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Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the Geomagnetic Polarity and Astronomical Time Scale

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Abstract

Planktonic foraminifera are widely utilized for the biostratigraphy of Cretaceous and Cenozoic marine sediments and are a fundamental component of Cenozoic chronostratigraphy. The recent enhancements in deep sea drilling recovery, multiple coring and high resolution sampling both offshore and onshore, has improved the planktonic foraminiferal calibrations to magnetostratigraphy and/or modified species ranges. This accumulated new information has allowed many of the planktonic foraminiferal bioevents of the Cenozoic to be revised and a reassessment of the planktonic foraminiferal calibrations. We incorporate these developments and amendments into the existing biostratigraphic zonal scheme.

In this paper we present an amended low-latitude (tropical and subtropical) Cenozoic planktonic foraminiferal zonation. We compile 187 revised calibrations of planktonic foraminiferal bioevents from multiple sources for the Cenozoic and have incorporated these recalibrations into a revised Cenozoic planktonic foraminiferal biochronology. We review and synthesize these calibrations to both the geomagnetic polarity time scale (GPTS) of the Cenozoic and astronomical time scale (ATS) of the Neogene and late Paleogene. On the whole, these recalibrations are consistent with previous work; however, in some cases, they have led to major adjustments to the duration of biochrons. Recalibrations of the early middle Eocene first appearance datums of *Globigerinatheka kugleri*, *Hantkenina singanoae, Guembelitrioides nuttalli* and *Turborotalia frontosa* have resulted in large changes in the durations of Biochrons E7, E8 and E9. We have introduced (upper Oligocene) Zone O7 utilizing the biostratigraphic utility of '*Paragloborotalia' pseudokugleri*. For the Neogene Period, major revisions are applied to the fohsellid lineage of the middle Miocene and we have modified the criteria for recognition of Zones M7, M8 and M9, with additional adjustments regarding the *Globigerinatella* lineage to Zones M2 and M3. The revised and recalibrated datums

provide a major advance in biochronologic resolution and a template for future progress to the Cenozoic time scale.

Keywords: Cenozoic time scale, planktonic foraminifera, time scale calibration, Neogene time scale; Paleogene time scale, biostratigraphy

1. Introduction

1.1 Cenozoic planktonic foraminiferal biostratigraphy

Robust stratigraphic correlations are essential to decipher Earth history. Planktonic foraminifera have many characteristics considered ideal for biostratigraphic index fossils – morphologically distinct, diverse, rapidly-evolving, highly abundant, often globally distributed and high preservation potential. As such, they are extensively used for the biostratigraphy of Cretaceous and Cenozoic marine sediments and are a fundamental component of Cenozoic chronostratigraphy. Regional biostratigraphic schemes developed in parallel with taxonomic and stratigraphic research, beginning in the 1940s in the oil-producing parts of the USA (e.g. Cushman and Stainforth, 1945) and reaching high levels of sophistication by mid-century for various key economic areas in the West (e.g. Bolli 1957a, b) and Former Soviet Union (e.g. Subbotina, 1953). The process of generalizing these essentially local schemes was underway in the 1960s (e.g., Bandy, 1964; Banner and Blow, 1965) but was accelerated by the Deep Sea Drilling Project (DSDP), when it soon became clear that even in the deep Pacific Ocean there were “the same species assemblages and faunal succession as reported from other areas” (Krasheninikov, 1971, p. 1055-1056). Hence integrated biostratigraphic schemes began to be regarded as global within broad latitudinal belts, although some degree of provincialism was also recognized in different ocean basins, the Mediterranean Sea (e.g. Cita, 1973), and areas of high productivity.

The starting point for all biostratigraphy is the recognition of so-called biostratigraphic horizons (biohorizons) that can be thought of as levels that can be correlated between stratigraphic sections where the fossil content changes in some measurable way (see McGowran, 2005 for discussion). The biostratigraphic resolution is determined by morphospecies evolution (appearances and disappearances of species). Additional biohorizons include prominent changes in coiling direction. Since at least the mid-nineteenth century (Hedberg et al., 1976) it has been standard biostratigraphic practice to divide stratigraphic sections into zones and subzones, which are non-overlapping slices of stratigraphy that lie between prominent biohorizons and are characterized by a particular fossil content (see McGowran, 2005). The zones and subzones allow recognition of fairly broad and easily identifiable intervals of stratigraphy that can be widely correlated with confidence. The practice of naming and/or sequentially numbering biozones provides the biostratigrapher with a useful mnemonic and easy means of communication. The five types of biozones that can logically be based on stratigraphic lowest and highest occurrences (LO and HO) are shown in Fig. 1.

Throughout the Cenozoic the planktonic foraminifera have been most abundant and diverse in the tropics and subtropics, hence it is for these latitudes that the zonal schemes are most detailed and easy to apply. Work in the temperate mid-latitudes and sub-polar oceans, especially in the Neogene when climatic gradients were more pronounced than in the Paleogene, either requires judicious use of secondary markers and the amalgamation of zones when key species are absent or the development of entirely separate zonal schemes (e.g. Jenkins 1966, 1967, 1971; Poore and Berggren, 1975; Kaneps, 1975; Kennett and Srinivasan, 1983; Stott and Kennett, 1990). Nevertheless the tropical / subtropical schemes have always provided the central standard, and within that standard an increasing number of key datum levels have been accurately calibrated against magneto- and astrochronological time scales.

The updated and revised tropical / subtropical zonation presented here is a much-modified and refined descendant of that originally developed by British Petroleum micropaleontologists in the Caribbean and Tanzania in the 1950s and 1960s (Bolli, 1957a, b, 1966; Blow, 1959; Blow and Banner, 1962; Bolli and Bermúdez, 1965). A significant innovation was made by Banner and Blow (1965) who partially described a set of zones using alphanumeric shorthand ('P' for Paleogene and 'N' for Neogene, with only the Neogene zones fully described, from N1 to N22). The remainder of this scheme was presented by Blow (1969) with extensive taxonomic and stratigraphic discussion; however note that one unfortunate consequence of this was that the Neogene began with Zone N4 due to uncertainty in the placement of the Oligocene/Miocene boundary. The Blow (1969) scheme was later revised and expanded upon by Blow (1979). A variant of this zonation was published by Berggren (1969) and originally attributed to "Blow and Berggren in Berggren (1969)"; see discussion in Berggren and Miller (1988). Numerous amendments to these zones have been suggested over the years, often for specific parts of the scheme that have failed to work optimally in certain areas. Comprehensive updates and correlations between alternative schemes were published by Stainforth et al. (1975), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Berggren and Miller (1988), and Berggren et al. (1995; referred to herein as BKSA95). This latter review introduced a new development to the alphanumeric notation for epoch-level intervals, namely the introduction of 'M' for Miocene, 'PL' for Pliocene and 'PT' for Pleistocene in place of the earlier 'N' for Neogene zones. Similarly, Berggren and Pearson (2005) produced a new revision for the Paleogene zones following extensive taxonomic work on the Paleocene and Eocene planktonic foraminifera (Olsson et al., 1999; Pearson et al., 2006), extending this practice to include 'P' for Paleocene, 'E' for Eocene and 'O' for Oligocene.

1.2. Recent developments and the necessity for Cenozoic biostratigraphic review

In 2009 the research vessel the *JOIDES Resolution,* part of the Integrated Ocean Drilling Program (IODP) was refloated for a new campaign of ocean drilling, following a two year renovation. During IODP, as in DSDP and Ocean Drilling Program (ODP), planktonic foraminiferal biostratigraphy is extensively employed during Shipboard and post-cruise work to establish age-depth relationships.

The compilation of BKSA95 brought together the planktonic foraminifera and calcareous nannoplankton bioevents for the Cenozoic and has been frequently applied in regional and global biostratigraphy and correlations. Consistency of nomenclature is extremely sought after in biostratigraphy, and revision of zonal scheme(s) should not be embarked upon without due consideration. However, since 1995, a number of apparent deficiencies in the tropical planktonic foraminiferal zonal schemes have been discovered through detailed biostratigraphic investigations and taxonomic developments. The enhancements in deep sea drilling recovery, multiple coring, high resolution sampling both offshore and onshore, has improved the calibrations with the magnetostratigraphy and/or modified the species ranges and allowed many of the planktonic foraminiferal bioevents to be revised. For example, detailed biostratigraphic investigations from Ceara Rise (Chaisson and Pearson, 1997; Pearson and Chaisson, 1997; Turco et al., 2002), equatorial Pacific Ocean (Wade et al., 2007), Indian Ocean (Hancock et al., 2002) and the Gorrondaxte and Agost sections in Spain (Payros et al., 2007, 2009; Ortiz et al., 2008; Larrasoaña et al., 2008) have resulted in revision of the calibrations of numerous bioevents. Most of these changes are small and incremental in nature, but some (e.g., the revision of the lower middle Eocene by Payros et al., 2007) are major developments. This accumulated new information presents the opportunity for a reassessment of the planktonic foraminiferal calibrations and to incorporate developments and amendments to the existing biostratigraphic zonal scheme.

Ocean Drilling Program Leg 154 (Ceara Rise, western tropical Atlantic Ocean) produced several new constraints on tropical planktonic foraminiferal biohorizons that are incorporated into the present study. The sedimentary succession on Ceara Rise is remarkably complete and continuous from the Paleocene to Recent (Curry et al., 1995). It is unfortunate that no magnetostratigraphy is available for the sites. Nevertheless a very complete series of foraminifera and nannofossil biohorizons was recorded (Chaisson and

Pearson, 1997; Pearson and Chaisson, 1997; Turco et al., 2002; Backman and Raffi, 1997). Datums that are derived from Leg 154 sites are indirectly calibrated to the geomagnetic magnetostratigraphic time scale by interpolation between other well calibrated events and through linear interpolation with the astrochronology of Lourens et al. (2004). To ensure consistency we have also recalculated bioevents from Ceara Rise (Chaisson and Pearson, 1997; Pearson and Chaisson, 1997; Turco et al., 2002) and converted them to the magnetochronology of Cande and Kent (1995) (Table 1, Fig. 2). A revised Cenozoic planktonic foraminiferal biochronology is a logical outcome of the improved age control, and the new campaign of ocean drilling by the *JOIDES Resolution* (e.g., Pälike et al., 2009; Lyle et al., 2009), as well as high-resolution biostratigraphic studies since 1995 that have acted as the catalyst to bring these new calibrations together.

1.3. A Cenozoic Astronomical Naming Scheme

The ~405 kyr cycle of Earth's eccentricity is regarded as relatively stable over geological time (Laskar, 1999). Neogene geochronology has undergone major advances with integrated magneto-, astro-stratigraphies of continuous open marine and outcrop sedimentary successions (Hilgen et al., 2006 and references therein) and a well constrained astro-magneto-chronology for the entire Neogene (Lourens et al., 2004). An orbitally calibrated magnetochronology for the Paleogene is still under development and is available to Chron C19n (Pälike et al., 2006). We propose here a naming scheme that relates astronomical (chronological) information with magnetostratigraphy. The naming scheme to define events by ~405 kyr eccentricity cycle follows the procedure used in Wade and Pälike (2004) and Pälike et al. (2006). The cycle count number is identified by the ~405 kyr eccentricity minima from Laskar et al. (2004), numerically coded, starting with number 1 for the most recent minimum and proceeding back in time (Table 2). As in Wade and Pälike (2004) we include a subscripted code for the geological epoch together with the magnetochron (excluding subchrons) closest to the ~405 kyr eccentricity minimum (Fig. 3).

1.4. Revision of Cenozoic tropical planktonic foraminiferal bio-, magneto-, astro-chronology

We have produced a revised and unified Cenozoic planktonic foraminiferal magnetobiochronology. We integrate planktonic foraminiferal data from multiple sources and have incorporated these recalibrations into a revised Cenozoic planktonic foraminiferal biochronology and review and synthesize these calibrations to both the geomagnetic polarity time scale (GPTS) and astronomical time scale (ATS). The biochronology has been derived from calibrations to the magnetostratigraphic polarity zones (chrons and subchrons) in deep sea and land sections where available. We have used linear interpolation to convert numerous bioevents to multiple time scales (Cande and Kent, 1995; Lourens et al., 2004; Luterbacher et al., 2004; Pälike et al., 2006) to provide the reader with convenient "look up" tables and figures for age models and biostratigraphic control. The new and former calibration ages are given in Tables 1, 3 and 4.

Here, we present an amended low-latitude (tropical and subtropical) Cenozoic planktonic foraminiferal biochronology of 187 planktonic foraminiferal events for the Cenozoic (108

Neogene and 79 Paleogene) (Figs. 2 and 4; Tables 1, 3 and 4). Bioevents have been recalibrated to the GPTS of Cande and Kent (1995) and Luterbacher et al. (2004) and to the ATS of Lourens et al. (2004) and Pälike et al. (2006, from the Oligocene/Miocene boundary to Zone E11) (Tables 1, 3 and 4). We recalibrate 61 primary and over 120 secondary bioevents for the Cenozoic. On the whole, these recalibrations are consistent with previous work. However, in some cases, they have led to major adjustments to the duration of biochrons (Figs. 2-4). Our revised and recalibrated datums provide a major advance in biochronologic resolution and a template for future progress to the Cenozoic time scale. The calibrations presented here represent the current status of Cenozoic tropical biostratigraphy and further updates and refinements are likely to follow with future IODP Expeditions. The enhanced recovery, multiple hole advanced piston coring, of successions with high sedimentation rates and paleomagnetic control (e.g., Pälike et al., 2009; Lyle et al., 2009) will enable high resolution biostratigraphic studies and extension of the ATS beyond 40 Ma. We use the PT, PL, and M zonal scheme of BKSA95 and the O, E and P zonal scheme of Berggren and Pearson (2005). The 21 zones of the Neogene Period (BKSA95) and 29 zones of the Paleogene Period (Berggren and Pearson, 2005) are retained and amended to reflect updated chronostratigraphic calibration to the GPTS.

As with previous compilations (e.g., Berggren et al., 1985, 1995b), our magnetobiochronology is founded on first order calibrations between biostratigraphic events and the magnetostratigraphy in ocean drilling cores, as well as outcrop sections. These are supplemented with orbital compilations in instances where a magnetostratigraphy was absent (e.g., Ceara Rise). Here the current status of Cenozoic planktonic foraminiferal biostratigraphy is reviewed, refined and recalibrated, with modifications to the zonal criteria where necessary. All calibrated bioevents are listed in Tables 1, 3 and 4, primary events that define zonal boundaries are shown in bold and on Figs. 2-4.

Our revised zonation is primarily for application in open ocean settings of the Pacific, Indian and Atlantic oceans, and therefore we have not incorporated biostratigraphic information that is regionally restricted, such as to the Mediterranean, the high latitudes and other localized environments and when studies subsequent to BKSA95 have indicated them to be diachronous, unreliable or require further evaluation. Secondary bioevents that have not been used include: the last appearance datum (LAD) *Globoquadrina pseudofoliata* (Chaproniere et al., 1994), first appearance datum (FAD) *Globorotalia hirsuta* (Pujol and Duprat, 1983), FAD *Globoconella inflata* (Berggren et al., 1995a), FAD *Pulleniatina finalis* (Chaproniere et al., 1994), LAD *Neogloboquadrina atlantica* (Weaver and Clement, 1987), LAD *Globoconella puncticulata* (Atlantic) (Zijderveld et al., 1991), LAD *Globoquadrina baroemoenensis* (Curry et al., 1995), FAD *Globorotalia sphericomiozea* and *Globorotalia pliozea* (Srinivasan and Sinha, 1992), LAD *Globorotalia zealandica* (Li et al., 1992), FAD *Globigerinoides altiaperturus* (Steininger et al., 1997), LAD *Globigerina labiacrassata* (BKSA95), FAD *Globigerinita boweni* (Li et al., 1992), LAD *Clavigerinella eocanica* (Pearson and Chaisson, 1997), LAD *Subbotina linaperta* (Wade, 2004), and LAD *Planorotalites capdevilensis* (Wade, 2004).

2. Neogene Period

The genus *Globorotalia* has been widely utilized in morphometric and biostratigraphic studies. Several subgenera exist in the literature for keeled forms, that have been somewhat inconsistently been applied by various workers. For example Cushman and Bermúdez (1949) named the subgenus *Globorotalia* (*Truncorotalia*) with *G. truncatulinoides* as the type species. Bandy (1972) named several other subgenera (*Menardella, Fohsella*, *Hirsutella*) though these were not formally described and no type species was designated. Kennett and Srinivasan (1983) used these as subgenera and designated type species. As in the Paleocene (Olsson et al., 1999) and Eocene (Pearson et al., 2006) taxonomic atlases we have chosen not to use subgenera and refer to most of the above forms as *Globorotalia*, which are all part of a single clade descended from Miocene *G. praescitula* (Kennett and Srinivasan, 1983). The exception to this is the distinct taxonomic lineage of *Fohsella* which we use at the generic level because it is very likely polyphyletic with respect to the true *Globorotalia* and has a subtly different wall texture.

For the Neogene Period, the incorporation of revised bioevents from Ceara Rise (adopted by Lourens et al., 2004) has led to some major modifications to the planktonic foraminiferal stratigraphy and zonal scheme. Lourens et al. (2004) did not discuss the implications of their revised chronology to planktonic foraminiferal biostratigraphy. We have re-evaluated and assessed these events and compared them to previous magnetochronologic calibrations. In the majority of events discussed below the concept of the zone has remained the same, with the exception of Zones M9, M8, M7, M3, and M2.

Since the initiation of this work, The International Commission on Stratigraphy have proposed to lower the base of the Quaternary Period and the Pleistocene epoch to 2.58 Ma, at the same time capping the Neogene Period at that age (Gibbard et al., 2009). As this is not yet formally ratified in publication and has been met with widespread opposition (e.g., Van Couvering et al., 2009), we have used the former definition of the "real" Neogene (McGowran et al., 2009) as consisting of the Miocene, Pliocene, Pleistocene and Holocene/Recent, while awaiting a resolution of the controversy.

2.1. Amendment to the Pleistocene PT Zones

Zone PT1. *Globigerinoides ruber* Partial-range Zone (herein renamed = Zone PT1 [*Globigerinoides fistulosus*-*Globorotalia truncatulinoides* Interval Zone] of BKSA95).

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the highest occurrence (HO) of *Globigerinoides fistulosus* and the Recent.

Magnetochronologic calibration: Chron C2n-Chron C1n (present day).

Astronomical cycle calibration: $5_{Pt\text{-}C1r}$ - present day.

Estimated age: 1.88–0 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pliocene-Recent.

Remarks: The definition of the zone remains the same as in BKSA95, however, it has been renamed here according to the convention in Fig. 1 and of Berggren and Pearson

(2005). Lourens et al. (2004) provided two astronomical ages for the LAD of *Globigerinoides fistulosus*, 1.77 Ma from Site 677 (Shipboard Scientific Party, 1988; Shackleton et al., 1990) and 1.88 Ma (Chaisson and Pearson, 1997). The calibration from Site 677 is poorly constrained between relatively widely spaced core catcher samples and requires further investigation, thus we use the LAD of *Globigerinoides fistulosus* from Ceara Rise of 1.88 Ma.

Subzone PT1b. *Globorotalia truncatulinoides* Partial-range Subzone

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the highest occurrence (HO) of *Globorotalia tosaensis* and the Recent.

Magnetochronologic calibration: Chron C1n.

Astronomical cycle calibration: $2_{Pt\text{-}C1n}$ - present day.

Estimated age: 0.61–0 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pleistocene (including Holocene).

Remarks: The nomenclature and definition of this subzone remain the same as in Berggren et al. (1995a) and BKSA95.

Subzone PT1a. *Globorotalia tosaensis* Highest-occurrence Subzone (herein renamed = Subzone PT1a [*Globigerinoides fistulosus-Globorotalia tosaensis* Interval Sub-Zone] of Berggren et al., 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Globigerinoides fistulosus* and the HO of the nominate taxon, *Globorotalia tosaensis*.

Magnetochronologic calibration: Chron C2n – Chron C1n.

Astronomical cycle calibration: $5_{Pt\text{-}C1r}$ - $2_{Pt\text{-}C1n}$.

Estimated age: 1.88–0.61 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pliocene to late Pleistocene.

Remarks: This subzone is the same as Subzone PT1a of Berggren et al. (1995a) and renamed according to the convention of Berggren and Pearson (2005). See discussion for Zone PT1 regarding the LAD of *Globigerinoides fistulosus*.

2.2. Amendment to the Pliocene PL Zones

Zone PL6 (Indo-Pacific). *Globigerinoides fistulosus* Highest-occurrence Zone (Indo-Pacific) (herein renamed = Zone PL6 [*Globorotalia pseudomiocenica - Globigerinoides fistulosus* Interval Zone] of Berggren et al., 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Globorotalia pseudomiocenica* and the HO of the nominate taxon, *Globigerinoides fistulosus* in the Indo-Pacific province.

Magnetochronologic calibration: Subchron C2r.2r to Chron C2n.

Astronomical cycle calibration: $6_{Pl\text{-}C2n}$ - $5_{Pt\text{-}C1r}$.

Estimated age: 2.30–1.88 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pliocene.

Remarks: This zone is the same as Zone PL6 (Indo-Pacific) of Berggren et al. (1995a) and BKSA95. This zone is specific to the Indo-Pacific realm because *Globorotalia pseudomiocenica* evolved into *G. miocenica* over the interval of Chron C2An.3n to Chron C2An.2n (~ 3.5-3.2 Ma) in the Atlantic realm (DSDP Site 502, Colombia Basin; Keigwin, 1982), whereas it persisted into younger biostratigraphic level in the Indo-

Pacific realm (BKSA95: 166). It is approximately equivalent in stratigraphic level to Zone PL6 (Atlantic). Renamed according to the convention of Berggren and Pearson (2005).

Zone PL6 (Atlantic). *Globigerinoides fistulosus* Highest-occurrence Zone (Atlantic) (herein renamed = Zone PL6 [*Globorotalia miocenica* -*Globigerinoides fistulosus* Interval Zone] of Berggren et al., 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Globorotalia miocenica* and the HO of the nominate taxon, *Globigerinoides fistulosus* in the Atlantic province.

Magnetochronologic calibration: Subchron C2r.2r-Subchron C1r.2r.

Astronomical cycle calibration: $7_{Pl\text{-}C2r}$ - $5_{Pt\text{-}C1r}$.

Estimated age: 2.39–1.88 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pliocene.

Remarks: This zone is the same as Zone PL6 (Atlantic) of Berggren et al. (1995a) and BKSA95. This zone is specific to the Atlantic Ocean (see remarks regarding Zone PL6 [Indo-Pacific]). It is approximately equivalent in stratigraphic level to Zone PL6 (Indo-Pacific). Renamed according to the convention of Berggren and Pearson (2005).

Zone PL5 (Indo-Pacific). *Globorotalia pseudomiocenica* Highest Occurrence Zone (herein renamed = Zone PL5 [Indo-Pacific] [*Dentoglobigerina altispira* - *Globorotalia pseudomiocenica* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Dentoglobigerina altispira* and

HO of the nominate taxon *Globorotalia pseudomiocenica* in the Indo-Pacific province.

Magnetochronologic calibration: Subchron C2An.3n-Subchron C2r.2r.

Astronomical cycle calibration: $9_{\text{Pl-C2An}}$ - $6_{\text{Pl-C2n}}$.

Estimated age: 3.46–2.30 Ma (as per Cande and Kent, 1995); 3.47-2.30 Ma (as per Lourens et al., 2004); late Pliocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Zone PL5 (Atlantic). *Globorotalia miocenica* Highest Occurrence Zone (herein renamed = Zone PL5 [Atlantic] [*Dentoglobigerina altispira* - *Globorotalia miocenica* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Dentoglobigerina altispira* and HO of the nominate taxon *Globorotalia miocenica* in the Atlantic province.

Magnetochronologic calibration: Subchron C2An.2n-Subchron C2r.2r.

Astronomical cycle calibration: $8_{\text{Pl-C2An}}$ - $7_{\text{Pl-C2r}}$.

Estimated age: 3.13–2.30 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); late Pliocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Zone PL4. *Dentoglobigerina altispira* Highest Occurrence Zone (herein renamed = Zone PL4 [*Sphaeroidinellopsis seminulina* – *Dentoglobigerina altispira* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Sphaeroidinellopsis seminulina* and HO of the nominate taxon *Dentoglobigerina altispira*.

Magnetochronologic calibration: Subchron C2An.2n (Atlantic); Subchron C2An.3n (Indo-Pacific).

Astronomical cycle calibration: $9_{Pl\text{-}C2An}$ - $8_{Pl\text{-}C2An}$ (Atlantic); $10_{Pl\text{-}C2An}$ - $9_{Pl\text{-}C2An}$ (Indo-Pacific).

Estimated age: Atlantic Ocean = 3.16–3.13 Ma (as per Cande and Kent, 1995; Lourens et al., 2004); Pacific Ocean = 3.57-3.46 Ma (as per Cande and Kent, 1995); 3.59-3.47 Ma (as per Lourens et al., 2004); late Pliocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005). A short biostratigraphic interval corresponding to 30 kyr between the LAD of *Sphaeroidinellopsis seminulina* and *Dentoglobigerina altispira* was recognized by BKSA95. Chaisson and Pearson (1997) recorded these events at approximately the same stratigraphic level at Ceara Rise, but their sampling resolution suggested a short duration as in BKSA95, hence we estimate the timing of these events at 3.13 and 3.16 consistent with the stratigraphic record at Ceara Rise (Chaisson and Pearson, 1997) and the observations of BKSA95. The duration of Biochron PL4 is estimated to be 30 kyr in the Atlantic Ocean and 110 kyr in the Pacific Ocean.

Zone PL3. *Sphaeroidinellopsis seminulina* Highest Occurrence Zone (herein renamed = Zone PL3 [*Globoquadrina altispira - Sphaeroidinellopsis subdehiscens* Partial Range Zone] of Berggren, 1973, [*Globorotalia margaritae – Sphaeroidinellopsis seminulina* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Globorotalia margaritae* and HO of the nominate taxon *Sphaeroidinellopsis seminulina*.

Magnetochronologic calibration: Chron C2Ar-Subchron C2An.2n (Atlantic); Chron C2Ar-Subchron C2An.3n (Indo-Pacific).

Astronomical cycle calibration: $10_{Pl\text{-}C2An}$ - $9_{Pl\text{-}C2An}$ (Atlantic); $10_{Pl\text{-}C2An}$ - $9_{Pl\text{-}C2An}$ (Indo-Pacific).

Estimated age: Atlantic Ocean = 3.84–3.16 Ma (as per Cande and Kent, 1995); 3.85-3.16 Ma (as per Lourens et al., 2004); Pacific Ocean = 3.84-3.57 Ma (as per Cande and Kent, 1995); 3.85-3.59 Ma (as per Lourens et al., 2004); early-late Pliocene.

Remarks: The definition of this zone is the same as that of Berggren (1973). Renamed according to the convention of Berggren and Pearson (2005).

Zone PL2. *Globorotalia margaritae* Highest Occurrence Zone (herein renamed = Zone PL2 [*Globorotalia margaritae – Sphaeroidinellopsis subdehiscens* Partial Range Zone] of Berggren, 1973, [*Globoturborotalita nepenthes - Globorotalia margaritae* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the HO of *Globoturborotalita nepenthes* and HO of the nominate taxon *Globorotalia margaritae*.

Magnetochronologic calibration: Subchron C3n.1r-Chron C2Ar.

Astronomical cycle calibration: $12_{Pl\text{-}C3n}$ - $10_{Pl\text{-}C2An}$.

Estimated age: 4.36–3.84 Ma (as per Cande and Kent, 1995); 4.37-3.85 Ma (as per Lourens et al., 2004); early Pliocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Zone PL1. *Globorotalia tumida / Globoturborotalita nepenthes* Concurrent-range

Zone (herein renamed = Zone PL1 [*Globigerina nepenthes - Globorotalia tumida* Partial Range Zone] of Berggren, 1973, [*Globorotalia tumida* – *Globoturborotalita nepenthes* Interval Zone] of Berggren et al. 1995a and BKSA95).

Definition: Biostratigraphic interval between the lowest occurrence (LO) of *Globorotalia tumida* and HO of *Globoturborotalita nepenthes*.

Magnetochronologic calibration: Chron C3r-Subchron C3n.1r.

Astronomical cycle calibration: $15_{\text{Mi-C3r}}$ - $12_{\text{Pl-C3n}}$.

Estimated age: Atlantic Ocean = 5.63–4.36 Ma (as per Cande and Kent, 1995); 5.72-4.37 Ma (as per Lourens et al., 2004); Pacific Ocean = 5.51-4.36 Ma (as per Cande and Kent, 1995); 5.57-4.37 Ma (as per Lourens et al., 2004); late Miocene-early Pliocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005). The extinction of *Globorotalia cibaoensis* was used to subdivide Zone PL1 and had a calibration of 4.6 Ma in BKSA95. However, Chaisson and Pearson (1997) reported a much younger LAD for this species which was adopted by Lourens et al. (2004) to give an astronomical age on 3.23 Ma. As the much younger LAD at Ceara Rise is yet to be confirmed we use the 4.6 Ma calibration of BKSA95. Due to this discrepancy, we have removed the subdivision of Zone PL1, pending further investigations.

Consistent with previous studies (e.g., Berggren, 1977; Srinivasan and Kennett, 1981b; Kennett and Srinivasan, 1983), there is a short stratigraphic interval (32 kyr) between the HO of *Globoquadrina dehiscens* and the LO of *Sphaeroidinella dehiscens* (see Fig. 2a, Table 1). The LO of *Globorotalia tumida* occurs between these two distinctive events

(Srinivasan and Chaturvedi, 1992). The FAD *Globorotalia tumida* has been revised to 5.63 and 5.51 Ma for the Atlantic and Pacific oceans respectively (Table 1). Thunell (1981), Srinivasan and Kennett (1981a) and Chaisson and Leckie (1993) record the FAD of *G. tumida* to be older than the LAD *G. dehiscens*. However, Hodell and Kennett (1986) have shown the LAD of *G. dehiscens* to be diachronous, and the extinction appears to occur earlier in higher latitudes in comparison to tropical sites (Srinivasan and Kennett, 1981b).

2.3. Amendment to the Miocene M Zones

It is remarkable how few low latitude open ocean sections exist with good recovery, high sedimentation rates, abundant planktonic foraminifera and a clearly defined magnetostratigraphy through the Miocene. This has significantly hindered direct correlations to the GPTS and the development of robust planktonic foraminifera magnetobiostratigraphy. Miller et al. (1985) produced a magnetobiostratigraphy DSDP Sites 563 and 558 (western North Atlantic Ocean), however even these records have unconformities. Many of the events through the Miocene have been calibrated from the Buff Bay, Jamaica (BKSA95) and not from deep sea cores. Following Lourens et al. (2004) we have recalibrated the ages from Ceara Rise, but note that these are not tied to a magnetostratigraphy, and the resulting ages are significantly younger than those recorded in BKSA95. Our recalibrations have led to major changes to the age assignments and duration of Biochrons M10 to M13. We highlight some of the major changes below, but emphasize that this interval requires detailed study to confirm the ages of the events as defined from Ceara Rise (Chaisson and Pearson, 1997; Turco et al., 2002). The lower-middle Miocene interval is divided on the diagnostic index genus *Praeorbulina*. However, these taxa were rare at Ceara Rise (Pearson and Chaisson, 1997) and therefore were not included in the revised calibration, and we have retained the ages reported in BKSA95 for FAD of *Orbulina suturalis* (15.1 Ma), FAD *Praeorbulina circularis* (16.0 Ma), FAD *Praeorbulina curva* (16.3 Ma) and *Praeorbulina sicana* (16.4 Ma).

Zone M14. *Globigerinoides extremus* Partial-range Zone (herein renamed = Zone M14 [*Globorotalia lenguaensis* - *Globorotalia tumida* Interval Zone] of BKSA95).

Definition: Partial range of the nominate taxon between the HO of *Globorotalia lenguaensis* and LO of *Globorotalia tumida*.

Magnetochronologic calibration: Subchron C3An.1n-Chron C3r.

Astronomical cycle calibration: $16_{\text{Mi-C3r}}$ - $15_{\text{Mi-C3r.}}$

Estimated age: Atlantic Ocean = 6.00–5.63 Ma (as per Cande and Kent, 1995); 6.13-5.72 Ma (as per Lourens et al., 2004); Pacific Ocean = 6.00-5.51 Ma (as per Cande and Kent, 1995); 6.13-5.57 Ma (as per Lourens et al., 2004); late Miocene.

Remarks: Following the detailed biostratigraphic investigations by Turco et al. (2002), Lourens et al. (2004) significantly revised the LAD of *Globorotalia lenguaensis* to 8.97 Ma. The revised age is appreciably older than reported in BKSA95 (derived from the Tonga Plateau; Chaproniere et al., 1994) and would place the event within the *Neogloboquadrina acostaensis* Lowest-occurrence Subzone (Subzone M13a), inconsistent with the established order of bioevents. However, it should be noted that Zhang et al. (1993) found the HO of *G. lenguaensis* near the same horizon as the HO *G. plesiotumida* (8.52 Ma; Table 1), which is more consistent with the older age suggested by Turco et al. (2002). For stability we have retained the age established in BKSA95, but this interval clearly requires further investigation. The zone is renamed according to the convention of Berggren and Pearson (2005).

Zone M13. *Neogloboquadrina acostaensis / Globorotalia lenguaensis* Concurrent-range Zone

Definition: Biostratigraphic interval between the LO of *Neogloboquadrina acostaensis* and HO of *Globorotalia lenguaensis*.

Magnetochronologic calibration: Subchron C5n.1n-Subchron C3An.1n.

Astronomical cycle calibration: $25_{\text{Mi-C4Ar}}$ - $16_{\text{Mi-C3r.}}$

Estimated age: 9.79–6.00 Ma (as per Cande and Kent, 1995); 9.83-6.13 Ma (as per Lourens et al., 2004); late Miocene.

Remarks: The nomenclature and definition of the zone remain the same as in BKSA95.

Subzone M13b. *Globorotalia plesiotumida / Globorotalia lenguaensis* Concurrent-range Subzone (herein amended and renamed, approximately equivalent to Subzone M13b [*Globigerinoides extremus / Globorotalia plesiotumida – Globorotalia lenguaensis* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Globorotalia plesiotumida* and HO of *Globorotalia lenguaensis*.

Magnetochronologic calibration: Subchron C4r.2r-Subchron C3An.1n.

Astronomical cycle calibration: $22_{\text{Mi-C4r}}$ - $16_{\text{Mi-C3r.}}$

Estimated age: 8.52–6.00 Ma (as per Cande and Kent, 1995); 8.58-6.13 Ma (as per

Lourens et al., 2004); late Miocene.

Remarks: The definition used here removes the operational ambiguity inherent in the "and/or" designation in BKSA95, in which the Subzone was defined as the biostratigraphic interval between the LO of *Globigerinoides extremus* and/or the LO of *Globorotalia plesiotumida* and the HO of *Globorotalia lenguaensis*. Evidence since BKSA95 indicates that the LOs of *Globigerinoides extremus* and *Globorotalia plesiotumida* may occur at different levels (compare Chaisson and Pearson, 1997 and Turco et al. 2002). The subzone is renamed here according to the convention of Berggren and Pearson (2005).

Subzone M13a. *Neogloboquadrina acostaensis* Lowest-occurrence Subzone (herein amended and renamed, approximately equivalent to Subzone M13a [*Neogloboquadrina acostaensis - Globigerinoides extremus / Globorotalia plesiotumida* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of the nominate taxon *Neogloboquadrina acostaensis* and LO of *Globorotalia plesiotumida*.

Magnetochronologic calibration: Subchron C5n.1n-Subchron C4r.2r.

Astronomical cycle calibration: $25_{\text{Mi-C4Ar}}$ - $22_{\text{Mi-C4r.}}$

Estimated age: 9.79–8.52 Ma (as per Cande and Kent, 1995); 9.83-8.58 Ma (as per Lourens et al., 2004); late Miocene.

Remarks: The definition used here removes the operational ambiguity inherent in the "and/or" designation in BKSA95, in which the Subzone was defined as the biostratigraphic interval between the LO of *Neogloboquadrina acostaensis* and the LO of

Globigerinoides extremus and/or the LO of *Globorotalia plesiotumida*. See remarks for Subzone M13b regarding the LADs of *Globigerinoides extremus* and *Globorotalia plesiotumida*. The subzone is renamed here according to the convention of Berggren and Pearson (2005).

There is a significant reduction in the duration of Sub-biochron M13a. The cyclostratraphic age of the LO of *Neogloboquadrina acostaensis* (9.83 Ma) is derived from Ceara Rise (Chaisson and Pearson, 1997). This calibration was adopted by Lourens et al. (2004) and is significantly younger (1.07 myr) than in BKSA95 (10.90 Ma) and moves this event from early Subchron C5n.2n to Subchron C5n.1n. In BKSA95 the duration of this sub-biochron is 2.6 myr, from 10.9 to 8.3 Ma. Following Chaisson and Pearson (1997) this sub-biochron is recalibrated to 9.79 to 8.52 Ma and results in a change in the duration of Sub-biochron M13a to 1.27 myr, a reduction of 1.3 myr. Turco et al. (2002) noted the diachrony of the LO of *Neogloboquadrina acostaensis* between low latitudes and the Mediterranean. The age used in BKSA95 is calibrated to the magnetostratigraphy at Site 563 (Miller et al., 1985) and the discrepancy in calibrated ages may be due to further diachrony between the tropical and subtropical Atlantic Ocean, however, we note that the order of bioevents is consistent between Ceara Rise and Site 563.

Zone M12. *Globigerinoides trilobus* Partial-range Zone (herein renamed = Zone M12 [*Neogloboquadrina mayeri* – *Neogloboquadrina acostaensis* Interval Zone] of BKSA95).

Definition: Partial range of the nominate taxon between the HO of *Paragloborotalia mayeri* and LO of *Neogloboquadrina acostaensis*.

Magnetochronologic calibration: Subchron C5n.2n-Subchron C5n.1n.

Astronomical cycle calibration: $27_{\text{Mi-C5n}}$ - $25_{\text{Mi-C4Ar}}$.

Estimated age: 10.53–9.79 Ma (as per Cande and Kent, 1995); 10.46-9.83 Ma (as per Lourens et al., 2004); late Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005). As for *Neogloboquadrina acostaensis* (discussed above), there is a large difference between the age established in BKSA95 and that at Ceara Rise for the LAD of *Paragloborotalia mayeri* (10.53 Ma, this study; 11.40 Ma, BKSA95). The extinction of *Paragloborotalia mayeri* has been recalibrated to 10.53 Ma as per Chaisson and Pearson (1997) (given as *siakensis* in Turco et al., 2002). This is significantly younger (870 kyr) than the previous reported age of 11.40 Ma in BKSA95. The interpolated age would place this event mid C5n.2n rather than C5r.2r. The age used in BKSA95 is calibrated to the magnetostratigraphy at Site 563 (Miller et al., 1985) and this discrepancy may be due to diachrony between the tropical and subtropical Atlantic Ocean. Hilgen et al. (2000) noted the diachrony in the extinction of *P. mayeri* between the tropical Atlantic Ocean and the Mediterranean and diachrony with higher latitudes was suggested by Miller et al. (1991).

The extinction of *Paragloborotalia mayeri/siakensis* and the LO of *Neogloboquadrina acostaensis* and *Fohsella peripheroronda,* have been shown to be diachronous between the Mediterranean and equatorial Atlantic Ocean (Turco et al., 2002). We suggest that the younger calibrations through this interval may be due to further diachronism of extinction events in the Jamaican sections. Clearly, further work is required to constrain the bioevents through this interval.

Zone M11. *Globoturborotalita nepenthes / Paragloborotalia mayeri* Concurrent-range Zone (herein renamed = Zone M11 [*Globoturborotalita nepenthes/Neogloboquadrina mayeri* Concurrent Range Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Globoturborotalita nepenthes* and the HO of *Paragloborotalia mayeri*.

Magnetochronologic calibration: Subchron C5r.3r-Subchron C5n.2n.

Astronomical cycle calibration: $29_{\text{Mi-C5r}}$ - $27_{\text{Mi-C5n}}$.

Estimated age: 11.55–10.53 Ma (as per Cande and Kent, 1995); 11.63-10.46 Ma (as per Lourens et al., 2004); middle-late Miocene.

Remarks: Renamed to reflect inclusion of the species *mayeri* in the genus *Paragloborotalia*. In Table 1, we have incorporated the age established for the LAD of *Cassigerinella chipolensis* by Turco et al. (2002). This is younger than the suggested age of this event as in Chaisson and Leckie (1993) but appears to be a useful secondary event within the *Globoturborotalita nepenthes / Paragloborotalia mayeri* Concurrent-range Zone (Zone M11). The HO of *Globigerinoides subquadratus* is found to be near-synchronous between Site 926 (equatorial Atlantic Ocean, Turco et al., 2002) and the Mediterranean (Hilgen et al., 2000).

Zone M10. *Globigerinella praesiphonifera* Partial-range Zone (herein amended and renamed = Zone M10 [*Globorotalia robusta – Globoturborotalita nepenthes*

Interval Zone] of BKSA95).

Definition: Partial range of the nominate taxon between the HO of *Fohsella fohsi* and LO of *Globoturborotalita nepenthes*.

Magnetochronologic calibration: Subchron C5r.3r.

Astronomical cycle calibration: $30_{\text{Mi-C5r}}$ - $29_{\text{Mi-C5r}}$.

Estimated age: 11.71–11.55 Ma (as per Cande and Kent, 1995); 11.79-11.63 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: Amended to reflect the use of the LO of *Fohsella fohsi* rather than the LO of *Fohsella lobata* and *F. robusta* as in BKSA95. Renamed according to the convention of Berggren and Pearson (2005).

Following Turco et al. (2002), Lourens et al. (2004) revised the LAD *Globorotalia praescitula* from 11.9 (BKSA95) to 13.73 Ma. This placed the extinction of *G. praescitula* between the LOs of *F. 'praefohsi'* and *F. fohsi (s.l.)* and thus moved the extinction of *G. praescitula* from Zone M10 to M7. Initial investigations from Site U1337 (Shipboard Scientific Party, in press) suggest that the biostratigraphic events are consistent with BKSA95 and therefore we have retained the calibration of 11.9 Ma here pending further investigations.

*2.3.1. Revision of Zones M7-M9 (*Fohsella *lineage)*

One of the key lineages used in the biostratigraphic subdivision of the middle Miocene is the fohsellid lineage (usually referred to in the earlier literature as *Globorotalia fohsi* and its various subspecies). All previous work agrees that early representatives of the lineage tend to be small forms with rounded peripheries, and that there is a gradual trend through time towards larger size and more acute peripheries which eventually results in keeled forms. After this more lobate morphotypes appear, as do more robust, biconvex forms. Taxonomic subdivision of this gradual chronocline into species and subspecies is inevitably subjective, and contrasting approaches were taken by Bolli (1957b), Blow (1957), Blow and Banner (1966), Olsson (1972), Stainforth et al. (1975), Kennett and Srinivasan (1983), Bolli and Saunders (1985) and Berggren (1993). These various taxonomic schemes are necessarily mirrored in different approaches to the biostratigraphic subdivision of the middle Miocene based upon the taxa.

The biostratigraphic scheme used here (in slightly modified form; see discussion below) is that first suggested by Banner and Blow (1965), Blow and Banner (1966) and N zonal concepts of Blow (1969). This scheme capitalizes on the biostratigraphic utility of this evolutionary lineage and uses the successive first occurrences of *F. peripheroacuta* (a morphotype that has a distinctly pinched or acute periphery), *F. 'praefohsi'* (which has a incipient keel on the final one or two chambers), and *F. fohsi* (which has a well-developed keel on the final chamber and an incipient keel throughout the last whorl), and finally the extinction of the group as successive zonal boundaries. These biohorizons originally delimited Zones N10-N12 (see also Kennett and Srinivasan, 1983) and in our scheme they delimit Zones M7-M9 (Fig. 5). We have found this scheme to provide excellent biostratigraphic control in the tropical Pacific and Atlantic Oceans (Pearson, 1995; Pearson and Chaisson, 1997).

There is, however, a taxonomic problem, as highlighted by Bolli and Saunders (1985), in that the morphology of the holotype of *Globorotalia (Fohsella) praefohsi* Blow and Banner does not seem to accord well with the *concept* of the taxon as originally suggested by Blow and Banner (1966). We agree with Bolli and Saunders that the *praefohsi* holotype can be regarded as a subjective synonym of *Globorotalia lobata* Bermúdez (= *Fohsella lobata*), which is a more 'advanced' member of the lineage. The paratype, however, is more in accord with the concept of *praefohsi* as originally articulated by Blow and Banner (1966). It is also pertinent that the holotype of *praefohsi* comes from a higher stratigraphic level than the paratype (Bolli and Saunders, 1985). Pearson (1995) and Pearson and Chaisson (1997) acknowledged this problem by referring to the N11 Zone fossil informally as *Fohsella 'praefohsi'*, as we have done, thereby retaining the concept of Blow and Banner (1966) as widely used subsequently (e.g. Kennett and Srinivasan, 1983) and deferring resolution of the taxonomic problem for future work. In contrast, BKSA95 placed *praefohsi* in synonymy with *lobata* and effectively eliminated the old biostratigraphic subdivision between Zones N11 and N12. At the same time BKSA95 introduced the first alphanumeric M-zone scheme for the Miocene and used the first occurrence of the most 'advanced' of all the fohsellids, *F. robusta* as a subzone marker for the first time (delimiting their Subzones M9a and M9b).

The problem with the solution of BKSA95 is that it eliminates a proven highly useful zone fossil (*F. 'praefohsi'*) along with the biostratigraphic resolution that it provides. It is clear that detailed taxonomic revision of *praefohsi* is required, based on new SEM micrographs of the relevant types and detailed descriptions. If the holotype does indeed prove to be a synonym of *lobata*, as the illustration suggests, then it may be desirable to name a new species that accords better with the intended concept of *praefohsi*, which could then be the zone fossil for Zone M8. It may be that Blow and Banner's paratype could be used to typify such a new species, or alternatively a holotype could be taken from well-preserved and well-dated assemblages from elsewhere. Pending such a resolution, we retain the informal taxon *F. 'praefohsi'* as the zone fossil for Zone M8 basing our concept not on the holotype illustration but on Blow and Banner's original description as well as subsequent illustrated specimens that accord with that concept such as those shown by Kennett and Srinivasan (1983).

Zone M9. *Fohsella fohsi* Taxon-range Zone (herein defined, approximately equivalent to Zone N12 [*Globorotalia (G.) fohsi* Partial-range Zone] of Blow, 1969; combined Zone M9 [*Globorotalia fohsi lobata - Globorotalia fohsi robusta* Interval Zone] and Zone M8 [*Globorotalia fohsi sensu stricto* Lineage Zone] of BKSA95).

Definition: Biostratigraphic interval characterized by the total range of the nominate taxon between its LO and HO.

Magnetochronologic calibration: Chron C5ABn-Subchron C5r.3r.

Astronomical cycle calibration: $34_{\text{Mi-C5AAr}}$ - $30_{\text{Mi-C5r}}$.

Estimated age: 13.34–11.71 Ma (as per Cande and Kent, 1995); 13.41-11.79 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: The new concept of Zone M9 follows from our modification of middle Miocene zonation discussed above. The HO of *Fohsella robusta* and *F. fohsi* are estimated to be at the same stratigraphic level. However, in the astronomical calibrations based on Ceara Rise, Turco et al. (2002) did not differentiate species within the fohsellid group and Chaisson and Pearson (1997) did not comment on the HO of *F. robusta*. Therefore we use HO of *F. fohsi* to define the top of Zone M9.

Subzone M9b. *Fohsella robusta* / *Fohsella fohsi* Concurrent-range Subzone (herein amended and renamed = Subzone M9b [*Globorotalia fohsi robusta* Total Range Zone] of BKSA95; [*Globorotalia fohsi robusta* Total Range Zone] of Bolli, 1957b).

Definition: Biostratigraphic interval between the LO of *Fohsella robusta* and the HO of *Fohsella fohsi*.

Magnetochronologic calibration: Chron C5AAn-Subchron C5r.3r.

Astronomical cycle calibration: $33_{\text{Mi-C5Ar}}$ - $30_{\text{Mi-C5r.}}$

Estimated age: 13.09–11.71 Ma (as per Cande and Kent, 1995); 13.13-11.79 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: The concept of Subzone M9b follows from our modification of middle Miocene zonation discussed above.

Subzone M9a. *Fohsella fohsi* Lowest-occurrence Subzone (herein defined, equivalent to Zone M8 [*Globorotalia fohsi sensu stricto* Lineage Zone] and Subzone M9a [*Globorotalia fohsi lobata* Lineage Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Fohsella fohsi* and the LO of *Fohsella robusta*.

Magnetochronologic calibration: Chron C5ABn-Chron C5AAn.

Astronomical cycle calibration: $34_{\text{Mi-C5AAr}}$ - $33_{\text{Mi-C5Ar}}$.

Estimated age: 13.34-13.09 Ma (as per Cande and Kent, 1995); 13.41-13.13 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: The new concept of Subzone M9a follows from our modification of middle Miocene zonation discussed above. The subzone differs from the concept of Subzone M9a (*Globorotalia fohsi lobata* Lineage Zone) as per BKSA95, which was defined as the biostratigraphic interval between LO of *Fohsella lobata* and LO of *Fohsella robusta*. We have been unable to utilize the LO of *F. lobata* as Chaisson and Pearson (1997) and Turco et al. (2002) did not provide stratigraphic constraints on this taxon from Ceara Rise and therefore there is presently no astronomical calibration (Lourens et al., 2004). This is unfortunate as *F. lobata* is a distinctive and the LO of this taxon appears isochronous in low latitudes (Srinivasan and Chaturvedi, 1992).

Turco et al. (2002) provided a refined calibration for the LAD of *Cassiginella martinezpicoi* at Ceara Rise, which is consistent with studies elsewhere (Chaisson and Leckie, 1993). We have incorporated the revised age for the LAD of *Cassiginella martinezpicoi* in tables 1 and 3.

Zone M8. *Fohsella* **'*praefohsi*'** Lowest-occurrence Zone (herein defined = Zone N11 [*Globorotalia (G.) praefohsi* Consecutive-range Zone] of Blow, 1969; and the upper part of Zone M7 [*Globorotalia peripheroacuta* Lineage Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of the nominate taxon *Fohsella 'praefohsi'* and the LO of *Fohsella fohsi*.

Magnetochronologic calibration: Chron C5ACn-Chron C5ABn.

Astronomical cycle calibration: $35_{\text{Mi-C5ABr}}$ - $34_{\text{Mi-C5AAr}}$.

Estimated age: 13.74–13.34 Ma (as per Cande and Kent, 1995); 13.77-13.41 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: The new concept of Zone M8 follows from our modification of middle Miocene zonation discussed above.

Zone M7. *Fohsella peripheroacuta* Lowest-occurrence Zone (herein defined = Zone N10 [*Globorotalia (Turborotalia) peripheroacuta* Consecutive-range Zone] of Blow, 1969; and the lower part of Zone M7 [*Globorotalia peripheroacuta* Lineage Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of the nominate taxon *Fohsella peripheroacuta* and the LO of *Fohsella 'praefohsi'*.

Magnetochronologic calibration: Chron C5ADn-Chron C5ACn.

Astronomical cycle calibration: $36_{\text{Mi-C5ACn}}$ - $35_{\text{Mi-C5ABr}}$.

Estimated age: 14.23–13.74 Ma (as per Cande and Kent, 1995); 14.24-13.77 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: The new concept of Zone M7 follows from our modification of middle Miocene zonation discussed above. Turco et al. (2002) provided a refined calibration for the LAD *Globorotalia archeomenardii* at Ceara Rise, which is consistent with studies elsewhere (Chaisson and Leckie, 1993). We have incorporated the refined calibration for the LAD *Globorotalia archeomenardii* in tables 1 and 3.

Zone M6. *Orbulina suturalis* Lowest-occurrence Zone (herein renamed = Zone M6 [*Globorotalia peripheroronda* Partial-range Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Orbulina suturalis* and the LO of *Fohsella peripheroacuta*.

Magnetochronologic calibration: Subchron C5Bn.2n-Chron C5ADn.

Astronomical cycle calibration: $38_{\text{Mi-C5Bn}}$ - $36_{\text{Mi-C5ACn}}$.

Estimated age: 15.10-14.23 Ma (as per Cande and Kent, 1995); 15.10-14.24 Ma (as per Lourens et al., 2004); middle Miocene.

Remarks: Because of the rarity of *Orbulina* at the beginning of its range at Ceara Rise (Pearson and Chaisson, 1997) we have retained the age estimate from BKSA95. The Zone is renamed according to the convention of Berggren and Pearson (2005).

Zone M5. *Praeorbulina sicana* Lowest-occurrence Zone (herein renamed = Zone M5 [*Praeorbulina sicana* – *Orbulina suturalis* Interval Zone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Praeorbulina sicana* and the LO of *Orbulina suturalis*.

Magnetochronologic calibration: Subchron C5Cn.2n-Subchron C5Bn.2n.

Astronomical cycle calibration: $41_{\text{Mi-C5Cn}}$ - $38_{\text{Mi-C5Bn}}$.

Estimated age: 16.40-15.10 Ma (as per Cande and Kent, 1995); 16.38-15.10 Ma (as per Lourens et al., 2004); early-middle Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005). We follow the criterion of Jenkins et al. (1981) for the identification of *sicana*, see also discussion in Kennett and Srinivasan (1983) and Pearson (1995).

Subzone M5b. *Praeorbulina glomerosa* Lowest-occurrence Subzone (herein renamed = Subzone M5b [*Praeorbulina glomerosa sensu stricto* – *Orbulina suturalis* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Praeorbulina glomerosa* and the LO of *Orbulina suturalis*.

Magnetochronologic calibration: Subchron C5Cn.1r-Subchron C5Bn.2n.

Astronomical cycle calibration: $41_{\text{Mi-C5Cn}}$ - $38_{\text{Mi-C5Bn}}$.

Estimated age: 16.29-15.10 Ma (as per Cande and Kent, 1995); 16.27-15.10 Ma (as per Lourens et al., 2004); early-middle Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Subzone M5a. *Praeorbulina sicana* Lowest-occurrence Subzone (herein renamed = Subzone M5a [*Praeorbulina sicana* - *Praeorbulina glomerosa sensu stricto* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Praeorbulina sicana* and the LO of *Praeorbulina glomerosa*.

Magnetochronologic calibration: Subchron C5Cn.2n-Subchron C5Cn.1r.

Astronomical cycle calibration: $41_{\text{Mi-C5Cn}}$.

Estimated age: 16.40-16.29 Ma (as per Cande and Kent, 1995); 16.38-16.27 Ma (as per

Lourens et al., 2004); early Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Zone M4. *Globigerinoides bisphericus* Partial-range Zone (herein renamed = Zone M4 [*Catapsydrax dissimilis* - *Praeorbulina sicana* Interval Subzone] of BKSA95).

Definition: Partial range of the nominate taxon between the HO of *Catapsydrax dissimilis* and the LO of *Praeorbulina sicana*.

Magnetochronologic calibration: Chron C5Dr-Subchron C5Cn.2n.

Astronomical cycle calibration: $44_{\text{Mi-C5Dn}}$ - $41_{\text{Mi-C5Cn}}$.

Estimated age: 17.62-16.40 Ma (as per Cande and Kent, 1995); 17.54-16.38 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Subzone M4b. *Fohsella birnageae* Lowest Occurrence Subzone (herein renamed = Subzone M4b [*Globigerinoides bisphericus* Partial-range Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Fohsella birnageae* and the LO of *Praeorbulina sicana*.

Magnetochronologic calibration: Subchron C5Cn.3n-Subchron C5Cn.2n.

Astronomical cycle calibration: $42_{\text{Mi-C5Cn}}$ - $41_{\text{Mi-C5Cn}}$.

Estimated age: 16.70-16.40 Ma (as per Cande and Kent, 1995); 16.69-16.38 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Renamed according to the convention of Berggren and Pearson (2005).

Subzone M4a. *Dentoglobigerina venezuelana* Partial-range Subzone (herein renamed = Subzone M4a [*Catapsydrax dissimilis* – *Globorotalia birnageae* Interval Subzone] of BKSA95).

Definition: Partial range of the nominate taxon between the HO of *Catapsydrax dissimilis* and the LO of *Globorotalia birnageae.*

Magnetochronologic calibration: Chron C5Dr-Subchron C5Cn.3n.

Astronomical cycle calibration: $44_{\text{Mi-C5Dn}}$ - $42_{\text{Mi-C5Cn.}}$

Estimated age: 17.62-16.70 Ma (as per Cande and Kent, 1995); 17.54-16.69 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Srinivasan and Chaturvedi (1992) point out the usefulness of the HO of *Catapsydrax dissimilis* as a dissolution resistant form recorded in sites from the tropics to the subantarctic. The HO of *C. dissimilis* is interpolated to within Chron C5Dr. This is consistent with studies at Site 608 (Miller et al., 1991), but inconsistent with Sites 516 and 558 where the HO of this species is reported within C5Dn (Berggren et al., 1983). Further work is required to confirm the age derived from Ceara Rise (Shackleton et al., 1999). Renamed according to the convention of Berggren and Pearson (2005).

2.3.2. Globigerinatella *spp. and* G. insueta

Cushman and Stainforth (1945) initially described the genus *Globigerinatella* from the Cipero Formation of Trinidad, with *G. insueta* as its only species, and used its first occurrence as the marker for the base of their *Globigerinatella insueta* Zone. The first occurrence of *G. insueta* remained a key zonal boundary through a number of subsequent, more highly subdivided biostratigraphic schemes (e.g. Bolli, 1957b; Banner and Blow, 1965; Blow 1969; Kennett and Srinivasan, 1984; Bolli and Saunders, 1985).

Chaisson and Leckie (1993) were the first to describe distinct evolutionary trends in *Globigerinatella* based on their observations at ODP Site 806 on the Ontong Java Plateau, western tropical Pacific Ocean. They observed that the number of areal apertures tends to increase up section and that in the more advanced forms the apertures tend to be localized in patches on the test. Pearson (1995) described and illustrated similar evolutionary trends in specimens from ODP Sites 871 and 873 in the Marshall Islands region of the western tropical Pacific Ocean. He also observed that the earliest representatives of *Globigerinatella* all lack supplementary apertures, an observation that was confirmed by Pearson and Chaisson (1997) from ODP Sites 925 and 926 on the Ceara Rise, western tropical Atlantic Ocean.

Pearson (1995) suggested that evolutionary trends in *Globigerinatella* might be useful for the biostratigraphic subdivision of the lower Miocene, an interval which is otherwise problematic for planktonic foraminifer biostratigraphy. He suggested splitting *Globigerinatella* into two taxa based on the presence or absence of areal apertures. From observations made on Cushman and Stainforth's (1945) type material at the US National Museum, Pearson (1995) reported that the holotype and all paratypes of *G. insueta* possess areal apertures, even though they were not mentioned in the original description and are not visible on all the type illustrations. Hence forms with areal apertures were included by Pearson (1995) and subsequently by Pearson and Chaisson (1997) in *G. insueta sensu stricto* and forms without were included as *Globigerinatella* sp. Pearson (1995) and Pearson and Chaisson (1997) suggested that the 'chambers' of *Globigerinatella* that possess areal and/or multiple sutural apertures are homologous with the bullae of *Globigerinita* spp., and that *Globigerinita* was the ancestral form (see also the ontogenetic studies of Bronnimann, 1951, and comments in Bolli and Saunders, 1985). The wall texture of *Globigerinatella* shows a typical microperforate structure identical to that seen in *Globigerinita* and *Tenuitella* (Pearson, 1995; Pearson and Wade, 2009). The evolution of *Globigerinatella* involved the development of highly swollen bullae which, critically, themselves have bullae superimposed upon them, the process being potentially repeated several times during the ontogeny of a single individual. The early growth stage is essentially identical to *Globigerinita,* such that it is only in the adult form that the diagnostic characters become clear. This being the case, designation of an individual to the genus *Globigerinatella* requires the presence of at least one additional bulla superimposed on the bulla-like chamber that is typical of adult *Globigerinita* (see also Bolli and Saunders, 1985, p. 189).

In evolutionary time, there appears to have been a trend in some *Globigerinita* toward more globular test shapes with large inflated bullae that eventually resulted in forms with more than one superimposed bulla; these are the first *Globigerinatella* sp. Only later did areal apertures evolve (the first *G. insueta sensu stricto*), initially as single apertures on the chamber wall (Pearson, 1995), then increasing in number and organization until over 60 apertures can be counted on the final chamber. The same trend has been observed in both the tropical Pacific Ocean (Chaisson and Leckie, 1993; Pearson, 1995) and tropical Atlantic Ocean (Pearson and Chaisson, 1997). The 'calibration' for the first occurrence of *Globigerinatella insueta* in BKSA95 was given as 18.8 Ma, although this was "inferred inasmuch as there is no direct calibration for the FAD of *G. insueta* at present", nor were BKSA95 aware of the gradual evolution described above.

Of the sites that have so far shown the full evolutionary lineage, the Atlantic Ocean site (Ceara Rise) provides the best opportunity for calibrating the successive first appearances of *Globigerinatella* sp. and *G. insueta sensu stricto*, although it is unfortunate that no magnetostratigraphy is available for them. Pearson and Chaisson (1997) calibrated the events at 20.2 Ma and 17.4 Ma respectively, based on interpolation between other foraminifera and nannofossil datums in the age models for ODP Sites 925 and 929. Of the two *Globigerinatella* FADs, the most useful for re-defining the M2/M3 Zone boundary (=N5/N6 Zone boundary in older schemes) is *Globigerinatella* sp., as there is only a short interval of time (~50 kyr) between the FAD of *G. insueta sensu stricto* and the LAD of *Catapsydrax dissimilis* which marks the M3/M4 (=N6/N7) Zone boundary (see also Pearson, 1995). We therefore revise the zonal definition of Zone M3 to utilize the LO of *Globigerinatella* sp.

Zone M3. *Globigerinatella* sp. / *Catapsydrax dissimilis* Concurrent-range Zone

(herein defined, equivalent to Zone M3 [*Globigerinatella insueta/ Catapsydrax dissimilis* Concurrent-range Zone] and upper part of Zone M2 [*Catapsydrax dissimilis* Partial-range Zone] of BKSA95).

Definition: Concurrent range of the nominate taxon between the LO of *Globigerinatella* sp. and the HO of *Catapsydrax dissimilis*.

Magnetochronologic calibration: Chron C6n-Chron C5Dr.

Astronomical cycle calibration: $48_{\text{Mi-C6n}}$ - $44_{\text{Mi-C5Dn}}$.

Estimated age: 19.66–17.62 Ma (as per Cande and Kent, 1995); 19.30-17.54 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: The new concept of Zone M3 follows from developments in the understanding of the *Globigerinatella* lineage (discussed above). Within the *Globigerinatella* sp./ *Catapsydrax dissimilis* Concurrent-range Zone (Zone M3) the LO of *Globigerinatella insueta* has been revised from ~18.8 Ma (BKSA95) to 17.69 Ma (interpolated from Pearson and Chaisson, 1997). The younger age of the LO of *G. insueta* is supported by studies from Site 1148 (South China Sea, Li et al., 2004), though unfortunately there is no magnetostratigraphy through this interval.

Zone M2. *Globoquadrina binaiensis* Partial-range Zone (herein amended = lower part of Zone M2 [*Catapsydrax dissimilis* Partial-range Zone] of BKSA95).

Definition: Partial-range of the nominate taxon between the HO of '*Paragloborotalia*' *kugleri* and the LO of *Globigerinatella* sp.

Magnetochronologic calibration: Chron C6AAn-Chron C6n.

Astronomical cycle calibration: $53_{\text{Mi-C6Ar}}$ - $48_{\text{Mi-C6n}}$.

Estimated age: 21.81–19.66 Ma (as per Cande and Kent, 1995); 21.12-19.30 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: The new concept of Zone M2 follows from developments in the understanding of the *Globigerinatella* lineage (discussed above). We provisionally refer to *kugleri* and *pseudokugleri* as '*Paragloborotalia'* pending further investigations of these taxa (see Pearson and Wade, 2009 for discussion).

Zone M1. '*Paragloborotalia' kugleri* Taxon-range Zone (herein renamed = Zone M1 [*Globorotalia kugleri* Total Range Zone] of BKSA95).

Definition: Total range of the nominate taxon.

Magnetochronologic calibration: Subchron C6Cn.2n-Chron C6AAn.

Astronomical cycle calibration: $57_{\text{Mi-C6Cn}}$ - $53_{\text{Mi-C6Ar}}$.

Estimated age: 23.73–21.81 Ma (as per Cande and Kent, 1995); 22.96-21.12 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Renamed to accord with assignment of the species *kugleri* to the temporary genus '*Paragloborotalia*'.

Subzone M1b. *Globoquadrina dehiscens* / '*Paragloborotalia' kugleri* Concurrent-range Subzone (herein renamed = Subzone M1b [*Globorotalia kugleri/Globoquadrina dehiscens* Concurrent-range Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Globoquadrina dehiscens* and the HO of '*Paragloborotalia' kugleri*.

Magnetochronologic calibration: Chron C6Br-Chron C6AAn.

Astronomical cycle calibration: $56_{\text{Mi-C6Bn}}$ - $53_{\text{Mi-C6Ar}}$.

Estimated age: 23.20–21.81 Ma (as per Cande and Kent, 1995); 22.44-21.12 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Renamed to accord with assignment of the species *kugleri* to the temporary genus '*Paragloborotalia*'.

Subzone M1a. '*Paragloborotalia*' *kugleri* Lowest-occurrence Subzone (herein renamed = Subzone M1a [*Globigerinoides primordius* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of '*Paragloborotalia*' *kugleri* and the LO of *Globoquadrina dehiscens*.

Magnetochronologic calibration: Subchron C6Cn.2n-Chron C6Br.

Astronomical cycle calibration: $57_{\text{Mi-C6Cn}}$ - $56_{\text{Mi-C6Bn}}$.

Estimated age: 23.73–23.20 Ma (as per Cande and Kent, 1995); 22.96-22.44 Ma (as per Lourens et al., 2004); early Miocene.

Remarks: Renamed to accord with assignment of the species *kugleri* to the genus '*Paragloborotalia*'.

3.3. Oligocene/Miocene Boundary

The closest planktonic foraminiferal biostratigraphic event to the Oligocene/Miocene Boundary is the LO of '*Paragloborotalia*' *kugleri*. Our recalibrated age from Ceara Rise (Pearson and Chaisson, 1997) of FAD '*P*'. *kugleri* is 23.73 Ma. This is 70 kyr younger than the previously published age in BKSA95 but is very consistent with studies from the Lemme-Carrosio Section, where the LO of '*P*'. *kugleri* is within Subchron C6Cn.2n (Steininger et al., 1997). Thus the uppermost Oligocene Zone O7 (this study; Zone O6 as per Berggren and Pearson, 2005) extends into the Miocene and reflects the short stratigraphic interval between the base of the Miocene as designated by the base of Subchron C6Cn.2n and the LO of '*P'. kugleri*.

3. Paleogene Period

For the Paleogene Period all zonal concepts have remained consistent with Berggren and Pearson (2005), except Zone O6 which we have amended and added Zone O7. The adjustments to the Paleogene magnetobiochronology are minor and mainly exhibit revised magnetostratigraphic calibrations. We have updated the calibrated ages of *Paragloborotalia opima* and *Chiloguembelina cubensis* as per Wade et al. (2007) which have slightly modified the duration of Biochrons O5 and O6. In addition we provide datum events calibrated to the ATS of Pälike et al. (2006) to Zone E11. We have not attempted to incorporate tuned ages from Ceara Rise for the Oligocene (Pearson and Chaisson, 1997; Shackleton et al., 1999), because of the significant differences in the age estimates between Site 925 and 929 (Shackleton et al., 1999, p. 1926). Substantial revisions occur in the early-mid Eocene (see below).

3.1. Amendment to the Oligocene O Zones

Zone O7. '*Paragloborotalia*' *pseudokugleri* Lowest-occurrence Zone (herein defined = upper part of Zone O6 [*Globigerina ciperoensis* Partial-range Zone] of Berggren and Pearson, 2005).

Definition: Biostratigraphic interval between the LO of the nominate taxon '*Paragloborotalia' pseudokugleri* and the LO of '*Paragloborotalia' kugleri*.

Magnetochronologic calibration: Subchron C8n.1n-Subchron C6Cn.2n.

Astronomical cycle calibration: $63_{Ol\text{-}C7Ar}$ - $57_{Mi\text{-}C6Cn}$.

Estimated age: 25.9–23.73 Ma (as per Cande and Kent, 1995); 25.4-22.96 Ma (as per Gradstein et al., 2004); 25.2 (as per Pälike et al., 2006) -22.96 Ma (as per Lourens et al., 2004); late Oligocene-earliest Miocene.

Remarks: The recalibration of the LAD *Paragloborotalia opima* from 27.1 Ma (BKSA95) to 27.5 Ma (Wade et al., 2007) has resulted in an increase in the duration of Biochron O6 as per Berggren and Pearson (2005) from 3.3 to 3.7 myr. The FAD of '*P*'. *pseudokugleri* allows greater resolution for this interval. We have subdivided the interval between HO *P. opima* and LO '*P*'. *kugleri*, using the LO of '*P*'. *pseudokugleri* resulting in a shorter duration of Biochron O6 and the introduction of Zone O7.

The age of the FAD of '*Paragloborotalia*' *pseudokugleri* in BKSA95 is derived from Hole 803D and Hole 628A (Leckie et al., 1993), where this bioevent was recorded within Chron C8n and Chron C7n, respectively. Further support for the stratigraphic utility of '*P*'. *pseudokugleri* come from sites drilled during ODP Leg 115 (Premoli Silva and Spezzaferri, 1990), ODP Leg 208 (Shipboard Scientific Party, 2004) and Site 1148 (Li et al., 2004); unfortunately, these sites either do not have magnetostratigraphy through this interval or the magnetostratigraphy is ambiguous. Although this taxon is rare at Site 1218 (equatorial Pacific Ocean), the LO of '*P*'. *pseudokugleri* at 121.56 ± 0.61 meters composite depth is within Subchron C8n.1n (Shipboard Scientific Party, 2002), consistent with the age estimate in BKSA95.

Zone O6. *Globigerina ciperoensis* Partial-range Zone (herein amended = lower part of

Zone O6 [*Globigerina ciperoensis* Partial-range Zone] of Berggren and Pearson, 2005).

Definition: Biostratigraphic interval characterized by the partial-range of the nominate taxon, between the HO of *Paragloborotalia opima* and the LO of '*Paragloborotalia*' *pseudokugleri*.

Magnetochronologic calibration: Chron C9n-Subchron C8n.1n.

Astronomical cycle calibration: $67_{\text{Ol-C9n}}$ - $63_{\text{Ol-C7Ar}}$.

Estimated age: 27.5–25.9 Ma (as per Cande and Kent, 1995); 27.3-25.4 Ma (as per Luterbacher et al., 2004); 26.9-25.2 Ma (as per Pälike et al., 2006); late Oligocene.

Remarks: See discussion above.

Zone O5. *Paragloborotalia opima* Highest-occurrence Zone

Definition: Biostratigraphic interval between the highest common occurrence (HCO) of *Chiloguembelina cubensis* and the HO of the nominate taxon *Paragloborotalia opima*.

Magnetochronologic calibration: Subchron C10n.1n-Chron C9n.

Astronomical cycle calibration: $70_{\text{Ol-C10n}}$ - $67_{\text{Ol-C9n}}$.

Estimated Age: 28.4–27.5 Ma (as per Cande and Kent, 1995); 28.3-27.3 Ma (as per Luterbacher et al., 2004); 28.0-26.9 Ma (as per Pälike et al., 2006); late Oligocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005). Coccioni et al. (2008) have confirmed that the HCO of *C. cubensis* is a robust stratigraphic marker for the Oligocene. The age of the LAD of *P. opima* and LAD of *C. cubensis* have been revised as per Wade et al. (2007).

Zone O4. *Globigerina angulisuturalis / Chiloguembelina cubensis* Concurrent-range Zone

Definition: Concurrent range of the nominate taxa between the LO of *Globigerina angulisuturalis* and the HCO of *Chiloguembelina cubensis*.

Magnetochronologic calibration: Subchron C11n.1n-C10n.1n.

Astronomical cycle calibration: $73_{Ol\text{-}C10r}$ - $70_{Ol\text{-}C10n}$.

Estimated age: 29.4–28.4 Ma (as per Cande and Kent, 1995); 29.5-28.3 Ma (as per Luterbacher et al., 2004); 29.2-28.0 Ma (as per Pälike et al., 2006); early Oligocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005). The FAD of *Globigerina angulisuturalis* has been recorded in Chron C11n.1n in DSDP Holes 516F (Rio Grande Rise, South Atlantic Ocean; Berggren et al., 1985) and Site 558 (North Atlantic Ocean; Miller et al., 1985) and (somewhat equivocally) in C11n.1n in ODP Holes 628A (Little Bahama Bank, North Atlantic Ocean) and 803D (Ontong Java Plateau, western Pacific Ocean; Leckie et al., 1993; see also BKSA95; p. 173, Table 10). More recently in the Contessa, Monte Cagnero and Pieve d'Accinelli sections in the Umbria-Marche Basin, Italy, Coccioni et al. (2008) have recorded the FAD of *G. angulisuturalis* approximately 400 kyr younger, within mid-Chron C10r. The discrepancy may lie in preservational bias or diachrony between the open ocean and Tethys. We retain the calibration of C11n.1n (BKSA95) in this work pending further investigations.

Zone O3. *Dentoglobigerina sellii* Partial-range Zone

Definition: Partial range of the nominate taxon between the HO of *Turborotalia ampliapertura* and the LO of *Globigerina angulisuturalis*.

Magnetochronologic calibration: Chron C11r-Subchron C11n.1n.

Astronomical cycle calibration: $76_{\text{Ol-C11r}}$ - $73_{\text{Ol-C10r}}$.

Estimated age: 30.3–29.4 Ma (as per Cande and Kent, 1995); 30.4-29.5 Ma (as per Luterbacher et al., 2004); 30.3-29.2 Ma (as per Pälike et al., 2006); early Oligocene.

Remarks: The nomenclature and definition of the zone remains the same as in BKSA95 and Berggren and Pearson (2005).

Zone O2. *Turborotalia ampliapertura* Highest-occurrence Zone

Definition: Biostratigraphic interval between the HO of *Pseudohastigerina naguewichiensis* and the HO of the nominate taxon *Turborotalia ampliapertura*.

Magnetochronologic calibration: Chron C12r- Chron C11r.

Astronomical cycle calibration: $80_{\text{Ol-C12r}}$ - $76_{\text{Ol-C11r}}$.

Estimated age: 32.0–30.3 Ma (as per Cande and Kent, 1995); 32.2-30.4 Ma (as per Luterbacher et al., 2004); 32.0-30.3 Ma (as per Pälike et al., 2006); early Oligocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone O1. *Pseudohastigerina naguewichiensis* Highest-occurrence Zone

Definition: Biostratigraphic interval between HO of *Hantkenina alabamensis* and HO of the nominate taxon *Pseudohastigerina naguewichiensis* (Berggren and Pearson, 2005).

Magnetochronologic calibration: Chron C13r-Chron C12r.

Astronomical cycle calibration: $84_{Ol\text{-}C13n}$ - $80_{Ol\text{-}C12r}$.

Estimated age: 33.7–32.0 Ma (as per Cande and Kent, 1995); 33.9-32.2 Ma (as per Luterbacher et al., 2004); 33.8-32.0 Ma (as per Pälike et al., 2006); early Oligocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

3.2. Amendment to the Eocene E Zones

Zone E16. *Hantkenina alabamensis* Highest-occurrence Zone

Definition: Partial range of the nominate taxon between the HO of *Globigerinatheka index* and the HO of *Hantkenina alabamensis*.

Magnetochronologic calibration: Chron C13r-Chron C12r.

Astronomical cycle calibration: $86_{Eo\text{-}C13r}$ - $84_{Ol\text{-}C13n}$.

Estimated age: 34.3-33.7 Ma (as per Cande and Kent, 1995); 34.5-33.9 Ma (as per Luterbacher et al., 2004); 34.5-33.8 Ma (as per Pälike et al., 2006); late Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005). We have added the HCO of *Pseudohastigerina micra* as a secondary marker for the Eocene/Oligocene boundary. *Pseudohastigerina micra* is common in upper Eocene sediments, and this form undergoes a significant size decrease coeval with the extinction of *Hantkenina* (Wade and Pearson, 2008; Wade and Olsson, 2009). This event appears to be coeval between the Indian Ocean (Wade and Pearson, 2008) and the Gulf of Mexico (Miller et al., 2008).

Zone E15. *Globigerinatheka index* Highest-occurrence Zone

Definition: Biostratigraphic interval between the HO of *Globigerinatheka semiinvoluta* and the HO of the nominate taxon *Globigerinatheka index*.

Magnetochronologic calibration: Subchron C16n.2n-Chron C13r.

Astronomical cycle calibration: $89_{Eo\text{-}C16n}$ - $86_{Eo\text{-}C13r.}$

Estimated age: 35.8-34.3 Ma (as per Cande and Kent, 1995); 35.8-34.5 Ma (as per Luterbacher et al., 2004); 35.8-34.5 Ma (as per Pälike et al., 2006); late Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E14. *Globigerinatheka semiinvoluta* Highest-occurrence Zone

Definition: Biostratigraphic interval between the HO of *Morozovelloides crassatus* and the HO of the nominate taxon, *Globigerinatheka semiinvoluta*.

Magnetochronologic calibration: Subchron C17n.3n- Subchron C16n.2n.

Astronomical cycle calibration: $95_{Eo\text{-}C17n}$ - $89_{Eo\text{-}C16n.}$

Estimated age: 38.0-35.8 Ma (as per Cande and Kent, 1995); 37.7-35.8 Ma (as per Luterbacher et al., 2004); 38.1-35.8 Ma (as per Pälike et al., 2006); middle-late Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E13. *Morozovelloides crassatus* Highest-occurrence Zone

Definition: Biostratigraphic interval between the HO of *Orbulinoides beckmanni* and the HO of the nominate taxon, *Morozovelloides crassatus*.

Magnetochronologic calibration: Subchron C18n.2n-Subchron C17n.3n.

Astronomical cycle calibration: $100_{\text{Eo-C18r}}$ - $95_{\text{Eo-C17n}}$.

Estimated age: 40.0-38.0 Ma (as per Cande and Kent, 1995); 39.4-37.7 Ma (as per Luterbacher et al., 2004); 40.0-38.1 Ma (as per Pälike et al., 2006); middle Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2006).

Zone E12. *Orbulinoides beckmanni* Taxon-range Zone

Definition: Total range of the nominate taxon between its LO and HO.

Magnetochronologic calibration: Chron C18r- Subchron C18n.2n.

Astronomical cycle calibration: $102_{\text{Eo-C18r}}$ - $100_{\text{Eo-C18r}}$.

Estimated age: 40.5-40.0 Ma (as per Cande and Kent, 1995); 39.8-39.4 Ma (as per Luterbacher et al., 2004); 40.8-40.0 Ma (as per Pälike et al., 2006); middle Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005). Note there are significant differences in the duration of this biochron depending upon which time scale is used. Recent studies have suggested that the LO of *Orbulinoides beckmanni* is diachronous (K. Edgar pers.comm.) and the HO in low latitudes is younger than previous calibrations (Luciani et al., 2010).

Zone E11. *Morozovelloides lehneri* Partial-range Zone

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of *Guembelitrioides nuttalli* and the LO of *Orbulinoides beckmanni*.

Magnetochronologic calibration: Chron C19r-Chron C18r.

Estimated age: 42.3-40.5 Ma (as per Cande and Kent, 1995); 41.4-39.8 Ma (as per Luterbacher et al., 2004); middle Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2006). The age of the HO of *Guembelitrioides nuttalli* in not well constrained and requires further study.

Zone E10. *Acarinina topilensis* Partial-range Zone

Definition: Partial range of the nominate taxon between the HO of *Morozovella aragonensis* and the HO of *Guembelitrioides nuttalli*

Magnetochronologic calibration: Chron C20n-Chron C19r.

Estimated age: 43.6-42.3 Ma (as per Cande and Kent, 1995); 42.6-41.4 Ma (as per Luterbacher et al., 2004); middle Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

3.2.1. Early-middle Eocene

Owing to the pervasive occurrence of chert in the early and middle Eocene (Muttoni and Kent, 2007), the interval corresponding to 50-44 Ma (late Ypresian-early Lutetian) and the lower/middle Eocene boundary has often proved difficult to recover in deep sea cores. This has significantly hampered the correlations of planktonic foraminiferal bioevents to the GPTS through this interval. The basal zone of the middle Eocene has traditionally been recognized by the lowest occurrence of *Hantkenina* (Bolli, 1957a, b, 1966; Berggren et al., 1985, BKSA95) which was calibrated by Lowrie et al. (1982) to within

Chron C22n. Due to inconsistencies between the nannofossil and planktonic foraminiferal biostratigraphies, Pearson et al. (2004) suggested that the initial appearance of *Hantkenina* was diachronous. Therefore Berggren and Pearson (2005) used the LO of *Guembelitrioides nuttalli* as the base of Zone E8 corresponding to the lower/middle Eocene (Ypresian-Lutetian) boundary.

In a detailed magnetobiostratigraphic study of an expanded lower-middle Eocene succession from the western Pyrenees, Payros et al. (2007) examined the divergence of planktonic foraminiferal Zones P9 and P10 and the standard zonation (BKSA95). Unlike BKSA95 which places the boundary between planktonic foraminiferal Zones P9 and P10 within calcareous nannofossil Zone NP14 (Subzone CP12a) and magnetic polarity Chrons C22n and C21r, they found the boundary to occur within Zone NP15 (= Zone CP13) and Chron C20r. This is consistent with the biostratigraphic results of Pearson et al. (2004) from Tanzania. Rögl and Egger (2010) have recently corroborated this by recognizing the evolutionary transition of *Clavigerinella* to *Hantkenina* in the upper part of Zone NP15b. The P9/P10 zonal boundary is therefore a surprising 3.1 myr younger than in BKSA95. The significantly younger calibrations for the LO of *Hantkenina* and *Guembelitrioides nuttalli* are also confirmed by Ortiz et al. (2008) and Larrasoaña et al. (2008) from the Agost section in Spain. Payros et al. (2007) used the Luterbacher et al. (2004) time scale, here we recalibrate the FAD of *Globigerinatheka kugleri*, *Hantkenina singanoae, Guembelitrioides nuttalli* and *Turborotalia frontosa* to Cande and Kent (1995), resulting in FADs of 44.4, 44.5, 46.4 and 49 Ma, respectively (Fig. 2c, Fig. 6, Table 1). This has major implications for the durations of Biochrons E7, E8 and E9 (Fig.

2c).

The revised FAD of *H. singanoae* (Payros et al., 2007) is younger than the previously accepted age of the FAD of *G. kugleri* (as per BKSA95). However, in Tanzania Drilling Project Site 2 and 20 (Nicholas et al., 2006) a short interval exists between these events, equivalent to about 100 kyr (Fig. 6) and suggests a revised age of ~44.4 for the FAD of *G. kugleri*.

The changes in the biochronology through this interval has resulted in the duration of Biochron E7 changing from 1.4 to 4 myr. Payros et al., (2007, 2009) point out the stratigraphic utility of the LO of *Turborotalia frontosa*. Following the earlier zonation of Blow (1979), we have used this event to subdivide Zone E7 into Subzones E7a and E7b (Fig. 2c, Fig. 4c, Fig. 6). Note the E7a/E7b subzonal boundary (this study) is not the same criterion as the E7/E8 zonal boundary of Berggren and Pearson (2005), although on Cande and Kent (1995) magnetochronology, our age for the E7a/E7b subzonal boundary is similar to the value of the E7/E8 zonal boundary in Berggren and Pearson (2005).

There is at present a proposal to define/place the GSSP for the base of the Lutetian Stage (base middle Eocene) at a level equivalent the LO of *Blackites inflatus* (mid-Zone NP14=CP12a/b boundary) within Chron C21r ~47.76 Ma (as per Gradstein et al., 2004) at the Gorrondatxe section, Biscaye Province, Spain (Molina et al., in press). This level is younger than the FAD of *Turborotalia frontosa* and within sub-biochron E7b.

Zone E9. *Globigerinatheka kugleri / Morozovella aragonensis* Concurrent-range Zone

Definition: Concurrent range of the nominate taxa between the LO of *Globigerinatheka kugleri* and the HO of *Morozovella aragonensis*.

Magnetochronologic calibration: Chron C20r (estimated)-Chron C20n.

Estimated age: 44.4-43.6 Ma (as per Cande and Kent, 1995); 43.4-42.6 Ma (as per Luterbacher et al., 2004); middle Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005). The age of the LO of *Globigerinatheka kugleri* in not well constrained and there is a significant need for further study of this interval in continuous sections with magnetostratigraphy (see discussion above).

Zone E8. *Guembelitrioides nuttalli* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Guembelitrioides nuttalli* and the LO of *Globigerinatheka kugleri*.

Magnetochronologic calibration: Chron C21n-Chron C20r (estimated).

Estimated age: 46.4-44.4 Ma (as per Cande and Kent, 1995); 45.5-43.4 Ma (as per Luterbacher et al., 2004); middle Eocene.

Remarks: While the nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005), the duration and boundary ages of the biochron have changed significantly (see discussion above). Payros et al. (2007) find the LO of *Guembelitrioides nuttalli* in upper Chron C21n. However, a slightly younger level within Chron C20r was found by Larrasoaña et al. (2008).

Zone E7. *Acarinina cuneicamerata* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Acarinina cuneicamerata* and the LO of *Guembelitrioides nuttalli*.

Magnetochronologic calibration: Chron C22r (estimated) to Chron C21n.

Estimated age: 50.4–46.4 Ma (as per Cande and Kent, 1995); 50.3-45.5 Ma (as per Luterbacher et al., 2004); early-middle Eocene.

Remarks: The definition of this zone remains the same as in Berggren and Pearson (2005), however, the estimated duration of the biochron is much longer because of recalibration of the LO of *Guembelitrioides nuttalli* (Payros et al., 2007).

Subzone E7b. *Turborotalia frontosa* Lowest-occurrence Subzone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Turborotalia frontosa* and the LO of *Guembelitrioides nuttalli*.

Magnetochronologic calibration: Chron C21r to Chron C21n.

Estimated age: 49.0–46.4 Ma (as per Cande and Kent, 1995); 48.6-45.5 Ma (as per Luterbacher et al., 2004); middle Eocene.

Remarks: Zone E7 has been subdivided based on the LO of *Turborotalia frontosa* (Payros et al., 2007). See discussion in Berggren and Miller (1988) regarding previous use of *T. frontosa* as a zonal marker

Subzone E7a. *Acarinina cuneicamerata* Lowest-occurrence Subzone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Acarinina* *cuneicamerata* and the LO *Turborotalia frontosa*.

Magnetochronologic calibration: Chron C22r-Chron C21r.

Estimated age: 50.4–49.0 Ma (as per Cande and Kent, 1995); 50.3-48.6 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: Zone E7 has been subdivided based on the LO of *Turborotalia frontosa* (Payros et al., 2007).

Zone E6. *Acarinina pentacamerata* Partial-range Zone

Definition: Partial range of the nominate taxon between the HO of *Morozovella subbotinae* and the LO of *Acarinina cuneicamerata*.

Magnetochronologic calibration: Subchron 23n.1n-Chron C22r.

Estimated age: 50.8-50.4 Ma (as per Cande and Kent, 1995); 50.8-50.3 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E5. *Morozovella aragonensis / Morozovella subbotinae* Concurrent-range Zone

Definition: Concurrent range of the nominate taxa between the LO of *Morozovella aragonensis* and the HO of *Morozovella subbotinae*.

Magnetochronologic calibration: Chron C23r-Subchron C23n.1n.

Estimated age: 52.3-50.8 Ma (as per Cande and Kent, 1995 and Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E4. *Morozovella formosa* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Morozovella formosa* and the LO of *Morozovella aragonensis*.

Magnetochronologic calibration: Chron C24r-Chron C23r.

Estimated age: 54.0-52.3 Ma (as per Cande and Kent, 1995); 54.4-52.3 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E3. *Morozovella marginodentata* Partial-range Zone

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of *Morozovella velascoensis* and LO of *Morozovella formosa*.

Magnetochronologic calibration: Chron C24r.

Estimated age: 54.5-54.0 Ma (as per Cande and Kent, 1995); 54.9-54.4 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E2. *Pseudohastigerina wilcoxensis / Morozovella velascoensis* Concurrent-range Zone

Definition: Biostratigraphic interval characterized by the concurrent biostratigraphic ranges of the nominate taxa between the LO of *Pseudohastigerina wilcoxensis* and the HO of *Morozovella velascoensis*.

Magnetochronologic calibration: Chron C24r.

Estimated age: 55.4-54.5 Ma (as per Cande and Kent, 1995); 55.7-54.9 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone E1. *Acarinina sibaiyaensis* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of the nominate taxon *Acarinina sibaiyaensis* and the LO of *Pseudohastigerina wilcoxensis*.

Magnetochronologic calibration: Chron C24r.

Estimated age: 55.5-55.4 Ma (as per Cande and Kent, 1995); 55.8-55.7 Ma (as per Luterbacher et al., 2004); early Eocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

3.3. Amendment to the Paleocene P Zones

Zone P5. *Morozovella velascoensis* Partial-range Zone

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of *Globanomalina pseudomenardii* and the LO of *Acarinina sibaiyaensis*.

Magnetochronologic calibration: Chron C25n-Chron C24r.

Estimated Age: 55.9-55.5 Ma (as per Cande and Kent, 1995); 56.7-55.8 Ma (as per Luterbacher et al., 2004); late Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone P4. *Globanomalina pseudomenardii* Taxon-range Zone.

Definition: Biostratigraphic interval characterized by the total range of the nominate taxon *Globanomalina pseudomenardii*.

Magnetochronologic calibration: Chron C26r-Chron C25n.

Estimated age: 59.4-55.9 Ma (as per Cande and Kent, 1995); 60.2-56.7 Ma (as per Luterbacher et al., 2004); middle-late Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Subzone P4c. *Acarinina soldadoensis / Globanomalina pseudomenardii* Concurrent-range Subzone.

Definition: Concurrent range of the nominate taxa from the LO of *Acarinina soldadoensis* to the HO of *Globanomalina pseudomenardii*.

Magnetic calibration: Chron C25r-Chron C25n.

Age estimate: 56.5-55.9 Ma (as per Cande and Kent, 1995); 57.3-56.7 Ma (as per Luterbacher et al., 2004); late Paleocene.

Remarks: The definition of this subzone remains the same as that of BKSA95.

Subzone P4b. *Acarinina subsphaerica* Partial-range Subzone

Definition: Partial range of the nominate taxon *Acarinina subsphaerica* from the HO of *Parasubbotina variospira* to the LO of *Acarinina soldadoensis*.

Magnetic calibration: Chron C26r-Chron 25r.

Age estimate: 59.2-56.5 Ma (as per Cande and Kent, 1995); 60.0-57.3 Ma (as per Luterbacher et al., 2004); middle-late Paleocene.

Remarks: The definition of this subzone remains the same as that of Berggren et al. (2000).

Subzone P4a. *Globanomalina pseudomenardii / Parasubbotina variospira* Concurrent-range Subzone

Definition: Concurrent range of the nominate taxa from the LO of *Globanomalina pseudomenardii* to the HO of *Parasubbotina variospira*.

Magnetic calibration: Chron C26r.

Age estimate: 59.4-59.2 Ma (as per Cande and Kent, 1995); 60.2-60.0 Ma (as per Luterbacher et al., 2004); middle Paleocene.

Remarks: The definition of this subzone remains the same as that of Berggren et al. (2000).

Zone P3. *Morozovella angulata* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of *Morozovella angulata* and the LO of *Globanomalina pseudomenardii*.

Magnetochronologic calibration: Chron C27n-Chron C26r.

Estimated age: 61.0-59.4 Ma (as per Cande and Kent, 1995); 61.7-60.2 Ma (as per Luterbacher et al., 2004); early-middle Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Subzone P3b. *Igorina albeari* Lowest-occurrence Subzone

Definition: Biostratigraphic interval from the LO of *Igorina albeari* to the LO of *Globanomalina pseudomenardii*.

Magnetic calibration: Chron C26r-Chron C26.

Age estimate: 60.0-59.4 Ma (as per Cande and Kent, 1995); 60.8-60.2 Ma (as per Luterbacher et al., 2004); middle Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Subzone P3a. *Igorina pusilla* Partial-range Subzone

Definition: Biostratigraphic interval defined by the partial range of *Igorina pusilla* between the LO of *Morozovella angulata* and the LO of *Igorina albeari*.

Magnetic calibration: Chron C27n-Chron 26r.

Age estimate: 61.0-60.0 Ma (as per Cande and Kent, 1995); 61.7-60.8 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone P2. *Praemurica uncinata* Lowest-occurrence Zone

Definition: Biostratigraphic interval between the LO of *Praemurica uncinata* and the LO of *Morozovella angulata*.

Magnetochronologic calibration: Chron C27r-Chron C27n.

Estimated age: 61.4-61.0 Ma (as per Cande and Kent, 1995); 62.1-61.7 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone P1. *Eoglobigerina edita* Partial-range Zone

Definition: Partial range of the nominate taxon between the HO of *Parvularugoglobigerina eugubina* and the LO of *Praemurica uncinata*.

Magnetochronologic calibration: Chron C29r-Chron C27r.

Estimated age: 64.8-61.4 (as per Cande and Kent, 1995); 65.2-62.1 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Subzone P1c. *Globanomalina compressa* Lowest-occurrence Subzone (herein amended and renamed = Subzone P1c [*Globanomalina compressa/Praemurica inconstans* Lowest-occurrence Subzone] of Berggren and Pearson, 2005; = Subzone P1c [*Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Globanomalina compressa* and the LO of *Praemurica uncinata*.

Magnetic calibration: Chron C28n-Chron C27r.

Age estimate: 62.9-61.4 (as per Cande and Kent, 1995); 63.5-62.1 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The definition used here removes the operational ambiguity inherent in the "and/or" designation in Berggren and Pearson, (2005), in which the Subzone was defined as the biostratigraphic interval between the LO of *Globanomalina compressa* and/or *Praemurica inconstans* and the LO of *Praemurica uncinata*.

Subzone P1b. *Subbotina triloculinoides* Lowest-occurrence Subzone (herein amended

= Subzone P1b [*Subbotina triloculinoides* Lowest-occurrence Subzone] of Berggren and Pearson, 2005; = Subzone P1b [*Subbotina triloculinoides-Globanomalina compressa/Praemurica inconstans* Interval Subzone] of BKSA95).

Definition: Biostratigraphic interval between the LO of *Subbotina triloculinoides* and the LO of *Globanomalina compressa*.

Magnetic calibration: Chron C29n-Chron C28n.

Estimated age: 64.3-62.9 (as per Cande and Kent, 1995); 64.7-63.5 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The definition used here removes the operational ambiguity inherent in the "and/or" designation in Berggren and Pearson, (2005), in which the subzone was defined as the biostratigraphic interval between the LO of *Subbotina triloculinoides* and the LOs of *Globanomalina compressa* and/or *Praemurica inconstans*.

Subzone P1a. *Parasubbotina pseudobulloides* Partial-range Subzone

Definition: Partial range of the nominate taxon between the HO of *Parvularugoglobigerina eugubina* and the LO of *Subbotina triloculinoides*.

Magnetic calibration: Chron C29r-Chron C29n.

Estimated age: 64.8-64.3 (as per Cande and Kent, 1995); 65.2-64.7 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone Pα. *Parvularugoglobigerina eugubina* Taxon-range Zone

Definition: Biostratigraphic interval characterized by the total range of the nominate taxon *Parvularugoglobigerina eugubina*.

Magnetochronologic calibration: Chron C29r.

Estimated age: 64.97-64.8 (as per Cande and Kent, 1995); 65.46-65.2 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

Zone P0. *Guembelitria cretacea* Partial-range Zone

Definition: Biostratigraphic interval characterized by the partial range of the nominate taxon between the HO of Cretaceous taxa (e.g., *Globotruncana, Rugoglobigerina,* *Globigerinelloides*) and the LO of *Parvularugoglobigerina eugubina*.

Magnetochronologic calibration: Chron C29r.

Estimated age: 65.0-64.97 (as per Cande and Kent, 1995); 65.5-65.46 Ma (as per Luterbacher et al., 2004); early Paleocene.

Remarks: The nomenclature and definition of the zone remains the same as in Berggren and Pearson (2005).

4. Conclusions

We compile 187 revised calibrations of planktonic foraminiferal bioevents for the Cenozoic and provide calibrations to the GPTS of the Cenozoic and ATS of the Neogene and late Paleogene. Our compilation provides a template for Cenozoic magnetobio- and magnetobioastro-chronology. With recent progress in astronomical tuning, it is clear that high resolution biostratigraphic work and integrated biochronologies are needed to reduce the uncertainty of a number of events and study potential diachrony between the Atlantic and Pacific oceans. Future developments in radioisotopic and astronomical dating will undoubtedly lead to further revision and refinements in Cenozoic planktonic foraminiferal biochronology.

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Table Caption

Table 1. Planktonic foraminiferal bioevents for the Cenozoic calibrated to the geomagnetic polarity time scale of Cande and Kent (1995). Marker taxa are highlighted in bold. Previously published ages are on multiple time scales and refer to the data in each given reference.

Table 2. Earth's ~405 kyr eccentricity cycle duration and ages for the Cenozoic with code names for the present to 41.5 Ma (base of Chron 19n).

Table 3. Planktonic foraminiferal bioevents for the Neogene Period calibrated to the geomagnetic polarity time scale and astronomical time scale of Lourens et al. (2004). Marker taxa are highlighted in bold.

Table 4. Planktonic foraminiferal bioevents for the Paleogene Period calibrated to the geomagnetic polarity time scale of Luterbacher et al. (2004) and astronomical time scale of Pälike et al. (2006). Marker taxa are highlighted in bold.

Figure Captions

Fig. 1. Nomenclature of biostratigraphical zones modified from Hedberg (1976) and Pearson (1998) to illustrate the convention of Berggren and Pearson (2005) and this paper. Note that examples C, D and E are described as 'interval zones' by the International Stratigraphic Guide (Hedberg, 1976) and all five examples are described as 'interval zones' by the North American Commission on Stratigraphy. We prefer to refer to the five different logical possibilities by different names. Note that our naming convention demands that the named species occur within the zone, hence the necessity of species C in example E.

Fig. 2. Primary planktonic foraminiferal bioevents for the Cenozoic against the polarity time scale of Cande and Kent (1995). BKSA95 = Berggren et al. (1995); BP05 = Berggren and Pearson (2005). (a) 0-25 Ma; (b) 20-45 Ma; (c) 40-65 Ma. A = Atlantic; IP = Indo-Pacific.

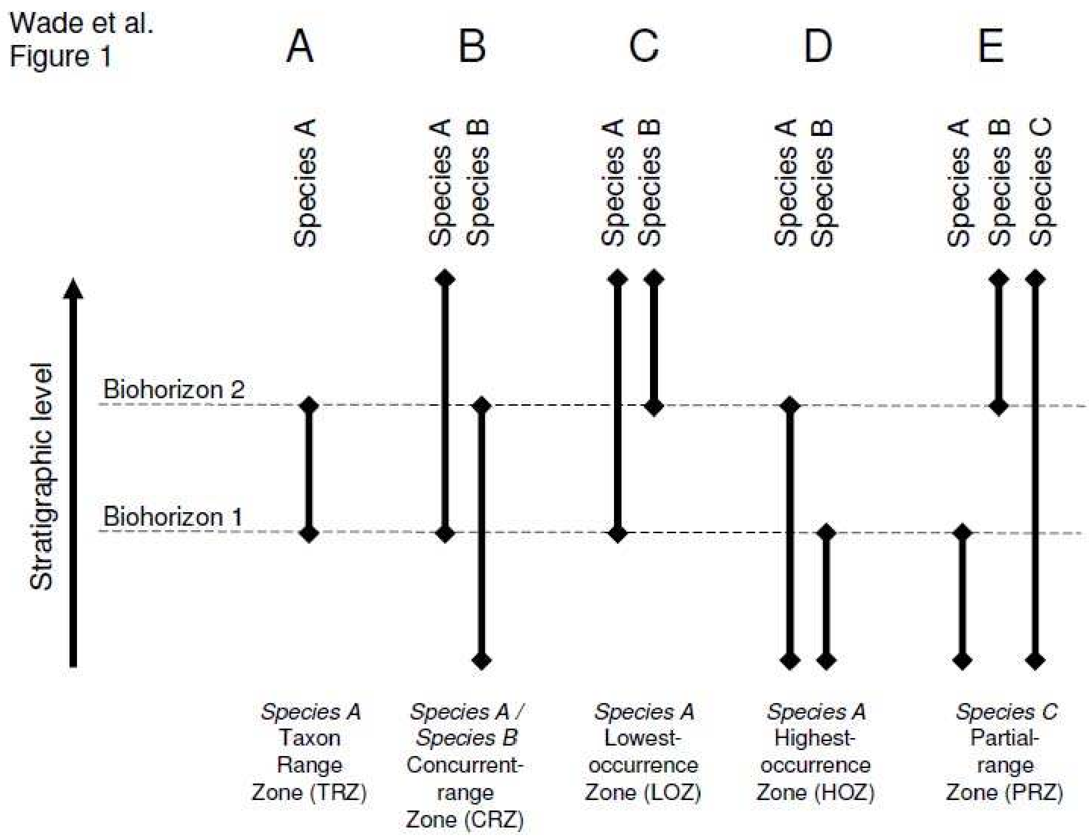
Fig. 3. Primary planktonic foraminiferal bioevents for the Neogene and late Paleogene against the astronomical time scale of Lourens et al. (2004, until base of Chron C6Cn.2n) and Pälike et al. (2006, from top Chron C6Cn.3n until base C19n). (a) 0-25 Ma; (b) 20-41.5 Ma. A = Atlantic; IP = Indo-Pacific. The ~405 kyr eccentricity cycle numbers are counted from the present.

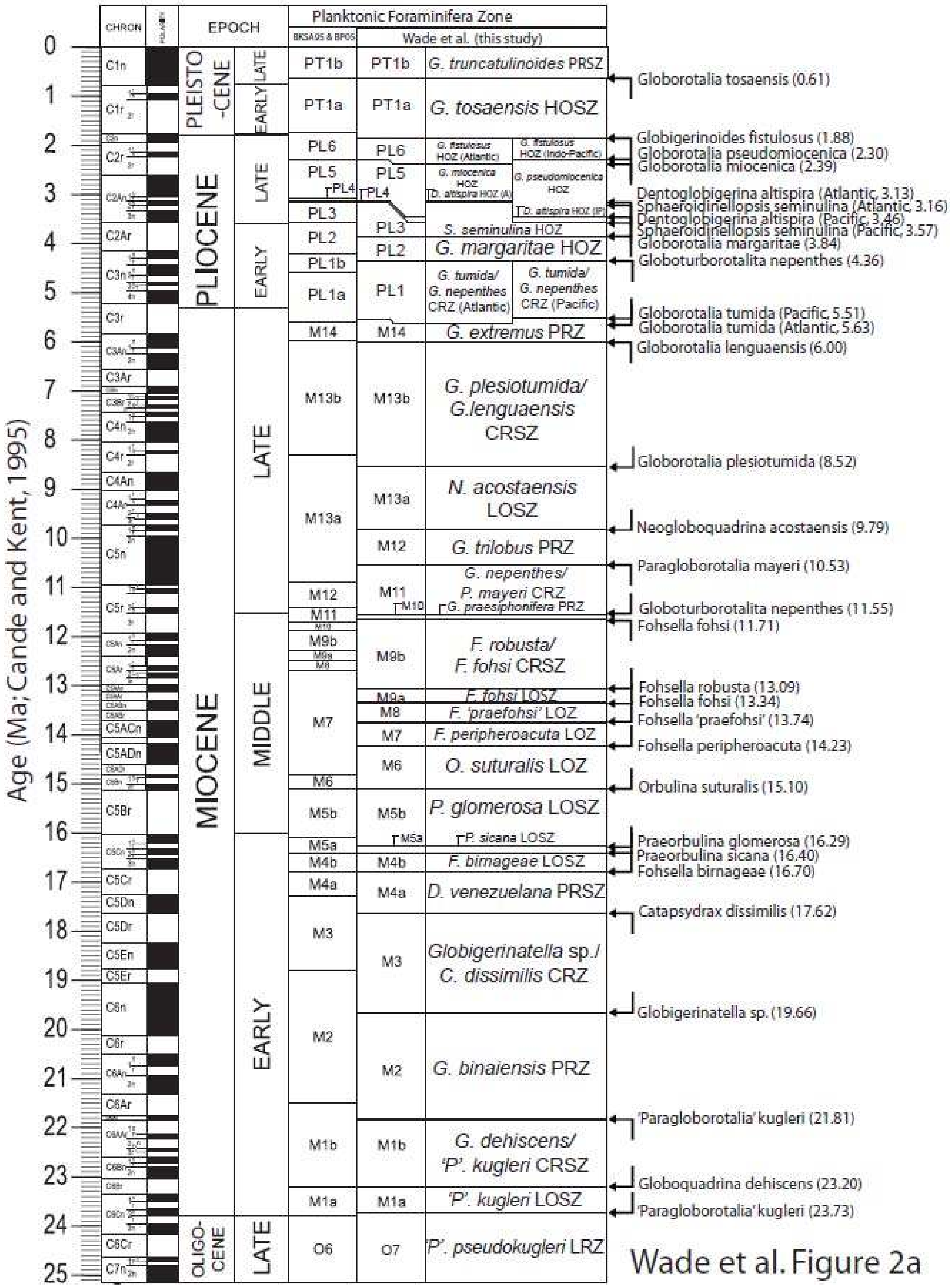
Fig. 4. Primary planktonic foraminiferal bioevents for the Cenozoic against the polarity time scale of Gradstein et al. (2004). (a) 0-25 Ma; (b) 20-45 Ma; (c) 40-65 Ma. A =

Atlantic; IP = Indo-Pacific.

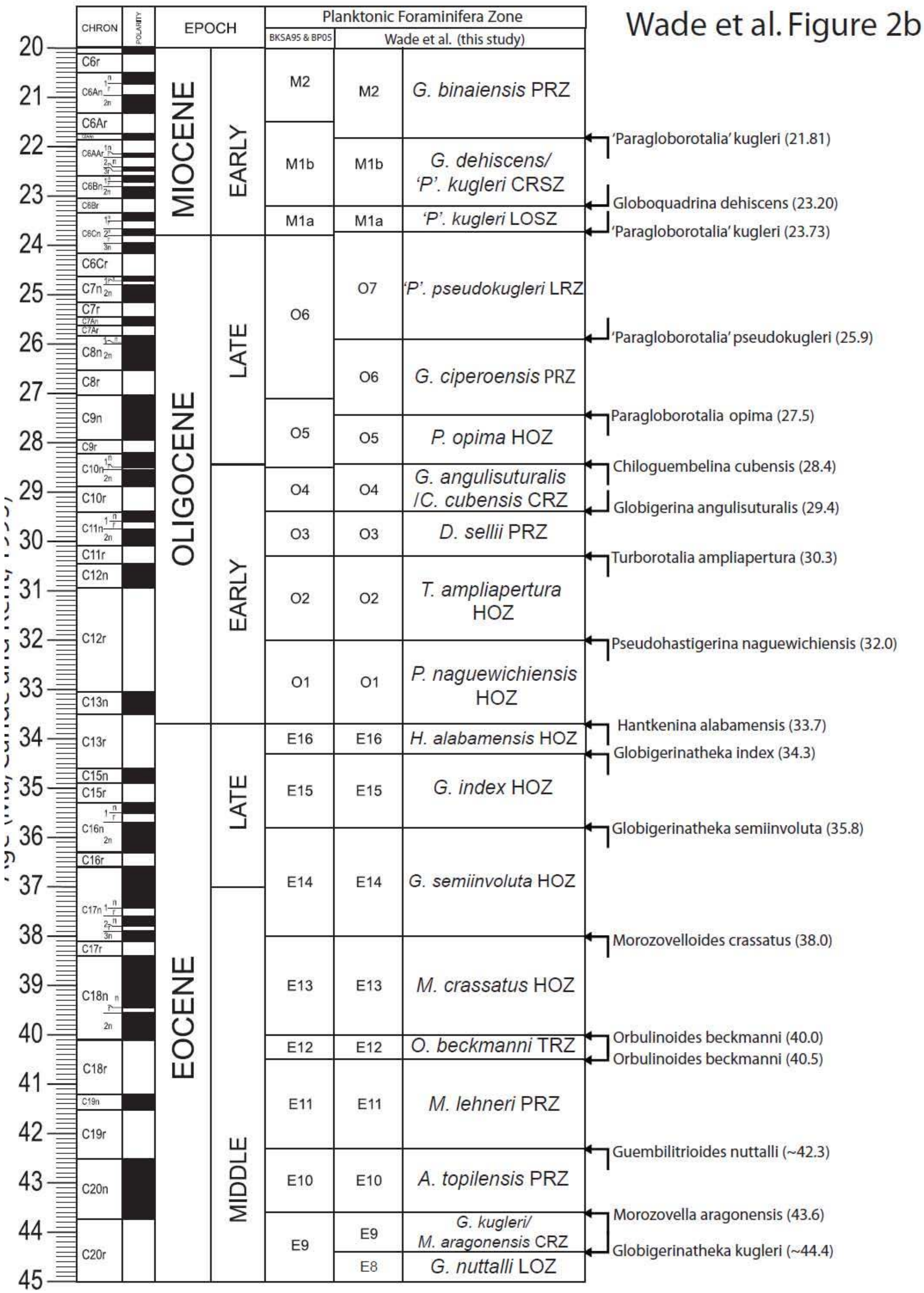
Fig. 5. Revision of mid Miocene “M” Zones and comparison to previous zonations.

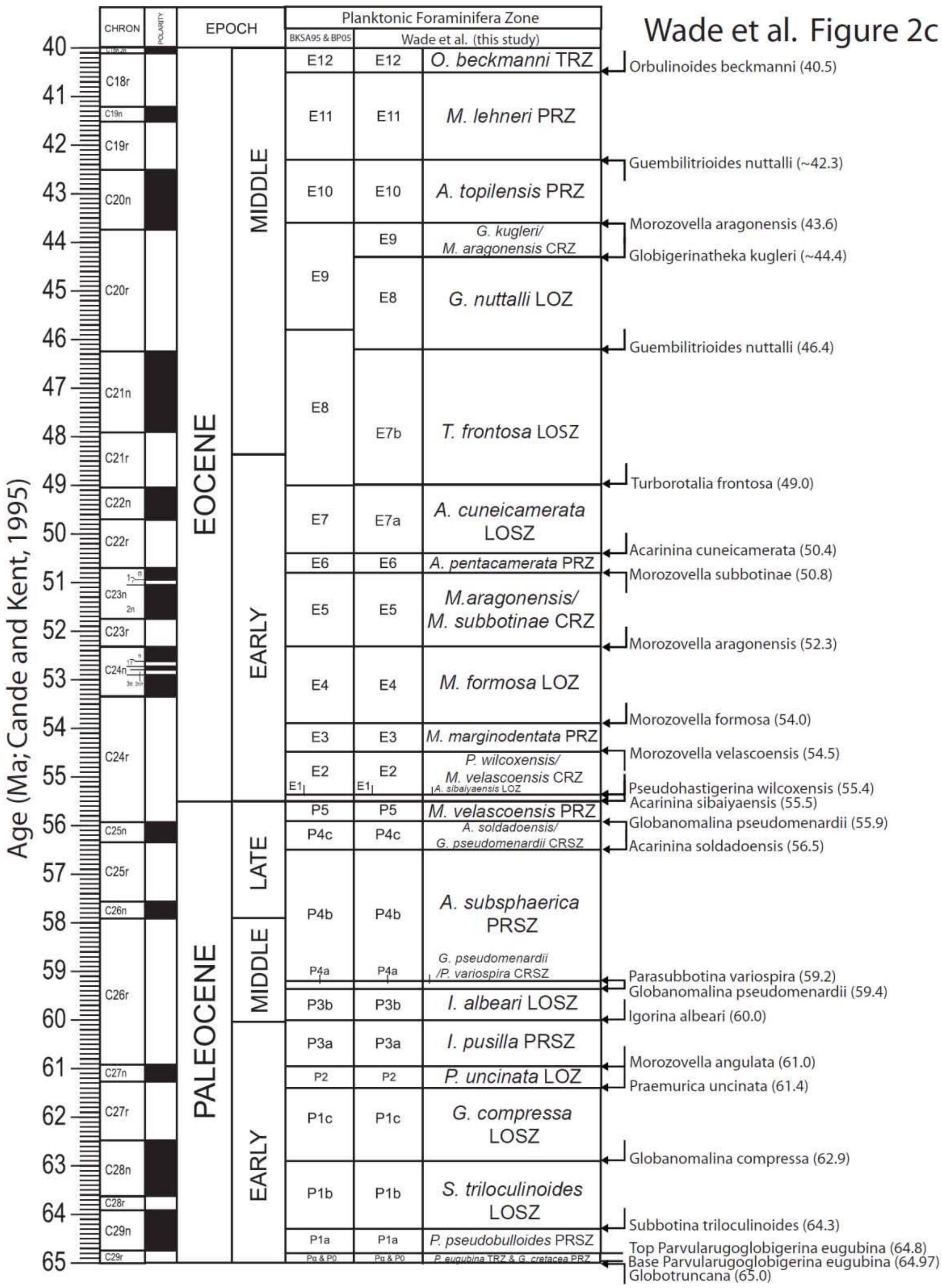
Fig. 6. Planktonic foraminiferal bioevents for the early-middle Eocene against the polarity time scale of Cande and Kent (1995). Primary marker taxa are in black, secondary markers and uncalibrated events to the magnetochronology are shown in grey. Planktonic foraminifera ranges are constrained from the Agost Section (Ortiz et al., 2008; Larrasoaña et al., 2008) and Tanzania Drilling Project Site 2 (Pearson, unpublished data).

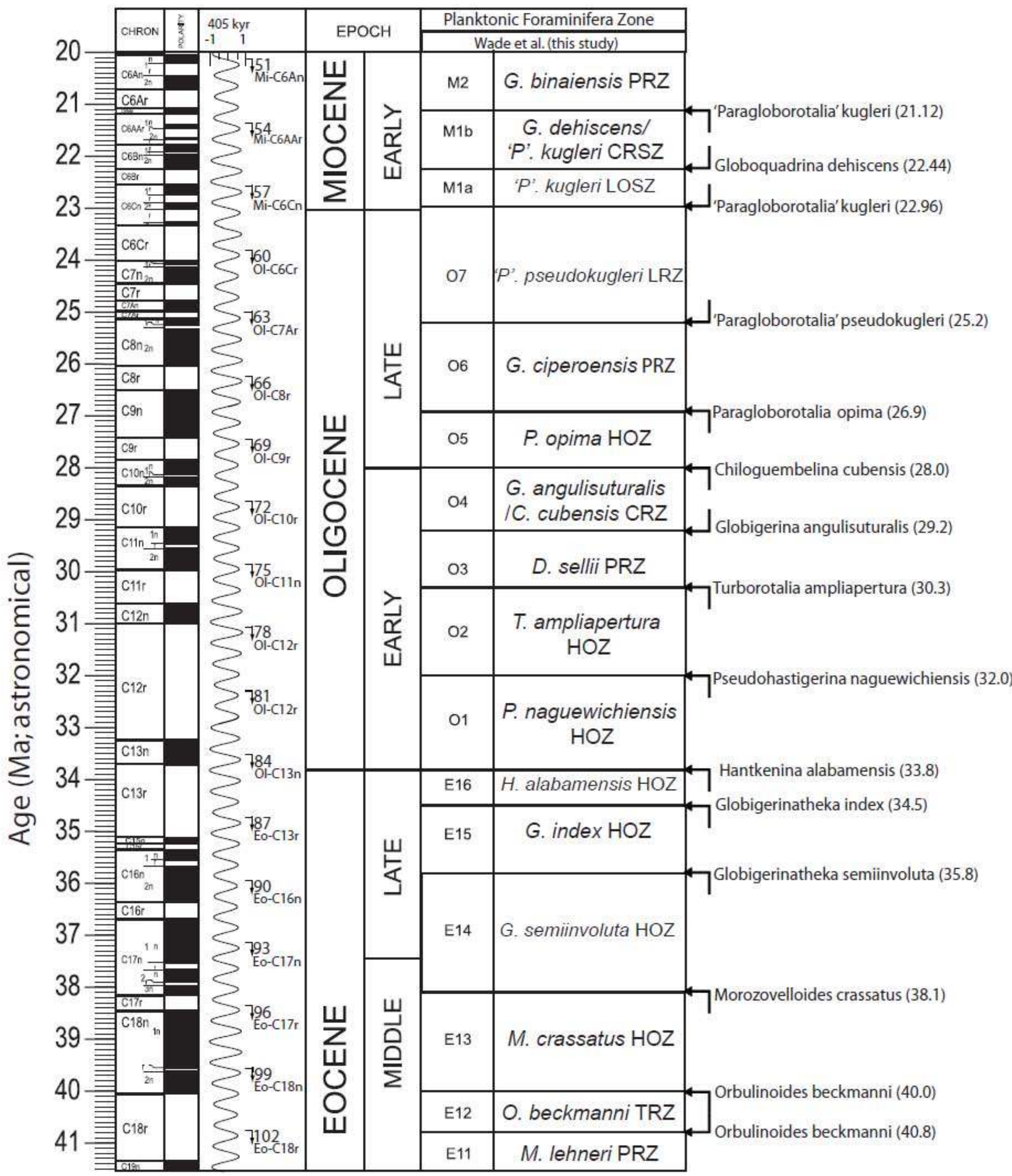

Wade et al.
Figure 1
A
B
C
D
E
Species A
Species A
Species B
Species A
Species B
Species A
Species B
Species A
Species B
Species C
Stratigraphic level
Biohorizon 2
Biohorizon 1
Species A
Taxon
Range
Zone (TRZ)
Species A /
Species B
Concurrent-
range
Zone (CRZ)
Species A
Lowest-
occurrence
Zone (LOZ)
Species A
Highest-
occurrence
Zone (HOZ)
Species C
Partial-
range
Zone (PRZ)



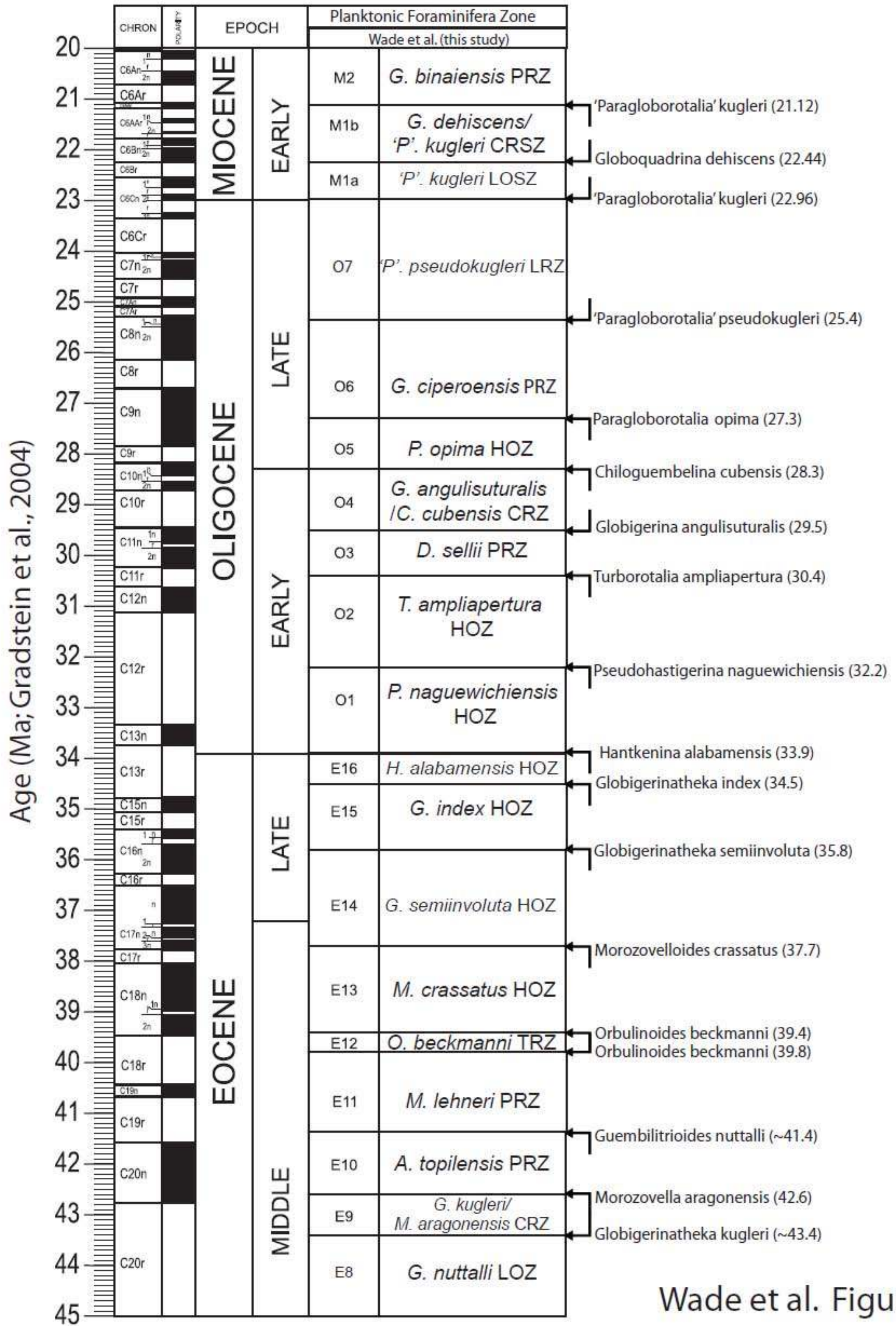
Wade et al. Figure 2a


Wade et al. Figure 2b
CHRON
POLARITY
EPOCH
Planktonic Foraminifera Zone
BKSA95 & BP05
Wade et al. (this study)
MIOCENE
OLIGOCENE
EOCENE
EARLY
LATE
EARLY
LATE
MIDDLE
G. binaiensis PRZ
G. dehiscens/ 'P'. kugleri CRSZ
'P'. kugleri LOSZ
'P'. pseudokugleri LRZ
G. ciperoensis PRZ
P. opima HOZ
G. angulisuturalis /C. cubensis CRZ
D. sellii PRZ
T. ampliapertura HOZ
P. naguewichiensis HOZ
H. alabamensis HOZ
G. index HOZ
G. semiinvoluta HOZ
M. crassatus HOZ
O. beckmanni TRZ
M. lehneri PRZ
A. topilensis PRZ
G. kugleri/ M. aragonensis CRZ
G. nuttalli LOZ
'Paragloborotalia' kugleri (21.81)
Globoquadrina dehiscens (23.20)
'Paragloborotalia' kugleri (23.73)
'Paragloborotalia' pseudokugleri (25.9)
Paragloborotalia opima (27.5)
Chiloguembelina cubensis (28.4)
Globigerina angulisuturalis (29.4)
Turborotalia ampliapertura (30.3)
Pseudohastigerina naguewichiensis (32.0)
Hantkenina alabamensis (33.7)
Globigerinatheka index (34.3)
Globigerinatheka semiinvoluta (35.8)
Morozovelloides crassatus (38.0)
Orbulinoides beckmanni (40.0)
Orbulinoides beckmanni (40.5)
Guembilitrioides nuttalli (~42.3)
Morozovella aragonensis (43.6)
Globigerinatheka kugleri (~44.4)

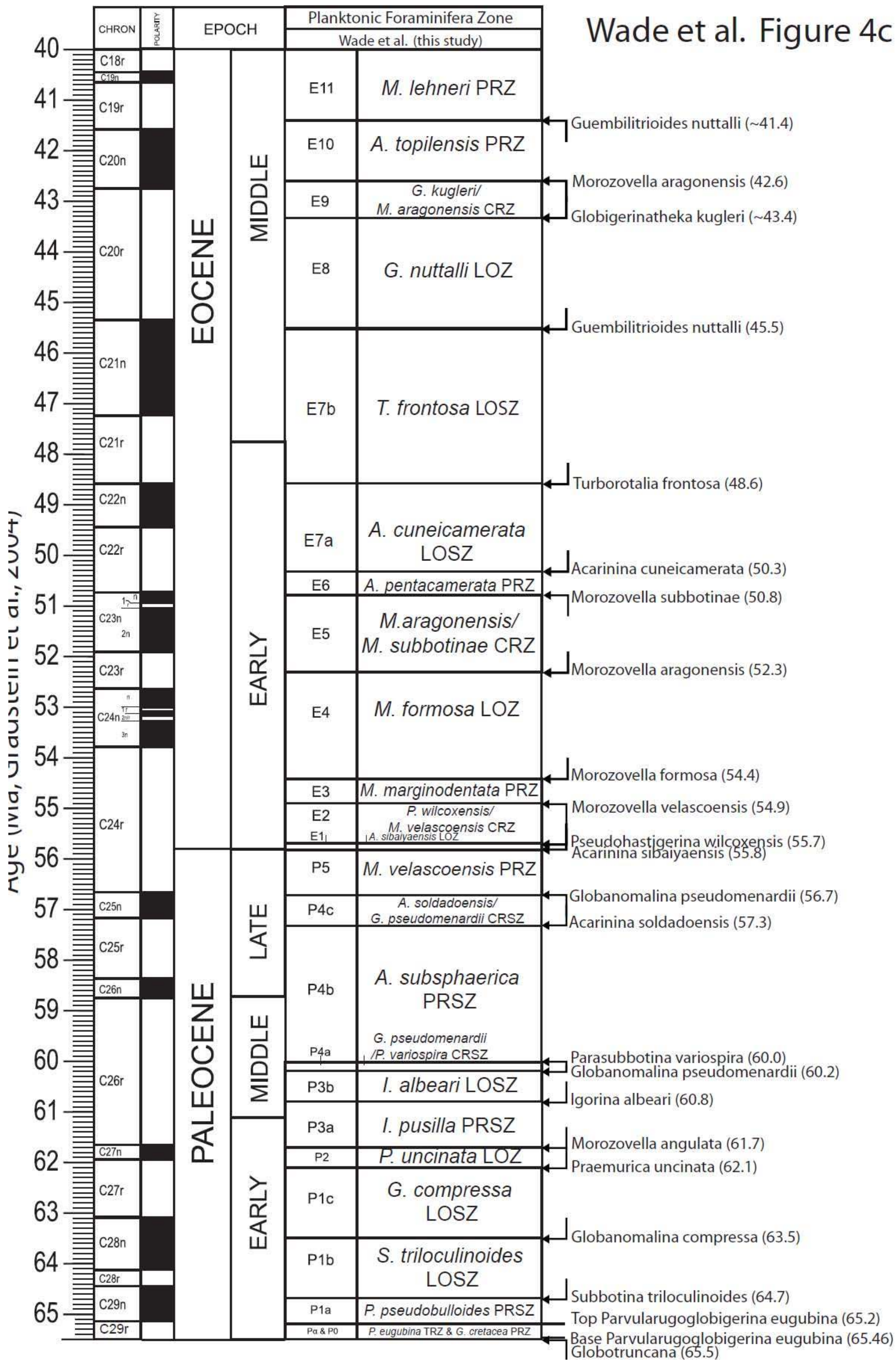

Wade et al. Figure 2c
Age (Ma; Cande and Kent, 1995)
CHRON
POLARITY
EPOCH
Planktonic Foraminifera Zone
BKSA95 & BP05
Wade et al. (this study)
EOCENE
PALEOCENE
MIDDLE
EARLY
LATE
O. beckmanni TRZ
M. lehneri PRZ
A. topilensis PRZ
G. kugleri/ M. aragonensis CRZ
G. nuttalli LOZ
T. frontosa LOSZ
A. cuneicamerata LOSZ
A. pentacamerata PRZ
M.aragonensis/ M. subbotinae CRZ
M. formosa LOZ
M. marginodentata PRZ
P. wilcoxensis/ M. velascoensis CRZ
A. sibaiyaensis LOZ
M. velascoensis PRZ
A. soldadoensis/ G. pseudomenardii CRSZ
A. subsphaerica PRSZ
G. pseudomenardii /P. variospira CRSZ
I. albeari LOSZ
I. pusilla PRSZ
P. uncinata LOZ
G. compressa LOSZ
S. triloculinoides LOSZ
P. pseudobulloides PRSZ
P. eugubina TRZ & G. cretacea PRZ
Orbulinoides beckmanni (40.5)
Guembilitrioides nuttalli (~42.3)
Morozovella aragonensis (43.6)
Globigerinatheka kugleri (~44.4)
Guembilitrioides nuttalli (46.4)
Turborotalia frontosa (49.0)
Acarinina cuneicamerata (50.4)
Morozovella subbotinae (50.8)
Morozovella aragonensis (52.3)
Morozovella formosa (54.0)
Morozovella velascoensis (54.5)
Pseudohastigerina wilcoxensis (55.4)
Acarinina sibaiyaensis (55.5)
Globanomalina pseudomenardii (55.9)
Acarinina soldadoensis (56.5)
Parasubbotina variospira (59.2)
Globanomalina pseudomenardii (59.4)
Igorina albeari (60.0)
Morozovella angulata (61.0)
Praemurica uncinata (61.4)
Globanomalina compressa (62.9)
Subbotina triloculinoides (64.3)
Top Parvularugoglobigerina eugubina (64.8)
Base Parvularugoglobigerina eugubina (64.97)
Globotruncana (65.0)

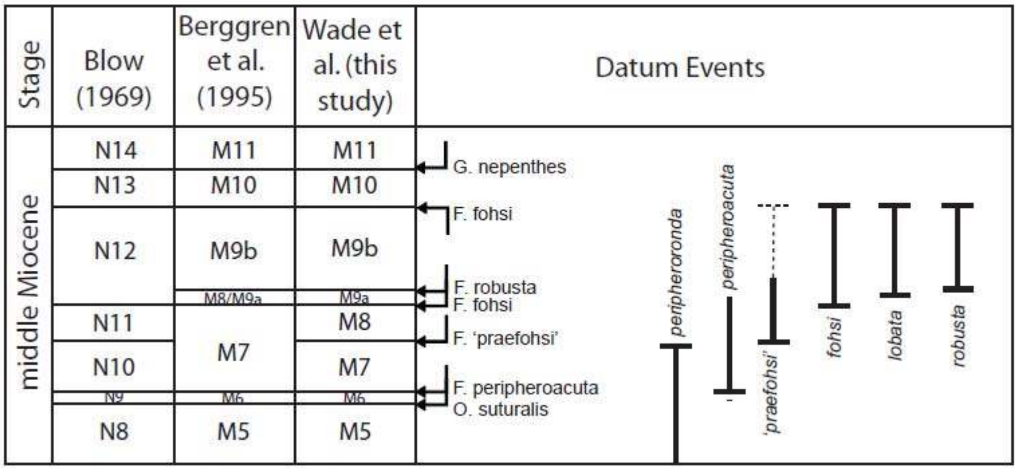


Wade et al. Fig 3b

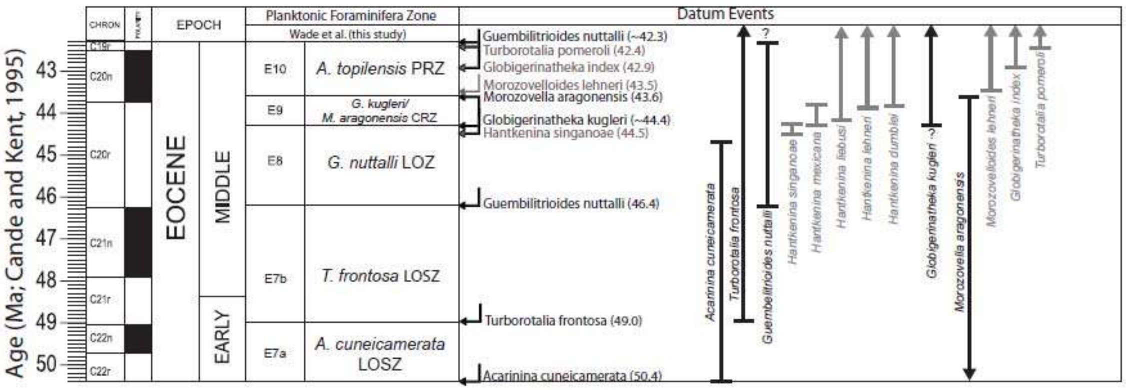


Wade et al. Figure 4b


Wade et al. Figure 4c
Age (Ma, Gradstein et al., 2004)
CHRON
POLARITY
EPOCH
Planktonic Foraminifera Zone
Wade et al. (this study)
EOCENE
MIDDLE
EARLY
PALEOCENE
LATE
MIDDLE
EARLY
E11 M. lehneri PRZ
E10 A. topilensis PRZ
E9 G. kugleri/ M. aragonensis CRZ
E8 G. nuttalli LOZ
E7b T. frontosa LOSZ
E7a A. cuneicamerata LOSZ
E6 A. pentacamerata PRZ
E5 M.aragonensis/ M. subbotinae CRZ
E4 M. formosa LOZ
E3 M. marginodentata PRZ
E2 P. wilcoxensis/ M. velascoensis CRZ
E1 A. sibaiyaensis LOZ
P5 M. velascoensis PRZ
P4c A. soldadoensis/ G. pseudomenardii CRSZ
P4b A. subsphaerica PRSZ
P4a G. pseudomenardii /P. variospira CRSZ
P3b I. albeari LOSZ
P3a I. pusilla PRSZ
P2 P. uncinata LOZ
P1c G. compressa LOSZ
P1b S. triloculinoides LOSZ
P1a P. pseudobulloides PRSZ
Pα & P0 P. eugubina TRZ & G. cretacea PRZ
Guembilitrioides nuttalli (~41.4)
Morozovella aragonensis (42.6)
Globigerinatheka kugleri (~43.4)
Guembilitrioides nuttalli (45.5)
Turborotalia frontosa (48.6)
Acarinina cuneicamerata (50.3)
Morozovella subbotinae (50.8)
Morozovella aragonensis (52.3)
Morozovella formosa (54.4)
Morozovella velascoensis (54.9)
Pseudohastigerina wilcoxensis (55.7)
Acarinina sibaiyaensis (55.8)
Globanomalina pseudomenardii (56.7)
Acarinina soldadoensis (57.3)
Parasubbotina variospira (60.0)
Globanomalina pseudomenardii (60.2)
Igorina albeari (60.8)
Morozovella angulata (61.7)
Praemurica uncinata (62.1)
Globanomalina compressa (63.5)
Subbotina triloculinoides (64.7)
Top Parvularugoglobigerina eugubina (65.2)
Base Parvularugoglobigerina eugubina (65.46)
Globotruncana (65.5)



Wade et al.
Figure 5



Wade et al. Figure 6

Table 1.

Wade et al Table 1

Zone (BKSA95 & BP05) (base)	Zone (This study) (base)		Datum		Notes	Age (Ma) This Study[a]	Published Age (Ma)	Reference		Berggren et al. (1995a,b)	Berggren & Pearson (2005)
		T	Globorotalia	flexuosa		0.07	0.07	Berggren et al.	1995 a	0.07	-
		T	Globigerinoides	ruber (pink)	(Indo-Pacific only)	0.12	0.12	Thompson et al.	1979	-	-
		B	Globigerinella	calida		0.22	0.22	Chaproniere et al.	1994	0.22	-
		B	Globorotalia	flexuosa		0.40	0.40	Berggren et al.	1995 a	0.40	-
		B	Globorotalia	hirsuta		0.45	0.45	Pujol and Duprat	1983	0.45	
PT1b	PT1b	T	Globorotalia	tosaensis		0.61	0.61	Mix et al.	1995	0.65	-
		B	Globorotalia	hessi		0.75	0.75	Chaproniere et al.	1994	0.75	-
		X	random to dextral in Pulleniatina		(Pacific)	0.80	0.80	Pearson	1995	-	-
		B	Globorotalia	excelsa		1.00	1.00	Berggren et al.	1995 a	1.00	-
		T	Globoturborotalita	obliquus		1.30	1.30	Chaisson and Pearson	1997	-	-
		T	Globoturborotalita	apertura		1.63	1.64	Chaisson and Pearson	1997	-	-
Pliocene/Pleistocene boundary							*1.80*	*Aguirre and Pasini*	*1985*	-	-
PT1a	PT1a	T	Globigerinoides	fistulosus	[k]	1.88	1.88	Chaisson and Pearson	1997	1.77	-
		B	Globorotalia	truncatulinoides	[s]	1.93	1.92	Chaisson and Pearson	1997	2.00	-
		T	Globigerinoides	extremus		1.99	1.98	Chaisson and Pearson	1997	1.77	-
		B	Pulleniatina	finalis		2.05	2.04	Chaisson and Pearson	1997	-	-
		T	Globorotalia	exilis	(Atlantic)	2.10	2.09	Chaisson and Pearson	1997	2.15	-
			Reappearance of Pulleniatina		(Atlantic)	2.26	2.26	Chaisson and Pearson	1997	2.30	-
		T	Globoturborotalita	woodi		2.30	2.33	Chaisson and Pearson	1997	-	-
		T	Globorotalia	pertenius		2.30	2.33	Chaisson and Pearson	1997	-	-
PL6	PL6 (Indo-Pacific)	T	Globorotalia	pseudomiocenica	(Indo-Pacific)	2.30	2.30	Berggren et al.	1995 a	2.30	-
PL6	PL6 (Atlantic)	T	Globorotalia	miocenica	(Atlantic)	2.39	2.38	Chaisson and Pearson	1997	2.30	-
		T	Globorotalia	limbata		2.39	2.38	Chaisson and Pearson	1997	-	-
		T	Globorotalia	pertenuis		2.60	2.60	Berggren et al.	1995 a	2.60	-
		T	Globoturborotalita	decoraperta		2.75	2.75	Chaisson and Pearson	1997	-	-
		T	Globorotalia	multicamerata		2.99	3.10	Chaisson and Pearson	1997	3.09	-
PL5	PL5 (Atlantic)	T	Dentoglobigerina	altispira	(Atlantic)[b]	3.13	3.11	Chaisson and Pearson	1997	3.09	-
PL4	PL4	T	Sphaeroidinellopsis	seminulina	(Atlantic)[b]	3.16	3.14	Chaisson and Pearson	1997	3.12	-
		B	Globigerinoides	fistulosus		3.33	3.33	Berggren et al.	1995 a	3.33	-
		B	Globorotalia	tosaensis		3.35	3.35	Berggren et al.	1995 a	3.35	-
		T	Pulleniatina	disappearance	(Atlantic)	3.41	3.41	Chaisson and Pearson	1997	-	-
PL5	PL5 (Indo-Pacific)	T	Dentoglobigerina	altispira	(Pacific)	3.46	3.05	Shackleton et al.	1995	-	-
		B	Globorotalia	pertenuis		3.51	3.52	Chaisson and Pearson	1997	3.45	-
PL4	PL4	T	Sphaeroidinellopsis	seminulina	(Pacific)	3.57	3.20	Shackleton et al.	1995	-	-
		T	Pulleniatina	primalis		3.65	3.65	Berggren et al.	1995 a	3.65	-
		B	Globorotalia	miocenica	(Atlantic)	3.76	3.77	Chaisson and Pearson	1997	3.55	-
		T	Globorotalia	plesiotumida		3.76	3.77	Chaisson and Pearson	1997	-	-
PL3	PL3	T	Globorotalia	margaritae		3.84	3.85	Chaisson and Pearson	1997	3.58	-
		X	Pulleniatina	sinis.-dext.		4.07	4.08	Chaisson and Pearson	1997	3.95	-
		T	Pulleniatina	spectabilis	(Pacific)	4.20	4.20	Berggren et al.	1995 a	4.20	-
		B	Globorotalia	crassaformis	sensu lato	4.30	4.31	Chaisson and Pearson	1997	4.50	-

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PL2	PL2	T	Globoturborotalita	nepenthes		4.36	4.39	Chaisson	and	Pearson	1997	4.20	-
		B	Globorotalia	exilis		4.44	4.45	Chaisson	and	Pearson	1997	-	-
		T	Sphaeroidinellopsis	kochi		4.52	4.53	Chaisson	and	Pearson	1997	-	-
PL1b		T	Globorotalia	cibaoensis		4.60	4.60	Berggren	et	al.	1995 b	4.60	-
Miocene/Pliocene boundary						*5.33*	*5.33*	*Van Couvering*	*et*	*al.*	*2000*	-	-
		B	Sphaeroidinella	dehiscens	sensu lato	5.48	5.54	Chaisson	and	Pearson	1997	5.20	-
PL1a	PL1	B	Globorotalia	tumida	(Pacific)	5.51	5.59	Shackleton	et	al.	1995	5.60	-
PL1a	PL1	B	Globorotalia	tumida	(Atlantic)	5.63	5.82	Chaisson	and	Pearson	1997	5.60	-
		B	Turborotalita	humilis		5.71	5.84	Chaisson	and	Pearson	1997		-
		T	Globoquadrina	dehiscens		5.80	5.80	Berggren	et	al.	1995 a	5.80	-
		B	Globorotalia	margaritae		5.95	6.09	Chaisson	and	Pearson	1997	6.40	-
M14	M14	T	Globorotalia	lenguaensis		6.00	6.00	Berggren	et	al.	1995	6.00	-
		B	Globigerinoides	conglobatus		6.08	6.20	Chaisson	and	Pearson	1997		-
		X	Neogloboquadrina	acostaensis	trans. sinis.-dext	6.20	6.20	Berggren	et	al.	1995 b	6.20	-
		B	Pulleniatina	primalis		6.40	6.40	Berggren	et	al.	1995 b	6.40	-
		X	Neogloboquadrina	acostaensis	trans. dext.-sinis	6.60	6.60	Berggren	et	al.	1995 b	6.60	-
		X	Neogloboquadrina	atlantica	trans. dext.-sinis	6.80	6.80	Berggren	et	al.	1995 b	6.80	-
		B	Neogloboquadrina	humerosa		8.50	8.50	Berggren	et	al.	1995 b	8.50	-
M13b	M13b	B	Globorotalia	plesiotumida	c (f)	8.52	8.58	Chaisson	and	Pearson	1997	-	-
		B	Globigerinoides	extremus	b	8.86	8.94	Turco	et	al.	2002	-	-
		B	Globorotalia	cibaoensis		9.34	9.44	Chaisson	and	Pearson	1997	-	-
		B	Globorotalia	juanai		9.62	9.76	Chaisson	and	Pearson	1997	-	-
M13a	M13a	B	Neogloboquadrina	acostaensis		9.79	9.82	Chaisson	and	Pearson	1997	10.90	-
M12	M12	T	Paragloborotalia	mayeri		10.53	10.49	Chaisson	and	Pearson	1997	11.40	-
		B	Globorotalia	limbata		10.66	10.57	Chaisson	and	Pearson	1997	-	-
		T	Cassigerinella	chipolensis	b	10.84	10.81	Turco	et	al.	2002	-	-
		B	Globoturborotalita	apertura		11.12	11.19	Chaisson	and	Pearson	1997	-	-
		B	Globoturborotalita	decoraperta		11.42	11.46	Chaisson	and	Pearson	1997	-	-
		T	Globigerinoides	subquadratus	b	11.46	11.55	Turco	et	al.	2002	-	-
M11	M11	B	Globoturborotalita	nepenthes	b	11.55	11.64	Turco	et	al.	2002	11.80	-
M10	M10	T	Fohsella	fohsi		11.71	11.68	Chaisson	and	Pearson	1997	11.90	-
		T	Globorotalia	praescitula		11.90	11.90	Berggren	et	al.	1995	11.90	-
		B	Globorotalia	lenguaensis	b	12.89	12.39	Turco	et	al.	2002	-	-
		B	Sphaeroidinellopsis	subdehiscens	b	13.00	13.03	Turco	et	al.	2002	-	-
M9b	M9b	B	Fohsella	robusta		13.09	13.18	Chaisson	and	Pearson	1997	12.30	-
M9a		B	Fohsella	lobata		-	12.50	Berggren	et	al.	1995 b	12.50	-
		T	Cassigerinella	martinezpicoi	b	13.22	13.28	Turco	et	al.	2002	-	-
M8	M9a	B	Fohsella	fohsi		13.34	13.42	Chaisson	and	Pearson	1997	12.70	-
	M8	B	Fohsella	"praefohsi"		13.74	14.00	Pearson	and	Chaisson	1997	-	-
		T	Fohsella	peripheroronda	b	13.77	13.87	Turco	et	al.	2002	14.60	-
		T	Clavatorella	bermudezi		13.79	14.20	Pearson	and	Chaisson	1997	-	-
		T	Globorotalia	archeomenardii	b	13.84	13.87	Turco	et	al.	2002	-	-
M7	M7	B	Fohsella	peripheroacuta	b	14.23	14.02	Turco	et	al.	2002	14.80	-
		B	Globorotalia	praemenardii		14.39	14.90	Pearson	and	Chaisson	1997	-	-

Wade et al Table 1

		T	Praeorbulina	sicana		14.56	14.40	Shackleton	et	al.	1999	14.80	-
		T	Globigerinatella	insueta		14.69	15.00	Pearson	and	Chaisson	1997	-	-
M6	**M6**	**B**	**Orbulina**	**suturalis**		**15.10**	**15.10**	**Berggren**	**et**	**al.**	**1995 b**	**15.10**	-
		B	Clavatorella	bermudezi	'	15.76	15.80	Pearson	and	Chaisson	1997	-	-
		B	Praeorbulina	circularis	*	16.00	16.00	Berggren	et	al.	1995 b	16.00	-
		B	Globorotalia	archeomenardii		16.29	16.20	Pearson	and	Chaisson	1997	-	-
M5b	**M5b**	**B**	**Praeorbulina**	**glomerosa**	sensu stricto	**16.29**	**16.20**	**Shackleton**	**et**	**al.**	**1999**	**16.10**	-
		B	Praeorbulina	curva		16.30	16.30	Berggren	et	al.	1995 b	16.30	-
M5a	**M5a**	**B**	**Praeorbulina**	**sicana**		**16.40**	**16.40**	**Berggren**	**et**	**al.**	**1995 b**	**16.40**	-
M4b	**M4b**	**B**	**Fohsella**	**birnageae**		**16.70**	**16.70**	**Berggren**	**et**	**al.**	**1995 b**	**16.70**	-
		B	Globorotalia	zealandica	'	17.30	17.30	Berggren	et	al.	1995 b	17.30	-
M4a	**M4a**	**T**	**Catapsydrax**	**dissimilis**		**17.62**	**17.50**	**Shackleton**	**et**	**al.**	**1999**	**17.30**	-
M3		B	Globigerinatella	insueta s. str.		17.69	17.40	Pearson	and	Chaisson	1997	(18.8)	-
		B	Globorotalia	praescitula		18.50	18.50	Berggren	et	al.	1995 b	18.50	-
		T	Globoquadrina	binaiensis		19.43	19.10	Pearson	and	Chaisson	1997	-	-
	M3	**B**	**Globigerinatella**	**sp.**		**19.66**	**20.20**	**Pearson**	**and**	**Chaisson**	**1997**	-	-
		B	Globigerinoides	altiaperturus		20.50	20.50	Berggren	et	al.	1995 b	20.50	-
		T	Tenuitella	munda		21.40	21.40	Berggren	et	al.	1995	21.40	-
		T	Globigerina	angulisuturalis		21.60	21.60	Berggren	et	al.	1995 b	21.60	-
M2	**M2**	**T**	**'Paragloborotalia'**	**kugleri**		**21.81**	**21.00**	**Shackleton**	**et**	**al.**	**1999**	**21.50**	-
		T	'Paragloborotalia'	pseudokugleri		22.04	21.10	Shackleton	et	al.	1999	21.60	-
M1b	**M1b**	**B**	**Globoquadrina**	**dehiscens**		**23.20**	**23.20**	**Berggren**	**et**	**al.**	**1995 b**	**23.20**	-
		T	Globigerina	ciperoensis		23.68	22.80	Shackleton	et	al.	1999	-	-
		B	Globigerinoides	trilobus	sensu lato	23.73	22.90	Shackleton	et	al.	1999	-	-
M1a	**M1a**	**B**	**'Paragloborotalia'**	**kugleri**		**23.73**	**22.90**	**Shackleton**	**et**	**al.**	**1999**	**23.80**	-
Oligocene/Miocene boundary							*23.80*	*Berggren*	*et*	*al.*	*1995 b*		
		T	Tenuitella	gemma		24.3	24.3	Berggren	et	al.	1995 b	24.3	-
		LCO	Globigerinoides	primordius		24.3	24.3	Berggren	et	al.	1995 b	24.3	-
	O7	**B**	**'Paragloborotalia'**	**pseudokugleri**		**25.9**	**25.9**	**Berggren**	**et**	**al.**	**1995 b**	**25.9**	-
		B	Globigerinoides	primordius		26.7	26.7	Berggren	et	al.	1995 b	26.7	-
O6	**O6**	**T**	**Paragloborotalia**	**opima**		**27.5**	**27.5**	**Wade**	**et**	**al.**	**2007**	**27.1**	**27.1**
O5	**O5**	**HCO**	**Chiloguembelina**	**cubensis**		**28.4**	**28.4**	**Wade**	**et**	**al.**	**2007**	**28.5**	**28.5**
O4	**O4**	**B**	**Globigerina**	**angulisuturalis**		**29.4**	**29.4**	**Berggren**	**et**	**al.**	**1995 b**	**29.4**	**29.4**
		T	Subbotina	angiporoides		30.0	30.0	Berggren	et	al.	1995 b	30.0	30.0
O3	**O3**	**T**	**Turborotalia**	**ampliapertura**		**30.3**	**30.3**	**Berggren**	**et**	**al.**	**1995 b**	**30.3**	**30.3**
		B	Paragloborotalia	opima		30.6	30.6	Berggren	et	al.	1995 b	30.6	-
O2	**O2**	**T**	**Pseudohastigerina**	**naguewichiensis**		**32.0**	**32.0**	**Berggren**	**et**	**al.**	**1995 b**	**32.0**	**32.0**
Eocene/Oligocene boundary							*33.7*	*Berggren*	*et*	*al.*	*1995 b*	-	-
O1	**O1**	**T**	**Hantkenina**	**alabamensis**		**33.7**	**33.7**	**Berggren**	**and**	**Pearson**	**2005**	**33.7**	**33.7**
		HCO	Pseudohastigerina	micra		33.7	33.7	Wade	and	Pearson	2008	-	-
		T	Turborotalia	cerroazulensis		33.8	33.8	Berggren	and	Pearson	2005	33.8	33.8
E16	**E16**	**T**	**Globigerinatheka**	**index**		**34.3**	**34.3**	**Berggren**	**and**	**Pearson**	**2005**	**34.3**	**34.3**
		B	Turborotalia	cunialensis		35.3	35.3	Berggren	and	Pearson	2005	35.2	35.3
E15	**E15**	**T**	**Globigerinatheka**	**semiinvoluta**		**35.8**	**35.8**	**Berggren**	**and**	**Pearson**	**2005**	**35.3**	**35.8**
		B	Globigerinatheka	semiinvoluta		38.0	38.0	Wade			2004	38.4	-

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E14	E14	T	Morozovelloides	crassatus		38.0	38.0	Wade			2004	38.1	38.0
		T	Acarinina	mcgowrani		38.0	38.0	Wade			2004	-	-
		T	Turborotalia	frontosa		39.3	39.3	Berggren	et	al.	1995 b	39.3	-
E13	E13	T	Orbulinoides	beckmanni		40.0	40.0	Wade			2004	40.1	40.0
E12	E12	B	Orbulinoides	beckmanni		40.5	40.5	Berggren	et	al.	1995 b	40.5	40.5
		T	Acarinina	bullbrooki		40.5	40.5	Berggren	et	al.	1995 b	40.5	-
E11	E11	T	Guembilitrioides	nuttalli		(42.3)	(42.3)	Berggren	and	Pearson	2005	-	(42.3)
		B	Turborotalia	pomeroli		42.4	42.4	Berggren	et	al.	1995 b	42.4	-
		B	Globigerinatheka	index		42.9	42.9	Berggren	et	al.	1995 b	42.9	-
		B	Morozovelloides	lehneri		43.5	43.5	Berggren	et	al.	1995 b	43.5	-
E10	E10	T	Morozovella	aragonensis		43.6	43.6	Berggren	et	al.	1995 b	43.6	43.6
E9	E9	B	Globigerinatheka	kugleri		(44.4)	-	Pearson	et	al.	2004	45.8	45.8
		B	Hantkenina	singanoae		44.5	43.5	Payros	et	al.	2009	49.0	-
E8	E8	B	Guembilitrioides	nuttalli		46.4	45.5	Payros	et	al.	2009	-	49.0
	E7b	B	Turborotalia	frontosa		49.0	48.6	Payros	et	al.	2009	-	-
E7	E7a	B	Acarinina	cuneicamerata		50.4	50.4	Hancock	et	al.	2002	-	50.4
		B	Planorotalites	palmerae		50.4	50.4	Berggren	et	al.	1995 b	50.4	-
E6	E6	T	Morozovella	subbotinae		50.8	50.8	Berggren	and	Pearson	2005	-	50.8
E5	E5	B	Morozovella	aragonensis		52.3	52.3	Berggren	et	al.	1995 b	52.3	52.3
		T	Morozovella	marginodentata		52.5	52.5	Berggren	et	al.	1995 b	52.5	-
		T	Morozovella	lensiformis		52.7	52.7	Berggren	et	al.	1995 b	52.7	-
		T	Morozovella	aequa		53.6	53.6	Berggren	et	al.	1995 b	53.6	-
E4	E4	B	Morozovella	formosa		54.0	54.0	Berggren	et	al.	1995 b	54.0	54.0
		B	Morozovella	lensiformis		54.0	54.0	Berggren	et	al.	1995 b	54.0	-
E3	E3	T	Morozovella	velascoensis		54.5	54.5	Berggren	and	Pearson	2005	54.7	54.5
		T	Morozovella	acuta		54.7	54.7	Berggren	et	al.	1995 b	54.7	
		B	Morozovella	gracilis		54.7	54.7	Berggren	et	al.	1995 b	54.7	-
		B	Igorina	broedermanni		54.7	54.7	Berggren	et	al.	1995 b	54.7	-
		B	Morozovella	marginodentata		54.8	54.8	Berggren	et	al.	1995 b	54.8	-
E2	E2	B	Pseudohastigerina	wilcoxensis		55.4	55.4	Berggren	and	Pearson	2005	-	55.4
		B	Globanomalina	australiformis		55.5	55.5	Berggren	et	al.	1995 b	55.5	-
E1	E1	B	Acarinina	sibaiyaensis		55.5	55.5	Berggren	and	Pearson	2005	-	55.5
Paleocene/Eocene boundary							*55.5*	*Ouda*	*and*	*Aubry*	*2003*		
P5	P5	T	Globanomalina	pseudomenardii		55.9	55.9	Berggren	et	al.	1995 b	55.9	55.9
		B	Morozovella	subbotinae		55.9	55.9	Berggren	et	al.	1995 b	55.9	-
		T	Acarinina	mckannai		56.3	56.3	Berggren	et	al.	1995 b	56.3	-
		T	Acarinina	acarinata		56.3	56.3	Berggren	et	al.	1995 b	56.3	-
P4c	P4c	B	Acarinina	soldadoensis	d	56.5	56.5	Berggren	et	al.	1995 b	56.5	56.5
		B	Acarinina	coalingensis		56.5	56.5	Berggren	et	al.	1995 b	56.5	-
		B	Morozovella	aequa		56.5	56.5	Berggren	et	al.	1995 b	56.5	-
		T	Acarinina	subsphaerica		57.1	57.1	Berggren	et	al.	1995 b	57.1	57.1
		B	Acarinina	mckannai		59.1	59.1	Berggren	et	al.	1995 b	59.1	-
P4b	P4b	T	Parasubbotina	variospira		59.2	59.2	Berggren	et	al.	1995 b	59.2	59.2
		B	Acarinina	acarinata		59.2	59.2	Berggren	et	al.	1995 b	59.2	-
		B	Acarinina	subsphaerica		59.2	59.2	Berggren	et	al.	1995 b	59.2	-

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P4a	P4a	B	Globanomalina	pseudomenardii		59.4	59.4	Berggren	et	al.	2000	59.2	59.4
P3b	P3b	B	Igorina	albeari		60.0	60.0	Berggren	et	al.	1995 b	60.0	60.0
		B	Morozovella	velascoensis		60.0	60.0	Berggren	et	al.	1995 b	60.0	-
		B	Morozovella	conicotruncata		60.9	60.9	Berggren	et	al.	1995 b	60.9	-
P3a	P3a	B	Morozovella	angulata		61.0	61.0	Berggren	et	al.	1995 b	61.0	61.0
		B	Igorina	pusilla		61.0	61.0	Berggren	et	al.	1995 b	61.0	-
		B	Morozovella	praeangulata		61.2	61.2	Berggren	et	al.	1995 b	61.2	-
		B	Globanomalina	imitata		(61.3)	(61.3)	Berggren	et	al.	1995 b	(61.3)	-
P2	P2	B	Praemurica	uncinata		61.4	61.4	Berggren	and	Pearson	2005	61.2	61.4
P1c	P1c	B	Globanomalina	compressa	c (2)	62.9	62.9	Berggren	and	Pearson	2005	63.0	62.9
		B	Praemurica	inconstans		62.9	62.9	Berggren	and	Pearson	2005	63.0	62.9
		B	Parasubbotina	varianta		63.0	63.0	Berggren	et	al.	1995 b	63.0	-
P1b	P1b	B	Subbotina	triloculinoides		64.3	64.3	Berggren	et	al.	1995 b	64.3	64.3
P1a	P1a	T	Parvularugoglobigerina	eugubina		64.8	64.8	Berggren	and	Pearson	2005	64.7	64.8
		B	Parvularugoglobigerina	extensa		64.9	64.9	Olsson	et	al.	1999	-	-
Pα	Pα	B	Parvularugoglobigerina	eugubina		64.97	64.97	Berggren	et	al.	1995 b	64.97	64.97
P0	P0	T	Globotruncana			65.0	65.0	Berggren	et	al.	1995 b	65.0	65.0

Notes

a	Calibrated to Cande and Kent (1995)
b	Calibration of Turco et al. (2002) on Astronomical Time Scale of Shackleton and Crowhurst (1997)
c	Replaces the and/or non zone of (1) BKSA95; (2) Berggren & Pearson (2005)
d	Note mistake in Berggren & Pearson (2005)
e	Note mistake in Lourens et al. (2004) Table A2.3, where Bottom *Praeorbulina circularis* should read Top *Praeorbulina circularis*
f	Note mistake in Shackleton et al. (1999) where 14.8 Ma should read 15.8 Ma. This mistake is also propogated in Lourens et al. (2004)
g	Traditionally used as base N22, this datum is considered highly diachronous between ocean basins (see Dowsett, 1988).
h	Age adjusted to reflect the short stratigraphic duration between *D. altispira* and *S. seminulina* - see text for discussion
i	Calibrated to Gradstein et al. (2004)
j	Note mistake in BKSA95 (page 174) where LAD should read FAD
k	Note mistake in Berggren et al. (1995a, Table 6) where 1.6 Ma should read 1.77 Ma
X	Change in coiling direction
HCO	Highest common occurrence
LCO	Lowest common occurrence
(44.4)	Estimated age

Table 2.

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~405 kyr cycle	Cycle Code/Chron	Younger end of cycle (Ma)	Older end of cycle (Ma)	Duration	Notes
1		-0.121	0.297	0.418	a
2	Pt-C1n	0.297	0.702	0.405	
3	Pt-C1n	0.702	1.106	0.405	
4	Pt-C1r	1.106	1.516	0.410	
5	Pt-C1r	1.516	1.922	0.406	
6	Pl-C2n	1.922	2.329	0.408	
7	Pl-C2r	2.329	2.736	0.407	
8	Pl-C2An	2.736	3.144	0.408	
9	Pl-C2An	3.144	3.543	0.399	
10	Pl-C2An	3.543	3.944	0.401	
11	Pl-C2Ar	3.944	4.341	0.397	
12	Pl-C3n	4.341	4.742	0.402	
13	Pl-C3n	4.742	5.155	0.413	
14	Pl-C3n	5.155	5.559	0.404	
15	Mi-C3r	5.559	5.968	0.409	
16	Mi-C3r	5.968	6.374	0.407	
17	Mi-C3An	6.374	6.765	0.391	
18	Mi-C3Ar	6.765	7.172	0.406	
19	Mi-C3Bn	7.172	7.574	0.403	
20	Mi-C4n	7.574	7.983	0.409	
21	Mi-C4n	7.983	8.395	0.412	
22	Mi-C4r	8.395	8.797	0.402	
23	Mi-C4An	8.797	9.205	0.409	
24	Mi-C4Ar	9.205	9.602	0.397	
25	Mi-C4Ar	9.602	10.008	0.406	
26	Mi-C5n	10.008	10.423	0.415	
27	Mi-C5n	10.423	10.834	0.412	
28	Mi-C5n	10.834	11.240	0.406	
29	Mi-C5r	11.240	11.644	0.405	
30	Mi-C5r	11.644	12.059	0.414	
31	Mi-C5An	12.059	12.461	0.403	
32	Mi-C5Ar	12.461	12.870	0.409	
33	Mi-C5Ar	12.870	13.273	0.403	
34	Mi-C5AAr	13.273	13.678	0.405	
35	Mi-C5ABr	13.678	14.078	0.400	
36	Mi-C5ACn	14.078	14.479	0.401	
37	Mi-C5ADn	14.479	14.895	0.416	
38	Mi-C5Bn	14.895	15.297	0.403	
39	Mi-C5Br	15.297	15.701	0.403	
40	Mi-C5Br	15.701	16.099	0.399	
41	Mi-C5Cn	16.099	16.493	0.393	
42	Mi-C5Cn	16.493	16.904	0.411	
43	Mi-C5Cr	16.904	17.308	0.404	
44	Mi-C5Dn	17.308	17.718	0.410	
45	Mi-C5Dr	17.718	18.134	0.416	
46	Mi-C5En	18.134	18.528	0.393	
47	Mi-C5Er	18.528	18.930	0.402	

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48 Mi-C6n	18.930	19.328	0.399
49 Mi-C6n	19.328	19.736	0.408
50 Mi-C6r	19.736	20.150	0.414
51 Mi-C6An	20.150	20.559	0.409
52 Mi-C6An	20.559	20.965	0.406
53 Mi-C6Ar	20.965	21.366	0.401
54 Mi-C6AAr	21.366	21.778	0.412
55 Mi-C6Bn	21.778	22.183	0.405
56 Mi-C6Bn	22.183	22.595	0.412
57 Mi-C6Cn	22.595	22.996	0.401
58 Ol-C6Cn	22.996	23.401	0.406
59 Ol-C6Cn	23.401	23.809	0.407
60 Ol-C6Cr	23.809	24.210	0.401
61 Ol-C7n	24.210	24.623	0.414
62 Ol-C7r	24.623	25.031	0.408
63 Ol-C7Ar	25.031	25.435	0.404
64 Ol-C8n	25.435	25.824	0.389
65 Ol-C8n	25.824	26.221	0.397
66 Ol-C8r	26.221	26.633	0.412
67 Ol-C9n	26.633	27.041	0.408
68 Ol-C9n	27.041	27.452	0.411
69 Ol-C9r	27.452	27.856	0.405
70 Ol-C10n	27.856	28.257	0.400
71 Ol-C10r	28.257	28.657	0.400
72 Ol-C10r	28.657	29.048	0.392
73 Ol-C10r	29.048	29.454	0.405
74 Ol-C11n	29.454	29.861	0.407
75 Ol-C11n	29.861	30.274	0.413
76 Ol-C11r	30.274	30.681	0.407
77 Ol-C12n	30.681	31.081	0.400
78 Ol-C12r	31.081	31.488	0.407
79 Ol-C12r	31.488	31.892	0.404
80 Ol-C12r	31.892	32.303	0.411
81 Ol-C12r	32.303	32.708	0.404
82 Ol-C12r	32.708	33.120	0.413
83 Ol-C12r	33.120	33.523	0.403
84 Ol-C13n	33.523	33.921	0.398
85 Eo-C13r	33.921	34.322	0.401
86 Eo-C13r	34.322	34.734	0.412
87 Eo-C13r	34.734	35.151	0.417
88 Eo-C15n	35.151	35.548	0.398
89 Eo-C16n	35.548	35.956	0.407
90 Eo-C16n	35.956	36.351	0.395
91 Eo-C16n	36.351	36.751	0.401
92 Eo-C17n	36.751	37.158	0.406
93 Eo-C17n	37.158	37.557	0.399
94 Eo-C17n	37.557	37.971	0.414
95 Eo-C17n	37.971	38.369	0.398
96 Eo-C17r	38.369	38.768	0.399

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97 Eo-C18n	38.768	39.179	0.410	
98 Eo-C18n	39.179	39.576	0.397	
99 Eo-C18n	39.576	39.979	0.403	
100 Eo-C18r	39.979	40.374	0.395	
101 Eo-C18r	40.374	40.781	0.407	
102 Eo-C18r	40.781	41.193	0.412	
103 Eo-C18r	41.193	41.601	0.408	
104	41.601	42.008	0.407	b
105	42.008	42.407	0.400	
106	42.407	42.814	0.407	
107	42.814	43.213	0.399	
108	43.213	43.625	0.413	
109	43.625	44.034	0.409	
110	44.034	44.442	0.408	
111	44.442	44.841	0.399	
112	44.841	45.238	0.396	
113	45.238	45.648	0.410	
114	45.648	46.063	0.415	
115	46.063	46.477	0.415	
116	46.477	46.875	0.398	
117	46.875	47.278	0.403	
118	47.278	47.675	0.397	
119	47.675	48.077	0.402	
120	48.077	48.485	0.409	
121	48.485	48.886	0.401	
122	48.886	49.297	0.411	
123	49.297	49.695	0.398	
124	49.695	50.100	0.405	
125	50.100	50.508	0.408	
126	50.508	50.899	0.391	
127	50.899	51.303	0.404	
128	51.303	51.704	0.401	
129	51.704	52.113	0.409	
130	52.113	52.532	0.419	
131	52.532	52.930	0.398	
132	52.930	53.331	0.401	
133	53.331	53.724	0.394	
134	53.724	54.129	0.405	
135	54.129	54.541	0.412	
136	54.541	54.953	0.412	
137	54.953	55.364	0.412	
138	55.364	55.763	0.399	
139	55.763	56.166	0.402	
140	56.166	56.568	0.402	
141	56.568	56.982	0.414	
142	56.982	57.388	0.406	
143	57.388	57.792	0.404	
144	57.792	58.202	0.410	
145	58.202	58.608	0.407	

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146	58.608	59.020	0.412
147	59.020	59.419	0.399
148	59.419	59.824	0.404
149	59.824	60.231	0.408
150	60.231	60.639	0.407
151	60.639	61.055	0.417
152	61.055	61.462	0.407
153	61.462	61.868	0.406
154	61.868	62.261	0.392
155	62.261	62.664	0.404
156	62.664	63.072	0.407
157	63.072	63.482	0.410
158	63.482	63.896	0.413
159	63.896	64.291	0.395
160	64.291	64.693	0.401
161	64.693	65.089	0.396
162	65.089	65.494	0.405
163	65.494	65.910	0.416
164	65.910	66.313	0.403
165	66.313	66.724	0.411
166	66.724	67.121	0.397
167	67.121	67.520	0.398

Notes

[a] This cycle ends in the future

[b] Cycles below Chron C19n are not named pending development on the Paleogene astronomcal time scale.

Table 3.

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Zone (BKSA 95 & BP05) (base)	Zone (This study) (base)		Datum		Notes	Astronomical Age[a]	Reference	Published Age (Ma)	Reference	Berggren et al. (1995a,b)
		T	Globorotalia	flexuosa		0.07	This study	0.07	Berggren et al. 1995 a	0.07
		T	Globigerinoides	ruber (pink)	(Indo-Pacific only)	0.12	This study	0.12	Thompson et al. 1979	-
		B	Globigerinella	calida		0.22	This study	0.22	Chaproniere et al. 1994	0.22
		B	Globorotalia	flexuosa		0.40	This study	0.40	Berggren et al. 1995 a	0.40
		B	Globorotalia	hirsuta		0.45	This study	0.45	Pujol and Duprat 1983	0.45
PT1b	**PT1b**	**T**	**Globorotalia**	**tosaensis**		**0.61**	**Lourens et al. 2004**	**0.61**	**Mix et al. 1995**	**0.65**
		B	Globorotalia	hessi		0.75	This study	0.75	Chaproniere et al. 1994	0.75
		X	random to dextral in Pulleniatina		(Pacific)	0.80	This study	0.80	Pearson 1995	-
		B	Globorotalia	excelsa		1.00	This study	1.00	Berggren et al. 1995 a	1.00
		T	Globoturborotalita	obliquus		1.30	Lourens et al. 2004	1.30	Chaisson and Pearson 1997	-
		T	Globoturborotalita	apertura		1.64	Lourens et al. 2004	1.64	Chaisson and Pearson 1997	-
Pliocene/Pleistocene boundary								*1.81*	*Aguirre and Pasini 1985*	-
PT1a	**PT1a**	**T**	**Globigerinoides**	**fistulosus**	!	**1.88**	**Lourens et al. 2004**	**1.88**	**Chaisson and Pearson 1997**	**1.77**
		B	Globorotalia	truncatulinoides	#	1.93	Lourens et al. 2004	1.92	Chaisson and Pearson 1997	2.00
		T	Globigerinoides	extremus		1.98	Lourens et al. 2004	1.98	Chaisson and Pearson 1997	1.77
		B	Pulleniatina	finalis		2.04	Lourens et al. 2004	2.04	Chaisson and Pearson 1997	-
		T	Globorotalia	exilis	(Atlantic)	2.09	Lourens et al. 2004	2.09	Chaisson and Pearson 1997	2.15
			Reappearance of Pulleniatina		(Atlantic)	2.26	Lourens et al. 2004	2.26	Chaisson and Pearson 1997	2.30
		T	Globoturborotalita	woodi		2.30	Lourens et al. 2004	2.33	Chaisson and Pearson 1997	-
		T	Globorotalia	pertenius		2.30	Lourens et al. 2004	2.33	Chaisson and Pearson 1997	-
PL6	**PL6 (Indo-Pacific)**	**T**	**Globorotalia**	**pseudomiocenica**	**(Indo-Pacific)**	**2.30**	**This study**	**2.30**	**Berggren et al. 1995 a**	**2.30**
PL6	**PL6 (Atlantic)**	**T**	**Globorotalia**	**miocenica**	**(Atlantic)**	**2.39**	**Lourens et al. 2004**	**2.38**	**Chaisson and Pearson 1997**	**2.30**
		T	Globorotalia	limbata		2.39	Lourens et al. 2004	2.38	Chaisson and Pearson 1997	-
		T	Globorotalia	pertenuis		2.60	This study	2.60	Berggren et al. 1995 a	2.60
		T	Globoturborotalita	decoraperta		2.75	Lourens et al. 2004	2.75	Chaisson and Pearson 1997	-
		T	Globorotalia	multicamerata		2.98	Lourens et al. 2004	3.10	Chaisson and Pearson 1997	3.09
PL5	**PL5 (Atlantic)**	**T**	**Dentoglobigerina**	**altispira**	**(Atlantic)**	**3.13**	**Lourens et al. 2004**	**3.11**	**Chaisson and Pearson 1997**	**3.09**
PL4	**PL4**	**T**	**Sphaeroidinellopsis**	**seminulina**	**(Atlantic)**	**3.16**	**Lourens et al. 2004**	**3.14**	**Chaisson and Pearson 1997**	**3.12**
		B	Globigerinoides	fistulosus		3.33	This study	3.33	Berggren et al. 1995 a	3.33
		B	Globorotalia	tosaensis		3.35	This study	3.35	Berggren et al. 1995 a	3.35
		T	Pulleniatina	disappearance	(Atlantic)	3.41	Lourens et al. 2004	3.41	Chaisson and Pearson 1997	-
PL5 (In	**PL5 (Indo-Pacific)**	**T**	**Dentoglobigerina**	**altispira**	**(Pacific)**	**3.47**	**Lourens et al. 2004**	**3.05**	**Shackleton et al. 1995**	-
		B	Globorotalia	pertenuis		3.52	Lourens et al. 2004	3.52	Chaisson and Pearson 1997	3.45
PL4	**PL4**	**T**	**Sphaeroidinellopsis**	**seminulina**	**(Pacific)**	**3.59**	**Lourens et al. 2004**	**3.20**	**Shackleton et al. 1995**	-
		T	Pulleniatina	primalis		3.66	This study	3.65	Berggren et al. 1995 a	3.65
		B	Globorotalia	miocenica	(Atlantic)	3.77	Lourens et al. 2004	3.77	Chaisson and Pearson 1997	3.55
		T	Globorotalia	plesiotumida		3.77	Lourens et al. 2004	3.77	Chaisson and Pearson 1997	-
PL3	**PL3**	**T**	**Globorotalia**	**margaritae**		**3.85**	**Lourens et al. 2004**	**3.85**	**Chaisson and Pearson 1997**	**3.58**

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		X	Pulleniatina	sinis.-dext.		4.08	Lourens et al.	2004	4.08	Chaisson and Pearson	1997	3.95
		T	Pulleniatina	spectabilis	(Pacific)	4.21	This study		4.20	Berggren et al.	1995 a	4.20
		B	Globorotalia	crassaformis	sensu lato	4.31	Lourens et al.	2004	4.31	Chaisson and Pearson	1997	4.50
PL2	**PL2**	**T**	**Globoturborotalita**	**nepenthes**		**4.37**	**Lourens et al.**	**2004**	**4.39**	**Chaisson and Pearson**	**1997**	**4.20**
		B	Globorotalia	exilis		4.45	Lourens et al.	2004	4.45	Chaisson and Pearson	1997	-
		T	Sphaeroidinellopsis	kochi		4.53	Lourens et al.	2004	4.53	Chaisson and Pearson	1997	-
PL1b		T	Globorotalia	cibaoensis		4.61	This study		4.60	Berggren et al.	1995 b	4.60
Miocene/Pliocene boundary						*5.33*	*Lourens et al.*	*2004*	*5.33*	*Van Couvering et al.*	*2000*	-
		B	Sphaeroidinella	dehiscens	sensu lato	5.53	Lourens et al.	2004	5.54	Chaisson and Pearson	1997	5.20
PL1a	**PL1**	**B**	**Globorotalia**	**tumida**	**(Pacific)**	**5.57**	**Lourens et al.**	**2004**	**5.59**	**Shackleton et al.**	**1995**	**5.60**
PL1a	**PL1**	**B**	**Globorotalia**	**tumida**	**(Atlantic)**	**5.72**	**Lourens et al.**	**2004**	**5.82**	**Chaisson and Pearson**	**1997**	**5.60**
		B	Turborotalita	humilis		5.81	Lourens et al.	2004	5.84	Chaisson and Pearson	1997	-
		T	Globoquadrina	dehiscens		5.92	This study		5.80	Berggren et al.	1995 a	5.80
		B	Globorotalia	margaritae		6.08	Lourens et al.	2004	6.09	Chaisson and Pearson	1997	6.40
M14	**M14**	**T**	**Globorotalia**	**lenguaensis**		**6.13**	**This study**		**6.00**	**Berggren et al.**	**1995**	**6.00**
		B	Globigerinoides	conglobatus		6.20	Lourens et al.	2004	6.20	Chaisson and Pearson	1997	-
		X	Neogloboquadrina	acostaensis	trans. sinis.-dext.	6.34	This study		6.20	Berggren et al.	1995 b	6.20
		B	Pulleniatina	primalis		6.60	This study		6.40	Berggren et al.	1995 b	6.40
		X	Neogloboquadrina	acostaensis	trans. dext.-sinis.	6.77	This study		6.60	Berggren et al.	1995 b	6.60
		X	Neogloboquadrina	atlantica	trans. dext.-sinis.	6.99	This study		6.80	Berggren et al.	1995 b	6.80
		B	Neogloboquadrina	humerosa		8.56	This study		8.50	Berggren et al.	1995 b	8.50
M13b	**M13b**	**B**	**Globorotalia**	**plesiotumida**	c	**8.58**	**Lourens et al.**	**2004**	**8.58**	**Chaisson and Pearson**	**1997**	-
		B	Globigerinoides	extremus	b	8.93	Lourens et al.	2004	8.94	Turco et al.	2002	-
		B	Globorotalia	cibaoensis		9.44	Lourens et al.	2004	9.44	Chaisson and Pearson	1997	-
		B	Globorotalia	juanai		9.69	Lourens et al.	2004	9.76	Chaisson and Pearson	1997	-
M13a	**M13a**	**B**	**Neogloboquadrina**	**acostaensis**		**9.83**	**Lourens et al.**	**2004**	**9.82**	**Chaisson and Pearson**	**1997**	**10.90**
M12	**M12**	**T**	**Paragloborotalia**	**mayeri**		**10.46**	**Lourens et al.**	**2004**	**10.49**	**Chaisson and Pearson**	**1997**	**11.40**
		B	Globorotalia	limbata		10.64	Lourens et al.	2004	10.57	Chaisson and Pearson	1997	-
		T	Cassigerinella	chipolensis	b	10.89	Lourens et al.	2004	10.81	Turco et al.	2002	-
		B	Globoturborotalita	apertura		11.18	Lourens et al.	2004	11.19	Chaisson and Pearson	1997	-
		B	Globoturborotalita	decoraperta		11.49	Lourens et al.	2004	11.46	Chaisson and Pearson	1997	-
		T	Globigerinoides	subquadratus	b	11.54	Lourens et al.	2004	11.55	Turco et al.	2002	-
M11	**M11**	**B**	**Globoturborotalita**	**nepenthes**	a	**11.63**	**Lourens et al.**	**2004**	**11.64**	**Turco et al.**	**2002**	**11.80**
M10	**M10**	**T**	**Fohsella**	**fohsi**		**11.79**	**Lourens et al.**	**2004**	**11.68**	**Chaisson and Pearson**	**1997**	**11.90**
		T	Globorotalia	praescitula		13.73	Lourens et al.	2004	11.90	Berggren et al.	1995	11.90
		B	Globorotalia	lenguaensis	a	12.84	Lourens et al.	2004	12.39	Turco et al.	2002	-
		B	Sphaeroidinellopsis	subdehiscens	b	13.02	Lourens et al.	2004	13.03	Turco et al.	2002	-
M9b	**M9b**	**B**	**Fohsella**	**robusta**		**13.13**	**Lourens et al.**	**2004**	**13.18**	**Chaisson and Pearson**	**1997**	**12.30**
M9a		B	Fohsella	lobata		-	-		12.50	Berggren et al.	1995 b	12.50
		T	Cassigerinella	martinezpicoi	b	13.27	Lourens et al.	2004	13.28	Turco et al.	2002	-
M8	**M9a**	**B**	**Fohsella**	**fohsi**		**13.41**	**Lourens et al.**	**2004**	**13.42**	**Chaisson and Pearson**	**1997**	**12.70**
	M8	**B**	**Fohsella**	**"praefohsi"**		**13.77**	**Lourens et al.**	**2004**	**14.00**	**Pearson and Chaisson**	**1997**	-
		T	Fohsella	peripheroronda	b	13.80	Lourens et al.	2004	13.87	Turco et al.	2002	14.60

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		T	Clavatorella	bermudezi			13.82	Lourens et al. 2004	14.20	Pearson and Chaisson 1997	-
		T	Globorotalia	archeomenardii	b		13.87	Lourens et al. 2004	13.87	Turco et al. 2002	-
M7	M7	B	Fohsella	peripheroacuta	a		14.24	Lourens et al. 2004	14.02	Turco et al. 2002	14.80
		B	Globorotalia	praemenardii			14.38	Lourens et al. 2004	14.90	Pearson and Chaisson 1997	-
		T	Praeorbulina	sicana			14.53	Lourens et al. 2004	14.40	Shackleton et al. 1999	14.80
		T	Globigerinatella	insueta			14.66	Lourens et al. 2004	15.00	Pearson and Chaisson 1997	-
M6	M6	B	Orbulina	suturalis			15.10	This study	15.10	Berggren et al. 1995 b	15.10
		B	Clavatorella	bermudezi	f		15.73	This study	15.80	Pearson and Chaisson 1997	-
		B	Praeorbulina	circularis	e		15.96	This study	16.00	Berggren et al. 1995 b	16.00
		B	Globorotalia	archeomenardii			16.26	Lourens et al. 2004	16.20	Pearson and Chaisson 1997	-
M5b	M5b	B	Praeorbulina	glomerosa		sensu stricto	16.27	Lourens et al. 2004	16.20	Shackleton et al. 1999	16.10
		B	Praeorbulina	curva			16.28	This study	16.30	Berggren et al. 1995 b	16.30
M5a	M5a	B	Praeorbulina	sicana			16.38	This study	16.40	Berggren et al. 1995 b	16.40
M4b	M4b	B	Fohsella	birnageae			16.69	This study	16.70	Berggren et al. 1995 b	16.70
		B	Globorotalia	zealandica	h		17.26	This study	17.30	Berggren et al. 1995 b	16.30
M4a	M4a	T	Catapsydrax	dissimilis			17.54	Lourens et al. 2004	17.50	Shackleton et al. 1999	17.30
M3		B	Globigerinatella	insueta s. str.			17.59	Lourens et al. 2004	17.40	Pearson and Chaisson 1997	(18.8)
		B	Globorotalia	praescitula			18.26	This study	18.50	Berggren et al. 1995 b	18.50
		T	Globoquadrina	binaiensis			19.09	Lourens et al. 2004	19.10	Pearson and Chaisson 1997	-
	M3	B	Globigerinatella	sp.			19.30	Lourens et al. 2004	20.20	Pearson and Chaisson 1997	-
		B	Globigerinoides	altiaperturus			20.03	This study	20.50	Berggren et al. 1995 b	20.50
		T	Tenuitella	munda			20.78	This study	21.40	Berggren et al. 1995	21.40
		T	Globigerina	angulisuturalis			20.94	This study	21.60	Berggren et al. 1995 b	21.60
M2	M2	T	'Paragloborotalia'	kugleri			21.12	Lourens et al. 2004	21.00	Shackleton et al. 1999	21.50
		T	'Paragloborotalia'	pseudokugleri			21.31	Lourens et al. 2004	21.10	Shackleton et al. 1999	21.60
M1b	M1b	B	Globoquadrina	dehiscens			22.44	This study	23.20	Berggren et al. 1995 b	23.20
		T	Globigerina	ciperoensis			22.90	Lourens et al. 2004	22.80	Shackleton et al. 1999	-
		B	Globigerinoides	trilobus		sensu lato	22.96	Lourens et al. 2004	22.90	Shackleton et al. 1999	-
M1a	M1a	B	'Paragloborotalia'	kugleri			22.96	Lourens et al. 2004	22.90	Shackleton et al. 1999	23.80
Oligocene/Miocene boundary							*23.03*	*Lourens et al. 2004*	*23.80*	*Berggren et al. 1995 b*	

Notes

a Calibrated to Lourens et al. (2004)

b Calibration of Turco et al. (2002) on Astronomical Time Scale of Shackleton and Crowhurst (1997)

c Replaces the and/or non zone of (†) BKSA95

e Note mistake in Lourens et al. (2004) Table A2.3, where Bottom *Praeorbulina circularis* should read Top *Praeorbulina circularis*

f Note mistake in Shackleton et al. (1999) where 14.8 Ma should read 15.8 Ma. This mistake is also propogated in Lourens et al. (2004)

g Traditionally used as base N22, this datum is considered highly diachronous between ocean basins (see Dowsett, 1988).

h Note mistake in BKSA95 (page 174) where LAD should read FAD

i Note mistake in Berggren et al. (1995a, Table 6) where 1.6 Ma should read 1.77 Ma

X Change in coiling direction

Table 4.

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Zone (BKSA95 & BP05) (base)	Zone (This study) (base)		Datum		Age (Ma) This Study[a]	Astronomical Age[b]	Published Age (Ma)	Reference	Berggren et al. (1995a,b)	Berggren & Pearson (2005)
		T	*Tenuitella*	*gemma*	23.6	23.5	24.3	Berggren et al. 1995 b	24.3	-
		LCO	*Globigerinoides*	*primordius*	23.6	23.5	24.3	Berggren et al. 1995 b	24.3	-
	O7	**B**	***'Paragloborotalia'***	***pseudokugleri***	**25.4**	**25.2**	**25.9**	**Berggren et al. 1995 b**	**25.9**	-
		B	*Globigerinoides*	*primordius*	26.3	26.1	26.7	Berggren et al. 1995 b	26.7	-
O6	**O6**	**T**	***Paragloborotalia***	***opima***	**27.3**	**26.9**	**27.5**	**Wade et al. 2007**	**27.1**	**27.1**
O5	**O5**	**HCO**	***Chiloguembelina***	***cubensis***	**28.3**	**28.0**	**28.4**	**Wade et al. 2007**	**28.5**	**28.5**
O4	**O4**	**B**	***Globigerina***	***angulisuturalis***	**29.5**	**29.2**	**29.4**	**Berggren et al. 1995 b**	**29.4**	**29.4**
		T	*Subbotina*	*angiporoides*	30.1	29.8	30.0	Berggren et al. 1995 b	30.0	30.0
O3	**O3**	**T**	***Turborotalia***	***ampliapertura***	**30.4**	**30.3**	**30.3**	**Berggren et al. 1995 b**	**30.3**	**30.3**
		B	*Paragloborotalia*	*opima*	30.8	30.8	30.6	Berggren et al. 1995 b	30.6	-
O2	**O2**	**T**	***Pseudohastigerina***	***naguewichiensis***	**32.2**	**32.0**	**32.0**	**Berggren et al. 1995 b**	**32.0**	**32.0**
Eocene/Oligocene boundary							*33.7*	*Berggren et al. 1995 b*	-	-
O1	**O1**	**T**	***Hantkenina***	***alabamensis***	**33.9**	**33.8**	**33.7**	**Berggren and Pearson 2005**	**33.7**	**33.7**
		HCO	*Pseudohastigerina*	*micra*	33.9	33.8	33.7	Wade and Pearson 2008	-	-
		T	*Turborotalia*	*cerroazulensis*	34.0	33.9	33.8	Berggren and Pearson 2005	33.8	33.8
E16	**E16**	**T**	***Globigerinatheka***	***index***	**34.5**	**34.5**	**34.3**	**Berggren and Pearson 2005**	**34.3**	**34.3**
		B	*Turborotalia*	*cunialensis*	35.4	35.4	35.3	Berggren and Pearson 2005	35.2	35.3
E15	**E15**	**T**	***Globigerinatheka***	***semiinvoluta***	**35.8**	**35.8**	**35.8**	**Berggren and Pearson 2005**	**35.3**	**35.8**
		B	*Globigerinatheka*	*semiinvoluta*	37.7	38.0	38.0	Wade 2004	38.4	-
E14	**E14**	**T**	***Morozovelloides***	***crassatus***	**37.7**	**38.1**	**38.0**	**Wade 2004**	**38.1**	**38.0**
		T	*Acarinina*	*mcgowrani*	37.7	38.1	38.0	Wade 2004	-	-
		T	*Turborotalia*	*frontosa*	38.8	39.3	39.3	Berggren et al. 1995 b	39.3	-
E13	**E13**	**T**	***Orbulinoides***	***beckmanni***	**39.4**	**40.0**	**40.0**	**Wade 2004**	**40.1**	**40.0**
E12	**E12**	**B**	***Orbulinoides***	***beckmanni***	**39.8**	**40.8**	**40.5**	**Berggren et al. 1995 b**	**40.5**	**40.5**
		T	*Acarinina*	*bullbrooki*	39.8	40.8	40.5	Berggren et al. 1995 b	40.5	-
E11	**E11**	**T**	***Guembilitrioides***	***nuttalli***	**(41.4)**	-	**(42.3)**	**Berggren and Pearson 2005**	-	**(42.3)**
		B	*Turborotalia*	*pomeroli*	41.5	-	42.4	Berggren et al. 1995 b	42.4	-
		B	*Globigerinatheka*	*index*	41.9	-	42.9	Berggren et al. 1995 b	42.9	-
		B	*Morozovelloides*	*lehneri*	42.5	-	43.5	Berggren et al. 1995 b	43.5	-
E10	**E10**	**T**	***Morozovella***	***aragonensis***	**42.6**	-	**43.6**	**Berggren et al. 1995 b**	**43.6**	**43.6**
E9	**E9**	**B**	***Globigerinatheka***	***kugleri***	**(43.4)**	-	-	**Pearson et al. 2004**	**45.8**	**45.8**
		B	*Hantkenina*	*singanoae*	43.5	-	43.5	Payros et al. 2009	49.0	-
E8	**E8**	**B**	***Guembilitrioides***	***nuttalli***	**45.5**	-	**45.5**	**Payros et al. 2009**	-	**49.0**
	E7b	**B**	***Turborotalia***	***frontosa***	**48.6**	-	**48.6**	**Payros et al. 2009**	-	-
E7	**E7a**	**B**	***Acarinina***	***cuneicamerata***	**50.3**	-	**50.4**	**Hancock et al. 2002**	-	**50.4**
		B	*Planorotalites*	*palmerae*	50.3	-	50.4	Berggren et al. 1995 b	50.4	-

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E6	E6	T	Morozovella	subbotinae		50.8	-	50.8	Berggren	and	Pearson	2005	-	50.8
E5	E5	B	Morozovella	aragonensis		52.3	-	52.3	Berggren	et	al.	1995 b	52.3	52.3
		T	Morozovella	marginodentata		52.8	-	52.5	Berggren	et	al.	1995 b	52.5	-
		T	Morozovella	lensiformis		53.1	-	52.7	Berggren	et	al.	1995 b	52.7	-
		T	Morozovella	aequa		54.0	-	53.6	Berggren	et	al.	1995 b	53.6	-
E4	E4	B	Morozovella	formosa		54.4	-	54.0	Berggren	et	al.	1995 b	54.0	54.0
		B	Morozovella	lensiformis		54.4	-	54.0	Berggren	et	al.	1995 b	54.0	-
E3	E3	T	Morozovella	velascoensis		54.9	-	54.5	Berggren	and	Pearson	2005	54.7	54.5
		T	Morozovella	acuta		55.1	-	54.7	Berggren	et	al.	1995 b	54.7	
		B	Morozovella	gracilis		55.1	-	54.7	Berggren	et	al.	1995 b	54.7	-
		B	Igorina	broedermanni		55.1	-	54.7	Berggren	et	al.	1995 b	54.7	-
		B	Morozovella	marginodentata		55.2	-	54.8	Berggren	et	al.	1995 b	54.8	-
E2	E2	B	Pseudohastigerina	wilcoxensis		55.7	-	55.4	Berggren	and	Pearson	2005	-	55.4
		B	Globanomalina	australiformis		55.8	-	55.5	Berggren	et	al.	1995 b	55.5	-
E1	E1	B	Acarinina	sibaiyaensis		55.8	-	55.5	Berggren	and	Pearson	2005	-	55.5
Paleocene/Eocene boundary						*55.8*	-	*55.5*	*Ouda*	*and*	*Aubry*	*2003*		
P5	P5	T	Globanomalina	pseudomenardii		56.7	-	55.9	Berggren	et	al.	1995 b	55.9	55.9
		B	Morozovella	subbotinae		56.7	-	55.9	Berggren	et	al.	1995 b	55.9	-
		T	Acarinina	mckannai		57.1	-	56.3	Berggren	et	al.	1995 b	56.3	-
		T	Acarinina	acarinata		57.1	-	56.3	Berggren	et	al.	1995 b	56.3	-
P4c	P4c	B	Acarinina	soldadoensis	d	57.3	-	56.5	Berggren	et	al.	1995 b	56.5	56.5
		B	Acarinina	coalingensis		57.3	-	56.5	Berggren	et	al.	1995 b	56.5	-
		B	Morozovella	aequa		57.3	-	56.5	Berggren	et	al.	1995 b	56.5	-
		T	Acarinina	subsphaerica		57.9	-	57.1	Berggren	et	al.	1995 b	57.1	57.1
		B	Acarinina	mckannai		59.9	-	59.1	Berggren	et	al.	1995 b	59.1	-
P4b	P4b	T	Parasubbotina	variospira		60.0	-	59.2	Berggren	et	al.	1995 b	59.2	59.2
		B	Acarinina	acarinata		60.0	-	59.2	Berggren	et	al.	1995 b	59.2	-
		B	Acarinina	subsphaerica		60.0	-	59.2	Berggren	et	al.	1995 b	59.2	-
P4a	P4a	B	Globanomalina	pseudomenardii		60.2	-	59.4	Berggren	et	al.	2000	59.2	59.4
P3b	P3b	B	Igorina	albeari		60.8	-	60.0	Berggren	et	al.	1995 b	60.0	60.0
		B	Morozovella	velascoensis		60.8	-	60.0	Berggren	et	al.	1995 b	60.0	-
		B	Morozovella	conicotruncata		61.7	-	60.9	Berggren	et	al.	1995 b	60.9	-
P3a	P3a	B	Morozovella	angulata		61.7	-	61.0	Berggren	et	al.	1995 b	61.0	61.0
		B	Igorina	pusilla		61.7	-	61.0	Berggren	et	al.	1995 b	61.0	-
		B	Morozovella	praeangulata		61.9	-	61.2	Berggren	et	al.	1995 b	61.2	-
		B	Globanomalina	imitata		(62.0)	-	(61.3)	Berggren	et	al.	1995 b	(61.3)	-
P2	P2	B	Praemurica	uncinata		62.1	-	61.4	Berggren	and	Pearson	2005	61.2	61.4
P1c	P1c	B	Globanomalina	compressa	c	63.5	-	62.9	Berggren	and	Pearson	2005	63.0	62.9
		B	Praemurica	inconstans		63.5	-	62.9	Berggren	and	Pearson	2005	63.0	62.9
		B	Parasubbotina	varianta		63.6	-	63.0	Berggren	et	al.	1995 b	63.0	-

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P1b	**P1b**	**B**	**Subbotina**	**triloculinoides**	**64.7**	-	**64.3**	**Berggren**	**et**	**al.**	**1995 b**	**64.3**	**64.3**
P1a	**P1a**	**T**	**Parvularugoglobige**	**eugubina**	**65.2**	-	**64.8**	**Berggren**	**and**	**Pearson**	**2005**	**64.7**	**64.8**
		B	Parvularugoglobigerir	extensa	65.4	-	64.9	Olsson	et	al.	1999	-	-
Pα	**Pα**	**B**	**Parvularugoglobige**	**eugubina**	**65.46**	-	**64.97**	**Berggren**	**et**	**al.**	**1995 b**	**64.97**	**64.97**
P0	**P0**	**T**	**Globotruncana**		**65.5**	-	**65.0**	**Berggren**	**et**	**al.**	**1995 b**	**65.0**	**65.0**

Notes

a Calibrated to Gradstein et al. (2004)

b Calibrated to Pälike et al. (2006)

c Replaces the and/or non zone of Berggren & Pearson (2005)

d Note mistake in Berggren & Pearson (2005)

HCO Highest common occurrence

LCO Lowest common occurrence

(43.4) Estimated age