

NEOGENE PLANKTONIC FORAMINIFERA



A
PHYLOGENETIC
ATLAS

J. P. KENNETT/M. S. SRINIVASAN

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NEOGENE PLANKTONIC FORAMINIFERA

A Phylogenetic Atlas

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and

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Hutchinson Ross Publishing Company

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Preface

Planktonic foraminifera are one of the two major marine calcareous microfossil groups employed in biostratigraphic studies of the Cenozoic and Cretaceous. Since the beginning of the Deep Sea Drilling Project in 1968, the group has been extensively employed in the study of deep sea marine sequences. Much has been learned about evolution, stratigraphic ranges, and geographic distribution of planktonic foraminiferal species. Planktonic foraminifera have been widely used in paleoceanographic, paleobiogeographic, and stable isotopic studies. Knowledge of the Neogene forms has increased to the point where phylogenetic relationships are now known for most abundant and many minor forms. As a result of the cumulative investigations of a large number of workers dealing with deep sea drilled sequences, the evolution and phylogenetic relationships are now much better known for Neogene planktonic foraminifera than for any other group of marine microfossils.

This atlas represents a synthesis of Neogene planktonic foraminifera of the world's oceans and of their evolutionary relationships. A comprehensive atlas illustrating most of the major Neogene representatives and many of the minor forms is needed to help future investigators with their identifications; but also one of our goals has been to summarize phylogenetic relationships among Neogene forms. A solid understanding of these phylogenetic relationships provides the necessary basis for accurate biostratigraphic and biochronological investigations. When biostratigraphy employs groups of poorly known phylogeny, mistakes often occur in stratigraphic assignment.

A synthesis of Neogene planktonic foraminifera must, by necessity, incorporate information from all latitudes of the oceans. Major separate evolutionary radiations have occurred in temperate and tropical regions. Some lineages began in temperate areas and later abandoned these areas for the tropics. This atlas is based on investigations of deep sea sedimentary sequences ranging from the tropics to subantarctic regions. Our interpretations on the phylogenetic relationships and classification of Neogene planktonic foraminifera have resulted from many years of work on Indo-Pacific sequences. Some phylogenetic information on forms restricted to the Atlantic region may not be included in the synthesis; nevertheless, most of the major Neogene phylogenetic lineages or forms occur in the Atlantic as in the Indo-Pacific region.

Previous atlases of planktonic foraminifera include Postuma (1971), Stainforth et al. (1975), and Saito et al. (1981). The forms treated in the latter are limited to the Quaternary.

We have illustrated by scanning electron microscopy the major and many minor forms that make up the individual lineages of Neogene planktonic foraminifera. One hundred and fifty species are illustrated and described. Data are provided on their stratigraphic ranges and distribution according to water mass. Stratigraphic ranges are plotted against the tropical N-zonations and a temperate zonal scheme depending on the latitudinal ranges of species. In all cases, the classification and treatment of the planktonic foraminifera is by phylogeny. A synthesis is provided of the lineages of Neogene planktonic foraminifera. The surface ultrastructure of planktonic foraminifera as revealed by scanning electron microscopy is both distinctive and highly conservative between many different lineages through the Neogene. This assists greatly in the differentiation and hence the phylogenetic classification of planktonic foraminifera. The surface ultrastructure for each of the genera and/or subgenera is exhibited in this atlas. The phylogenetic approach has allowed a more critical evaluation of those forms that potentially represent junior synonyms. We deal only with those taxa considered to represent phylogenetically valid species.

The globorotaliids are treated within a phylogenetic framework. The earlier classifications of *Globorotalia* were often artificial. We have instead traced the evolution of these forms within a phylogenetic framework and placed them within subgenera: *Fohsella*, *Globoconella*, *Menardella*, *Hirsutella*, *Truncorotalia*, *Globorotalia*, *Tenuitella*, and *Jenkinsella* n. subgen.

A new subgenus, *Jenkinsella*, represents the lineage of forms from *Globorotalia* (*Jenkinsella*) *opima* → *Gr. (J.) semivera* → *Gr. (J.) siakensis* → *Gr. (J.) bella* → *Gr. (J.) mayeri* and *Gr. (J.) acrostoma*.

Globigerina also is treated within a lineage framework. The evolution of these forms occurs within two broad phylogenies: a temperate line represented by a new subgenus *Globigerina* (*Zeaglobigerina*) and the temperate to tropical forms included within *Globigerina* (*Globigerina*). *Zeaglobigerina* is characterized by distinct reticulate surface ultrastructure and includes the lineage of forms from *Globigerina* (*Zeaglobigerina*) *woodi* → *Gg. (Zg.) brazieri*, *Gg. (Zg.) connecta*, *Gg. (Zg.) druryi* → *Gg. (Zg.) nepenthes* *Gg. (Zg.) decoraperta*, *Gg. (Zg.) apertura*, and *Gg. (Zg.) rubescens*.

"*Globigerinoides*" is polyphyletic and hence an artificial genus. Forms with supplementary apertures on the spiral surface (referred to as "*Globigerinoides*") split off from different *Globigerina* lineages at least five times during the Neogene. Ancestral forms for each lineage include *Globigerinoides primordius* (from *Globigerina* (*Globigerina*) *praebulloides*) in the latest Oligocene; *Globigerinoides triloba* (from *Globigerina* (*Zeaglobigerina*) *connecta*) in the earliest Miocene (Zone N4B); *Globigerinoides subquadratus* (from *Globigerina* (*Zeaglobigerina*) *brazieri*) in the earliest Miocene (Zone N4B); *Globigerinoides bollii* (from *Globigerina* (*Zeaglobigerina*) *woodi*) in the Middle Miocene; *Globigerinoides bulloideus* (from *Globigerina* (*Globigerina*) *bulloides*) in the late Miocene; and *Globigerinoides tenellus* (from *Globigerina* (*Zeaglobigerina*) *rubescens*) in the late Pliocene.

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James P. Kennett
M. S. Srinivasan

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Biostratigraphic Background

HISTORY OF CLASSIFICATION OF PLANKTONIC FORAMINIFERA

Most workers classify planktonic foraminifera according to simple morphological criteria such as the type and position of aperture, presence or absence of keels, shape of chambers, and the basic coiling mode and other factors. Bolli et al. (1957) briefly reviewed earlier attempts at planktonic foraminiferal classifications and proposed new groupings based upon wall composition, chamber arrangement, and position of the primary aperture. Banner and Blow (1959) proposed another classification, based on external modifications of the primary aperture. In general, early classifications (Bolli et al., 1957; Morozova, 1957; Sigal, 1958; Pokorny, 1958; Banner and Blow, 1959; Loeblich and Tappan, 1964; El-Naggar, 1971) were classical typological approaches, and, although they are easy to apply, they usually ignored the phylogenetic interrelationships of species. The classification employed by most workers is still largely artificial.

The development of phylogenetic classification has required a thorough understanding of ancestor-descendant relationships between taxa and also a discovery of conservative morphological features that distinguish different lineages. Surface ultrastructure seems to be one of the few conservative features within individual lineages, as first recognized by Parker (1962) who classified planktonic foraminifera on the presence or absence of spines in living forms. This work was followed by Lipps (1966) who introduced a scheme based on wall structural differences. Increased

use of scanning electron microscopy on planktonic foraminifera since the late 1960s led to rapid progress in knowledge of the surface ultrastructure. Collen and Vella (1973) and Fleisher (1974) were the first to recognize distinct surface ultrastructure within different phylogenetic groups and the potential for utilizing this criterion in classification. The presence or absence of spine bases, cancellate (reticulate) surface, pore pits, and pustules or crystallites imparts distinctive surface ultrastructural patterns, which remain relatively conservative within individual lineages (Bé, 1969; Collen and Vella, 1973; Srinivasan and Kennett, 1975, 1976b; Saito et al., 1976; Huang, 1981). Srinivasan and Kennett (1976b) demonstrated that, although surface ultrastructure can change in certain groups due to phenotypic variation in different water masses, basic characteristics remain unchanged.

The classification of Neogene planktonic foraminifera still largely ignores phylogenetic considerations and hence is primarily artificial in its character. The first workers to suggest the concept of phylogenetic classification in planktonic foraminifera were Berggren (1968), Steineck (1971), and Bandy (1972, 1975). To improve understanding of the different phylogenies and classification of the Neogene globorotaliids, Bandy (1972, 1975) devised a number of phylogenetically defined subgenera. The only workers who have followed this classification are Fleisher (1974) and Srinivasan and Kennett (1981a, 1981b). We continue with this approach in this book and have established additional phylogenetic subgenera. For instance, *Globorotalia* is an artificial genus with little phylogenetic

meaning. It consists of at least eight distinctly different evolutionary lineages within the Neogene. Individual evolutionary lineages may contain a wide variety of morphologic types that cut across artificial classifications. For instance, the *Globoconella* and *Fohsella* lineages include both keeled and nonkeeled forms and compressed and inflated forms. Nevertheless, one major morphological character that does remain the same in the different *Globorotalia* lineages is the presence of an umbilical to extraumbilical aperture.

Similar phylogenetic classification has been employed for Paleogene planktonic foraminifera by McGowran (1968), Steineck and Fleisher (1978), and Fleisher and Steineck (1981). They have argued that it is time to replace the earlier typological approach to classification above the species level by more meaningful grouping of planktonic foraminifera based on phylogenetic considerations. Since the current knowledge of evolutionary lineages of Neogene planktonic foraminifera is adequate to justify such an approach, we have done so in this book.

NEOGENE PLANKTONIC FORAMINIFERAL ZONATIONS

The Deep Sea Drilling Project (DSDP) has led to an extraordinary increase in the study of Cenozoic planktonic foraminifera. Hundreds of drilled sequences throughout the ocean basins have been studied and stratigraphically subdivided by a large number of workers. Despite this, there has been much constraint in the development of new biostratigraphic schemes. Almost all of the biostratigraphers have employed existing zonal schemes or made only relatively minor modifications of the schemes. The most widely employed have been those developed by Bolli (1957a, 1966) and by Banner and Blow (1965) and Blow (1969) for the tropical regions and by Jenkins (1967, 1971) for temperate regions. These zonal schemes were mainly established on faunas from uplifted sediments originally laid down on continental shelves and upper continental slopes.

Tropical Zonation

Bolli (1957a, 1957b) first published a planktonic foraminiferal zonal scheme for the Trinidad Paleocene to Miocene and subsequently subdivided the Pliocene and Pleistocene into zones and subzones (Bolli and Bermudez, 1965; Bolli, 1966). Initially Bolli (1966) divided the Miocene into fifteen zones and the Pliocene into two zones. Later, with additional data from the DSDP Legs 4 and 15, Bolli (1970) and Bolli and Premoli Silva (1973) presented a revised zonal scheme with fourteen zones in the Miocene, subdivided the Pliocene into three zones, and the Pleistocene *Gr. truncatulinoides* zone was subdivided into four subzones and a Holocene subzone (Text Fig. 1). Bolli's scheme has been emended by a few later workers. For instance, Lamb and Beard (1972) suggested modifications to the correlations between the Caribbean sequences and the European stages. This modified scheme was later adopted by Smith and Beard (1973). Cita (1973) proposed new Pliocene zones in the Mediterranean basin using evolution of the *Globorotalia* (*H.*) *margaritae* plexus. Overall most workers have found Bolli's zonal scheme broadly applicable, although few have directly employed it, despite its priority (Stainforth et al., 1975; Srinivasan, 1977). The most commonly used biostratigraphic scheme is that of Banner and Blow (1965) and Blow (1969). In many ways, their scheme is similar to that of Bolli and has not led to any greater stratigraphic refinements. Both zonal schemes, for instance, contain approximately forty-five zones for the entire Cenozoic (Bolli, 1966, forty-two zones; Blow, 1969, forty-three zones). The widespread application of Blow's (1969) zones has largely resulted because of its numerical designation for each zone. The Paleogene thus contains twenty-two zones—from P1 in the early Paleocene to P22 in the latest Oligocene. The Neogene is subdivided into twenty N zones from N4 in the earliest Miocene to N23 in the Late Quaternary (Text Fig. 2). It is unfortunate, however, that Banner and Blow (1965) and Blow (1969) did not designate their earliest Neogene zone as N1. The widespread acceptance of this scheme

NEOGENE PLANKTONIC FORAMINIFERAL ZONATIONS

EPOCH		PLANKTONIC FORAMINIFERAL ZONES	FIRST APPEARANCES (F.A.) and LAST APPEARANCES (L.A.) of SPECIES and SUBSPECIES used to DELIMIT ZONES	
PLEISTOCENE		<i>G. bermudezi</i> <i>Globorotalia</i> <i>G. calida</i> <i>truncatulinoides</i> <i>G. hessi</i> <i>G. viola</i>	← <i>G. fimbriata</i> F.A. ← <i>G. tumida flexuosa</i> L.A. ← <i>G. calida calida</i> F.A. ← <i>G. hessi</i> F.A. ← <i>G. truncatulinoides</i> F.A.	
PLIOCENE	LATE	<i>Globorotalia truncatulinoides</i> cf. <i>tosaensis</i>	← <i>G. miocenica</i> L.A.	
	MIDDLE	<i>Globorotalia</i> <i>G. exilis</i> <i>miocenica</i> <i>G. fistulosus</i>	← <i>G. trilobus fistulosus</i> L.A. ← <i>G. margaritae evoluta</i> L.A.	
	EARLY	<i>Globorotalia</i> <i>G. evoluta</i> <i>margaritae</i> <i>G. marg.</i>	← <i>G. margaritae evoluta</i> F.A. ← <i>G. margaritae margaritae</i> F.A.	
MIOCENE	LATE	<i>Neogloboquadrina dutertrei</i>	← <i>N. dutertrei</i> F.A.	
		<i>Globorotalia acostaensis</i>	← <i>G. acostaensis</i> F.A.	
	MIDDLE	<i>Globorotalia menardii</i>	← <i>G. mayeri</i> L.A.	
		<i>Globorotalia mayeri</i>	← <i>G. ruber</i> L.A.	
		<i>Globigerinoides ruber</i>	← <i>G. fohsi robusta</i> L.A.	
		<i>Globorotalia fohsi robusta</i>	← <i>G. fohsi robusta</i> F.A.	
		<i>Globorotalia fohsi lobata</i>	← <i>G. fohsi lobata</i> F.A.	
		<i>Globorotalia fohsi fohsi</i>	← <i>G. fohsi fohsi</i> F.A.	
		<i>Globorotalia fohsi peripheroronda</i>	← <i>G. insueta</i> L.A.	
		<i>Praeorbulina glomerosa</i>	← <i>P. glomerosa</i> F.A.	
	EARLY	<i>Globigerinatella insueta</i>	← <i>C. dissimilis</i> L.A.	
		<i>Catapsydrax stainforthi</i>	← <i>G. insueta</i> F.A.	
		<i>Catapsydrax dissimilis</i>	← <i>G. kugleri</i> L.A.	
		<i>Globigerinoides primordius</i>	← <i>G. primordius</i> F.A.	
		LATE OLIGOCENE	<i>Globorotalia kugleri</i>	

TEXT FIGURE 1. Tropical Neogene planktonic foraminiferal zonation of Bolli (1957a, 1966, 1970) and Bolli and Premoli-Silva (1973) and species used for zone definitions. (F.A. = first appearance; L.A. = last appearance). Since this work was carried out, the ranges of some species are now known to be different. For instance, the first appearance of *Gs. primordius* is in the Late Oligocene and does not mark the Oligocene-Miocene boundary.

NEOGENE PLANKTONIC FORAMINIFERAL ZONATIONS

EPOCH		PLANKTONIC FORAMINIFERAL ZONES		FIRST APPEARANCES (F.A.) and LAST APPEARANCES (L.A.) of SPECIES and SUBSPECIES used to DELIMIT ZONES	
PLEISTOCENE	N23	<i>G. calida calida</i> - <i>S. dehiscent excavata</i> A-Z		← <i>G. calida calida</i>	F.A.
	N22	<i>G. truncatulinoides</i> P-R-Z		← <i>G. truncatulinoides</i>	F.A.
PLIOCENE	N21	<i>G. tosaensis tenuithec</i> cons-R-Z		← <i>G. tosaensis tenuithec</i>	F.A.
	N20	<i>G. multicamerata</i> - <i>P. obliquiloculata</i> P-R-Z		← <i>G. pseudopima</i>	F.A.
	N19	<i>S. dehiscent</i> - <i>G. altispira</i> P-R-Z		← <i>S. dehiscent</i>	F.A.
	N18	<i>G. tumida</i> - <i>S. subdehiscent poenedehiscent</i> P-R-Z		← <i>G. tumida tumida</i>	F.A.
MIOCENE	LATE	N17	<i>G. tumida plesiotumida</i> cons-R-Z	← <i>G. tumida plesiotumida</i>	F.A.
		N16	<i>G. acostaensis</i> - <i>G. marotumida</i> P-R-Z	← <i>G. acostaensis</i>	F.A.
		N15	<i>G. continuosa</i> R-Z	← <i>G. siakensis</i>	L.A.
	MIDDLE	N14	<i>G. nepenthes</i> - <i>G. siakensis</i> cons-R-Z	← <i>G. nepenthes</i>	F.A.
		N13	<i>S. subdehiscent</i> - <i>G. druryi</i> P-R-Z	← <i>S. subdehiscent</i>	F.A.
		N12	<i>G. fohsi</i> P-R-Z	← <i>G. fohsi (s.l.)</i>	F.A.
		N11	<i>G. praefohsi</i> cons-R-Z	← <i>G. praefohsi</i>	F.A.
		N10	<i>G. peripheroacuta</i> cons-R-Z	← <i>G. peripheroacuta</i>	F.A.
		N9	<i>O. suturalis</i> - <i>G. peripheroranda</i> P-R-Z	← <i>O. suturalis</i>	F.A.
	EARLY	N8	<i>G. sicanus</i> - <i>G. insueta</i> P-R-Z	← <i>G. bisphericus</i>	F.A.
		N7	<i>G. insueta</i> - <i>G. quadrilobatus trilobus</i> P-R-Z	← <i>C. dissimilis (s.l.)</i>	L.A.
		N6	<i>C. insueta</i> - <i>G. dissimilis</i> cons-R-Z	← <i>G. insueta</i>	F.A.
		N5	<i>G. dehiscent praedeiscent</i> - <i>G. dehiscent</i> P-R-Z	← <i>G. kugleri</i>	L.A.
		N4	<i>G. quadrilobatus primordius</i> - <i>G. kugleri</i> cons-R-Z	← <i>G. primordius</i>	F.A.
	OLIGOCENE	N3/P22			

TEXT FIGURE 2. Tropical Neogene planktonic foraminiferal zonation of Banner and Blow (1965) and Blow (1969) and species used for zone definitions. (A-Z = assemblage zone; P-R-Z = partial range zone; cons.-R.-Z = consecutive range zone; R-Z = range zone). Since this work was carried out, the ranges of some species are now known to be different. For instance, the first appearance of *Gs. primordius* is in the Late Oligocene and does not mark the Oligocene-Miocene boundary. For further discussion on the Paleogene-Neogene boundary, see Cati (1981).