Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia

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Kuwait J. Sci. **48 (1)** pp. 116-126, 2021

Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia

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Abstract

The Limestone research within the Limboto Basin of Gorontalo Province becomes a new challenge, particularly for the study of planktonic foraminiferal biostratigraphy. This study uses the data obtained from the measured section in the north-western part of Limboto Lake. The purpose of this study is to determine the planktonic foraminiferal biozonation and the relative age of Limboto Limestones. The analyzed planktonic foraminiferal fossils can be classified as well to moderately preserved of various species, in the context of abundance, categorized as frequent to abundant. There are three recognized planktonic foraminiferal biozones, i.e., two biozones for Miocene age (M13b and M14) and one biozone for Pliocene age (PL1). The Miocene biozones are named as *Globorotalia plesiotumida partial range zone* (M13b) and *Pulleniatina primalis*-*Globoquadrina dehiscens* concurrent range zone (M14), while the name of Pliocene biozone is *Globorotalia acostaensis* partial range zone (PL1). The results of this study can be a reference to propose an age of Limboto Limestone Formation. Identification and demarcation of the Limboto Limestone Formation are based on the time interval and relative age of the formation based on planktonic foraminifera.

Keywords: Foraminiferal biostratigraphy; Limboto Limestone.

1. Introduction

The Indonesian archipelago is geologically located in the center of three main active plates, i.e., the slowly moving Eurasian Continental Plate to the south-southeast direction, the Pacific Oceanic Plate moving to the west-northwest direction, and the Indian-Australian Oceanic Plate moving to the north-northeast direction (Hamilton, 1979) (Figure 1). Located in the middle of the archipelago, Sulawesi Island is inevitably influenced by the movement of the three plates (Hamilton, 1979; Hutchison, 1989). This condition gives an implication of Sulawesi K-shaped Island, which comprises the southern arm, the middle part, the northern arm, the eastern arm, the southeastern arm, and the Sulawesi neck. The tectonic conditions of Sulawesi are extremely complex, which were formed during the Oligocene to Miocene age (Sukamto, 1975c; Hamilton, 1979; Daly *et al.*, 1991). The basement rocks of the North Sulawesi arm originated from the pre-Tertiary Pacific Oceanic Plate (Taylor and Leeuwen, 1980; Katili, 1989). The northern arm of Sulawesi underwent a tectonic evolution from the Eocene or Early Miocene to the Pliocene-Pleistocene age (Surmont *et al.*, 1994). Based on paleomagnetic studies, the northern arm underwent 90^0 clockwise rotations in the Early Eocene-Miocene age with a rotation center situated close to Manado. The rotation stopped during the Pliocene-Pleistocene (Otofuji *et al.*, 1981; Nishimura and Suparka, 1986). Different paleomagnetic results were obtained at the latitude of 120-122^0 E (Surmont *et al.*, 1994). The clockwise rotation is only 20-25^0, which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al.*, 1994).

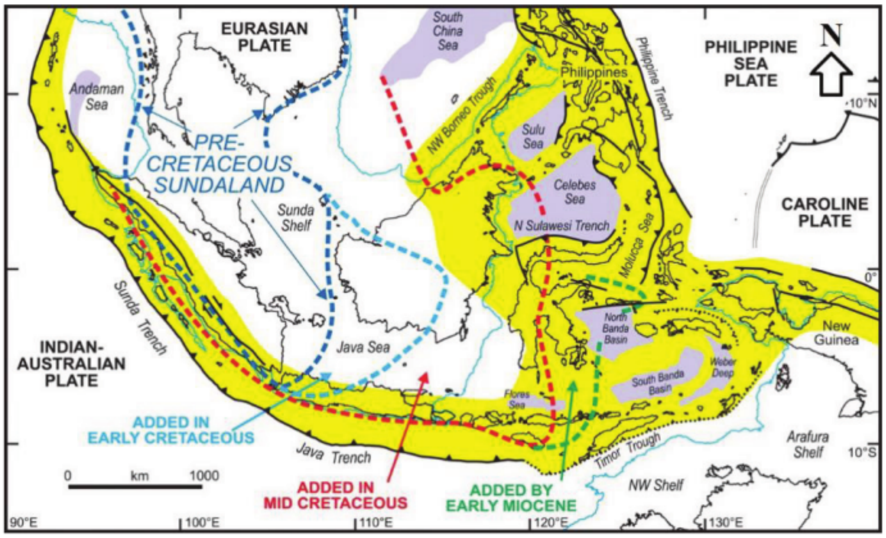

Fig. 1. Tectonic map of Indonesia showing the interaction of major plates (modified from Hamilton, 1979).

The geomorphological condition in the central part of the northern arm consists of the east-west Limboto Basin with a width of 35 - 110 km. Several river valleys and Limboto Lake formed this basin. Limboto Lake has a northwest-southeast orientation influenced by Gorontalo's main fault zone, which has a dextral movement in the same direction (Van Bemmelen, 1949; Katili, 1970; 1989; Eraku and Permana, 2020). The main fault zone can be seen from the Patente River, Tombuililato cape, and Gorontalo coastline lineament pattern. The evidence of the intensive tectonics in this area can be seen from the Quartenary reef Limestones near Gorontalo and Tanjung Daka on the northern coast, which experienced an uplift to elevation of more than 1,000 meters, even though it was only formed at the Quaternary age (Van Bemmelen, 1949; Katili, 1970; 1989 and Permana *et al*., 2019a).

Limestone research in the new Limboto Basin is only carried out regionally. The first study states that the Limestone distribution can be found around Lake Limboto valley and the south coast (Trail *et al*., 1974). Coral Limestone is formed at the Pliocene-Pleistocene age, similar to the Limestone distributed in the western part of the north coast. The presence of macrofossils and red algae in Limboto Lake's Limestones at Early Miocene is a result of Limestone conglomerates reworking from the southern part of Paguyaman Beach (Trail *et al*., 1974).

The previous study (Bachri *et al*., 1997) was conducted to produce a regional geological map with the scale of 1 : 250,000 (Figure 2). Limestone distribution on regional geological maps is divided into two formations including Clastic Limestone Formation (TQL) and Coral Limestone Formation (QL). Clastic Limestone Formation (TQL), which spreads in the northern and western parts of Limboto Lake, has Pliocene-Pleistocene age, consisting of calcarenite, calcirudite, and coral Limestone. This formation has a thickness ranging from 100 to 200 meters (Bachri *et al*., 1997). Coral Limestone Formation (QL), distributed in southern part of the lake, consisting of reef Limestone, which contains coral fragments as the main constituent, is deposited contemporaneously with the Clastic Limestone Formation (TQL) and assigned a Holocene age (Bachri *et al*., 1997).

The difference in determining the Limestone age in the Limboto Basin by Trail *et al*. (1974) and Bachri *et al*. (1997) makes this research interesting for revealing the relative Limestone age. Moreover, this study conducted a detailed research by using measured outcrop section and biostratigraphic analysis, which was done for the first time in this formation. So, the purpose of the current research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

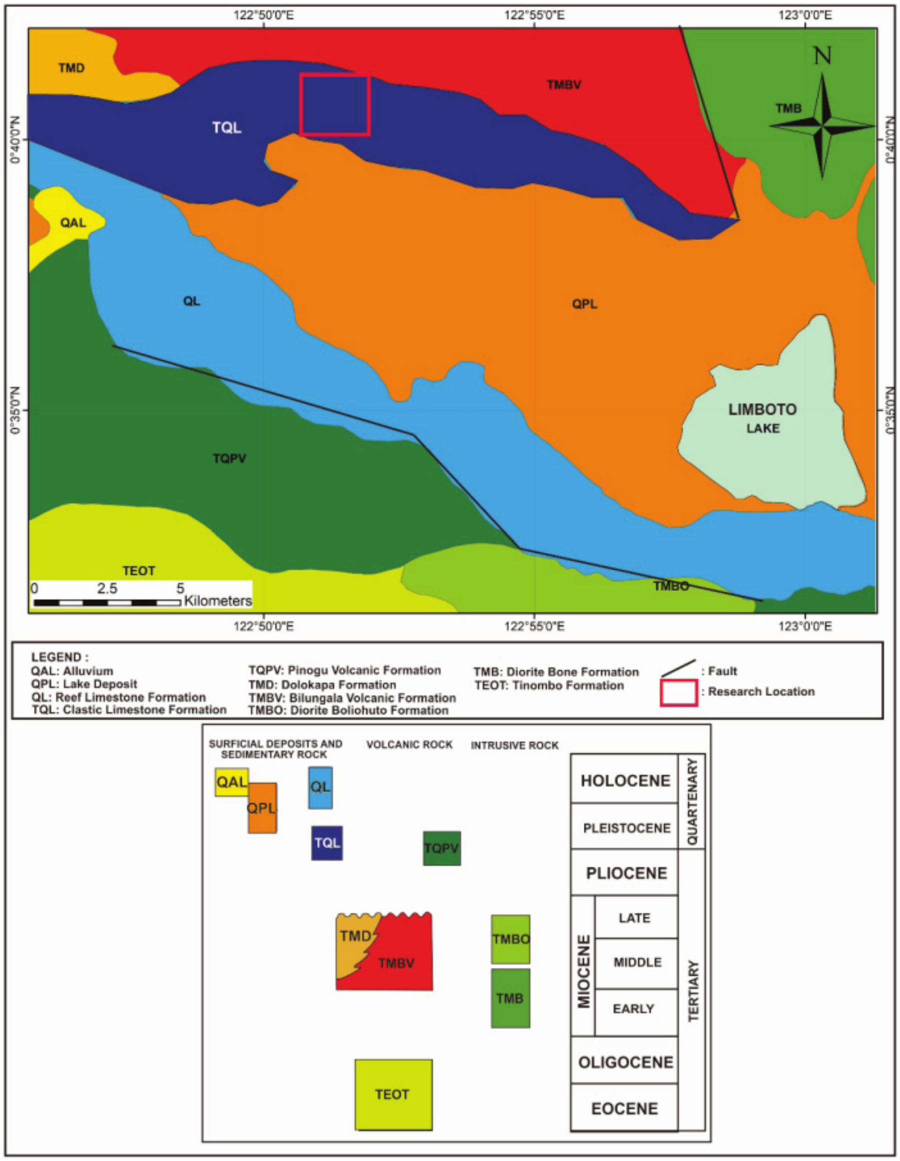

Fig. 2. Regional Geological Map of Gorontalo (Bachri *et al*., 1997). The present research location (Limboto area) is marked with box having pink color outline.

2. Materials and methods

The present research area location is a part of the Limboto Basin, Gorontalo Province, Indonesia, within the coordinates of 0°40′5.917″North, 122°51′11.939″East to 0°39′40.670″North, 122°52′16.205″East (Figure 3). The research material is chiefly collected from Limestone outcrop with a total thickness of 64 meters, which belong to Limboto track. The Measuring Section (MS) uses a Jacob's staff, following the method of Compton (1985) and Permana *et al.* (2019b) with an interval of 1.5 meters. Then, the sample was taken in every 1 to 1.5 meters. The collected samples usually consist of fine (clay-silt) size, soft (not yet compacted and not hard), and having calcareous material proved by the 0.1 N Hydrogen Chloride (HCl) solution test (Figure 4).

The biostratigraphy of a total of 34 Limestone samples was analyzed. Rock samples are crushed and mashed to a finer size than the size of sand. Each sample was prepared with a weight of 100 grams. After that, the H_2O_2 solution is added with a concentration of 30%; the sample is left for about 2-5 hours to separate the fossil from the clay that covers it. Samples were washed with 60, 100, 125, and 200 mesh filters. The size of used sample ranges from 125 and 200 microns, and then it is dried up (in an oven at 70° Celsius) and packed using plastic bags.

The identification of planktonic foraminifera fossil uses Olympus binocular SZ61 microscope, which is equipped with a camera connected to a computer (Al-Enezi *et al.*, 2019; Permana *et al.*, 2019a; Permana *et al.*, 2020). The samples generally contain moderately preserved (good enough) planktonic foraminifera, and the abundance ranges from frequent to abundant. The identification of planktonic foraminifera fossils refers to Postuma (1971), Bolli *et al*. (1985), Berggren (1992), and Li *et al.* (2003).

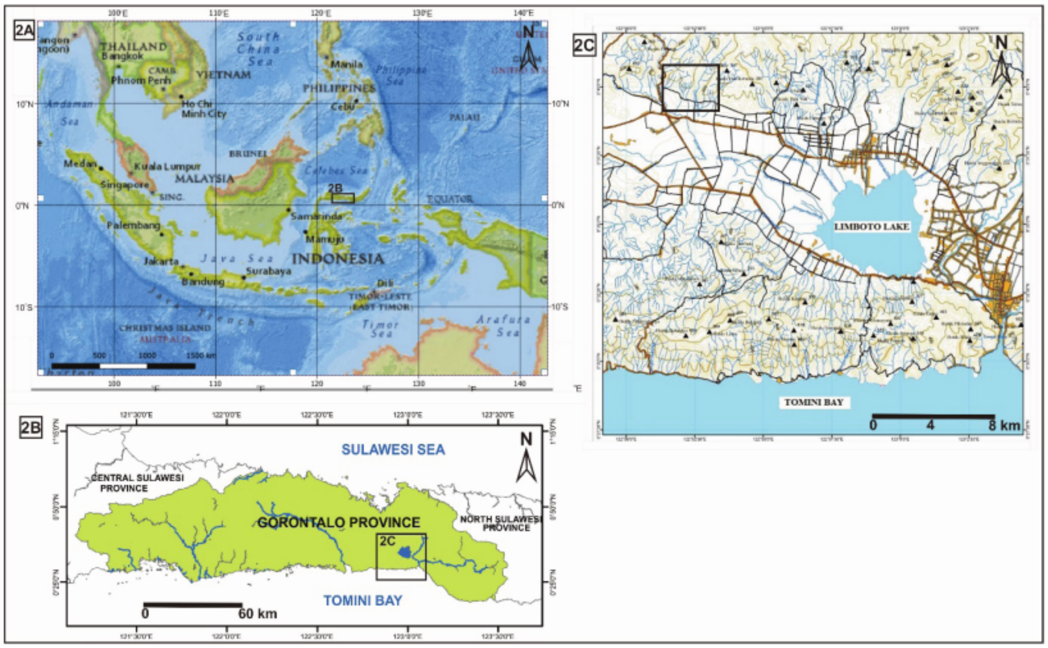

Fig. 3. Basin of Limboto, Gorontalo Province, with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limboto Lake on the map of Gorontalo Province (GIS map), and (2C) the map of research location (Isimu area).

Fig. 4. Outcrop photograph of the Limboto Limestone. Samples 11, 12, 29, and 30 positions are also marked. Man, having 5 feet height, for scale.

3. Results and discussion

3.1 Planktonic foraminifera biozones

The planktonic foraminiferal biozonations used in this study refer to Blow (1969) and Wade *et al.* (2011) biozonations. Blow (1969) biozonation divided the Cenozoic biozonation into two parts, namely, Paleogene (Paleocene-Oligocene) and Neogene (Miocene-Pleistocene). Overall, in the present study, biozonation is based on Blow (1969) biozonation, which is consisting of 22 main Paleogene biozones from P1 to P22 notation, and 23 main Neogene biozones having N1 to N23 notation.

Wade *et al*. (2011) biozonation shows the increasing number of foraminifera studies in the tropic to the subtropic area, resulting in many standard biodata for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the earth's magnetism over the geological timespan (Wade *et al.,* 2011). The most recent study (i.e., Wade *et al*., 2011) divided the Cenozoic into more details using the "P" notation for Paleocene, "E" for Eocene, "O" for Oligocene, "M" for Miocene, "PL" for Pliocene, and "PT" for Pleistocene. The zonation scheme makes Wade *et al*. (2011) biozonation tend to be more detailed than Blow (1969) biozonation.

The biozones boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal biozone. The abbreviations used in the description of biozones include FO (first occurrence) and LO (last occurrence). FO and LO define biozone from taxa obtained from a particular region (Saraswati and Srinivasan, 2016). Different types of biostratigraphic zones are range zone, concurrent range zone, interval zone, partial range zone, assemblage zone, phylo zone, and acme zone (Saraswati and Srinivasan, 2016). The biozonation of this study can be seen in Table 1.

Biozone M13b (*Globorotalia plesiotumida partial range zone)*

Definition: The upper boundary of biozone M13b is the FO of *Pulleniatina primalis* (Figure 4; Table 1). The lower boundary is not reached in the studied intervals. This zone is *Globorotalia plesiotumida* partial range zone (Table 1).

Discussion: Biozone M13b is equivalent to biozone N17a (Blow, 1969) and biozone M13b (Wade *et al*., 2011). The lower boundary of this zone is not found because of the limitation of the sample being analyzed. The upper boundary of this zone is marked by FO *Pulleniatina primalis* (Berggren *et al*., 1995b; Wade *et al*., 2011) in sample 4 (Figure 5; Table 1). The name of this zone, according to the species that commonly found and characterized the Late Miocene age, is *Globorotalia plesiotumida*.

The fossil association of this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins, 1934), *Globigerina praebulloides* (Blow, 1959), *Globigerinoides immaturus* (de Leroy, 1939), *Globigerinoides obliquus extremus* (Bolli and Bermudez, 1965), and *Globigerinoides obliquus obliquus* (Bolli, 1957). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny, 1846), *Globigerinoides ruber* (d'Orbigny, 1846), *Globigerinoides subquadratus* (Bronnimann, 1954), *Globorotalia acostaensis* (Blow, 1959), and *Globorotalia humerosa* (Takayanagi and Saito, 1962) are also identified (Figure 5). Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady, 1865), *Globorotalia plesiotumida* (Blow and Banner, 1965a), and *Globorotalia tumida flexuosa* (Koch, 1923), which can be seen in Figures 6 and 7.

Several reworked fossils are identified in this zone, such as *Globorotalia exilis* (Blow, 1969). The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rocks above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters at the bottom in the stratigraphic column, i.e., Figure 5 of this study).

Age : Late Miocene or older than 6.40 Ma (Wade *et al*., 2011).

Biozone M14 (*Pulleniatina primalis-Globoquadrina dehiscens* concurrent range zone)

Definition: The lower boundary is marked by the FO of *Pulleniatina primalis* (Table 1; Figure 5). The upper boundary is marked by the LO of *Globoquadrina dehiscens.* This biozone is *Pulleniatina primalis-Globoquadrina dehiscens* concurrent range zone (Table 1).

Discussion: This zone is equivalent to biozone N17b of Blow (1969) and biozone M14 of Wade *et al.* (2011). The lower boundary of this biozone is marked by the FO of *Pulleniatina primalis* (Berggren *et al*., 1995b; Wade *et al*., 2011). The occurrence of *Pulleniatina primalis* is observed in samples 4, 5, 6, 7, 8, 9, 10, 11, 12, to 34. The occurrence of this species is not found in the lowest intervals of the stratigraphic column, i.e., samples 1, 2, and 3 (Figure 5). In the middle part of this zone (interval from 17 to 32 sample). The distribution of *Pulleniatina primalis* is not continuous and possibly caused by ecological changes along Miocene and Pliocene boundary. The upper boundary of this zone is the LO of *Globoquadrina dehiscens* (Berggren *et al*., 1995a; Wade *et al*., 2011), where it was last found in sample 28.

The occurrence of *Globoquadrina dehiscens* is reported in samples 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 21, , 23, 24, 25, 26, 27, to 28, then not found further in the upper samples 29, 30, 31, 32, 33, and 34 (Figure 5).

The contents of fossil association within this zone comprise *Globigerina bulloides* (d'Orbigny, 1826), *Globigerina nepenthes* (Todd, 1957), *Globigerina praebulloides* (Blow, 1959), *Globigerinoides conglobatus* (Brady, 1879), *Globigerinoides immaturus* (de Leroy, 1939), and *Globigerinoides obliquus obliquus* (Bolli, 1957). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny, 1846), *Globigerinoides ruber* (d'Orbigny, 1846), *Globigerinoides subquadratus* (Bronnimann, 1954), *Globigerinoides trilobus trilobus (*Reus, 1850), *Globorotalia acostaensis* (Blow, 1959), *Globorotalia crassaformis* (Galloway and Wissler, 1927), and *Sphaerodinelopsis seminulina* (Schwager, 1866) are also found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito, 1962), *Globorotalia plesiotumida* (Blow and Banner, 1965a), *Globorotalia tumida tumida* (Brady, 1877), *Orbulina universa* (d'Orbigny, 1839a), and *Pulleniatina praecursor* (Banner and Blow, 1967), which can be seen in Figures 6 and 7.

The reworked fossils of *Catapsydrax dissimilis* (Cushman and Bermudez, 1937), *Globorotalia juanai* (Bermudez and Bolli, 1969), and *Globorotalia mayeri* (Cushman and Ellisor, 1939) are also identified. The occurrence of these species is estimated to be reworked from the older rocks, that is, Dolokapa Formation, which has Middle Miocene age. The thickness of this zone is 43.5 meters (interval of 4.5–48 meters in Figure 5).

Age: Late Miocene or 5.80-6.40 Ma (Wade *et al*., 2011).

Biozone PL1 (*Globorotalia acostaensis* partial range zone)

Definition: The lower boundary is marked by the LO of *Globoquadrina dehiscens* (Table 1; Figure 5). The upper boundary of PL1 is not reached in the studied intervals. This zone is *Globorotalia acostaensis* partial range zone (Tabel 1).

Discussion: Zone PL1 is equivalent to Zone N18 of Blow (1969) and Zone PL1 of Wade *et al*. (2011). This zone represents the youngest planktonic foraminifera (uppermost) in this area. LO of *Globoquadrina dehiscens* (Berggren *et al*., 1995a; Wade *et al*., 2011) is found within sample 28 (Figure 5).

The contents of fossil association within this zone are *Globigerina praebulloides* (Blow, 1959), *Globigerinoides immaturus* (de Leroy, 1939), *Globigerinoides obliquus obliquus* (Bolli, 1957), *Globigerinoides quadrilobatus* (d'Orbigny, 1846), and *Globigerinoides ruber* (d'Orbigny, 1846). Moreover, species of *Globigerinoides subquadratus* (Bronnimann, 1954), *Globorotalia acostaensis* (Blow, 1959), *Globorotalia humerosa* (Takayanagi and Saito, 1962), *Globorotalia dutertrei* (d'Orbigny, 1839), and *Globorotalia plesiotumida* (Blow and Banner, 1965a) are also found. Also there are fossil species *Pulleniatina praecursor* (Banner and Blow, 1967) and *Pulleniatina primalis* (Banner and Blow, 1967), which can be seen in Figures 6 and 7.

Several reworked fossils such as *Globorotalia continuosa* (Blow, 1959), *Globorotalia juanai* (Bermudez and Bolli, 1969), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady, 1865), and *Praeorbulina transitoria* (Blow, 1956) species are also identified from this zone. The occurrence of these species is interpreted to be reworked from the older rocks, which is Dolokapa Formation, which has Middle Miocene age. The thickness of this zone is 16 meters (interval of 48-76 meters).

Age : Early Pliocene–or younger than 5.80 Ma (Wade *et al*., 2011).

Table 1. Planktonic foraminifera biozonation proposed in this study compared to those of Blow (1969) and Wade *et al*. (2011).

Age (Ma)	Epoch		Planktonic Foraminifera Zone: Blow(1969)	Wade *et al* (2011)	Permana *et al* (2019) (This Study)	Bioevents/Biodatums used in this study (Age in Ma)	Biostratigraphic Zonations of the present study
0, 1, 2, 3, 4, 5	PLIOCENE	EARLY	N18	PL1	PL1	LO *Globoquadrina dehiscens* (5.80)	*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N17b	M14	M14	FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurrent Range Zone
7, 8	MIOCENE	LATE	N17a	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

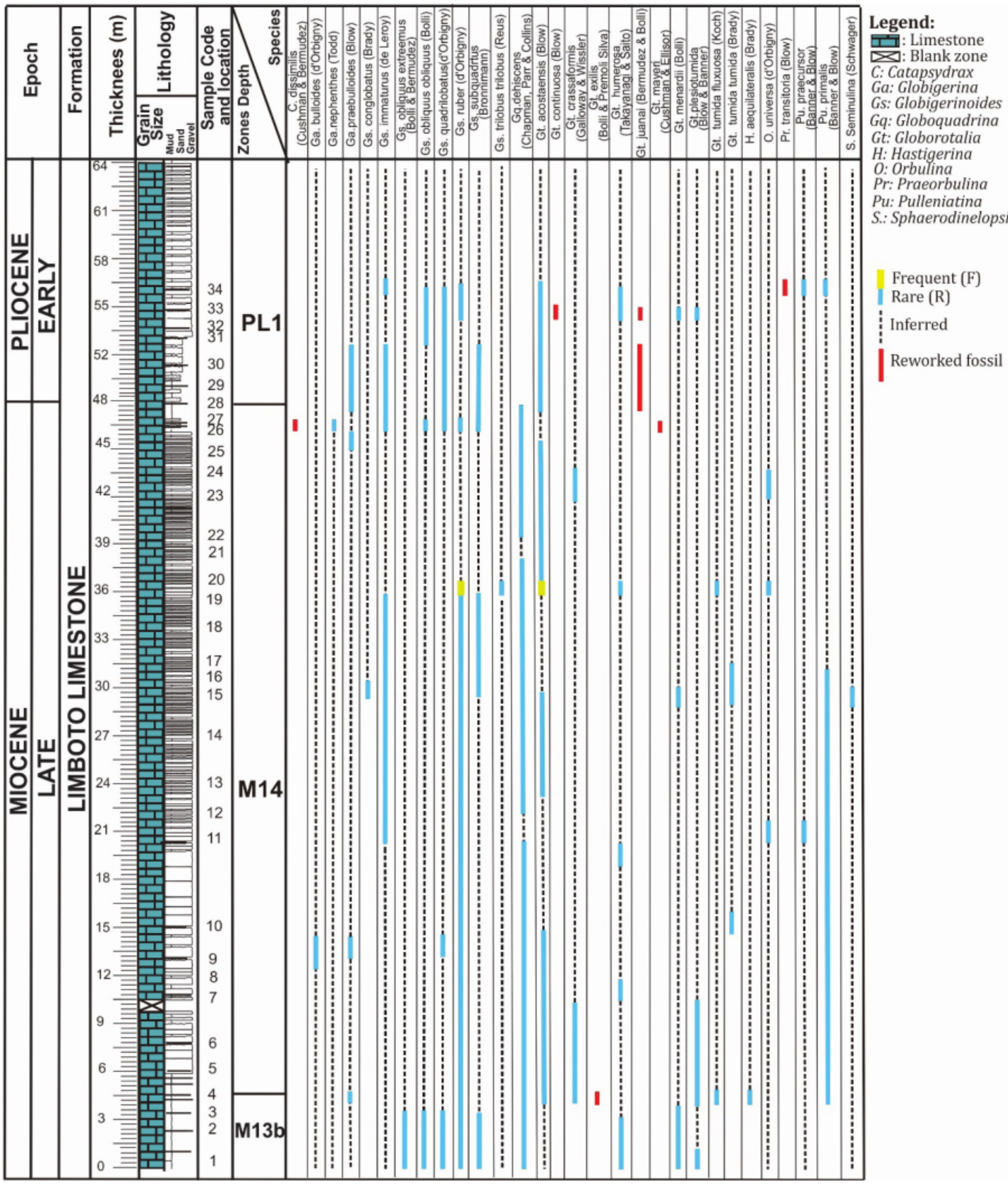

Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto Limestone can be divided to three biozonations, namely, M13b, M14, and PL1 zones, which shows the Late Miocene to Early Pliocene ages.

PLATE 1

1. *Catapsydrax dissimilis* (Cushman & Bermudez, 1937), sample 26
2 *Globigerina bulloides* (d'Orbigny,1826), sample 8
3. *Globigerina nephenthes* (Todd,1957), sample 26
4. *Globigerina praebulloides* (Blow,1959), sample 4
5. *Globigerinoides immaturus* (de Leroy, 1939), sample 26
6. *Globigerinoides obliquus extreemus* (Bolli & Bermudez, 1965), sample 1
7 *Globigerinoides obliquus obliquus* (Bolli, 1957), sample 1
8. *Globigerinoides quadrilobatus* (d'Orbigny, 1846), sampl
9. *Globigerinoides ruber* (d'Orbigny, 1846), sample 4
10. *Globigerinoides subquadratus* (Bronnimann, 1954), samp 1
11. *Globoquadrina dehiscens* (Chapman, Parr & Collins, 193 sample 1
12. *Globorotalia acostaensis* (Blow,1959), sample 4
13. *Globorotalia continuosa* (Blow,`1969), sample 33
14. *Globorotalia crassaformis* (Galloway & Wissler,1927), sample 1

Fig. 6. Photomicrographs of planktonic foraminifera noticed in the present study.

1. *Globorotalia exilis* (Blow, 1969), sample 4
2 *Globorotalia humerosa* (Takayanagi & Saito,1962), sample 1
3. *Globorotalia dutertrei* (d'Orbigny, 1839), sample 33
4. *Globorotalia juanai* (Bermudez & Bolli, 1969), sample 33
5. *Globorotalia mayeri* (Cushman & Ellisor,1939), sample 27
6. *Globorotalia menardii* (d'Orbigny dalam Parker, Jones & Brady, 1865), sample 1
7 *Globorotalia plesiotumida* (Blow & Banner,1965a), sample 1
8. *Globorotalia tumida fluxuosa* (Koch,1923), sample 1
9. *Globorotalia tumida tumida* (Brady,1877), sample 33
10. *Hastigerina aequilateralis* (Brady,1884), sample 1
11. *Orbulina universa* (d'Orbigny,1839a), sample 1
12. *Praeorbulina transitoria* (Blow,1956), sample 34
13. *Pulleniatina praecursor* (Banner & Blow,1967), sample 3
14. *Pulleniatina primalis* (Banner & Blow,1967), sample 4
15. *Sphaerodinelopsis seminulina* (Schwager, 1866), sample

Fig. 7. Photomicrographs of planktonic foraminifera noticed in the present study.

4. Conclusions

Based on the measured section (MS) data, the planktonic foraminiferal zonation of Limestones in the Limboto Basin is divided into three main biozonations, namely, the *Globorotalia plesiotumida* partial range zone (Biozone M13b, Late Miocene), *Pulleniatina primalis–Globoquadrina dehiscens* concurrent range zone (Biozone M14, Late Miocene), and *Globorotalia acostaensis* partial range zone (Biozone PL1, Early Pliocene). The Miocene age consists of two biozones (i.e., M13b and M14) and the Pliocene age consists of only one biozone (PL1). The total biozonation of planktonic foraminifera comprises 3 biozones. The planktonic foraminiferal biozonation uses the standard biozonation of Blow (1969) and Wade *et al.* (2011). In total, there were two used pieces of biodata such as the LO of *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first study about biostratigraphy in Limboto Limestone Formation. These results give an idea of the age and planktonic foraminifera zonation of the Limboto Limestone that is Late Miocene – Early Pliocene, which has never been studied before. Based on the results of this study, it is appropriate to propose the name of a new formation, Limboto Limestone Formation, replacing the name of the previous formation known as Clastic Limestone Formation.

ACKNOWLEDGEMENTS

The authors thank the Indonesian Endowment Fund for Education (LPDP) for helping provide superior scholarships for Indonesian lecturers (BUDI-DN).

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Submitted : 31/10/2018
Revised : 18/03/2020
Accepted : 19/03/2020
DOI : 10.48129/kjs.v48i1.6916

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