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MIOCENE DEEP-SEA BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY OF SOUTHEASTERN INDIAN OCEAN

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ABSTRACT

The Miocene sections at ODP sites 754A (Broken Ridge) and 760A and 761B (Wombat Plateau) in the southeastern Indian Ocean were examined to understand the biostratigraphic significance of benthic foraminifera. Detailed benthic foraminiferal biochronology at each site is used to record the total stratigraphic ranges of taxa. Most of the benthic foraminiferal species recorded in the present study are long ranging and distributed throughout the studied section. However, some of them show their first and last appearances within the studied sections. On the basis of total stratigraphic ranges of significant taxa, seven distinct benthic foraminiferal zones have been proposed. The proposed biozones, in stratigraphic ascending order, are *Uvigerina proboscidea* Interval Zone, *Ehrenbergina praebicornis* Interval Zone, *Gavelinopsis lobatulus* Interval Zone, *Bulimina glomarchallengeri – Globocassidulina tumida* Concurrent Range Zone, *Buliminella grata spinosa* Interval Zone, *Uvigerina flintii* Interval Zone and *Bulimina macilenta* Interval Zone. The first appearances of *Uvigerina proboscidea* Schwager, *Ehrenbergina praebicornis* Rai and Srinivasan, *Gavelinopsis lobatulus* (Parr), *Globocassidulina tumida* (Heron-Allen and Earland) and the last appearances of *Bulimina glomarchallengeri* Tjalsma and Lohmann, *Buliminella grata spinosa* Parker and Bermudez, *Uvigerina flintii* Cushman and *Bulimina macilenta* Cushman and Parker are taken as zonal markers to define the zonal boundaries.

Keywords: Miocene, Benthic Foraminifera, Biostratigraphy, southeastern Indian Ocean

INTRODUCTION

Benthic foraminifera have not been much used as biostratigraphic tool due to increased emphasis on planktic foraminifera for biostratigraphic subdivision and correlation of marine sequences. The long ranging nature and relatively greater endemic behavior of majority of benthic foraminiferal taxa are the serious problems in utilizing them for the purposes of biostratigraphic subdivision. In addition, considerable time and energy are required to sort out the sufficient number of benthic foraminiferal tests for biostratigraphic studies. Also, the changing depth preferences with time in different basins made the benthic foraminifera less significant for biostratigraphic purposes (Douglas and Woodruff, 1981; Tjalsma and Lohmann, 1983; Kurihara and Kennett, 1992).

The study of deep-sea benthic foraminifera from Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) cores has provided improved taxonomic base to better understand their biostratigraphic distribution. The deep-sea benthic foraminifera from various uninterrupted sequences through the Cenozoic reveals that large numbers of them have distinct morphology and wide geographic distribution and some of them also have short stratigraphic ranges to be used for biostratigraphic purposes. Boltovskoy (1978) attempted to demarcate major late Cenozoic boundaries in the northern Indian Ocean on the basis of relative occurrences of important deep-sea benthic foraminiferal assemblages. He (1978) broadly grouped these assemblages characterizing different time intervals without proposing any biozonal scheme. Based on benthic foraminifera of DSDP site 397, Lutze (1979) subdivided the Neogene and Quaternary sequences of northwest African continental margin in five faunal units (NB 5a to NB 6c). Berggren and Miller (1989) proposed a comprehensive Cenozoic benthic foraminiferal zonal scheme by using deep water benthic foraminiferal data of van Morkhoven *et al.* (1986). Srinivasan *et al.* (1993) suggested ten distinct Neogene deep-sea benthic foraminiferal zones of the northern Indian Ocean deep sea sequences using the total observed stratigraphic ranges. A late Neogene deep sea benthic foraminiferal zonation for the southeastern Indian Ocean was proposed by Rai and Singh (2004) using data from ODP sites 762B and 763A. In the present work, an attempt has been made to propose Miocene deep sea benthic foraminiferal zones on the basis of faunal data at ODP sites 754A, 760A and 761B in the southeastern Indian Ocean.

SITE LOCATION AND OCEANOGRAPHIC SETTING

ODP site 754A (Latitude 30°56.43'S; Longitude 93°33.99'E; water depth: 1074m) is located on the Broken Ridge in the subtropical area and influenced by the West Wind Drift (WWD), South Equatorial Current (SEC) and Subtropical Convergence Zone (STCZ). ODP sites 760A (Latitude 16°55.32'S; Longitude 115°32.48'E, water depth 1969.7 m) and 761B (Latitude 16°44.23'S; Longitude 115°32.10'E water depth: 2167.9m) are located on the Wombat Plateau in the tropical–subtropical transition (TRANS). The Wombat Plateau region has more complex current pattern than the Broken Ridge region because (i) The Wombat Plateau is contemporarily influenced by the monsoonal climate, which causes periodical reversal of wind direction and surface current. (ii) The Wombat plateau lies in the direct confluence of Indonesian Through Flow (ITF), which connects Pacific and Indian Ocean (Rockford, 1961; van Aken *et al.*, 1988). Wombat Plateau is bathed by current system off the coast of Western Australia consisting of South Equatorial Current (SEC), the Leeuwin Current (LC) and the South Indian Current (SIC) a synonym of West Australian Current (WAC). The SEC and SIC flowing west

and north, respectively, are the eastern wing of an anticlockwise gyre in the south Indian Ocean (Tomczak and Godfrey, 1994). The water flow of the SIC is called the Indian Central Water (ICW). A part of Indonesian throughflow water (Tomczak and Godfrey, 1994) starts flowing southward along the western Australian coast as the Leeuwin current (Cresswell and Golding, 1980). Beneath the LC, high salinity water, and South Indian Central Water are carried northward by the under current (Creswell, 1991) acting as a part of SIC. This current, in turn, influences water masses as deep as 2000m (Tchernia, 1980) and is part of a major Southern Hemisphere gyre, moving anticlockwise in the Indian Ocean (Fig. 1).

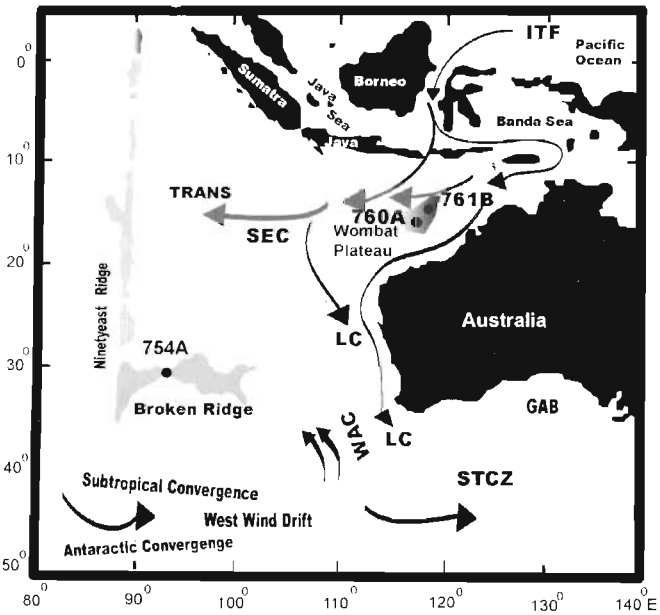


Fig. 1. Map showing locations of ODP site 754A (Broken Ridge) and sites 760A and 761B (Wombat Plateau) in the southeastern Indian Ocean (Modified after Nomura, 1991; Wijffels *et al.*, 1996 and Murgese and Deckker, 2005). SEC: South Equatorial Current; LC: Leeuwin Current; WAC: West Australian Current; SIC: South Indian Current; ITF: Indonesian Through Flow; WAC: West Australian Current; TRANS: Tropical-Subtropical Transition; STCZ: Subtropical Convergence Zone (after Tomczak and Godfrey, 1994).

MATERIAL AND METHODS

A total of 98 core samples of 96.6m thick section at ODP site 754A were analyzed. In general, the time interval between samples at site 754A is ~220 kyrs except samples of middle/late Miocene period which are of higher resolution (~80 kyrs interval). At ODP site 760A a total of 64 samples from about 47.5m thick section at interval of ~400 kyrs and at ODP site 761B a total of samples from ~38.0m thick section at interval of ~450 kyrs were analyzed. Approximately, 10 cm^3 of core samples were disintegrated by soaking in water with small amount of baking soda for over night before wet screening over >63μm and >125 μm sized Tyler sieves and oven dried at about 50°C. After drying, a microsplitter was used to separate a representative proportion of the >125 μm size fraction estimated to contain ~300 specimens of benthic foraminifera. All the specimens of various species from the splitted samples are picked and mounted on faunal assemblage slides for identification. The encountered species were compared with those recorded earlier from various Neogene and Quaternary deep-sea sections (Barker, 1960; Boltovskoy, 1978; Srinivasan and Sharma, 1980; Gupta and Srinivasan, 1992; Rai, 1992; Nomura, 1991, 1995; Bornmalm, 1997 and others). In general, Miocene sections at all the three sites have closely similar species distribution pattern of benthic foraminifera.

BENTHIC FORAMINIFERAL ZONES

To record the benthic foraminiferal first and last appearances each core sample is carefully examined at ODP sites 754A (Broken Ridge), 760A and 761B (Wombat Plateau) in the southeastern Indian Ocean. Benthic/planktic ratio was relatively higher (up to 10% at site 761B and 7% at sites 760A and 754A) during late Oligocene-early Miocene transition which decreased considerably there on and reached to less than 1% during middle Miocene at the examined sites. A total of 176 benthic foraminiferal species has been recorded. Among the recorded population, calcareous forms constitute the major portion (>90%) of Miocene benthic foraminiferal population at the examined sites. However, agglutinated and porcellaneous foraminifera constitute <10% of the total benthic foraminiferal population. The total stratigraphic ranges of important and frequently occurring benthic foraminiferal species at all the studied sites reveal that only few of them have their true first or last appearances within the studied section (Figs. 4a,b). The detailed benthic foraminiferal biochronology for all the three studied sites have been worked out. In the present work seven distinct benthic foraminiferal zones are proposed (Fig. 2). The first appearances of *Uvigerina proboscidea* Schwager, *Ehrenbergina praebicornis* Rai and Srinivasan, *Gavelinopsis lobatulus* (Parr), *Globocassidulina tumida* (Heron-Allen and Earland) and the last appearances of *Bulimina glomarchallengeri* Tjalsma and Lohmann, *Buliminella grata spinosa* Parker and Bermudez, *Uvigerina flintii* Cushman and *Bulimina macilenta* Cushman and Parker within the examined sections are taken as zonal markers (Fig. 2, Plate. 1). The observed total stratigraphic ranges of zonal markers from the examined sites are given in Fig. 3. The proposed biozones have been correlated with the calcareous nannofossil zones (CN and NN Zones) in the southeastern Indian Ocean (Peirce *et al.*, 1989 and Siesser and Bralower, 1992) and geomagnetic polarity chron on a newly astronomically calibrated chronology of Gradstein *et al.* (2004) to provide time framework to proposed benthic foraminiferal zonal boundaries (Fig. 5). In addition, the proposed biozones have also been compared with the deep sea benthic foraminiferal zonal scheme of the northern Indian Ocean (Srinivasan *et al.*, 1993) and planktic foraminiferal zones (Srinivasan and Chaturvedi, 1992) (Fig. 5). The proposed benthic foraminiferal zones are described here in ascending stratigraphic order.

Uvigerina proboscidea Interval Zone

Definition: This zone is based on the partial range of nominate taxon between its first appearance (base) and first appearance of *Ehrenbergina praebicornis* (top).

Remarks: The upper boundary of this zone roughly corresponds to the upper boundary of *Bolivina pseudopunctata* IZ of the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). The first appearances of *Pleurostomella brevis* Cushman and Stainforth, *Dentalina neugeboreni* (Schwager) and *Pullenia salisburyi* Stewart and Stewart may be considered as datums to define the lower boundary of this zone (Fig. 4b). *Orthomorphina* aff. *antillea* (Cushman), *Siphotextularia solita*

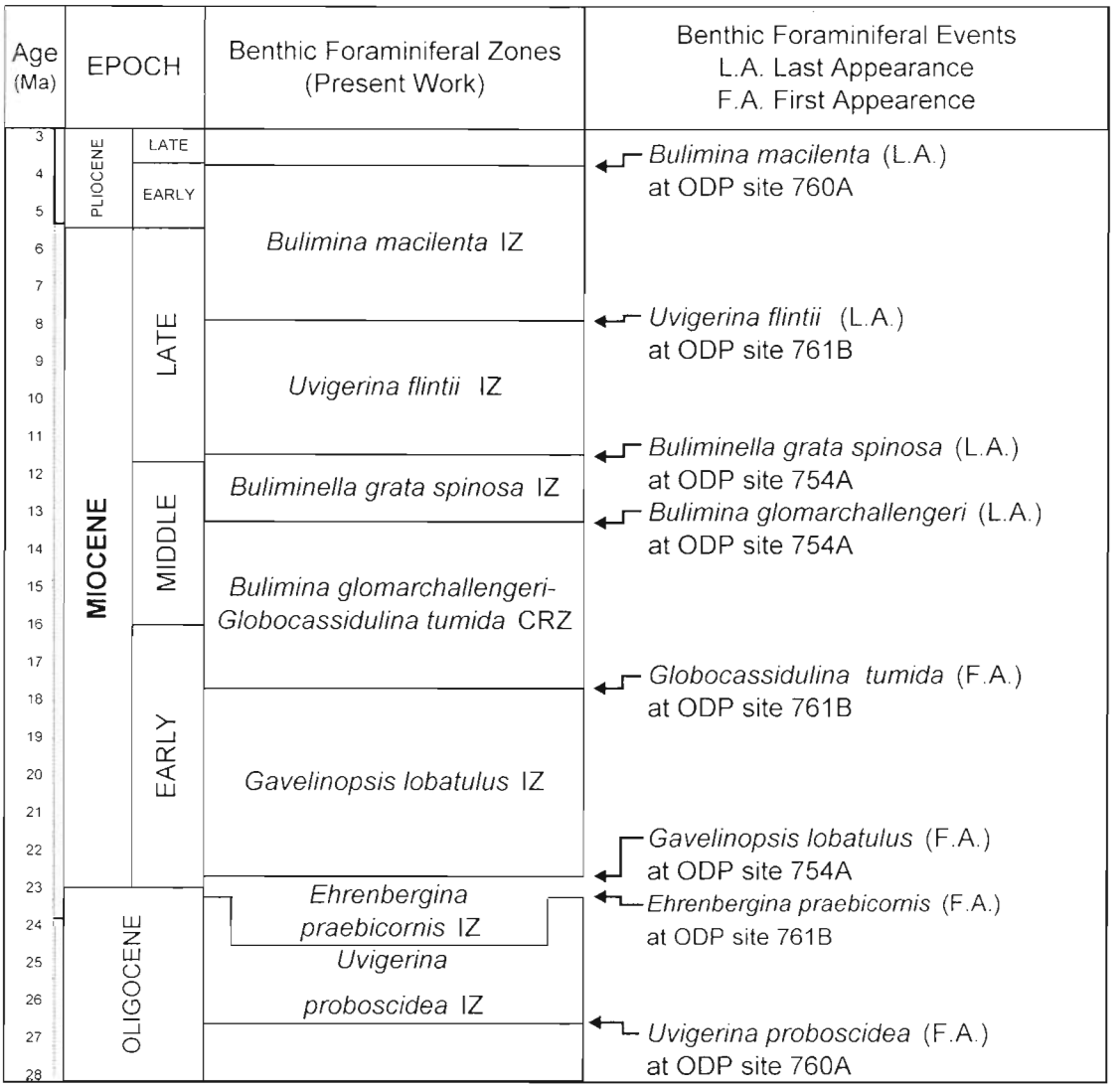


Fig. 2. Benthic foraminiferal zones and zonal marker faunal events in the eastern Indian Ocean (Ages after Gradstein *et al.*, 2004).

(Schwager) show their initial appearances in the upper part of this zone and *Pleurostomella* cf. *rimosa* Cushman and Bermudez show its first appearance in the lower middle part of this zone (Fig. 4b).

Occurrence: *Uvigerina proboscidea* IZ is represented by about 6.0m thick section of nanno-foram ooze at site 754A and 6.27m and 4.94m thick sequences of nannofossil ooze with foraminifera at sites 760A and 761B comprises respectively (Fig. 6). The entire zone is recorded at site 760A however, lower part of this zone is absent at sites 754A and 761B due to unavailability of the samples.

Age: The lower boundary of this zone lies very close to the base of *Globigerina ciperoensis* Zone whereas top of *Globorotalia kugleri* Zone corresponds well to the upper boundary of this zone (Fig. 5). This zone ranges within the late Oligocene (~26.7-23.3 Ma). The zone approximately represents 3.4 myrs duration.

Ehrenbergina praebicornis Interval Zone

Definition: The partial range of nominate taxon between its first appearance (base) and the first appearance of *Gavelinopsis lobatulus* (top).

Remarks: The lower boundary of this zone roughly corresponds to the upper boundary of *Bolivina pseudopunctata* IZ of the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). *Pleurostomella concava* Hermelin shows its first appearance at the base of this zone and this event may be used to define the lower boundary of this zone (Fig. 4b).

Occurrence: At site 754A 3.0m thick section of nanno-foram ooze represents this entire zone. The complete zone is also recorded by 2.25 and 1.23m thick section of nannofossil ooze with foraminifera at sites 760A and 761B respectively (Fig. 6).

Age: The lower boundary of this zone roughly corresponds to the upper boundary of *Globorotalia kugleri* Zone of the Indian Ocean (Srinivasan and Chaturvedi, 1992) and the upper boundary of this zone corresponds to the middle part of *Globoquadrina dehiscens* Zone (Fig. 5). This zone ranges from latest Oligocene (~23.3 Ma) to early Miocene (~ 22.7 Ma) and spanning a time interval of about 0.6 myr.

Gavelinopsis lobatulus Interval Zone

Definition: This zone is based on the partial range of nominate taxon between its first appearance (base) and first ap-

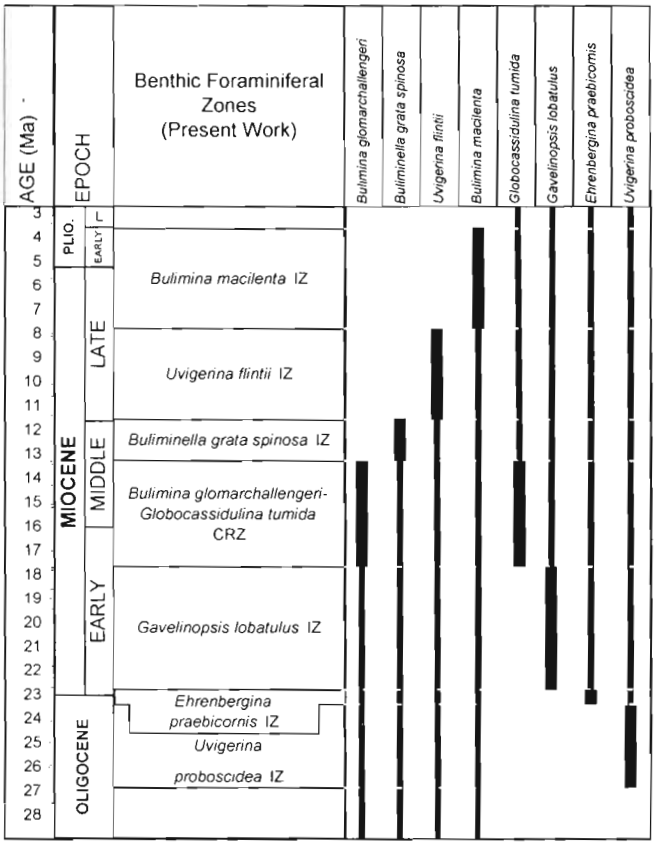


Fig. 3. Total observed stratigraphic ranges of zonal markers. Ages after Gradstein *et al.* (2004).

pearance of *Globocassidulina tumida* (top).

Remarks: This zone ranges between the lower part of *Karreriella subrotundata* IZ and middle part of *Martinottiella scabra* IZ in the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). *Bulimina alazanensis* Cushman, *Rectuvigerina royoi* Bermudez and Fuenmayor, *Trifarina bradyi* Cushman, *Ehrenbergina hystrix* Brady, *Textularia lythostrota* (Schwager), *Siphotextularia rolshauseni* Phleger and Parker, *Buliminella andamanica* Srinivasan and Singh, *Bolivinopsis praelonga* (Schwager) and *Cylindroclavulina bradyi* (Cushman) show their initial appearances within the zone (Figs. 4a,b). However, elsewhere in the northern Indian Ocean *B. alazanensis*, *B. praelonga* and *S. rolshauseni* appeared earlier during the late Oligocene (Boltovskoy, 1978; Rai, 1992).

Occurrence: The entire zone is recorded at ODP site 754A and 761B representing ~17.9m thick sequences of nanno-foram ooze and ~9.0m thick sequence of nannofossil ooze with foraminifera. At site 760A ~5.87m thick sequence represents the upper part of this zone and lower part is missing due to presence of hiatus (Fig. 6) (Siesser and Bralower, 1992).

Age: The upper boundary of this zone is roughly correlated with the middle part of *Globigerinatella insueta* Zone and lower boundary corresponds to the lower middle part of *Globoquadrina dehiscens* Zone (Fig. 5). This zone ranges within the early Miocene (~22.7 to 17.7 Ma). The zone approximately represents 5 myrs duration.

Bulimina glomarchallengeri – Globocassidulina tumida Concurrent Range Zone

Definition: The concurrent partial ranges of nominate taxa between the first appearance of *Globocassidulina tumida* (base) and last appearance of *Bulimina glomarchallengeri* (top).

Remarks: This zone is characterized by the co-occurrence of *Bulimina glomarchallengeri* and *Globocassidulina tumida*. This zone corresponds to an interval from the middle part of *Martinottiella scabra* IZ to the lower part of *Cibicides helferi* IZ of the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). The first appearances of *Uvigerina cushmani* Todd and *Sigmoilopsis schlumbergeri* Silvestri and last appearance of *Cylindroclavulina bradyi* (Cushman) took place within this zone (Fig. 4b).

Occurrence: *Bulimina glomarchallengeri – Globocassidulina tumida* CRZ is represented by 11.83m, 8.25m and 6.25m thick sections at ODP sites 754A, 760A and 761B respectively comprising mainly of nannofossil ooze with foraminifera (Fig. 6). The lower part of this zone is not recorded at site 760A due to presence of deep sea hiatus (Siesser and Bralower, 1992) (Fig. 6).

Age: The upper boundary of this zone corresponds to the upper part of *Globorotalia praefoshi* Zone and lower boundary corresponds to the middle part of *Globigerinatella insueta* Zone (Fig. 5). This zone ranges from latest early Miocene (~17.7 Ma) to middle Miocene (~13.3 Ma) and represents the duration of about 4.4 myrs.

Buliminella grata spinosa Interval Zone

Definition: This zone ranges between the last appearance of *Bulimina glomarchallengeri* (base) and last appearance of *Buliminella grata spinosa* (top).

Remarks: *Buliminella grata spinosa* IZ is ranging within the *Cibicides helferi* IZ of the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). A large number of faunal events are recorded within this zone (i.e. first appearances of *Biloculina murrhina* Schwager, *Ehrenbergina trigona* Goës, *Favocassidulina favus* (Brady) and last appearances of *Nodosaria* aff. *spirostriolata*, *Discorbis subvilardeboanus* (Rhezak) and *Rectuvigerina striata* Schwager) (Fig. 4a).

Occurrence: The entire zone is present at ODP sites 754A, 760A and 761B representing about 21.4m, 4.5m and 4.23m thick nannofossil ooze with foraminifera respectively. However, an ash bearing layer of about 10.0m thick was observed in the lower part of this zone at site 754A with an estimated age between 13.2 Ma and 12.4 Ma (Fig. 6).

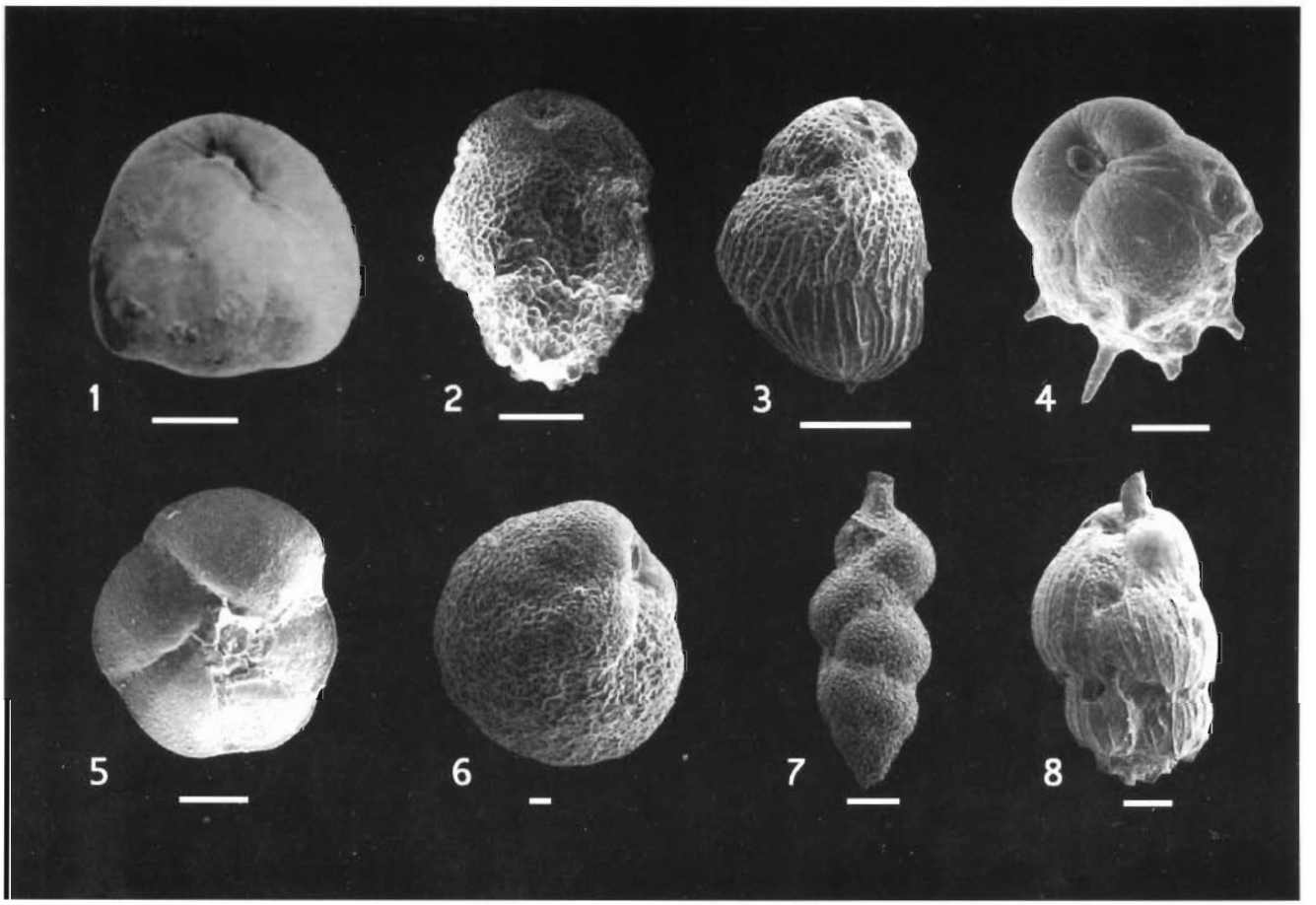
Age: The top of *Buliminella grata spinosa* IZ closely corresponds to the base of *Globorotalia menardii* Zone and lower boundary of this zone correlated with the upper part of *Globorotalia praefoshi* Zone in the Indian Ocean (Srinivasan and Chaturvedi, 1992) (Fig. 5). This zone ranges at least from the middle Middle Miocene (~13.3 Ma) to earliest Late Miocene (~11.5 Ma) representing 1.8 myrs duration.

Uvigerina flintii Interval Zone

Definition: This zone is defined on the basis of last appearance of *Buliminella grata spinosa* (base) and last appearance of *Uvigerina flintii* (top).

Remarks: *Uvigerina flintii* IZ ranges from the upper middle part of *Cibicides helferi* IZ to middle part of *Cibicides marialana gigas* IZ in the northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). The last appearance of *Pleurostomella concava* Hermelin may also be used to define the base of this zone (Fig. 4b). *Bulimina jarvisi* Parker and Jones and *Cibicides*

Plate I



EXPLANATION OF PLATE I

1. Scanning Electron Microphotographs (SEM) of zonal markers benthic foraminiferal species in the southeastern Indian Ocean. (Scale bar: 100μm for figs. 1-5, 7-8 and 10μm for fig.6). 1. ***Ehrenbergina praebicornis*** Rai and Srinivasan (Site 760A, 5H-05, 101-103cm). 2. ***Bulimina macilenta*** Cushman and Parker (Site 754A, 7H-01, 148-149cm). 3. ***Bulimina glomarchallengeri*** (Tjalsma and Lohmann) (Site 760A, 5H-05, 25-27cm). 4. ***Buliminella grata spinosa*** Parker and Bermudez (Site 760A, 6H-02, 101-103cm). 5. ***Gavelinopsis lobatulus*** (Parr) (Site 754A, 3H-02, 28-30cm). 6. ***Globocassidulina tumida*** (Heron-Allen and Earland) (Site 754A, 3H-02, 28-30cm). 7. ***Uvigerina proboscidea*** Schwager (Site 761B, 7H-02, 25-27cm). 8. ***Uvigerina flintii*** Cushman (760A, 7H-06, 101-103 cm).

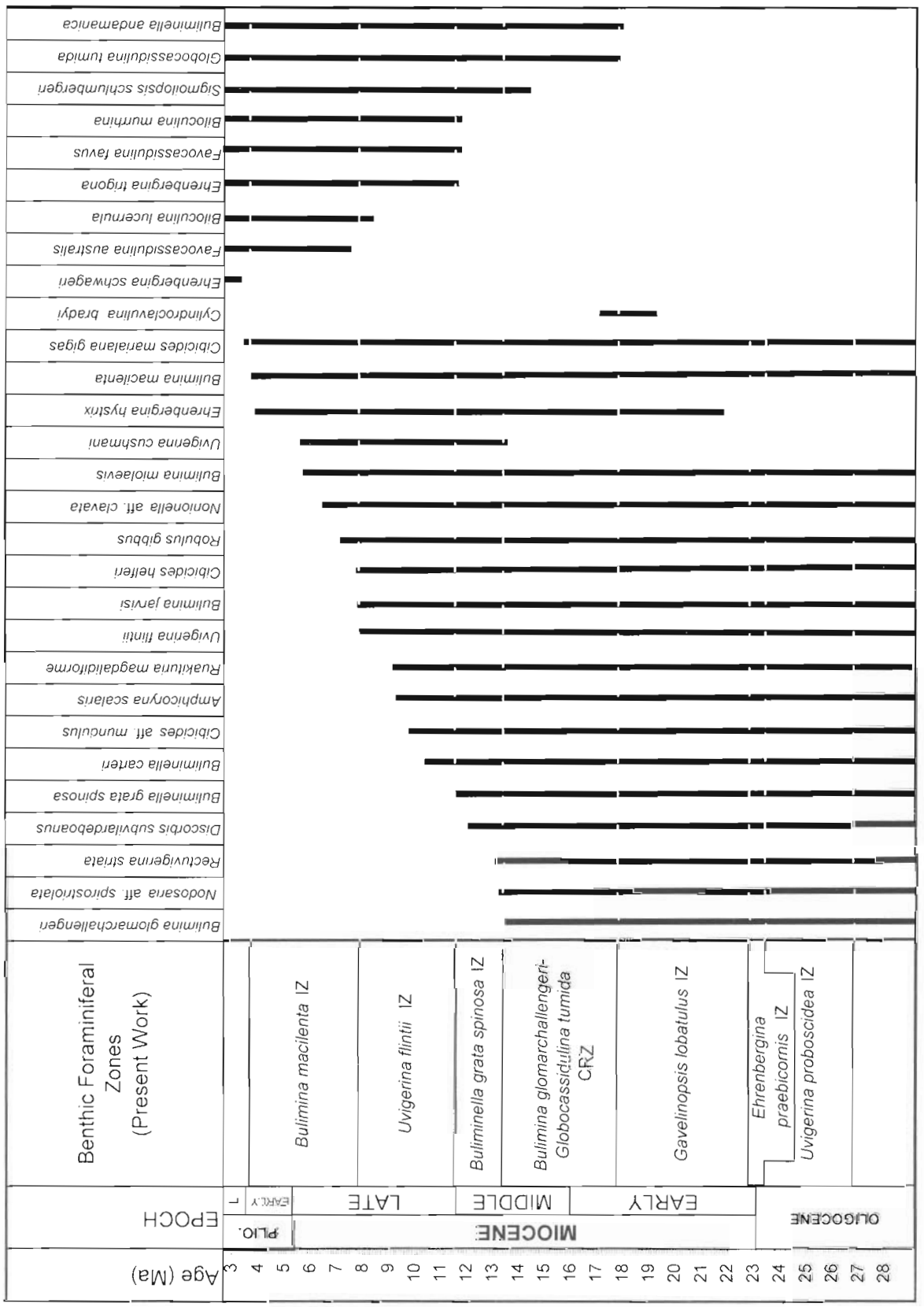


Fig. 4a. Total observed stratigraphic ranges of selected benthic foraminiferal species. Benthic Foraminiferal Zones (present work). (Ages after Gradstein *et al.*, 2004).

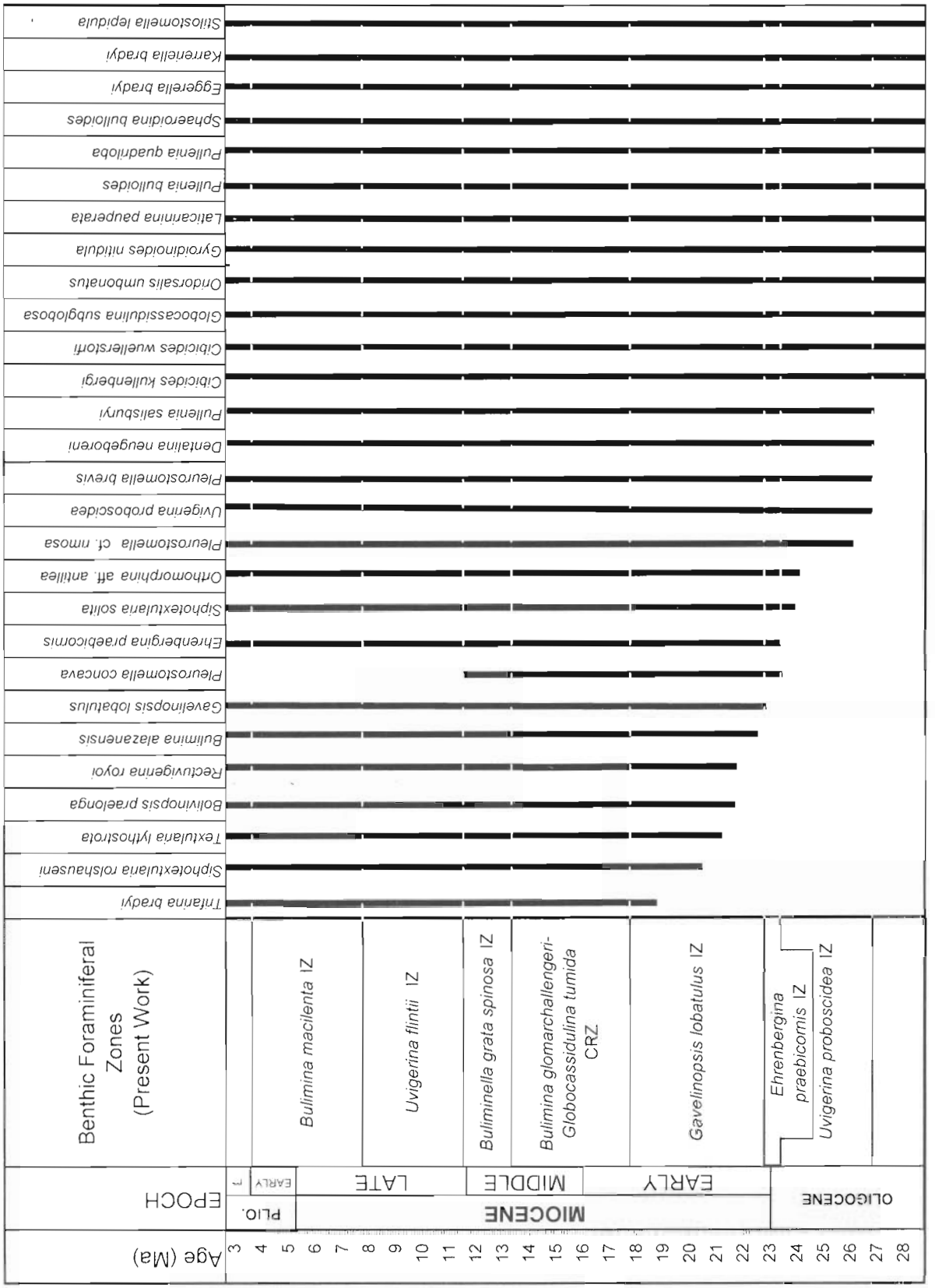


Fig. 4b. Total observed stratigraphic ranges of selected benthic foraminiferal species. Benthic foraminiferal zones (present work). (Ages after Gradstein *et al.*, 2004).

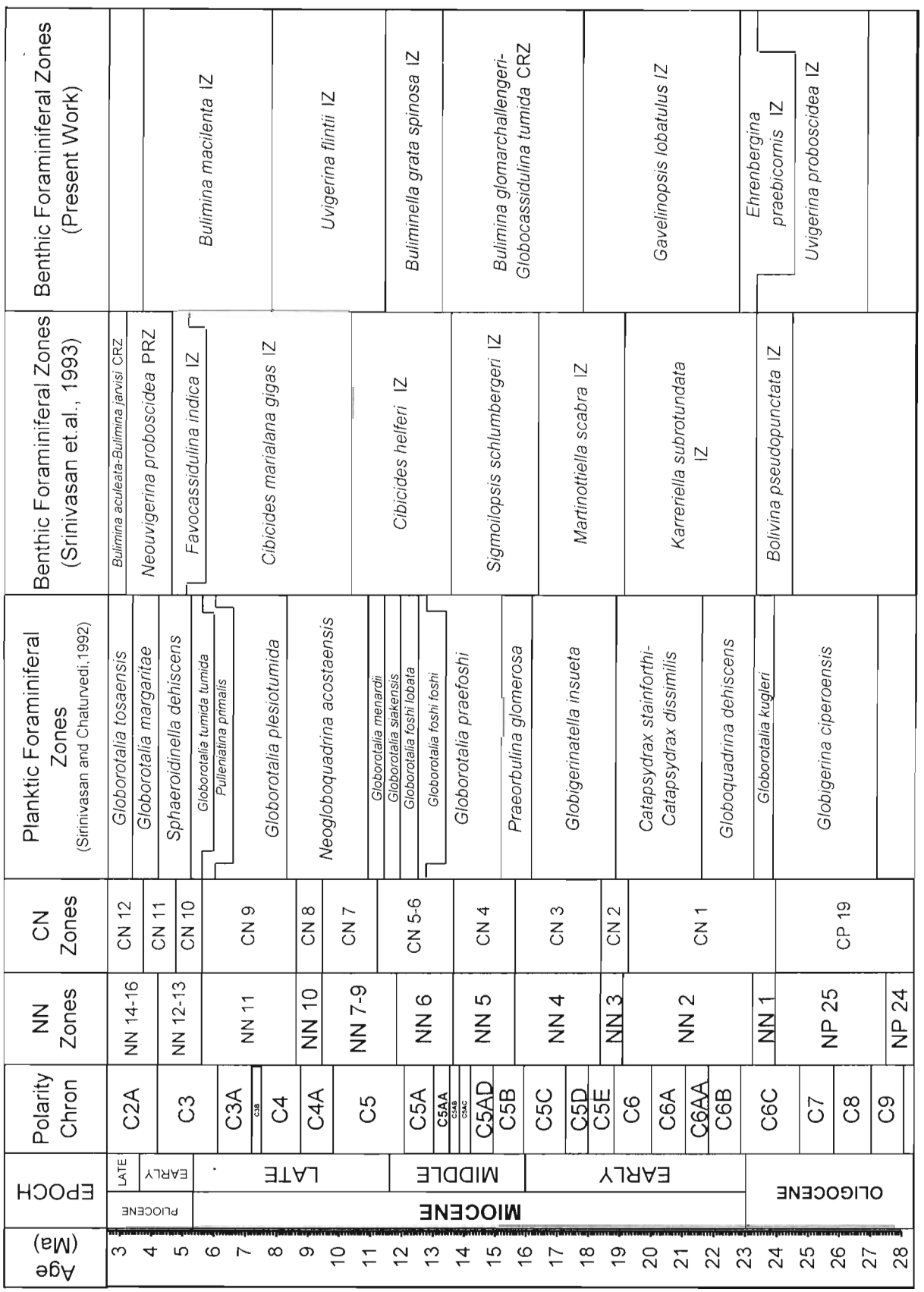


Fig. 5. Correlation of benthic foraminiferal zones (present work) with the calcareous nannofossil zones (NN and CN Zones) after Siesser and Bralower (1992) and Peirce *et al.*, (1989) of the eastern Indian Ocean, planktic foraminiferal zones after Srinivasan and Chaturvedi (1992), benthic foraminiferal zones after Srinivasan *et al.* (1993) of the northern Indian Ocean. (Ages after Gradstein *et al.*, 2004).

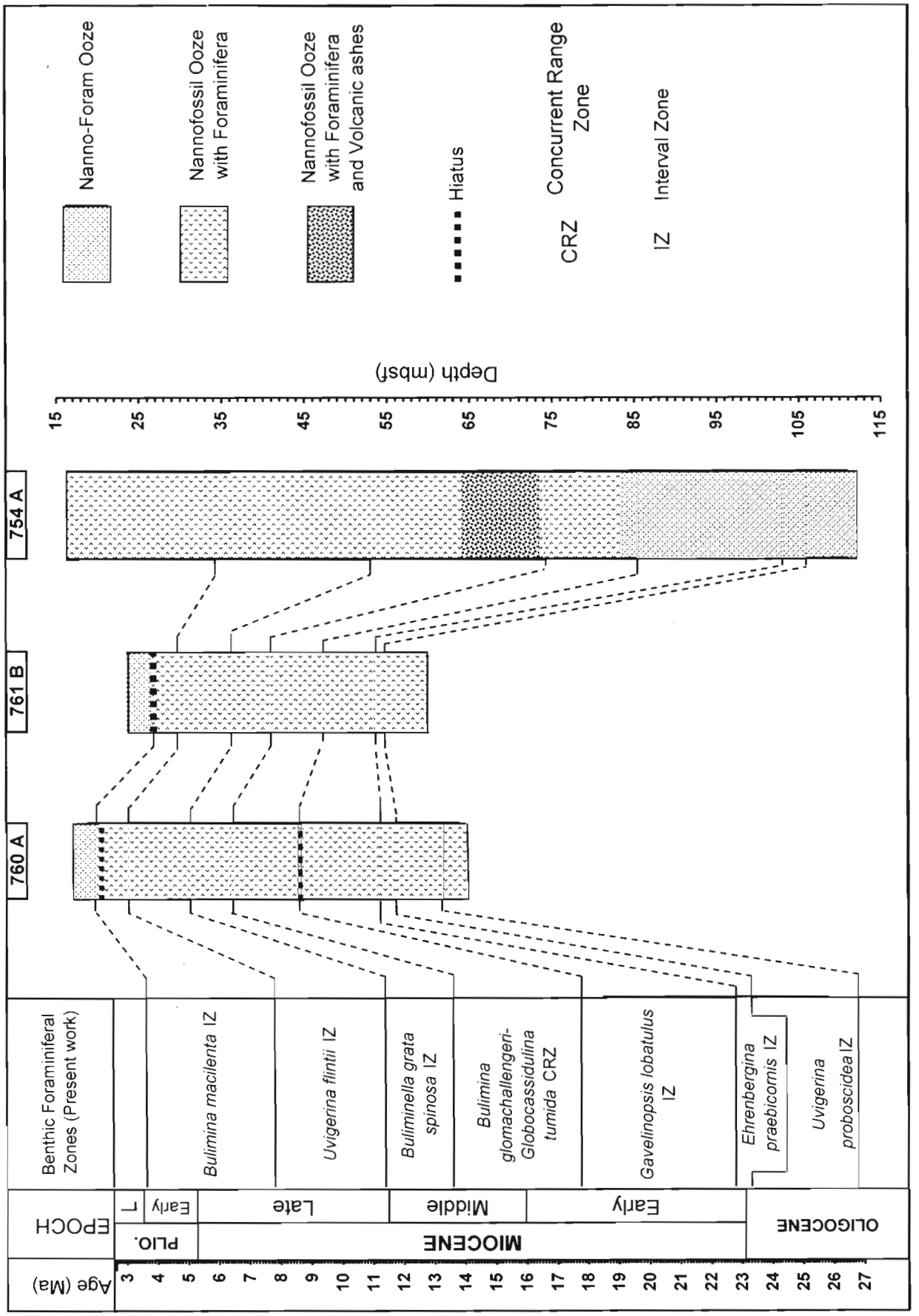


Fig. 6. Lithologs and benthic foraminiferal zones recorded at ODP sites 754A, 760A and 761B. (Ages after Gradstein *et al.*, 2004).

helferi also show their last appearances very close to the upper boundary of this zone (Fig. 4a). *Buliminella carteri* Bhatia, *Cibicides* aff. *mundulus* (Brady, Parker and Jones), *Amphicoryna scalaris* (Batsch) and *Ruakituria magdalidiformae* (Schwager) show their last appearances and *Biloculina lucernula* Schwager shows its first appearance within this zone (Fig. 4a).

Occurrence: *Uvigerina flintii* IZ is represented by about 18.59m, 7.98m and 6.75m thick sequence of nannofossil ooze with foraminifers at ODP sites 754A, 760A and 761B respectively (Fig. 6). The entire zone is recorded at all the three sites.

Age: The base of *Uvigerina flintii* IZ closely corresponds to the base of *Globorotalia menardii* Zone and upper boundary corresponds to the lower middle part of *Globorotalia plesiotumida* Zone. This zone ranges within the late Miocene (~11.5 Ma to ~7.83 Ma) and spanning a time interval of about 3.67 myrs.

Bulimina macilenta Interval Zone

Definition: This zone is based on the partial range of nominate taxon between the last appearance of *Uvigerina flintii* (base) and last appearance of nominate taxon (top).

Remarks: *Bulimina macilenta* IZ roughly corresponds with an interval from the middle part of *Cibicides marialana gigas* IZ to upper part of *Neouvigerina proboscidea* PRZ of northern Indian Ocean (Srinivasan *et al.*, 1993) (Fig. 5). *Favocassidulina australis* Eade shows its first appearance and *Robulus gibbus* (d'Orbigny), *Nonionella* aff. *clavata* Cushman, *Bulimina miolaevis* Finlay, *Uvigerina cushmani* Todd and *Ehrenbergina hystrix* show their last appearances within this zone (Figs. 4a, b). However, *R. gibbus and B. miolaevis* are reported from the Pleistocene sediment of the northern Indian Ocean (Rai, 1992; Gupta 1994) and last appearance of *Uvigerina cushmani* has been reported earlier during the middle Miocene (~15 Ma) in the Indian Ocean (Singh and Gupta, 2004).

Occurrence: This zone is recorded at sites 754A, 760A and 761B representing 19.22m, 3.27m and 3m thick deep sea sequences mainly comprising nannofossil ooze with foraminifera respectively. The upper part of this zone at site 760A comprises nanno-foram ooze (Fig. 6). The top of this zone is not recorded at site 754A due to non-availability of samples however, upper middle part and top of this zone is absent at sites 760A and 761B respectively due to presence of hiatuses (Siesser and Bralower, 1992) (Fig. 6).

Age: The lower boundary of this zone closely corresponds to the base of *Globorotalia menardii* Zone and upper boundary roughly corresponds to the lower boundary of *Globorotalia tossensis* Zone (Fig. 5). This zone ranges at least from late Miocene (~7.83 Ma) to early Pliocene (~3.68 Ma) and spanning a time interval of about 4.15 myrs.

GENERAL REMARKS

In general, the abysso-bathyal benthic foraminifera of southeastern Indian Ocean are relatively long ranging which occur throughout the Miocene interval. However, several species also show their first and last appearances within the studied interval (Figs. 4a, b). Some benthic foraminiferal species also appeared during early Miocene (Figs. 4a. b). However, origination and extinction of large number of species took place during the late middle Miocene interval (~14-11.5 Ma) (Figs. 4a, b) which corresponds with the period of well-known middle Miocene faunal turnover in response to relatively more unstable deep sea conditions (Douglas and Woodruff, 1981; Nomura, 1995; Rai *et. al.*, 2007). The proposed zones are of much unequal duration. *Ehrenbergina praebicornis* IZ across Oligocene/Miocene boundary is the shortest zone of 0.6 myrs duration between 23.3 Ma and 22.7 Ma, Whereas, longest zone proposed in this study is *Gavelinopsis lobatulus* IZ of ~5 myrs duration which ranges between 22.7 Ma and 17.7 Ma during early Miocene.

In the present work, no benthic foraminiferal event could be recorded to precisely delineate the Oligocene/Miocene boundary which is present within the *Ehrenbergina praebicornis* IZ. However, first appearance of *Orthomorphina* aff. *antillea* and *Siphotextularia solita* are very close to this boundary (Figs.4a, b). The first appearance of *Sigmoilopsis schlumbergeri* is close to early/middle Miocene boundary and this event lies within the *B. glomarchallengeri-G. tumida* CRZ (Fig. 4a). The upper boundary of *Buliminella grata spinosa* IZ lies very close to the middle/late Miocene boundary. The first appearances of *Biloculina murrhina*, *Ehrenbergina trigona*, *Favocassidulina favus* and last appearance of *Pleurostomella concava* are also very close to the middle/late Miocene transition (Figs. 4a,b). The last appearance of *Uvigerina cushmani* in the southeastern Indian Ocean may be used to delineate the Miocene/Pliocene boundary in this region (Figs. 4a, b). The top of *Bulimina macilenta* IZ roughly marks the early/late Pliocene boundary in the southeastern Indian Ocean.

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