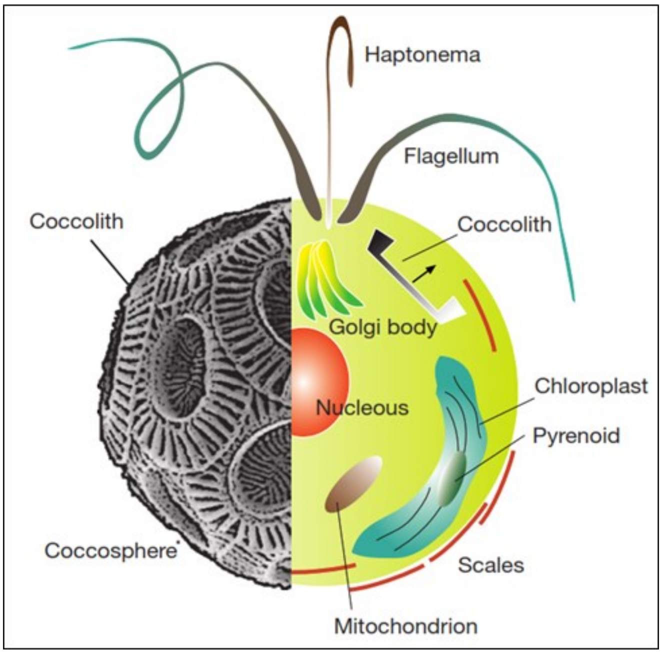

Figure 1. Schematic of a coccolithophore cell showing the coccolith non-motile (left) and motile (right) phases (Flores & Sierro 2013).

Thus, assemblages of nannoplankton fossils in rock strata will be useful for biostratigraphy. Biostratigraphy is defined as the branch of stratigraphy or stratigraphy by paleontological methods (McGowran 2005). Nannoplankton is also known as a high-resolution tool for determining biostratigraphic age because it is an abundant organism with a short age range and a wide geographical distribution throughout the world (Kapid 2003). Biostratigraphy is one of the stages of hydrocarbon exploration. Biostratigraphy plays a role as the main method because it provides a cost-effective, fast, and simple way to determine the age of sedimentary rock layers (strata) that are the constituents of a geological formation based on their fossil content (Simmons 2019; Ulfah et al. 2023). Furthermore, the results of the biostratigraphy will be used for stratigraphic correlation or rock layer correlation. This correlation is the process of determining the equivalence of age or stratigraphic position of layered rocks in different areas (Lucas et al. 2020).

The stratigraphy of the Banggai-Sula Basin results from two different depositional periods. First, the Salodik Group consists of the Tomori, Matindok, and Minahaki formations (as a division of formations for the subsurface), a series of continental margin rifts/drifts composed of limestone and clastic sedimentary rocks deposited before the collision. Second, it reflects the sequence deposited following the post-collision, consisting of flysch facies (Kintom Formation) and molasses sediments (Biak Formation) (Figure 2). Moreover, the Tomori, Matindok, and Minahaki Formations have been shown to generate hydrocarbons in the Banggai-Sula Basin. The Bangai-Sula Basin is one of the basins in Indonesia that has the "Giant" gas field on the island of Sulawesi in eastern Indonesia and has become a basin with the status of a production well (Hasanusi et al. 2004).

Kurniasih et al. (2021) used planktonic foraminifera to conduct a biostratigraphic study in the Banggai-Sula Basin. They identified the Minahaki Formations as Middle Miocene, while the Kintom Formation is Late Miocene to Holocene. However, the age of this formation differs from studies also conducted in Banggai-Sula Basin by Nugraha et al. (2022), who propose that the Minahaki Formation is Middle-Late Miocene, Kintom Formation is Early Pliocene, and Biak Formation (Mollase sediments) is Pleistocene.

Therefore, it is interesting to study its biostratigraphy using nannoplanktons in more detail because of the difference in age between the Kintom and the Minahaki Formations from two previous studies, Kurniasih et al. (2021) and Nugraha et al. (2022). The research location is in the "SN" Field, a productive hydrocarbon-producing field that records the complete formations in the Banggai-Sula Basin (Figure 3). Stratigraphically, the MH-2 well was chosen because it is composed of the Minahaki, Kintom, and Biak Formations, which have not been reported previously for biostratigraphic results. Thus, based on these reasons, it is interesting to carry out biostratigraphic analysis and determine the age using nannoplankton for each formation in more detail.

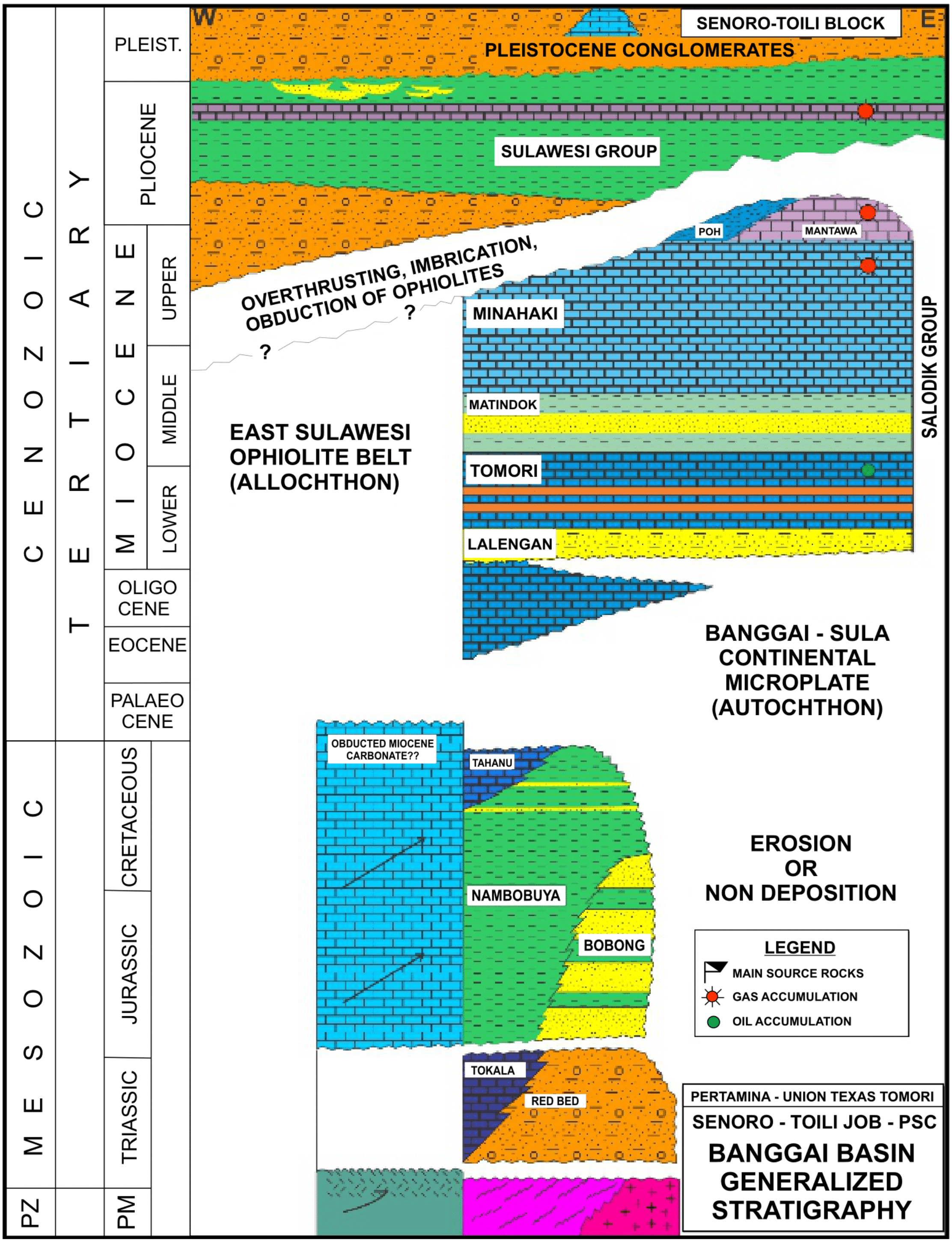

Figure 2. Regional Stratigraphy of the Banggai-Sula Basin (Pertamina-BPKA, 1996) in Hasanusi et al. (2004).

Figure 3. Locations of research well (red font), Central Sulawesi, Indonesia (image from Google Earth taken on July 20, 2023)

MATERIALS AND METHODS

Biostratigraphic analysis using nannoplankton was conducted using ditch -cutting samples from the MH-2 exploration well, which has a depth of 10 to 9100 feet (ft). Thirty-four cutting samples were used in this research, with sample intervals ranging from 30 to 230 ft (Figure 4).

Ditch-cutting sample preparation for nannoplankton was carried out using the gravity settling method according to the preparation rules based on Bown & Young (1998). A 1000x magnification Olympus polarizing microscope with XPL and PPL views was used to observe nannoplankton. Then, nannoplankton image capture was supported by the Olympus camera software. Data collection used a quantitative method by counting all specimens from 200 microslide sample fields of view (size 22mm x 22mm).

According to Bown & Young (1998), the semi-quantitative and qualitative species abundance notation is abundant (A) means >10 specimens/field of view, common (C) means 1–10 specimens/field of view, few (F) means 1 specimen/1–10 field of view, and rare (R) means 1 specimen/ >10 field of view. It was determined that specimen preservation was G (good) for nannoplankton showing no or minor dissolution and overgrowth, M (moderate) for specimens showing some dissolution and overgrowth, and P (poor) for specimens showing significant dissolution and overgrowth, morphology was damaged, and many specimens were difficult to identify.

Identification of nannoplankton specimens based on morphological features using the Nannotax3 website (Young et al. 2023). The name of the biostratigraphic zone is given based on the biodatum or index fossils specimens found in the zone. The zone was determined using Martini (1971), Okada & Bukry (1980), and Backman et al. (2012) standard method based on the first (FO) and last (LO) occurrences of zone marker species. We used the absolute age of each identified marker species based on Backman et al. (2012), Bergen et al. (2017), Boesiger et al. (2017), and Bergen et al. (2019) (Table 1).

Table 1. Resume of the absolute age biodatum in the MH-2 well of Banggai-Sula Basin.

Biodatum	Bioevent	Martini (1971)	Absolute Age (Ma)	Source	Depth (feet)
Discoaster brouweri	FO	Base NN8	10.606	Backman et al. (2012)	8150
Discoaster berggrenii	FO	Base NN11	8.2	Backman et al. (2012)	8150
Amaurolithus primus	FO	Top NN11	7.374	Bergen et al. (2019)	6810
Discoaster quinqueramus	LO	Top NN11	5.53	Backman et al. (2012)	6540
Helicosphaera sellii	FO	Base NN13	4.978	Boesiger et al. (2017)	5220
Reticulofenestra pseudoumbilicus	LO	Top NN15	3.727	Bergen et al. (2019)	1620

RESULTS AND DISCUSSION

The results of nannoplankton observations for 34 samples showed moderate to good preservation, with frequencies ranging from rare to abundant. A total of 39 nannoplankton species from 14 genera were identified, resulting in seven nannoplankton biodatum species, *Sphenolithus abies*, *Discoaster brouweri*, *Discoaster berggrenii*, *Amaurolithus primus*, *Discoaster quinqueramus*, *Helicosphaera sellii*, and *Reticulofenestra pseudoumbilicus*. The six nannoplankton zonations have been successfully divided based on the six biodatum species including *Discoaster signus* zone (NN5), *Discoaster exilis* zone (NN6-NN7), *Discoaster berggrenii* zone (NN11), *Ceratolithus acustus* zone (NN12), *Helicosphaera sellii* zone (NN13- NN15), and the *Discoaster tamalis* Zone (NN16) (Table 2.). Based on the division of zones, it is known that there are three zones (zones NN8-NN10) absent in this study. The results of biostratigraphic analysis of each formation in the MH-2 well show that the Minahaki Formation is Middle Miocene - Late Miocene (NN5 – NN7 zone), the Kintom Formation is Late Miocene – Early Pliocene (Zone NN11 – NN15), and the Biak Formation is Early Pliocene - Middle Pliocene (Zone NN16) (Figure 4). The sections below briefly describe the six discovered nannoplankton zonations.

Discoaster signus/NN5 zone

The *Discoaster signus* zone is a partial range zone that is divided at the top by the first occurrence (FO) biodatum of *Sphenolithus abies* with an absolute age of 13.706 Ma (sample 8690), while the biodatum at the bottom is not found. *Discoaster signus* zone are equivalent to the *Sphenolithus heteromorphus*/NN5 zone (Martini 1971), and similar with CN4 zone (Okada & Bukry 1980), and the CNM7 zone (Backman et al. 2012). This zone is Middle Miocene age and is observed at a depth of 8690 ft to 9100 ft with a thickness of 410 ft. Another species that has the same age in this interval is *Sphenolithus neoabies*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age, and *Cyclagelosphaera wiedmannii* and *Cyclagelosphaera lacuna*, which are Jurassic in age.

Discoaster exilis/ NN6 – NN7 zone

The *Discoaster exilis* zone is a concurrent range zone that is divided by the first occurrence (FO) FO *Sphenolithus abies* (13.706 Ma) at the bottom (sample 8150) and the first occurrence (FO) FO *Discoaster brouweri* (10.606 Ma) and at the top (sample 8690). *Discoaster exilis* zone is equiva-

Table 2. The distribution chart of nannoplankton in the MH-2 well shows the abundance of species from 34 samples and 7 biodatum species.

NUMBER	DEPTH (FT)	FORMATION	PRESERVATION	1 *Arkhangelskiella cymbiformis*	2 *Amaurolithus primus*	3 *Calcidiscus premacintyrei*	4 *Catinaster calyculus*	5 *Coccolithus miopelagicus*	6 *Coccolithus pelagicus*	7 *Cyclagelosphaera brezae*	8 *Cyclagelosphaera jiangii*	9 *Cyclagelosphaera wiedmannii*	10 *Cyclagelosphaera lacuna*	11 *Cyclicargolithus abisectus*	12 *Cyclicargolithus floridanus*	13 *Discoaster berggrenii*	14 *Discoaster brouweri*	15 *Discoaster druggii*	16 *Discoaster deflandrei*	17 *Discoaster exilis*	18 *Discoaster loeblichii*	19 *Discoaster patulus*	20 *Discoaster quinqueramus*	21 *Discoaster surculus*	22 *Discoaster variabilis*	23 *Helicospahera carteri*	24 *Helicosphaera princei*	25 *Helicosphaera sellii*	26 *Pseudoemiliania lacunosa*	27 *Pontosphaera discopora*	28 *Pontosphaera multipora*	29 *Reticulofenestra bisecta*	30 *Reticulofenestra haqii*	31 *Reticulofenestra minuta*	32 *Reticulofenestra pseudoumbilicus*	33 *Reticulofenestra umbilicus*	34 *Small reticulofenestra*	35 *Sphenolithus abies*	36 *Sphenolithus apoxis*	37 *Sphenolithus disbelemnos*	38 *Sphenolithus neoabies*	39 *Watznaueria barnesiae*	CALCAREOUS NANNOFOSSILS BIODATUM
1	900	Biak	M							*R					*R																												
2	1350	Biak	G							*F																F	F					*F		R									
3	1620	Biak	G														F									C		F	F	R			R	C	**F**							*R	
4	1920	Biak	G										*F				R									R		R							F		F	C				*F	LO *Reticulofenestra pseudoumbilicus* (3,727 Ma)
5	2130	Biak	G												*R											F			F					F			F						
6	2460	Biak	M						R	*F		*R																						F	F		F					*F	
7	2520	Kintom	G														R									F		F		R			F	C	F		C	C				*F	
8	2760	Kintom	G							*R		*R	*F													F							F	F	F		C	F					
9	3240	Kintom	M				*R				F				*F		F									R			R				F	C	F		F	F					
10	4080	Kintom	G								`			*R		F	F									C		C					C	C	F		C	F			F	*F	
11	4650	Kintom	G														F																				F	C				*F	
12	5220	Kintom	G				*R		R	*F			*F			R	R	R			*F					C		**R**		R	R		F	C	F		A	A	*F		C		FO *Helicosphaera sellii* (4.978 Ma)
13	5460	Kintom	G								*F			*R	*F		F									C							R	C	F		C	A			F	*C	
14	5760	Kintom	G		F							*R				R	R	R								C							F	F			C	C			F	*F	
15	6150	Kintom	G									*F	*R			F	F									C				F			F	A	F		A	A			F		
16	6360	Kintom	M								*R						R								R	F								C	F			A					
17	6450	Kintom	M					*R				*C		*R	*F											F							R	F	F		C	F					LO *Discoaster quinqueramus* (5.53 Ma)
18	6540	Kintom	G	*R	R	*R			R		*R	*F				R	R						**F**		F	C							F	C	F	*R	A	C			A	*F	
19	6810	Kintom	G		**F**			F					*C				F			R						F				F				F	F		A	A			A		
20	6990	Kintom	G				*R					*F		*R		R							R	R		R								F				C	*R		C		FO *Amaurolithus primus* (7.374 Ma)
21	7200	Kintom	G						R		*F	*F			*R	F	R						F			F				R				F	F		C	F			C	*F	
22	7410	Kintom	G							*F							R	F				R	F	R	R	F				R			F	C			C				A	*F	
23	7620	Kintom	G						R														F		R	F							F	C	F		A	F			A		
24	7740	Kintom	G								*F	*A														C				R				F	F	*F	C	F			C		FO *Discoaster berggrenii* (8,20 Ma)
25	7890	Kintom	M													F				R			F			F								F	R		F	R			F	*F	
26	8000	Kintom	M													R	R						F											F	F	*R	C	F			F		
27	8070	Kintom	G									*A	*C		*R											F							R	F	F			R			C		FO *Discoaster brouweri* (10.606 Ma)
28	8150	Minahaki	G						R			*F				**F**	**F**		*R	R						F							R	F			F	R			F	*F	unconformity
29	8280	Minahaki	M							*F			*C	*F																			F	C			C	F	*R		F		
30	8500	Minahaki	G						R						*F				*R							C							F	A				R			F	*R	
31	8690	Minahaki	G						R	*F			*A		*F											F								A				**R**	*F	*F	F	*F	FO *Sphenolithus abies* (13.706 Ma)
32	8900	Minahaki	M									*F																						F						*R			
33	9000	Minahaki	M																															F									
34	9100	Minahaki	M									*F	*C											F								F								*F	

(wavy line) unconformity

A (abundant) = >10 specimens per field of view; C (common) = 1–10 specimens per field of view; F (frequent) = 1 specimen/1-10 per field of view; R (rare) = 1 specimen/>10 per field of view

G = Good; M = Moderate; * = Rework fossil

FO = First Occurrence; LO = Last Occurrence

lent to the *Discoaster exilis* and *Discoaster kugleri*/NN6-NN7 zone (Martini 1971), and similar with CN5a - CN45b zone (Okada & Bukry 1980), and the CNM8 - CNM11 (Backman et al. 2012). This zone is the Middle-Late Miocene age (13.706 – 10.606 Ma) and is observed at a depth of 8150 ft to 8690 ft with a thickness of 540 ft.

In this interval, other species of the same age are *Discoaster exilis* and *Discoaster bolli*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age, and *Cyclagelosphaera wiedmannii* and *Cyclagelosphaera lacuna*, which are Jurassic in age.

Discoaster berggrenii/NN11 zone

The *Discoaster berggrenii* zone is a concurrent range zone that is divided by the first occurrence (FO) of *Discoaster berggrenii* (8.20 Ma) at the bottom (sample 8150) and the last occurrence (LO) of *Discoaster quinqueramus* (5.53 Ma) at the top (sample 6540). *Discoaster berggrenii* zone is equivalent to the *Discoaster quinqueramus* /NN11 zone (Martini 1971) and similar to the CN9 zone (Okada & Bukry 1980), and the CNM16 – CNM19 zones (Backman et al. 2012). This zone is the Late Miocene age (8.20 – 5.53 Ma) and is observed at a depth of 6540 ft to 8150 ft with a thickness of 1610 ft.

In this interval, other species with the same age are *Discoaster surculus*, *Discoaster variabilis*, and *Amaurolithus primus*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age, *Cyclagelo-*

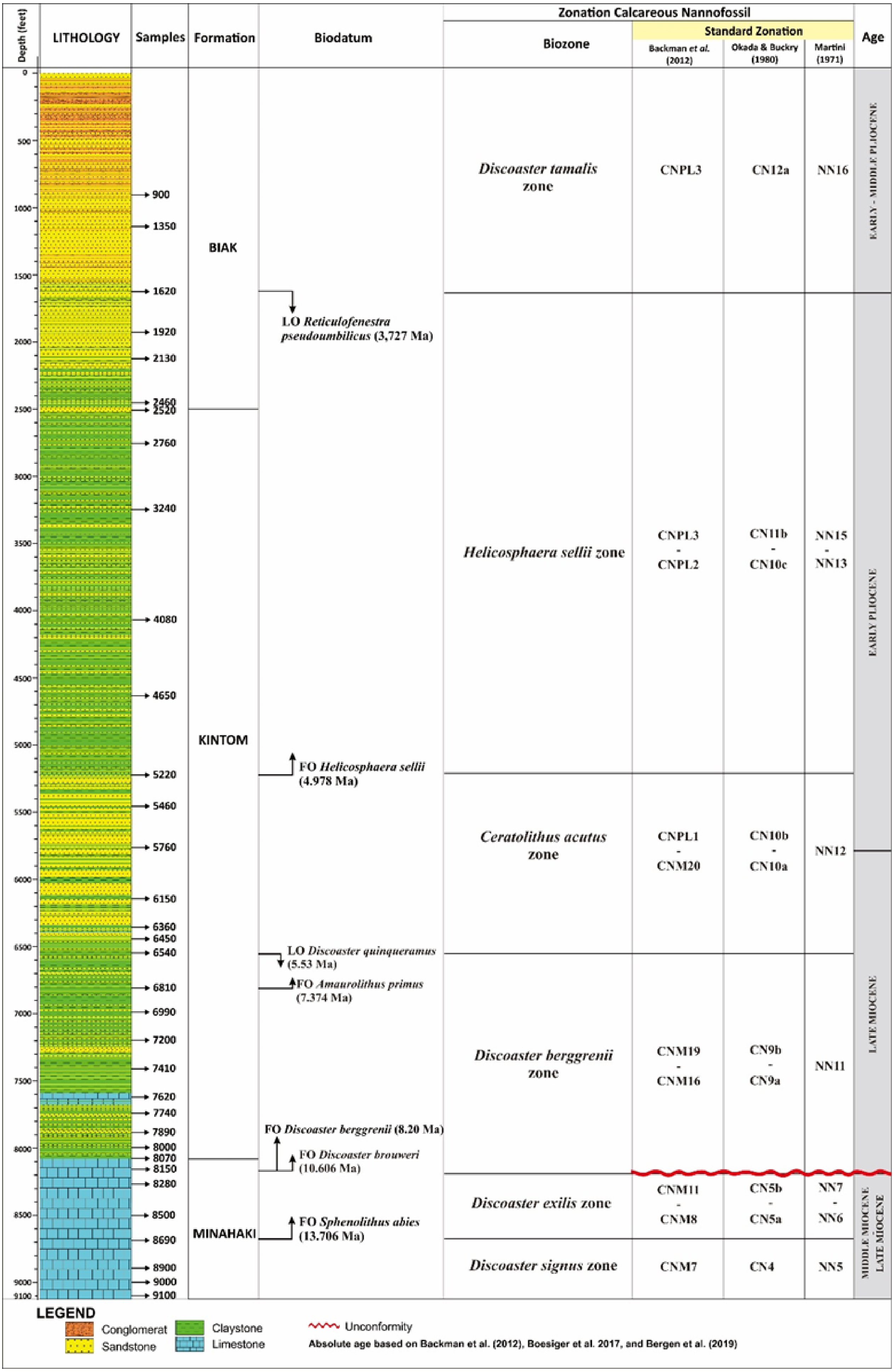

Figure 4. Calcareous nannoplankton biostratigraphic zone in the MH2 well of the Banggai-Sula Basin according to Backman et al. (2012), Okada & Bukry (1980), and Martini (1971). The biozonation calcareous nannoplankton of Minahaki, Kintom, and Biak formations can divided into 6 zones.

sphaera jiangii, which are Cretaceous age, *Cyclagelosphaera wiedmannii* and *Cyclagelosphaera lacuna* which are Jurrasic in age.

Ceratolithus acutus/NN12 zone

The *Ceratolithus acutus* zone is a concurrent range zone that is divided by the last occurrence (LO) of *Discoaster quinqueramus* (5.53 Ma) at the bottom (sample 6540) and the first occurrence (FO) of *Helicosphaera sellii* (4.978) at the top (sample 5220). *Ceratolithus acustus* zone is equivalent to the *Amaurolithus tricorniculatus*/NN12 zone (Martini 1971) and similar to the CN10a – CN10b zones (Okada & Bukry 1980), and the CNM20 – CNPL1 zones (Backman et al. 2012). The zone name from (Backman et al. 2012) was used to create the *Ceratolithus acutus* zone name. This zone is the Late Miocene – Early Pliocene age (5.53 Ma – 4.978 Ma) and is observed at a depth of 5220 ft to 6540 ft with a thickness of 1320 ft.

Another species that have the same age in this interval is *Amaurolithus primus*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age, *Cyclagelosphaera jiangii*, which are Cretaceous age, *Cyclagelosphaera wiedmannii* and *Cyclagelosphaera lacuna* which are Jurrasic in age.

Helicosphaera sellii/NN13-NN15 zone

The *Helicosphaera sellii* zone is a concurrent range zone that is divided by the first occurrence (FO) of *Helicosphaera sellii* (4.978 Ma) at the bottom (sample 5220) and the last occurrence (LO) of *Reticulofenestra pseudoumbilicus* (3.727 Ma) at the top (sample 1620). *Helicosphaera sellii* zone are equivalent to the *Ceratholithus rugosus*, *Discoaster asymmetricus*, and *Reticulofenestra pseudoumbilicus*/NN13 – NN15 zones (Martini 1971) and similar with CN10c – CN11 zones (Okada & Bukry 1980), and the CNPL2 – CNPL3 zones (Backman et al. 2012). This zone is the Early Pliocene age (4.978 – 3.727 Ma) and is observed at a depth of 1620 ft to 5220 ft with a thickness of 330 ft.

Another species that has the same age in this interval is *Helicosphaera princei*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age, *Cyclagelosphaera jiangii*, which is Cretaceous age, *Cyclagelosphaera wiedmannii* and *Cyclagelosphaera lacuna* which is Jurrasic in age.

Discoaster tamalis/NN16 zone

The *Discoaster tamalis* zone is a partial range zone that is divided by the last occurrence (LO) of *Reticulofenestra pseudoumbilicus* (3.727 Ma) at the bottom (sample 1620), and the biodatum at the top in this zone is not found. *Discoaster tamalis* zone are equivalent to the *Discoaster surculus*/NN16 zone (Martini 1971), and similar with CN12a zone (Okada & Bukry 1980), and the CNPL4 zone (3.82 – 2.76 Ma) (Backman et al. 2012). This zone is the Early Pliocene – Middle Pliocene age and is observed at a depth of 900 ft to 1620 ft with a thickness of 1020 ft.

In this interval, other species of the same age are *Pseudoemiliania lacunosa* and the absence of the genus *Sphenolithus*. Rework fossils from the Mesozoic age were also identified in this zone, *Cyclagelosphaera brezae* and *Watznaueria barnesiae*, which are Jurassic to Cretaceous in age.

The results of the biostratigraphic analysis of the MH-2 well show different results and can be compared with the age and stratigraphic data of the Banggai-Sula Basin by previous researchers Kurniasih et al. (2021) and Nugraha et al. (2022) (Figure 5). New age for Kintom Formation in this study is Late Miocene – Early Pliocene (NN11-NN15) in age, while Kurniasih et al. (2021) are late Miocene - Holocene (N14-N23) and Nugraha et al. (2022) is Pliocene (Zanclean). Based on comparisons with previous researchers, it shows that the rocks from the Kintom Formation in this study are older than Kurniasih et al. (2021) and Nugraha et al. (2022). The results of the age analysis in this study prove that the Kintom Formation was formed before collision tectonic events occurred in Banggai-Sula basin. Hence, it is different from the previous regional stratigraphic age studies by Nugraha et al. (2022) and Hasanusi et al. (2004), which mention that the Kintom Formation was deposited in the Early Pliocene as post-collision deposits.

In addition, our biostratigraphic data show an indication of unconformity, which is identified by the presence of two biodatum with different relative ages in the same sample (sample 8150), FO *Discoaster berggrenii* (8.20 Ma) and FO *Discoaster brouweri* (10.606 Ma) (Table 2 and Figure 5). Based on the mud log data, the unconformity is at the boundary between the Minahaki Formation and the Kintom Formation. There is a difference in age and time gap with the disappearance of the NN8 zone to the NN10 zone with an age interval of 10.606 to 8.20 million years, equivalent to the Late Miocene age. The hiatus is presumably caused by subaerial erosion due to the Late Miocene sea-level drop based on the eustatic curve (Miller et al. 2020) (Figure 5). The position of the MH-2 well on the upper part of the Banggai continental shelf is easily subjected to sea level change. The tectonic uplift only occurred in Pliocene, as indicated by the deposition of Biak coarse clastics (Husein et al. 2014) and (Nugraha et al. 2022).

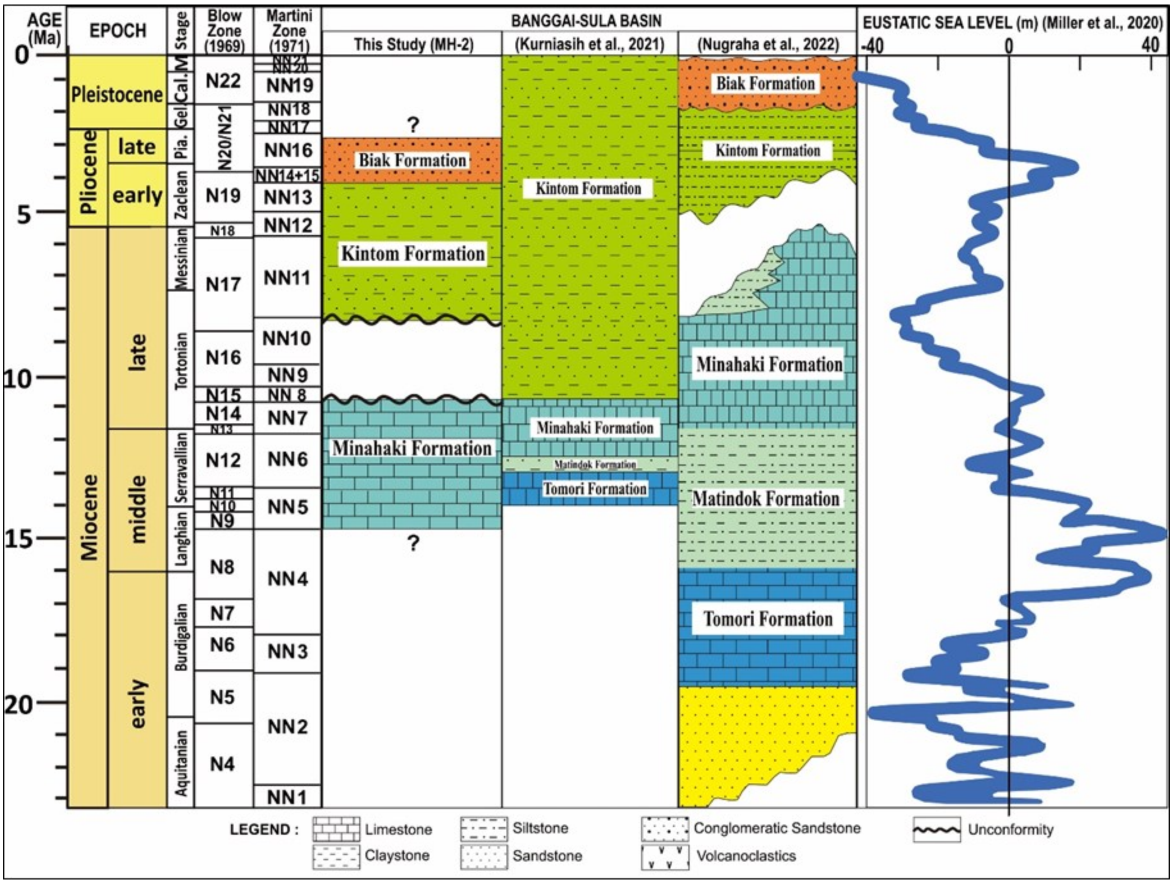

Figure 5. Comparison of the age stratigraphy of the Minahaki, Kintom, and Biak Formations from this study with the results of the ages of Kurniasih et al. (2021) using planktonic foraminifera and Nugraha et al. (2022) using planktonic foraminifera and U-Pb Zircon in the Banggai-Sula Basin. Unconformity in this study also correlates with a decrease in global sea levels (Miller et al. 2020).

Diversity and Systematic Taxonomy

Using combined data from coccolithophore biology and nannoplankton paleontology based on calcareous nannoplankton, Galović and Young (2012) and Nannotax website (https://www.mikrotax.org/Nannotax3/) (Young et al. 2023) to found more information on synonyms and species variants. Table 3 provides a summary of calcareous nannoplankton taxonomy. Selected sample species of calcareous nannoplankton in the MH-2 well can be seen in Figure 6-7.

Coccolithophores are categorized as follows by the ICBN (International Code of Botanical Nomenclature):
Protoctista Kingdom
Haptophyta Division
Prymnesiophyceae Class

Group Heterococcoliths Young and Bown 1997
Order Coccolithales Schwarz 1932 Jorand et al. 2004
Family Coccolithaceae Poche 1913 emend Young and Bown 1997
Genus Coccolithus Schwartz 1894

1. Species *Coccolithus miopelagicus* (Bukry 1971), (Figure 6, number 1)
Description: Placoliths of a large size and broad ellipse distinguished from *C. pelagicus*. Moreover, the central open is small, and the rim is relatively broad compared to the center area. This species is > 13µm, usually 15-17 µm. This species is present in samples 6450 and 6810.

2. Species *Coccolithus pelagicus* (Wallich 1877), (Figure 6, number 2)
Description: Most elliptical laccoliths have an open center and are of medium size. The average size of this species is 7 to 10 µm or about 13 µm. This species is present in samples 2460, 5220, 6540, 7200, 8150, 8500, dan 8690.

Order Coccolithales Schwarz, 1932
Family Calcidiscaceae Young and Bown 1997
Genus Calcidiscus Kamptner 1950

3. Species *Calcidiscus premacintyrei* (Theodoridis, 1984), (Figure 6, number 3)
Description: The elliptical and subcircular coccoliths are distinct, large, and have a closed center. Size ranges from 14 to 18 µm for this species. This species is present in sample 6540.

Order Prinsiales Young and Bown (1997)
Family Noelaerhabdaceae Jerkovic, 1970 Emend Young & Bown 1997
Genus Cyclicargolithus Bukry, 1971

4. Species *Cyclicargolithus abisectus* (Muller, 1970), (Figure 6, number 4)
Description: Large, sub-circular coccoliths typically have a narrow central area. The size of this species is >11 µm and is present in samples 8280, 6990, 6450, 5460, and 4080.

5. Species *Cyclicargolithus floridanus* (Roth and Hay in Hay et al., 1967), (Figure 6,number 5)
Description: The coccoliths are distinct, large, and have closed centers in the elliptical and subcircular varieties. The size of this species ranges

Table 3. Resume of the taxonomic ranks in MH-2 well.

Group	Order	Family	Genus	Species
Heterococcoliths	Coccolithales	Coccolithaceae	*Coccolithus*	*Coccolithus miopelagicus* (Bukry 1971)
				Coccolithus pelagicus (Wallich 1877)
		Calcidiscaceae	*Calcidiscus*	*Calcidiscus premacintyrei* (Theodoridis, 1984)
	Isochrysidales	Noelaerhabdaceae	*Cyclicargolithus*	*Cyclicargolithus abisectus* (Muller, 1970)
				Cyclicargolithus floridanus (Roth and Hay 1967)
			Reticulofenestra	*Reticulofenestra bisecta* (Hay, Mohler and Wade, 1966)
				Reticulofenestra haqii (Backman 1978)
				Reticulofenestra minuta (Roth 1970)
				Reticulofenestra pseudoumbilicus (Gartner 1967)
				Reticulofenestra umbilicus (Martini & Ritzkowski, 1968)
			Pseudoemiliania	*Pseudoemiliania lacunosa* Kamptner, 1963
	Arkhangelskiales	Arkhangelskiellaceae	*Arkhangelskiella*	*Arkhangelskiella cymbiformis* (Vekshina, 1959)
	Watznaueriales	Watznaueriales	*Watznaueria*	*Watznaueria barnesiae* (Black in Black & Barnes, 1959)
			Cyclagelosphaera	*Cyclagelosphaera brezae* (Applegate & Bergen, 1988)
				Cyclagelosphaera jiangii (Covington & Wise, 1987)
				Cyclagelosphaera wiedmannii (Reale & Monechi, 1994)
				Cyclagelosphaera lacuna (Varol & Girgis 1994)
	Zygodiscales	Helicosphaeraceae	*Helicosphaera*	*Helicosphaera carteri* (Wallich 1877)
				Helicosphaera princei (da Gama & Varol 2013)
				Helicosphaera sellii (Bukry and Bramlette, 1969)
		Pontosphaeraceae	*Pontosphaera*	*Pontosphaera discopora* (Schiller, 1925)
				Pontosphaera multipora (Kamptner 1948)

Table 3. Contd.

Group	Order	Family	Genus	Species
Namnoliths	Discoasterales	Ceratolithaceae	Amaurolithus	*Amaurolithus primus* (Bukry and Percival, 1971)
				Catinaster calyculus (Martini and Bramlette, 1963)
		Discoastersceae	*Discoaster*	*Discoaster berggrenii* (Bukry, 1971)
				Discoaster brouweri (Bramlette and Riedel, 1954)
				Discoaster druggii (Bramlette and Wilcoxon, 1967)
				Discoaster deflandrei (Bramlette & Riedel, 1954)
				Discoaster exilis (Martini and Bramlette 1963)
				Discoaster loeblichii (Bukry, 1971)
				Discoaster patulus (de Kaenel & Bergen)
				Discoaster quinqueramus (Gartner, 1969)
				Discoaster surculus (Martini and Bramlette, 1963)
				Discoaster variabilis (Martini and Bramlette 1963)
		Sphenolithaceae	*Sphenolithus*	*Sphenolithus abies* (Deflandre in Deflandre and Fert, 1954)
				Sphenolithus apoxis (Bergen & de Kaenel in Bergen et al. 2017)
				Sphenolithus disbelemnos (Fornaciari and Rio, 1996)
				Sphenolithus neoabies (Bukry & Bramlette 1969)

from 14 to 18 µm. This species is present in samples 900, 2130, 3240, 5460, 6450, 7200, 8070, 8500, and 8690.

Genus Reticulofenestra Hay, Mohler and Wade 1966

6. Species *Reticulofenestra bisecta* (Hay, Mohler and Wade, 1966), (Figure 6, number 6)
Description: Reticulofenestrids are large, with a central area covered by a solid and prominent distal 'plug' (birefringent). This species has a size of 5 - 10 µm. This species is present in sample 1350.

7. Species *Reticulofenestra haqii* (Backman 1978), (Figure 6, number 7)
Description: Similar to *Reticulofenestra pseudoumbilicus*, Reticulofenestra is small and has an open central area. This species has a size of 2 - 4 µm. This species is present in samples 8070, 8150, 8280, 8500, 7620, 7410, 6540, 6450, 6150, 5220, 5460, 5760, 2520, 2760, 3240, 4080, and 1620.

8. Species *Reticulofenestra minuta* (Roth 1970), (Figure 6, number 8)
Description: Reticulofenestrid has an open central area and is relatively compact. Sizes of this species range from 1 to 2 µm. This species is present in samples 1350, 1620, 2130, 2460, 2520, 2760, 3240, 4080, 5220, 5460, 5760, 6150, 6360, 6450, 6540, 6810, 6990, 7200, 7410, 7620, 7620, 8070, 8150, 8280, 8500, 8690, 8900, 9000, and 9100.

9. Species *Reticulofenestra pseudoumbilicus* (Gartner 1967), (Figure 6, number 9)
Description: Reticulofenestrid is medium size with a central open area of about 2 μm. This species has a size of 6 - 10 μm. This species was present in samples 1620, 1920, 2460, 2520, 2760, 3240, 4080, 5220, 5460, 6150, 6360, 6450, 6540, 6810, 7200, 7620, 7740, 7890, 8000, and 8070.

10. Species *Reticulofenestra umbilicus* (Martini & Ritzkowski, 1968), (Figure 6, number 10)
Description: The reticulofenestra is large with an open center and an elliptical form. Sizes for this species range from 14 to 18 μm. This species is present in samples 6540, 7740, 7890, and 8000.

Genus Pseudoemiliania Gartner, 1969

11. Species *Pseudoemiliania lacunosa* (Kamptner, 1963) (Figure 6, number 11)
Description: The coccolith is a square-shaped open area in a circular or subcircular structure. Reticulofenestrid is large, elliptical in shape, and has an open center. This species has a size of 5 μm and is present in samples 1620, 2130, and 3240.

Order Arkhangelskiales Bown & Hampton 1997 (in Bown & Young 1997)

Family Arkhangelskiellaceae Bukry, 1969 emend. Bown & Hampton
Genus *Arkhangelskiella* Vekshina, 1959

12. Species *Arkhangelskiella cymbiformis* (Vekshina, 1959), (Figure 6, number 12)
Description: This species varies in size, with narrow rims (<1.5 μm). This species has a size of 8 μm. This species is present in sample 6540.

Order Watznaueriales Bown, 1987

Family Watznaueriaceae Rood, Hay & Barnard, 1971
Genus Watznaueria Reinhardt 1964

13. Species *Watznaueria barnesiae* (Black in Black & Barnes, 1959) (Figure 6, number 13)
Description: This species has a narrow and closed central area with no structure in the middle area and a size of 6 - 8 μm. This species is present in samples 1620, 1920, 2460, 2520, 4080, 4650, 5460, 5760, 6540, 7200, 7410, 7890, 8150, 8500, 8690, and 9100.

Genus Cyclagelosphaera Noel, 1965

14. Species *Cyclagelosphaera brezae* (Applegate & Bergen, 1988), (Figure 6, number 14)
Description: Cyclagelosphaera moderate to large with a closed central area, a small proximal shield, large elements, and an indistinct cycle unit V. This species has a size of 6 - 8 μm. This species was present in samples 900, 1350, 2460, 2760, 5220, 7410, 8280, and 8690.

15. Species *Cyclagelosphaera jiangii* (Covington & Wise, 1987), (Figure 6, number 15)

Description: Cyclagelosphaera, which has a large central opening. This species has a size of 5 µm. This species is present in samples 3240, 5460, 6360, 6540, 7200, and 7740.

16. Species *Cyclagelosphaera wiedmannii* (Reale & Monechi, 1994), (Figure 6, number 15)
Description: The Cyclagelosphaera are large (8 - 9 µm) with small central openings and inconspicuous tube cycles. This species has a size of 8 – 10 µm. This species was present in samples 2460, 2760, 5760, 6150, 6450, 6540, 6990, 7200, 7740, 8070, 8150, 8900, and 9100.

17. Species *Cyclagelosphaera lacuna* (Varol & Girgis 1994), (Figure 6, number 16)
Description: Cyclagelosphaera has a small to medium size with a central opening. This species has a size of 4 µm. This species is present in samples 1920, 2760, 5220, 6150, 6810, 8070, 8280, 8690, and 9100.

Group Heterococcoliths Young and Bown 1997
Order Zygodiscales Young and Bown 1997
Family Helicosphaeraceae Black 1971
Genus Helicosphaera Kamptner 1954
{synonym: *Helicopontosphaera* Hay and Mohler 1967}

18. Species *Helicosphaera carteri* (Wallich 1877), (Figure 7, number 1)
Description: The wings of medium to large-sized *helicosphaera* are wide and thick to the edges, and they feature a closed core area with two pores in the center. This species has a size of 7 - 8 µm. This species is present in samples 1350, 1620, 1920, 2130, 2520, 2760, 3240, 4080, 5220, 5460, 5760, 6150, 6360, 6450, 6540, 6810, 6990, 7200, 7410, 740, 770, 7620, 8150, 8500, 8690, and 9100.

19. Species *Helicosphaera princei* (da Gama & Varol 2013), (Figure 7, number 2)
Description: A relatively large helicolith with a mantle of the *Helicosphaera carteri* type, broad wings, and a long longitudinal slit in the central area. This species has a size of 7 µm. This species was present in sample 1350.

20. Species *Helicosphaera sellii* (Bukry and Bramlette, 1969), (Figure 7, number 3)
Description: Like *H. carteri*, the central hole in the XPL view is larger. This species has a size of 7 - 8 µm. This species is present in samples 1620, 1920, 2520, 4080, and 5220.

Family Pontosphaeraceae Lemmermann, 1908
Genus Pontosphaera Lohmann, 1902

21. Species *Pontosphaera discopora* (Schiller, 1925), (Figure 7, number 4)
Description: A central area with few pores and a clear, high rim. This species has a size of 8 – 10 µm. This species is present in samples 1620, 2520, 5220, 6150, 810, 7200, 7410, and 7740.

22. Species *Pontosphaera multipora* (Kamptner 1948), (Figure 7, number 5)
Description: This species has pores on the outer cycle that are usually

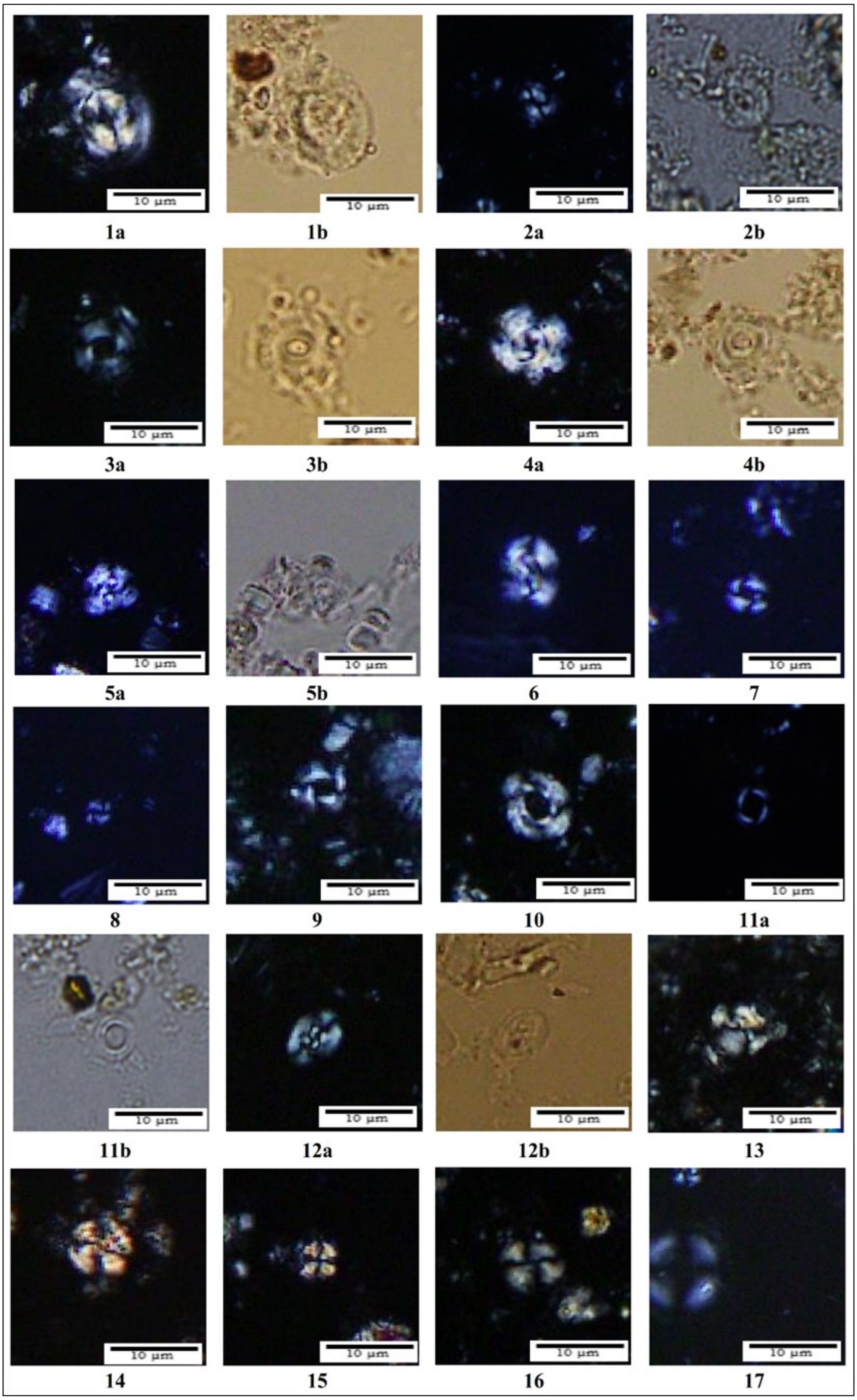

Figure 6. Selected image of nannoplanktons species in this research. XPL views (a) and PPL views (b). The Genus *Coccolithus* consists of (1) *Coccolithus miopelagicus* (sample 6810) and (2) *Coccolithus pelagicus* (sample 7620). The Genus *Calcidiscus* consists of (3) *Calcidiscus premacintyrei* (sample 6540). The Genus *Cyclicargolithus* consists of (4) *Cyclicargolithus abisectus* (sample 6450) and (5) *Cyclicargolithus floridanus* (sample 7200). The Genus *Reticulofenestra* consists of (6) *Reticulofenestra bisecta* (sample 1350), (7) *Reticulofenestra haqii* (sample 6540), (8) *Reticulofenestra minuta* (sample 6540), (9) *Reticulofenestra pseudoumbilicus* (sample 6150), (10) *Reticulofenestra umbilicus* (sample 6540). The Genus *Pseudoemiliania* consists of (11) *Pseudoemiliania lacunosa* (sample 1620). The Genus *Arkhangelskiella* consists of (12) *Arkhangelskiella cymbiformis* (sample 6540). The Genus *Watznaueria* consists of (13) *Watznaueria barnesiae* (sample 5220). The Genus *Cyclagelosphaera* consists of (14) *Cyclagelosphaera wiedmannii* (sample 6150), (15) *Cyclagelosphaera lacuna* (sample 3240), (16) *Cyclagelosphaera brezae* (sample 5220), and (17) *Cyclagelosphaera jiangii* (sample 5460).

elongated radially, the inner cycle is somewhat irregular, and the rim has a varying width. The size range for this species is 5 - 10 µm. Sample 5220 includes this species.

Group Nannoliths Young and Bown 1997
Order Discoasterales Hay 1977
Family Ceratolithaceae Norris, 1965
Genus Amaurolithus Gartner and Bukry, 1975

23. Species *Amaurolithus primus* (Bukry and Percival, 1971), (Figure 7, number 6)
Description: With curving arms, this species has a horseshoe-like form. This species is 7 µm in size. This species has samples 5760, 6540, and 6810.

Genus Catinaster Martini and Bramlette 1963

24. Species *Catinaster calyculus* (Martini and Bramlette, 1963), (Figure 7, number 7)
Description: Discoasterids have a basket-like structure with six arms extending beyond the basket. This species has a size of 7 - 9 µm. This species is present in samples 3240, 5220, and 6990.

Family Discoastersceae Tan 1927
Genus Discoaster Tan 1927

25. Species *Discoaster berggrenii* (Bukry, 1971), (Figure 7, number 8)
Description: Discoaster with five symmetrical arms and a prominent center. This species measures 8 - 11 µm. This species occurs in samples 4080, 5220, 5760, 6150, 6540, 6990, 7200, 7890, 8000, and 8150.

26. Species *Discoaster brouweri* (Bramlette and Riedel, 1954), (Figure 7, number 9)
Description: Discoaster with six symmetrical arms without branching and a proximal bulge; the central part has a protruding chip. This species has a size of 10 - 13 µm. This species is present in samples 1620, 1920, 2520, 3240, 4080, 4650, 5220, 5460, 5760, 6150, 6360, 6540, 6810, 7200, 7410, 8000, and 8150.

27. Species *Discoaster druggii* (Bramlette and Wilcoxon, 1967), (Figure 7, number 10)
Description: Similar to *D. deflandrei* but larger >15 µm. The asterolith is large and highly variable in its peripheral outline, with six arms that may be obtusely rounded or truncated with a broad and nearly flat central area. This species has a size of 15 µm. This species is present in samples 5220, 5760, and 7410.

28. Species *Discoaster deflandrei* (Bramlette & Riedel, 1954), (Figure 7, number 11)
Description: Has six arms, with the ends of the arms terminating in short, broad bifurcations that are strong and branched. This species has a size of 8 - 10 µm. This species is present in samples 8150 and 8500.

29. Species *Discoaster exilis* (Martini and Bramlette, 1963), (Figure 7, number 12)
Description: This discoaster has six arms with a small central area, usu-

ally with a bulge in the middle and slight ramifications at the ends of each arm. This species has a size of 8 µm. This species is present in samples 6810, 7890, and 8150.

30. Species *Discoaster loeblichii* (Bukry, 1971), (Figure 7, number 13)
Description: Has six arms, similar to *D.variabilis* like, but asymmetrical. The ends of the arms in the distal view are curved counter-clockwise. This species has a size of 10 - 12 µm. This species is present in sample 5220.

31. Species *Discoaster patulus* (de Kaenel & Bergen), (Figure 7, number 14)
Description: comparable to *D. exilis* in that it has six arms but differs in that it only has a central bulge larger than the distal bulge. This species has a size of 10 - 12 µm. This species is present in sample 7410.

32. Species *Discoaster quinqueramus* (Gartner, 1969), (Figure 7, number 15)
Description: Has five symmetrical arms, similar to *D. berggrenii*, with the central area having a large, prominent suture with a blunt tip. This species has a size of 6 - 8 µm. This species is present in samples 6540, 6990, 7200, 7410, 7620, 7890, and 8000.

33. Species *Discoaster surculus* (Martini and Bramlette, 1963), (Figure 7, number 16)
Description: This discoaster has six arms, similar to *D. variabilis*, but with a trifurcation appearance at the ends of the arms. This species has a size of 10 µm. This species is present in samples 6990 and 7410.

34. Species *Discoaster variabilis* (Martini and Bramlette, 1963), (Figure 7, number 17)
Description: This *discoaster* has six arms, the ends of which branch off at an approximately 90° angle. There is a bulge in the center of the central area. This species has a size of 8 µm and is present in samples 6360, 6540, 7410, and 7620.

Family Sphenolithaceae Deflandre 1952
Genus Sphenolithus Deflandre 1952

35. Species *Sphenolithus abies* **(**Deflandre in Deflandre and Fert, 1954), (Figure 7, number 18)
Description: Similar to *S. moriformis* but higher. The sphenolith is medium, with a sharp upper end and a downwardly elongated spine. This species has a size of 3-4 µm. This species is present in samples 1920, 2520, 2760, 3240, 4080, 4650, 5220, 5460, 5760, 6150, 6360, 6450, 6540, 6810, 6990, 7200, 7620, 7740, 7890, 8000, 8070, 8150, 8280, 8500, dan 8690.

36. Species *Sphenolithus apoxis* (Bergen & de Kaenel in Bergen et al. 2017), (Figure 7, number 19)
Description: Sphenolith is conical with multiple spines. This species has a size of 3 µm. This species is present in samples 5220, 6990, and 8690.

37. Species *Sphenolithus disbelemnos* (Fornaciari and Rio, 1996), (Figure 7, number 20)
Description: Similar to *S. belemnos*, but has a shorter spine. This species

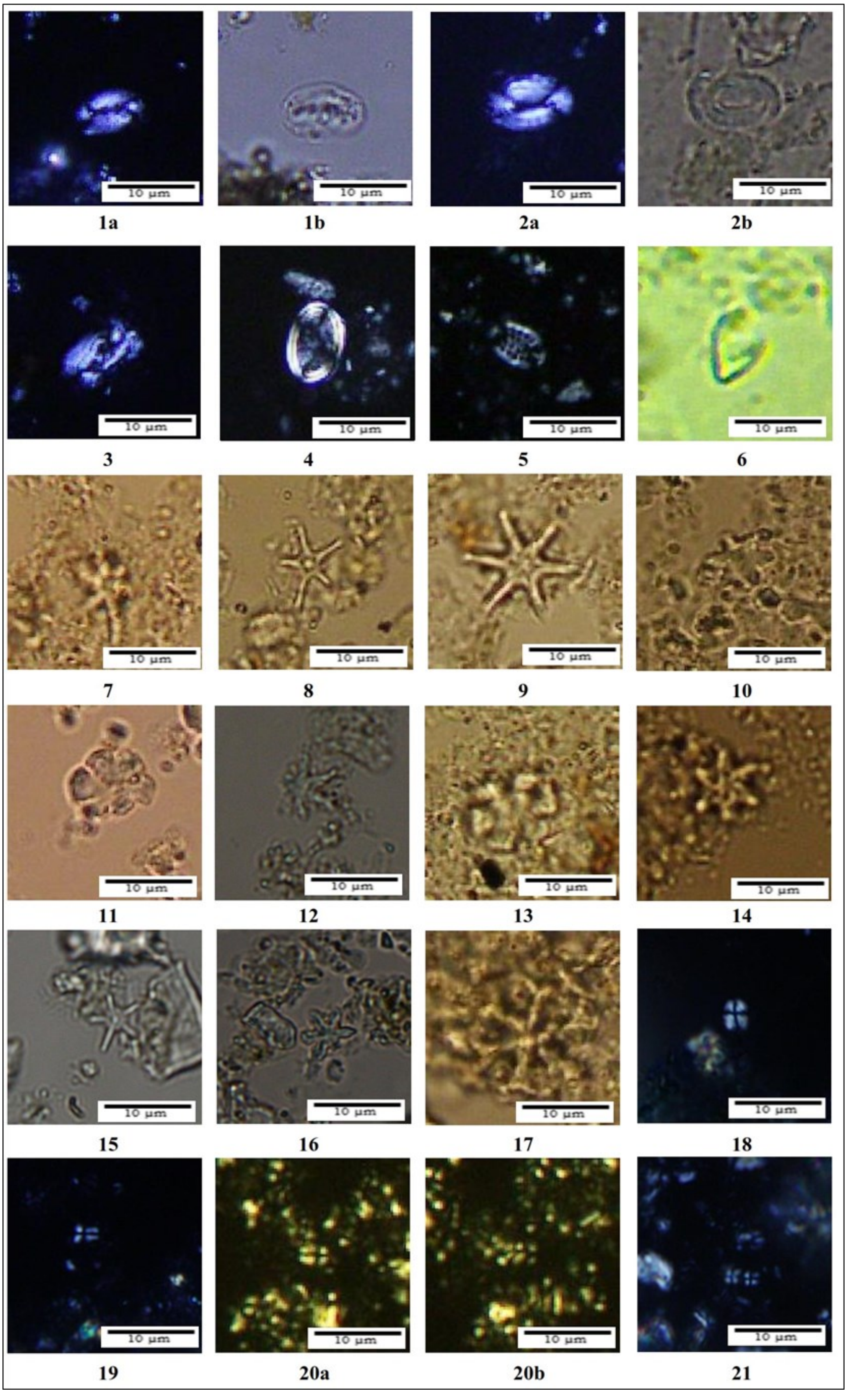

Figure 7. Selected image of nannoplanktons species in this research. XPL views (a) and PPL views (b). The Genus *Helicospahera* consists of (1) *Helicospahera carteri* (sample 4080), (2) *Helicosphaera princei* (sample 1350), (3) *Helicosphaera sellii* (sample 5220). The Genus *Pontosphaera* consists of (4) *Pontosphaera discopora* (sample 6150) and (5) *Pontosphaera multipora* (sample 5220). The Genus *Amaurolithus* consist of (6) *Amaurolithus primus* (sample 6810). The Genus *Catinaster* consist of (7) *Catinaster calyculus* (sample 5220). Genus *Discoaster* consists of (8) *Discoaster berggrenii* (sample 8150), (9) *Discoaster brouwreri* (sample 6150), (10) *Discoaster druggii* (sample 7410), (11) *Discoaster deflandrei* (sample 8150), (12) *Discoaster exilis* (sample 8150), (13) *Discoaster loeblichii* (sample 5220), (14) *Discoaster patulus* (sample 7410), (15) *Discoaster quinqueramus* (sample 6540), and (16) *Discoaster surculus* (sample 7410), and (17) *Discoaster variabilis* (sample 6540). Genus *Sphenolithus* consists of (18) *Sphenolithus abies* (sample 8690), (19) *Sphenolithus apoxis* (sample 8690), (20) *Sphenolithus disbelemnos* (Sample 8690), and (21) *Sphenolithus neoabies* (sample 6540).

has a size of 3 μm. This species was present in samples 8690 dan 8900.

38. Species *Sphenolithus neoabies* (Bukry & Bramlette 1969), (Figure 7, number 21)
Description: They are smaller, less conical, and less elongated on the apical spine. This species has a size of <4 μm. This species was present in samples 4080, 5220, 5460, 5760, 6150, 6540, 6810, 6990, 7200, 7410, 7620, 7740, 7890, 8000, 8070, 8150, 8280, and 8500.

CONCLUSION

The results of calcareous nannoplankton biostratigraphy obtained six zones using six biodatum, namely FO *Sphenolithus abies* as the top *Discoaster signus* zone (NN5), FO *Discoaster brouweri* as top *Discoaster exilis* zone (NN6-NN7), FO *Discoaster berggrenii* as base *Discoaster berggrenii* zone (NN11), LO *Discoaster quinqueramus* as base *Ceratolithus acutus* zone (NN12), FO *Helicosphaera sellii* as base *Helicosphaera sellii* zone (NN13-NN15), LO *Reticulofenestra pseudoumbilicus* as the base for the *Discoaster tamalis* zone (NN16). Formation ages were obtained in this study for the Middle Miocene–Late Miocene Minahaki Formation, the Late Miocene-Early Pliocene Kintom Formation, and the Early Pliocene-Middle Pliocene Biak Formation. The unconformity occurred in the Late Miocene age, equivalent to 10.606 Ma–8.20 Ma, with a duration of 2.406 million years.

AUTHORS CONTRIBUTION

E.M.N. collected data, analyzed data, and wrote scripts. A., D.H.B., S.H, and A.S. designed the research, supervised all the analysis processes, and corrected the manuscript's contents.

ACKNOWLEDGMENTS

The authors would like to thank SKK MIGAS and JOB Pertamina-Medco E&P Tomori Sulawesi for their permission to publish this data.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the research or funding.

REFERENCES

Armstrong, H.A. & Brasier, M.D., 2005. *Microfossils* 2nd Editio., USA: Blackwell Publishing.

Backman, J. et al., 2012. Biozonation and biochronology of Paleogene calcareous nannofossils from low and middle latitudes. *Newsletters on Stratigraphy*, 47(2), pp.131–181. doi: 10.1127/0078-0421/2014/0042.

Bergen, J. et al., 2017. Oligocene-Pliocene taxonomy and stratigraphy of the genus Sphenolithus in the circum North Atlantic Basin: Gulf of Mexico and ODP Leg 154. *Journal of Nannoplankton Research*, 37(2–3), pp.77–112.

Bergen, J. et al., 2019. BP Gulf of Mexico Neogene Astronomically-tuned Time Scale (BP GNATTS). *Bulletin of the Geological Society of America*, 131(11–12), pp.1871–1888. doi: 10.1130/B35062.1.

Boesiger, T. et al., 2017. Oligocene to Pleistocene taxonomy and stratigraphy of the genus Helicosphaera and other placolith taxa in the circum North Atlantic Basin. *Journal of Nannoplankton Research*, 37(2–3), pp.145–175.

Bown, P. & Young, J.R., 1998. *Techniques*. In *Calcareous Nannofossil Biostratigraphy*, Kluwer, Dordrecht: British Micropalaeontological Society publication series.

Flores, J.A. & Sierro, F.J., 2013. Coccolithophores. *Encyclopedia of Quaternary Science: Second Edition*, pp.783–794. doi: 10.1016/B978-0-444-53643-3.00281-8.

Galović, I. & Young, J., 2012. Revised taxonomy and stratigraphy of Middle Miocene calcareous nannofossils of the Paratethys. *Micropaleontology*, 58(4), pp.305–334. doi: 10.47894/mpal.58.4.01.

Hasanusi, D. et al., 2004. Prominent Senoro Gas Field Discovery In Central Sulawesi. *Indonesian Petroleum Association Proceedings, Deepwater And Frontier Exploration In Asia & Australasia Symposium*, 101(3), p.55.

Husein, S., Novian, M.I. & Barianto, D.H., 2014. Geological Structures and Tectonic Reconstruction of Luwuk, East Sulawesi. *Proceedings, Indonesian Petroleum Association Thirty-Eighth Annual Convention & Exhibition, May 2014*, (October 2015). doi: 10.29118/ipa.0.14.g.137.

Kapid, R., 2003. *Nanofosil Gampingan: Pengenalan dan Aplikasi Biostratigrafi*, Bandung: ITB.

Kurniasih, A. et al., 2021. Biostratigraphy Analysis of Barbatos-1 Exploration Well in Tomori Block, Banggai Basin, East Arm of Sulawesi. *RISET Geologi dan Pertambangan*, 31(1), p.51. doi: 10.14203/risetgeotam2021.v31.1150.

Lucas, S.G., History, N. & States, U., 2020. Biostratigraphy. *Encyclopedia of Geology, 2nd edition*, pp.1–7. doi: 10.1016/B978-0-08-102908-4.00076-X.

Martini, E., 1971. *Standard Tertiary and Quaternary calcareous Nannoplankton biozonation*. In *Nannofossils Biostratigraphy Part III:12 Cenozoic Biostratigraphy*. Stroudsburg, Pensylvanian: Hutchinson Ross Publishing Company.

McGowran, B., 2005. *Biostratigraphy Microfossils and Geological Time*, U.S.A: Cambridge University Press.

Miller, K.G. et al., 2020. Cenozoic sea-level and cryospheric evolution from deep-sea geochemical and continental margin records. *Science Advances*, 6(20). doi: 10.1126/sciadv.aaz1346.

Nugraha, A.M.S., Hall, R. & BouDagher-Fadel, M., 2022. The Celebes Molasse: A revised Neogene stratigraphy for Sulawesi, Indonesia. *Journal of Asian Earth Sciences*, 228, 105140. doi: 10.1016/j.jseaes.2022.105140.

Okada, H. & Bukry, D., 1980. Supplementary Modification and Introuction of Code Number to the Low-Latitude Coccolith Biostratigraphic Zonation (Bukry, 1973; 1975). *Marine Micropaleontology*, 5(3), pp.321–325. Available at: doi:10.1016/0377-8398(80)90016-x.

Simmons, M., 2019. Biostratigraphy in Exploration – Exploration Handbook. In Halliburton Landmark, London.

Ulfah, A.A., Akmaluddin & Barianto, D.H., 2023. Biostratigraphy and Climate Change in the Late Miocene Age Based on Foraminifera in the Oyo Formation , Oyo River Section , Gunung Kidul , Yogyakarta. *Journal of Tropical Biodiversity and Biotechnology*, 8(2), jtbb81769. doi: 10.22146/jtbb.81769.

Young, J.R., Bown, P.R. & Lees, J.A., 2023, 'Nannotax3' in *Mikrotax*, viewed 8 March 2023, from https://www.mikrotax.org/Nannotax3/