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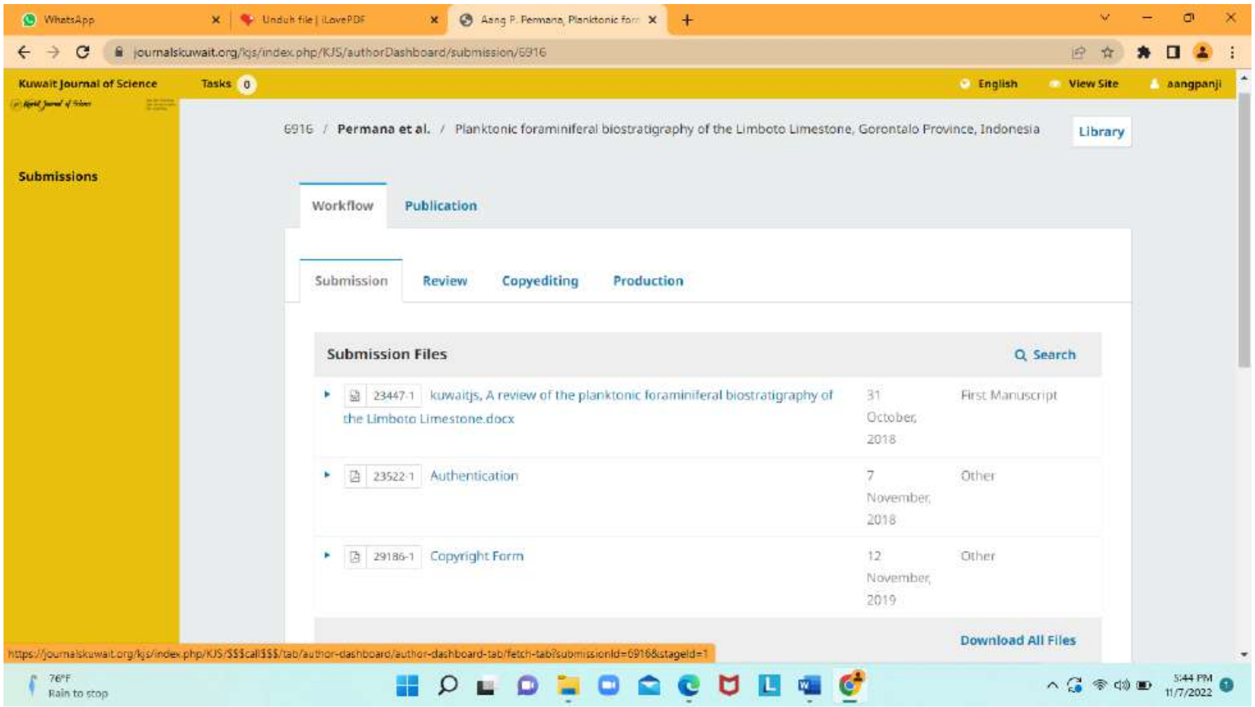

A review of the planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia

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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 northern part of Lake Limboto. The purpose of this study was to determine the planktonic foraminiferal zonation and the absolute age of Limboto limestones. The analyzed planktonic foraminiferal fossils can be classified to well-moderately preserved condition with many fossils categorized as several to abundant. There are three recognized planktonic foraminiferal zonations which are proposed to follow the standard zonation: one zonation for Miocene age (M14) and two zonations for Pliocene age (PL1 - PL2). The zone boundary comprises two biodatums: one biodatum of FO (first occurrence) and one biodatum of LO (last occurrence). The results of this study can be a reference to propose a new formation called as Limboto Limestone Formation that was previously known as Clastic Limestone Formation and

Coral Limestone Formation. The new finding based of the time interval and absolute age of the formation.

Keywords: Age; Limboto; Limestone; Planktonic; Zonation

1. Introduction

The Indonesian archipelago is geologically located in the center of three main active plates: 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. 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-shape 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 very complex which were formed during the Oligocene to Miocene age (Sukamto, 1975c; Hamilton, 1979; Daly et al., 1991).

The basement rock of the North Sulawesi arm was originated from the pre-Tertiary Pacific Oceanic plate (Taylor & Leeuwen, 1980; Katili, 1989). The northern arm of Sulawesi underwent a tectonic evolution from the Eocene or Early Miocene to the Pliocene-Pleistocene age. 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 & Suparka, 1986). Different paleomagnetic results were obtained at the latitude of $120\text{-}122^0$ E. The clockwise rotation is only $20\text{-}25^0$ which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont et al., 1994).

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 Lake Limboto formed this basin. Lake Limboto has a northwest-southeast orientation influenced by Gorontalo's main fault zone which has a dextral movement in the same direction. The main fault zone can be seen from the Patente river lineament pattern, Tanjung Tombuililato and Gorontalo coastline. The uplifting of Quartenary reef limestones near Gorontalo and Tanjung Daka on the northern coast which reached the elevation of more than 1,000 meters is evidence to the massive uplifting (Bemmelen, 1949; Katilli, 1970; 1989).

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. Coral limestone is the main rock of Pliocene-Pleistocene age, similar to the Limestone distributed in the western part of the north coast. The presence of macrofossils in limestones in Limboto Lake in Miocene and red algae in Early Miocene is a result of limestone conglomerates reworking from the southern part of Paguyaman Beach (Trail et al., 1974).

The second study was conducted to produce a regional geological map with the scale of 1 : 250,000. Limestone distribution on regional geological maps is divided into two formations: Clastic Limestone Formation (TQl) and Coral Limestone Formation (Ql). Clastic Limestone Formation (TQl), which spreads in the northern and western part of Limboto lake, has Pliocene-Pleistocene age consisting of calcarenite, calcirudite and coral limestone. This formation has a thickness ranging from 100-200 meters. Coral Limestone Unit Formation (Ql), distributed in the south of the lake, is deposited contemporaneously with the Clastic Limestone Formation (TQl) estimated to be in Holocene age. This reef limestone unit is uplifted with the coral as the main constituent (Bachri et al., 1997).

The difference in determining the limestone age in the Limboto Basin in two previous studies makes this research interesting for revealing the absolute limestone age. Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section` and biostratigraphic analysis. It is expected to produce a biostratigraphic zonation for the first planktonic foraminifera. So the purpose of the research is to make biostratigraphic zonation for planktonic foraminifera Limboto limestone, Gorontalo, Indonesia and to determine the absolute age.

2. Material and Methods

The research location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of (0°40'5,917"N, 122°51'11,939"East) to (0°39'40,670"N, 122°52'16,205"East) (Fig. 1). The research material is chiefly collected from limestone outcrops with a total thickness of 64 meters which belong to Isimu track. The thickness of thin limestone outcrops and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The implementation of MS uses a jacob's staff with an interval of 1.5 meters (Compton, 1985). Every interval of 1-1,5 meters, a potential sample containing foraminifera fossils is collected. These samples usually have the characteristics of a fine (clay-silt) size, soft (not yet compacted and not hard) and having carbonaceous material proved by the 0.1 N HCl solution test (Fig. 2)

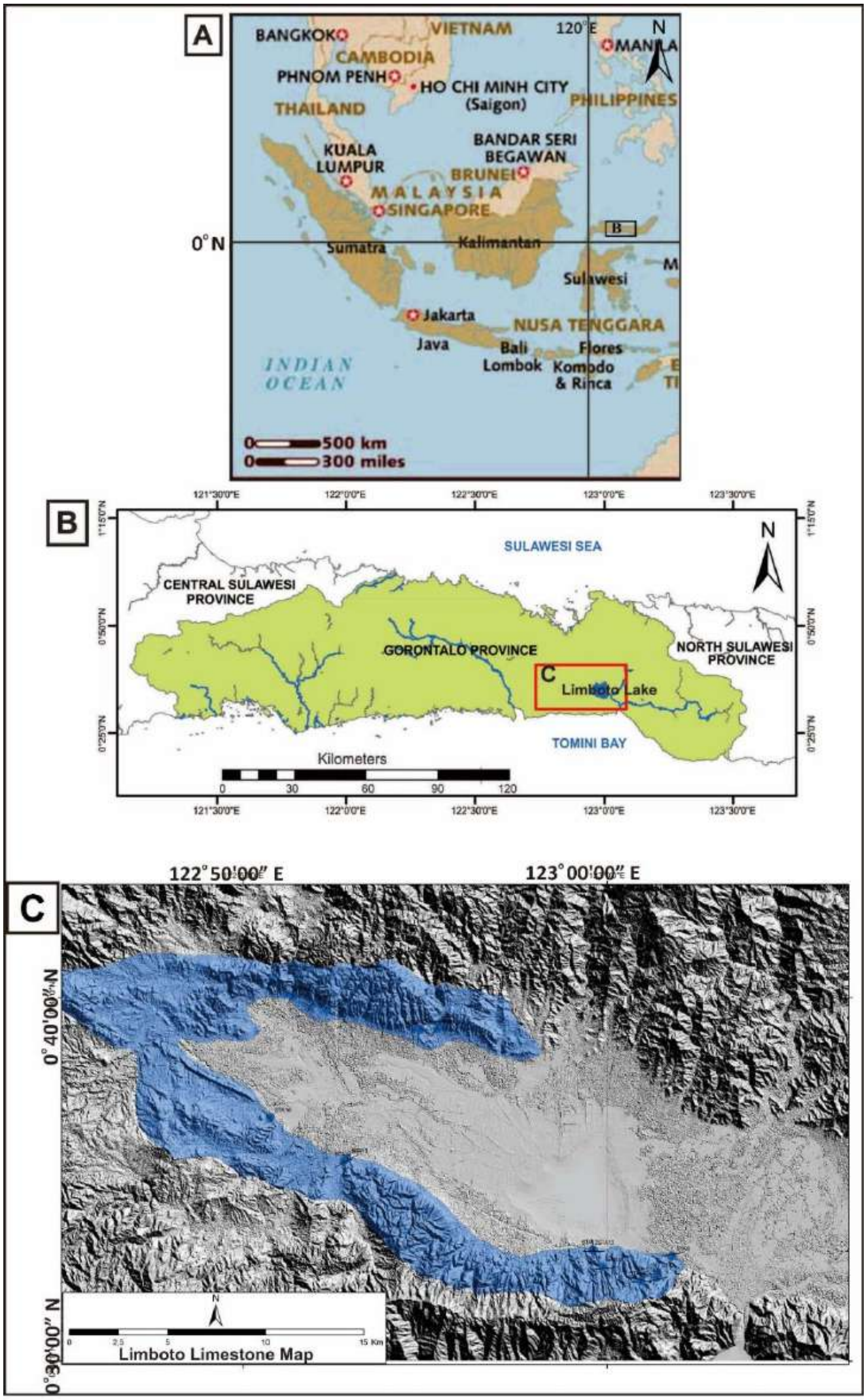


Fig 1. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area

Fig.2. Measured section at the research location using a jacob's staff

The biostratigraphy of a total of 20 samples was analyzed. A compact rock samples are pounded with porcelain pounding to ease the reaction with H_2O_2 solution. The sample is weighed 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 (ovened 70^o Celsius) and packed using plastic bags. The identification of fossil types for planktonic foraminifera uses Olympus binocular SZ61 microscope equipped with a computer-connected camera. Sediment samples generally contain moderately preserved (good enough) planktonic foraminiferas, and the abundance ranges from several to abundant. The distribution of fossil species is shown in (Fig. 3).

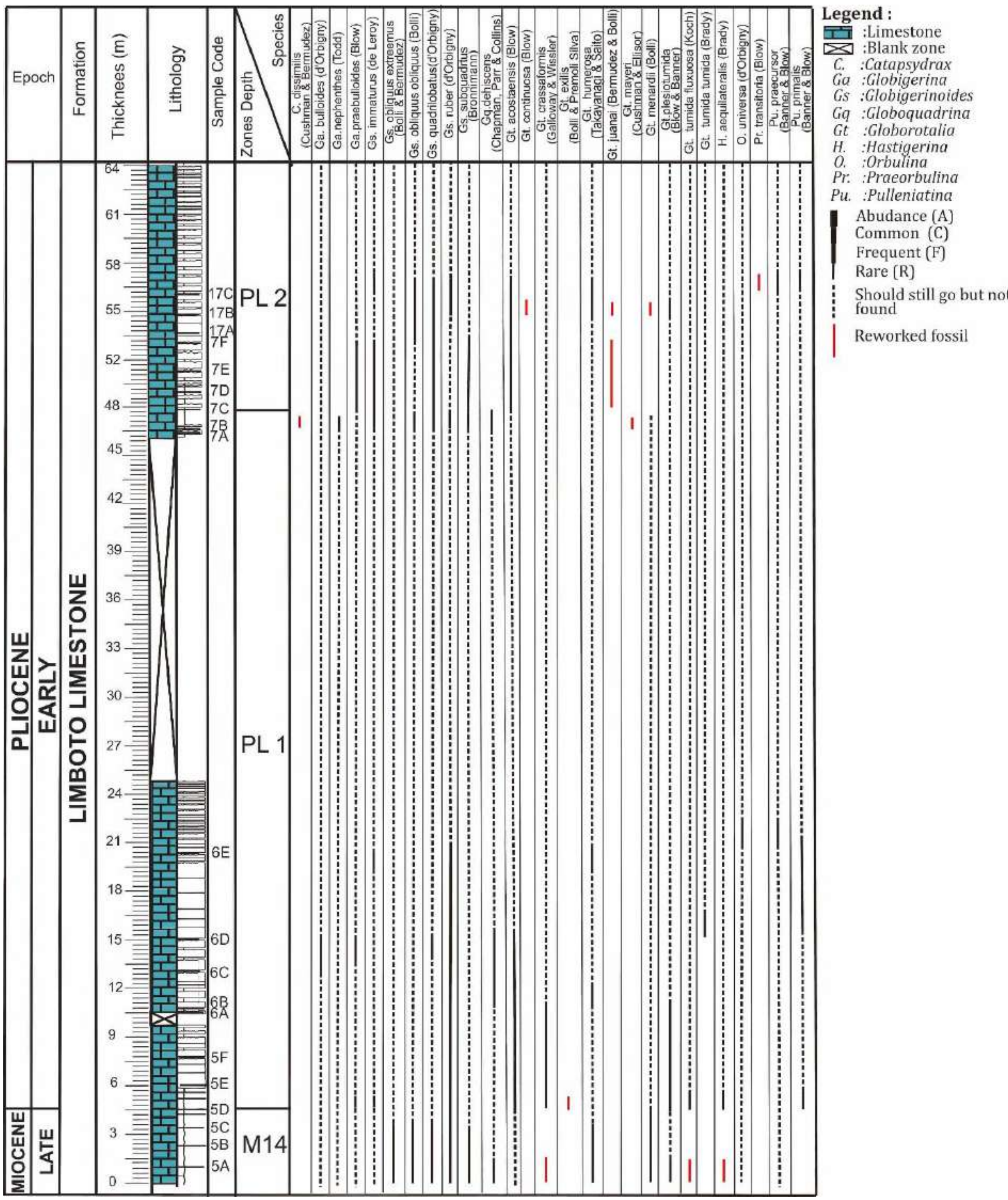


Fig. 3. Stratigraphic ranges of marker taxa of planktonic foraminifera in location research

3. Planktonic Foraminifera Zones

The planktonic foraminiferal zonation used in this study refers to Blow Biozonation (Blow, 1969) and Wade Biozonation (Wade et al., 2011). Blow Biozonation (Blow, 1969) is referred to as standard zonation because the research is carried out based on samples originating from almost all parts of the world. Blow divided the Cenozoic biozonation into two parts, namely Paleogene (Paleocene-Oligocene) and Neogen (Miocene-Pleistocene). Overall, biozonation is based on Blow Biozonation consisting of 22 main Paleogene zones with "P1" - "P22" notation, as well as 23 Neogen main zones with "N1-N23" notation.

Wade Biozonation (Wade et al., 2011) shows the increasing number of foraminifera studies in the tropic to the subtropic area, resulting in many standard biodatums for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the Earth's magnetism over the geological timespan. The most recent study (Wade et al., 2011) divides the Cenozoic to be more detail using the "P" notation for Paleocene, "E" for Eocene, "O" for Oligocene, "M" for Miocene, "OT" for Pliocene, and "PT" for the Pleistocene. This will result in a more detailed biozonation compared to the previous notation.

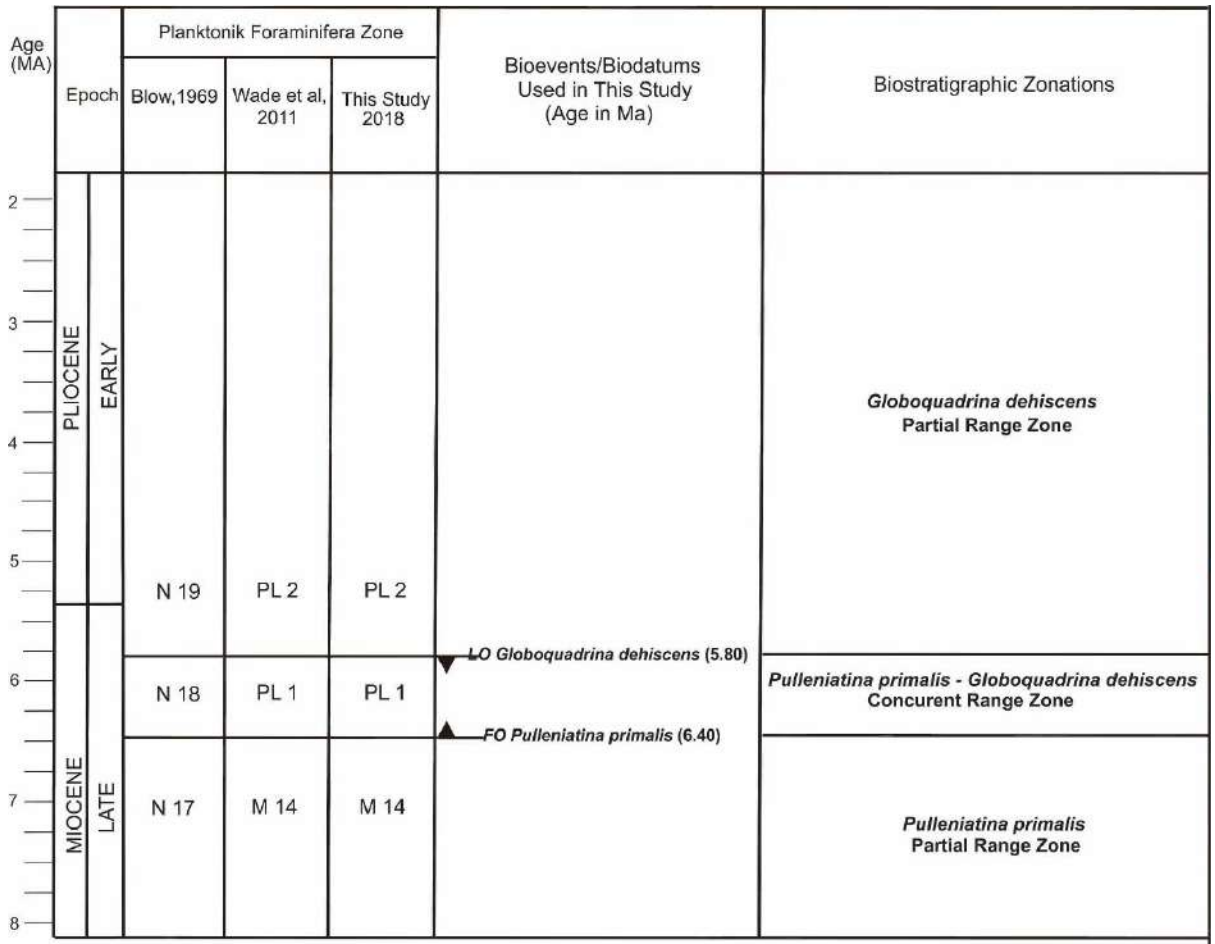
The zonation boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal zone. The following abbreviations are used in the description of zonation: FO = first occurrence and LO = the last occurrence. FO and LO define biozonation from taxa obtained from a particular region (Saraswati & Srinivasan, 2016). Biostratigraphic zone uses the terms range zone, concurrent range zone, interval zone, partial range zone, assemblage zone, phylo zone and acme zone (Saraswati & Srinivasan, 2016) (Table 1).

Zone PL2 (part)

Definition: The upper boundary of PL2 is not found. The lower boundary is marked by the LO of *Globoquadrina dehiscens.*

Discussion: This zone is *Globoquadrina dehiscens* partial range zone. Zone PL2 (part) is equivalent to Zone PL2 (Wade *et al.*, 2011) and Zone N19 (Blow, 1969). This zone represents the youngest planktonic foraminifera (uppermost). LO of *Globoquadrina dehiscens* (Berggren *et al.*, 1995a; Wade *et al.*, 2011) is found within sample 7C. The occurrence of *Globoquadrina dehiscens* is contained in the sample 5A, 5D, 6B, 6D, 7B and 7C. These following species do not show any occurrence within the upper sample of 7F, 17B, 17C.

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



The contents of fossil association within this zone are *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and *Globorotalia plesiotumida* (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow).

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this sample. The occurrence of this species is interpreted to be reworked from the older rock. The thickness of this zone is 16 meters (interval of 48-76 meters).

Age : Early Pliocene. ? - 5.80 Ma.

Zone PL1

Definition: The upper part boundary of Zone PL1 is marked by the LO of *Globoquadrina dehiscens.* The lower boundary is marked by the FO of *Pulleniatina primalis*.

Discussion: This zone is *Pulleniatina primalis- Globoquadrina dehiscens* concurrent range zone. Zone PL1 is equivalent to Zone PL1 (Wade *et al.*, 2011) and zone N18 (Blow, 1969). The first occurrence datum of this zone is marked by the FO of *Pulleniatina primalis* (Berggren *et al.*, 1995b; Wade *et al.*, 2011). The occurrence of *Pulleniatina primalis* is contained in sample 5D, 6D, 6E and 17C. The occurrence of this species is not found in the lowest sample of 5A and 5C. The latest datum of this zone is the LO of *Globoquadrina dehiscens* (Berggren *et al.*, 1995a; Wade *et al.*, 2011). The occurrence of *Globoquadrina dehiscens* is within sample 5A, 5C, 6B, 6D, 7B and 7C. The occurrence of this sample is not found in the uppermost part consisting of sample 7F, 17B and 17C.

The content of fossil association within this zone comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus*

(Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia crassaformis* (Galloway and Wissler) are found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow).

The reworked fossil of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) are also identified. The occurrence of this species is estimated to be reworked from the older rock. The thickness of this zone is 43.5 meters (interval of 4.5 – 48 meters).

Age: Early Pliocene. 5.80 - 6.40 Ma.

Zone M14

Definition: The upper boundary of Zone M14 is the FO of *Pulleniatina primalis*. The lower boundary is not found.

Discussion: This zone is *Pulleniatina primalis partial range* zone. Zone M14 is equivalent to Zone M14 (Wade *et al.*, 2011) and Zone N17 (Blow, 1969). The first occurrence datum of this zone is not found. The boundary of the last occurence datum of this zone is FO *Pulleniatina primalis* (Berggren *et al*., 1995b; Wade *et al.*, 2011) in sample 5D. The occurrence of *Pulleniatina primalis* is contained in sample 5D, 6D, 6E and 17C. The occurrence of this sample is not identified in the lowest part consisting of sample 5A and 5C.

The content of fossil association within this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus extreemus* (Bolli and Bermudez), *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia humerosa* (Takayanagi and Saito) are also identified. Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady), *Globorotalia plesiotumida* (Blow in Banner) and *Globorotalia tumida fluxuosa* (Koch).

From this sample, several reworked fossils of *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida fluxuosa* (Koch) and *Hastigerina aequilateralis* (Brady) species are identified. The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rock above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters).

Age : Early Pliocene. 6.40 - ? Ma.

4. Conclusions Remarks

Based on the measured section (MS) data, the planktonic foraminiferal zonation of limestones in the Limboto Basin is divided into two main zonations namely the Miocene (Late Miocene) and Pliocene (Early Pliocene) zones. The Miocene age consists of only one zone. Meanwhile, there are two zones in the Pliocene age (PL1 and PL2 zones). The total zonation of planktonic foraminifera comprises 3 zones. The planktonic foraminiferal zonation uses the standard zonation of Blow (Blow, 1969) and Wade (Wade et al., 2011). It is also correlated with the absolute time of the astronomical time scale (Lourens et al., 2004) and the polarity time scale (Gradstein et al., 2004). In total, there were two used biodatums such as the LO *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first finding considering that Limboto limestone has not been thoroughly studied regarding the zonation division of planktonic foraminifera. 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 (Bachri et al., 1997). The new finding facts is a matter of different ranges of formation age (Late Miocene - Early Pliocene) with the absolute age of Limboto limestone (? - 5.80 MA) to (6.40 -? Ma).

5. Acknowledgement

I would like to thank *Educational Fund Management Agency* (LPDP) for helping me provide the educational scholarships through *Indonesian lecturer main scholarship* (BUDI DN).

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Kuwait Journal of Science
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An International Refereed Journal

MS Submitted: 31/10/2018 **First Author: AANG PANJI PERMANA**

MS Title : A review of the planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia

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Limboto Limestone, Gorontalo Province, Indonesia Aang P. Permana1*,2, Subagyo Pramumijoyo2, Akmaluddin2

1 Geological Engineering Department, Gorontalo State University, Gorontalo, Indonesia 2 Geological Engineering Department, Gadjah Mada University, 14

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1. Introduction The Indonesian archipelago is geologically located in the center of three main active plates: the 9

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northeast direction. 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-shape 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 very complex which were formed during the Oligocene to Miocene age (Sukamto, 1975c;

Hamilton, 1979; Daly et al., 1991). The basement rock of 20

the North Sulawesi arm was originated from the pre-Tertiary Pacific Oceanic plate (Taylor & Leeuwen, 1980; Katili, 1989). The northern arm of Sulawesi underwent a tectonic evolution from the Eocene or Early Miocene to the Pliocene-Pleistocene age. Based on paleomagnetic studies, the northern arm underwent 900 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 & Suparka, 1986). Different paleomagnetic results were obtained at the latitude of 120-1220 E. The clockwise rotation is only 20-250 which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont et al., 1994). 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 Lake Limboto formed this basin. Lake Limboto has a northwest-southeast orientation influenced by Gorontalo's main fault zone which has a dextral movement in the same direction. The main fault zone can be seen from the Patente river lineament pattern, Tanjung Tombuililato and Gorontalo coastline. The uplifting of Quartenary reef limestones near Gorontalo and Tanjung Daka on the northern coast which reached the elevation of more than 1,000 meters is evidence to the massive uplifting (Bemmelen, 1949; Katilli, 1970; 1989). 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. Coral limestone is the main rock of Pliocene-Pleistocene age, similar to the Limestone distributed in the western part of the north coast. The presence of macrofossils in limestones in Limboto Lake in Miocene and red algae in Early Miocene is a result of limestone conglomerates reworking from the southern part of Paguyaman Beach (Trail et al., 1974). The second study was conducted to produce a regional geological map with the scale of 1 : 250,000. Limestone distribution on regional geological maps is divided into two formations: Clastic Limestone Formation (TQl) and Coral Limestone Formation (Ql). Clastic Limestone Formation (TQl), which spreads in the northern and western part of Limboto lake, has Pliocene- Pleistocene age consisting of calcarenite, calcirudite and coral limestone. This formation has a thickness ranging from 100-200 meters. Coral Limestone Unit Formation (Ql), distributed in the south of the lake, is deposited contemporaneously with the Clastic Limestone Formation (TQl) estimated to be in Holocene age. This reef limestone unit is uplifted with the coral as the main constituent (Bachri et al., 1997). The difference in determining the limestone age in the Limboto Basin in two previous studies makes this research interesting for revealing the absolute limestone age. Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section` and biostratigraphic analysis. It is expected to produce a biostratigraphic zonation for the first planktonic foraminifera. So the purpose of the research is to make biostratigraphic zonation for planktonic foraminifera Limboto limestone, Gorontalo, Indonesia and to determine the absolute age. 2. Material and Methods The research location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of (0o40’5,917”N, 122o51’11,939”East) to (0o39’40,670”N, 122o52’16,205”East) (Fig. 1). The research material is chiefly collected from limestone outcrops with a total thickness of 64 meters which belong to Isimu track. The thickness of thin limestone outcrops and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The implementation of MS uses a jacob’s staff with an interval of 1.5 meters (Compton, 1985). Every interval of 1-1,5 meters, a potential sample containing foraminifera fossils is collected. These samples usually have the characteristics of a fine (clay-silt) size, soft (not yet compacted and not hard) and having carbonaceous material proved by the 0.1 N HCl solution test (Fig. 2) Fig 1. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area Fig.2. Measured section at the research location using a jacob’s staff The biostratigraphy of a total of 20 samples was analyzed. A compact rock samples are pounded with porcelain pounding to ease the reaction with H2O2 solution. The sample is weighed 100 grams. After that, the H2O2 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 (ovened 70o Celsius) and packed using plastic bags. The identification of fossil types for planktonic foraminifera uses Olympus binocular SZ61 microscope equipped with a computer-connected camera. Sediment samples generally contain moderately preserved (good enough) planktonic foraminiferas, and the abundance ranges from several to abundant. The distribution of fossil species is shown in (Fig. 3).

Fig. 3. Stratigraphic ranges of marker taxa of **planktonic foraminifera in**	22

location research

3. Planktonic Foraminifera Zones **The planktonic foraminiferal** zonation used **in this**	21

study refers to Blow Biozonation (Blow, 1969) and Wade Biozonation (Wade et al., 2011). Blow Biozonation (Blow, 1969) is referred to as standard zonation because the research is carried out based on samples originating from almost all parts of the world. Blow divided the Cenozoic biozonation into two parts, namely Paleogene (Paleocene-Oligocene) and Neogen (Miocene-Pleistocene). Overall, biozonation is based on Blow Biozonation consisting of 22 main Paleogene zones with "P1" - "P22" notation, as well as 23 Neogen main zones with "N1-N23" notation. Wade Biozonation (Wade et al., 2011) shows the increasing number of foraminifera studies in the tropic to the subtropic area, resulting in many standard biodatums for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the Earth's magnetism over the geological timespan. The most recent study (Wade et al., 2011) divides the Cenozoic to be more detail using the "P" notation

for Paleocene, "E" for Eocene, "O" for Oligocene, 2

"M" for Miocene, "OT" **for Pliocene, and "PT" for** the **Pleistocene.** This will result **in** 2

a more detailed biozonation compared to the previous notation. The zonation boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal zone. The following abbreviations are used in the description of zonation: FO =

first occurrence and LO = the **last occurrence. FO** 24

and LO define biozonation from taxa obtained from a particular region (Saraswati & Srinivasan, 2016). Biostratigraphic zone uses the terms

range zone, concurrent range zone, interval zone, partial **range zone,** assemblage **zone,** phylo **zone** and acme **zone** 13

(Saraswati & Srinivasan, 2016) (Table 1). Zone PL2 (part) Definition: The

upper boundary of PL2 **is** not found. **The lower boundary** is marked by **the** 19

LO of Globoquadrina dehiscens. Discussion: This zone is Globoquadrina dehiscens partial range zone. Zone PL2 (part) is equivalent to Zone PL2 (Wade et al., 2011) and Zone N19 (Blow, 1969). This zone represents the youngest planktonic foraminifera (uppermost). LO of Globoquadrina dehiscens

(Berggren et al., 1995a; Wade et al., 2011) is 16

found within sample 7C. The occurrence of Globoquadrina dehiscens is contained in the sample 5A, 5D, 6B, 6D, 7B and 7C. These following species do not show any occurrence within the upper sample of 7F, 17B, 17C. Table 1. Planktonic foraminifera zonation proposed in this study compared to those of (Blow, 1969) and (Wade et al., 2011) The contents of fossil association within this zone are Globigerina praebulloides (Blow),

Globigerinoides immaturus (de Leroy), Globigerinoides obliquus obliquus (Bolli), Globigerinoides quadrilobatus (d'Orbigny) and Globigerinoides ruber (d'Orbigny). Moreover, species of Globigerinoides subquadratus (Bronnimann), Globorotalia acostaensis (Blow), Globorotalia 1

humerosa (Takayanagi and Saito), Globorotalia dutertrei (d'Orbigny) and Globorotalia plesiotumida (Blow and Banner) are also found. Also there are fossil species Praeorbulina transitoria (Blow),

Pulleniatina praecursor (Banner and Blow) and Pulleniatina primalis (Banner and Blow). 1

Several reworked fossils such as Globorotalia continuosa (Blow), Globorotalia juanai (Bermudez and Bolli), Globorotalia menardii (d'Orbigny in Parker, Jones and Brady) and Praeorbulina transitoria (Blow) species are also identified from this sample. The occurrence of this species is interpreted to be reworked from the older rock. The thickness of this zone is 16 meters (interval of 48-76 meters). Age : Early Pliocene. ? - 5.80 Ma. Zone PL1

Definition: The upper part boundary of Zone PL1 is marked by the LO of 5

Globoquadrina dehiscens. The lower boundary is marked by the FO of Pulleniatina primalis. Discussion: This zone is Pulleniatina primalis- Globoquadrina dehiscens concurrent range zone. Zone PL1 is equivalent to Zone PL1 (Wade et al., 2011) and zone N18 (Blow, 1969). The first occurrence datum of this zone

is marked by the FO of Pulleniatina primalis (Berggren et al., 7

1995b;

Wade et al., 2011). The occurrence of Pulleniatina primalis is contained in 3

sample 5D, 6D, 6E and 17C. The occurrence of this species is not found in the lowest sample of 5A and 5C. The latest datum of this zone is the LO of Globoquadrina dehiscens

(Berggren et al., 1995a; Wade et al., 2011). The occurrence of 15

Globoquadrina dehiscens is within sample 5A, 5C, 6B, 6D, 7B and 7C. The occurrence of this sample is not found in the uppermost part consisting of sample 7F, 17B and 17C. The content of fossil association within this zone comprises

Globigerina bulloides (d'Orbigny), Globigerina nepenthes (Todd), Globigerina praebulloides (Blow), 23

Globigerinoides immaturus (de Leroy) and Globigerinoides obliquus obliquus (Bolli). Moreover, Globigerinoides quadrilobatus (d'Orbigny), Globigerinoides ruber (d'Orbigny), Globigerinoides subquadratus (Bronnimann), Globorotalia acostaensis (Blow) and Globorotalia 1

crassaformis (Galloway and Wissler) are found. Also there are fossil species

Globorotalia humerosa (Takayanagi and Saito), Globorotalia plesiotumida (Blow and Banner), Globorotalia 11

tumida tumida (Brady),

Orbulina universa (d'Orbigny) and Pulleniatina praecursor (Banner and Blow). 1

The reworked fossil of Catapsydrax dissimilis (Cushman and Bermudez), Globorotalia juanai (Bermudez and Bolli) and Globorotalia mayeri (Cushman and Ellisor) are also identified. The occurrence of this species is estimated to be reworked from the older rock. The thickness of this zone is 43.5 meters (interval of 4.5 – 48 meters). Age: Early Pliocene. 5.80 - 6.40 Ma. Zone M14

Definition: The upper boundary of Zone M14 is the FO of 5

Pulleniatina primalis. The lower boundary is not found. Discussion: This zone is Pulleniatina primalis partial range zone. Zone M14 is equivalent to Zone M14 (Wade et al., 2011) and Zone N17 (Blow, 1969). The first occurrence datum of this zone is not found. The boundary of the last occurence datum of this zone is FO Pulleniatina primalis (Berggren et al., 1995b;

Wade et al., 2011) in sample 5D. The occurrence of Pulleniatina primalis is contained in 3

sample 5D, 6D, 6E and 17C. The occurrence of this sample is not identified in the lowest part consisting of sample 5A and 5C. The content of fossil association within this zone is

Globoquadrina dehiscens (Chapman, Parr and Collins), Globigerina praebulloides (Blow), 7

Globigerinoides immaturus (de Leroy),

Globigerinoides obliquus extreemus (Bolli and Bermudez), Globigerinoides obliquus obliquus (Bolli). Moreover, Globigerinoides quadrilobatus (d'Orbigny), Globigerinoides ruber (d'Orbigny), Globigerinoides 6

subquadratus (Bronnimann), Globorotalia acostaensis (Blow) and Globorotalia humerosa (Takayanagi and Saito) are also identified. Also there are fossil species Globorotalia menardii (d'Orbigny in

Parker, Jones and Brady), Globorotalia plesiotumida (Blow in Banner) and Globorotalia 4

tumida fluxuosa (Koch). From this sample, several reworked fossils of

Globorotalia crassaformis (Galloway and Wissler), Globorotalia exilis (Blow), Globorotalia 4 tumida fluxuosa (Koch) and Hastigerina aequilateralis (Brady) species are identified. The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rock above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters). Age : Early Pliocene. 6.40 - ? Ma. 4. Conclusions Remarks Based on the measured section (MS) data, the planktonic foraminiferal zonation of limestones in the Limboto Basin is divided into two main zonations namely the Miocene (Late Miocene) and Pliocene (Early Pliocene) zones. The Miocene age consists of only one zone. Meanwhile, there are two zones in the Pliocene age (PL1 and PL2 zones). The total zonation of planktonic foraminifera comprises 3 zones. The planktonic foraminiferal zonation uses the standard zonation of Blow (Blow, 1969) and Wade (Wade et al., 2011). It is also correlated with the absolute time of the astronomical

time scale (Lourens **et al., 2004) and** the polarity **time scale** (Gradstein **et al.,** 12

2004). In total, there were two used biodatums such as the LO Globoquadrina dehiscens and FO of Pulleniatina primalis. This result is the first finding considering that Limboto limestone has not been thoroughly studied regarding the zonation division of planktonic foraminifera.

Based on the results of this study, it 17

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 (Bachri et al., 1997). The new finding facts is a matter of different ranges of formation age (Late Miocene - Early Pliocene) with the absolute age of Limboto limestone (? - 5.80 MA) to (6.40 -? Ma). 5. Acknowledgement I would like to thank Educational Fund Management Agency (LPDP) for helping me provide the educational scholarships through Indonesian lecturer main scholarship (BUDI DN). References Bachri, S., Partoyo, E., Bawono, S.S., Sukarna, D., Surono. & Supandjono, J.B. (1997) Regional geology of Gorontalo, North Sulawesi. Collection of research and mapping results papers centre for geological research and development : Pp. 18-30. Bemmelen, R.W. van. (1949) The Geology of Indonesia Vol 1A. Government Printing Office The Hauge. Pp 732. Berggren, W. A., Hilgen, F. J., Langereis, C. G., Kent, D. V., Obradovich, J. D., Raffi, I., Raymo, M. E. & Shackleton, N. J. (1995a) Late neogene chronology: new perspectives in highresolution stratigraphy. Geol. Soc. Am. Bull, 107 : 1272–1287. Berggren, W. A., Kent, D. V., Swisher III, C. C. & Aubry, M.-P. (1995b) A revised cenozoic geochronology and chronostratigraphy. In: Berggren, W. A., Kent, D. V., Aubry, M. P. & Hardenbol, J. Geochronology, time scales and global stratigraphic correlation : A uniteed temporal framework for an historical geology: SEPM Spec. Publ, 54 : 129–212. Blow, W. H. (1969) Late middle eocene to recent planktonic foraminiferal biostratigraphy, In: Brönnimann, P., Renz, H.H. (Eds.). Proceedings of the First International Conference on Planktonic Microfossils, E.J. Brill, Leiden, 1 : 199–422. Compton, R. R. (1985) Geology in the field. Wiley Press-New York. Pp. 416. Daly, M. C., Hooper, B. G. D., & Smith, D. G. (1991) Tertiary plate tectonics and basin evolution in Indonesia. Proc. 16th Ann. Con. Indon. Petroleum Assoc, Jakarta : 399-427. Gradstein, F. M., Ogg, J. G. & Smith, A. G. (2004) A Geologic Time Scale 2004. Cambridge University Press, Cambridge, UK. Pp. 500. Hamilton, W. (1979) Tectonics of the Indonesian region.

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Revised Results/ Authors Response

Round 1

Part	Comments from Reviewer A (6916-31783-2-RV)	Author's Response
	Why the area is left blank on page # 7 and 8? There should be no blank area within the text of the paper. However, it might be covered during final preparation and editing of the manuscript.	Thank you for your input. Improvements have been made so that there are no more free spaces on pages 7 and 8.
	Text (especially codes of different geological formations or rock units) on map part of fig. 2 is not legible. Increase the font size so that the text can be readable.	Thank you for your input. Improvements have been made so that the letter size on the rock formation has been enlarged so that it appears clear.
	I don't know why the authors are ignoring my comment again and again about insertion of outcrop photographs. They can simply answer in response to my comment that unfortunately, we haven't got outcrop photograph(s). It is not adequate and suitable to avoid answering a comment of reviewer. Each and every comment(s) of reviewer should be considered and answered with great care.	Thank you for your input. Improvements have been made by replacing outcrop photos taken by measured setions (MS) with two new, clearer photos.
	Insert photomicrograph(s) of fossil species *Globigerina bulloides* (d'Orbigny). It is mentioned in the text but no photomicrograph(s) is provided.	Thank you for your input. Improvements have been made by adding fossil species of Globigerina bulloides (d'Orbigny).
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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 is 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 very 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 was 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).

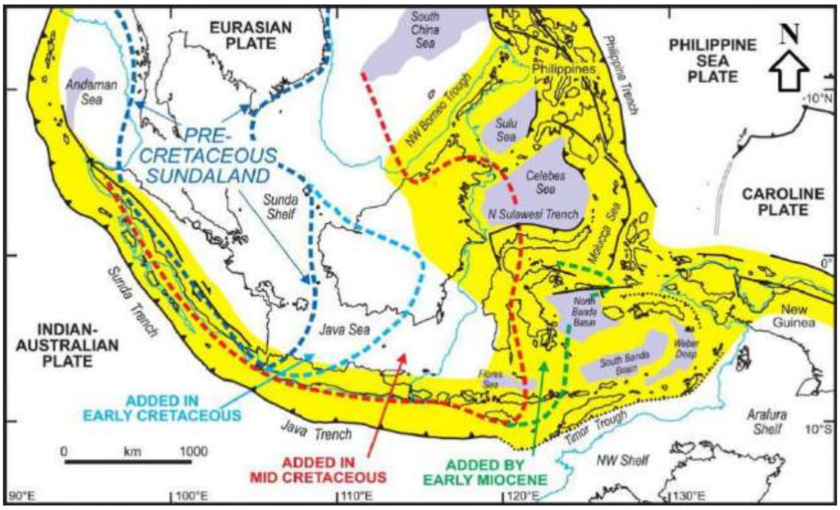

Fig. 1. Tectonic map of Indonesia showing the interaction of major plates (modified from Hamilton, 1979)

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 and 1989). 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 and 1989).

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 - 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 was conduct detailed research by using measured outcrop section and biostratigraphic analysis, which was done for the first time in this formation. So the purpose of current research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

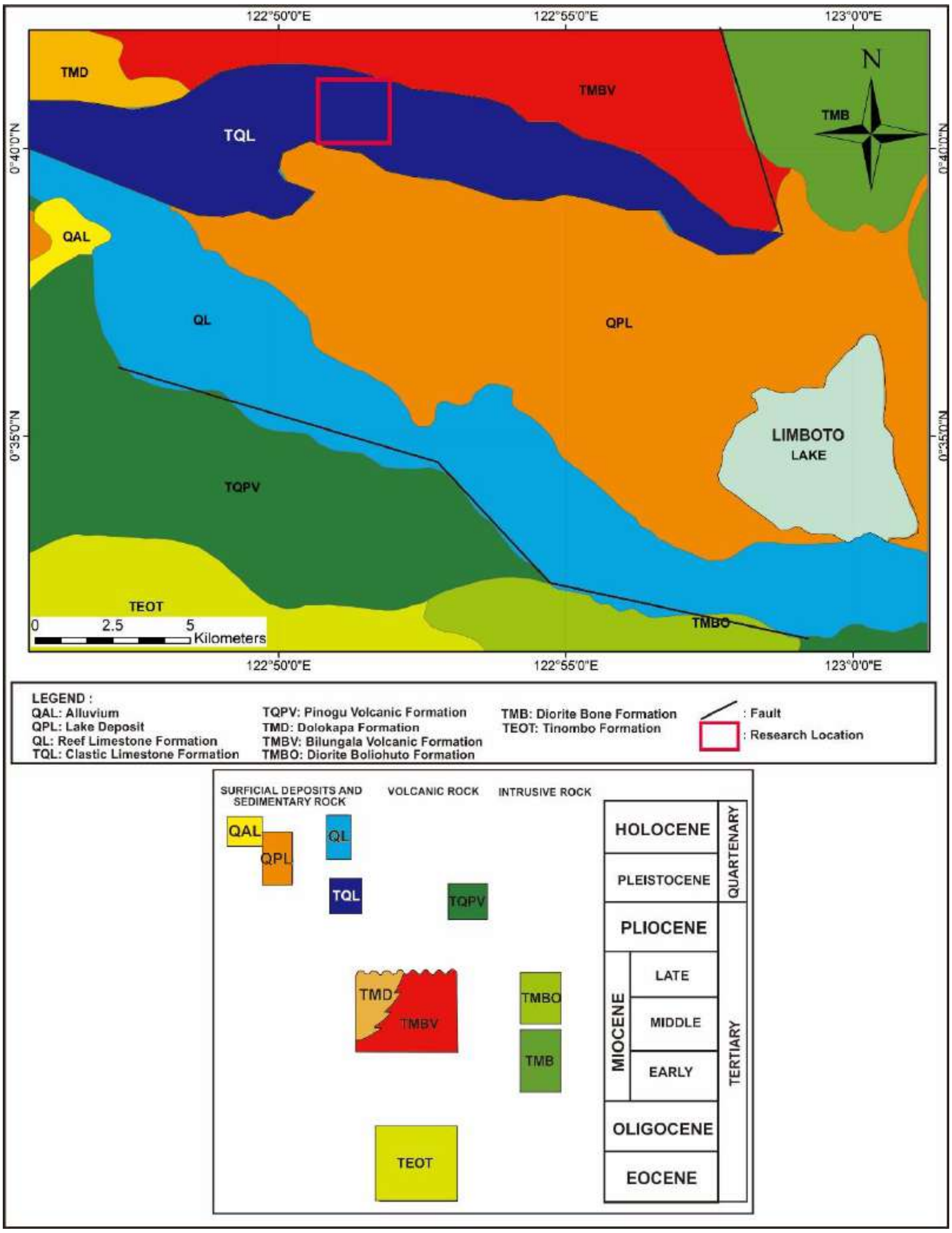

Fig. 2. Regional Geological Map of Gorontalo (Bachri *et al*., 1997). The present research location (Limboto area) is marked with box having pink color outline.

2. Materials and Methods

The present research area location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of $0^{o}40'5.917''$North, $122^{o}51'11.939''$East) to $0^{o}39'40.670''$North, $122^{o}52'16.205''$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 method of Compton (1985) with an interval of 1.5 meters. Then, the sample was taken in every 1 to 1.5 meter. The collected samples usually consists 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 (ovened 70^{o} 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). 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).

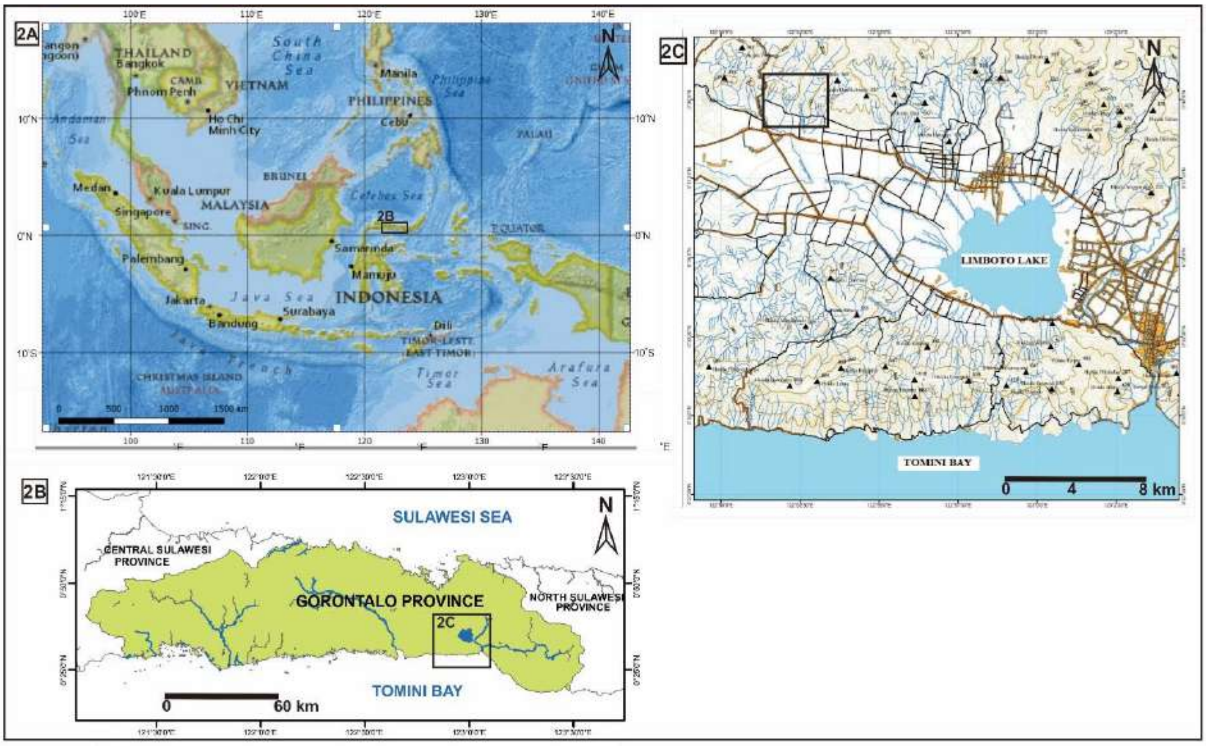

Fig. 3. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limbolo Lake on the map of Gorontalo Province (GIS map) and (2C) the map of research location (Isimu 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 refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 biodatums 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 detail 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 *etal*. (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 includes 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 zone(s) 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 the limitation of sample that analyze. The upper boundaryof 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 species which commonly found and characterized the Late Miocene age, that is *Globorotalia plesiotumida.*

The fossil association of this zone are *Globoquadrina dehiscens* (Chapman, Parr and Collins, 1934), *Globigerina praebulloides* (Blow, 1959), *Globigerinoides immaturus* (de Leroy, 1939), *Globigerinoides obliquus extreemus* (Bolli and Bermudez, 1965), *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), that 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 comprises *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), that 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) that can be seen in Figures 6 and 7.

Several reworked fossils such as *Globorotalia continuosa* (Blow, 1969), *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, that 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)

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
PLIOCENE	EARLY	N18	PL1	PL1		*Globorotalia Acostaensis* Partial Range Zone
MIOCENE	LATE	N17b	M14	M14	LO *Globoquadrina dehiscens* (5.80); FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurent Range Zone
MIOCENE	LATE	N17a	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

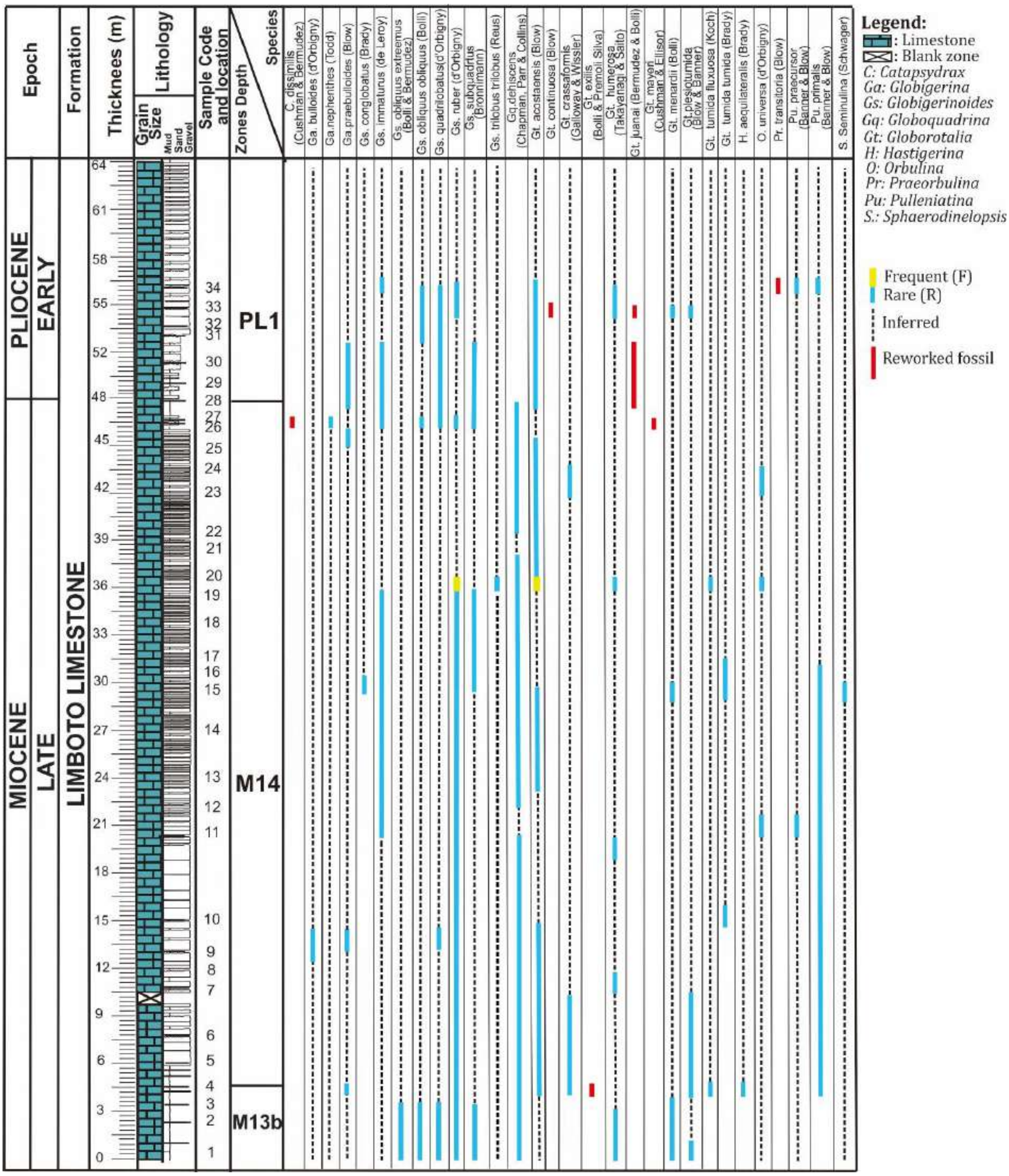

Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto limestone, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age

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), sampk
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 present study

PLATE 2

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 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 primales – 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 biodatums such as the LO *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 to 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.

5. Acknowledgement

Thanks to the Indonesian Endowment Fund for Education (LPDP) for helping to provide superior scholarships for Indonesian lecturers (BUDI-DN).

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ROUND 2

Part	Comments from Reviewer A (6916-Ref.1)	Author's Response
Topic Title	Formatted : Left	Thank you for the question.
	Formatted : English (United State)	Thank you for your input. We have already revised it.
	Why a review ?	Thank you for your input. We have already revised it.
Abstract	This term is reserved for geochronology. Biostratigraphy is a part of chronostratigraphy.	Thank you for your input. In this study we only analysis of foraminiferal biostratigraphy, then the absolute age is not analysis in this study, but we refer to Wade et.al., (2011). Therefore, this study not using the term of geochronology.
	This is standard procedurę in biostratigraphic analysis thus I,m not sure whether this sentence should be placed in your abstract.	Thank you for your input. We have already removed it from the abstract text.
	Formatted : English (United State)	Thank you for your input. We have already revised it.
Introduction	What second?	Thank you for your question. The “second” word is mean the second previous study in the text. We have already revised it into “previous study”.
	See coment above, based on fossils you can only estimate chronostratigraphic position.	Thank you for your input. The absolute age is not analysis in this study, but we refer to Wade et.al., (2011) according to biodatum in this study.
	The main aim i.e., biostratigraphy is repeated at least 3 times in these short paragraph.	Thank you for your input. We have already revised it.
	What do you mean by first?	Thank you for your input. We have already revised it.
Materials and Methods	Onlu one sample?	The biostratigraphy of a total of 34 samples was analyzed.
Results and Discussion	Which?	Thank you for your input. We have already revised it.
	You do not use all these zones e.g., assemblage or phylo zones. Why you put this information without and discussion?	Thank you for your input. We have already revised it.
	Please present zonations from oldest to youngest	Thank you for your input. We have already revised it.
	Images of the index fossils are absolutly neede	Thank you for your input. We have already inserted the photo of biodatum and other species in the text.
	The species range is very discontinuous in the studied section, so the las tor first	Thank you for your question. The discontinuouity of *Pulleniatina primalis* is only on upper part of the

	occurrence can be rather ecological instead on evolutionary	section. So, we interpret that the first occurrence of that species in sample 5D is the real FO.
	What youngest??? Where?	Thank you for your question. The point is that the zone is the youngest zone in this study.
	What about 17A?	Thank you for your question. We have already insert it.
	By who?	Thank you for your input. We have already revised it.
	Discontinous range, the LO of the species might be ecological. This should be discussed	Thank you for your question. The discontinuouity of *Pulleniatina primalis* is only on upper part of the section. So, we interpret that the first occurrence of that species in sample 5D is the real FO.
	This sentence is written above	Thank you for your input. We have already revised it.
	What about 17A?	Thank you for your question. We have already insert it.
	See comment above	Thank you for your input.
	How it is possible, samples should be washed before processing. Samples must be collected from fresh wall of the outcrops.	Thank you for your question. The leakage fossil indicated cause by rockfall or grainfall from above of outcrop.
	Why not ecological?	Thank you for your question. The discontinuouity of *Pulleniatina primalis* is only on upper part of the section. So, we interpret that the first occurrence of that species in sample 5D is the real FO.
	The first occurence datum of taxa not zone	Thank you for your input.
	What about 5B?	Thank you for your question. We have already insert it.
	ibid	
	so it looks like the rock procedure was wrong	Thank you for your input. However, we have carried out the process of sampling, preparation and sample observation according to standard procedures.

Part	**Comments from Reviewer B (6916-Ref.2)**	**Author's Response**
Abstract	rephrase	Thank you for your input.
	rephrase	Thank you for your input.
	rephrase	Thank you for your input.

	there is no need to mention the word "Formation" because surname of the Formation is most often its dominant lithology, however, if the rock unit is a mixture of multiple lithologies then the term 'Formation' can be used.	Thank you for your input. We have already revised it.
	Confusing. Rephrase it.	Thank you for your input. We have already revised it.
	Not a good one.	Thank you for your input. We have already revised it.
Introduction	Insert pertinent reference(s).	Thank you for your input. We have already inserted the reference.
	Reference(s).	Thank you for your input. We have already inserted the reference.
	rephrase	Thank you for your input.
	rephrase	Thank you for your input.
	Earlier, in the above text, Coral Limestone Formation is used. Therefore, the word 'unit' should be deleted. Otherwise, check and confirm it.	Thank you for your input. We have already revised it.
	rephrase	Thank you for your input.
	confusing, rephrase it.	Thank you for your input.
	Mention the references of these two studies.	Thank you for your input. We have already inserted the reference.
	If the authors are referring to figure 1C, then there should also be an explicit details of procedure(s) followed for the present mapping. Likewise, manuscript title, abstract, portion of results and discussion and conclusions will be modified accordingly.	Thank you for your input.
	rephrase	Thank you for your input.
Material and Methods	Formatted : Indent : First line : 1,27 cm	Thank you for your input.
	is it a dot (.), if yes, then the comma (,) should be replaced with dot (.)	Thank you for your input.
	use proper signs / symbols of degree, minute and seconds.	Thank you for your input.
	Replace it with relevant synonym.	Thank you for your input.
	rephrase	Thank you for your input.
	rephrase	Thank you for your input.
	write complete terms/words on first use.	Thank you for your input. We have already revised it.
	Formatted : English (United State)	
	In Fig.1B, the rectangle labeled as 'C' should be labeled as Fig. 1C.	Thank you for your input.

		Previously, in the latest text, the image you meant became image 2. In the picture, we have added a label to the box.
	It will be much better if the authors can mark the areas on Figure 1C from where the studied rock samples are collected.	Thank you for your input. We have already revised it.
	There are two colors (darker and blue) in Figure 1C. Therefore, it is suggested to incorporate a legend reflecting / demonstrating the depth / elevation readings of different areas.	Thank you for your input. Figure C has changed the basic map to a topographic map.
	In Figure1C, the latitude and longitude readings contain overwriting. It should be corrected.	Thank you for your input. We have already inserted it.
	In Fig. 1C, there is title of map below the legend. So this title should be deleted as it will be already mentioned in the figure 1C caption in order to avoid repetition.	Thank you for your input. We have already revised it.
	Reference for Fig. 1B should be inserted, however, if it is generated by authors then it should be defined as GIS / Global mapper map of the Sulawesi area and so on.	Thank you for your input. We have already revised it.
	In Fig.1A, the rectangle labeled as 'B' should be labeled as Fig. 1B.	Thank you for your input. We have already revised it.
	Insert reference for Figure 1A. It would be great if the authors can improve the quality of this map. It is a bit blur.	Thank you for your input. We have already revised it.
	As the figure consists of three component figures, so there should be a genera caption followed by caption of Fig. 1A, 1B and 1C.	Thank you for your input. We have already revised it.
	rephrase	Thank you for your input. We have already revised it.
	Is it possible to mark samples locations on this outcrop photograph?	Thank you for your input. In the draft that I have improved, we have added sample images and sampling.
	insert north arrow on the map.	Thank you for your input. We have already inserted the North arrow.
	Mention full name of the research location.	Thank you for your input. We have already revised it
	rephrase	
	rephrase	
	rephrase	
Result and Discussions	Column 5 heading should be modified to 'Sample code and location'. Why the sample number starts from 5 and ranges up to 17. It should be from 1 to 20. Clarify this confusion.	Thank you for your input. We have already revised it. Sampling positions are carried out sequentially from STA 5, 6 and 7 while 17 is a continuation of the top part of STA 7
	Delete space between alphabets and digits of biozones (PL1 and PL2) mentioned in column 6 of Figure 3.	Thank you for your input. We have already revised it
	The planktonic fossils distribution area of Figure 3 should be under the heading	Thank you for your input. We have already revised it

	'**Species**'. Likewise the column 6 heading will become biozones / zones depth.	
	The font size in column titled 'Epoch' and 'Formation' should be identical.	Thank you for your input. We have already revised it
	In the figure, the distribution of different fossils is shown by the symbols of Abundant (A), Common (C), Frequent (F) and Rare (R). The differences between the symbols of these terms are quite obvious in legend, however, in the main figure such differences are not prominent. Modify it please.	Thank you for your input. We have already revised it into using the different color.
	In legend dash lines refers to "should still go but not found". It should be replaced with the word 'inferred'.	Thank you for your input. We have already revised it
	In legend, abundance (A) should be replaced with 'Abundant'.	Thank you for your input. We have already revised it
	In column 6 (Zones depth), you are referring to the zones in the depositional environment and settings where the identified fossils live or preserved or you are actually referring to the depth at which samples are collected? It is because the present samples are collected from outcrop section. Clarify this confusion, please.	Thank you for your input. In the text, we are actually referring to the depth at which samples are collected.
	in legend the colons (:) should be directly adjacent to the used term and there should be space after colon (:).	Thank you for your input. We have already revised it
	The 'Blank zone' is exposed rock unit with negligible fossils or it is a rock exposure covered with soil or vegetation? Clarify it please.	Thank you for your input. In the text, we have added data at intervals that were previously blank zones. The blank zone is the upper 5F and the lower 6A, which is a layer of soil covered with plants
	delete space after legend and before colon (:)..	Thank you for your input. We have already revised it
	in lithology column, the symbols to the right of limestone are not clear….What they are showing actually?	Thank you for your input. We have already revised it
	correct the spelling of thickness i.e. heading of column 3.	Thank you for your input. We have already revised it
	rephrase	
	this statement is confusing. Rephrase the sentence.	Thank you for your input. We have already revised it
	rephrase	Thank you for your input. We have already revised it.
	Formatted : Space After : 8 pt	Thank you for your input. We have already revised it.
	Modify the heading, for example, Biozones in the Limboto Limestone Name of the biozone	Thank you for your input. We have already revised it
	?	Thank you for your input. We have already revised it.

	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Confusing…..rephrase it..	Thank you for your input. We have already revised it
	Formatted : Justified, Space After : 0 pt, Tab stops : Not at 5,73 cm	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Delete space between alphabets and digits of biozones (N 17, N 18, N 19; M14; PL1 and PL2) of Blow (1969), Wade et al. (2011) and This study (2019) mentioned in column 3.	Thank you for your input. We have already revised it
	In the first column million years ago is shown by MA, however, in the fourth column it is shown by Ma. You are advised to consistently use uniform abbreviations. The second one (Ma) will be fine.	Thank you for your input. We have already revised it
	Last column should be changed to Biostratigraphic Zonations of the present study	Thank you for your input. We have already revised it
	In the fourth column (Bioevents/Biodatums), the first alphabet of used (U), this (T) and study (S) should be written in small letters.	Thank you for your input. We have already revised it
	In the third sub-column of third main column i.e. Planktonic Foraminifera Zone, the present column heading (This Study 2018) should be replaced with the following heading: Permana et al., 2019 (this study)	Thank you for your input. We have already revised it
	In the third major column, ‘k’ should be replaced with ‘c’ in the planktonic…………	Thank you for your input. We have already revised it
	Formatted : Left, Space After : 8 pt, Tab stops : Not at 5,73 cm	Thank you for your input. We have already revised it.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied samples.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	Mention the sample code.	Thank you for your input. We have already revised it.
	Can the authors mention the age and name of geological formations for older rocks?	Thank you for your input. We have already insert it in the text. The older rock is Dolokapa Formation which has Middle Miocene age

	?	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
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	?	Thank you for your input. We have already revised it.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	Can the authors specify the age and name of geological formations for older rocks?	Thank you for your input. We have already insert it in the text. The older rock is Dolokapa Formation which has Middle Miocene age
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	Formatted : Font : Not Italic	Thank you for your input. We have already revised it.
	?	Thank you for your input. We have already revised it.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	There should be photographic evidence(s) to support the identification and presence of such planktonic foraminifera in the studied area.	Thank you for your input. We have already inserted the photographic of biodatum and other species in the text.
	Any information about the relative age and even about the name of these younger rocks? If yes, then mention the age and name as well…	Thank you for your question. The leakage fossil indicated cause by rockfall or grainfall from above of outcrop.
	?	Thank you for your input. We have already revised it. Thickness of the biozone interval from the measured section
	?	Thank you for your input. We have already revised it. The lower limit of

		biozone is unknown (lowest age is unknown)
	Rewrite conclusions	Thank you for your input. We have already revised it
	Usually conclusion(s) section concludes any manuscript with some insights / projections of the field of study without considering / citing any reference. This reference should be cited somewhere in the results and discussion section.	Thank you for your input. We have already revised it
	Usually conclusion(s) section concludes any manuscript with some insights / projections of the field of study without considering / citing any reference. This reference should be cited somewhere in the results and discussion section.	Thank you for your input. We have already revised it
	rephrase	Thank you for your input. We have already revised it.
	rephrase	Thank you for your input. We have already revised it.

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 with many fossils, 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 results of this study can be a reference to propose a new formation called as Limboto Limestone Formation that was previously known as Clastic Limestone Formation and Coral Limestone Formation. Identification and demarcation of the Limboto Limestone Formation is based on the time interval and relative age of the formation based on planktonic foraminifera.

Keywords: Foraminiferal biostratigraphy, Limboto Limestone

2. 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 very 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 was 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 $120\text{-}122^0$ E (Surmont *et al.*, 1994). The clockwise rotation is only $20\text{-}25^0$ which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al.*, 1994).

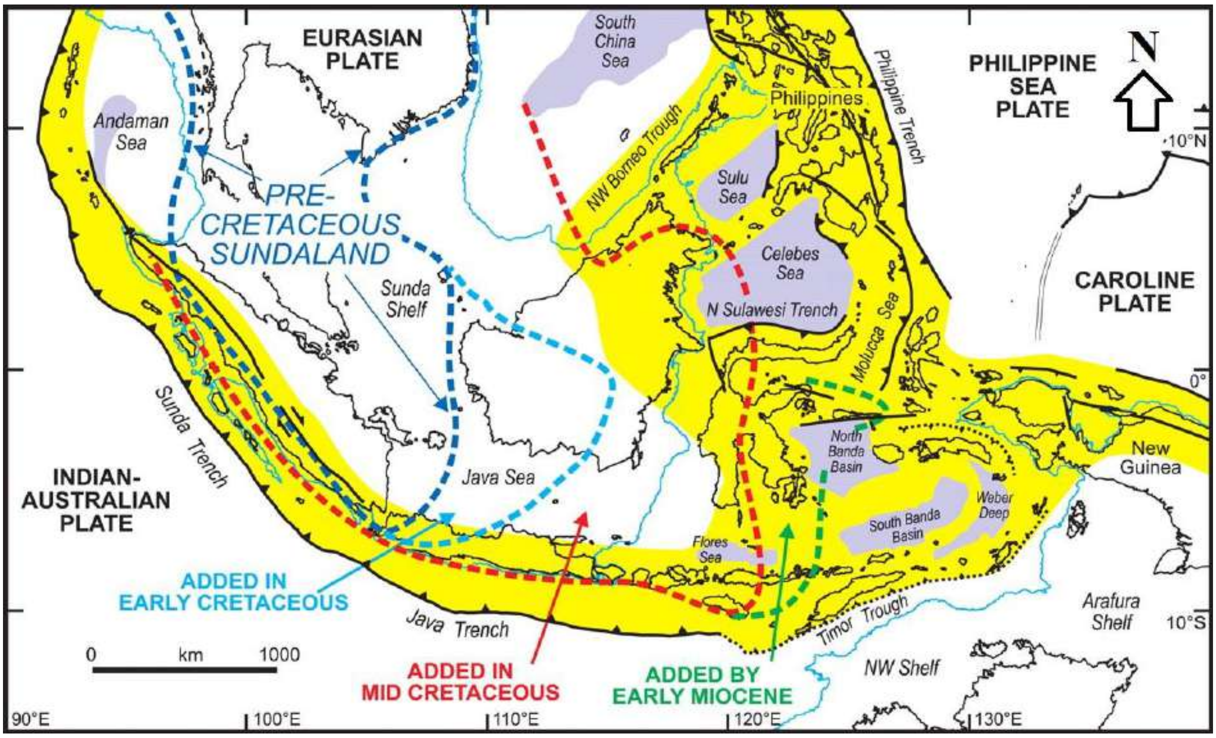

Fig. 1. Tectonic map of Indonesia showing the interaction of major plates, modified from (Hamilton, 1979)

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 and 1989). 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 and 1989).

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 - 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 is not only to map the limestone distribution but also to conduct detailed research by using measured outcrop section and biostratigraphic analysis, which was done for the first time e in this formation. So the purpose of current research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

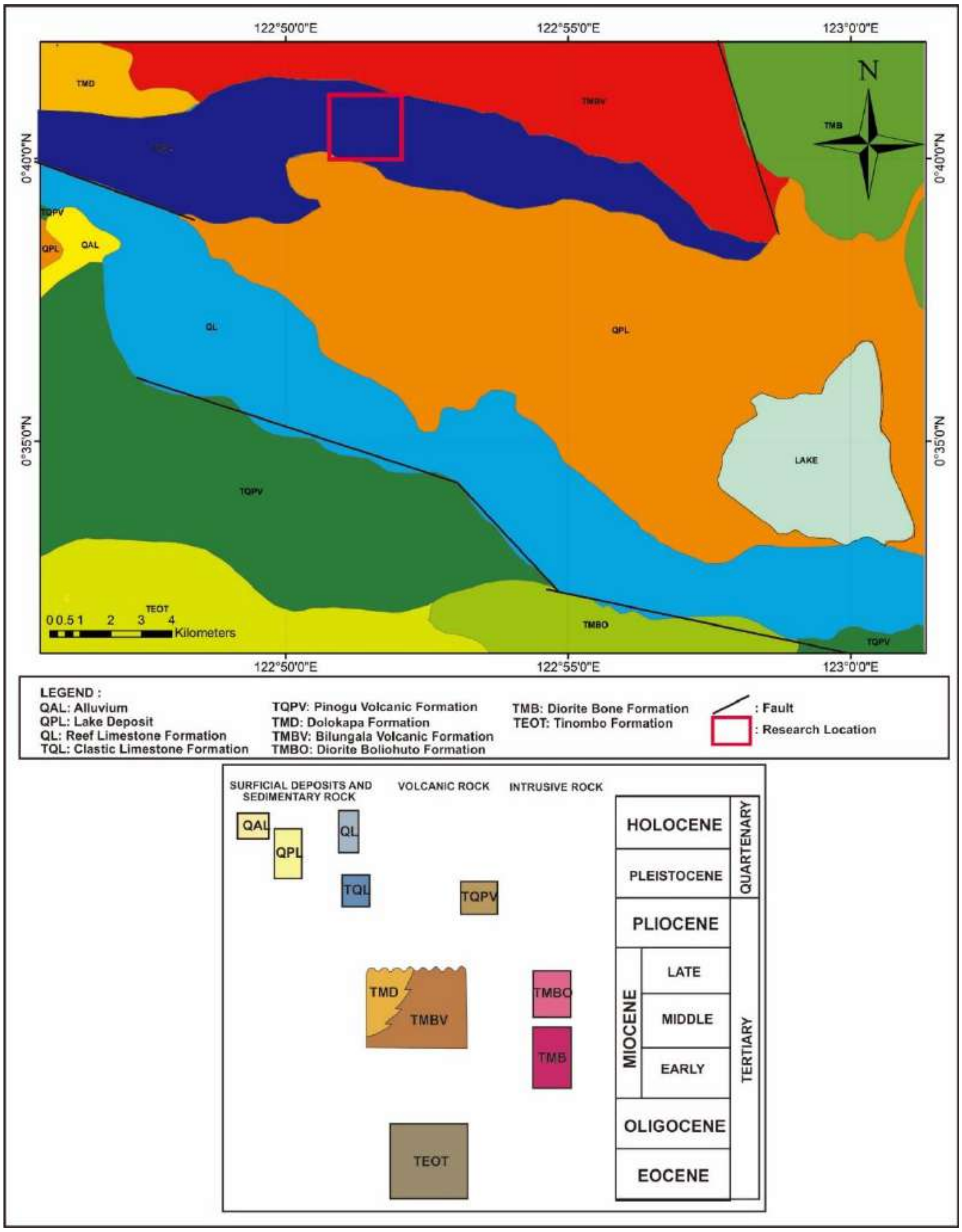

Fig. 2. Regional Geological Map of Gorontalo (Bachri *et.al*., 1997).The present research location (Limboto area) is marked with red box.

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 thickness of limestone outcrop and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The Measuring Section (MS) uses a jacob's staff, following method of Compton (1985) with an interval of 1.5 meters and every 1 to 1.5 meters a sample is taken that is suspected to contain foraminifera . The collected samples usually consists 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 (ovened 70^o 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). 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).

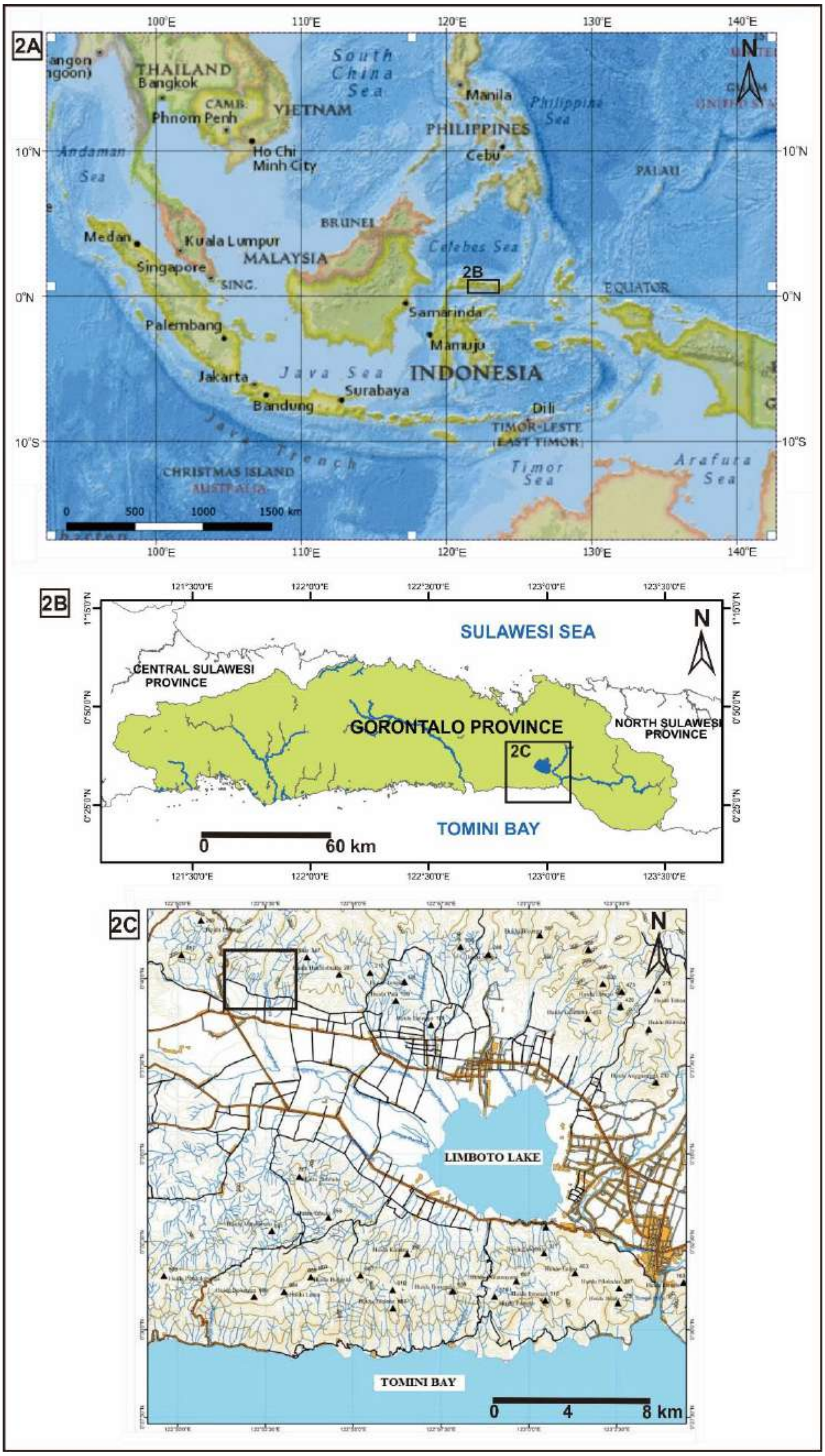

Fig. 3. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limbolo Lake on the map of Gorontalo Province and (2C) the map of research location (Isimu area)

Fig. 4. Outcrop photograph of the Limboto Limestone. Samples 27 and 28 positions are also marked. Man, having 5 feet height, for scale

6. Results and Discussion

3.1 Planktonic Foraminifera Biozones

The planktonic foraminiferal biozonations used in this study refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 biodatums 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 detail 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 *etal*. (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 includes 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 zone(s) 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.

Discussion: This zone is *Globorotalia plesiotumida* partial range zone (Table 1). Biozone M13b is equivalent to biozone N17a (Blow, 1969) and biozone M13b (Wade *et al*., 2011). The FO datum of this biozone is not reached in the studied intervals. The boundary of LO datum of this zone is FO *Pulleniatina primalis* (Figure 4; Table 1*;* Berggren *et al*., 1995b; Wade *et al*., 2011) in sample 4 (Figure 6).

The contents of fossil association within this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus extreemus* (Bolli and Bermudez), *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia humerosa* (Takayanagi and Saito) are also identified (Figure 4). Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady), *Globorotalia plesiotumida* (Blow in Banner) and *Globorotalia tumida flexuosa* (Koch), that can be seen in Figures 6 and 7.

From this sample, several reworked fossils of *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida flexuosa* (Koch) and *Hastigerina aequilateralis* (Brady) species are identified. 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 4 of this study).

Age : Late Miocene or older than 6.40 Ma.

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

Definition: The lower boundary is marked by the FO of *Pulleniatina primalis* (Table 1; Figure 4). The upper boundary is marked by the LO of *Globoquadrina dehiscens* (Table 1; Figure 5).

Discussion: This biozone is *Pulleniatina primalis* - *Globoquadrina dehiscens* concurrent range zone. This zone is equivalent to biozone N17b of Blow (1969) and biozone M14 of Wade *et al.* (2011). The FO datum 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 4). The distribution of *Pulleniatina primalis* is not continuous in sample interval from 17 to 32, and possibly caused by ecological changes along Miocene and Pliocene boundary. The latest datum 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 contents of fossil association within this zone comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) *Globorotalia crassaformis*

(Galloway and Wissler) and *Sphaerodinelopsis seminulina* (Schwager) are also found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow), that can be seen in Figures 6 and 7.

The reworked fossils of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) 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 4).

Age: Late Miocene or 5.80 - 6.40 Ma.

Biozone PL1 (*Globorotalia acostaensis* partial range zone)

Definition: The lower boundary is marked by the LO of *Globoquadrina dehiscens* (Table 1; Figure 4). The upper boundary of PL1 is not reached in the studied intervals.

Discussion: This zone is *Globorotalia acostaensis* partial range zone. 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 4). The occurrence of *Globoquadrina dehiscens* is reported in samples 1, 2, 3, 4, 5, 6, ,7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 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 are *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and *Globorotalia plesiotumida* (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow) that can be seen in Figures 6 and 7.

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this zone. The occurrence of these species is interpreted to be reworked from the older rocks, that 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.

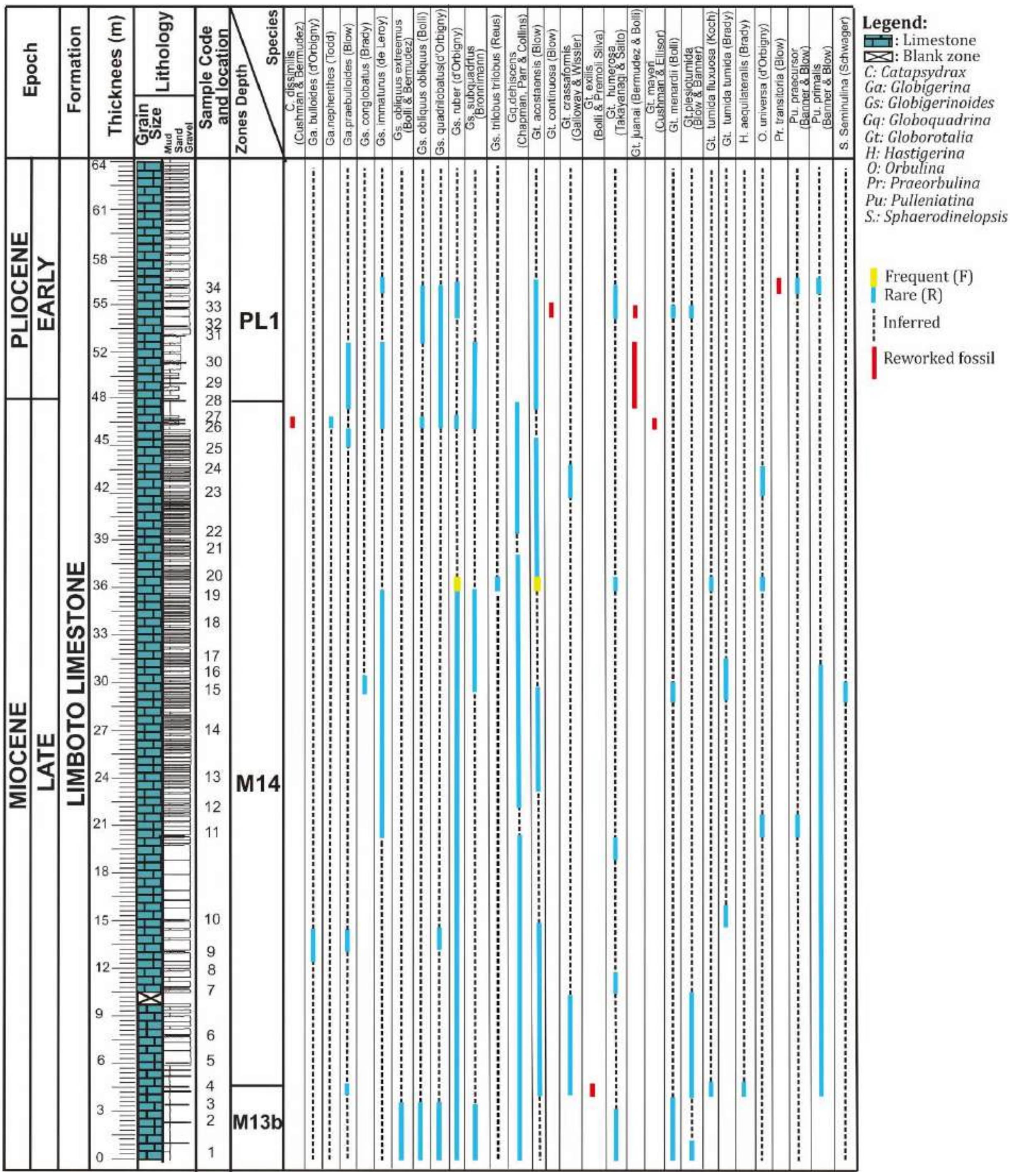

Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto limestone, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age

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)	Planktonic Foraminifera Zone: Wade *et al* (2011)	Planktonic Foraminifera Zone: 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		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N17b	M14	M14	LO *Globoquadrina dehiscens* (5.80) FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurent Range Zone
7, 8	MIOCENE	LATE	N17a	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

1. *Orbulina universa*, sample 5A
2. *Globorotalia acostaensis*, sample 5D
3. *Globorotalia continuosa*, sample 8B
4. *Globorotalia crassaformis*, sample 5A
5. *Globorotalia dutertrei*, sample 8B
6. *Globorotalia exilis*, sample 5D
7. *Globorotalia humerosa*, sample 5A
8. *Globorotalia juanai*, sample 8B
9. *Globorotalia mayeri*, sample 7B
10. *Globorotalia menardii*, sample 5A
11. *Pulleniatina primalis*, *sample* 5D
12. *Globorotalia plesiotumida*, sample 5A
13. *Globorotalia tumida flexuosa*, sample 5A
14. *Globorotalia tumida tumida*, sample 8B
15. *Hastigerina aequilateralis*, sample 5A

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

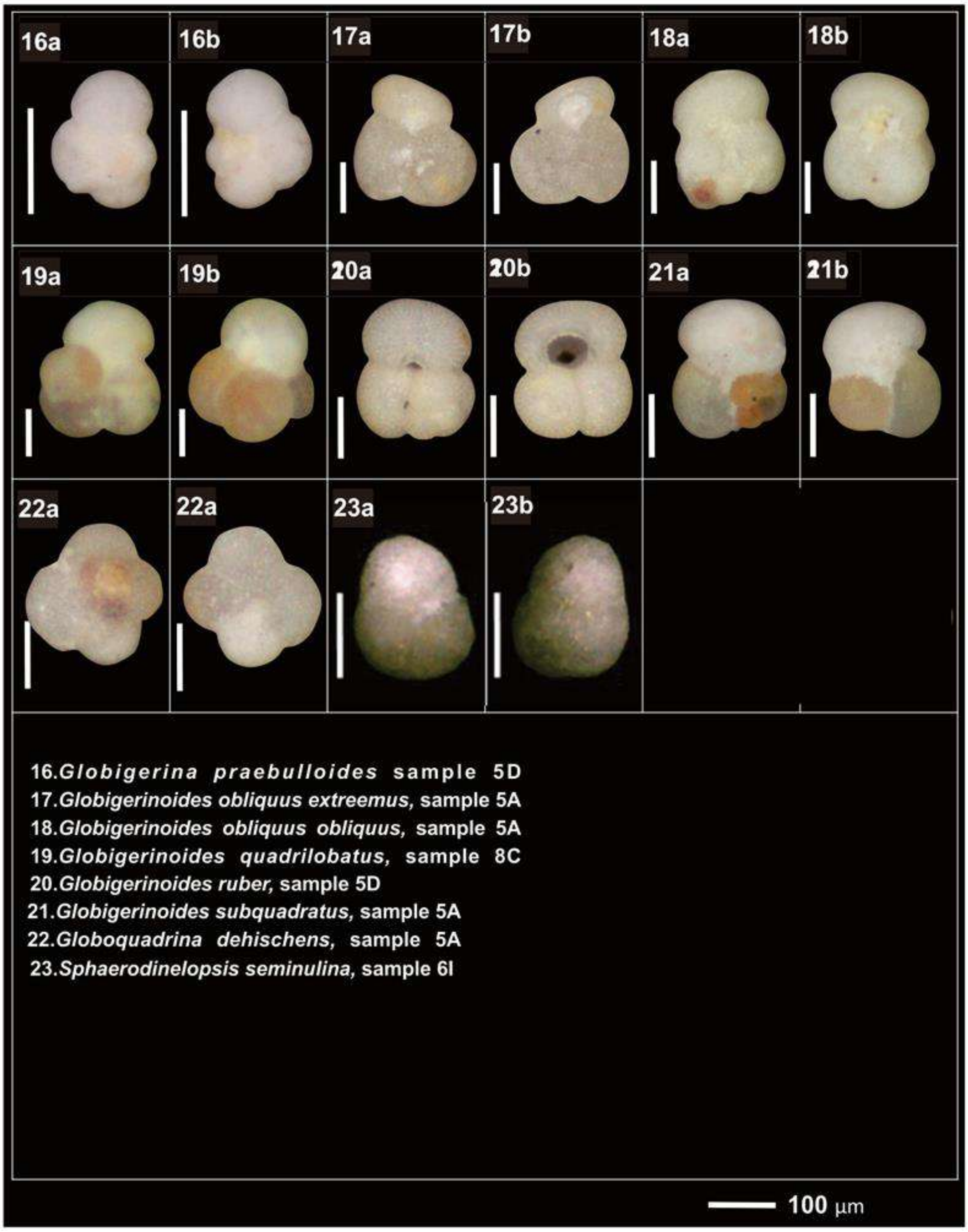

Fig. 7. Photomicrographs of planktonic foraminifera noticed in present study

7. 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 Miocene (Late Miocene) and Pliocene (Early Pliocene) biozones. 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 biodatums such as the LO *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first finding considering that Limboto Limestone has not been thoroughly studied regarding the biozonation of planktonic foraminifera. These results give an idea of the age and planktonic foraminifera zonation of the Limboto Limestone that is Late Miocene to 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.

8. Acknowledgement

Thanks to the Indonesian Endowment Fund for Education (LPDP) for helping to provide superior scholarships for Indonesian lecturers (BUDI-DN).

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Part	Comments from Reviewer C (321-746-1-5-20191007)	Author's Response
Abstract	In the abstract, mention names of three identified planktonic foraminiferal biozones i.e. *Globorotalia plesiotumida partial range zone; Pulleniatina primalis - Globoquadrina dehiscens* concurrent range zone and *Globorotalia acostaensis* partial range zone.	Thank you for your comment. I already revised it.
Material and Methods	Mention the atlas of planktonic foraminifera and or research articles which are followed for the identification of planktonic foraminifera reported in the preset study.	Thank you for your comment. I already revised it. We have included references to identify the planktonic atlas used.
Result and Discussions	In the reference list, the year is 1997 with Bachri et al., so if it is a separate reference then incorporate it in the reference list. Otherwise, correct the year to 1997.	Thank you for your comment. I already revised it.
	Capital 'L' will be much better to mention here.	Yes, I already to revised the TQl into TQL.
	TQl should be uniform throughout the manuscript. However, it is not the case at present. In the text and main map TQl is used where in Fig. 1 caption 'Tql' is used… In case of TQl, 'L' should be written in capital letters, so it becomes 'TQL'. Likewise, same should also be followed for 'QL'	Thank you for your suggestion.
	Mention name of the atlas of planktonic foraminifera and or research articles which are followed for the identification of planktonic foraminifera reported in the present study.	Yes, I already to add the methods of fossil identification in the last paragraph of Methods chapter.
	Insert reference in caption for Figure 2A. It would be great if the authors can improve the quality of this map. It is a bit blur and low resolution image.	Yes, I already to revised that. The image quality of the map has been upgraded to clear and sharp images.
	In Fig. 2A, the rectangle labeled as 'B' should be labeled as Fig. 2B.	Yes, I already to revised that. the shape of the image has been changed according to its size.
	Reference for Fig. 2B should be inserted, however, if it is generated by authors then it should be defined as GIS / Global mapper map of the Sulawesi area and so on. Such methodology should also be incorporated in the materials and methods section.	Thank you for your comment. I already revised it.
	It will be much better if the authors can mark the areas on Figure 1C from where the studied rock samples are collected.	Thank you for your comment. I already revised it.
	In Fig.1B, the rectangle labeled as 'C' should be labeled as Fig. 1C.	Thank you for your comment. I already revised it.
	Text of sample codes should be aligned in column 5.	Thank you for your comment. I already revised it.
	The species marked by blue color are called as rare, R, in legend, however, they are quite	Rare is meant the amount of abundance of each species in each sample that is less than 5

	widely distributed in the range chart i.e. Figure 4?	fossils not the presence of each species at intervals of the entire sample. This is based on the Kadar classification (1986).
	Also recheck and modify (if there is error) the terms used for availability, abundance and distribution of different fossil species.	We have checked very carefully for the availability, abundance, and distribution of each different fossil species so that no more mistakes occur.
	Rare, R, fossils are shown by blue color, however, the fossil species range chart also contains purple color lines. Please kindly recheck and correct / modify it.	Yes, I already to revised that. The entire abundance of rare uniforms are blue.
	Abundant (A) and common (C) species are not mentioned in the range chart?	There is no abundance of species Abundant (A) and common (C) so we delete the list of legends in the picture.
	There is some overlapping of rare and inferred fossils. Such overlapping should be removed.	Yes, I already to revised that. We have changed it so that there is no overlay anymore.
	Lower most margin of Figure 4 should coincide with the O meter point of the lithological column.	Yes, I already to revised that. Species range starts at 0 meters.
	The distribution of microfacies (mudstone, packstone and rudstone) are mentioned in the lithology column, however, nothing has been described about these microfacies in the text?	Yes, I already to revised that. We no longer use the term microfacies so we have changed to grain size consisting of mud, sand and gravel.
	Extend the distribution line of '*Globoquadrina dehiscens' up to sample 7C.*	Thank you for your comment. I already revised it.
	Photomicrograph of this fossil is missing in Figures 5 and 6. Insert it also.	Thank you for your comment. I already to added the species that missing in the new photograph.
	Table 1 should be referred and mentioned once all biozones are described.	Thank you for your comment. I already revised it.
	~6.45 according to table 1?	Yes, I already to revised that. No, age 6.40 MA so we have revised the scale of the bar in the table to be more detailed and thorough.
	Define the length of bars used as scale in the photomicrographs used in Table 1	Thank you for your comment. I already to revised it.
	Reconfirm it again.	Thank you for your comment. The paragraph should be included in the previous sub-chapter. I already revised it.
	Check and reconfirm it in table 1. Estimate/determine the numerical age carefully.	Thank you for your comment. The absolute age is according to Wade et.al (2011).
	labeled figures i.e. 1, 2a, 2b, 3a, 3b and so on are not mentioned in a sequence. Arrange them in a sequence.	Thank you for your comment. The labeled figures (i.e. 1a, 2a etc) is described in fossil name in below of the picture.
	Figures are labeled as 2a, 2b, 3a, 3b and so on, hence there should be description for both figures, for example, 6a Globorotalia exilis dorsal part, sample x 6b Globorotalia exilis ventral part, sample y Or 6a Globorotalia exilis involute, sample x	Thank you for your comment. The notes about a, b, and c label was added in the picture.

	6b Globorotalia exilis evolute, sample y Or you can make it section-wise i.e. equatorial section and vice versa	
	Insert photomicrographs of following fossil species in relevant figures. *Globigerinoides immaturus* (de Leroy) *Globigerina bulloides* (d'Orbigny) *Globigerina nepenthes* (Todd) *Pulleniatina praecursor* (Banner and Blow) *Catapsydrax dissimilis* (Cushman and Bermudez) *Praeorbulina transitoria* (Blow).	Thank you for your comment. I already revised it. Additional fossil species have been included in the picture.
	The scientist's names are mentioned at the end of each and every species, so it is also advised to mention year at the end of scientist(s) name(s). Such pattern should be followed throughout the text as well as figures of the manuscript.	Thank you for your comment. I already revised it.
	The scientists names are mentioned at the end of each and every species, so it is also advised to mention year at the end of scientist name. Such pattern should be followed throughout the text as well as figures of the manuscript.	Thank you for your comment. I already revised it.
	Why the sample number starts from 5 and ranges upto 17 in Figure 4? It should be from 1 to 34 because it is mentioned in methodology section of the manuscript that total of 34 samples are used for biostratigraphic analysis. Although the samples plotted in figure 4 are 34 in number, however, the sample codes are a bit confusing due to their non-systematic nature. Clarify this confusion.	Thank you for your comment. I already revised it. We have changed the order of the samples from 1 to 34 so that they are systematically sequential.
	In the first draft of the manuscript, you mentioned that 20 samples are used for biostratigraphic analyses. However, in the 2nd revised draft it is mentioned that 34 samples are used for biostratigraphic studies. Likewise, the stratigraphic column (Figure 3) of first draft of manuscript is different from the stratigraphic column (Figure 4) of the 2nd revised draft. You are advised to justify such changes, please.	Thank you for your comment. We check back to the field location, especially the blank zone so after checking the zone is known, it can still be done by MS with additional sampling so that the data is more accurate.
	Globorotalia exilis i.e. Fig. 5-6a and 6b seems normal, however, this species is considered as a reworked fossil. Check it please.	Thank you for your comment. In my opinion, it might be caused by the preservation of that species. For example, previously the fossil was preserved in fine-grained lithology with minor cementation, so that the condition of the fossil test would still look normal. Alternatively, the species may have a different age range at the local scale in the study area. Need more detailed research to prove this.

	The scale bar mentioned in lower right corner of the figure should be changed to vertical direction.	Thank you for your comment. I already revised it.
	Correct spelling of *dehiscens in Figure 6. There is no 'h' after 'c' in the above mentioned fossil name.*	Thank you for your comment. I already revised it.
	Confirm the year of publication. Throughout the manuscript Bachri et al., 1994 is mentioned. Please check and confirm/modify it.	Thank you for your comment. I already revised it.
	Why the area is left blank on page # 2, 4, 6, 8, 9, 10, 11? There should be no blank area within the text of the paper. However, it might be covered during final preparation and editing of the manuscript.	Thank you for your comment. I already revised it.

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 results of this study can be a reference to propose an age of Limboto Limestone Formation. Identification and demarcation of the Limboto Limestone Formation is based on the time interval and relative age of the formation based on planktonic foraminifera.

Keywords: Foraminiferal biostratigraphy, Limboto Limestone

3. 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 very 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 was 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 $120\text{-}122^0$ E (Surmont *et al*., 1994). The clockwise rotation is only $20\text{-}25^0$ which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al*., 1994).

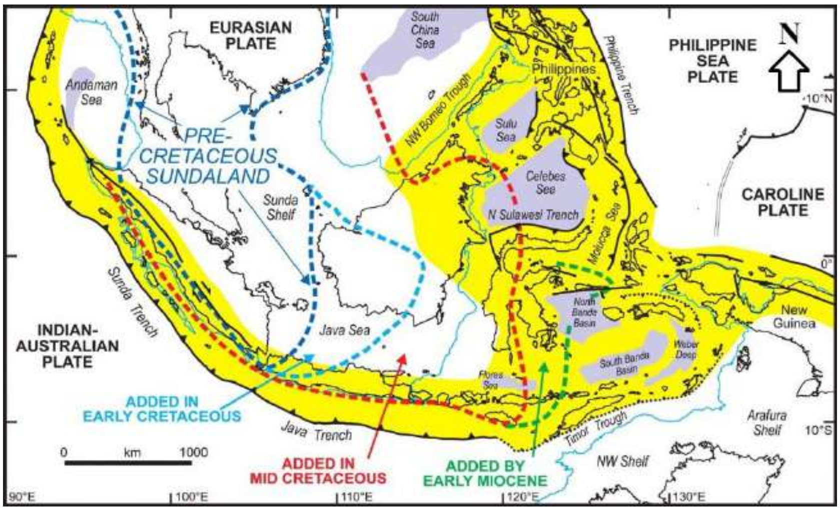


Fig. 1. Tectonic map of Indonesia showing the interaction of major plates, modified from (Hamilton, 1979)

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 and 1989). 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 and 1989).

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 - 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 was conduct detailed research by using measured outcrop section and biostratigraphic analysis, which was done for the first time in this formation. So the purpose of current research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

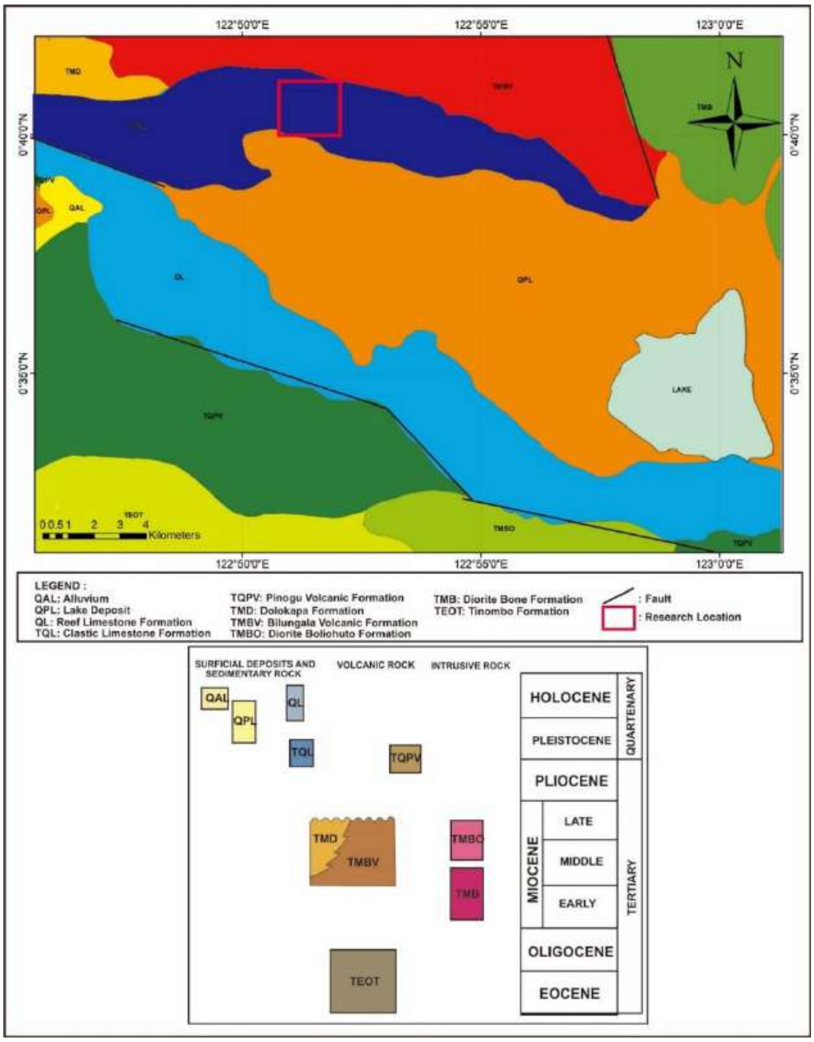


Fig. 2. Regional Geological Map of Gorontalo (Bachri *et.al*., 1997).The present research location (Limboto area) is marked with red box.

2. Materials and Methods

The present research area location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of 0^{o}40′5.917″North, 122^{o}51′11.939″East) to 0^{o}39′40.670″North, 122^{o}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 method of Compton (1985) with an interval of 1.5 meters. Then, the sample will be taken in every 1 to 1.5 meter. The collected samples usually consists 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 (ovened 70^{o} 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). 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).

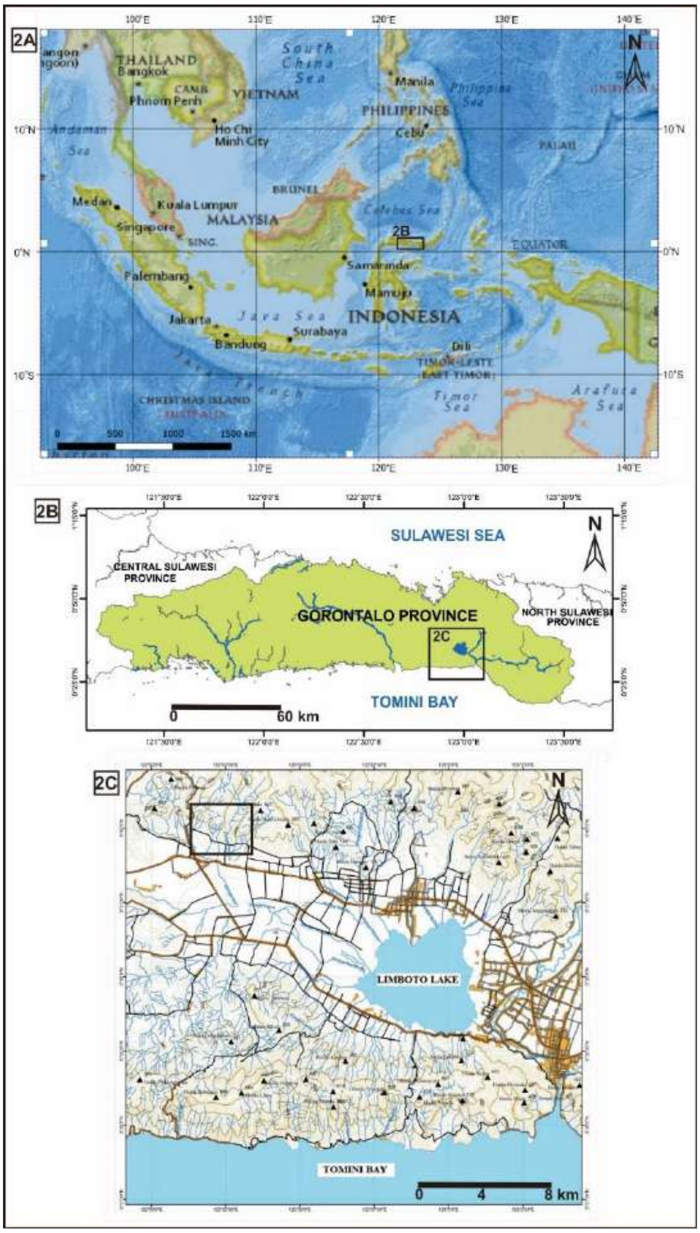


Fig. 3. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limbolo Lake on the map of Gorontalo Province (GIS map) and (2C) the map of research location (Isimu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

Fig. 4. Outcrop photograph of the Limboto Limestone. Samples 27 and 28 positions are also marked. Man, having 5 feet height, for scale

9. Results and Discussion

3.1 Planktonic Foraminifera Biozones

The planktonic foraminiferal biozonations used in this study refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 biodatums 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 detail 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 *etal*. (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 includes 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 zone(s) 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 the limitation of sample that analyze. The upper boundaryof 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 species which commonly found and characterized the Late Miocene age, that is *Globorotalia plesiotumida.*

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

Several reworked fossils are identified in this zone, such as *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida flexuosa* (Koch) and *Hastigerina aequilateralis* (Brady. 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 comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia crassaformis* (Galloway and Wissler) and *Sphaerodinelopsis seminulina* (Schwager) are also found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow), that can be seen in Figures 6 and 7.

The reworked fossils of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) 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), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and *Globorotalia plesiotumida* (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow) that can be seen in Figures 6 and 7.

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this zone. The occurrence of these species is interpreted to be reworked from the older rocks, that 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		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N17b	M14	M14	LO *Globoquadrina dehiscens* (5.80)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurrent Range Zone
7 8	MIOCENE	LATE	N17a	M13b	M13b	FO *Pulleniatina primalis* (6.40)	*Globorotalia Plesiotumida* Partial Range Zone

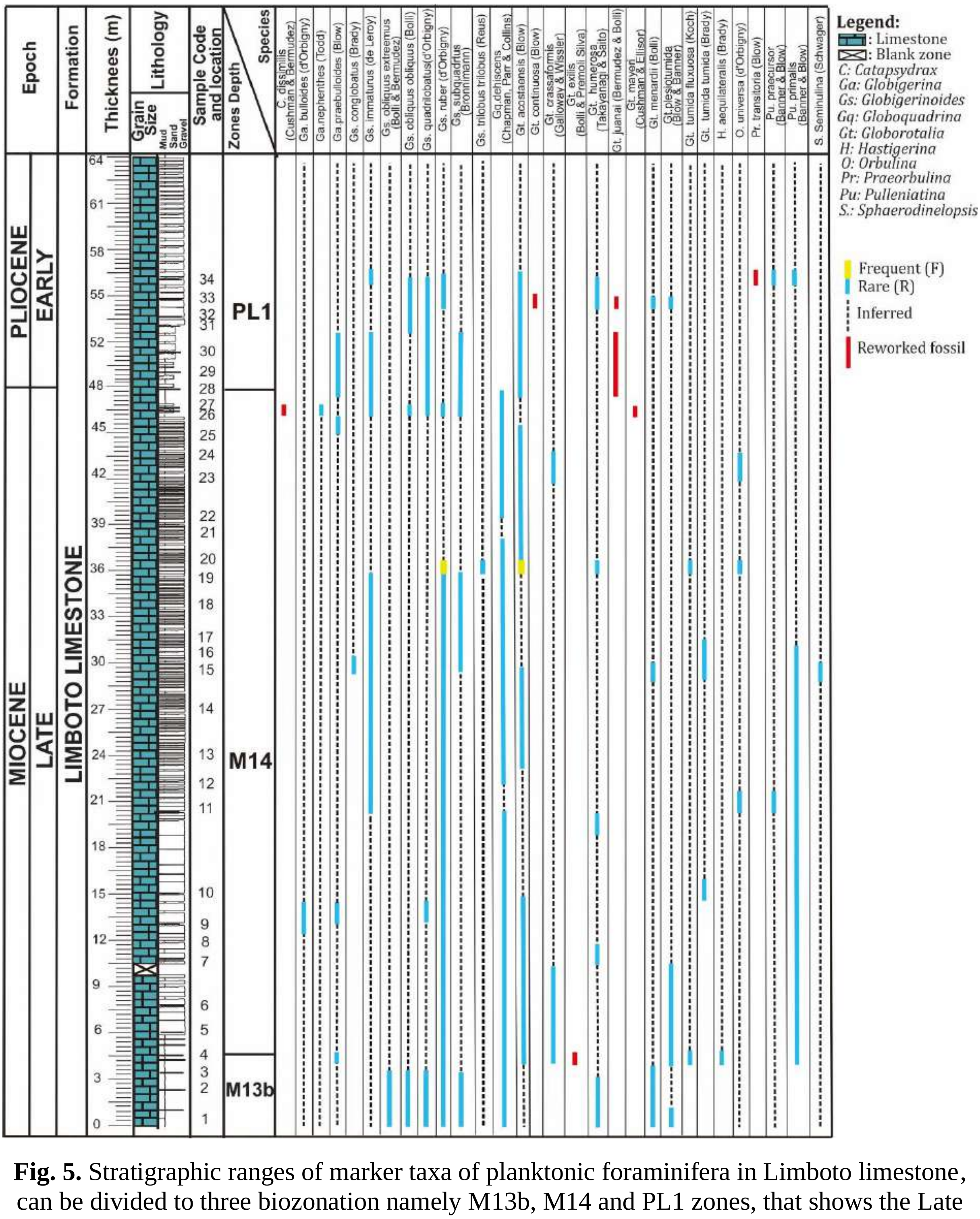
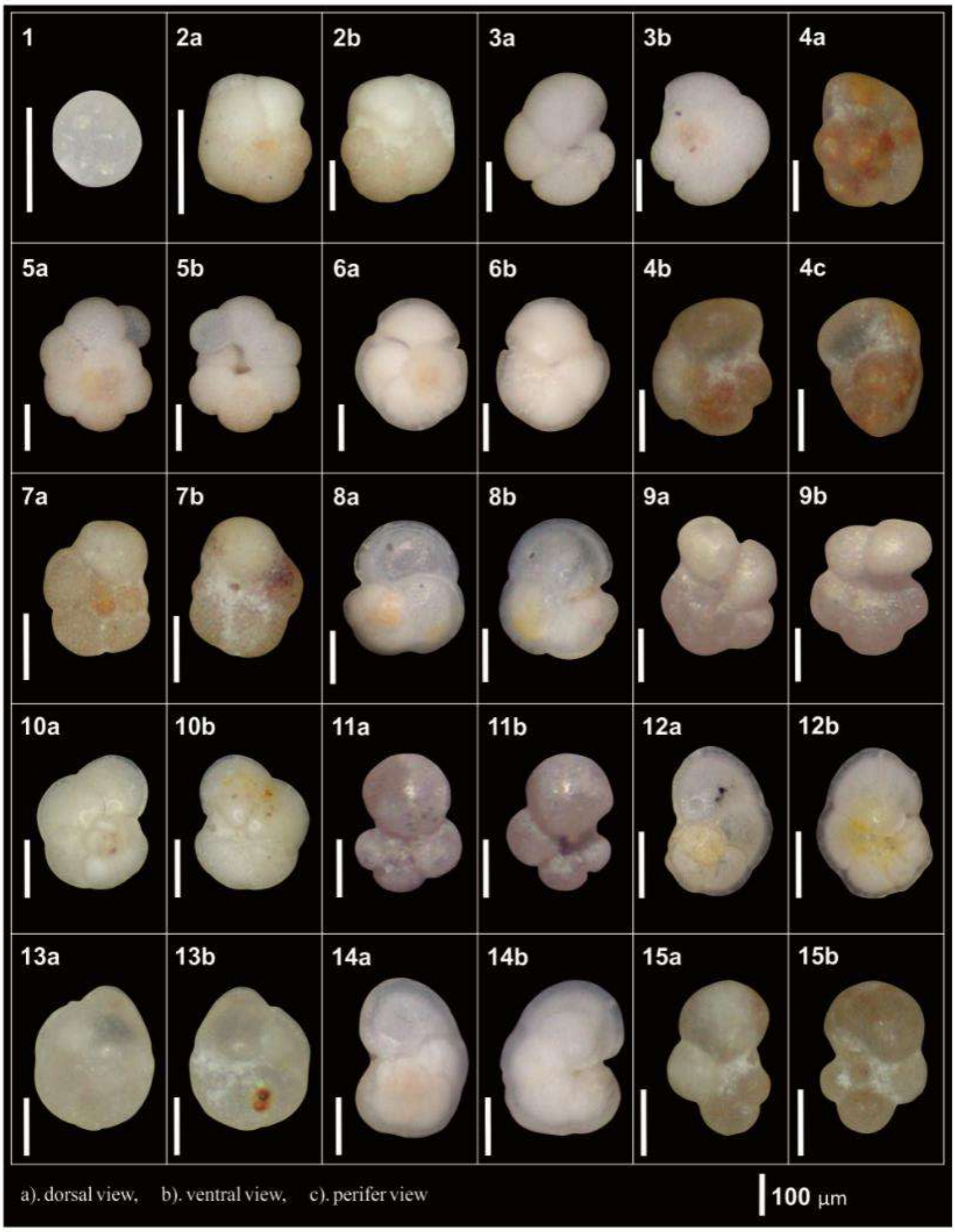


Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto limestone, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age



1. *Orbulina universa* (d'Orbigny), sample 5A
2. *Globorotalia acostaensis* (Blow), sample 5D
3. *Globorotalia continuosa* (Blow), sample 17B
4. *Globorotalia crassaformis* (Galloway & Wissler), sample 5A
5. *Globorotalia dutertrei* (d'Orbigny), sample 17B
6. *Globorotalia exilis* (Blow), sample 5D
7. *Globorotalia humerosa* (Takayanagi & Saito), sample 5A
8. *Globorotalia juanai* (Bermúdez & Bolli), sample 17B
9. *Globorotalia mayeri* (Cushman & Ellisor), sample 1R
10. *Globorotalia menardii* (d'Orbigny), sample 5A
11. *Globorotalia obesa* (Bolli), sample 9B
12. *Globorotalia plesiotumida* (Blow & Banner), sample 5A
13. *Globorotalia tumida flexuosa* (Koch), sample 5A
14. *Globorotalia tumida tumida* (Brady), sample 17B
15. *Hastigerina aequilateralis* (Brady), sample 5A

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

1. *Globigerina praebulloides* (Bolli), sample 5D
2. *Globigerinoides obliquus extreemus* (Bolli & Bermudez), sample 5A
3. *Globigerinoides obliquus obliquus* (Bolli), sample 5A
4. Globigerinoides quadrilobatus (d'Orbigny), sample 4B
5. *Globigerinoides ruber* (d'Orbigny), sample 5D
6. *Globigerinoides subquadratus* (Brönnimann), sample 5A
7. *Globoquadrina dehiscens* (Chapman), sample 5A
8. *Neogloboquadrina nympha* (Jenkins), sample 4B
9. *Pulleniatina primalis* (Banner & Blow), sample 5D
10. *Praeorbulina transitoria* (Blow), sample 17C
11. *Pulleniatina praecursor* (Banner & Blow), sample 17C
12. *Catapsydrax dissimilis* (Cushman & Bermúdez), sample 7A
13. *Globigerina nepenthes* (Todd), sample 7A
14. *Globigerinoides immaturus* (Le Roy), sample 7A

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

10. 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 primales – 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 biodatums such as the LO *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 to 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.

11. Acknowledgement

Thanks to the Indonesian Endowment Fund for Education (LPDP) for helping to provide superior scholarships for Indonesian lecturers (BUDI-DN).

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ROUND 3

Part	Comments from Reviewer A (6916-31783-2-RV)	Author's Response
	Why the area is left blank on page # 7 and 8? There should be no blank area within the text of the paper. However, it might be covered during final preparation and editing of the manuscript.	Thank you for your input. Improvements have been made so that there are no more free spaces on pages 7 and 8.
	Text (especially codes of different geological formations or rock units) on map part of fig. 2 is not legible. Increase the font size so that the text can be readable.	Thank you for your input. Improvements have been made so that the letter size on the rock formation has been enlarged so that it appears clear.
	I don’t know why the authors are ignoring my comment again and again about insertion of outcrop photographs. They can simply answer in response to my comment that unfortunately, we haven’t got outcrop photograph(s). It is not adequate and suitable to avoid answering a comment of reviewer. Each and every comment(s) of reviewer should be considered and answered with great care.	Thank you for your input. Improvements have been made by replacing outcrop photos taken by measured setions (MS) with two new, clearer photos.
	Insert photomicrograph(s) of fossil species *Globigerina bulloides* (d'Orbigny). It is mentioned in the text but no photomicrograph(s) is provided.	Thank you for your input. Improvements have been made by adding fossil species of Globigerina bulloides (d'Orbigny).
	It is once again advised to check the sequence of fossils photomicrographs in text and then in the related figures. They should be arranged in an order in which they are discussed/mentioned in the text of the manuscript.	Thank you for your input. Improvements have been made by sorting photos of the species in alphabetical order.
	The scientist’s names are mentioned at the end of each and every species, so it is also advised to mention year at the end of scientist(s) name(s). Such pattern should be followed throughout the text as well as figures of the manuscript.	Thank you for your input. Improvements have been made by adding the year at the end of each author's name.

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 is based on the time interval and relative age of the formation based on planktonic foraminifera.

Keywords: Foraminiferal biostratigraphy, Limboto Limestone

4. 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 very 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 was 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).

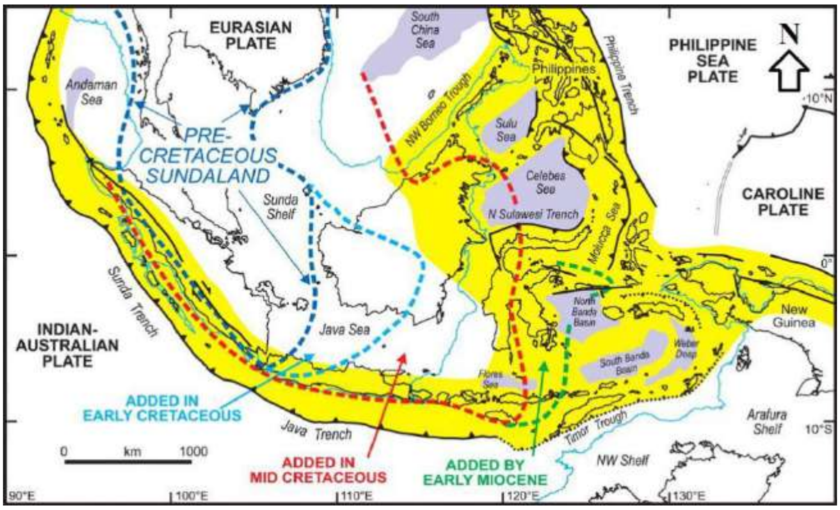

Fig. 1. Tectonic map of Indonesia showing the interaction of major plates (modified from Hamilton, 1979)

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 - 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 was conduct detailed research by using measured outcrop section and biostratigraphic analysis, which was done for the first time in this formation. So the purpose of current research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

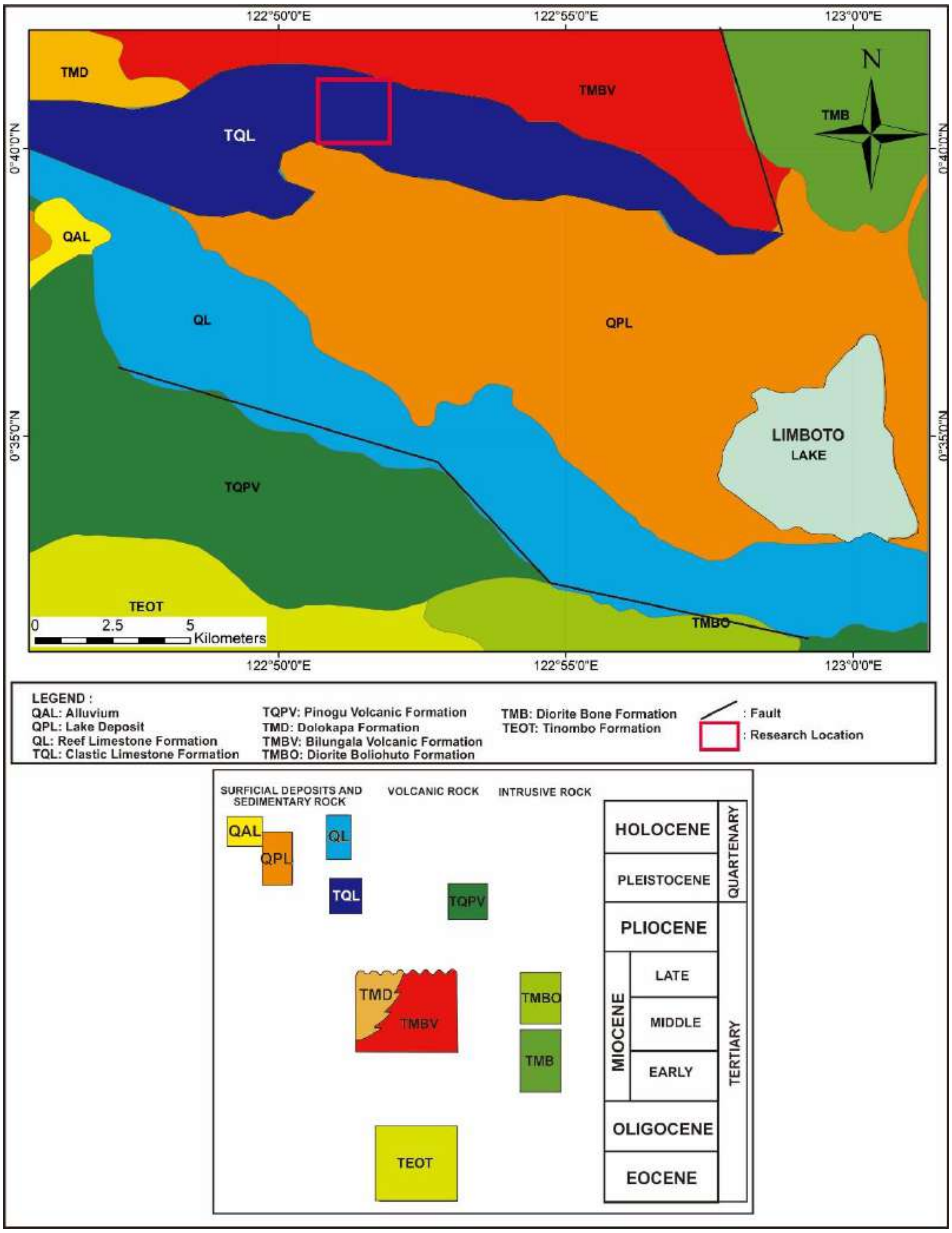

Fig. 2. Regional Geological Map of Gorontalo (Bachri *et al*., 1997). The present research location (Limboto area) is marked with box having pink color outline.

2. Materials and Methods

The present research area location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of $0^{o}40′5.917″$North, $122^{o}51′11.939″$East) to $0^{o}39′40.670″$North, $122^{o}52′16.205″$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 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 meter. The collected samples usually consists 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 (ovened 70^{o} 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).

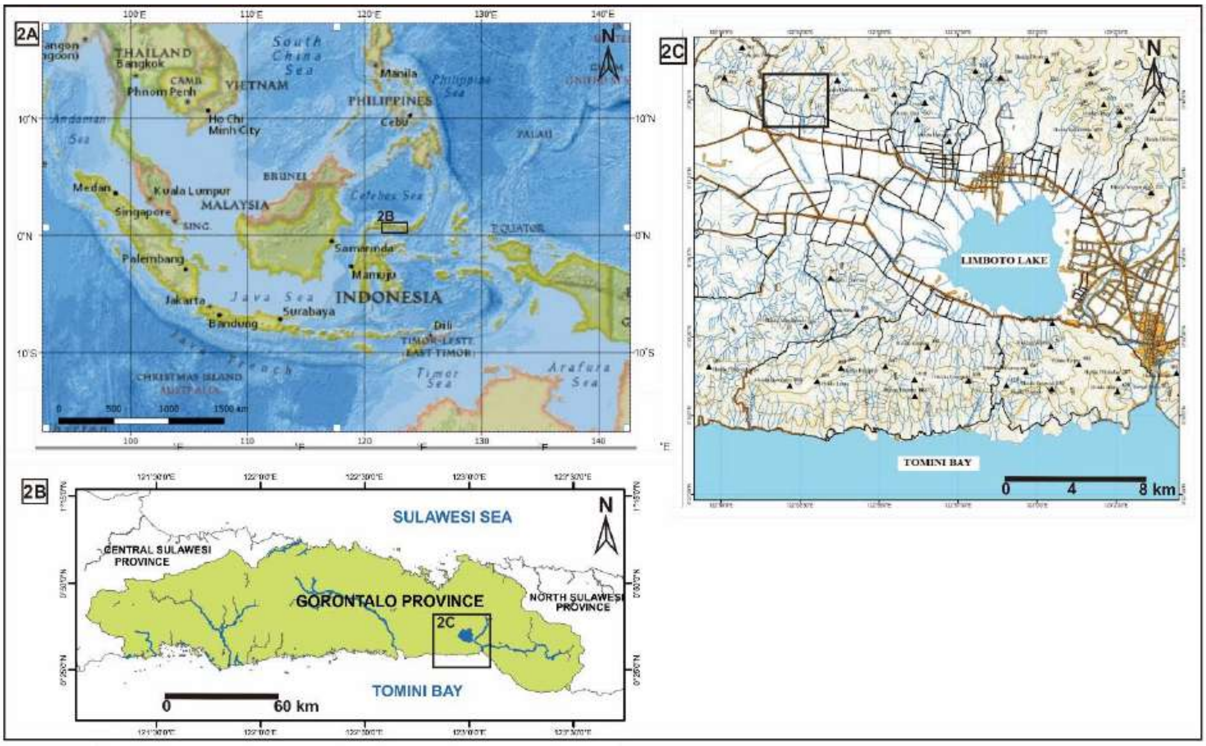

Fig. 3. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limbolo Lake on the map of Gorontalo Province (GIS map) and (2C) the map of research location (Isimu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

12. Results and Discussion

3.1 Planktonic Foraminifera Biozones

The planktonic foraminiferal biozonations used in this study refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 biodatums 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 detail 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 *etal*. (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 includes 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 zone(s) 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 the limitation of sample that analyze. The upper boundaryof 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 species which commonly found and characterized the Late Miocene age, that is *Globorotalia plesiotumida.*

The fossil association of this zone are *Globoquadrina dehiscens* (Chapman, Parr and Collins, 1934), *Globigerina praebulloides* (Blow, 1959), *Globigerinoides immaturus* (de Leroy, 1939), *Globigerinoides obliquus extreemus* (Bolli and Bermudez, 1965), *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), that 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 comprises *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), that 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) that can be seen in Figures 6 and 7.

Several reworked fossils such as *Globorotalia continuosa* (Blow, 1969), *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, that 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		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N17b	M14	M14	LO *Globoquadrina dehiscens* (5.80) FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurent Range Zone
7 8	MIOCENE	LATE	N17a	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

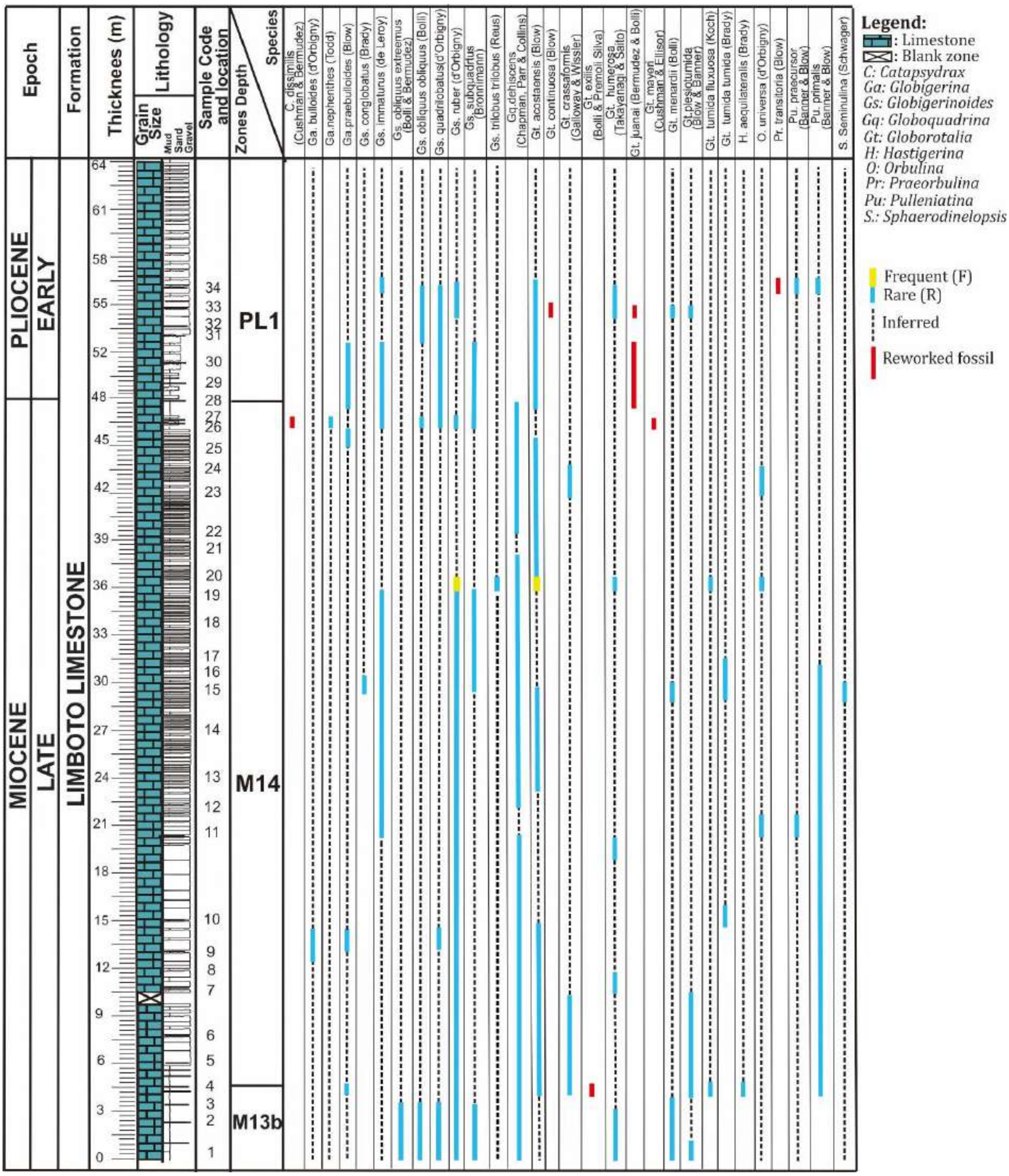

Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto limestone, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age

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 present study

PLATE 2

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 present study

13. 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 primales – 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 biodatums such as the LO *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 to 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.

14. Acknowledgement

Thanks to the Indonesian Endowment Fund for Education (LPDP) for helping to provide superior scholarships for Indonesian lecturers (BUDI-DN).

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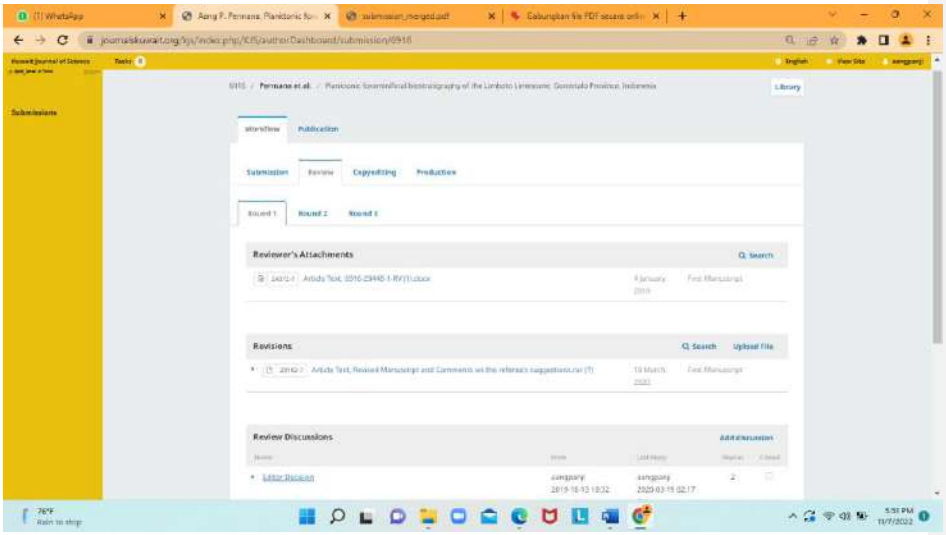
Wade, B. S., Pearson, P. N., Berggren, W. & Palike, H. (2011) Review and revision of cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. Earth Science Reviews, 104: 111-142.

Journal Revision Instructions

Round 1



Dear Dr. Assalamualaykum Aang Panji Permana,

aangpanji 2019-10-13 10:32 AM

We have reached a decision regarding your submission # 6916 to Kuwait Journal of Science, "A review of the planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia".

Our decision is: Revision Required.

The paper was assigned to the referees. Your manuscript needs major revision. I hope you will kindly carry out all necessary corrections/modifications as suggested by the referees. Please note the following:

- Read the referees reports carefully and carry out the required major corrections/modifications.

- We would also like you to consider citing some papers related to your work, which are already published in KJS, with a view to demonstrate the relevancy of our Journal.

- Once you prepare the revised MS, your revision should include a covering letter detailing point by point your response to the referees in the revision. Please upload the revised version

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- An Arabic abstract of the paper should be typed as per the style of this journal, and should accompany the revised MS (not required from authors with no Arabic Proficiency).

- The revised version MUST be in double columned in word format (or Latex) and should be typed single-spaced throughout.

- References list should be: (a) no numberings should be made, (b) list of references should only include citations mentioned in the text. No other references are acceptable. (c) Citations of references both in the text and list should be in accordance with the style of this journal.

Kindly note that the revised MS should be strictly as per our format and the MS should be professionally checked and corrected by a language editor (if needed).

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Also you can refer our previous publications by visiting "CURRENT" to follow the KJS style.

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Please make the zip file including "Revised manuscript" in word format and the "comments on the referee's suggestions", and then upload this file in "Upload Author Version" which is in "review".

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Please confirm and acknowledge the receipt of this mail.

Kind Regards

Prof. Lakdere Benkherouf
Editor-in-Chief

Reviewer A:Attached

Reviewer B:Attached

Reviewers Comments for Communication to the Authors(Do not include Reviewer Contact Details here):
The manuscript titled “A review of the planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia” has been thoroughly reviewed. The research paper is based on planktonic foraminiferal biozonation of the Limboto limestone in the Gorontalo Province of Indonesia.
The authors are advised to consider the following comments / suggestions.
Title of the Manuscript
Is it a review paper? I think no! The word “review” should be deleted from the title because from the contents of the manuscript, it seems an original research paper. However, the present title is reflecting that it is a review paper. Therefore, the title of the manuscript will be modified and revised. One possible suggestion is as follows:
“Planktonic foraminiferal biostratigraphy of Miocene-Pliocene carbonates of the Limboto Basin, Gorontalo Province, Indonesia”
Abstract
• Rewrite the abstract.
• Mention the names of three identified planktonic foraminiferal biozones.

• Abstract contains sufficient information, however, most of the sentences are vague. It would be better to rewrite the abstract.

Introduction

The introduction section is not well elaborated. The introduction contains insufficient contents. There is no map in this section to show the present study area. Concisely introduce the study area i.e. further elaborate contents of introduction. Comprehensively describe and incorporate the already published work on the Clastic Limestone Formation and Coral Limestone Formation.

New section / heading to be inserted in the manuscript

Geological Settings

This section should be incorporated after the introduction section. The generalized geological setting(s) and stratigraphy of the study area and or adjacent area(s) should be defined. Such description should be supported by insertion of pertinent geological map(s) and generalized stratigraphic column(s).

Results and Discussions

• Insert few outcrop photographs, if possible.

• There should be photographic evidence(s) (petrographic and scanning electron microscope photomicrographs) to support the identification and presence of planktonic foraminifera in the studied area.

• In the present manuscript, the authors have proposed a new geological formation i.e. Limboto Limestone. Their efforts are highly appreciated. However, I will request them to put forward / present their manuscript (once it is published) to official stratigraphic committee in Indonesia to officially approve the newly established geological formation.

• For detailed comments and suggestions, the annotated manuscript draft should be consulted.

Conclusions

• The conclusion section includes references such as Gradstein et al. (2004) and Lourens et al. (2004). Usually conclusion(s) section concludes any manuscript with some insights / projections of the field of study without considering / citing any reference. These references should be cited somewhere in the results and discussion section of the manuscript.

• Rewrite conclusions.

References

• Majority of the references are quite old. The authors are advised to consult latest references of identical type of research and cite them at pertinent locations in the manuscript.

• There are certain sentences which should be supported by insertion of pertinent references.

• For detailed comments and suggestions, the annotated draft should be consulted.

Generalized comments

• The English of the manuscript needs significant improvement.

• The organization and presentation of the manuscript needs improvement. Most of the headings are confused, especially the one's referring to different biozones.
• The word 'zone' should be replaced with the term 'biozone'.
• It is mentioned in the last paragraph of the Introduction section that "Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section and biostratigraphic analysis". If the authors are referring to figure 1C, then there should also be an explicit details of procedure(s) followed for the present mapping. Likewise, manuscript title, abstract, portion of results and discussion and conclusions will be modified accordingly.
• In Figure 3, column 5 heading should be modified to 'Sample code and location'. Why the sample number starts from 5 and ranges upto 17 in Figure 3? It should be from 1 to 20 because it is mentioned in methodology section of the manuscript that total of 20 samples are used for biostratigraphic analysis. Although the samples plotted in figure 3 are 20 in number, however, the sample codes are a bit confusing due to their non-systematic nature. Clarify this confusion.

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SettingsDear Dr. Assalamualaykum Aang Panji Permana,

aangpanji 2020-03-17 07:15 PM

We have reached a decision regarding your submission # 6916 to Kuwait Journal of Science, "Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia".

Our decision is: Revision Required.

The paper was assigned to the referees. Your manuscript needs (minor) revision. I hope you will kindly carry out all the necessary corrections/modifications as suggested by the referees.

Please note the following:

- Read the referees reports carefully and carry out the required major corrections/modifications.

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Prof. Ameer Al Haddad
Editor-in-Chief

Reviewer Report: Attached

____

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SettingsDear Dr. Permana,

I am pleased to inform you that your paper entitled: "Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia" has been accepted for publication in Kuwait Journal of Science.

We would also like you to consider citing some papers related to your work, which are already published in KJS, with a view to demonstrating the relevancy of our Journal.

Please confirm and acknowledge the receipt of this mail.

With best wishes.

Kind Regards,
Prof. Ameer Al Haddad
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Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia

Commented [A1]: Why a review?

Aang P. Permana[1*,2], Subagyo Pramumijoyo[2], Akmaluddin[2]

[1] *Geological Engineering Department, Gorontalo State University, Gorontalo, Indonesia*

[2] *Geological Engineering Department, Gadjah Mada University, Yogyakarta, Indonesia*

* *Corresponding autor : aang@ung.ac,id*

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 northern part of Lake Limboto. The purpose of this study was to determine the planktonic foraminiferal zonation and the absolute age of Limboto limestones. The analyzed planktonic foraminiferal fossils can be classified to well-moderately preserved condition with many fossils categorized as several to abundant. There are three recognized planktonic foraminiferal zonations which are proposed to follow the standard zonation: one zonation for Miocene age (M14) and two zonations for Pliocene age (PL1 - PL2). The zone boundaries comprise two biodatums: one biodatum of FO (first occurrence) and one biodatum of LO (last occurrence). The results of this study can be a reference to propose a new formation called as Limboto Limestone Formation that was previously known as Clastic Limestone Formation and Coral Limestone Formation. The new finding based of the time interval and absolute age of the formation.

Commented [A2]: This term is reserved for geochronology. Biostratigraphy is a part of chronostratigraphy.

Commented [A3]: This is standard procedurę in biostratigraphic analysis thus I,m not sure whether this sentence should be placed in your abstract.

Keywords: Age; Limboto; Limestone; Planktonic; Zonation

1. Introduction

The Indonesian archipelago is geologically located in the center of three main active plates: 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. 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-shape 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 very complex which were formed during the Oligocene to Miocene age (Sukamto, 1975c; Hamilton, 1979; Daly et al., 1991).

The basement rock of the North Sulawesi arm was originated from the pre-Tertiary Pacific Oceanic plate (Taylor & Leeuwen, 1980; Katili, 1989). The northern arm of Sulawesi underwent a tectonic evolution from the Eocene or Early Miocene to the Pliocene-Pleistocene age. 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 & Suparka, 1986). Different paleomagnetic results were obtained at the latitude of $120-122^0$ E. 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). 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 Lake Limboto formed this basin. Lake Limboto has a northwest-southeast orientation influenced by Gorontalo's main fault zone which has a dextral movement in the same direction. The main fault zone can be seen from the Patente river lineament pattern, Tanjung Tombuililato and Gorontalo coastline. The uplifting of Quartenary reef limestones near Gorontalo and Tanjung Daka on the northern coast which reached the elevation of more than 1,000 meters is evidence to the massive uplifting (Bemmelen, 1949; Katilli, 1970; 1989).

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. Coral limestone is the main rock of Pliocene-Pleistocene age, similar to the Limestone distributed in the western part of the north coast. The presence of macrofossils in limestones in Limboto Lake in Miocene and red algae in Early Miocene is a result of limestone conglomerates reworking from the southern part of Paguyaman Beach (Trail et al., 1974).

The second study was conducted to produce a regional geological map with the scale of 1 : 250000. Limestone distribution on regional geological maps is divided into two formations: Clastic Limestone Formation (TQl) and Coral Limestone Formation (Ql). Clastic Limestone Formation (TQl), which spreads in the northern and western part of Limboto lake, has Pliocene-Pleistocene age consisting of calcarenite, calcirudite and coral limestone. This formation has a thickness ranging from 100-200 meters. Coral Limestone Unit Formation (Ql), distributed in the south of the lake, is deposited contemporaneously with the Clastic Limestone Formation (TQl) estimated to be in Holocene age. This reef limestone unit is uplifted with the coral as the main constituent (Bachri et al., 1997).

Commented [A4]: What second?

The difference in determining the limestone age in the Limboto Basin in two previous studies makes this research interesting for revealing the absolute limestone age. Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section` and biostratigraphic analysis. It is expected to produce a biostratigraphic zonation for the first planktonic foraminifera. So the purpose of the research is to make biostratigraphic zonation for planktonic foraminifera Limboto limestone, Gorontalo, Indonesia and to determine the absolute age.

Commented [A5]: See coment above, based on fossils you can only estimate chronostratigraphic possition

Commented [A6]: What do you mean by first?

Commented [A7]: The main aim i.e., biostratigraphy is repeated at least 3 times in these short paragraph.

2. Material and Methods

The research location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of (0°40’5,917”N, 122°51’11,939”East) to (0°39’40,670”N, 122°52’16,205”East) (Fig. 1). The research material is chiefly collected from limestone outcrops with a total thickness of 64 meters which belong to Isimu track. The thickness of thin limestone outcrops and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The implementation of MS uses a jacob’s staff with an interval of 1.5 meters (Compton, 1985). Every interval of 1-1,5 meters, a potential sample containing foraminifera fossils is collected. These samples usually have the characteristics of a fine (clay-silt) size, soft (not yet compacted and not hard) and having carbonaceous material proved by the 0.1 N HCl solution test (Fig. 2)

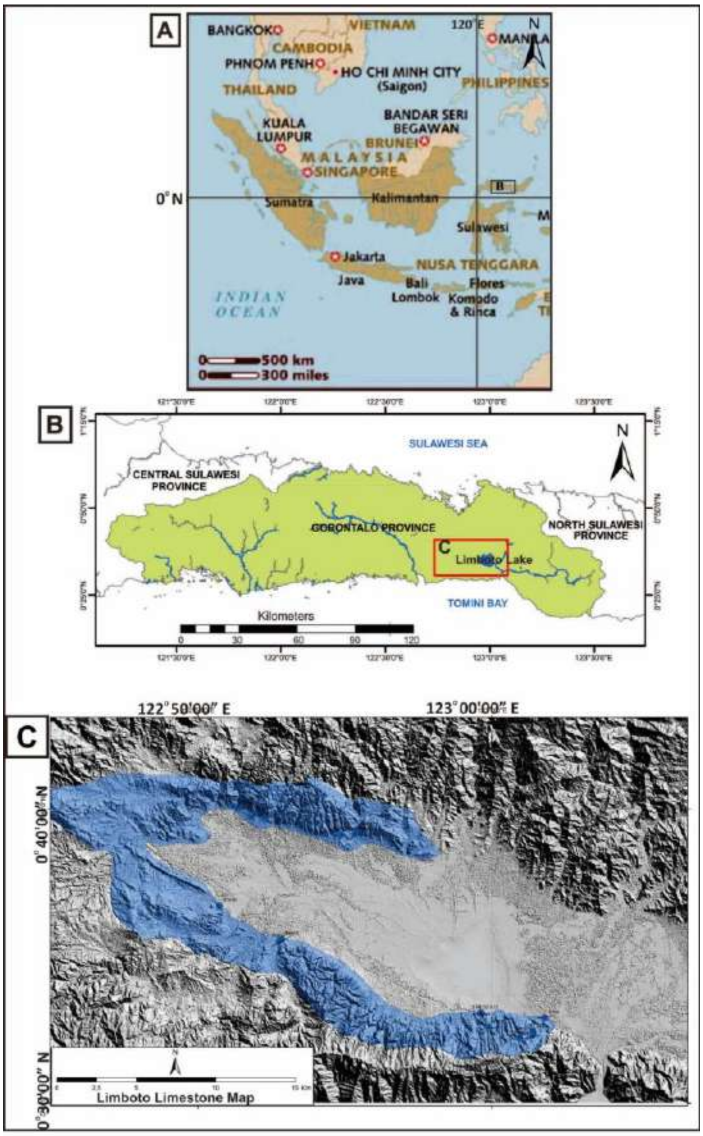

Fig 1. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area

Fig.2. Measured section at the research location using a jacob's staff

The biostratigraphy of a total of 20 samples was analyzed. A compact rock samples are pounded with porcelain pounding to ease the reaction with H_2O_2 solution. The sample is weighed 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 (ovened 70^o Celsius) and packed using plastic bags. The identification of fossil types for planktonic foraminifera uses Olympus binocular SZ61 microscope equipped with a computer-connected camera. Sediment samples generally contain moderately preserved (good enough) planktonic foraminiferas, and the abundance ranges from several to abundant. The distribution of fossil species is shown in (Fig. 3).

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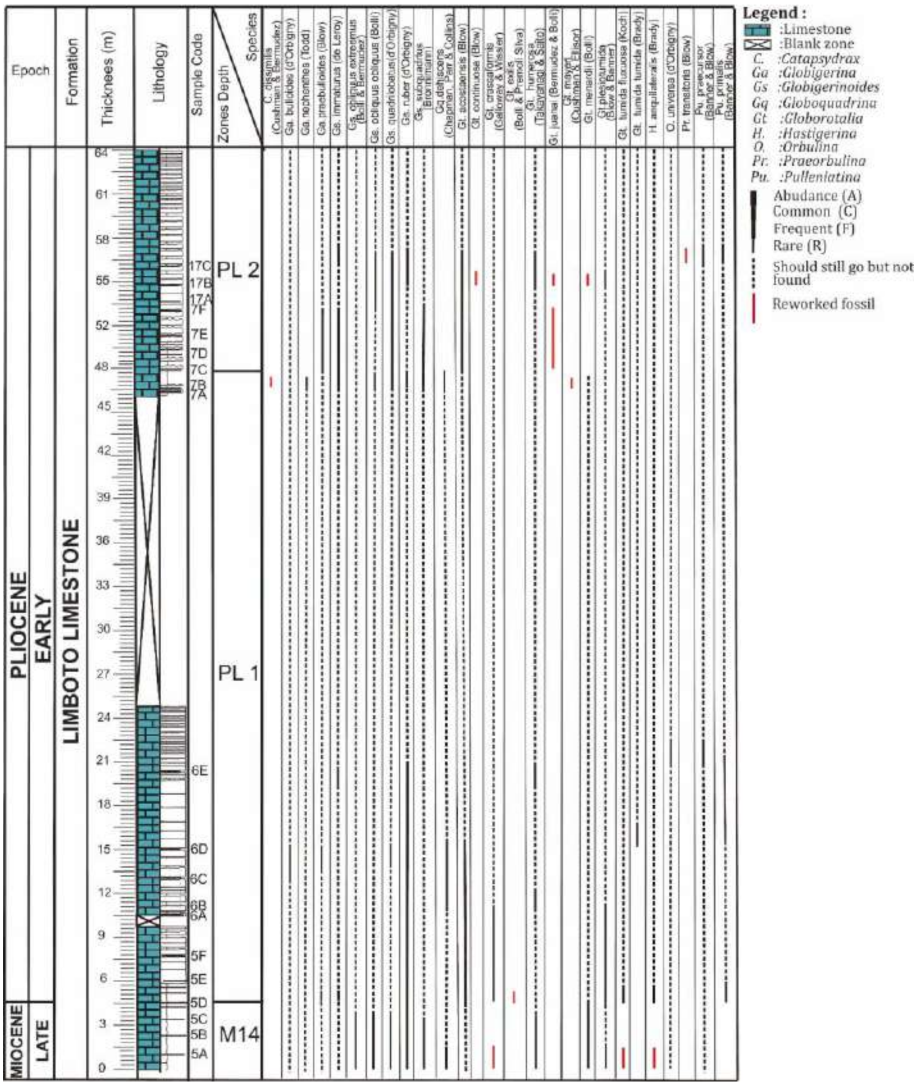

Fig. 3. Stratigraphic ranges of marker taxa of planktonic foraminifera in location research

3. Planktonic Foraminifera Zones

The planktonic foraminiferal zonation used in this study refers to Blow Biozonation (Blow, 1969) and Wade Biozonation (Wade et al., 2011). Blow Biozonation (Blow, 1969) is referred to as standard zonation because the research is carried out based on samples originating from almost all parts of the world. Blow divided the Cenozoic biozonation into two parts, namely Paleogene (Paleocene-Oligocene) and Neogen (Miocene-Pleistocene). Overall, biozonation is based on Blow Biozonation consisting of 22 main Paleogene zones with "P1" - "P22" notation, as well as 23 Neogen main zones with "N1-N23" notation.

Wade Biozonation (Wade et al., 2011) shows the increasing number of foraminifera studies in the tropic to the subtropic area, resulting in many standard biodatums for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the Earth's magnetism over the geological timespan. The most recent study (Wade et al., 2011) divides the Cenozoic to be more detail using the "P" notation for Paleocene, "E" for Eocene, "O" for Oligocene, "M" for Miocene, "OT" for Pliocene, and "PT" for the Pleistocene. This will result in a more detailed biozonation compared to the previous notation.

The zonation boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal zone. The following abbreviations are used in the description of zonation: FO = first occurrence and LO = the last occurrence. FO and LO define biozonation from taxa obtained from a particular region (Saraswati & Srinivasan, 2016). Biostratigraphic zone uses the terms range zone, concurrent range zone, interval zone, partial range zone, assemblage zone, phylo zone and acme zone (Saraswati & Srinivasan, 2016) (Table 1).

Zone PL2 (part)

Definition: The upper boundary of PL2 is not found. The lower boundary is marked by the LO of *Globoquadrina dehiscens*.

Discussion: This zone is *Globoquadrina dehiscens* partial range zone. Zone PL2 (part) is equivalent to Zone PL2 (Wade *et al.*, 2011) and Zone N19 (Blow, 1969). This zone represents the youngest planktonic foraminifera (uppermost). LO of *Globoquadrina dehiscens* (Berggren *et al.*, 1995a; Wade *et al.*, 2011) is found within sample 7C. The occurrence of *Globoquadrina*

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Commented [A10]: You do not use all these zones e.g., assemblage or phylo zones. Why you put this information without and discussion?

Commented [A11]: Please present zonations from oldest to youngest

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Commented [A13]: The species range is very discontinuous in the studied section, so the las tor first occurrence can be rather ecological instead on evolutionary

Commented [A14]: What youngest??? Where?

dehiscens is contained in the sample 5A, 5D, 6B, 6D, 7B and 7C. These following species do not show any occurrence within the upper sample of 7F, 17B, 17C.

Commented [A15]: What about 17A?

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

Age (MA)	Epoch		Planktonik Foraminifera Zone: Blow,1969	Wade et al, 2011	This Study 2018	Bioevents/Biodatums Used in This Study (Age in Ma)	Biostratigraphic Zonations
2, 3, 4, 5	PLIOCENE	EARLY	N 19	PL 2	PL 2		***Globoquadrina dehiscens*** **Partial Range Zone**
						LO *Globoquadrina dehiscens* (5.80)	
6	MIOCENE	LATE	N 18	PL 1	PL 1		***Pulleniatina primalis - Globoquadrina dehiscens*** **Concurrent Range Zone**
						FO *Pulleniatina primalis* (6.40)	
7, 8	MIOCENE	LATE	N 17	M 14	M 14		***Pulleniatina primalis*** **Partial Range Zone**

The contents of fossil association within this zone are *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and

Globorotalia plesiotumida (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow).

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this sample. The occurrence of this species is interpreted to be reworked from the older rock. The thickness of this zone is 16 meters (interval of 48-76 meters).

Commented [A16]: How do you know it? Did you make any taphonomic study?

Age : Early Pliocene. ? - 5.80 Ma.

Zone PL1

Definition: The upper part boundary of Zone PL1 is marked by the LO of *Globoquadrina dehiscens.* The lower boundary is marked by the FO of *Pulleniatina primalis*.

Discussion: This zone is *Pulleniatina primalis- Globoquadrina dehiscens* concurrent range zone. Zone PL1 is equivalent to Zone PL1 (Wade *et al.*, 2011) and zone N18 (Blow, 1969). The base of this zone is marked by the FO of *Pulleniatina primalis* (Berggren *et al.,* 1995b; Wade *et al.*, 2011). The occurrence of *Pulleniatina primalis* is contained in sample 5D, 6D, 6E and 17C. The occurrence of this species is not found in the lowest sample of 5A and 5C. The latest datum of this zone is the LO of *Globoquadrina dehiscens* (Berggren *et al.*, 1995a; Wade *et al.*, 2011). The occurrence of *Globoquadrina dehiscens* is within sample 5A, 5C, 6B, 6D, 7B and 7C. The occurrence of this sample is not found in the uppermost part consisting of sample 7F, 17B and 17C.

Commented [A17]: By who?

Commented [A18]: Discontinous range, the LO of the species might be ecological. This should be discussed

Commented [A19]: What about 17A?

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The content of fossil association within this zone comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli).

Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia crassaformis* (Galloway and Wissler) are found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow).

The reworked fossil of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) are also identified. The occurrence of this species is estimated to be reworked from the older rock. The thickness of this zone is 43.5 meters (interval of 4.5 – 48 meters).

Commented [A21]: See comment above

Commented [A22]: How it is possible, samples should be washed before processing.

Samples must be collected from fresh wall of the outcrops.

Age: Early Pliocene. 5.80 - 6.40 Ma.

Zone M14

Definition: The upper boundary of Zone M14 is the FO of *Pulleniatina primalis*. The lower boundary is not found.

Commented [A23]: Why not ecological?

Discussion: This zone is *Pulleniatina primalis* partial range zone. Zone M14 is equivalent to Zone M14 (Wade *et al.*, 2011) and Zone N17 (Blow, 1969). The first occurrence datum of this zone is not found. The boundary of the last occurence datum of this zone is FO *Pulleniatina primalis* (Berggren *et al*., 1995b; Wade *et al.*, 2011) in sample 5D. The occurrence of *Pulleniatina primalis* is contained in sample 5D, 6D, 6E and 17C. The occurrence of this sample is not identified in the lowest part consisting of sample 5A and 5C.

Commented [A24]: The first occurence datum of taxa not zone

Commented [A25]: What about 5B?

The content of fossil association within this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus extreemus* (Bolli and Bermudez), *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia humerosa* (Takayanagi and Saito) are also identified. Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady), *Globorotalia plesiotumida* (Blow in Banner) and *Globorotalia tumida fluxuosa* (Koch).

From this sample, several reworked fossils of *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida fluxuosa* (Koch) and *Hastigerina aequilateralis* (Brady) species are identified. The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rock above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters).

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Age : Early Pliocene. 6.40 - ? Ma.

4. Conclusions Remarks

Based on the measured section (MS) data, the planktonic foraminiferal zonation of limestones in the Limboto Basin is divided into two main zonations namely the Miocene (Late Miocene) and Pliocene (Early Pliocene) zones. The Miocene age consists of only one zone. Meanwhile, there are two zones in the Pliocene age (PL1 and PL2 zones). The total zonation of planktonic foraminifera comprises 3 zones. The planktonic foraminiferal zonation uses the standard zonation of Blow (Blow, 1969) and Wade (Wade et al., 2011). It is also correlated with the absolute time of the astronomical time scale (Lourens et al., 2004) and the polarity time scale (Gradstein et al., 2004). In total, there were two used biodatums such as the LO *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first finding considering that Limboto limestone has not been thoroughly studied regarding the zonation division of planktonic foraminifera. 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 (Bachri et al., 1997). The new finding facts is a matter of different ranges of formation age (Late Miocene - Early Pliocene) with the absolute age of Limboto limestone (? - 5.80 MA) to (6.40 -? Ma).

5. Acknowledgement

I would like to thank *Educational Fund Management Agency* (LPDP) for helping me provide the educational scholarships through *Indonesian lecturer main scholarship* (BUDI DN).

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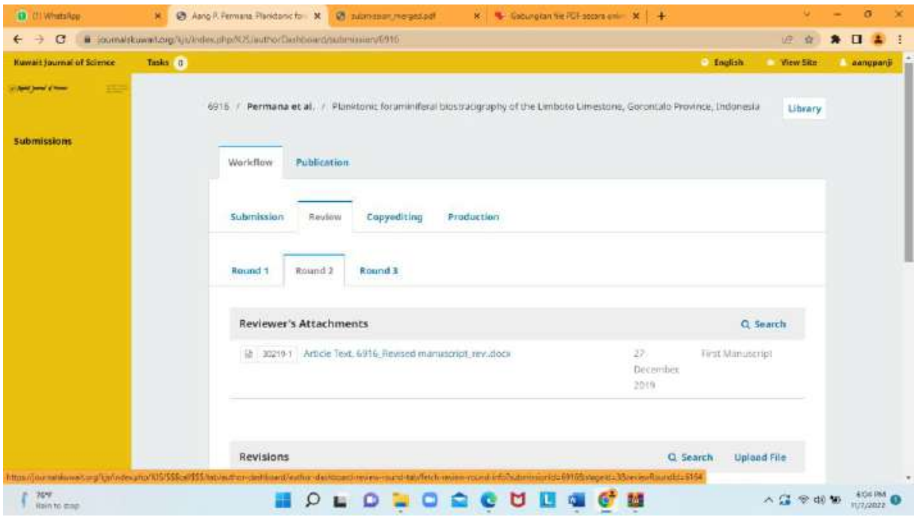
Round 2



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 northern part of Limboto Lake. The purpose of this study was to determine the planktonic foraminiferal biozonation and the absolute age of Limboto limestones. The analyzed planktonic foraminiferal fossils can be classified as well to moderately preserved with many fossils, in the context of abundance, categorized as frequent to abundant. There are three recognized planktonic foraminiferal biozones which are proposed to follow the standard biozonation: two biozone for Miocene age (M13b and M14) and one biozones for Pliocene age (PL1). The results of this study can be a reference to propose a new formation called as Limboto Limestone Formation that was previously known as Clastic Limestone Formation and Coral Limestone Formation. Determination of the Limboto Limestone Formation is based on the time interval and relative age of the formation.

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As far as I understand your study was only biostratigraphic

Keywords: Foraminiferal biostratigraphy, Limboto Limestone

2. Introduction

The Indonesian archipelago is geologically located in the center of three main active plates: 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 (Hutchison, 1989). 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-shape 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 very complex which were formed during the Oligocene to Miocene age (Sukamto, 1975c; Hamilton, 1979; Daly *et al.*, 1991).

The basement rock of the North Sulawesi arm was 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 $120\text{-}122^0$ E (Surmont *et al.*, 1994. The clockwise rotation is only $20\text{-}25^0$ which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al*., 1994).

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 (Bemmelen, 1949; Katili, 1970 and 1989). The main fault zone can be seen from the Patente river, Tombuililato cape and Gorontalo coastline lineament pattern. The evidence of the intensive tectonic 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 Quatenary age (Bemmelen, 1949; Katili, 1970 and 1989).

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.*, 1994) was conducted to produce a regional geological map with the scale of 1 : 250,000 (Figure1). Limestone distribution on regional geological maps is divided into two formations: 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 - 200 meters. Coral Limestone Formation (Ql), distributed in south part of the lake, consisting of reef limestone which contain the coral fragment as the main constituent, is deposited contemporaneously with the Clastic Limestone Formation (TQl) and

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The difference in determining the limestone age in the Limboto Basin in Bachri *et.al*., (1994) and Trail *et al*., (1974) makes this research interesting for revealing the relative limestone age. Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section and biostratigraphy analysis, it was the first time done in this formation. So the purpose of the research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

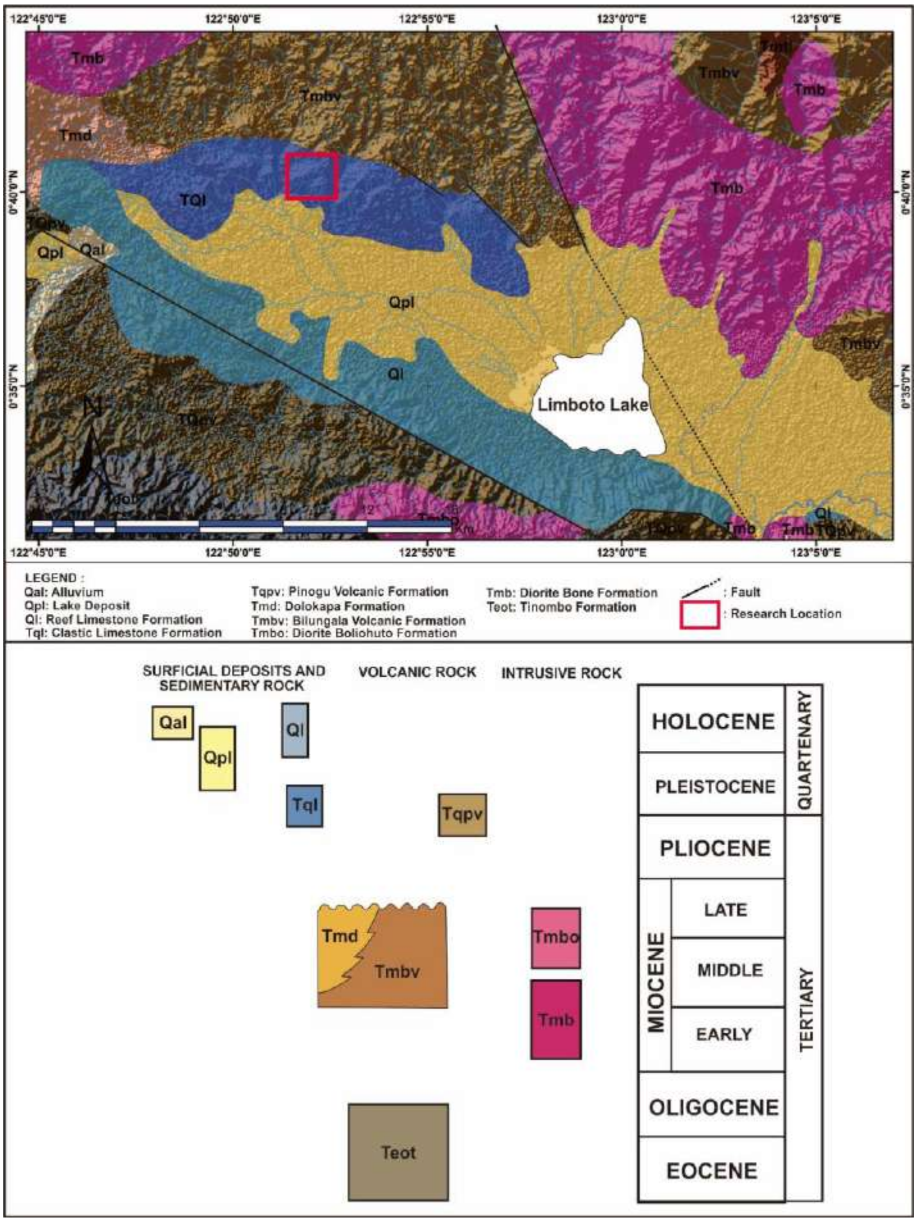

Fig. 1. Regional Geological Map of Gorontalo sheet (Bachri *et.al*., 1994) and the research location (Isimu area)

2. Material and Methods

The research 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 2). The research material is chiefly collected from limestone outcrops with a total thickness of 64 meters which belong to Isimu track. The thickness of limestone outcrops and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The Measuring Section (MS) uses a jacob’s staff with an interval of 1.5 meters and every 1 to 1.5 meters a sample is taken that is suspected to contain foraminifera (Compton, 1985). These samples usually have the characteristics of a fine (clay-silt) size, soft (not yet compacted and not hard) and having calcareous material proved by the 0.1 N Hydrogen Chloride solution test (Figure 3).

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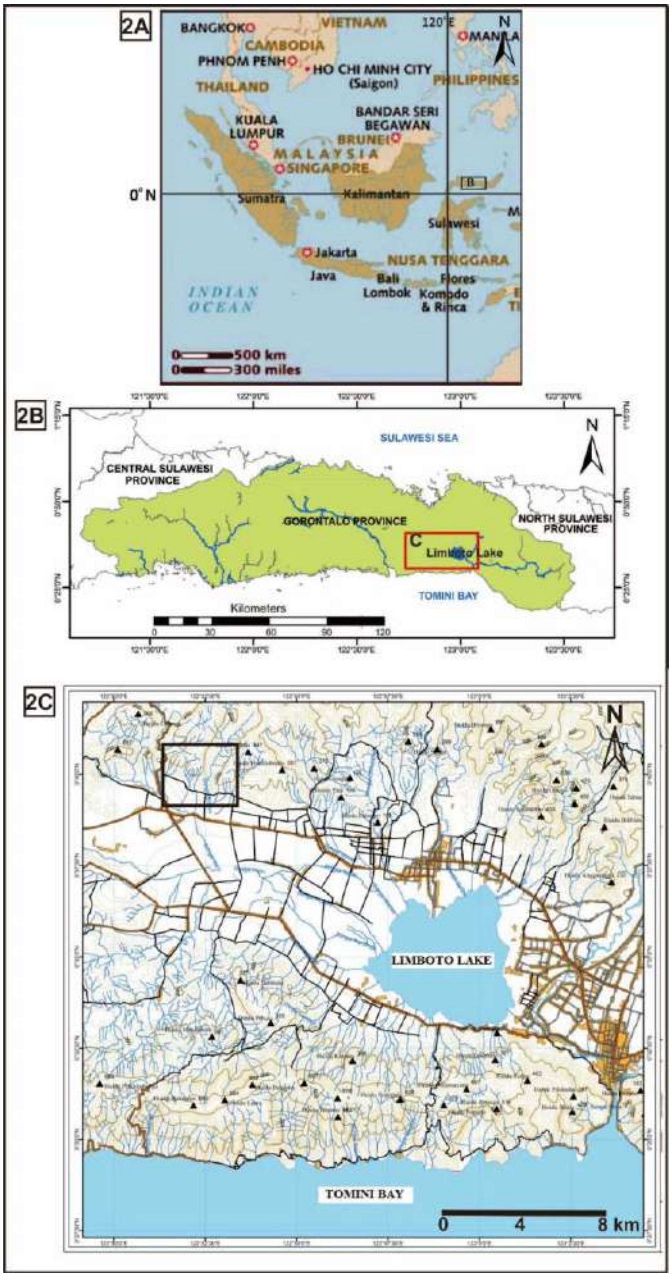

Fig. 2. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (A) the location of the island of Sulawesi on the map of the country of Indonesia, (B) the location of Limbolo Lake on the map of Gorontalo Province and (C) the map of research location (Isimu area)

Fig. 3. Appearance of the Limboto Limestone outcrop in the Isimu area. The measured section were made using a jacob's staff

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The biostratigraphy of a total of 34 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 (ovened 70^{o} Celsius) and packed using plastic bags. The identification of planktonic foraminifera fossil uses Olympus binocular SZ61 microscope which is equipped by a camera connected to a computer (Al-Enezi *et al.*, 2019). The samples generally contain moderately preserved (good enough) planktonic foraminiferas, and the abundance ranges from frequent to abundant. The distribution of fossil species is shown in Figure 4.

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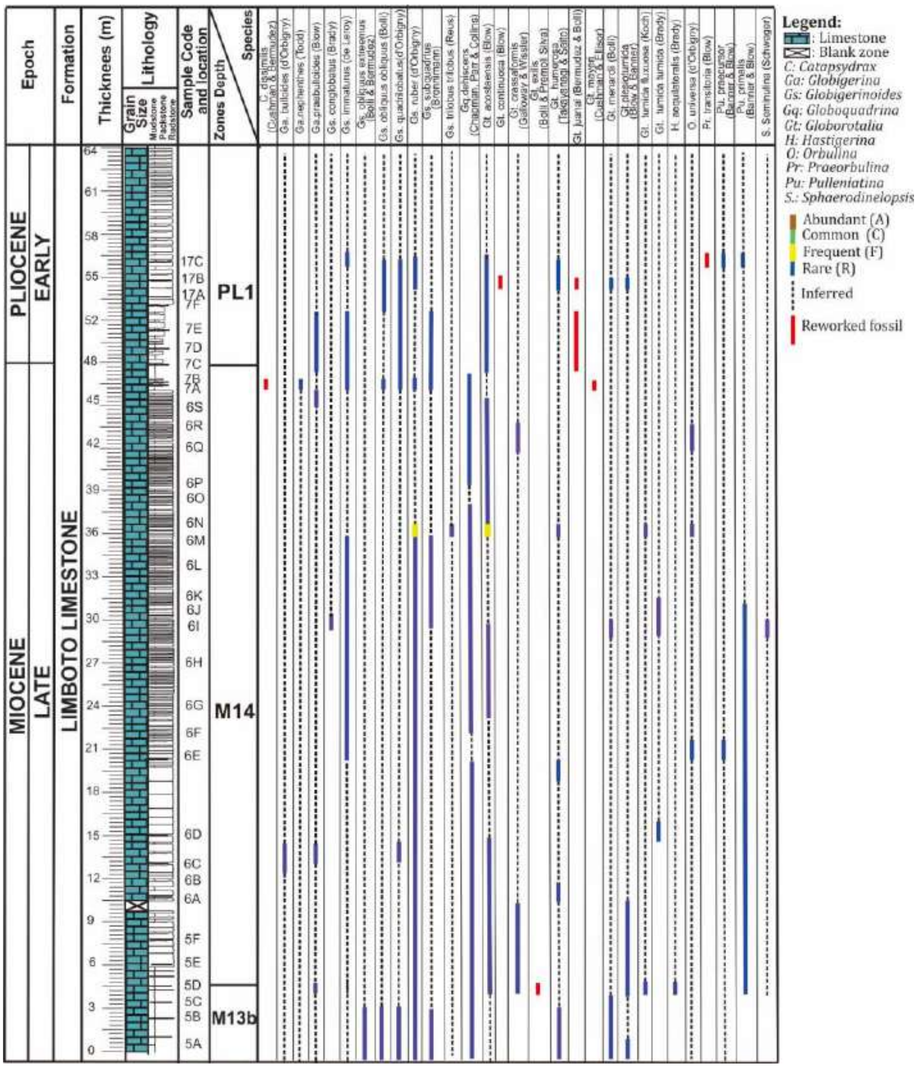

Fig. 4. Stratigraphic ranges of marker taxa of planktonic foraminifera in research location, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age

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6. Planktonic Foraminifera Biozones

The planktonic foraminiferal biozonations used in this study refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 consisting of 22 main Paleogene biozones with P1 to P22 notation, and 23 Neogene main biozones with 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 biodatums for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the earth's magnetism over the geological timespan. The most recent study (i.e. Wade *et al.*, 2011) divides the Cenozoic to be more detail using the "P" notation for Paleocene, "E" for Eocene, "O" for Oligocene, "M" for Miocene, "PL" for Pliocene and "PT" for Pleistocene. The zonation division makes Wade *etal*. (2011) biozonation tend to be more detailed than Blow (1969) biozonation) .

The biozone boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal biozone. The abbreviations used in the description of biozonation includes FO (first occurrence) and LO (last occurrence). FO and LO define biozones from taxa obtained from a particular region (Saraswati and Srinivasan, 2016). Biostratigraphic zone(s) uses the terms 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
Definition: The upper boundary of biozone M13b is the FO of *Pulleniatina primalis* (Table 1). The lower boundary is not found.
Discussion: This zone is *Globorotalia plesiotumida* partial range zone (Table 1). Biozone M13b is equivalent to biozone N17 (Blow, 1969) and biozone M13b (Wade *et al*., 2011). The FO datum of this zone is not found. The boundary of LO datum of this zone is FO *Pulleniatina primalis* (Table 1; Berggren *et al*., 1995b; Wade *et al*., 2011) in sample 5D.

The contents of fossil association within this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus extreemus* (Bolli and Bermudez), *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia humerosa* (Takayanagi and Saito) are also identified. Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady), *Globorotalia plesiotumida* (Blow in Banner) and *Globorotalia tumida fluxuosa* (Koch), thtat can be seen in Figure 5 and 6.

From this sample, several reworked fossils of *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida fluxuosa* (Koch) and *Hastigerina aequilateralis* (Brady) species are identified. The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rock above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters, in this study).
Age : Late Miocene or older than 6.40 Ma.

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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
2, 3, 4, 5	PLIOCENE	EARLY	N19	PL1	PL1		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N18	M14	M14	LO *Globoquadrina dehiscens* (5.80); FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurent Range Zone
7, 8			N17	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

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

Definition: The lower boundary is marked by the FO of *Pulleniatina primalis* (Table 1). The upper part boundary is marked by the LO of *Globoquadrina dehiscens (*Table 1*).*

Discussion: This biozone is *Pulleniatina primalis - Globoquadrina dehiscens* concurrent range zone. This zone is equivalent to biozone N18 (Blow, 1969) and biozone M14 (Wade *et al.*, 2011) . The FO datum 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 5D, 5E, 5F, 6A, 6B, 6C 6D, 6E, 6F to 17C. The occurrence of this species is not found in the lowest samples of 5A, 5B and 5C. The distribution of *Pulleniatina primalis* tend to not continuous in sample interval of 6K to 17A, and possibly caused by ecological changes in Miocene and Pliocene boundary. The latest datum of this zone is the LO of *Globoquadrina dehiscens* (Berggren *et al.*,

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1995a; Wade et al., 2011), where it was last found in sample 7C.

The contents of fossil association within this zone comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia crassaformis* (Galloway and Wissler) are also found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow), that can be seen in Figure 5 and 6.

The reworked fossils of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) 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).

Age: Late Miocene or 5.80 - 6.40 Ma.

Biozone PL1 (*Globorotalia acostaensis* partial range zone)

Definition: The lower boundary is marked by the LO of *Globoquadrina dehiscens* (Table 1). The upper boundary of PL2 is not found.

Discussion: This zone is *Globorotalia acostaensis* partial range zone. Zone PL1 is equivalent to Zone N19 (Blow, 1969) and Zone PL1 (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 7C. The occurrence of *Globoquadrina dehiscens* is reported in samples 5A, 5B, 5C, 5D, 5E, 5F, 6A 6B, 6C, 6D, 6E, 6G, 6H, 6I, 6J, 6K, 6L, 6M, 6N, 6O, 6Q, 6R, 6S, 7A, 7B to 7C, then not found further in the upper sample of 7D, 7E, 7F, 17A, 17B, and 17C.

The contents of fossil association within this zone are *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and *Globorotalia plesiotumida* (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow) that can be seen in Figure 5 and 6.

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this zone. The occurrence of these species is interpreted to be reworked from the older rocks, that 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.

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1. *Orbulina universa*, sample 5A
2. *Globorotalia acostaensis*, sample 5D
3. *Globorotalia continuosa*, sample 8B
4. *Globorotalia crassaformis*, sample 5A
5. *Globorotalia dutertrei*, sample 8B
6. *Globorotalia exilis*, sample 5D
7. *Globorotalia humerosa*, sample 5A
8. *Globorotalia juanai*, sample 8B
9. *Globorotalia mayeri*, sample 7B
10. *Globorotalia menardii*, sample 5A
11. *Pulleniatina primalis*, sample 5D
12. *Globorotalia plesiotumida*, sample 5A
13. *Globorotalia tumida flexuosa*, sample 5A
14. *Globorotalia tumida tumida*, sample 8B
15. *Hastigerina aequilateralis*, sample 5A

Fig. 5. Photomicrograph of planktonic foraminifera that found in this study (1)

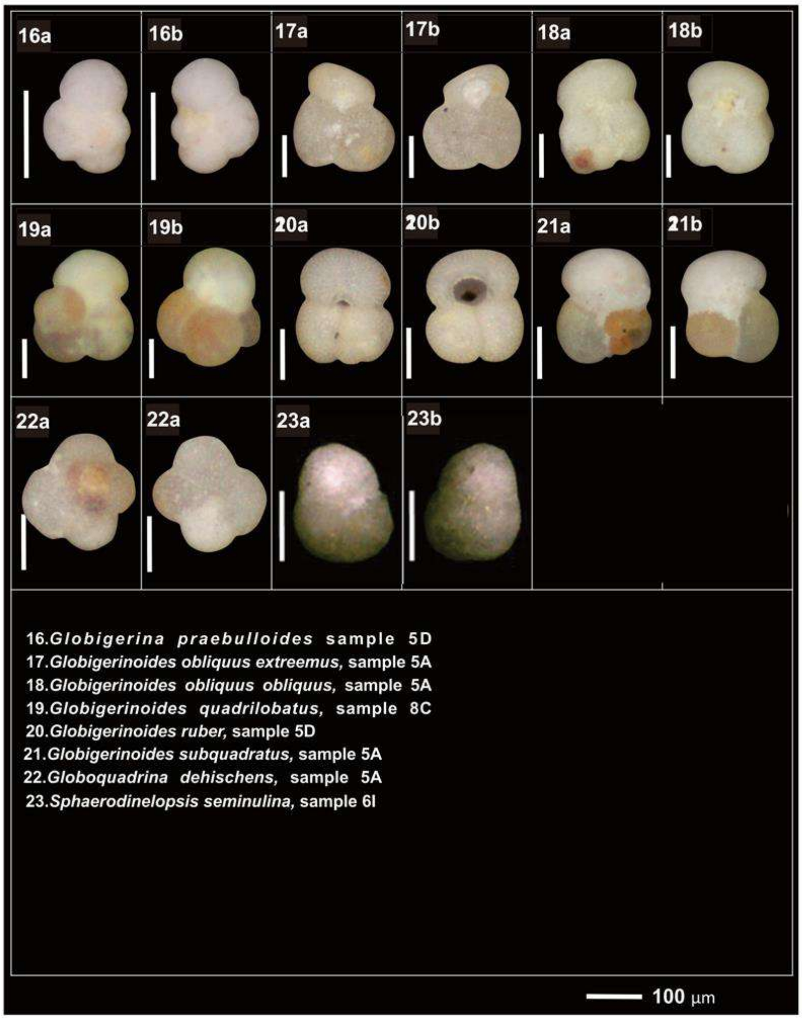

Fig. 6. Photomicrograph of planktonic foraminifera that found in this study (2)

7. Conclusions

Based on the measured section (MS) data, the planktonic foraminiferal zonation of limestones in the Limboto Basin is divided into two main biozonations namely the Miocene (Late Miocene) and Pliocene (Early Pliocene) biozones. The Miocene age consists of two biozone (M13b and M14) and the Pliocene age consists of only one biozones (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 biodatums such

Commented [A43]: Based on foraminiferal studied, the Limbato? Section can be assigned to three biozones...

as the LO *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first finding considering that Limboto Limestone has not been thoroughly studied regarding the biozonation of planktonic foraminifera. These results give an idea of the age and planktonic foraminifera zonation of the Limboto Limestone that is Late Miocene to 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.

8. Acknowledgement

We would like to thank *Educational Fund Management Agency* (LPDP) for helping us and awarding the educational scholarships through *Indonesian lecturer main scholarship* (BUDI DN).

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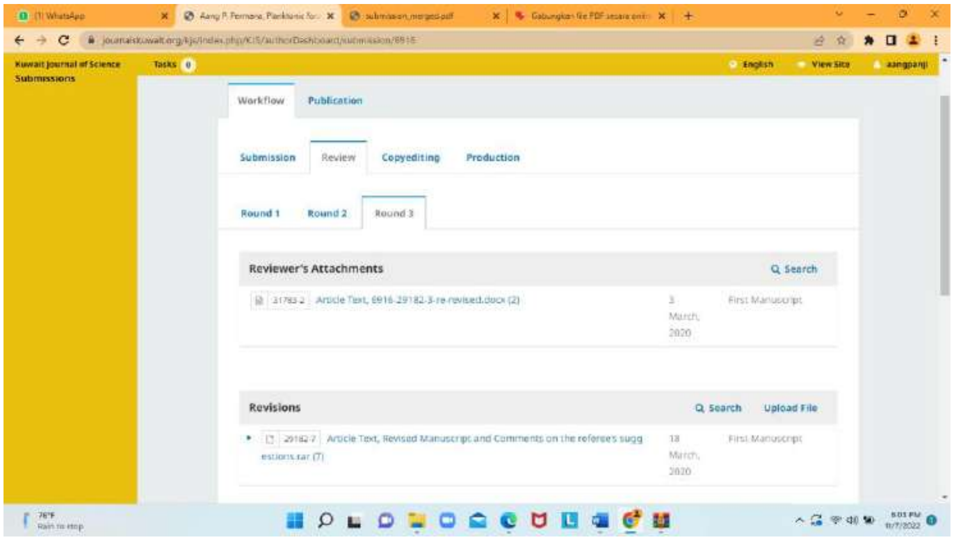
ROUND 3



Review Report of Re-revised Manuscript # 6916-23522-1-SP

The re-revised manuscript titled "**Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia"** has been thoroughly reviewed.

The authors are advised to consider the following comments / suggestions.

- English of the manuscript needs improvement.
- Why the area is left blank on page # 7 and 8? There should be no blank area within the text of the paper. However, it might be covered during final preparation and editing of the manuscript.
- Text (especially codes of different geological formations or rock units) on map part of fig. 2 is not legible. Increase the font size so that the text can be readable.
- I don't know why the authors are ignoring my comment again and again about insertion of outcrop photographs. They can simply answer in response to my comment that unfortunately, we haven't got outcrop photograph(s). It is not adequate and suitable to avoid answering a comment of reviewer. Each and every comment(s) of reviewer should be considered and answered with great care.

- Insert photomicrograph(s) of fossil species *Globigerina bulloides* (d'Orbigny). It is mentioned in the text but no photomicrograph(s) is provided.
- It is once again advised to check the sequence of fossils photomicrographs in text and then in the related figures. They should be arranged in an order in which they are discussed/mentioned in the text of the manuscript.
- The scientist's names are mentioned at the end of each and every species, so it is also advised to mention year at the end of scientist(s) name(s). Such pattern should be followed throughout the text as well as figures of the manuscript.
- For minor comments and suggestions, the annotated manuscript draft should be consulted.

Remarks about status of the manuscript

- The manuscript is accepted after minor revision for publication in Kuwait Journal of Science.

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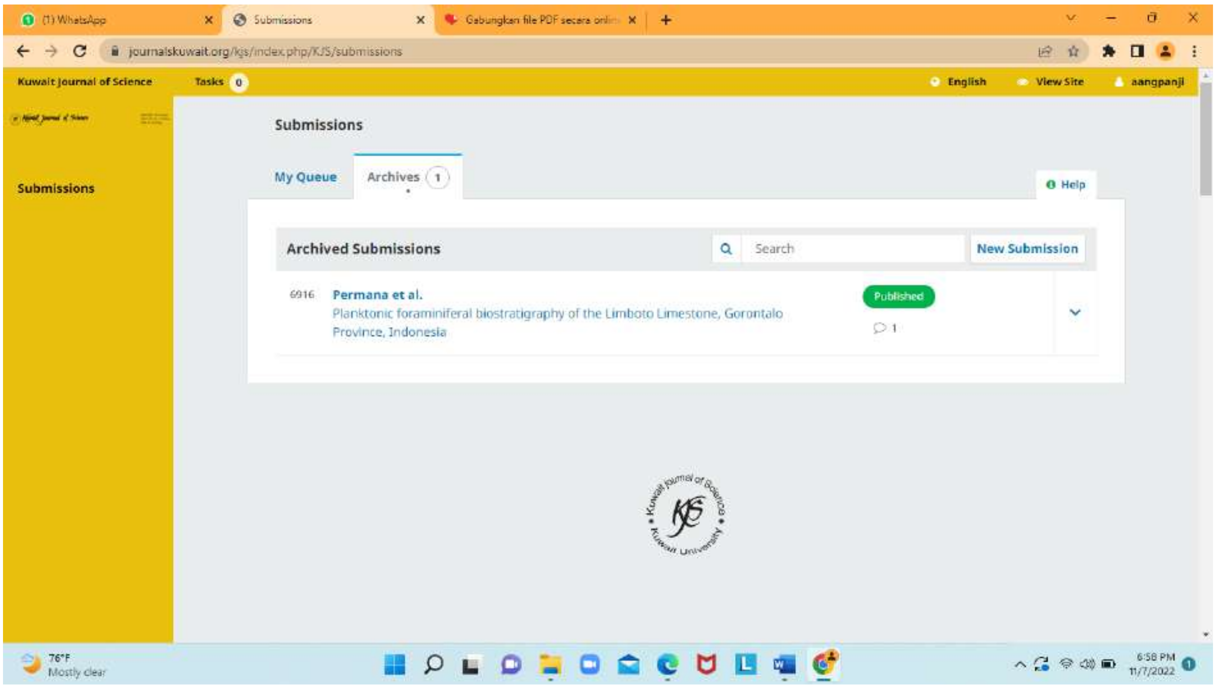

Accepted paper 6916 (jan.2021 issue)

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Kindly note that we are preparing the Jan.2021 issue, please check your paper entitled "**Planktonic foraminiferal biostratigraphy of the Limboto Limestone, Gorontalo Province, Indonesia** "before we sent it to the language editor and confirm the Final version of your paper.

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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 northern part of Limboto Lake. The purpose of this study was to determine the planktonic foraminiferal biozonation and the absolute age of Limboto limestones. The analyzed planktonic foraminiferal fossils can be classified as well to moderately preserved with many fossils, in the context of abundance, categorized as frequent to abundant. There are three recognized planktonic foraminiferal biozones which are proposed to follow the standard biozonation: two biozone for Miocene age (M13b and M14) and one biozones for Pliocene age (PL1). The results of this study can be a reference to propose a new formation called as Limboto Limestone Formation that was previously known as Clastic Limestone Formation and Coral Limestone Formation. Determination of the Limboto Limestone Formation is based on the time interval and relative age of the formation.

Keywords: Foraminiferal biostratigraphy, Limboto Limestone

1. Introduction

The Indonesian archipelago is geologically located in the center of three main active plates: 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 (Hutchison, 1989). 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-shape 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 very complex which were formed during the Oligocene to Miocene age (Sukamto, 1975c; Hamilton, 1979; Daly *et al.*, 1991).

The basement rock of the North Sulawesi arm was 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 $120\text{-}122^0$ E (Surmont *et al.*, 1994. The clockwise rotation is only $20\text{-}25^0$ which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al.*, 1994).

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 (Bemmelen, 1949; Katili, 1970 and 1989). The main fault zone can be seen from the Patente river, Tombuililato cape and Gorontalo coastline lineament pattern. The evidence of the intensive tectonic 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 Quatenary age (Bemmelen, 1949; Katili, 1970 and 1989).

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*., 1994) was conducted to produce a regional geological map with the scale of 1 : 250,000 (Figure1). Limestone distribution on regional geological maps is divided into two formations: 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 - 200 meters. Coral Limestone Formation (Ql), distributed in south part of the lake, consisting of reef limestone which contain the coral fragment as the main constituent, is deposited contemporaneously with the Clastic Limestone Formation (TQl) and estimated has a Holocene age (Bachri *et al*., 1997).

The difference in determining the limestone age in the Limboto Basin in (Bachri *et.al*., 1994) and (Trail *et al*., 1974) makes this research interesting for revealing the relative limestone age. Moreover, this study is not only to map the limestone distribution but also to conduct detailed research by using measured section and biostratigraphy analysis, it was the first time done in this formation. So the purpose of the research is to make planktonic foraminiferal biostratigraphic zonation to determine the relative age of Limboto Limestone, Gorontalo Province, Indonesia.

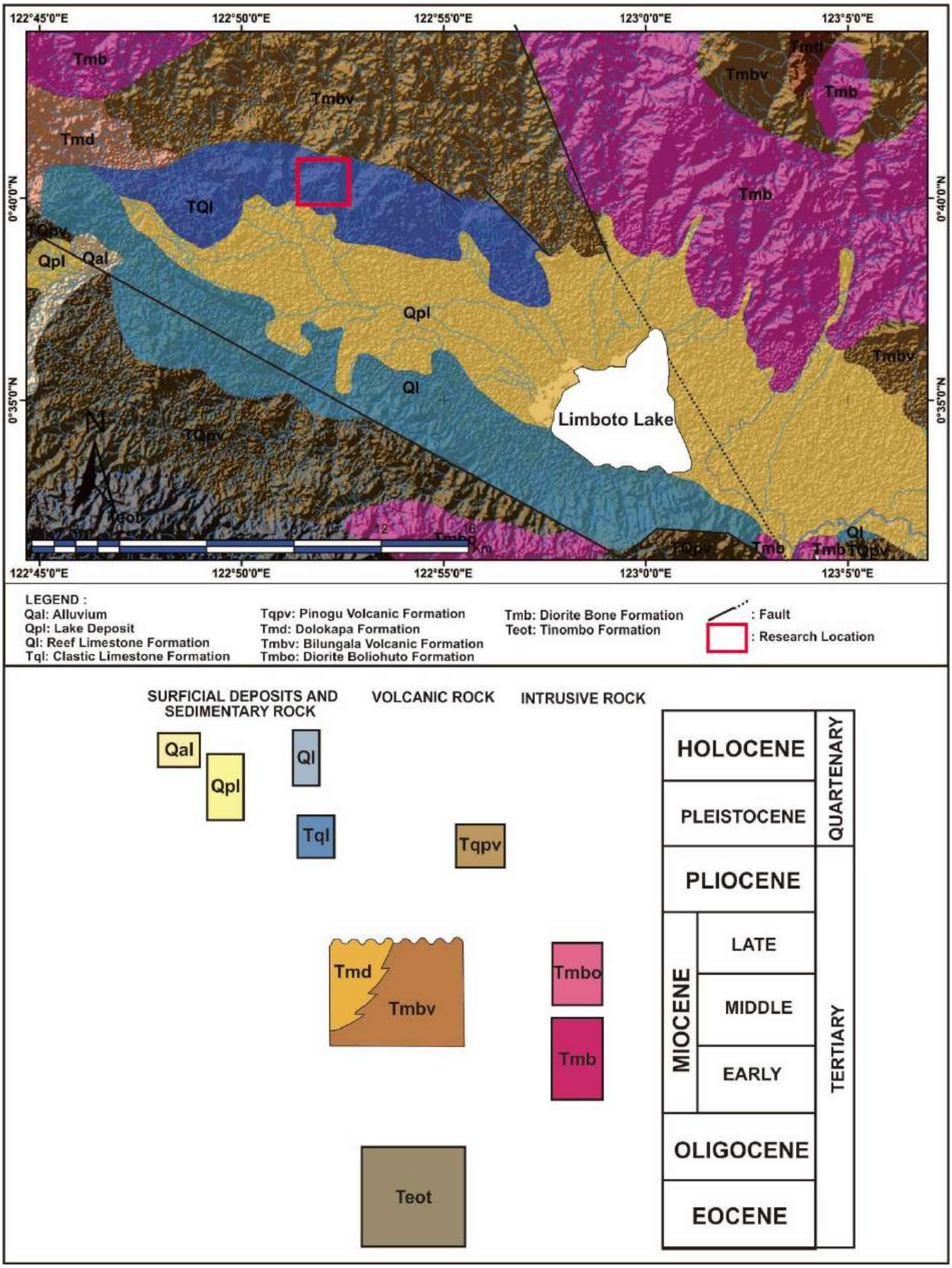

Fig. 1. Regional Geological Map of Gorontalo sheet (Bachri *et.al.*, 1994) and the research location (Isimu area)

2. Material and Methods

The research location is a part of the Limboto Basin, Gorontalo Province, Indonesia within the coordinates of $0^o40'5.917''$North, $122^o51'11.939''$East) to $0^o39'40.670''$North, $122^o52'16.205''$East) (Figure 2). The research material is chiefly collected from limestone outcrops with a total thickness of 64 meters which belong to Isimu track. The thickness of limestone outcrops and the flat slope position requires a careful and systematic measured section that follows the stratigraphical order from the lower to the upper part (from older to younger strata). The Measuring Section (MS) uses a jacob's staff with an interval of 1.5 meters and every 1 to 1.5 meters a sample is taken that is suspected to contain foraminifera (Compton, 1985). These samples usually have the characteristics of a fine (clay-silt) size, soft (not yet compacted and not hard) and having calcareous material proved by the 0.1 N Hydrogen Chloride solution test (Figure 3).

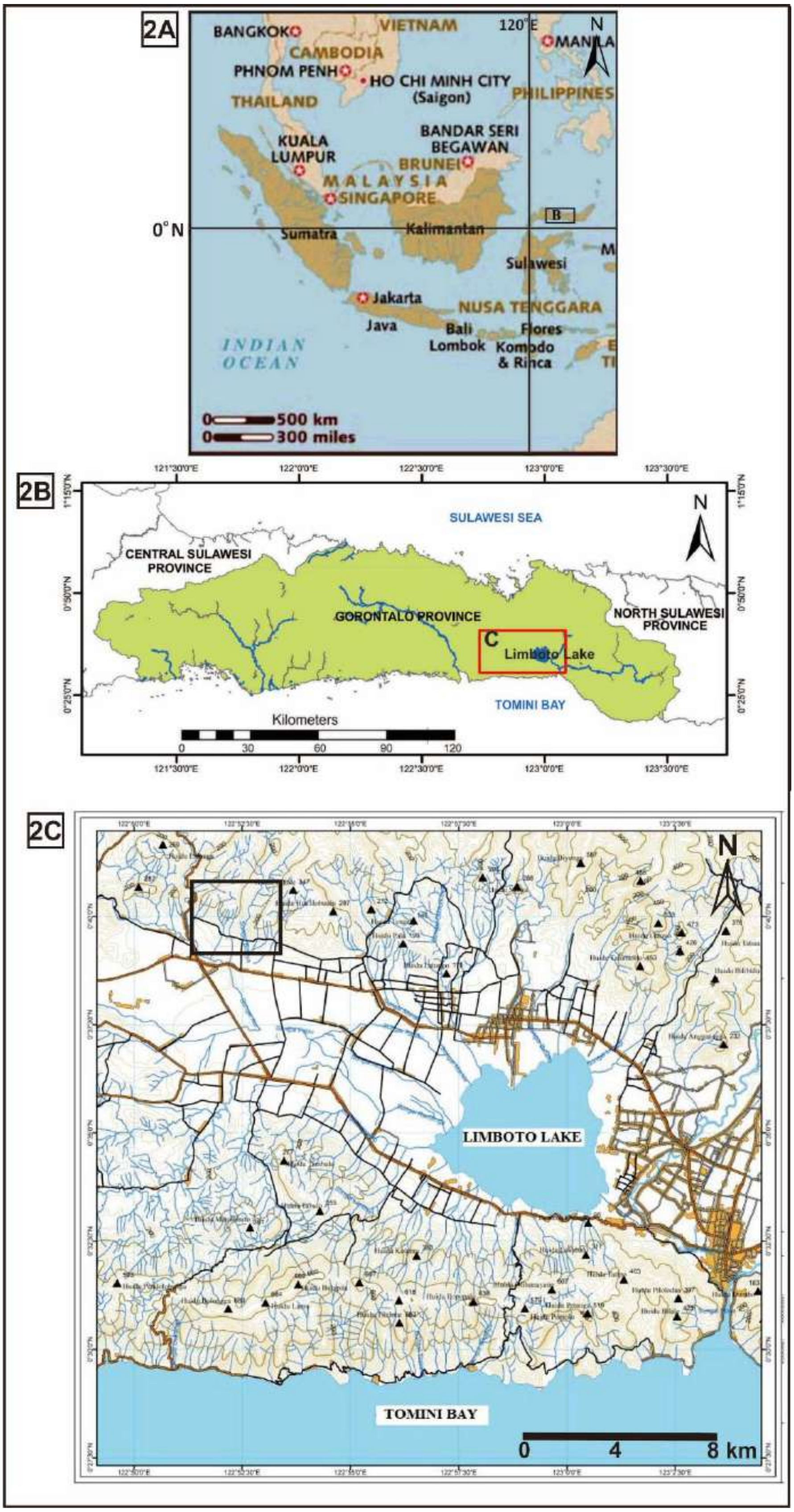

Fig. 2. Basin of Limboto, Gorontalo Province with measured section (MS) location of this study area. (A) the location of the island of Sulawesi on the map of the country of Indonesia, (B) the location of Limbolo Lake on the map of Gorontalo Province and (C) the map of research location (Isimu area)

Fig. 3. Appearance of the Limboto Limestone outcrop in the Isimu area. The measured section were made using a jacob's staff

The biostratigraphy of a total of 34 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 (ovened 70^o Celsius) and packed using plastic bags. The identification of planktonic foraminifera fossil uses Olympus binocular SZ61 microscope which is equipped by a camera connected to a computer (Al-Enezi *et al.*, 2019). The samples generally contain moderately preserved (good enough) planktonic foraminiferas, and the abundance ranges from frequent to abundant. The distribution of fossil species is shown in Figure 4.

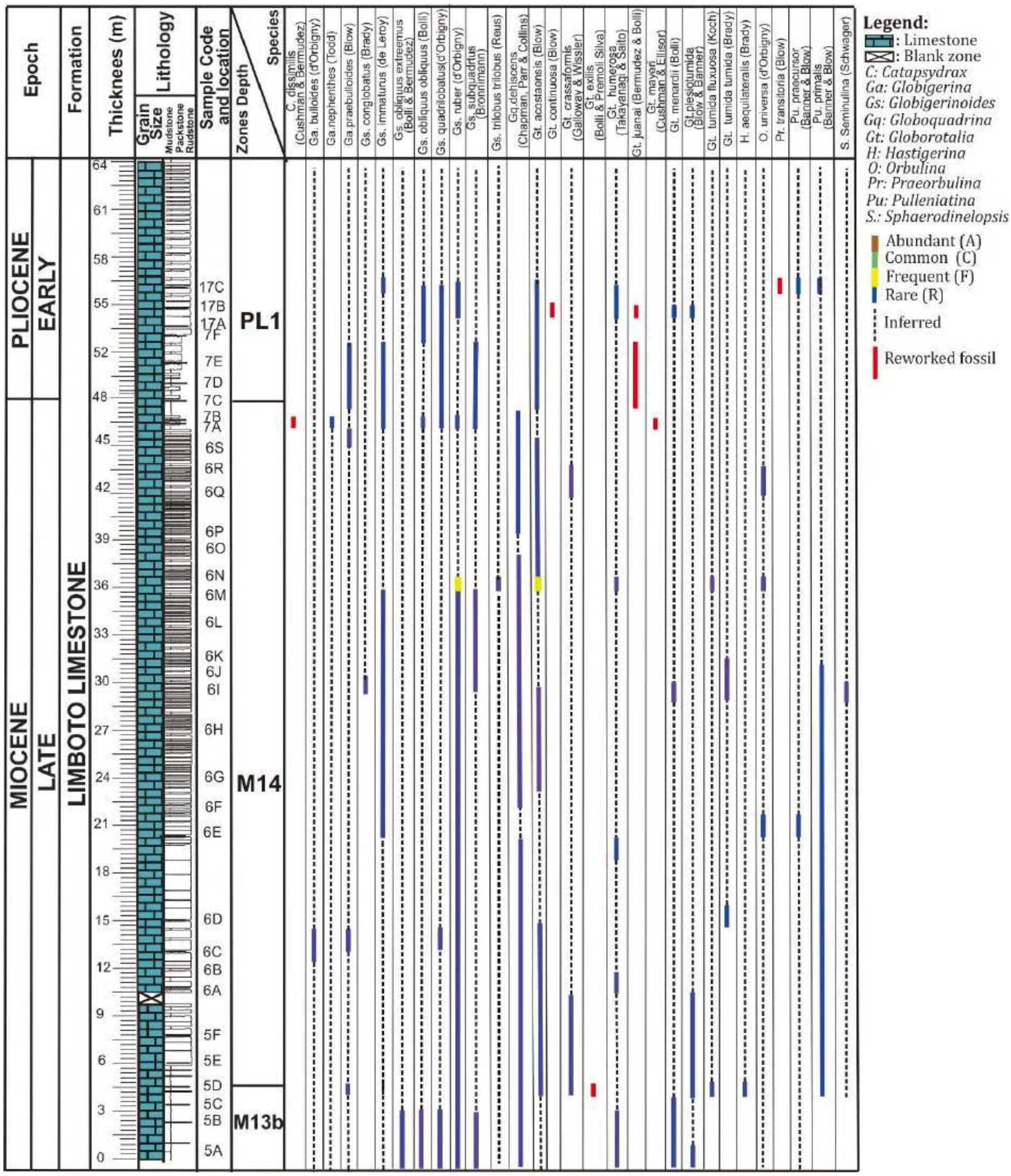

Fig. 4. Stratigraphic ranges of marker taxa of planktonic foraminifera in research location, can be divided to three biozonation namely M13b, M14 and PL1 zones, that shows the Late Miocene to Early Pliocene age

3. Planktonic Foraminifera Biozones

The planktonic foraminiferal biozonations used in this study refers to Blow (1969) and Wade *et al.* (2011) biozonation. 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 consisting of 22 main Paleogene biozones with P1 to P22 notation, and 23 Neogene main biozones with 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 biodatums for biostratigraphy. Research is increasingly accurate because it has been calibrated with changes in the earth's magnetism over the geological timespan. The most recent study (i.e. Wade *et al*., 2011) divides the Cenozoic to be more detail using the "P" notation for Paleocene, "E" for Eocene, "O" for Oligocene, "M" for Miocene, "PL" for Pliocene and "PT" for Pleistocene. The zonation division makes Wade *etal*. (2011) biozonation tend to be more detailed than Blow (1969) biozonation) .

The biozonation boundaries of the study area are defined by the taxa datum of the planktonic foraminiferal biozone. The abbreviations used in the description of biozonation includes FO (first occurrence) and LO (last occurrence). FO and LO define biozonation from taxa obtained from a particular region (Saraswati and Srinivasan, 2016). Biostratigraphic zone(s) uses the terms 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

Definition: The upper boundary of biozone M13b is the FO of *Pulleniatina primalis* (Table 1). The lower boundary is not found.

Discussion: This zone is *Globorotalia plesiotumida* partial range zone (Table 1). Biozone M13b is equivalent to biozone N17 (Blow, 1969) and biozone M13b (Wade *et al*., 2011). The FO datum of this zone is not found. The boundary of LO datum of this zone is FO *Pulleniatina primalis* (Table 1*;* Berggren *et al*., 1995b; Wade *et al*., 2011) in sample 5D.

The contents of fossil association within this zone is *Globoquadrina dehiscens* (Chapman, Parr and Collins), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus extreemus* (Bolli and Bermudez), *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia humerosa* (Takayanagi and Saito) are also identified. Also there are fossil species *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady), *Globorotalia plesiotumida* (Blow in Banner) and *Globorotalia tumida fluxuosa* (Koch), thtat can be seen in Figure 5 and 6.

From this sample, several reworked fossils of *Globorotalia crassaformis* (Galloway and Wissler), *Globorotalia exilis* (Blow), *Globorotalia tumida fluxuosa* (Koch) and *Hastigerina aequilateralis* (Brady) species are identified. The occurrence of these fossils is estimated to be derived from a collapsed and fallen material from the younger rock above this zone. The thickness of this zone is 4.5 meters (interval of 0 – 4.5 meters, in this study).

Age : Late Miocene or older than 6.40 Ma.

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
2, 3, 4, 5	PLIOCENE	EARLY	N19	PL1	PL1		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N18	M14	M14	LO *Globoquadrina dehiscens* (5.80) FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurent Range Zone
7, 8	MIOCENE	LATE	N17	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

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

Definition: The lower boundary is marked by the FO of *Pulleniatina primalis* (Table 1). The upper part boundary is marked by the LO of *Globoquadrina dehiscens (*Table 1*).*

Discussion: This biozone is *Pulleniatina primalis - Globoquadrina dehiscens* concurrent range zone. This zone is equivalent to biozone N18 (Blow, 1969) and biozone M14 (Wade *et al.*, 2011) . The FO datum 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 5D, 5E, 5F, 6A, 6B, 6C 6D, 6E, 6F to 17C. The occurrence of this species is not found in the lowest samples of 5A, 5B and 5C. The distribution of *Pulleniatina primalis* tend to not continuous in sample interval of 6K to 17A, and possibly caused by ecological changes in Miocene and Pliocene boundary. The latest datum of this zone is the LO of *Globoquadrina dehiscens* (Berggren *et al.*, 1995a; Wade et al., 2011), where it was last found in sample 7C.

The contents of fossil association within this zone comprises *Globigerina bulloides* (d'Orbigny), *Globigerina nepenthes* (Todd), *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy) and *Globigerinoides obliquus obliquus* (Bolli). Moreover, *Globigerinoides quadrilobatus* (d'Orbigny), *Globigerinoides ruber* (d'Orbigny), *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow) and *Globorotalia crassaformis* (Galloway and Wissler) are also found. Also there are fossil species *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia plesiotumida* (Blow and Banner), *Globorotalia tumida tumida* (Brady), *Orbulina universa* (d'Orbigny) and *Pulleniatina praecursor* (Banner and Blow), that can be seen in Figure 5 and 6.

The reworked fossils of *Catapsydrax dissimilis* (Cushman and Bermudez), *Globorotalia juanai* (Bermudez and Bolli) and *Globorotalia mayeri* (Cushman and Ellisor) 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).

Age: Late Miocene or 5.80 - 6.40 Ma.

Biozone PL1 (*Globorotalia acostaensis* partial range zone)

Definition: The lower boundary is marked by the LO of *Globoquadrina dehiscens* (Table 1). The upper boundary of PL2 is not found.

Discussion: This zone is *Globorotalia acostaensis* partial range zone. Zone PL1 is equivalent to Zone N19 (Blow, 1969) and Zone PL1 (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 7C. The occurrence of *Globoquadrina dehiscens* is reported in samples 5A, 5B, 5C, 5D, 5E, 5F, 6A 6B, 6C, 6D, 6E, 6G, 6H, 6I, 6J, 6K, 6L, 6M, 6N, 6O, 6Q, 6R, 6S, 7A, 7B to 7C, then not found further in the upper sample of 7D, 7E, 7F, 17A, 17B, and 17C.

The contents of fossil association within this zone are *Globigerina praebulloides* (Blow), *Globigerinoides immaturus* (de Leroy), *Globigerinoides obliquus obliquus* (Bolli), *Globigerinoides quadrilobatus* (d'Orbigny) and *Globigerinoides ruber* (d'Orbigny). Moreover, species of *Globigerinoides subquadratus* (Bronnimann), *Globorotalia acostaensis* (Blow), *Globorotalia humerosa* (Takayanagi and Saito), *Globorotalia dutertrei* (d'Orbigny) and *Globorotalia plesiotumida* (Blow and Banner) are also found. Also there are fossil species *Praeorbulina transitoria* (Blow), *Pulleniatina praecursor* (Banner and Blow) and *Pulleniatina primalis* (Banner and Blow) that can be seen in Figure 5 and 6.

Several reworked fossils such as *Globorotalia continuosa* (Blow), *Globorotalia juanai* (Bermudez and Bolli), *Globorotalia menardii* (d'Orbigny in Parker, Jones and Brady) and *Praeorbulina transitoria* (Blow) species are also identified from this zone. The occurrence of these species is interpreted to be reworked from the older rocks, that 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.

1. *Orbulina universa*, sample 5A
2. *Globorotalia acostaensis*, sample 5D
3. *Globorotalia continuosa*, sample 8B
4. *Globorotalia crassaformis*, sample 5A
5. *Globorotalia dutertrei*, sample 8B
6. *Globorotalia exilis*, sample 5D
7. *Globorotalia humerosa*, sample 5A
8. *Globorotalia juanai*, sample 8B
9. *Globorotalia mayeri*, sample 7B
10. *Globorotalia menardii*, sample 5A
11. *Pulleniatina primalis*, *sample* 5D
12. *Globorotalia plesiotumida*, sample 5A
13. *Globorotalia tumida flexuosa*, sample 5A
14. *Globorotalia tumida tumida*, sample 8B
15. *Hastigerina aequilateralis*, sample 5A

Fig. 5. Photomicrograph of planktonic foraminifera that found in this study (1)

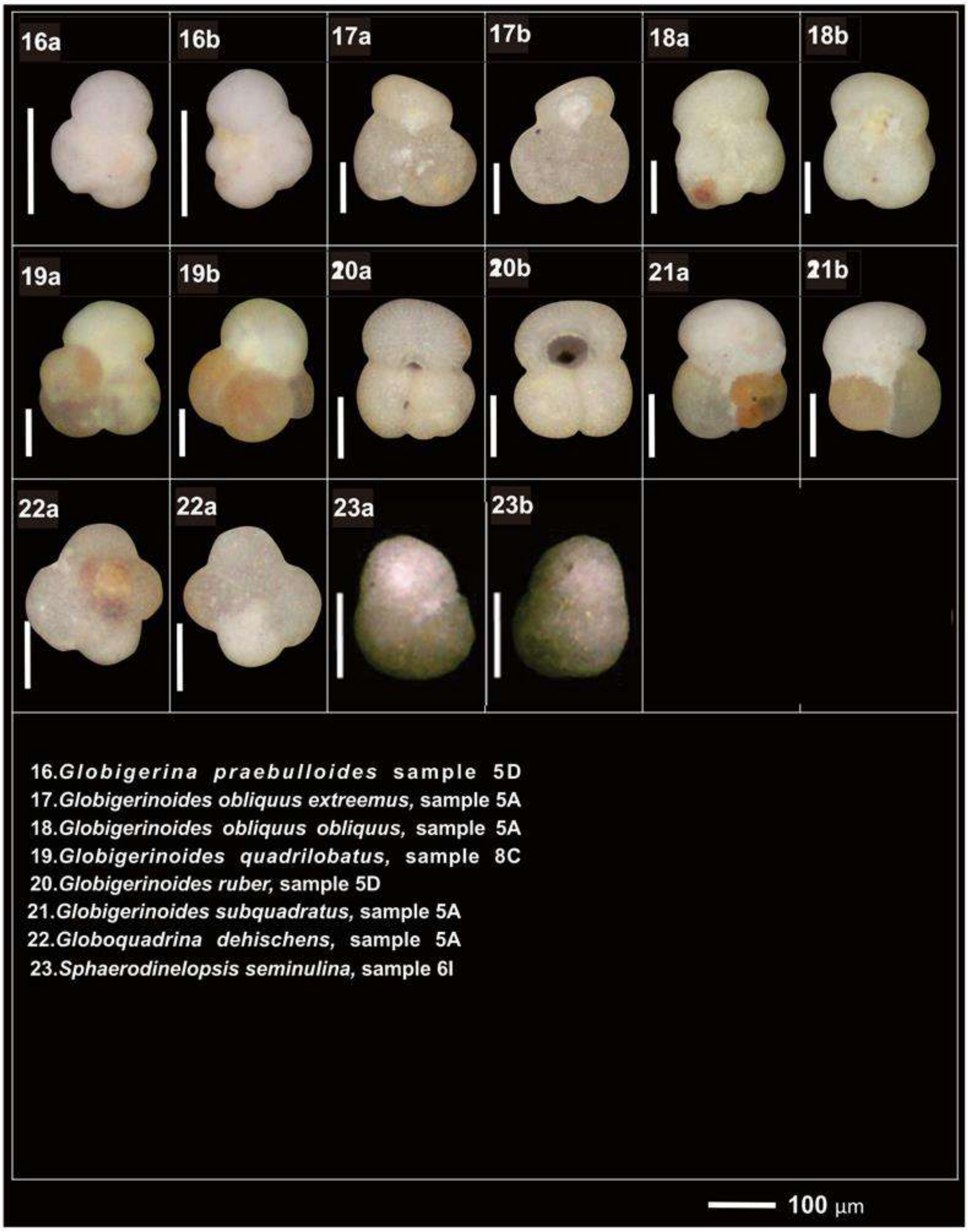

Fig. 6. Photomicrograph of planktonic foraminifera that found in this study (2)

4. Conclusions

Based on the measured section (MS) data, the planktonic foraminiferal zonation of limestones in the Limboto Basin is divided into two main biozonations namely the Miocene (Late Miocene) and Pliocene (Early Pliocene) biozones. The Miocene age consists of two biozone (M13b and M14) and the Pliocene age consists of only one biozones (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 biodatums such as the LO *Globoquadrina dehiscens* and FO of *Pulleniatina primalis*. This result is the first finding considering that Limboto Limestone has not been thoroughly studied regarding the biozonation of planktonic foraminifera. These results give an idea of the age and planktonic foraminifera zonation of the Limboto Limestone that is Late Miocene to 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.

5. Acknowledgement

We would like to thank *Educational Fund Management Agency* (LPDP) for helping us and awarding the educational scholarships through *Indonesian lecturer main scholarship* (BUDI DN).

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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 $120\text{-}122^0$ E (Surmont *et al.*, 1994). The clockwise rotation is only $20\text{-}25^0$, which occurred after the Miocene. Similar results were obtained from SPOT imagery analysis of Gorontalo and Kotamobagu shear fault zones (Surmont *et al.*, 1994).

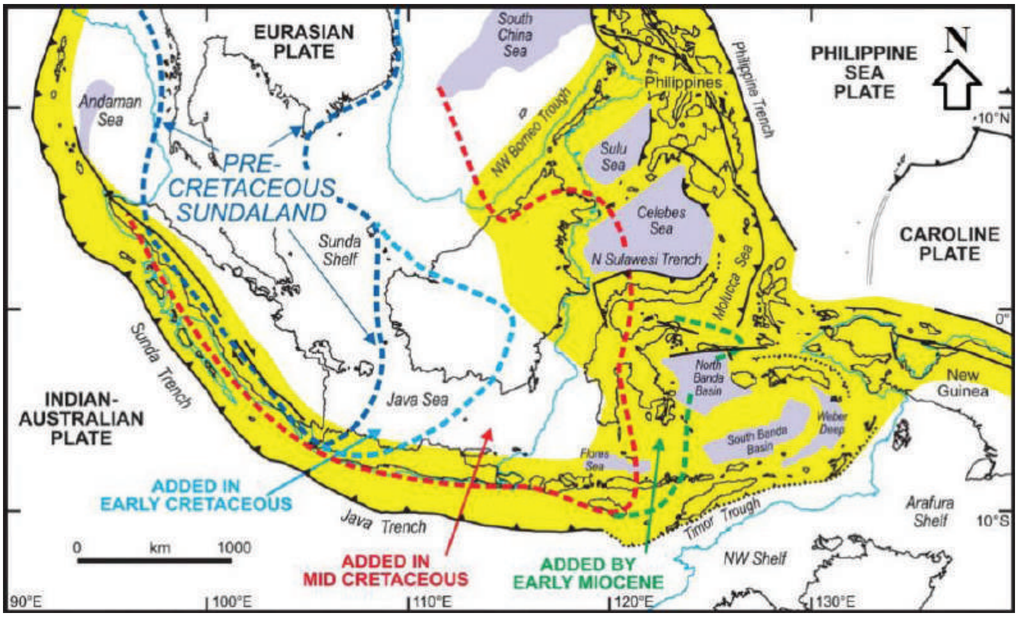

Fig. 1. Tectonic map of Indonesia showing the interaction of major plates (modified from Hamilton, 1979).

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.

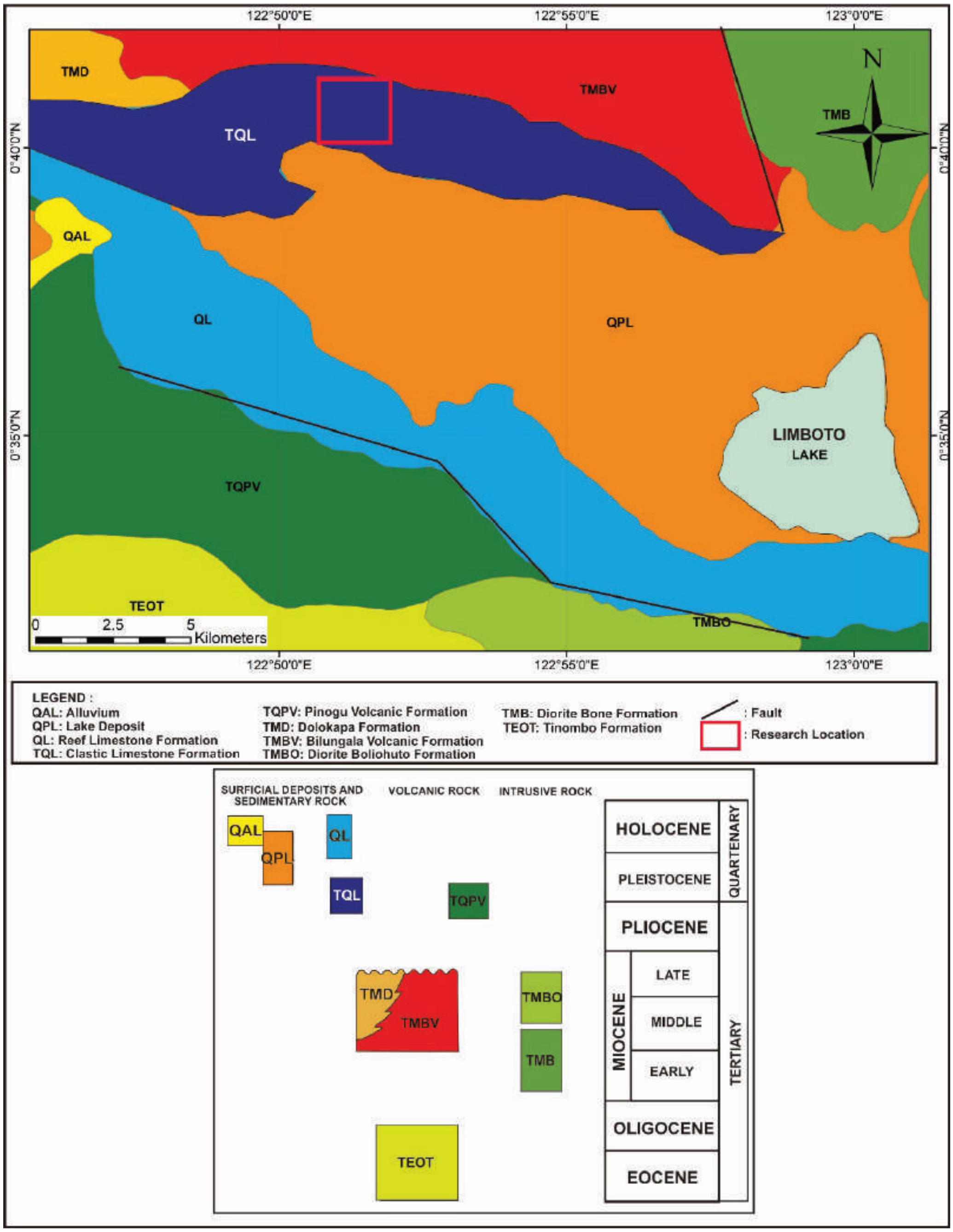

Fig. 2. Regional Geological Map of Gorontalo (Bachri *et al*., 1997). The present research location (Limboto area) is marked with box having pink color outline.

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).

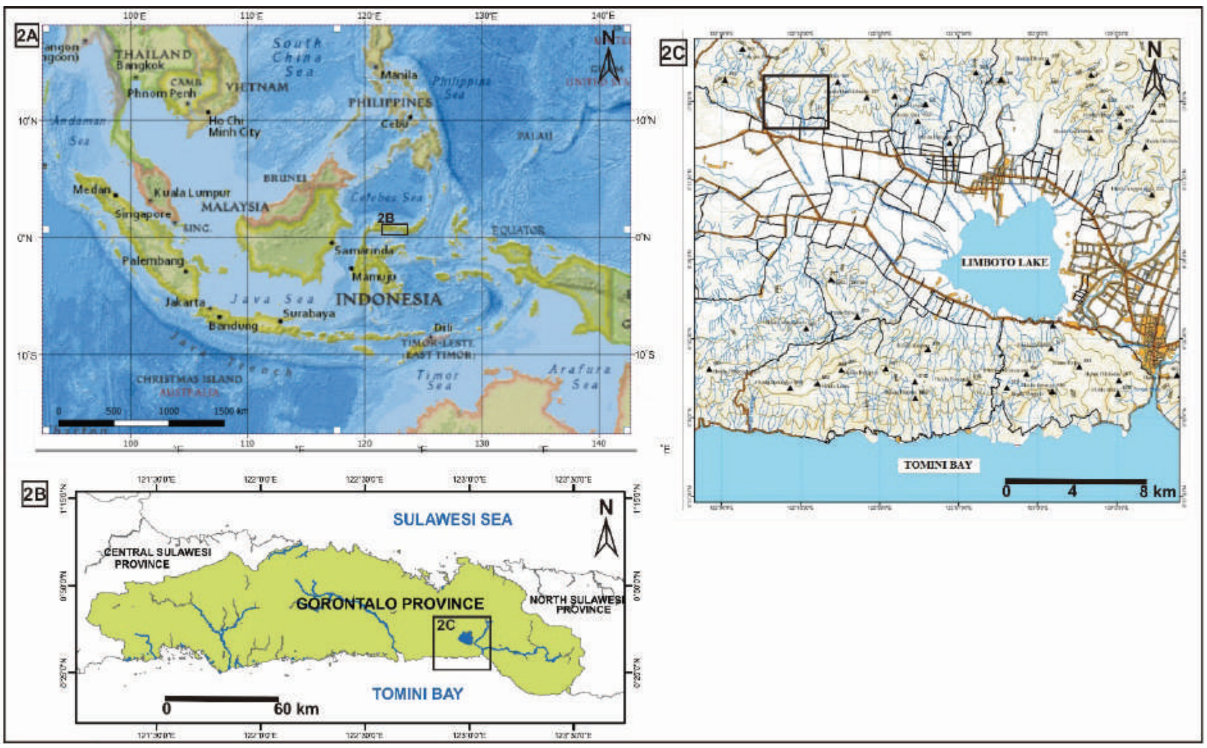

Fig. 3. Basin of Limboto, Gorontalo Province, with measured section (MS) location of this study area. (2A) the location of the island of Sulawesi on the map of the country of Indonesia, (2B) the location of Limboto Lake on the map of Gorontalo Province (GIS map), and (2C) the map of research location (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, 1969), *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			Bioevents/Biodatums used in this study (Age in Ma)	Biostratigraphic Zonations of the present study
			Blow(1969)	Wade *et al* (2011)	Permana *et al* (2019) (This Study)		
0, 1, 2, 3, 4, 5	PLIOCENE	EARLY	N18	PL1	PL1		*Globorotalia Acostaensis* Partial Range Zone
6	MIOCENE	LATE	N17b	M14	M14	LO *Globoquadrina dehiscens* (5.80); FO *Pulleniatina primalis* (6.40)	*Pulleniatina primalis - Globoquadrina dehiscens* Concurrent Range Zone
7, 8			N17a	M13b	M13b		*Globorotalia Plesiotumida* Partial Range Zone

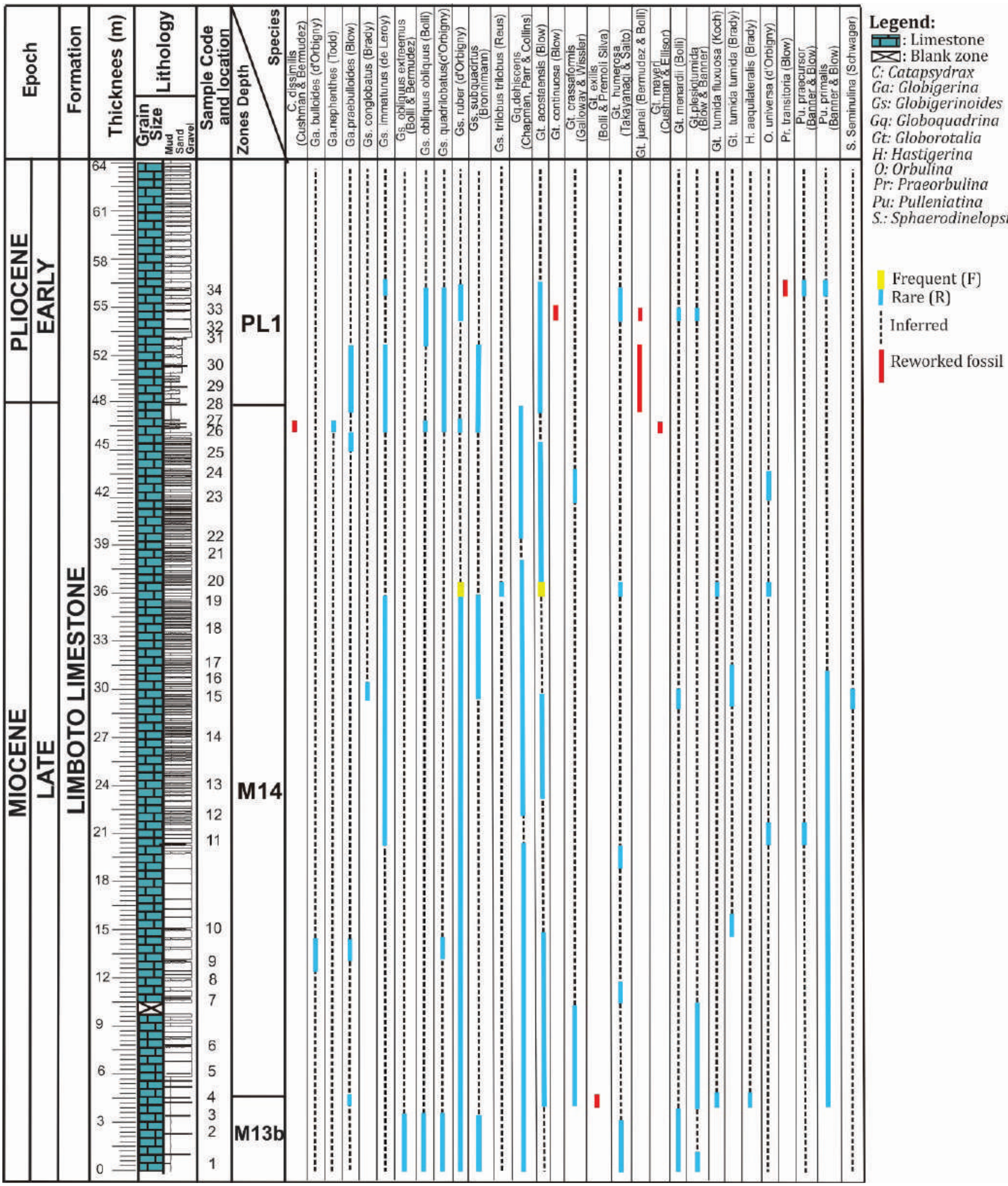

Fig. 5. Stratigraphic ranges of marker taxa of planktonic foraminifera in Limboto Limestone can be divided to three biozonations, namely, M13b, M14, and PL1 zones, which shows the Late Miocene to Early Pliocene ages.

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 to 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