

Eocene-Oligocene boundary: Biostratigraphic recognition and gradual paleoceanographic change at DSDP Site 549

Scott W. Snyder

Department of Geology, East Carolina University, Greenville, North Carolina 27834

Carla Müller

Geologisch-Paläontologisches Institut der Universität Frankfurt am Main, Germany

Kenneth G. Miller

Lamont-Doherty Geological Observatory, Palisades, New York 10964

ABSTRACT

Drilling at Site 549, located on the Goban Spur in the northern Bay of Biscay (Irish continental margin), penetrated an apparently continuous section of upper Eocene-lower Oligocene nannofossil chalks. The Eocene-Oligocene boundary as identified by nannofossils does not coincide with that recognized using planktonic foraminifers. Regardless of which biostratigraphic criteria are used, no dramatic nannofloral or planktonic foraminiferal change occurred at the boundary. There was a gradual transition from warm-water to cool-water assemblages through the late Eocene, with more intense cooling indicated by low-diversity assemblages in lower Oligocene sediments. A bottom-water temperature drop occurred in the late Eocene through early Oligocene as indicated by an ^{18}O enrichment in benthic foraminifers, although some of this enrichment may have been caused by increased ice volume. A major benthic foraminiferal faunal change, from a *Nuttallides truempyi*-dominated assemblage to one dominated by wide- and long-ranging taxa, occurred in the early late Eocene. No major benthic assemblage changes occurred at the Eocene-Oligocene boundary.

INTRODUCTION

Two holes were cored at Deep Sea Drilling Project (DSDP) Site 549 in the North Atlantic (lat 49°05.29'N, long 13°05.89'W; water depth 2,513 m, corrected). Hole 549A (Pleistocene to late Eocene) was hydraulic piston cored; hole 549 (middle Eocene and older) was rotary drilled.

The composite Eocene-Oligocene sedimentary section within these holes is about 278 m thick. Lower Eocene sediments are light-brown marly chalks; the remainder of the Eocene and the Oligocene sections are bluish-white to light greenish-gray nannofossil chalks. Average sedimentation rates are 20 m/m.y. for the late Eocene and 13 m/m.y. for the earliest Oligocene. Core-recovery rates through this part of the section provided the sampling density required for relatively precise stratigraphic interpretations (Fig. 1).

Except for a middle Oligocene disconformity within nannofossil Zone NP23, the Eocene-Oligocene strata at Site 549 appear to represent continuous deposition. If any hiatus occurs in the late Eocene-early Oligocene section, its duration is less than can be resolved by biostratigraphy and isotopic stratigraphy (i.e., <0.5 m.y.).

METHODS

The stratigraphic distributions of microfossils shown in Figures 1 and 2 are drawn from Müller (1984) for calcareous nannofossils, Snyder and Waters (1984) for planktonic foraminifers, and Miller et al. (1984) for benthic foraminifers. Calcareous nannofossil distributions are recorded as partial ranges and expressed in terms of standard NP Zones (Martini, 1971). Planktonic foraminiferal distributions, recorded as qualitative abundance estimates based on strewn slides, are related to the zonal scheme of Stainforth et al. (1975). Census data for benthic taxa are quantitative counts (>150 μm size fraction) and are presented as percentage of total benthic foraminifers counted. Isotopic analyses were performed on monogeneric samples of the benthic foraminiferal genus *Cibicidoides*, and results are presented as per mil differences from PDB (Miller et al., 1984).

BIOSTRATIGRAPHY

Upper Eocene through lower Oligocene chalks at Site 549 contain abundant, generally well-preserved nannofossils and planktonic foraminifers. Those foraminifers most useful for recognition of the Eocene-Oligocene boundary are subspecies of *Globorotalia cerroazulensis* (Cole). Toumarkine and Bolli (1970) described the evolutionary development of this lineage from *Globigerina frontosa* Subbotina, showing that the stratigraphic ranges of its successive subspecies could be used to subdivide the middle and upper Eocene of higher latitude regions. The stratigraphic occurrences of these subspecies at Site 549 (Fig. 2) correspond closely to the ranges that they noted. Only one of their subspecies, *G. c. possagnoensis*, has not been identified at Site 549. The stratigraphic interval where this form might be expected to occur (hole 549, cores 4 and 5) is characterized by fairly extensive dissolution and breakage (Snyder and Waters, 1984), and representatives of the *G. cerroazulensis* lineage have not been recovered from it. According to Toumarkine and Bolli (1970), the last appearance datum (LAD) for each of three subspecies (*G. c. cerroazulensis*, *G. c. cocoaensis*, and *G. c. cunialensis*) marks the Eocene-Oligocene boundary. On the basis of their criteria, this series boundary is placed at 123 m below sea floor in hole 549A (Fig. 2).

The nannofossil-based placement of the Eocene-Oligocene boundary, as interpreted here, coincides with the LAD of certain rosette-shaped discoasters, namely *Discoaster saipanensis* and *D. barbadiensis* (= base of Zone NP21). Because discoasters are warm-water forms that disappear progressively earlier in higher latitude areas (Van Couvering et

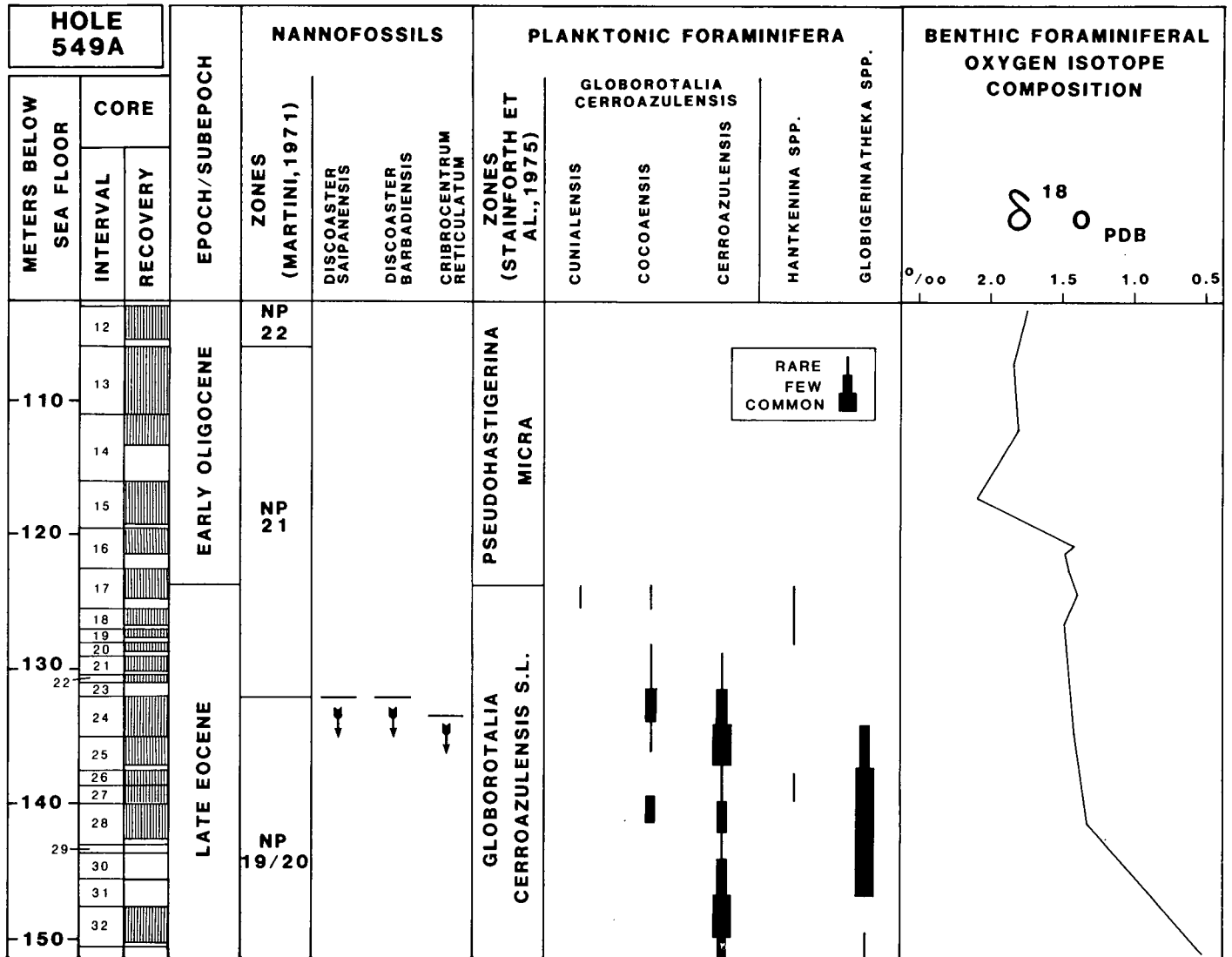


Figure 1. Biostratigraphy and benthic foraminiferal isotopic composition across Eocene-Oligocene boundary at DSDP Site 549 (series boundary plotted according to planktonic foraminiferal evidence). Arrows denote continuation of distributional ranges.

al., 1981), their value as biostratigraphic markers at Site 549 might be questioned. However, the occurrence of *Criboecentrum reticulatum* at Site 549 supports the interpretation based on these discoaster extinctions. Müller (1978) proposed using the LAD of *C. reticulatum* in high latitudes to approximate the position of the Eocene-Oligocene boundary. At Site 549 it ranges into the uppermost Eocene, disappearing just below the discoaster extinction (Fig. 1). Thus, the Eocene-Oligocene boundary has been interpreted to lie at 132 m below sea floor.

Resolving the foraminifer- versus nannofossil-based boundary question at Site 549 involves the broader question of boundary definition. The disappearance of *D. saipanensis* and *D. barbadiensis* is used to define the NP20-NP21 zonal boundary, which has traditionally been considered to correspond to the top of the Eocene. This interpretation has recently been disputed; Van Couvering et al. (1981) outlined the conflicting viewpoints as follows. Martini and Ritzkowski (1968) equated the stratotype of the lower Oligocene (Lattorfian) with Zone NP21 and proposed redefining the base of the Oligocene at the base of Zone NP21. However, Cavalier (1979) stated that material from the Lattorfian type

locality lies within Zone NP19/NP20 (late Eocene), a view that agrees with molluscan evidence which also suggests that the base of the Lattorfian is diachronous. Preserving the Lattorfian as a time-stratigraphic unit for global reference (1) requires redefinition of its base (impossible since the type locality is not accessible); (2) results in an Oligocene that incorporates an interval normally included in the late Eocene; and (3) creates controversy because it uses a biostratigraphic datum known to be latitudinally time-transgressive to define a time-stratigraphic unit. Van Couvering et al. (1981) recognized the extinctions of *D. saipanensis* and *D. barbadiensis*, which are still acceptable for defining the NP20/NP21 zonal boundary, well below the epoch boundary (i.e., the Eocene-Oligocene boundary lies within Zone NP21). The same boundary-zonal relationship was noted by Hardenbol and Berggren (1978).

The views of Toumarkine and Bolli (that the extinction of the *Globorotalia cerroazulensis* lineage marks the Eocene-Oligocene boundary) are favored here for several reasons.

1. The simultaneous extinction of *Hantkenina* spp. and the *Globorotalia cerroazulensis* lineage is now widely accepted as a biostratigraphic

datum that marks the Eocene-Oligocene boundary. The scientific validity of an argument is not guaranteed by majority opinion (Berggren et al., 1984), but the widespread utility of this datum provides greater consistency than do other paleontological criteria.

2. The extinction of the *G. cerroazulensis* lineage appears to be synchronous across broad geographic distances. It occurred within the reverse-polarity interval that follows anomaly 15 (Lowrie and Alvarez, 1981; Poore et al., 1982). At Site 549 the extinction apparently occurred just at the top of anomaly 15 (Townsend, 1984), although low magnetic intensities make magnetostratigraphic interpretations tentative. The only other apparent exception to this magnetobiostratigraphic correlation is on the Rio Grande Rise, where Pujol (1983) noted the LAD of the *G. cerroazulensis* lineage at the top of anomaly 15; this, however, is probably the result of dissolution at Site 516. A sharp increase (i.e., <0.5 m.y.) in $\delta^{18}O$ in the lowermost Oligocene at Site 549 (Fig. 1; Miller et al., 1984) and at Pacific Sites 277 and 292 (Keigwin, 1980) occurs just above the extinctions of *Hantkenina* spp. and the *Globorotalia cerroazulensis* lineage. Two possibilities exist: the enrichment and the extinctions are synchronous (a possibility that we favor); or both the enrichment and extinctions are diachronous. Neither has yet been shown to be diachronous.

3. Identifying the boundary using planktonic foraminifers does not introduce the complex stratigraphic problems associated with use of the discoaster extinction datum (Van Couvering et al., 1981).

However, the Eocene-Oligocene boundary question must be viewed within the context of data from numerous localities. Perhaps the best solution to this problem is the selection of a new boundary stratotype and the driving of a "golden spike" into this section to mark the boundary. The Jackson-Vicksburg contact in the United States Gulf Coast represents a possible boundary stratotype (see Berggren et al., 1984). Of course, before this is done, the location of the spike must be

determined—viz., whether to place it in the section at the last appearance of the *G. cerroazulensis* lineage, at the last appearance of the rosette-shaped discoasters, or at yet another faunal or lithic discontinuity. Any current interpretation should be considered provisional.

PALEOCEANOGRAPHY

Changes in planktonic foraminiferal and nannofossil assemblages were gradual during late Eocene through early Oligocene time, suggesting that no sudden change in surface waters occurred at the epoch boundary. Because *G. cerroazulensis* and *Hantkenina* spp. are rare in upper Eocene sediments, their disappearance at the boundary is not a particularly conspicuous faunal change. Lower Oligocene sediments contain slightly lower diversity, predominantly globigeriniform assemblages, but many of these forms are also present in the uppermost Eocene section. The most prominent faunal abundance change occurs lower within the *Globorotalia cerroazulensis* (s.l.) Zone with the disappearance of *Globigerinatheka* spp. (Fig. 1).

The gradual disappearance of warm-water nannofossil species during middle and late Eocene time and the occurrence of cold- to temperate-water species (*Chiasmolithus oamaruensis*, *Ismolithus recurvus*) in the late Eocene indicate progressive cooling through this stratigraphic interval. Low-diversity early Oligocene assemblages indicate more intense cooling, but there is no evidence of a sudden climatic change at or near the boundary.

Characteristics of bottom water during the same interval also changed gradually, as indicated by benthic foraminiferal fauna and isotopic composition (Miller et al., 1984). At Site 549 (2.0–2.5 km paleodepth), the major faunal abundance change was the replacement of a *Nuttallides truempyi* assemblage just above the middle Eocene-late Eocene boundary; this event can be recognized throughout the North Atlantic, South Atlantic, Caribbean, and Gulf of Mexico at this time (Tjalsma

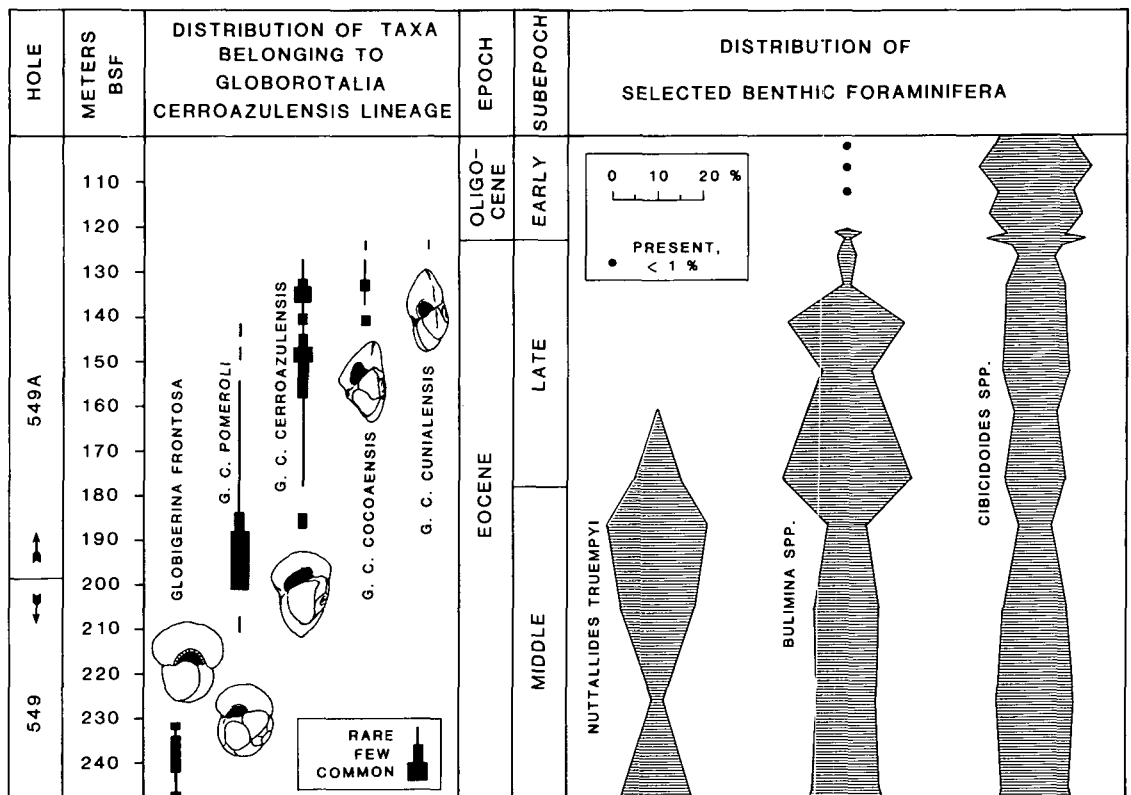


Figure 2. Stratigraphic distribution of selected benthic foraminiferal species compared to distribution of taxa in *Globorotalia cerroazulensis* lineage.

and Lohmann, 1983; Miller et al., 1984). Other faunal changes at Site 549 included (1) a series of extinctions and local last appearances of taxa in the late Eocene; (2) a series of first appearances (some of which are local) in the late Eocene to earliest Oligocene; and (3) the replacement of a buliminid assemblage just below the Eocene-Oligocene boundary. The record at Site 549 firmly establishes that no major benthic foraminiferal changes (in the >150 μm size fraction) were associated with the Eocene-Oligocene boundary in the North Atlantic. Instead, such changes occurred throughout the late Eocene and earliest Oligocene interval.

In deep abyssal sites (those >3 km paleodepth), the benthic faunal change was more dramatic (e.g., Sites 119 and 401 in the Bay of Biscay). Here many abyssal taxa (including *Nuttallides truempyi*, *Clinapertina* spp., *Abysamina* spp., *Aragonia* spp., and *Alabama dissonata*) became extinct between the middle Eocene and earliest Oligocene (Miller, 1984). Unfortunately, the timing of these extinctions cannot be fully resolved due to a major late Eocene hiatus noted in most deep abyssal locations.

Many of the first and last appearances and the replacement of the buliminid assemblage at Site 549 were probably local phenomena; however, the decreased abundance and the extinctions of *Nuttallides truempyi* and associated abyssal taxa represent a dramatic benthic foraminiferal change that occurred throughout the Atlantic Ocean (Tjalsma and Lohmann, 1983; Miller et al., 1984). During the Cenozoic evolution of deep-sea benthic foraminifera, only the massive extinctions of the latest Paleocene (Schnitker, 1979; Tjalsma and Lohmann, 1983) and assemblage changes of the middle and late Miocene (Douglas and Woodruff, 1982) rival the importance of changes that occurred between the middle Eocene and the early Oligocene.

The benthic foraminiferal isotopic interval reported from the Eocene and Oligocene at Site 549 (Miller et al., 1984) shows that a major enrichment in ^{18}O began in the latest Eocene. This culminated in a rapid (i.e., <0.5 m.y.) enrichment just above the Eocene-Oligocene boundary (Fig. 1). Assuming that the extinctions of planktonic foraminifera used to recognize the boundary were synchronous, the enrichment correlates with a similar enrichment noted in the Pacific and Southern Oceans (e.g., Keigwin, 1980). Although this enrichment may, in part, reflect a sea-water compositional change due to ice-volume build-up (Mathews and Poore, 1980), it appears to represent a temperature drop of bottom water of at least 2 $^{\circ}\text{C}$ (Keigwin, 1980; Miller and Curry, 1982; Miller et al., 1984).

The lack of any dramatic floral, faunal, or isotopic changes at the Eocene-Oligocene boundary indicates that there was no traumatic terminal Eocene event at Site 549 (e.g., Ganapathy, 1982; Alvarez et al., 1982).

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