ABSTRACT

Benthic foraminifers from Ocean Drilling Program Leg 199 Holes 1215A, 1220B, and 1221C were examined across the Paleocene/Eocene boundary. Assemblages were studied in 240 samples. The benthic foraminiferal extinction event that correlates with the Paleocene/Eocene epoch boundary was recognized at these sites. Benthic assemblages before the event are characterized by high diversity, but those after the event are low in diversity. An assemblage of agglutinated foraminifers without carbonate cement was recognized at Sites 1220 and 1221. These assemblages were typically found after the event. The discovery of such agglutinated assemblages has never been reported before at this boundary.

INTRODUCTION

The benthic foraminiferal extinction event across the Paleocene/Eocene boundary has been recognized in both deep-ocean and terrestrial sections in diverse locations (Thomas, 1998). However, biostratigraphic studies that identify detailed assemblage changes before and after the event are still too low in resolution. Previous studies suggest that the event occurred in a very short chronostratigraphic interval (Kennett and Stott, 1991; Thomas and Shackleton, 1996).
Biostratigraphic studies of this event have mostly been performed on sections from the oceanic ridges at upper-bathyal to mid-bathyal paleodepths. Little information has been reported from abyssal paleodepths. Thus, the benthic assemblages at Sites 1215, 1220, and 1221 are particularly significant because these sites were located in an abyssal zone at ~3000 m paleodepth (Shipboard Scientific Party, 2002).

**METHODS**

A total of 238 sediment samples from Leg 199 Holes 1215A, 1220B, and 1221C were analyzed for benthic foraminifers at the following intervals:

**Hole 1215A: 103 samples**
- 1–2 cm (Samples 199-1215A-8X-3, 0–1 cm, to 8X-3, 111–112 cm, and 8H-4, 14–15 cm, to 8H-4, 40–41 cm)
- 1 cm (Samples 199-1215A-8X-3, 113–114 cm, to 8X-4, 12–13 cm)

**Hole 1220B: 65 samples**
- 2 cm (Samples 199-1220B-20X-2, 0–2 cm, to 20X-2, 46–48 cm)
- 1 cm (Samples 199-1220B-20X-2, 48–49 cm, to 20X-2, 88–89 cm)

**Hole 1221C: 72 samples**
- 3–20 cm (Samples 199-1221C-11X-1, 3–5 cm, to 11X-3, 28–30 cm, and 11X-3, 113–115 cm, to 12X-1, 18–20 cm)
- 2 cm (Samples 199-1221C-11X-3, 40–42 cm, to 11X-3, 108–110 cm)

Sediment samples (1–2 cm³) were dried at 80°C overnight and then weighed. Dried sediment samples were treated with 3% hydrogen peroxide solution overnight and washed through a 63-µm sieve. Foraminifers were picked from an aliquot of the >149-µm size fraction. A minimum of 200 specimens were picked, but because of limited sample volume and poor preservation in some sections, the number of foraminifers picked was sometimes <200.


**RESULTS**

**Site 1215**

A total of 99 benthic foraminiferal taxa were recognized at this site (Table T1). In general, benthic foraminifers at Site 1215 were well preserved. Some forms such as *Abyssamina quadrata* show very good preservation, which retains the original calcareous crystalline structure of test walls. The number of specimens per gram of sediment ranges from 1.1 to 99.7; Sample 199-1215A-8H-3, 130–131 cm, contains the fewest foraminifers, and Sample 8H-3, 60–61 cm, contains the most foraminifers. These foraminiferal counts are low compared to those from the other two sites (see “Site 1220” and “Site 1221” below). The number of foraminifers decreases in several stratigraphic intervals, particularly in nine
samples in the interval from 199-1215A-8H-3, 127–128 cm, to 8H-3, 135–136 cm, a black layer of nannofossil clay (Fig. F1).

Primary species recognized include A. quadrata, Anomalainoides praeacutus, Globocassidulina globosa, Nautiallides truempi, Pullenia subcarinata, Quadrirhophephora profund, Tappanina selimensis, Paralabamina elevata, Globorotalites micheliniana, Gavelinella beccariiformis, and buliminids. Agglutinated foraminifers are rare at this site.

Site 1220

A total of 111 benthic foraminiferal taxa were recognized at this site (Table T2). In contrast to the other sites, foraminifers were poorly preserved with recrystallized walls. Preservation is particularly poor in the interval from Sample 199-1220B-20X-2, 46–48 cm, to 20X-2, 78–79 cm, which correlates to an interval of multicolored layers. The maximum of 318 specimens/g is found in Sample 199-1220B-20X-2, 2–4 cm, and the minimum of 0 specimens/g is found in Samples 20X-2, 51–52 cm, 58–59 cm, 61–62 cm, and 67–69 cm.

Agglutinated foraminifers with no calcareous cement dominated in multicolored sediment layers. Because carbonate-free and cylindrical agglutinated forms such as Saccorhiza and Rhabdammina are found in the modern deeper ocean below the calcium carbonate compensation depth, we suggest that carbonate-corrosive bottom water covered the site during the time of deposition.

Primary species identified in lower Eocene sediments include A. quadrata, A. praeacutus, Bulimina bradburyi, Bulimina trihedra, G. globosa, N. truempi, Oridorsalis umbonatus, Pleurostomella paleocenica, P. subcarinata, Q. profunda, T. selimensis, and Valvalabamina spp. Primary species identified in the uppermost Paleocene sediments include Bulimina cf. denticulata, Bulimina beaumonti, Cibicidoides eocaenus, G. beccariiformis, G. micheliniana, Neoeponides hillebrandti, P. elevata, and Valvalabamina spp. Paleocene assemblages are characterized by high diversity, and Eocene assemblages are characterized by high abundance of individuals of the primary species but are less diversified.

Site 1221

A total of 139 taxa were recognized at this site (Table T3). The benthic assemblages at this site are similar to those at Site 1220 except that the hyaline calcareous foraminifers are well preserved. Agglutinated foraminifers were developed in the multicolored interval of zeolitic clay (Fig. F1), but preservation is as poor as at Site 1220. The test walls are typically deformed.

Very high foraminiferal numbers (400–700 specimens/g) were found in the calcareous chalk layers above the multicolored interval from 199-1221C-11X-3, 28–30 cm, to 11X-3, 56–58 cm. However, the diversity of foraminifers in these assemblages is low and dominated by few species such as A. quadrata, A. praeacutus, G. globosa, and N. truempi. The assemblages below the multicolored interval are characterized by both high foraminiferal numbers and high diversity. Some calcareous forms such as C. eocaenus, Globorotalites conicus, Gyroidinoides globosus, O. umbonatus, and Osangularia plummerae, are characterized by large tests with thick walls.
PALEOCENE/EOCENE BOUNDARY

An abrupt decrease in diversity and foraminiferal number occurs in Samples 199-1220B-20X-2, 78–79 cm, and 199-1221C-11X-3, 88–90 cm, and 11X-3, 90–92 cm. This stratigraphic level represents the benthic extinction event. Most Paleocene taxa, such as *G. beccariiformis*, *G. conicus*, *N. hillebrandti*, and *Pullenia coryelli*, disappear at the same stratigraphic level in each section, but some Paleocene taxa were observed above this level. The individual numbers of such Paleocene taxa, however, are very low, suggesting reworking. This evidence clearly suggests that the benthic event is represented by the abrupt change in the Paleocene assemblages. At Sites 1220 and 1221 this extinction event is correlated with the base of a brown layer, marked by massive zeolitic chalk, which is devoid of distinct bioturbation. At Site 1215, the event is less distinct compared to the other two sites. However, the last occurrence of typical Paleocene taxon *G. beccariiformis* is found in Sample 199-1215A-8H-3, 126–127 cm. Many Paleocene foraminifers became extinct by this stratigraphic level. Thus, the benthic Paleocene/Eocene boundary event is placed between Sample 199-1215A-8H-3, 126–127 cm, and 8H-3, 125–126 cm, at Site 1215.

It is well known that the abrupt decrease in the Paleocene assemblages correlates with a shift to lower values in the oxygen and carbon isotope records (i.e., Kennett and Stott, 1991). *Nunes and Norris* (this volume) show that the shift in $\delta^{13}$C occurs in Sample 199-1221C-11X-3, 58–60 cm, ~30 cm above the benthic event. This result conflicts with the previous concept of synchronous biostratigraphy and chemostratigraphy events. We will discuss this discrepancy between the isotopic record and the benthic assemblage evidence elsewhere.

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REFERENCES


APPENDIX

Faunal Reference List

Faunal examples are presented in Plates P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, and P21.

_Abyssamina quadra_ta_ Schnitker and Tjalsma, 1980.
_Alabamina dissonata_ (Cushman and Renz) = _Pulvinulinella atlantisae_ Cushman var. _dissonata_ Cushman and Renz, 1948.

_Agglutinated Forms_

_Alabamina_ sp.
_Alabamina_ sp. 1
_Alabamina_ sp. 3
_Alabamina_ sp. 4
_Alabamina_ sp. 5
_Allomorphina minuta_ Cushman, 1944.
_Ammoglobigerina_ sp.
_Anomalinoidea praecutus_ (Vasilenko) = _Anomalina praecutus_ Vasilenko, 1950.
_Anomalinoidea_ sp.
_Aragonina aragonensis_ (Nuttall) = _Textularia aragonensis_ Nuttall, 1930.
_Aragonina ouezzanensis_ (Rey) = _Bolivinoides ouezzanensis_ Rey, 1955.
_Aragonina_ sp.
_Astacolus_ spp.
_Botellina_ sp.
_Bulimina bradburyi_ Martin, 1943.
_Bulimina denticulata_ Cushman and Parker, 1936.
_Bulimina cf. denticulata_ Cushman and Parker, 1936.
_Bulimina impendens_ Parker and Bermudez, 1937.
_Bulimina jarvisi_ Cushman and Parker, 1936.
_Bulimina midwayensis_ Cushman and Parker = _Bulimina arkadelphiana_ Cushman and Parker _midwayensis_ Cushman and Parker, 1936.
_Bulimina cf. midwayensis_ Cushman and Parker.
_Bulimina prolixa_ Cushman and Parker, 1935.
_Bulimina_ sp.
_Bulimina_ sp. 1
_Bulimina_ sp. 2
_Bulimina_ spp.
_Bulimina triangularis_ Cushman and Parker, 1935.
_Bulimina trihedra_ Cushman, 1926.
_Bulimina tuxpanensis_ Cole, 1928.
_Bulimina velascoensis_ (Cushman) = _Gaudryina velascoensis_ Cushman, 1925.
_Buliminella beamonti_ Cushman and Renz, 1946.
_Buliminella cf. grata_ Parker and Bermudez, 1937 = cf. _Buliminella grata_ Parker and Bermudez, 1937.
_Buliminella_ sp. 1
_Buliminella_ sp.
_Cibicidoides eocaenus_ = _Rotalia eocaena_ Gümbel, 1868.
_Cibicidoides cf. dayi_ (White) = cf. _Planulina dayi_ White, 1928.
_Cibicidoides grimsdalei_ (Nuttall) = _Cibicidoides grimsdalei_ Nuttall, 1930.
_Cibicidoides cf. pseudоперlucidus_ (Bykova) = cf. _Cibicidoides (Gemellides) pseudоперlucidus_ Bykova, 1954.
_Cibicidoides_ sp.
_Cibicidoides_ sp. 2
_Cibicidoides_ sp. 3
_Cibicidoides_ spp.
Cibicidoides subcarinatus (Cushman and Deaderick) = Cibicides subcarinatus Cushman and Deaderick, 1944.

Coryphostoma crenulata (Cushman) = Bolivina crenulata Cushman, 1936.

Coryphostoma incrassata (Reuss) = Bolivina incrassata Reuss, 1851.

Coryphostoma cf. midwayensis (Cushman) = cf. Bolivina midwayensis Cushman, 1936.

Coryphostoma sp.

Dentalina inornata d’Orbigny, 1846.

Dentalina spp.

Dentalina wilcoensis Cushman, 1944.

Dorothia bulletta (Carsey) = Gaudryina bulletta Carsey, 1926.

Eggerella spp.

Ellipsoglandulina paleocenica Cushman and Todd, 1946.

Ellipsoglandulina labiata (Schwager) = Glandulina labiata Schwager, 1866.

Ellipsoglandulina plummerae (Cushman) = Ellipsoglandulina plummerae Cushman, 1940.

Ellipsoglandulina spp.

Ellipsoglandulina velascoensis Cushman, 1926.

Ellipsoidella pleurostomelloides Heron-Allen and Earland, 1910.

Ellipsoidella spp.

Ellipsoidina ellipsoides Seguenza, 1859.

Ellipsoidina spp.

Ellipsopolyphona fornasini Galloway, 1933.

Ellipsopolyphona spp.

Eouvigerina sp.

Falsoguttulina sp. 1

Falsoguttulina volbuffi Bartenstein and Brand, 1949.

Fursenkoina sp.

Gavelinella beccariiformis (White) = Rotalia beccariiformis White, 1928.

Globimorphina trochoida (Reuss) = Globigerina trochoides Reuss, 1845.

Globocassidulina globosa (Hantken) = Cassidulina globosa Hantken, 1875.

Globocassidulina sp.

Globocassidulina sp. 1

Globorotalites conicus (Boomgaart) = Eponides conicus Boomgaart, 1949.

Globorotalites micheliniana (d’Orbigny) = Rotalina (Rotalina) micheliniana d’Orbigny, 1840.

Globulina? sp.

Gubkinella asiatica Suleymanov, 1955.

Gyroidinoides beisseli (White) = Gyroidina beisseli White, 1928.

Gyroidinoides cf. girardanus (Nuttall) = cf. Rotalina girardana Reuss, 1851.

Gyroidinoides girardanus (Reuss) = Rotalina girardana Reuss, 1851.

Gyroidinoides globosus (Hagenow) = Nonionia globosa Von Hagenow, 1842.

Gyroidinoides cf. globosus (Hagenow).


Gyroidinoides nitidus (Reuss) = Rotalina nitida Reuss, 1844.

Gyroidinoides octocameratus (Subbotina) = Eponides octocameratus Subbotina, 1960.

Gyroidinoides subangulatus (Plummer) = Rotalia soldani (d’Orbigny) var. subangu-lata Plummer, 1927.

Gyroidinoides sp. 1

Gyroidinoides spp.

Haplophragmoides sp.

Haplophragmoides? sp.

Hemirobulina cf. arcuatula (Stache) = Cristellaria (Hemirobulina) arcuatula Stache, 1864.

Heronalleni sp.

Hippocrepinella sp.

Hormosina sp.

Hyperammina? sp.

Lenticulina insulsus (Cushman) = Robulus insulsus Cushman, 1947.

Lenticulina spp.
**DATA REPORT: PALEOCENE/EOCENE BENTHIC FORAMINIFERS**

- *Marssonella trochoidea* (d’Orbigny) = *Textularia trochoidea* d’Orbigny, 1852.
- *Neoeponides haizingeri* (d’Orbigny) = *Eponides haizingeri* (d’Orbigny) of Cushman, 1931.
- *Neoeponides infrequens* (Plummer) = *Discorbis infrequens* Plummer, 1927.
- *Neoeponides spp.*
- *Neoflabellina rugosa* (d’Orbigny) = *Flabellina rugosa* d’Orbigny, 1840.
- *Nodosaria affinis* (Reuss) = *Nonionina affinis* Reuss, 1851.
- *Nodosaria aspera* Reuss, 1845.
- *Nodosaria monile* Hagenow, 1842.
- *Nodosaria paleocenica* Cushman and Todd, 1946.
- *Nodosaria spp.*
- *Nodosarella paleocenica* Cushman and Bermudez, 1937.
- *Nobion sp. 1*
- *Nobion sp.*
- *Nuttallides sp. 1*
- *Nuttallides sp. 2*
- *Oridoras plummerae* (Cushman) = *Eponides plummerae* Cushman, 1948.
- *Oridoras sp.*
- *Oridoras umbonatus* (Reuss) = *Rotalina umbonata* Reuss, 1851.
- *Orthokarstenia brevispinosa* (Cushman) = *Siphogenerinoides brevispinosa* Cushman, 1939.
- *Orthokarstenia cf. brevispinosa* (Cushman) = *Siphogenerinoides brevispinosa* Cushman, 1939.
- *Orthokarstenia clarki* (Cushman and Campbell) = *Siphogenerinoides clarki* Cushman and Campbell, 1936.
- *Osangularia plummerae* Brotzen, 1940.
- *Osangularia spp.*
- *Paleopolymorphina pleurostomelloides* (Franke) = *Polymorphina pleurostomelloides* Franke, 1928.
- *Paralabamina sp. 1*
- *Paralabamina sp. 4*
- *Pleurostomella clavata* Cushman, 1926.
- *Pleurostomella paleocenica* Cushman, 1947.
- *Pleurostomella rimosa* Cushman and Bermudez, 1937.
- *Pleurostomella subnodosa* Reuss, 1860.
- *Pleurostomella velascoensis* Cushman, 1926.
- *Pleurostomella spp.*
- *Polymorphina sp.*
- *Pseudoglobulina spp.*
- *Pseudonodosaria spp.*
- *Pullenia cf. eocenica* Cushman and Siegfus, 1939.
- *Pullenia coryelli* White, 1929.
- *Pullenia cretacea* Cushman, 1936.
- *Pullenia jarvisi* Cushman, 1936.
- *Pullenia sp.*
- *Pullenia subcarinata* (d’Orbigny) = *Nonionina subcarinata* d’Orbigny, 1839.
- *Pyrulinae acuminatus* (d’Orbigny) = *Pyrulina acuminata* d’Orbigny, 1840.
- *Pyrulina sp.*
- *Quadratobuliminella pyramidalis* Klasz, 1953.
- *Quadratobuliminella spp.*

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P14. Cibicidoides, p. 27.

P15. Cibicidoides, Oridorsalis, p. 28.

Quadrimorphina profunda Schnitker and Tjalsma, 1980.
Rhabdammina sp.
Saccammina sp.
Saccorhiza ramosa (Brady) = Hyperammina ramosa Brady, 1879.
Saracenaria midwayensis Kline, 1943.
Scheibnerovia? sp.
Sigmomorphina sp.
Sigmomorphina terquemiana (Fornasini) = Sigmomorphina semitecta (Reuss) var.
terquemiana (Fornasini) of Cushman and Ozawa, 1930.
Spiroplectammina jarvisi Cushman, 1939.
Spiroplectammina sp.
Spiroplectammina spectabilis (Grzybowski) = Spiroplecta spectabilis Grzybowski, 1898.
Spiroplectammina subglabra (Cushman) = Textularia subglabra Cushman, 1926.
Stilostomella paleocenica (Cushman and Todd) = Ellipsonodosaria paleocenica Cushman and Todd, 1946.
Stilostomella plummerae (Cushman) = Ellipsonodosaria plummerae Cushman, 1940.
Stilostomella rugosa Guppy, 1894.
Stilostomella sp.
Tappanina selmensis (Cushman) = Bolivina selmensis Cushman, 1933.
Tritaxia globulifera (ten Dam and Sigal) = Pseudoclavulina globulifera ten Dam and Sigal, 1950.
Tritaxia paleocenica Tjalsma and Lohmann, 1983.
Tritaxia pyramidata (Cushman) = Gaudryina laevigata Franke var. pyramidata Cushman, 1926.
Tritaxia sp.
Unilocular forms
Valvalabamina depressa (Cushman and Church) = Gyroidina depressa Cushman and Church, 1929.
Valvalabamina sp. 1
Valvalabamina sp. 2
Valvalabamina sp. 3
Valvalabamina sp. 4
Valvulineria spp.
Vulvulina spinosa Cushman, 1927.
Figure F1. Stratigraphic level of the benthic foraminiferal extinction event and the lithostratigraphic color units at Sites 1215, 1220, and 1221.
Table T1. Distribution of benthic foraminifers, Hole 1215A. (This table is available in an oversized format.)
Table T2. Distribution of benthic foraminifers, Hole 1220B. (This table is available in an oversized format.)
Table T3. Distribution of benthic foraminifers, Hole 1221C. (This table is available in an oversized format.)
Plate P5. Scale bar = 100 µm. 1. *Aragonina aragonensis* (Nuttall) (Sample 199-1221C-11X-1, 23–25 cm). 2–4. *Aragonina ouezzanensis* (Rey); (2) Sample 199-1215A-8H-4, 10–11 cm, (3) Sample 199-1221C-11X-3, 118–120 cm, (4) Sample 199-1215A-8H-4, 0–1 cm. 5, 6. *Tappanina selmensis* (Cushman); (5) Sample 199-1215A-8H-3, 9–10 cm, (6) Sample 199-1220B-20X-2, 4–6 cm. 7, 9, 10. *Falsoguttulina* sp. 1; (7) Sample 199-1215A-8H-4, 32–33 cm, (9) Sample 199-1215A-8H-4, 12–13 cm, (10) Sample 199-1221C-11X-3, 118–120 cm. 8, 11. *Falsoguttulina wolburgi* Bartenstein and Brand; (8) Sample 199-1215A-8H-4, 11–12 cm, (11) Sample 199-1221C-11X-3, 118–120 cm.
Plate P15. Scale bar = 100 µm. 1. *Cibicidoides* sp. 2 (Sample 199-1221C-11X-2, 88–90 cm). 2. *Cibicidoides grimsdalei* (Nuttall) (Sample 199-1221C-12X-1, 8–10 cm). 3, 4. *Oridorsalis umbonatus* (Reuss); (3) Sample 199-1215A-8H-4, 11–12 cm, (4) Sample 199-1221C-11X-3, 123–125 cm. 5. *Oridorsalis plummerae* (Cushman) (Sample 199-1220B-20X-2, 2–4 cm).
Plate P18. Scale bar = 100 µm. 1, 2. Neoeponides hillebrandti (Fisher); (1) Sample 199-1215A-8H-3, 143–144 cm, (2) Sample 199-1221C-11X-3, 94–96 cm. 3. Paralabamina sp. 1 (Sample 199-1221C-11X-3, 123–125 cm). 4, 8, 9. Paralabamina elevata (Plummer); (4, 9) Sample 199-1215A-8H-4, 11–12 cm, (8) Sample 199-1221C-11X-3, 94–96 cm. 5, 7. Paralabamina lunata (Brotzen); (5) Sample 199-1221C-11X-1, 23–25 cm, (7) Sample 199-1221C-11X-1, 63–65 cm. 6. Paralabamina sp. (Sample 199-1221C-11X-1, 23–25 cm).