The Miocene (25.2 – 5.6 million years ago) climate changes recorded by foraminifera and nannofossils assemblages in Bogor Basin, Western Java

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Abstract. The Miocene composite sections reveal that a bathyal to the inner neritic setting (20 - 500 m sea level depth) was being filled dominantly by fine siliciclastic, which deposited in fluctuate of warm to a temperate climate. The quantitative data of total abundancy, species number, marker species ratio, shell coiling direction ratio and size guided to sea surface temperature realms. The warm zone was determined based on high total abundance and diversity, a high frequency of foraminifera and nannofossil tropical marker species, dominated by dextral coiling direction, and relatively big size-specific foraminifera taxa. On the contrary, warm temperate zones were identified by lower total abundance and diversity. In the lower part, the sediments contain medium to high -abundance and -diversity of foraminifera as well as nannofossil assemblages indicated a warm climate at the Earliest Miocene (25.2-24 Ma). The low -total abundancy and -species number that indicates a decrease in temperature were recorded until the earliest Middle Miocene (24-20 Ma). The dominance of Orbulina group with a high frequency of tropical species marker (Globoquadrina altispira, G. globosa, Globigerinoides trilobus, G. sacculiferus and Discoaster group) indicated significant increase in temperature. The optimum of total- and individual- abundance along with the dominated of big size-Orbulina, increased tropical foraminifera, and nannofossil species markers indicate a warm climate at Middle Miocene (16-13.8 Ma). The decreased dextral relative shell coiling ratio of Globorotalia menardii and Globorotalia acostaensis, abundance and diversity of assemblages or taxa markers that indicate the temperature decrease is recorded in Late Miocene interval several times. An increased number of Calcidiscus leptoporus, Coccolithus pelagicus, Discoaster challengeri, D. variabilis, and Hayaster perplexus, the less -total abundance and -diversity indicated a warm temperate climate (10 to 6.2 Ma). It is considered to correlate with the global glaciation period.

1. Introduction
Climate change phenomena over the past few million years have had a significant impact on abundance and diversification patterns in many extant species [1–3]. The occurrence, evolution, and adaption of microorganisms have been considered to be correlated with climatic changes. Numerous studies have shown that there are differences in type and abundance of specific species, called marker species, in cooler and warmer conditions.
Since sea surface temperature indicator significance of Recent planktic forms first become apparent, several micropaleontology studies have been carried out to reconstruct climate history. Based on the quantitative analysis on sea surface temperature marker foraminifera remains, it can be concluded that tropical assemblages are marked by optimum total abundance and species number. Increasing in number or dominating are Globigerinoides trilobus/saccularis group, Globorotalia menardii group, Globorotalia tumida group, Globoquadrida alitipia, Orbulina spp., Pulleniatina spp., and Spheroindinae dehiscens identified tropical zone. Whereas, Globigerina bulloides group, Globigerina inflata and Globorotalia truncatulinoides group are recorded well adapted in the warm temperate zone [4–8].

Some study confirmed that coiling ratio changes in specific planktic foraminifera, such as Candeina nitida, Globigerina bulloides group, Globigerina glutinata, Globigerina quinqueloba, Globigerinoides conglobatus, Globigerinoides trilobus/saccularis group, Globoquadrida dutoitrei group, Globorotalia acostaensis group, Globorotalia crassaformis, Globorotalia inflata, Globorotalia menardii group, Globorotalia scitula group, Globorotalia truncatulinoides group (including G.t. pachyderma) and Pulleniatina spp. More related to paleoclimate changes. The decrease in average diameter of Orbulina spp. can be guidance on temperature drop [9–12].

The research on nannofossils evaluating the occurrence marker taxa [13–15]. These studies are concluded that optimum total abundance and species number were recorded in tropical zone where Discoaster spp. are recorded in optimum abundance. While Discoaster asymmetricus, D. pentaradiatus, D. quinqueramus, D. surculus, Gephyrocapsa omega, and G. oceanica are abundant in the tropical zone, whereas Calcidiscus leptoporus, Coccolithus pelagicus, Discoaster challengeri, D. variabilis, Gephyrocapsa carribenica, G. mediterranea, Hayaster perplexus and Thoracosphaera saxaëu trend more common in a cooler area.

The study on paleoclimate in Java was started by van Gorsel and Troelstra (1981), who reconstructed Late Miocene to Earliest Pleistocene deep water sediments of River Solo in Central Java using planktic foraminiferal fauna [16]. Umiyatun (1999) evaluated the same sedimentary section using nannofossils flora [17]. Two decades later, Akmaludin, et al. (2010) confirmed the Miocene warm tropical climate based on oxygen isotope records of multi-species planktic and benthic foraminifera from the southern ward of that area [18]. The occurrence of tropical and warm temperate foraminifera and nannofossils marked climate change during Neogene has reported from the Northern East Java basin.

The relative stratigraphic position and age of sediment succession can be correlated based on the first appearance (FA) and last appearance (LA) datums of age index species [19]. Blow (1969), Postuma (1971) and Bolli and Saunders (1986) coincided Tertiary foraminifera datum levels [19,20]. Martini (1971), Okada and Bukry (1981), and Perch-Nielsen (1986) arranged datum levels based on nannofossil appearance [21–23].

2. Geology
Java island indicates the transition between subduction between westward frontal subduction beneath Sumatra. This area is considered to continuously active tectonically since its rifting throughout South East Asia in the Eocene (45 Ma). It was probably related to the collision between India and Asia Plates [24].

Java island is subdivided into two parts of the sedimentary domain: platform/shelf and turbidite sedimentary basin. Based on its sedimentary pattern, western part of Java can be divided into three tectonic, sedimentary provinces, namely:

a. The northern basinal province is a relatively stable continental platform province, part of Sunda continent, with North-South trending rift basin offshore and adjacent onshore. Eocene-Oligocene terrestrial clastic, overlain by Miocene and younger shallow shelf sediment;

b. Banten sedimentary province, subdivided from north to south into Seribu Carbonate Platform, Rangkas Bitung sedimentary sub-basin dan Bayah high, with minor heights and lower part in the west (Ujung Kulon and Honje High, Ujung Kulon and Malingping low).
c. Bogor basin province as the central depression of the foreland basin, filled by Eocene-Oligocene dominated with coarse clastic, overlain by Miocene and younger sediment mostly deeper water-sediment gravity flow facies with more influenced by subduction associated volcanic activities and limestone forming [25,26].

This research focused on Bogor basin extends about 150 kilometers wide in a north-south direction in western Java.

**Figure 1.** The study area of Bogor Basin [25].

**Figure 2.** Bogor basin is located on the turbidite sedimentary domain in Java Island (a), with a stratigraphic section in south-north direction (b) [26].

The oldest rock unit included in Bogor Basin is the Late Cretaceous to Early Eocene mélangé complex. This complex partly forms the basement and acts as a pre-rift complex. Middle Eocene tectonic rifting has formed Bogor Basin and also undergone all sedimentary basins to the east and south of the Sunda land. This basin was a forearc basin located relatively in front of the volcanic arc composed by Ciletuh and Bayah Formations. Ciletuh rock unit was formed as pond deposit at the lower trench’s slope. This process was continued by the regressive deposition of non-marine to shallow marine Bayah Formation. At the end of Eocene, subsidence at the southern Bogor basin was accommodated by the Cimandiri fault, which down to the north. Batuasih marl was deposited in this part; carbonate reef grew distributed at the rim of Cimandiri fault (southern margin of Bogor basin) spread in SW-NE direction from Sukabumi through Rajamandala to Gunung Kromong (Majalengka).
At the north of Cimandiri fault, the basin was deeper. In Early Miocene, turbiditic gravity flows from northern and southern highs were established. The volcanic arc had migrated to the south trending west-east parallel with present axis Java island. The Bogor basin became a deep back-arc basin. The submarine volcanic arc had contributed volcaniclastic sediments of Citarum Formation. During Middle Miocene, the gravity flow deposited breccias intercalated with sand and clay of Saguling Formation. In the upper Middle Miocene, several regional lobes of deep-sea turbiditic fans developed from southern areas. The fans formed breccias and sands of Bantargadung Formation (in the west) and Cimambo Formation (in the east). During the Late Miocene, thrust and reverse faults deformed (Saguling, Jatigede, Cirata, and Cimapag-Cihoe-Pangpiran) trending WNW-ESE causing the basin was uplifted. In the western part of the basin, breccias, sands, and clays volcanic sediments of Cantayan Formation were deposited, while in the eastern part, the turbiditic sediments of Halang Formation were still deposited. Starting from the Mio-Pliocene, the magmatic arc of Java shifted northward and partly occupied the Bogor basin so parts of basins become land areas. No sediments younger than Cantayan Formation are found might be due to erosion in the late Pliocene. However, Pliocene shallow marine deposits equivalent to Kaliwangu Formation are recorded in the eastern basin. In Plio-Pleistocene, the whole of West Java, mainly southern and central parts, were uplifted. Alluvial and volcanic sediments (Citalang Formation) were mainly founded in the northern areas. Baribis reverse movement faulted Kaliwangu and Citalang formations. In Late Pleistocene, most of the areas become emergent and has continued nowadays [25,26].

3. Materials and Methods

In this study, surficial rock samples were collected from systematic random sections on Bogor Through. A total of 443 samples examined in this work selected from Miocene open marine sediment. They came from the following localities: (a) 19 samples from Cileungsi – Bogor (Cikarang and Cilegok river); (b) 44 samples from Cipamingkis river – Bogor; (c) 63 samples from Walat – Sukabumi, (d) 38 samples from Jatiluhur (near Jatiluhur reservoir, rivers-side of Cihergang, Cikao, Cijagah, Cisaray, Cikekep, Cibinbin and Cigaruguy) – Purwakarta; (e) 26 samples from Cikeruh river – Sumedang; (f) 34 samples from Bantarujeg – Majalengka; (g) 113 samples from Cilutung river – Majalengka, (h) 84 samples from Cadasangampar river – Sumedang; and (i) 22 samples from Ciniru – Kuningan (Cipedak, Cilemit, Cisanggarung, Cileungsir, Ciawi, Citapen, Cijamaka, Cibongkot, Cileungli, Cimonte, Cisrigading, and Cijulang rivers, Salam and Panjang hills) (figure 3).

A hundred grams of dry samples were crushed and disaggregated in 15% hydrogen peroxide during 2 to 5 hours. It washed and sieved using 30 to 80 mesh screens to remove rock materials and cement on foraminifera shells, then the remaining residues were oven-dried at 60° C. Well-preserved planktic and benthic foraminifera were handpicked and observed using a binocular microscope at 40 magnifications.
The standard smear slides preparation processing was applied to the same samples to observe nannofossils assemblages. These specimens determined under a polarization microscope at 1000 magnification in both parallel and cross Nicol. The laboratory works were carried out at the Universitas Padjadjaran – Akita University joint laboratory in Jatinangor, Sumedang.

Identification of foraminifera refers to Bolli and Saunders (1986), nannoplankton refers to Perch-Nielsen (1986) [23,27]. A detailed determination of both foraminifera and nannofossil assemblages were conducted to find out the age index species and the climatic marker species. The selected datums of the first appearance (FA) and the last appearance (LA) of index species were used to define the geologic age and used as a tool for establishing the level of correlation.

The quantitative of foraminifera and nannofossils assemblages were analysed to facilitated paleoclimate interpretation. The tropical element groups (Globigerinoides trilobus/saccularis, Globorotalia menardii, Globoquadrina altispira/globosa, Orbulina, and Globorotalia tumida) bearing sediment samples were accounted to determine the abundance of climatic marker. The nannofossil tropical marker species (D. pentaradiatus, D. quinqueramus, D. surculus) and also the nannofossil warm temperate marker species (Calciscus leptoporus, Coccolithus pelagicus, Discoaster challengeri, D. variabilis, and Hayaster perplexus) were calculated. Shells coiling direction of Globorotalia acostaensis group and Globorotalia menardii group have been observed clearly as all known examples of species with coiling reversal, dextral (right) coiling corresponds with high temperature. In some samples, a sufficient number of Orbulina group was measured. The abundance of each species and total, the frequency of marker species, the frequency of right and left shell coiling directions and the size of taxon were also recorded.

4. Result and Discussion

Several age index species have been detected in both foraminifera and nannofossils assemblages on criteria that distinctive, easily identified and have significant lateral and vertical distribution. A detailed age index species of foraminifera and nannofossil determination in each section was reported in separate papers [28,29].

Fifteen foraminifera index species recorded in samples are: Globigerinoides subquadratus, G. trilobus, Globorotalia acostaensis, G. dutertrei, G. fohsi fohsi, G. margaritae, G. merotumida, G. peripheroronda, G. plesirotumida, G. primordius, G. siakensis, G. tumida, Orbulina suturalis, Sphaeroidinella dehiscens, and Sphaeriodinellopsis subdehiscens. Based on first appearance (FA) and last appearance (LA) of these foraminifera age index species, the stratigraphic datums were established. Those are, starting from the oldest:

a. First appearance datum (FAD) of Globorotalia primordius
   This datum has used to define base N.4 of Blow’s zone (1969) (Earliest Miocene) or 25.2 million years before present (Ma) (Saito, 1977). It is identified in the shallow marine section of Walat (c) section [12,30]

b. FAD Globigerinoides trilobus group, base N.5 (Early Miocene) or 22.6 Ma (Saito, 1977), on Walat (c) section [12]

c. FAD Globorotalia peripheroronda, base N.6 (Early Miocene) or 18.0 Ma (Saito, 1977), on Walat (c) section [12]

d. FAD Orbulina suturalis, base N.9 (Middle Miocene/Langhian-Serravallian) or 15.2 Ma (van Gorsel, 1988), on Cileunsgi (a) and Jatiluhur (d) [29]

e. FAD Globorotalia fohsi fohsi, base N.12 (Middle Miocene) or 13.8 Ma (Saito, 1977), on Cipamingkis river (b) section [12]

f. FAD Sphaeriodinellopsis subdehiscens, base N.13 (Middle Miocene) or 12.5 Ma (Saito, 1977), on Cipamingkis river (b) and Ciniru (i) sections [12]

g. Last appearance datum (LAD) of Globigerinoides subquadratus, top N.13 (Middle Miocene) or 12 Ma (Saito, 1977), on Jatiluhur (d) and Cipamingkis river (b) sections (Isnaniawardhani and Nurdrajat, 2015) [12,29].
h. LAD *Globorotalia siakensis*, top N.14 (Middle Miocene/Serravallian-Tortonian) or 10.2 Ma (van Gorsel, 1988), on Cipamingkis river (b), Ciniru (i), and Cilutung (g) sections [16,29]

i. FAD *Globorotalia acostaensis*, base N.16 (Late Miocene) or 10.0 Ma (Bolli and Saunders, 1986), on Jatiluhur (d), Ciniru (i), Cilutung (g), and Bantarujeg (f) sections [29]

j. FAD *Globorotalia pesiotumida*, base N.17 (Late Miocene, Tortonian) or 6.2 Ma (Saito, 1977), on Jatiluhur (d), Cilutung (g), Bantarujeg (f), and Cikeruh (e) sections (Isnaniawardhani, *et al*., 2013; Isnaniawardhani and Nurdrajat, 2015); correlated to FAD *Globorotalia dutertrei* on Cadasngampar (h) section and FAD *Globorotalia merotumida* on Ciniru section (i) [29]

k. FAD *Globorotalia tumida*, base N.18 (close to Miocene-Pliocene boundary) or 5.2 Ma (van Gorsel, 1988), on Cilutung (g) and Bantarujeg (f) sections; correlated to FAD *Globorotalia margaritae* on Jatiluhur (d) section [29]

Nine nannofossil index species recorded in samples are Catinaster coalitus, *Cyclicargolithus abisectus*, *Discoaster berggreni*, *D. druggi*, *D. hamatus*, *D. neorectus*, *D. quinqueramus*, *Sphenolithus ciperoensis*, and S. heteromorphus. Based on FA and LA these species, the datums are:

a. LAD *Sphenolithus ciperoensis*, top NP 25 of Martini’s zone (1971) (close to Oligocene-Miocene boundary) eq. top CP19 of Okada and Bukry’s zone (1980) or 24 Ma (Okada & Bukry, 1980) on Walat (c) section [21,22]

b. LAD *Cyclicargolithus abisectus*, top CN 1a (Early Miocene) or 23 Ma (Okada & Bukry, 1980) on Walat (c) section [22]

c. FAD *Discoaster druggi*, base NN2 eq. CN 1c (Early Miocene) or 21 Ma (Okada & Bukry, 1980) on Walat (c) section [22]

d. LAD *Sphenolithus heteromorphus*, top NN5 eq. CN4 (Middle Miocene) or 13.65 Ma (Pratiwi and Sato, 2016), on Jatiluhur (d) section (Isnaniawardhani and Sunardi, 2014) [31,32]

e. FAD *Catinaster coalitus*, base NN8 eq. CN7 (Middle Miocene) or 10.78 Ma (Pratiwi and Sato, 2016), on Jatiluhur (d) section (Isnaniawardhani and Sunardi, 2014) [32]

f. FAD *Discoaster hamatus*, base NN9 eq. CN7 (Late Miocene), on Jatiluhur (d) section (Isnaniawardhani and Sunardi, 2014) [32]

g. FAD *Discoaster neorectus*, NN 10 eq. base CN8b (Late Miocene), on Cadasngampar (h) section

h. FAD *Discoaster berggreni*, base NN11 eq. CN9a (Late Miocene) or 8.29 Ma (Imay, *et al*., 2013), on Cadasngampar (h) section; correlated to FAD *Discoaster quinqueramus* on Jatiluhur (d) section (Isnaniawardhani and Sunardi, 2014) [32]

i. LAD *Discoaster quinqueramus*, top of NN11 eq. CN10 (Early Pliocene/Messinian-Zanclean) or 5.59 Ma (Imay *et al*., 2013; Pratiwi and Sato, 2016), on Jatiluhur (d) section (Isnaniawardhani and Sunardi, 2014) [31–33]

Datum correlation between first appearance (FA) and last appearance (LA) of foraminifera and nannofossil index species is shown in figure 4.

Based on the quantitative analysis (abundance, diversity, species marker frequency, evolution and adaption in shape, size and coiling direction) recorded for foraminifera and nannofossil, paleoclimate reconstruction during Miocene (25.2-5.6 million years) explained as follows (figure 5):

a. N.4 or NP25 (= CP 19) (Early Miocene, 25.2 to 24.0 Ma) on Walat (c) section

The medium to high -abundance and -diversity of foraminifera as well as nannofossil assemblages with the common appearance of *Globoquadrina altispira* and *Discoaster* groups indicate a warm temperature climate at earliest Miocene.

b. N.4 or CP20-CN1a (Early Miocene, 24 to 23 Ma) on Walat (c) section

A decreased -total abundance and -species number suggest a relatively decrease in temperature.

c. N.4 to N.5 or CN 1b (Early Miocene, 23 to 21 Ma) on Walat (c) section

The more common appearance of tropical species marker of foraminifera (*Globoquadrina altispira, G. globosa, Globigerinoides trilobus, and G. sacculiferus*) and nannofossil (*Discoaster* group) marks slightly increasing in temperature.
d. Lower part N.5 or NN2 to NN5 (=CN1c to CN4) (Early Miocene, 21 to 20 Ma) on Walat (c) section
The low-frequency and -diversity are recorded at the lower part and then distinctly rises.

e. Upper part N.5 or NN2 to NN5 (=CN1c to CN4) (Early Miocene, 20 to 18 Ma) on Walat (c) section
The optimum abundancy and diversity recorded at the upper part correspond with increases in temperature.

f. N.6 to N.8 or NN2 to NN5 (Early-Middle Miocene, 18.0 to 15.2 Ma) on Walat (c), Cileungsi (a), and Jatiluhur (d) sections
This interval is characterized by a trend of decreased -abundance and -diversity of foraminifera as well as nannofossil assemblages. The appearance of *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *D. variabilis*, and *Hayaster perplexus* in samples indicated a relatively warm temperate climate during its deposition.

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**Figure 4.** Foraminifera and nannofossil datum correlation in each section in Bogor Basin.
g. N.9 to N.11 or NN2 to NN5 (Middle Miocene, 15.2 to 13.8 Ma) on Cileungsi (a), Jatiluhur (d) and Cipamingkis river (b) sections
The dominance of *Orbulina* group with a high frequency of tropical species marker is indicative of significantly increased temperature.

h. N.12 to N.14 or NN2 to NN7 (Middle Miocene, 13.8 to 12.0 Ma) on Jatiluhur (d), Cipamingkis River (b), and Ciniru (i) sections
The abundance is slightly less in this section than in the lower part indicate a decrease in temperature. Some shells of *Globorotalia menardii* show left coiling directions.

i. N.14 or NN6 to NN7 (Middle Miocene, 12.0 to 10.78 Ma) on Jatiluhur (d), Cipamingkis River (b), and Ciniru (i) sections
The abundance and diversity of assemblages, as well as the specific marker species, slightly increase.

j. N.14 to N.15 or NN8 to NN9 (= CN6) (Middle Miocene, 10.78 to 10.0 Ma) on Jatiluhur (d), Cipamingkis River (b), Ciniru (i), Cilutung (g) and Bantarujeg (f) sections
The optimum of total and individual abundance is reached during its deposition. They dominated big size-*Orbulina*, increased tropical foraminifera, and nannofossil species markers indicate a warm climate.

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**Figure 5.** Paleoclimate reconstruction during Miocene (25.2 to 5.6 million years) in Bogor Basin.
k. N.16 or NN9 to NN11 (CN7 to CN9) (Late Miocene, 10.0 to 6.2 Ma) on Jatiluhur (d), Ciniru (i), Cilutung (g), Bantarujeg (f), Cadasngampar (h), and Cikeruh (e) sections

The low relative shell coiling ratio of *Globorotalia menardii* and *Globorotalia acostaensis*, along with the low abundance and diversity of assemblages or taxa marker, indicate the temperature decrease in this interval several times. In the upper part, an increased number of *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Discoaster challengeri*, *D. variabilis* and *Hayaster perplexus*, the lower total abundance and diversity indicated a warm temperate climate. This temperature drop is considered to correlate with the global glaciation period.

l. N.17 or NN11 (Late Miocene, 6.2 to 5.59 Ma) on Jatiluhur (d), Ciniru (i), Cilutung (g), Bantarujeg (f), Cadasngampar (h), and Cikeruh (e) sections

In the upper part of Miocene sections, the shell coiling direction of *Globorotalia acostaensis* change to the right. The more common appearance of tropical species marker (associated with *Discoaster pentaradiatus*, *Discoaster quinqueramus*, and *Discoaster surculus*) and the higher total number and diversity indicate the slight increase in temperature.

5. Conclusion

In paleoclimate study, the relative stratigraphic and age of sediment succession (datum) on nine sections in the study area are determined based on the appearance datum (FAD) and last appearance datum (LAD) of age index species. Twenty foraminifera and nannofossils datums can be identified, starting from the oldest:

- FAD *Globorotalia primordius*, base N.4 (Earliest Miocene, 25.2 Ma)
- LAD *Sphenolithus ciperoensis*, top NP 25 eq. CP19 (Early Miocene, 24 Ma)
- LAD *Cyclicargolithus abisectus*, top CN 1a (Early Miocene, 23 Ma)
- FAD *Globigerinoides trilobus* group, base N.5 (Early Miocene, 22.6 Ma)
- FAD *Discoaster druggi*, base NN2 eq. CN 1c (Early Miocene, 21 Ma)
- FAD *Globorotalia peripheroronda*, base N.6 (Early Miocene, 18.0 Ma)
- FAD *Orbulina suturalis*, base N.9 (Middle Miocene/Langhian-Serravallian, 15.2 Ma)
- FAD *Globorotalia fohsi fohsi*, base N.12 (Middle Miocene, 13.8 Ma)
- LAD *Sphenolithus heteromorphus*, top NN5 eq. CN4 (Middle Miocene, 13.65 Ma)
- FAD *Sphaeriodinellopsis subdehiscens*, base N.13 (Middle Miocene, 12.5 Ma)
- FAD *Globigerinoides subquadratus*, top N.13 (Middle Miocene, 12 Ma)
- FAD *Catnaster coalitus*, base NN8 eq. CN7 (Middle Miocene, 10.78 Ma)
- FAD *Discoaster hamatus*, base NN9 eq. base CN7 (Late Miocene)
- LAD *Globorotalia siakensis*, top N.14 (Middle Miocene/Serravallian-Tortonian, 10.2 Ma)
- FAD *Globorotalia acostaensis*, base N.16 (Late Miocene,10.0 Ma)
- FAD *Discoaster neorectus*, NN 10 eq. base CN8b (Late Miocene)
- FAD *Discoaster berggreni*, NN11 eq. base CN9a (Late Miocene, 8.29 Ma); correlated to FAD *Discoaster quinqueramus*
- FAD *Globorotalia pesiotumida*, base N.17 (Late Miocene, Tortonian-Messinian, 6.2 Ma); correlated to FAD *Globorotalia dutertrei* and FAD *Globorotalia merotumida*
- LAD *Discoaster quinqueramus*, top of NN11 eq. CN10 (Early Pliocene/Messinian-Zancian, 5.59 Ma)
- FAD *Globorotalia tumida*, base N.18 (close to Miocene-Pliocene boundary, 5.2 Ma); correlated to FAD *Globorotalia margaritae*

Paleoclimate reconstruction during the Miocene (25.2-5.6 million years) based on some of the indicators mentioned above such as abundance, diversity, frequency of species markers, evolution and adaptation (size and coiling direction) recorded by foraminifera and nannofossil. The medium to high abundance and diversity of foraminifera as well as nannofossil assemblages indicated a warm climate at Earliest Miocene (25.2 to 24 Ma). A decreased -total abundance and -species number occurred until early Middle Miocene (24 to 20 Ma). The dominance of *Orbulina* group with a high frequency of tropical species marker (*Globoquadrina altispira*, *G. globosa*, *Globigerinoides trilobus*, *G.
sacculiferus, and Discoaster group) are indicative of significantly increased temperature. The optimum of total- and individual- abundance along with the dominated big size-Orbulina, increased tropical foraminifera, and nannofossil species markers indicate a warm climate in Middle Miocene (16 to 13.8 Ma). The low dextral relative shell coiling ratio of Globorotalia menardii and Globorotalia acostaensis along with the low abundance and diversity of assemblages or taxa marker that indicate the temperature decrease is recorded in Late Miocene interval several times. In the upper part, an increased number of Calcidiscus leptoporus, Coccolithus pelagicus, Discoaster challengeri, D. variabilis and Hayaster perplexus, the lower total abundance and diversity indicated a warm temperate climate. The low abundance and diversity of foraminifera as well as nannofossils along with the decreased tropical taxon abundance is indicated a temperature drop in Late Miocene (10.0 to 6.2 Ma).

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