Journal of Foraminiferal Research, v. 35, no. 4, p. 279–298, October 2005

A REVISED TROPICAL TO SUBTROPICAL PALEOGENE PLANKTONIC FORAMINIFERAL ZONATION

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ABSTRACT

New biostratigraphic investigations on deep sea cores and outcrop sections have revealed several shortcomings in currently used tropical to subtropical Eocene planktonic foraminiferal zonal schemes in the form of: 1) modified taxonomic concepts, 2) modified/different ranges of taxa, and 3) improved calibrations with magnetostratigraphy. This new information provides us with an opportunity to make some necessary improvements to existing Eocene biostratigraphic schemes. At the same time, we provide an alphanumeric notation for Paleogene zones using the prefix 'P' (for Paleocene), 'E' (for Eocene) and 'O' (for Oligocene) to achieve consistency with recent short-hand notation for other Cenozoic zones (Miocene ['M'], Pliocene [PL] and Pleistocene [PT]).

Sixteen Eocene (E) zones are introduced (or nomenclaturally emended) to replace the 13 zones and subzones of Berggren and others (1995). This new zonation serves as a template for the taxonomic and phylogenetic studies in the forthcoming *Atlas of Eocene Planktonic Foraminifera* (Pearson and others, in press). The 10 zones and subzones of the Paleocene (Berggren and others, 1995) are retained and renamed and/or emended to reflect improved taxonomy and an updated chronologic calibration to the Global Polarity Time Scale (GPTS) (Berggren and others, 2000). The Paleocene/Eocene boundary is correlated with the lowest occurrence (LO) of *Acarinina sibaiyaensis* (base of Zone E1), at the top of the truncated and redefined (former) Zone P5.

The five-fold zonation of the Oligocene (Berggren and others, 1995) is modified to a six-fold zonation with the elevation of (former) Subzones P21a and P21b to zonal status. The Oligocene (O) zonal components are renamed and/or nomenclaturally emended.

INTRODUCTION

The application of planktonic foraminiferal biostratigraphic studies may be said to be an essentially post-World War II phenomenon (although there were several pre-war contributions of less than lasting value) which resulted from the recognition of their usefulness in local and regional biostratigraphic zonation and correlation. These studies were often, but not exclusively, connected with petroleum exploration, particularly in the North Caucasus, Crimea, Tadzhik Depression and other areas of the southwestern (former) Soviet Union (Subbotina, 1947, 1953; Morozova, 1939, 1961; Alimarina, 1962, 1963; Leonov and Alimarina, 1961; Shutskaya, 1956, 1958, 1960a, b, 1970; Shutskaya and others, 1965). A largely independent zonal scheme was developed in the Caribbean region (Brönniman, 1952; Bolli, 1957a, b; 1966), and was subsequently applied to the United States Gulf Coast and Atlantic Coastal Plain (Loeblich and Tappan, 1957) and expanded in various petroleum exploration regions of the world (Blow and Banner, 1962; Blow, 1969, 1979; Stainforth and others, 1975). Various biostratigraphic zonal schemes were developed by these authors, among others, and have been firmly ensconced in the classic biostratigraphic literature of the past half century.

Since the advent of the Deep Sea Drilling Project (DSDP; 1968–1984) and its successor programs, the Ocean Drilling Program (ODP) and Integrated Ocean Drilling Program (IODP), these various zonal schemes have found widespread application in regional and global biostratigraphic studies. In the following section, we supplement recent reviews of Paleocene zonations of the West by presenting a brief review of the major Paleogene biostratigraphic studies and zonal schemes developed over the past 50 years in the Former Soviet Union (FSU) and the West, with a particular focus on the Eocene. It should be remembered that many of these studies were conducted as part of a larger study of the Paleogene or, indeed, the entire Cenozoic, so that reference to the larger framework is unavoidable in certain instances.

Following this overview, we introduce a revised low-latitude (tropical and subtropical) Paleogene planktonic foraminiferal zonation. There are several reasons (discussed below) why a revised zonation has become necessary at this time. These reasons arise variously from taxonomic developments, new stratigraphic information or perceived shortcomings in previous schemes. The new zonation is intended to accompany the publication of a new *Atlas of Eocene Planktonic Foraminifera* (Pearson and others, in press) which uses the zonation outlined here as its biostratigraphic basis. Most of the updates presented here refer to the Eocene, but the Paleocene and Oligocene zones are also treated for sake of completeness and numerical continuity.

REVIEW OF EOCENE PLANKTONIC FORAMINIFERAL ZONATIONS

A history of Paleogene planktonic foraminiferal zonations in the Former Soviet Union (FSU) was presented by Berggren (1960), and an updated review of Paleocene zonations of the FSU was presented by Berggren and Norris (1997). Comparable reviews of Paleogene zonations of the Caribbean and Mediterranean may be found in Bolli and others (1985). These need not be repeated here. Inasmuch as the emphasis in this paper is on a revised zonation for the low-latitude (tropical and subtropical) Eocene, we present below a more extensive review of that interval as expressed in the FSU and Middle East.

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The Former Soviet Union and Middle East

Biostratigraphic studies of planktonic foraminifera in general (and of Eocene assemblages in particular) may be said to have originated in the FSU. In careers that spanned more than 50 years, Martin Glaessner (Moscow) and Nina Nikolaevna Subbotina (Leningrad/St. Petersburg) became the "patron saints". Subbotina died in the early 1980s; the Austrian-born Glaessner left Moscow for Vienna during the infamous Stalin trials in 1937, subsequently relocating (1938) to pursue a career in Australia. He died in 1989; see Gruzman and others (1986) and McGowan (1994), respectively, for moving tributes to these two pioneering micropaleontologists. In the mid-late 1930's both authors published seminal papers on the biostratigraphy of the Caucasus Mountains (Glaessner, 1934, 1937a, b; Subbotina, 1934, 1936, 1939; see also Morozova, 1939), which basically established the use of planktonic foraminifera in regional biostratigraphic studies. Subbotina was able to establish several zones for the Paleogene (and, in particular, the Eocene) of the northern Caucasus; in 1947 she expanded her studies into the northeastern Caucasus and, subsequently, published her now famous synoptic monograph (Subbotina, 1953) on Upper Cretaceous and Paleogene planktonic foraminifera.

Important biostratigraphic studies/reviews concerning at least part of the Eocene were subsequently published by Alimarina (1962, 1963), Leonov and Alimarina (1964), Shutskaya (1956, 1958, 1960a, b, 1970), and Shutskaya and others (1965). The study by Shutskaya (1970) is notable in that it presents a synthesis of her decade-long studies in the southwest FSU, including a review of the detailed zonation of the Paleocene-lower Eocene succession which she developed in the 1960s, and an exhaustive historical overview of the Paleogene biostratgraphic succession and faunal characteristics of the Crimean Peninsula, northern Precaucasus and Transcaspian region and western part of central Asia. In the latter work (Shutskaya, 1970) she included 40 plates with detailed illustrations of the assemblage content (planktonic and benthic taxa) of each Paleocene and lower Eocene zone from each region, which makes it possible to understand better the basis for biostratigraphic subdivision of the Paleogene of the FSU. It also permits her zonal scheme to be correlated with those proposed contemporaneously, and subsequently, in the West. Finally, Krasheninnikov (1965, 1969) made important contributions to Eocene biostratigraphy in the FSU, as well as other (sub)tropical regions of the world (see below), including correlation of planktonic and calcareous nannoplankton biostratigraphies in the North Caucasus (Krasheninnikov and Muzylev, 1975).

A thorough review of early (early 1930's–late 1950's) Soviet publications on Paleogene planktonic foraminiferal biostratigraphic studies was published by Berggren (1960). An up-to-date review of Paleocene-lower Eocene zonal schemes formulated by Shutskaya was presented by Berggren and Norris (1997), and a correlation framework of Soviet and western Paleogene (including the Eocene) zonal schemes was published by Blow (1979).

Valery Krasheninnikov has devoted a significant effort to presenting overviews and comparisons of planktonic foraminiferal zonal biostratigraphy on a global basis. These include Syria (Krasheninnikov, 1964a, b; Krasheninnikov and others, 1964; Ponikarov and others, 1969; Krasheninnikov and Nemkov, 1975), Armenia (Krasheninnikov and Ptukhyan, 1973), Egypt (Krasheninnikov and Ponikarov, 1964),Yugoslavia (Krasheninnikov and others, 1968), the North Pacific Ocean (Krasheninnikov, 1982; Krasheninnikov and others, 1988), the Southern Oceans (Krashennikov and Basov, 1986) and the (sub)tropical regions of the world (Krasheninnikov, 1969), resulting in a synoptic overview of Paleogene global biostratigraphy (Bolli and Krasheninnikov (1977). Among the pertinent observations relevant to this study (Krasheninnikov, 1969; Bolli and Krasheninnikov, 1977) we can cite the following:

1) There is a general, but systematic, change in taxic composition and a decrease in diversity among Eocene planktonic foraminiferal faunas in a northerly direction from the Mediterranean (Egypt and Syria), through the intermediately situated Armenia, to the Crimea-North Caucasus region.
2) Some taxa appear to have had different stratigraphic ranges in different (sub)provinces. The reasons for this appear to be that ranges have been partly biofacies-controlled (nummultiic versus open-ocean biofacies) and partly latitudinally controlled.
3) Planktonic foraminiferal assemblages are essentially similar in taxic composition throughout the Caucasus, Armenia, Syria and Egypt (allowing for facies changes in given stratigraphic settings, such as the presence of nummulitic deposits in shallow-water environments), with the following notable exceptions:

   early Eocene: absence (or extreme rarity) in the northern Caucasus, Crimean regions of *Astrorotalia palmerae* and *Subbotina senni,* and rarity of *Acarinina aspensis*;

   middle Eocene: absence in the Crimea-Caucasus of such forms as *Orbulinoides, Globigerinatheka, Globorotaloides, Clavigerinella, Planorotalites renzi* (=*P. pseudoscitula*), *"Morozovella" spinulosa, "M." lehneri, Acarinina spinuloinflata, "Subbotina" bolivariana, Guembelitrioides higginsi* (=*G. nuttalli* of this paper), *Subbotina senni, Acarinina rohri, Hantkenina mexicana, H. dumblei, H. alabamensis* i.al.;

   upper Eocene: absence or extreme rarity in the Crimea—Caucasus of such forms as *Hantkenina, Cribrohantkenina, Turborotalia ampliapertura, Catapsydrax unicavus, Turborotalia cerroazulensis, Globigerinatheka semiinvoluta,* i.al.
4) Disjunct and sporadic occurrences/ranges of several taxa are noted. For example, in the Mediterranean and Armenian regions, *Turborotalia cerroazulensis* s.l. appears in the *Orbulinoides beckmanni* Zone and ranges to the top of the Eocene, whereas it is representative only of the late/upper Eocene in the northern Caucasus. *Globigerinatheka index* is a long-ranging form (*G. kugleri* Zone to the top of the Eocene) in the Mediterranean-Armenian area, whereas in the Crimea-Caucasus it has a discontinuous range: it is rare in the *Acarinina rotundimaginata* Zone, abundant in the *Hantkenina alabamensis* Zone and absent in the *"Globigerina" turcmenica* Zone; it reappears in the lower and middle parts of the upper Eocene.

These disjunct or anomalous stratigraphic distribution patterns reflect the gradual growth of faunal provincialism that followed the planktonic foraminiferal (and larger nummulitic) major extra-tropical Eocene excursions into high latitudes. Excursions into northern (Berggren, 1970, 1971) and southern (McGowran, 1977, 1978, 1986) latitudes occurred during the early Eocene "Climatic Optimum" (Zone P6b-P7 of Berggren and others, 1995, zonation) and, again, in the late middle Eocene, during the so-called Khirthar Transgression of the Indo-Pacific region, correlative with Zones E10-E13 as defined below. This transgression brought warm biotic elements to Australia (McGowran, 1977; McGowran and Li, 2000) and hantkeninids as far north as 53° N (DSDP Site 647, southern Labrador Sea; observation by WAB based on samples from M. Kaminski, 1995).

Following the major climatic warming associated with the first of these events and centered on Chrons C24r-C23n (~ 55–51 Ma) in particular, there was a gradual decline in extra-tropical surface-water temperatures, which is reflected in the gradual biogeographic compartmentalization of planktonic foraminiferal assemblages. This has resulted in a need for independent biostratigraphic zonal schemes to reflect the changing distribution patterns. For instance, although typical (sub)tropical planktonic foraminiferal taxa occur throughout the lower Eocene of the southern Indian Ocean, keeled morozovellids were restricted to the E4-E5 (as defined below) excursion (Kerguelen Plateau; Huber, 1991; Berggren, 1992), and acarininids and subbotinids characterize the contemporaneous high-latitude, austral South Atlantic assemblages in the absence of keeled morozovellids (Maud Rise; Stott and Kennett, 1990; Huber, 1991; see paper by Huber and Quillévéré, this volume). However, by the middle Eocene, austral faunas were characterized by low-diversity acarininid (*A. collactea, A. primitiva*), subbotinid (*S. angiporoides, S. linaperta*) and globigerinathekid (abundant *G. index*) assemblages. The acarininids were replaced in the late Eocene by catapsydracids (*C. dissimilis, C. unicavus*), *Globorotaloides* (the form referred to as "*G. suteri*" by most authors), subbotinids (*S. angiporoides,* S. *hagni-eocaena* group) and small globigerinids (*G. officinalis* group). These austral assemblages have their contemporaneous, taxically comparable counterparts in the upper Eocene of the North Atlantic (Berggren, 1972), the North Sea (Berggren, 1970; King, 1981, 1989; Gradstein and others, 1994) and northwestern Europe (Søvind Marl Formation of Denmark).

The West

Eocene planktonic foraminiferal biostratigraphy in the West was essentially initiated in the form of a detailed zonation developed for the stratigraphic succession in Trinidad by Bolli (1957a, b). His zonation was subsequently followed by zonal schemes developed for (sub)tropical regions in general by Berggren (1969, 1971b), and modified and redefined by Berggren and Miller (1988), Berggren (in Berggren and others, 1995) and Blow (1969, 1979). Premoli Silva and Bolli (1973) made minor changes to the earlier version of Bolli (1957a) with the insertion of the *Globorotalia edgari* Zone between the *Globorotalia velascoensis* Zone (below) and the *Globorotalia rex* (= *G. subbotinae*) Zone (above). Comprehensive reviews of Paleogene (sub)tropical zonal biostratigraphy were given by Blow (1979) and Berggren and Miller (1988), and particularly by Toumarkine and Luterbacher (1985).

Jenkins (1971), as part of a larger Cenozoic study, formulated a relatively broad biostratigraphic scheme for the Eocene succession of New Zealand. With the recognition that Paleocene low-latitude, (sub)tropical zonations are not fully applicable at high latitudes, Stott and Kennett (1990) developed a zonal biostratigraphy for high austral latitudes (Maud Rise) which also found application in the southern Indian Ocean (Kerguelen Plateau) in studies by Huber (1991) and Berggren (1992). A modified zonation for the Antarctic Paleogene is provided in a companion paper by Huber and Quillévéré (this issue).

Major Faunal Trends

A brief summary of the main biotic trends observed in the planktonic foraminifera during the Eocene is presented below. Aspects of these trends have been used by various authors in the delineation of zonal schemes over the past 50 years.

1. Conical morozovellids and robust acarininids reached their highest diversity in the latest Paleocene and early Eocene, respectively (Berggren, 1971b, Figure 1). Subsequent taxonomic studies (Berggren, 1977; Berggren and Norris, 1997; Blow, 1979) have not changed this picture significantly, with the exception of the morphologic/taxonomic change noted below.
2. The appearance during the late early to early middle Eocene of a keeled lineage that is considered homeomorphic with *Morozovella* (*M. bandy, M. crassata, M.coronata, M. lehneri*), which is being ascribed to a new genus in the forthcoming *Atlas of Eocene Planktonic Foraminifera* (Pearson and Berggren, in press). The middle Eocene is characterized by the sequential flattening of tests (*M. crassata*/*M. spinulosa* and *M. lehneri*) and the extinction of this lineage near the middle/upper Eocene boundary. Also occurring in the early middle Eocene was the disappearance of the true *Morozovella* lineage (represented by *M. aragonensis*) within the lower middle Eocene (upper Lutetian Stage).
3. Modification of the basic acarininid morphology by the development of supplementary apertures in the majority of individuals in populations led in the middle Eocene to the appearance of forms generally assigned to the genus *Truncorotaloides* in the midde Eocene and to which the group is restricted. In the Eocene Atlas (Pearson and others, in press) we retain these forms in the genus *Acarinina,* however.
4. The igorinid lineage, while never taxically diverse, underwent a reduction in diversity during the early Eocene and became extinct during the early middle Eocene. Test form became more planoconvex and more weakly muricate during the early Eocene than in late Paleocene antecedents, whereas the terminal member of the lineage (*I. anapetes*) is characterized by up to nine chambers in the final whorl and a more evolute test.
5. Planispirality returned as a morphogenetic novelty near the Paleocene/Eocene boundary with the evolution of

Pseudohastigerina from *Globanomalina*, and, again, with the independent origin of *"Subbotina" bolivariana* (a form assigned to a new genus in the Eocene Atlas [Pearson and others, in press]) from *Parasubbotina* near the early/middle Eocene boundary.

6. In the early Eocene, radially elongate chambers developedon a weakly spinose test (*Parasubbotina eoclava*), followed by formation of clavate chambers bearing a dense pore pattern within a wall having narrow cancellate ridges (*Clavigerinella*). Subsequently, there was a reduction of the surficial cancellation and concomitant acquisition in the middle Eocene of elongate, hollow tubulospines at the midpoint of chamber extremities and, later, during the latest Eocene at intercameral loci (*Hantkenina*) and multiple apertures located on the apertural face (*Cribrohantkenina*).
7. Globular tests with multiple supplementary apertures appeared in the middle Eocene (*Guembelitrioides, Globigerinatheka, Orbulinoides*) and extended to near the end of the Eocene, where the disappearance of the globigerinathekid lineage (*G. index, G. luterbacheri and G. tropicalis*) occurred.
8. The turborotaliids, a long-ranging conservative group, appeared during the late early Eocene with *Turborotalia frontosa* through the modification of a globanomalinid (*Globanomalina australiformis*) morphology. However, the turborotaliids developed a distinct, and biostratigraphically useful, morphologic trend during the middle and late Eocene consisting of a gradual reduction in wall cancellation and test compression, leading to a smooth-walled carinate test (*T. cunialensis*) during the terminal Eocene.
9. Subbotinids continued to diversify during the Eocene, particularly in austral latitudes where the *S. linaperta* and *S. angiporoides* plexi dominated.
10. Spinose and cancellate 'globigerinids' appeared in the late Eocene (*Globigerina officinalis* and *Globoturborotalita ouachitaensis* groups, respectively) and gradually replaced the subbotinids during the Oligocene. Their origin remains an enigma, although a relationship with *Subbotina* appears logical.
11. The globoquadrinid (geometrically oriented honeycomb) wall texture appeared in the late middle Eocene with the evolution of the nonspinose genus *Dentoglobigerina.*

Documentation and an extended discussion of these morphogenetic trends are presented in the Eocene Atlas (Pearson and others, in press).

UPDATED PALEOGENE PLANKTONIC FORAMINIFERAL ZONATION

We are acutely aware that stability of nomenclature is highly desirable in biostratigraphy, and that alteration or modification of existing (and generally accepted and applied) zonal scheme(s) should not be undertaken lightly. For the past 15 years, the Paleogene Planktonic Foraminifera Working Group (PPFWG) has been meeting under the auspices of the International Subcommision on Paleogene Stratigraphy (ISPS) with a view to publishing comprehensive revisions to the taxonomy and biostratigraphy of Paleogene taxa. A first volume, the *Atlas of Paleocene Planktonic Foraminifera* has been published (Olsson and others, 1999). An Eocene Atlas (Pearson and others, in press) represents the second contribution in this series.

Unfortunately, the use of the acronym 'LO' has been used in the literature to denote two different types of datum level (both 'lowest' and 'last' occurrence) and is thus subject to confusion and misunderstanding unless their meaning is clarified. In the discussion below, we differentiate between the lowest (LO) and highest (HO) occurrences of paleontologic events used to define the limits of a biozone, and the first appearance datum (FAD) and last appearance datum (LAD) of paleontologic events used to define temporal limits of a biochron (*sensu* Aubry, 1995; see discussion below).

In the course of our investigations we have discovered, or been made aware of, several shortcomings in the zonal scheme of Berggren and others (1995). The main areas for improvement are as follows:

1. It is now well established that a discrete, temporally short (<150 k.y.) stratigraphic interval exists at the base of the Eocene (as now recognized; Ouda and Aubry, 2003; Gradstein and others, 2004, p. 87) that is characterized in pelagic carbonates by geochemical evidence of rapid climatic warming and a carbon isotope excursion (CIE; Zachos and others, 1993). This interval, which is associated with several distinct and stratigraphically limited planktonic foraminiferal "excursion taxa" that are of great utility in identifying the Paleocene/Eocene boundary (Kelly and others, 1996, 1998), lies within the middle part of Zone P5 of Berggren and others (1995). We follow the suggestion of Pardo and others (1999) and Molina and others (1999) in using the LO of one of the excursion taxa, *Acarinina sibaiyaensis,* to subdivide the old Zone P5 of Berggren and others (1995). We also use the now well-documented LO of *Pseudohastigerina wilcoxensis* to further subdivide the old Zone P5.
2. Several of the lower and middle Eocene zones listed in Berggren and others (1995) need to be redefined to conform more rigorously with the subtypes of Interval Zones listed in the International Stratigraphic Guide (Salvador, 1994), which is used in this study as the convention for zonal nomenclature.
3. New information from drill cores in Tanzania (Pearson and others, 2004) has indicated that the LO of *Hantkenina* in the early middle Eocene is probably diachronous, with the first *Hantkenina* having a restricted geographic range. A more easily recognized datum at a very similar level is the LO of *Guembelitriodes nuttalli.* Note that *Globigerinoides nuttalli* Hamilton is now recognized as a prior synonym of *"Globigerinoides" higginsi* Bolli (Olsson and others, in press). The latter was a frequently used name for this species. However, reasons for adopting this synonymy are that *nuttalli* was clearly described and illustrated in a prominent publication, the name has been used, if rarely, and new study of its holotype confirms its identity.
4. As part of this study we have recollected the Eocene—Oligocene stratotype section at Massignano, Italy at a 10-cm resolution in order to locate key upper Eocene biostratigraphic datums with greater accuracy than has hith-

TABLE 1. Age estimates of planktonic foraminiferal datum levels in Massignano section, Italy based on study in this work on recollected sample material.

Event	Reference	Top (m)	Bottom (m)	Estimated level	Age (Ma)
LAD *H. alabamensis*	Berggren and others (1995)				33.7
(E/O GSSP)	Coccioni and others (1988)	19.00	19.50	19.25 ± 0.25	
Base Zone O1	Gonzalvo and Molina (1992)	19.00	19.50	19.25 ± 0.25	
	This study	19.00	19.03	19.02 ± 0.01	**33.7**
LAD *T. cerroazulensis*	Berggren and others (1995)				33.8
	Coccioni and others (1988)	18.50	18.60	18.55 ± 0.05	
	Gonzalvo and Molina (1992)	18.50	18.80	18.65 ± 0.15	
	This study	18.55	18.60	18.58 ± 0.03	**33.8**
LAD *C. inflata*	Berggren and others (1995)				34.0
	Coccioni and others (1988)	15.00	15.50	15.25 ± .25	
	Gonzalvo and Molina (1992)	15.00	16.50	15.75 ± .75	
	This study	19.00	19.03	19.02 ± 0.01	**33.7**
LAD *G. index*	Berggren and others (1995)				34.3
Base Zone E16	Coccioni and others (1988)	13.50	14.00	13.75 ± 0.25	
	Gonzalvo and Molina (1992)	13.00	14.00	13.50 ± 0.50	
	This study	14.10	14.50	14.30 ± 0.20	**34.3**
FAD *T. cunialensis*	Berggren and others (1995)				35.2
	Coccioni and others (1988)	7.20	7.50	7.35 ± 0.15	
	Gonzalvo and Molina (1992)	15.00	16.50	15.75 ± 0.75	
	This study	7.00	7.50	7.25 ± 0.25	**35.3**
LAD *T. pomeroli*	Berggren and others (1995)				35.3
	Coccioni and others (1988)	5.00	5.50	5.25 ± 0.25	
	Gonzalvo and Molina (1992)	11.00	12.00	11.50 ± 0.50	
	This study	4.50	5.00	4.75 ± 0.25	**35.7**
LAD *G. semiinvoluta*	Berggren and others (1995)				35.3
Base Zone E15	Coccioni and others (1988)	4.50	5.00	4.75 ± 0.25	
	Gonzalvo and Molina (1992)	4.00	5.00	4.50 ± 0.50	
	This study	4.50	4.60	4.55 ± 0.05	**35.8**
FAD *C. inflata*	Berggren and others (1995)				(35.5)
	This study			Not reliable in this section	

erto been achieved. A list of datums and their positions in comparison to earlier work (Coccioni and others, 1988; Gonzalvo and Molina 1992) is shown in Table 1. The cited ages of the LADs of *Hantkenina alabamensis* (base of Zone O1), *Turborotalia cerroazulensis,* and *Globigerinatheka index* (base of Zone E16) are essentially identical with those compiled by Berggren and others (1995). The FAD of *Turborotalia cunialensis* at 35.3 Ma is slightly older than quoted in Berggren and others (1985, 35.2 Ma). A greater discrepancy exists for the LADs of *Turborotalia pomeroli* (35.7 Ma, compared to 35.3 Ma in Berggren and others, 1995) and *Globigerinatheka semiinvoluta* (Base of Zone E15; 35.8 Ma, compared to 35.3 Ma in Berggren and others, 1985). These datums clearly lie within Chron C16n in the Massignano section (see Lowrie and Lanci, 1994, for paleomagnetic data), not C15r as stated in Berggren and others (1985). The LAD of *G. semiinvoluta* is very well characterized at Massignano, as it is continuously present (although rare) through the lower part of the section until its abrupt disappearance at 4.55 m above the base of the stratotype section. The age of the FAD of *Cribrohantkenina inflata* is not reliably determined at Massignano (contradictory to Berggren and others, 1995) because all hantkeninids are absent in the lower part of the section, and their first appearance in the section represents a local influx.

5. We have encountered significant taxonomic problems regarding the recognition of *Cribrohantkenina lazzarii* (Pericoli), which affects the concept of uppermost Eocene Zone P17 as used by Berggren and others (1985). Zone P17 was introduced by Blow (1969, 1979), who identified it as a biostratigraphic interval between the LADs of *Cribrohantkenina* and *Hantkenina* spp., the latter of which is now regarded as denoting the Eocene/Oligocene boundary. For Blow, *Cribrohantkenina* was a monospecific genus with *C. inflata* as the only valid species and with *C. lazzarii* listed among its synonyms. Martinez-Gallego and Molina (1975) introduced a different concept of Zone P17 in which *Cribrohantkenina* was split into two distinct species (*C. inflata* and *C. lazzarii*). *Cribrohantkenina inflata,* which was regarded as a more rounded and inflated form, was documented as disappearing first from the record, whereas the more polygonal *C. lazzarii* was observed to persist to the same level as the disappearance of *Hantkenina* spp. In effect, these observations, which have been supported by subsequent studies on several of the Italian and Spanish sections (Molina 1986; Nocchi and others, 1986; Molina and others, 1988; Coccioni and others, 1988), indicated that Zone P17 in the sense of Blow (1969, 1979) does not exist. Nevertheless, by splitting *Cribrohantkenina,* these authors were able to form an alternative concept of Zone P17, namely the interval between the HO's of the inflated species of *Cribrohantkenina* (*C. inflata,* according to their taxonomic concept) and *Hantkenina* spp.

Therefore, the concept of Zone P17 according to Martinez-Gallego and Molina (1975) and the subsequent studies listed above depends upon: 1) the taxonomic validity of splitting *Cribrohantkenina* into two distinct species, and 2) the observation that one of those species (*C. inflata*) disappears from the record at a lower level than the Eocene/Oligocene boundary. We have examined the holotype of *C. lazzarii* (Coxall and Pearson, in press) and found it to be a very poorly preserved and distorted specimen which may be an internal mold. The type illustration of Pericoli (1958) is highly stylized and potentially misleading. Therefore, it is difficult to form a clear taxonomic concept of *C. lazzarii*. Furthermore, our own stratigraphical observations on the sections at Massignano (Italy), Fuente Caldera (Spain) and Tanzania Drilling Project Sites 11 and 12 (Pande, Tanzania) indicate that although there is indeed a tendency for *Cribrohantkenina* to become more compressed and polygonal in the uppermost Eocene, rounded *Cribrohantkenina* (*C. inflata* s.s.) persists to the Eocene/Oligocene boundary in all four sections and disappears at the same level as *Hantkenina* spp. For these reasons, we do not advocate the taxonomic splitting of *Cribrohantkenina* and we do not recognize Zone P17 in the sense of Martinez-Gallego and Molina (1975).

These new discoveries have compelled us to make several modifications to the zonal scheme of Berggren and others (1995). Zonal magnetobiochronology has been based, as in the case of Berggren and others (1985, 1995), on a compilation and evaluation of first-order correlations between biostratigraphic datums and magnetostratigraphy in DSDP and ODP boreholes, as well as land sections.

We have not recalibrated or updated the chronology of the Eocene zones because the state of Paleogene geochronology is in a state of flux at present. For example:

1) There is currently a conflict between a revised astronomical age for the Oligocene/Miocene boundary, which is tied to Chron C6n.2n(o) of 22.9 Ma (Shackleton and others, 2000), and a magnetobioradiosotopic age estimate of 24.0 Ma (Naish and others, 2001; Wilson and others, 2002), which appears to have been resolved in favor of the astronomical age estimate (Pälike and Shackleton, 2003).
2) Recently published data suggest that the currently accepted age of Chron C22r may be ~1.5–2.5 m.y. too old (Machlus and others, 2004).
3) There is currently a considerable debate on the appropriate calibration for the late Oligocene Fish Canyon Tuff. Berggren and others (1995) used a calibration age of 27.84 Ma in constructing their Cenozoic time scale. Currently debated values range from 27.55 Ma to 28.52 Ma with a value of 28.24 Ma apparently now gaining favor (Hilgen, communication to WAB, 2003). The point here is that the age of the Cretaceous/Paleogene boundary would range from 64.4 Ma to 66.6 Ma (a 2 m.y. spread), depending upon which calibration is accepted. Until this uncertainty is resolved among radioisotopic specialists we view any attempts at constructing a revised Paleogene time scale as premature, and potentially misleading.
4) A new Paleogene time scale appeared (Luterbacher and others, 2004) as this paper was nearing completion. We have chosen to retain the chronology used in Berggren and others (1995) for the sake of continuity with the Paleocene Atlas (Olsson and others, 1999) and the Eocene Atlas (Pearson and others, in press). The methodology used in constructing the time scale of Berggren and others (1995) consisted of fitting a cubic spline functon to nine age-calibration-anomaly distance tie-points (plus the zero-axis ridge axis) back to Chron $C34n_{(y)}$. The ages of Pliocene and Pleistocene polarity intervals, corresponding to Subchron C3n.4n and younger subchrons, were inserted from the astrochronology that had been recently developed by others. Four of the nine calibration points bracketed or spanned the Paleogene. Biostratigraphic datums were correlated to the magnetic polarity time scale (GPTS), and the chronology of biostratigraphic datums was then estimated by linear interpolation between the various calibration tie-points, as well as that of chronostratigraphic boundaries.

The new time scale of Luterbacher and others (2004) involves the integration of comparable data sets to those utilized by Berggren and others (1995). However, spline fitting to 18 (eventually reduced to 17) original radioisotopic ages and estimated/extrapolated ages of polarity chrons spanning the interval from earliest Miocene Chron C6An.1r $_{(0)}$ to late Santonian Chron $C33_{(o)}$ has resulted in a higher density data set than that used in Berggren and others (1995). Twelve of the calibration tie-points span the Paleogene. Two-sigma error values were estimated for chronostratigraphic boundaries in the belief that it is better to underestimate than overestimate time scale uncertainties associated with $^{40}Ar/^{39}Ar$ ages and the likelihood that ^{40}K decay constants will soon be revised. Biostratigraphic datums/zonal boundaries were calibrated to (the newly revised chronology of) the magnetic polarity time scale record of Berggren and others (1995) and, over parts of the stratigraphic record (particularly Paleocene-lower Eocene, and, to a lesser extent, upper Eocene and Oligocene), by cyclostratigraphy (unavailable to Berggren and others, 1995). Cycle tuning thus constrains the age assignments of most datum levels.

The correlation of P zones to the revised Paleogene chronology by Luterbacher and others (2004) and that presented herein can be compared by reference to the zonal schemes presented in the respective papers. The duration of P zones is seen to be remain relatively constant with minor differences, as discussed herein. Differences in age estimates for some chronostratigraphic boundaries between the two papers are primarily due to the use of different age calibrations and differing chronostratigraphic correlations, discussion of which is beyond the scope of this paper. The main differences in chronostratigraphic age assignments between the two papers are listed below, with the value in Luterbacher and others (2004) given first, and that of Berggren and others given second:

a) Oligocene/Miocene boundary: 23.03 ± 0 Ma vs. 23.8 Ma
b) Eocene/Oligocene boundary: 33.9 ± 0.1 Ma vs. 33.7 Ma
c) Paleocene/Eocene boundary: 55.8 ± 0.2 Ma vs. 55.5 Ma
d) Cretaceous/Paleogene boundary: 65.5 ± 0.3 Ma vs. 65 Ma

The notation "E" is used herein to denote a series of subtropical-tropical zones applicable on a global scale (exclusive of high southern and northern latitudes; see Huber and Quillévéré, this issue). This shorthand system is a development of that adopted by Blow (1969, 1979) for his Paleogene (P) and Neogene (N) zones, and Berggren (1969 and subsequent papers) for his Paleogene (P), Miocene (M), Pliocene (Pl) and Pleistocene (Pt) zones. For the sake of completeness, and to provide biostratigraphic continuity with the newly defined zonal scheme, we update the Paleocene zones and subzones as used in the *Atlas of Paleocene Planktonic Foraminifera* (Olsson and others, 1999) including an emended definition of uppermost Paleocene Zone P5. We also provide a partial emendation and numbering of the Oligocene zones. To avoid confusion with the denomination P for Paleogene zones, we replace the notation P by Pa for Paleogene and we denote the Paleocene zones by the abbreviation P. Thus the zones of this paper ('P', 'E' and 'O' zones), in conjunction with the Neogene zones of Berggren and others (1995) ('M', 'Pl' and 'Pt' zones), constitute a coherent set of zones for the Cenozoic systems.

All of the zones that we recognize are interval zones (IZ) according to the International Stratigraphic Guide's "the body of fossiliferous strata between two specified biohorizons" (Salvador, 1994). We stress this point because there is some ambiguity in the guide as to whether range zones are a type of interval zone or form a separate category. We have elected as a convention to always use nominate taxa that occur within the zones in question. This is a different convention than that used by Berggren and others (1995); hence, some of the zones have been renamed, but their definitions remain the same. Some of the Paleocene subzones have been renamed to reflect improvements in biostratigraphic data (Berggren and others, 2000).

We recognize five categories of interval zone, as follows. The first is the taxon-range zone (TRZ), where the bounding biohorizons are the lowest occurrence (LO) and highest occurrence (HO) of a single taxon. In each case, the nominate taxon for the TRZ is the species in question. The second category is the concurrent-range zone (CRZ), which is the interval of overlap between the LO of one taxon and the HO of another. For these zones we use both defining taxa as nominate taxa. Two further types of interval zone are those in which just one of the two taxa that define its bounding biohoriozons are present within the zone. These are the highest-occurrence zone (HOZ), where both bounding biohorizons are the highest HO's (e.g., Zone E15, the biostratigraphic interval between the HO of *Globigerinatheka semiinvoluta* and the HO of the nominate taxon *G. index*); and the lowest-occurrence zone (LOZ), where both bounding biohorizons are LO's (e.g., Zone E4, the biostratigraphic interval between the LO of the nominate taxon *Morozovella formosa* and the LO of *M. aragonensis*). In each case, the zone is named after the one defining taxon that is present in the zone. The fifth category of interval zone is the partial-range zone (PRZ). This is the interval of occurrence of a nominate taxon between two specified biohorizons, neither of which is defined by the nominate taxon. Generally, the PRZ is the interval between the HO of one taxon at its base and the LO of another at its top. Hence, we use the PRZ to provide a nominate taxon that is present within the zone. However, we also recognize one example of a PRZ that is between two highest occurrences because the logical choice for the nominate taxon is used elsewhere as the nominate taxon of another zone, and we wish to avoid having two zones with the same name.

When stratigraphic sections are continuous, and in the absence of evidence of diachrony, the LO and HO of a taxon are also its FAD and LAD, respectively (Aubry, 1995; Berggren and others, 2000). The biozone is thus converted into a chronozone whose boundaries record the FAD and LAD of the nominate taxon/taxa.

PALEOCENE

We enumerate here the Paleocene zones and subzones of Berggren and others (1995) for completeness, but we revise the definitions to recognize that the notation 'P' now designates "Paleocene" rather than "Paleogene" in order to maintain consistency with the 'E' zonation introduced herein for the Eocene. We have also renamed and/or nomenclaturally emended some of the zones and subzones (without changing their numbering) to accord with the convention that the nominate taxa should be present within the zone or subzone, and to accord with the definitions of the types of interval zones given above. The Paleocene zones are presented in graphical form in Figure 1 and the chronology of datum/boundary events shown in Table 2.

Zone P0. *Guembelitria cretacea* Partial-range Zone (Keller, 1988; emendation of Smit, 1982).

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 (late).

Estimated age: 65.0–64.97 Ma; earliest Paleocene (Danian).

Zone Pα. *Parvularugoglobigerina eugubina* Taxon-range Zone (Liu, 1993; emendation of *Globorotalia (Turborotalia) longiapertura* Zone [Pα] of Blow, 1979; *Globigerina eugubina* Zone of Luterbacher and Premoli Silva, 1964).

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

Magnetochronologic calibration: Chron C29r (late).

Estimated age: 64.97–64.8 Ma; early Paleocene (Danian).

Zone P1. *Eoglobigerina edita* Partial-range Zone (renamed from *Parvularugoglobigerina eugubina-Praemurica uncinata* Zone [P1] of Berggren and others, 1995; emendation of *Subbotina pseudobulloides-Globoconusa daubjergensis* Zone [P1] of Berggren and Miller, 1988).

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

Magnetochronologic calibration: Chron C29r (late)-Chron $C27n_{(0)}$.

Estimated age: 64.8–61.37 Ma; early Paleocene (Danian).

Remarks: This zone is biostratigraphically identical to the *Parvularugoglobigerina eugubina-Praemurica uncinata* Interval Zone of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the zone that is designated a partial-range zone. *Eoglobigerina edita* is a typical representative of the zone and occurs throughout its extent.

Subzone P1a. *Parasubbotina pseudobulloides* Partial-range Subzone (renamed from *Parvularugoglobigerina eugubina-Subbotina triloculinoides* Zone [P1a] of Berggren and others, 1995; emendation of Berggren and Miller, 1988).

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

Magnetic calibration: Chron C29r (later part)-Chron C29 (mid-part).

Estimated age: 64.8–64.3 Ma; early Paleocene (early Danian).

Remarks: This subzone is biostratigraphically identical to the *Parvularugoglobigerina eugubina-Subbotina triloculinoides* Interval Subzone (P1a) of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the subzone. *Parasubbotina pseudobulloides* is a common component of this interval and has its FAD only slightly below the LAD of *P. eugubina* (Berggren and others, 1995, p. 146). See Berggren and others (1995, p. 147) for additional information on characteristic elements of this subzone. The LAD of *P. eugubina* has been located in the younger part of Chron C29r; thus the age estimate of 64.7 Ma given in Berggren and others (1995, p. 149, Table 8) is incorrect, as this age lies within the earliest part of Chron C29 (Berggren and others, 1995, p. 1323, Table 2). Berggren and others (1995) gave an age of 64.9 Ma (p. 147) in the original definition of Subzone P1a, and an age of 64.8 Ma to Zone Pα (Remarks, 1995, p. 146). The latter value is used here and is essentially the same as the age (64.76 Ma) of the FAD of *Globoconusa daubjergensis,* nominate taxon for Zone AP1 in the austral zonation of Huber and Quillévéré (this issue). Characteristic elements of this subzone include: spinose eoglobigerinids (*Eoglobigerina edita, E. eobulloides*), parasubbotinids (*P. pseudobulloides*), nonspinose praemorozovellids (*P. pseudoinconstans, P. taurica*) and globanomalinids (*G. planocompressa*), and *Globoconusa daubjergensis.*

Subzone P1b. *Subbotina triloculinoides* Lowest-occurrence Subzone. (renamed from *Subbotina triloculinoides-Globanomalina compressa/Praemurica inconstans* Subzone [P1b], Berggren and others, 1995; emendation of Berggren and Miller, 1988).

Definition: Biostratigraphic interval between the LO of *Subbotina triloculinoides* and the LOs of *Globanomalina compressa* and/or *Praemurica inconstans.*

Magnetic calibration: Chron Chron C29n (mid-part)-Chron C28n (mid-part).

Estimated age: 64.3–62.87 Ma; early Paleocene (early to mid-Danian).

Remarks: This subzone is biostratigraphically identical to the *Subbotina triloculinoides-Globanomalina compressa/Praemurica inconstans* Interval Subzone (P1b) of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the subzone and designated a lowest occurrence subzone. *Parasubbotina varianta* has its LO within this biostratigraphic interval, although it does not become a significant and morphologically distinct element in Paleocene faunas until Zone P3. See Berggren and others (1995) for additional information on this subzone.

Subzone P1c. *Globanomalina compressa/Praemurica inconstans* Lowest-occurrence Subzone (renamed from *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Subzone [P1c] of Berggren and others, 1995; emendation of *Morozovella trinidadensis-Planorotalites compressus* Subzone of Berggren and Miller, 1988).

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

Magnetic calibration: Chron C28n (mid)-C27r (younger part).

Age estimate: 62.87–61.37 Ma; early Paleocene (mid-late Danian).

Remarks: This subzone is biostratigraphically identical to the *Globanomalina compressa/Praemurica inconstans-Praemurica uncinata* Subzone (P1c) of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the subzone and designated a lowest occurrence subzone. See Berggren and others (1995, p. 147) for additional information on this subzone. The HO of *Praemurica taurica* may serve to denote the base of of Subzone P1c (defined by the LO of *Globanomalina compressa*), as the two datum events have been found to essentially coincide in Chron C28n at 62.87 Ma (Berggren and others, 2000, p. 36).

Zone P2. *Praemurica uncinata* Lowest-occurrence Zone (renamed from *Praemurica uncinata-Morozovella angulata* zone [P2] of Berggren and others, 1995; emendation of, but biostratigraphically equivalent to, *Morozovella uncinata-Igorina spiralis* zone [P2] of Berggren and Miller, 1988).

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

Magnetobiochronologic calibration: Chron $C27n_{(o)}$-Chron $C27n_{(y)}$.

Estimated age: 61.37–61.0 Ma; late early Paleocene (late Danian).

Remarks: This zone is biostratigraphically identical to the *Praemurica uncinata–Morozovella angulata* interval Zone of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the zone. The age estimate for the FAD of *Praemurica uncinata* has been revised to 61.37 Ma (Berggren and others, 2000, p. 36) and found to coincide with the LAD of *Globoconusa daubjergensis,* nominate taxon for austral Zone AP1 of Huber and Quillévéré (this issue). Thus, Zones P1 and AP1 are biochronologically correlative and equivalent. Further discussion of Zone P2 is presented in Berggren and others (1995, p. 147).

Zone P3. *Morozovella angulata* Lowest-occurrence Zone (renamed from *Morozovella angulata-Globanomalina pseudomenardii* zone [P3] of Berggren and others, 1995; emendation of Berggren and Miller, 1988).

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

Magnetochronologic calibration: Chron $C27n_{(y)}$-Chron C26r (middle).

Estimated age: 61.0–59.4 Ma; early late Paleocene (Selandian).

Remarks: This zone is biostratigraphically identical to the *Morozovella angulata-Globanomalina pseudomenardii* Interval Zone (Zone P3) of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present within the zone. The FAD of *Globanomalina pseudomenardii* has been recalibrated from 59.2 Ma (Berggren and others, 1995, p. 148, Table 8) to 59.4 Ma (Berggren and others, 2000, p. 36) based on higher resolution studies of material from DSDP Site 384.

Subzone P3a. *Igorina pusilla* Partial-range Subzone (herein redefined; emendation of Bolli, 1957a; renamed from *Morozovella angulata-Igorina albeari* Subzone of Berggren and others, 1995).

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 $_{(y)}$-Chron 26r (early).

Age estimate: 61.0–60.0 Ma; early late Paleocene (Selandian).

Remarks: Bolli (1957a, p. 64) designated the *Globorotalia pusilla pusilla* Zone for the biostratigraphic interval from the HO of *Globorotalia uncinata* to the LO of *Globorotalia pseudomenardii,* and indicated that *Globorotalia laevigata* (=*Igorina albeari*) had its LO simultaneous with *G. pseudomenardii.* This misconception was probably due to a combination of factors: low sample resolution and poor preservation, among others. The FAD of *I. albeari* is now known to occur approximately midway (temporally) between that of *I. pusilla* and *G. pseudomenardii* (Berggren and others, 1995; Berggren and others, 2000). Thus, a two-fold subdivision of Zone P3 was made by Berggren and others (1995). The lower subzone was designated the *Morozovella angulata-Igorina albeari* Interval Subzone (P3a) (Berggren and others, 1995). However, it is renamed here to accord with the convention that the nominate taxon should be present in the subzone and is redefined to avoid the use of the name *Morozovella angulata* as nominate taxon for both Zone P3 and Subzone P3a. In DSDP Hole 384, *Igorina pusilla* has its FAD simultaneous with that of *M. angulata* at the base of Zone P3 (Berggren and others, 2000, p. 6, 35) in early Chron C26r with an estimated age of 61.0 Ma.

Subzone P3b. *Igorina albeari* Lowest-occurrence Subzone (renamed here from *Igorina albeari-Globanomalina pseudomenardii* Subzone [P3b] of Berggren and others, 1995).

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

Magnetic calibration: Chron C26r (early)-Chron C26 (mid).

Age estimate: 60.0–59.4 Ma; late Paleocene (Selandian).

Remarks: This subzone is biostratigraphically identical to the *Igorina albeari-Globanomalina pseudomenardii* Interval Subzone (P3b) of Berggren and others (1995). However, it is renamed here to accord with the convention that the nominate taxon should be present in the subzone. Further discussion of this subzone is presented in Berggren and others (1995, p. 149).

Zone P4. *Globanomalina pseudomenardii* Taxon-range Zone (Bolli, 1957a).

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

Magnetochronologic calibration: Chron C26r (middle)-Chron $C25n_{(y)}$

Estimated age: 59.4 Ma-55.9 Ma; middle part of late Paleocene (late Selandian—Thanetian).

Remarks: The age of the FAD of *Globanomalina pseudomenardii* has been revised from 59.2 Ma (Berggren and others, 1995, p. 148, Table 8) to 59.4 Ma (Berggren and others, 2000, p. 35) based on quantitative studies on more closely spaced samples from DSDP Hole 384. Further discussion of Zone P4 may be found in Berggren and others (1995, p. 150).

Subzone P4a. ***Globanomalina pseudomenardii/Parasubbotina variospira*** **Concurrent-range Subzone** (Berggren and others, 2000; emendation of *Globanomalina pseudomenardii-Acarinina subsphaerica* Subzone [P4a] of Berggren and others, 1995).

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

Magnetic calibration: Chron C26r (middle).

Age estimate: 59.4–59.2 Ma; late Paleocene (late Selandian).

Remarks: The original definition of Subzone P4a was the concurrent range of *Globanomalina pseudomenardii* and *Acarinina subsphaerica* Berggren and others, 1995, p. 150). Subsequent studies have shown that the supposed LAD of *A. subsphaerica* in early Chron C25r (57.1 Ma) is actually its Latest Common Occurrence (LCO) and that the taxon persists into Subzone P4c at DSDP Site 465 and ODP Sites 690 and 758 (Berggren and others, 2000, p. 36) and, in fact, we have observed it, if sporadically, up to Zone P6a (Zone E3 of this paper). Accordingly, this subzone was redefined in Berggren and others (2000, p. 37) by substituting as the nominate taxon the distinct, umbilically "toothed" parasubbotinid *P. variospira* which has a short, brief overlap with *G. pseudomenardii* at DSDP Site 384 (Berggren and others, 2000).

Subzone P4b. ***Acarinina subsphaerica*** **Partial-range Subzone** (Berggren and others, 2000).

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 (middle)-Chron 25r (late).

Age estimate: 59.2–56.5 Ma; late Paleocene (late Selandian-Thanetian).

Remarks: With the substitution of the HO of *Parasubbotina variospira* (59.2 Ma) for the supposed HO (= LCO) of *Acarinina subsphaerica* (57.1 Ma) to define Subzone P4b, it will be seen that the temporal extent of Subzones P4a and P4b have been reversed from Berggren and others (1995) to Berggren and others (2000) and this paper: P4a: 2.1 m.y. vs. 0.2 m.y.; P4b: 0.6 m.y. vs. 2.7 m.y.

Subzone P4c. ***Acarinina soldadoensis/Globanomalina pseudomenardii*** **Concurrent-range Subzone** (Berggren and others, 1995).

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

Magnetic calibration: Chron C25r (late)- Chron $C25n_{(y)}$.

Age estimate: 56.5–55.9 Ma; late Paleocene (late Thanetian).

Remarks: The definition of this subzone remains that of Berggren and others (1995), where further remarks can be found.

Zone P5. ***Morozovella velascoensis*** **Partial-range Zone** (herein amended; = lower part *Morozovella velascoensis* Zone of Bolli, 1957a; lower part *Morozovella velascoensis* Interval Zone (Zone P5) of Berggren and others, 1995).

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

Magnetobiochronologic calibration: Chron $C25n_{(y)}$-C24r.

Estimated Age: 55.9–55.5 Ma; latest Paleocene (latest Thanetian).

Remarks: In this work, Zone P5 is used to recognize the lower (Paleocene) part of the former Zone P5 of Berggren and others (1995). There have been several attempts to subdivide the former Zone P5 in order to increase biostratigraphic resolution through the stratigraphic interval bracketing (and including) the "Late Paleocene" Thermal Maximum (LPTM now variously referred to as the P/E Thermal Maximum or PETM in recognition of the fact that this interval straddles the Paleocene/Eocene boundary as it is now being recognized, or as the Initial Eocene Thermal Maximum or IETM because it lies in the earliest Eocene). Highlights of these recent studies include the following:

1. Arenillas and Molina (1996) proposed an *Igorina laevigata* Subzone for the lower part of the *M. velascoensis* Zone. This was subsequently abandoned (Molina and others, 1999) in view of the fact that *I. laevigata* as recorded by these authors may be a junior synonym of *I. albeari* (Blow, 1979; Berggren and Norris, 1997).

2. Pardo and others (1999) subdivided Zone P5 based on the LO of *Acarinina sibaiyaensis* and/or *A. africana.* The uppermost division (Subzone P5b) was denominated a concurrent-range subzone, with the base placed at the LO of *A. sibaiyaensis* and/or *A. africana*, which they assumed was coincident with the base of the $\delta^{13}C$ (CIE) isotope excursion and the benthic extinction event (BEE), and the top placed at the HO of *M. velascoensis.* A duration of 0.078 m.y. (57.78 Ma–57.7 Ma) was estimated for this subzone based, supposedly, on the time scale of Berggren and others (1995). However, there are two problems with this definition and temporal estimate: 1) A concurrent range (sub)zone is defined on the basis of the biostratigraphic overlap of two taxa between the respective initial and terminal occurrence of each of the two taxa. *Acarinina sibaiyaensis* and *A. africana* are restricted to the stratigraphic interval of the $\delta^{13}C$ excursion (now estimated to have spanned ~158 k.y.; Kelly and others. 1996; Norris and Röhl, 1999), whereas *M. velascoensis* extends ~1 m.y. beyond the $\delta^{13}C$ excursion, to 54.7 Ma in the time scale of Berggren and others (1995) and 54.48 Ma in the revised chronology of Berggren and Aubry, 1998, p. 31). 2) The $\delta^{13}C$ excursion is at ~55.5 Ma (Berggren and others, 1995). It is not clear how the number 54.78 Ma is derived/estimated for the $\delta^{13}C$ excursion and/or BEE.

3. Molina and others (1999) have proposed a five-fold subdivison of Zone P5 (from the base) into the: a) *Morozovella aequa* Subzone (interval from the HO of "*Luterbacheria*" *pseudomenardii* to the LO of *Morozovella gracilis*); b) *Morozovella gracilis* Subzone (interval from the LO of *M. gracilis* to the LO of *Acarinina berggreni*); c) *Acarinina berggreni* Subzone (interval from the LO of *Acarinina berggreni* to the LO of *Acarinina sibaiyaensis*); d) *Acarinina sibaiyaensis* Subzone (interval from the LO of *A. sibaiyaensis* to the LO of *Pseudohastigerina wilcoxensis*); and e) *Pseudohastigerina wilcoxensis* Subzone (interval between the LO of *P. wilcoxensis* and the HO of *M. velascoensis*). We have not found it possible to systematically recognize the threefold subdivsion proposed by Molina and colleagues for the lower part of Zone P5, but the upper two divisions are easier to recognize.

4. Speijer and others (2000) have proposed a three-fold subdivision of Zone P5 as follows (from the bottom): a) Subzone P5a: *Globanomalina chapmani* Interval Subzone (interval between the HO of *G. pseudomenardii* and/or LO of *M. subbotinae*) and the LO of *Morozovella allisonensis*; b) Subzone P5b: *Morozovella allisonensis* Total Range Subzone (total range of nominate taxon; restricted to the interval of the $\delta^{13}C$ excursion); c) Subzone P5c: *Globanomalina luxorensis* Subzone (interval between the HO of *M. allisonensis* and the HO of *M. velascoensis*). These divisions are potentially useful, but we have found *Morozovella allisonensis* rarer and probably patchier in its geographic distribution than *Acarinina sibaiyaensis,* and also that the HOs of the excursion taxa less easy to identify than the LOs because of their rarity and potential problems with reworking. Also, it does not make use of the LO of *Pseudohastigerina wilcoxensis*, which is a prominent event just above the carbon isotope excursion (Molina and others, 1999).

Our solution, based on these earlier suggestions, is to subdivide the former Zone P5 into three parts. The lowest part, Zone P5 in its restricted definition, is confined to the Paleocene, and we use the LO of *Acarinina sibaiyaensis* as the most reliable planktonic foraminiferal marker for the base of the Eocene. The higher divisions of the old/former Zone P5, which utilize the LO of *Pseudohastigerina wilcoxensis* to divide the upper part of the range of *Morozovella velascoensis*, are discussed in the appropriate sections below.

Eocene

Zone E1. ***Acarinina sibaiyaensis*** **Lowest-occurrence Zone** (*Acarinina sibaiyaensis* Subzone of Molina and others, 1999; = lower part

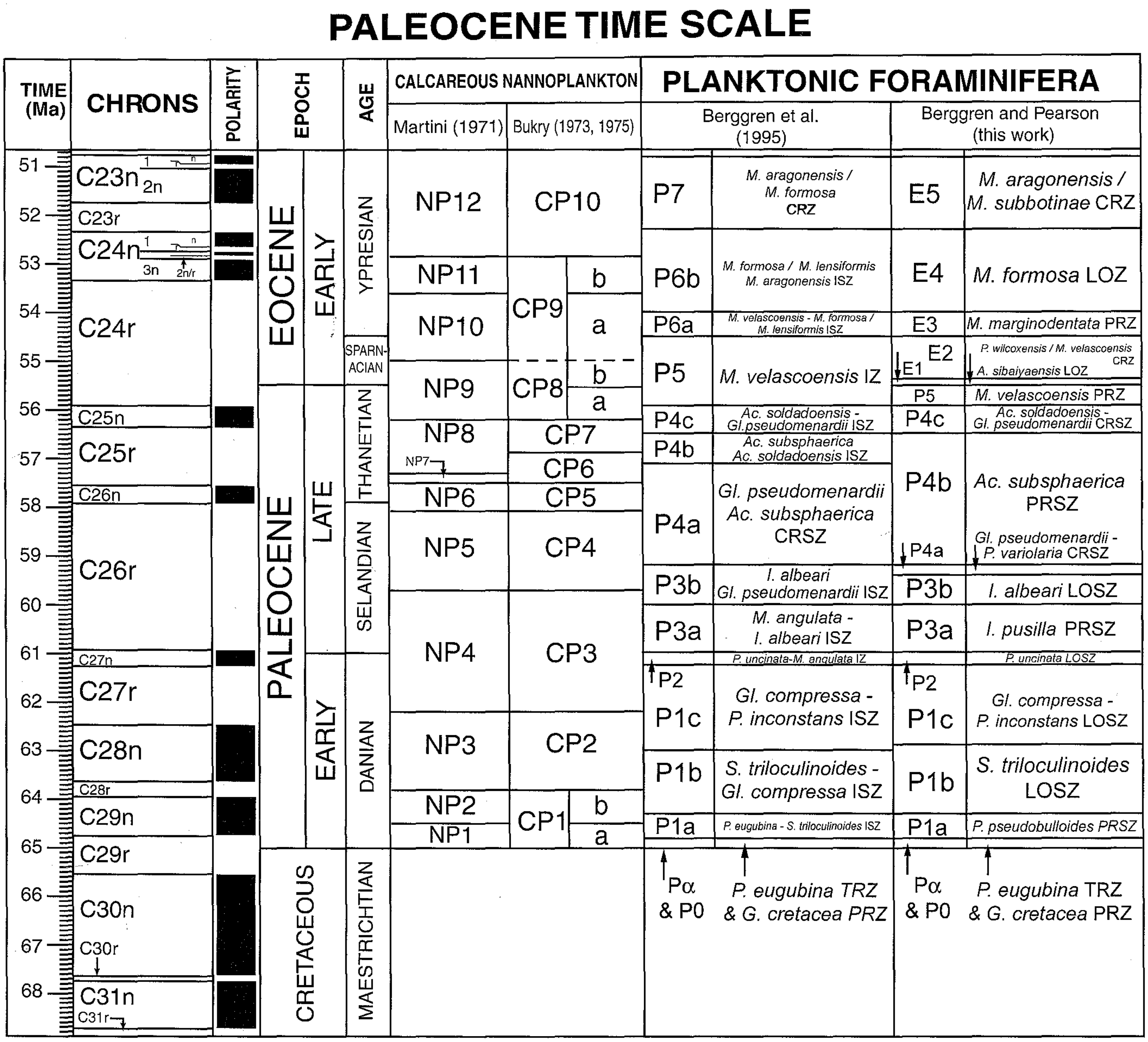

FIGURE 1. Integrated magnetobiochronologic scale for the Paleocene. Modified/emended Paleocene (P) tropical to subtropical zonation shown in right column compared to earlier (Berggren and others, 1995) zonal scheme. Correlation with the magnetostratigraphic/magnetochronologic scale follows that in Berggren and others (1995) with modifications discussed in the text. The base of calcareous nannoplankton Zone NP6/CP5 has been modified to 58.07 Ma (Berggren and others, 2000).

of *Acarinina sibaiyaensis* Subzone of Pardo and others, 1999; middle part of *Morozovella velascoensis* [P5] interval zone of Berggren and others, 1995).

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

Magnetochronologic calibration: Chron C24r (early).

Estimated age: 55.5–55.35 Ma; earliest Eocene (earliest Sparnacian).

Remarks: We agree with Molina and others (1999) and Speijer and others (2000) that the distribution of the "excursion taxa" (*M. allisonensis, Acarinina sibaiyaensis* and *A. africana*) and the LO of *Pseudohastigerina* represent a useful set of datums within the middle part of (former) Zone P5. We have chosen to adopt the criteria of Pardo and others (1999) and Molina and others (1999) in recognizing a twofold zonation of the upper part of (former) Zone P5. Our Zone E1 is the lower of these zones and the same as the *Acarinina sibaiyaensis* Subzone of Molina and others (1999).

The use of Sparnacian as the lowest stage of the Eocene follows that of Aubry and others (2003, 2005) in which the Sparnacian Stage was inserted between the Ypresian Stage *sensu stricto* and the Thanetian Stage. This avoids the lowering of the base of the Ypresian Stage by ~1 m.y. to coincide with the newly defined GSSP for the base of the Eocene Series.

Zone E2. *Pseudohastigerina wilcoxensis/Morozovella velascoensis* Concurrent-range Zone (herein defined; =*Pseudohastigerina wilcoxensis* Subzone of Molina and others, 1999; upper part *Morozovella velascoensis* [P5] Interval Zone of Berggren and others, 1995).

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: C24r (early).

Estimated age: 55.35–54.5 Ma; earliest Eocene (earliest Sparnacian-late Sparnacian).

TABLE 2. Age estimates of Paleocene (sub)tropical planktonic foraminiferal zone and subzone base datums.

Zones		Base datum	Age (Ma)
P5	*Morozovella velascoensis* PRZ	LAD *Globanomalina pseudomenardii*	55.9[a]
P4c	*Acarina soldabdoensis/Globanomalina pseudomenardii* CRSZ	FAD *Acarinina soldadoensis*	58.5[b]
P4b	*Acarinina subsphaerica* PRSZ	LAD *Parasubbotina variospira*	59.2[c]
P4a	*Globanomalina pseudomenardii/Parasubbotina variospira* CRSZ	FAD *Globanomalina pseudomenardii*	59.4[c]
P4	*Globanomalina pseudomenardii* TRZ	FAD *Globanomalina pseudomenardii*	59.4[d]
P3b	*Igorina albeari* LOSZ	FAD *Igorina albeari*	60.0[a,b]
P3a	*Igorina pusilla* PRSZ	FAD *Morozovella angulata*	61.0[a]
P3	*Morozovella angulata* LOZ	FAD *Morozovella angulata*	61.0[a, b, c]
P2	*Praemurica uncinata* LOZ	FAD *Praemurica uncinata*	61.37[a, b]
P1c	*Globanomalina compressa/Praemurica* inconstans LOSZ	FAD *Globanomalina compressa* and/or *Praemurica inconstans*	62.87[a, b]
P1b	*Subbotina triloculinoides* LOSZ	FAD *Subbotina triloculinoides*	64.3[a, b]
P1a	*Parasubbotina pseudobulloides* PRSZ	LAD *Parvularugoglobigerina eugubina*	64.8[a, b]
P1	*Eoglobigerina edita* PRZ	LAD *Parvularugoglobigerina eugubina*	64.8[a, b]
Pa	*Parvularugoglobigerina* eugubina TRZ	FAD *Parvularugoglobigerina eugubina*	64.97[e, f, g]
P0	*Guembelitria cretacea* PRZ	LAD Cretaceous taxa (*Globotruncana* spp., etc.)	65.0[h, i]

(a) This work.
(b) Berggren and others (1995).
(c) Berggren and others (2000).
(d) Bolli (1957a)
(e) Liu (1993).
(f) Blow (1979).
(g) Luterbacher and Premoli Silva (1968).
(h) Keller (1988).
(i) Smit (1982).

Remarks: As noted for Zone E1, we agree with Molina and others (1999) that the LO of *Pseudohastigerina wilcoxensis* is a useful datum with which to divide the upper part of the former Zone P5 of Berggren and others (1995). Our Zone E2 is biostratigraphically identical to the *Pseudohastigerina wilcoxensis* Subzone of Molina and others (1999), although it bears a different name. It is also biostratigraphically equivalent to 'Subzone P5c', the *Globanomalina luxorensis* Subzone (interval between the HO of *M. allisonensis* and the HO of *M. velascoensis*) of Speijer and others (2000). We have observed in the course of our studies, and particularly in Egypt, but also in the Bass River core of coastal New Jersey (Cramer and others, 1999) that slightly asymmetrical, transitional forms between globanomalinids (*G. luxorensis*) and planispiral pseudohastigerinids (*P. wilcoxensis*) occur in floods within the CIE interval. The LO of planispiral *Pseudohastigerina* denotes a biostratigraphically distinct datum/horizon at the top of the PETM, as observed by Molina and others (1999) in Spain and by one of us (WAB) in the course of the search for a GSSP for the Paleocene/Eocene boundary in Egypt (Ouda and Aubry, 2003). This overlap and concurrent range of *P. wilcoxensis* and *M. velascoensis* was originally observed over 35 years ago in Egypt by Berggren and subsequently used in the original proposal of a Paleogene (P) zonation (Berggren, 1969, Table 1, p. 352; see also further delineation of this overlap in Berggren, 1971a, and at that time considered to be appropriate for zonal biostratigraphy. The LO of *Pseudohastigerina* was shown to be situated within the concurrent-range of *Morozovella subbotinae* (LO) and *M. velascoensis* (HO).

Zone E3. *Morozovella marginodentata* Partial-range Zone (herein defined; =*Morozovella velascoensis-Morozovella formosa formosa* and/or *Morozovella lensiformis* Interval Zone [P6a] of Berggren and others, 1995; =*Morozovella subbotinae / Pseudohastigerina wilcoxensis* Partial Range Zone [P6b] of Berggren and Miller, 1988; =*Globorotalia edgari* Zone of Premoli Silva and Bolli, 1973, *in part*).

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 (mid).

Estimated age: 54.5–54.0 Ma; earliest Eocene (latest Sparnacian-early Ypresian).

Remarks: This zone is defined on basically the same biostratigraphic criteria as Zone P6a (the *Morozovella velascoensis-Morozovella formosa formosa* and/or *M. lensiformis* Interval Zone) of Bergggren and others (1995), the difference being the use of the LO of *M. lensiformis* as an alternate marker for the top of the zone by Berggren and others (1995). *Morozovella marginodentata* is a typical constituent of this zone and is thus designated the nominate taxon. It is also biostratigraphically, but not nomenclaturally, equivalent to the *Morozovella subbotinae-Pseudohastigerina wilcoxensis* Partial Range Zone (P6b) of Berggren and Miller (1988). It is approximately the same as the *Acarinina wilcoxensis berggreni* Partial-range Zone (P7) of Blow (1979), and the *Globorotalia edgari* Zone of Premoli Silva and Bolli, 1973. It corresponds closely to the *Globorotalia rex* Zone of Bolli (1957b) and the *Globorotalia subbotinae* Zone as used extensively in Soviet literature of the post-war years (1950's–1980's). Characteristic elements of this zone include low (*M. aequa, M. edgari, M. gracilis, M. marginodentata*) and high (*M. subbotinae*) angulo-conical morozovellids, and rounded (*A. coalingensis*), subangular (*A. angulosa, A. pseudotopilensis, A. wilcoxensis*), globular (*A. soldadoensis*) and high-spired (*A. appressocamerata*) acarininids. *Subbotina patagonica* diversifies and is the dominant subbotinid in this zone, whereas *Subbotina velascoensis* has its HO in this zone.

Zone E4. *Morozovella formosa* Lowest-occurrence Zone (herein defined; =*Morozovella formosa formosa/Morozovella lensiformis-Morozovella aragonensis* Interval Zone [P6b] of Berggren and others, 1995; =*Morozovella formosa-Morozovella lensiformis* Partial-range Subzone [P6c] of Berggren and Miller, 1988; =*Morozovella formosa-Morozovella lensiformis* Partial-range Subzone [P8a] of Blow, 1979).

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

Magnetochronologic calibration: Chron C24r (late)-Chron C23r (earliest).

Estimated age: 54.0–52.3 Ma; early Eocene (early Ypresian).

Remarks: This zone is biostratigraphically, but not nomenclaturally, equivalent to the *Morozovella formosa-Morozovella lensiformis* Partial-range Subzone (P8a) of Blow (1979, p. 276). It has also been recognized as the *Morozovella formosa-Morozovella lensiformis* Partial-range Subzone (P6c) of Berggren and Miller, 1988; the *Morozo-*

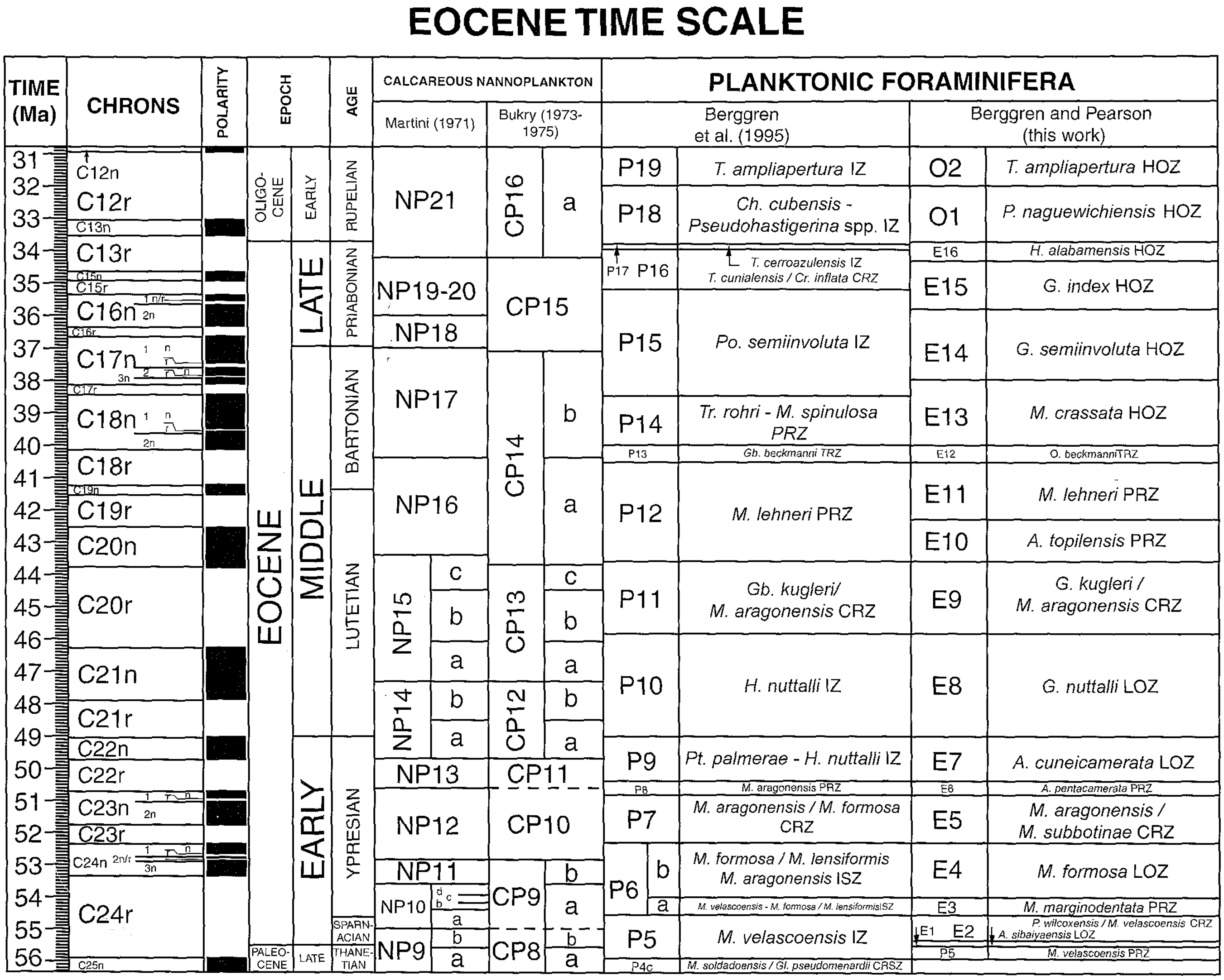

FIGURE 2. Integrated magnetobiochronologic scale for the Eocene. The newly defined Eocene tropical to subtropical planktonic foraminiferal zonation (E-zones) is shown comparison with earlier tropical to subtropical zones (so-called P-zones of Berggren and others, 1995) and standard calcareous nannoplankton biostratigraphies (Martini, 1971; Bukry, 1973, 1975).Correlation with the magnetostratigraphic/magnetochronologic scale follows that in Berggren and others (1995) with modifications discussed in the text.

vella formosa formosa/Morozovella lensiformis-Morozovella aragonensis Interval Zone (P6b) of Berggren and others (1995); and, earlier, as the *Globorotalia lensiformis* Zone of Hillebrandt, 1965 (see also Blow, 1979, p. 276, for additional synonomy). In renaming this zone, we have simply dropped one of the two nominate taxa of this zone. Characteristic elements include forms listed above under Zone E3 with the addition of the nominate taxon of this zone and the initial appearance of *Acarinina interposita, A. quetra, A. primitiva* and *Morozovella crater.*

Zone E5. *Morozovella aragonensis/Morozovella subbotinae* Concurrent-range Zone (herein defined; approximately = *Morozovella aragonensis/Morozovella formosa formosa* Concurrent-range Zone [P7] of Berggren and others, 1995; *Morozovella aragonensis/Morozovella formosa* Partial-range Subzone P8b of Blow, 1979; *Morozovella aragonensis/Morozovella formosa* Concurrent-range Zone [P7] of Berggren and Miller, 1988, p. 371; *Globorotalia formosa* Zone of Berggren, 1969; combined *Globorotalia formosa* and *Globorotalia aragonensis* Zones of Bolli, 1966).

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

Magnetochronologic calibration: Chron C23r-Chron $C23n_{(y)}$.

Estimated age: 52.3–50.8 Ma; early Eocene (Ypresian).

Remarks: Our studies have shown that the HO's of several morozovellids (*M. gracilis, M. marginodentata, M. formosa* and *M. subbotinae*) appear to be closely grouped within the lower part of the range of *M. aragonensis* (see also Blow, 1979, Fig. 50; Toumarkine and Luterbacher, 1985, p. 102, Fig. 7). We have found that the taxon *M. formosa* is often rare and difficult to differentiate clearly in the terminal part of its range. Therefore, we have defined it herein as essentially equivalent to the *Morozovella aragonensis/Morozovella formosa formosa* Concurrent-range Zone (P7) of Berggren and Miller (1988) and Berggren and others (1995) to the extent that we use the HO of *Morozovella subbotinae* rather than *M. formosa* to denote the upper limit/boundary of this zone. This zone is also essentially the same as Zone P8b of Blow (1979), except that the top of that zone was defined by the LO of *Acarinina aspensis.*

Zone E6. *Acarinina pentacamerata* Partial-range Zone (herein defined; approximately = *Globorotalia aragonensis* Zone [P8] of Berggren, 1969; *Morozovella aragonensis* Zone [P8] of Berggren and Miller, 1988, p. 371, and Berggren and others, 1995, p. 153).

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

TABLE 3. Age estimates of Eocene (sub)tropical planktonic foraminiferal zone base datums.

	Zone	Base datum	Age (Ma)
O1	*Pseudohastigerina naguewichiensis* HOZ	LAD *Hantkenina alabamensis*	33.7[a]
E16	*Hantkenina alabamensis* HOZ	LAD *Globigerinatheka* index	34.3[a]
E15	*Globigerinatheka index* HOZ	LAD *Globigerinatheka semiinvoluta*	35.8[a]
E14	*Globigerinatheka semiinvoluta* HOZ	LAD *"Morozovella" crassata*	38.0[a]
E13	*"Morozovella" crassata* HOZ	LAD *Orbulinoides beckmanni*	40.0[b]
E12	*Orbulinoides beckmanni* TRZ	FAD *Orbulinoides beckmanni*	40.5[a]
E11	*"Morozovella" lehneri* PRZ	LAD *Guembilitrioides nuttalli*	(42.3)[c]
E10	*Acarinina topilensis* PRZ	LAD *Morozovella aragonensis*	43.6[a]
E9	*Globigerinatheka kugleri/Morozovella aragonensis* CRZ	FAD *Globigerinatheka kugleri*	45.8[a]
E8	*Guembelitrioides nuttalli* LOZ	FAD *Guembelitrioides nuttalli*	49.0[d]
E7	*Acarinina cuneicamerata* LOZ	FAD *Acarinina cuneicamerata*	50.4[d]
E6	*Acarinina pentacamerata* PRZ	LAD *Morozovella subbotinae*	50.8[a]
E5	*Morozovella aragonensis/Morozovella subbotinae* CRZ	FAD *Morozovella aragonensis*	52.3[a]
E4	*Morozovella formosa* LOZ	FAD *Morozovella formosa*	54.0[a]
E3	*Morozovella marginodentata* PRZ	LAD *Morozovella velascoensis*	54.5[a]
E2	*Pseudohastigerina wilcoxensis/Morozovella velascoensis* CRZ	FAD *Pseudohastigerina wilcoxensis*	53.35[c]
E1	*Acarinina sibaiyaensis* LOZ	FAD *Acarinina sibaiyaensis*	55.5[e]

[a] Berggren and others (1995).
[b] Wade (2004).
[c] R. D. Norris (communication, 2002).
[d] Hancock and others (2002).
[e] This paper.
Chronology of datum events paleomagnetically calibrated (54.5Ma) or estimated (45.8Ma).

Magnetochronologic calibration: Chron $23n_{(y)}$-Chron C22r (estimated).

Estimated age: 50.8–50.4 Ma; late early Eocene (late Ypresian).

Remarks: The zone is defined herein to reflect the use of the HO of *M. subbotinae* (rather than the HO of *M. formosa)* as the criterion for the base of the zone. For the top of the zone, we have substituted the LO of *A. cuneicamerata* at essentially the same (estimated) level as the LO of *Astrorotalia palmerae,* which has been used to denote the top of Zone P8. The FAD of *A. cuneicamerata* has recently been calibrated to Chron C22r at ~50.4 Ma by Hancock and others (2002) at ODP Hole 762C, Exmouth Plateau, northwest Australian margin. *Astrorotalia palmerae* has proven to be an elusive taxon and would appear to have a very discontinuous geographic distribution (Toumarkine and Luterbacher, 1985; Hancock and others, 2002).

Zone E7. *Acarinina cuneicamerata* Lowest-occurrence Zone (herein defined; approximately = *Planorotalites palmerae-Hantkenina nuttalli* Interval Zone [P9] of Berggren and others, 1995; and the *Subbotina inaequispira* Partial-range Zone [P9] of Berggren and Miller, 1988—see p. 372 for extensive discussion of this zone).

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

Magnetochronologic calibration: Chron C22r (estimated)-Chron $C22n_{(y)}$.

Estimated age: 50.4–49.0 Ma; late early Eocene (latest Ypresian).

Remarks: Since the extensive review by Berggren and Miller (1988) of the problems associated with the characterization of an appropriate biostratigraphic zone for the stratigraphic interval spanning the lower/middle Eocene (Ypresian/Lutetian) boundary, we remain without a fully satisfactory explanation for the discrepant or discordant ranges recorded by various investigators for the initial appearance of *Hantkenina* and *Astrorotalia (=Planorotalites) palmerae.* We remain convinced, however, that, in addition to various taxonomic problems associated with the earliest *Hantkenina,* at least part of the problem lies with the global lowering of sea level that characterized and spanned the late early and early middle Eocene (late Ypresian-early Lutetian; Haq and others, 1988; Aubry, 1995; Vandenberghe and others, 1998) resultant unconformities/hiatuses, and concomitant discrepant or delayed entries of taxa.

The initial entry of *Hantkenina* has been used for nearly 45 years as the definitive (if not nominate) taxon for the basal zone of the middle Eocene (Bolli, 1957a, b, 1966). Its FAD has been calibrated to the GPTS (Chron $C22n_{(y)}$) by Lowrie et al (1982) in the deep-water biofacies of the Apennines, and we (Berggren and others, 1985; 1995) have continued to use this calibration as an anchor point in the Eocene part of the Paleogene zonal scheme. However, the continued discrepant records of the initial entry of this taxon in the stratigraphic record and new taxonomic observations on the evolutionary transition from *Clavigerinella* to *Hantkenina* (Coxall and Pearson, in press) have led us to consider use of a different taxon *Guembelitrioides nuttalli,* to denote the base of the middle Eocene and base of Zone E8, respectively. The FAD of this taxon (as *Guembelitrioides higginsi*) has been recently calibrated to Chron $C22n_{(y)}$ at ODP site 761 in the Indian Ocean (Hancock and others, 2002) and we view the use of this distinct, high-spired, multiapertured homeomorph of *Globigerinoides* as an appropriate substitute for the enigmatic, erratic initial entry of *Hantkenina.*

With regards to the base of this zone, we have observed that *A. cuneicamerata* is a distinct form which occurs together with *Acarinina bullbrooki, A. collactea, A. interposita, A. pentacamerata, A. primitiva, A. soldadoensis, Subbotina senni, S. frontosa* and *S. inaequispira,* among others, in the interval formerly regarded as Zone P9 (Berggren and Miller, 1988; Berggren and others, 1995). In view of the rarity of *Astrorotalia palmerae* in the stratigraphic record, we have adopted the LO of *A. cuneicamerata* as denotative of the base of Zone E7.

Zone E8. *Guembelitrioides nuttalli* Lowest-occurrence Zone (herein defined; approximately = *Hantkenina nuttalli* Partial-range Zone [P10] of Berggren and Miller, 1988, p. 383, and Berggren and others, 1995; *Hantkenina aragonensis* Zone of Bolli, 1957b, emended by Stainforth and others, 1975, and renamed by Toumarkine, 1981).

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

Magnetochronologic calibration: Chron $C22n_{(y)}$-Chron C20(r), estimated.

Estimated age: 49.0–45.8 Ma; early middle Eocene (Lutetian).

Remarks: Characteristic elements of this zone include *Morozovella aragonensis, Acarinina bullbrooki, A. collactea, A. praetopilensis, Turborotalia frontosa, Subbotina crociapertura, S. griffinae, S. inaequispira* and *Globigerinatheka index.* The extinction of *Morozovella caucasica* occurs within this zone.

Zone E9. *Globigerinatheka kugleri/Morozovella aragonensis* Concurrent-range Zone (=*Globigerapsis kugleri/Morozovella aragonensis* Concurrent-range Zone [P11] of Berggren and others, 1995; *Globigerapsis kugleri/Subbotina frontosa* Partial-range Zone [P11] of Berggren and Miller, 1988; upper part of *Globigerapsis kugleri* Zone [P11] of Berggren, 1969; upper part of *Globigerapsis kugleri* Zone of Bolli, 1957b, 1966).

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 $C20n_{(o)}$.
Estimated age: 45.8–43.6 Ma; middle Eocene (Lutetian).
Remarks: See Berggren and others (1995, p. 153) and Berggren and Miller (1988, p. 373) for further discussion of this zone.

Zone E10. *Acarinina topilensis* Partial-range Zone (herein defined; = lower part of *Globorotalia lehneri* Zone [P12] of Berggren, 1969; lower part of *Morozovella lehneri* Zone [P12] of Berggren and Miller, 1988, and Berggren and others, 1995; essentially = lower part *Morozovella lehneri* Zone [P12] of Blow, 1979.

Definition: Partial range of the nominate taxon between the HO of *Morozovella aragonensis* and the HO of *Guembelitrioides nuttalli*
Magnetochronologic calibration: Chron $C20n_{(o)}$-Chron C19r.
Estimated age: 43.6–42.3 Ma; late middle Eocene (late Lutetian).
Remarks: The *Morozovella lehneri* Zone has been used heretofore as the biostratigraphic interval between the HO *of Morozovella aragonensis* and the LO of *Orbulinoides beckmanni.* Blow (1979, p. 285–287) defined the base of the *M. lehneri* Zone using the HO of *Subbotina frontosa boweri,* which he said was virtually equivalent to the HO of *M. aragonensis.* As such, the zone/biochron had a duration of about 3.1 m.y. (43.6–40.5 Ma in Berggren and others, 1995, p. 154). In the course of recent work, the LAD of *Guembelitrioides nuttalli* at ODP Sites 1050 and 1051 has been calibrated to Chron C19r (at ~ 42.3 Ma; R. D. Norris, communication, 2002). Accordingly we have found it useful to subdivide the biostratigraphic interval denoted as Zone P12 into two parts based on the HO of *G. nuttalli.* We denote this zone a Partial-range zone (with *Acarinina topilensis* as the nominate taxon) rather than a Highest-occurrence zone (with *Guembelitrioides nuttalli* as the nominate taxon) because *G. nuttalli* is already used as the nominate taxon for Zone E8 and we wish to avoid having two zones with the same single nominate taxon. Note that in the forthcoming *Atlas of Eocene Planktonic Foraminifera* (Pearson and others, in press), the genus *Truncorotaloides* has been suppressed and constituent taxa (*topilensis, rohri,* etc.) subsumed under the genus *Acarinina.*

Zone E11. *'Morozovella' lehneri* Partial-range Zone (herein emended; = upper part of *Morozovella lehneri* Partial-range Zone [P12] of Blow, 1979, Berggren and Miller, 1988, and Berggren and others, 1995.

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; late middle Eocene (late Lutetian-early Bartonian).
Remarks: The greater biostratigraphic and biochronologic resolution afforded by using the HO of *Guembelitrioides higginsi* justfies the subdivision of (former) Zone P12 of Berggren and others (1995) into two parts. The herein emended *'Morozovella' lehneri* Partial-range Zone, designated Zone E11, represents the upper part. Note that the nominate taxon, *'Morozovella' lehneri,* is the type species of a new genus named by Pearson and Berggren (in press); hence, the zone name will be modified to match that genus when it is formally named.

Zone E12. *Orbulinoides beckmanni* Taxon-range Zone (=*Porticulasphaera mexicana* Zone of Bolli, 1957b, 1966; *Globigerapsis beckmanni* Zone [P13] of Berggren, 1969, Blow, 1979, Berggren and Miller, 1988, p. 373, and Berggren and others, 1995, p. 154)

Definition: Total range of the nominate taxon between its LO and HO.
Magnetochronologic calibration: Chron C18r-Chron $C18n_{(o)}$.
Estimated age: 40.5–40.0 Ma; late middle Eocene (Bartonian).
Remarks: The occurrence of abundant, large, spherical representatives of *Orbulinoides beckmanni* constitutes a very useful biostratigraphic interval in the middle Eocene, subdividing what would otherwise be a very long zone (the totality of Zones E11-E13). The age of the LAD of *O. beckmanni,* nominate form of this taxon range zone, has been modified slightly to 40.0 Ma (vs. 40.1 Ma in Berggren and others, 1995) following the observations of Wade (2004) on ODP Site 1052. To permit consistent identification of the base of the zone, it is important that workers employ a relatively broad concept for this taxon that encompasses the morphology of the holotype, as distinct from *Globigerinatheka euganea,* and not just the highly spherical forms illustrated by Bolli and others (1957).

Zone E13. *'Morozovella' crassata* Highest-occurrence Zone (herein defined; approximately = *Truncorotaloides rohri-Morozovella spinulosa* Partial-range Zone [P14] of Berggren and Miller, 1988, p. 373; Berggren and others, 1995, p. 154; approximately = *Truncorotaloides rohri-Globigerinita howei* Partial-range Zone [P14] of Blow, 1979, p. 290, 291, emended)

Definition: Biostratigraphic interval between the HO of *Orbulinoides beckmanni* and the HO of the nominate taxon, *'Morozovella' crassata.*
Magnetochronologic calibration: Chron $C18n_{(o)}$-Subchron C17n.3n.
Estimated age: 40.0–38.0 Ma; (late Bartonian).
Remarks: We have chosen to modify the definition of the upper limit of this zone (formerly recognized by the LO of *Globigerinatheka semiinvoluta*) to reflect the distinct horizon at which Eocene *'Morozovella'* disappears. This occurs at a level very close to the extinction of *Acarinina* spp. (Wade, 2004). In our discussion of the taxonomy of *'Morozovella'* (Pearson and Berggren, in press) we note that *'M.' crassata* is the senior synonym of *M. spinulosa,* requiring a change in name for one of the nominate taxa (*M. spinulosa*) of Zone P14 of Blow (1979) and Berggren and Miller (1988). We also include *'M.' crassata* in the same new genus as *'Morozovella' lehneri* (see above).

Zone E14. *Globigerinatheka semiinvoluta* Highest-occurrence Zone (emended herein; approximately = *Porticulasphaera semiinvoluta* Interval Zone [P15] of Berggren and others, 1995, p.154; *Porticulasphaera semiinvoluta* Partial-range Zone [P15] of Berggren and Miller, 1988; *Globigerapsis mexicana* Zone of Berggren, 1969; *Globigerapsis mexicana* Zone [P15] of Blow, 1969).

Definition: Biostratigraphic interval between the HO of *'Morozovella' crassata* and the HO of the nominate taxon, *Globigerinatheka semiinvoluta.*
Magnetochronologic calibration: Subchron C17n.3n-Chron C16n.
Estimated age: 38.0–35.8 Ma; middle to late Eocene (late Bartonian to early Priabonian).
Remarks: In terms of temporal extent, this is a relatively long biochron (~3+ m.y.). We have chosen to modify the definition of the lower limits (as discussed for the previous zone) and upper limits of (the former) Zone P15 because of the equivocal nature of several other "datum events" that have been used in the past. The HO of *Cribrohantkenina inflata,* which has been used to delimit the top of P15, remains poorly calibrated (see Table 1). The "FAD" of *C. inflata* in Italian and Spanish sections is based on a local influx of hantkeninids and the calibration in Berggren and others (1995) is based on this influx, not on an evolutionary appearance in sections with hantkeninids always present.

The LO of *Turborotalia cunialensis,* which was used by Berggren and others (1995) to define the top of Zone P15/base of Zone P16, is highly diachronous between studies and authors (e.g., Coccioni and others, 1988; Gonzalvo and Molina, 1986, Massignano section; Table 1) and is probably a function of taxonomic concepts (e.g., presence of imperforate band on terminal chambers).

A point of interest with regard to Zone E14 is that the LAD of the minute, muricocarinate *Planorotalites capdevillensis* (=*P. renzi* in older literature) has been found to be associated with Chron C16n3n at ~36.2 Ma at Site 1052 (Wade, 2004), more than 2 m.y. younger than its "extinction" in Chron C18n.2n (~38.5 Ma) reported by Berggren and others (1995).

Zone E15. *Globigerinatheka index* Highest-occurrence Zone (herein defined; approximately = upper part of *Porticulasphaera semiinvoluta* Interval Zone [P15] and lower part of *Turborotalia cunialensis/Cribrohantkenina inflata* Concurrent-range Zone [P16] of Berggren and others, 1995).

OLIGOCENE TIME SCALE

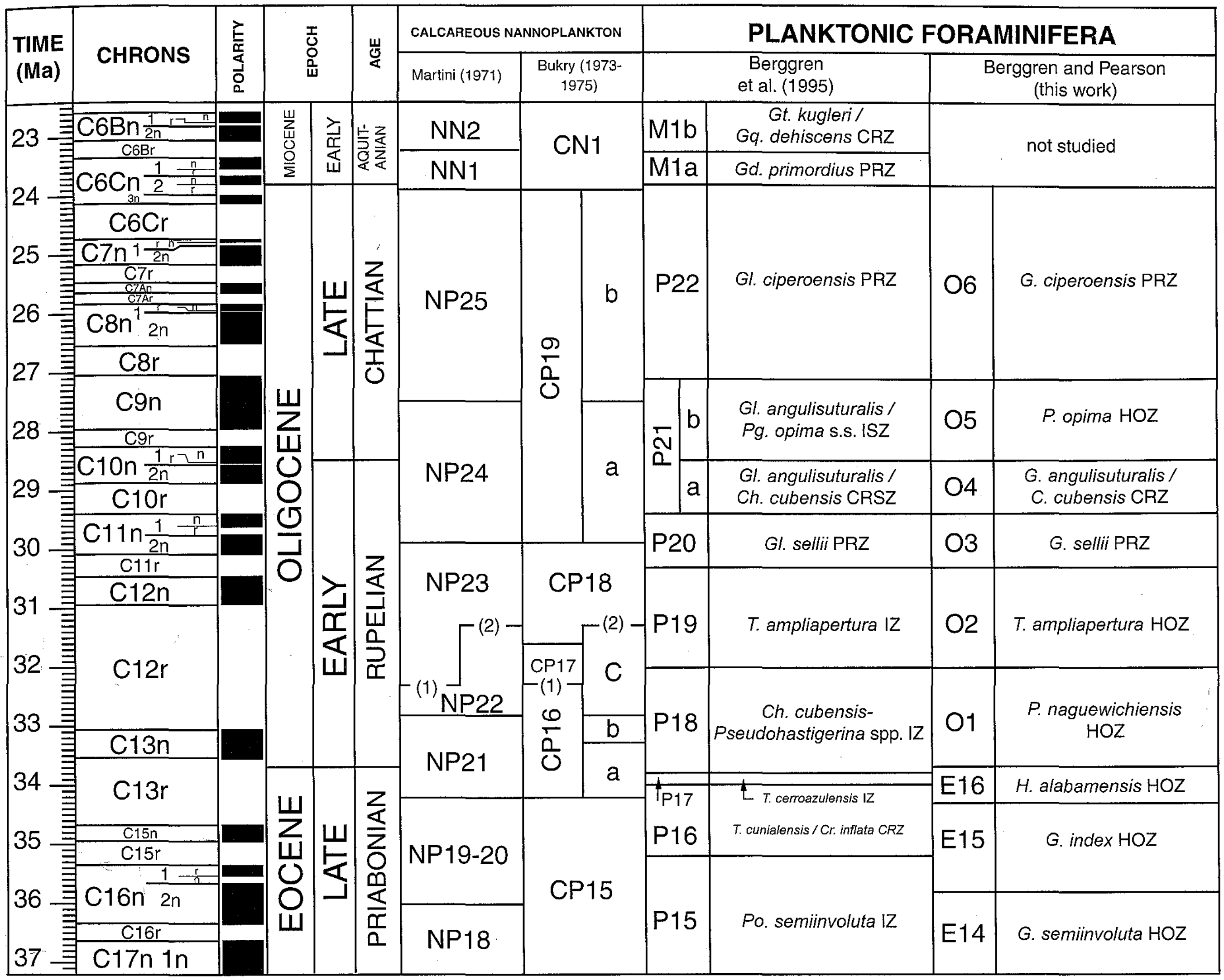

FIGURE 3. Integrated magnetobiochronologic scale for the Oligocene. Modified numerical notation system for, and emendation of, Oligocene tropical to subtropical zones shown in right column compared to earlier (Berggren and others, 1995) zonal scheme. Correlation with the magnetostratigraphic/magnetochronologic scale follows that in Berggren and others (1995) with modifications discussed in the text. The notation (1) and (2) refer to diachronous LAD's of *Reticulofenestra umbilicus*/*R. hillae* (and the NP22 and NP23 zonal boundary) in early Chron ClZr in low-mid latitudes (1) and late Chron ClZr in high southern latitudes (2), respectively (Berggren and others, 1995, p. 186, Table 2).

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

Magnetochronologic calibration: Chron C16n-Chron C13r.

Estimated age: 35.8–34.3 Ma; late Eocene (Priabonian).

Remarks: This zone is approximately correlative with the upper part of Zone P15 and the lower part of Zone P16 of Berggren and others (1995). However, with the recent recognition (Coxall and Pearson, in press; see above) that there is but one morphospecies of *Cribrohantkenina,* and that the HO of *Cribrohantkenina inflata* is coincident with the extinction of *Hantkenina* spp., it is apparent that Zone P16 as previously defined (Berggren and Miller, 1988, p. 374; Berggren and others, 1995, p. 154) is no longer tenable.

The HO of *Globigerinatheka index* is a distinct bioevent within the upper part of the range of *Hantkenina* spp., *Cribrohantkenina,* and the terminal members of the *Turborotalia cerroazulensis* s.l. lineage, including *Turborotalia cunialensis. Globigerinatheka index* is one of the few taxa whose LAD can be shown to be isochronous between low (sub)tropical and high, austral latitudes and provinces (Berggren and others, 1995, p. 155; Table 9, item 4). Accordingly, we use the HO of *G. index* to denote the upper boundary of Zone E15, which approximates, but is slightly older, than the top of Zone P16 of Berggren and Miller (1988) and Berggren and others (1995). *Globigerinatheka index* was used as a zonal marker by Jenkins (1966), but with the significantly different denotation of a middle Eocene (Lutetian) interval zone.

Zone E16. *Hantkenina alabamensis* Highest-occurrence Zone (herein defined; approximately = upper part of *Turborotalia cunialensis/Cribrohantkenina inflata* Concurrent-range Zone [P16] and totality of *Globigerina gortanii gortanii-Turborotalia centralis* Consecutive-range Zone [P17] of Blow, 1969, 1979; *Turborotalia cerroazulensis* Interval/Partial-range Zone [P17] of Berggren and Miller, 1988, p. 374, and Berggren and others, 1995, p. 154, 156).

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

Magnetochronologic calibration: Chron C13r (midpart)-Chron C13r (late).

Estimated age: 34.3–33.7 Ma (late Priabonian).

Remarks: Blow and Banner (1962) were the first to recognize a distinct stratigraphic interval between the LAD of *Globigerinatheka*

TABLE 4. Age estimates of Oligocene (sub)tropical planktonic foraminiferal zone base datums.

	Zones	Base datum	Age (Ma)
O6	*Globigerina ciperoensis* PRZ	LAD *Paragloborotalia opima*	27.1[a]
O5	*Paragloborotalia opima* HOZ	LCO *Chiloguembelina cubensis*	28.5[a, b]
O4	*Globigerina angulisuturalis/Chiloguembelina cubensis* CRZ	FAD *Globigerina angulisuturalis*	29.4[a]
O3	*Globigerina sellii* PRZ	LAD *Turborotalia ampliapertura*	30.3[a]
O2	*Turborotalia ampliapertura* HOZ	LAD *Pseudohastigerina naguewichiensis*	32.0[a]
O1	*Pseudohastigerina naguewichiensis* HOZ	LAD *Hantkenina alabamensis*	33.7[a, c]

(a) Berggren and Miller (1988).
(b) This work.
(c) Berggren and others (1995).

spp. and the LAD of *Hantkenina,* the latter of which now denotes the Eocene /Oligocene boundary. This zone is an easily recognized interval that includes within it the totality of the old Zone P17 (Berggren and others, 1995) which we now contend is unworkable (see discussion above).

Berggren and Miller (1988) and Berggren and others (1995) used the LAD of *Turborotalia cerroazulensis* as their biohorizon of the top Eocene in the belief of its greater potential for preservation, but our own detailed studies of the type section at Massignano (Table 1) have confirmed the observation of Coccioni and others (1998) that a short stratigraphic interval exists between this datum and the LAD of *Hantkenina* spp., which is identical to the Eocene/Oligocene GSSP at Massignano. At Massignano, the thickness of this interval is 44 cm (±4 cm), which corresponds to about 65 k.y. assuming a constant sedimentation rate through the upper part of the section.

OLIGOCENE

We include/enumerate here (with minimal discussion/comment) the Oligocene zones of Berggren and others (1995) in order to complete the Paleogene, but introduce the notation 'O' in order to maintain consistency with the 'E' zonation introduced herein (Figure 3). We recognize that modifications to the Oligocene zonation may be expected in the course of future continued work on the Oligocene by the Paleogene Planktonic Foraminiferal Working Group.

Zone O1. *Pseudohastigerina naguewichiensis* Highest-occurrence Zone (herein emended; approximately = *Turborotalia cerroazulensis-Pseudohastigerina* spp. Interval Zone [P18] of Berggren and others, 1995).

Definition: Biostratigraphic interval between HO of *Hantkenina alabamensis* and HO of the nominate taxon *Pseudohastigerina naguewichiensis.*

Magnetochronologic calibration: Chron C13r (late)-Chron C12r.

Estimated age: 33.7–32.0 Ma; early Oligocene (early Rupelian).

Remarks: We have emended the definition of this zone to reflect the substitution of the HO of *Hantkenina alabamensis* for that of *Turborotalia cerroazulensis* as the denotative element in the definition of its lower boundary (see discussion above). The definition of the top of the zone is the same, with the name modified according to the synonymization of *Pseudohastigherina barbadoensis* under *P. naguewichiensis* (grouped as *Pseudohastigerina* spp. in Berggren and others, 1995) in the forthcoming Eocene Atlas (Pearson and others, in press). See Berggren and others (1995, p. 156) for further discussion of the history of this Zone.

Zone O2. *Turborotalia ampliapertura* Highest-occurrence Zone (emended herein; *"Turborotalia ampliapertura"* Partial-range/Interval Zone [P19] of Berggren and Miller, 1988, and Berggren and others, 1995).

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

Magnetochronologic calibration: Chron C12r-Chron C11r.

Estimated age: 32.0–30.3 Ma; early Oligocene (middle-late Rupelian).

Remarks: See remarks above regarding the definition of the boundary with the underlying Zone O1. The definition of this zone is emended here to reflect the use of the HO of *Pseudohastigerina naguewichiensis* (rather than simply *Pseudohastigerina* spp.) to denote its base.

Zone O3. *Globigerina sellii* Partial-range Zone (=*Globigerina sellii* Partial-range Zone [P20] of Berggren and Miller, 1988, and Berggren and others, 1995).

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

Magnetochronologic calibration: Chron C11r-Chron C11n$_{(y)}$.

Estimated age: 30.3–29.4 Ma; late early Oligocene (late Rupelian).

Remarks: The nomenclature and definition of the zone remain the same as in Berggren and others (1995).

Zone O4. *Globigerina angulisuturalis/Chiloguembelina cubensis* Concurrent-range Zone (herein emended; =*Globigerina angulisuturalis/Chiloguembelina cubensis* Concurrent-range Subzone [P21a] of Berggren and Miller, 1988, and Berggren and others, 1995).

Definition: Concurrent range of the nominate taxa between the LO of *Globigerina angulisuturalis* and the highest common occurrence (HCO) of *Chiloguembelina cubensis.*

Magnetochronologic calibration: Chron C11n$_{(y)}$-Subchron C10n.1n.

Estimated age: 29.4–28.5 Ma; late early Oligocene (latest Rupelian).

Remarks: The *Globigerina angulisuturalis/Paragloborotalia opima opima* Concurrent-range Zone [P21] was divided into two subzones by Berggren and Miller (1988) and Berggren and others (1995) based on the supposed LAD of *Chiloguembelina cubensis* within the mid-part of the concurrent range of *G. angulisuturalis* and *Paragloborotalia opima.* Reported sporadic occurrences (including our own work) of *C. cubensis* at stratigraphically higher levels has led us to modify the criterion for the upper limit of this zone to the HCO of *C. cubensis* rather than its HO. The lower part of Zone P21, Subzone P21a, is herein elevated to the rank of zone.

Zone O5. *Paragloborotalia opima* Highest-occurrence Zone (herein emended; =*Globigerina angulisuturalis/Paragloborotalia opima opima* Interval Subzone [P21b] of Berggren and Miller, 1988, and Berggren and others, 1995).

Definition: Biostratigraphic interval between the HCO of *Chiloguembelina cubensis* and the HO of the nominate taxon *Paragloborotalia opima.*

Magnetochronologic calibration: Subchron C10n.1n-Chron C9n$_{(y)}$.

Estimated Age: 28.5–27.1 Ma; early late Oligocene (early Chattian).

Remarks: This zone represents the same biostratigraphic interval as Subzone P21b, herein elevated to rank of zone. See remarks above. The use of the taxon *P. opima* refers to *P. opima sensu stricto.* We do not use subspecies in our taxonomy.

Zone O6. *Globigerina ciperoensis* Partial-range Zone (=*Globigerina ciperoensis* Partial-range Zone [P22] of Berggren and Miller, 1988, and Berggren and others, 1995).

Definition: Partial range of the nominate taxon between the HO of *Paragloborotalia opima* and the LO of *Globorotalia kugleri sensu stricto.*

Magnetochronologic calibration: Chron C9n$_{(y)}$- Subchron C6Cn.2$_{(o)}$.

Estimated Age: 27.1–23.8 Ma; late Oligocene (mid-late Chattian).

Remarks: Zone O6 terminates the Paleogene planktonic foraminiferal biostratigraphic zonal record and is followed by a series of Neogene zones that are denominated M zones (for Miocene; see Berggren and others, 1995).

CONCLUSIONS

The revised (sub)tropical Paleogene planktonic foraminiferal zonation presented herein is the latest incarnation of biostratigraphic efforts spanning over 50 years, and it will undoubtedly not be the final word. It is, however, consistent with the latest taxonomic and biostratigraphic investigations of the Paleogene Planktonic Foraminifera Working Group as collated in the forthcoming *Atlas of Eocene Planktonic Foraminifera* (Pearson and others, in press). We have consciously avoided erecting a formal system of subzones for the Eocene at this stage, but we recognize that several of the zones could usefully be subdivided. In every case, the chronozonal boundaries have been calibrated as accurately as possible to magnetostratigraphy. The numerical ages for the various chronozonal boundaries quoted in this paper are consistent with the time scale of Berggren and others (1995), but we emphasize that new revisions to the chronology will probably be necessary in the near future given recent developments in isotopic dating and astrochronology. The new Paleogene zonal notation scheme ('P', 'E' and 'O' zones) is intended to bring the Paleogene in line with the Neogene nomenclature of Berggren and others (1995).

ACKNOWLEDGMENTS

We thank Helen Coxall, Huw Boulton and Megan Harrison for help in collecting samples from Massignano, Italy, and Gregory Simpson for collecting samples from Torre Cardela in Spain. We extend our gratitude likewise to our colleagues in the Paleogene Planktonic Foraminiferal Working Group for ongoing discussions on the taxonomy and biostratigraphy of Eocene planktonic foraminifera in the course of preparing the Eocene Atlas over the past several years. We also thank Jack Cook for drafting the figures. The manuscript benefitted extremely from helpful reviews by Peter McLaughlin, Bob Fleisher, Clay Kelly and Silvia Spezzaferri.

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Received 4 January 2005
Accepted 24 August 2005