Norris, R.D., Kroon, D., Klaus, A., et al., 1998
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8. SYNTHESIS[1]

Shipboard Scientific Party[2]

INTRODUCTION

Ocean Drilling Program (ODP) Leg 171B was designed to recover a series of "critical boundaries" in the Earth's history during which abrupt changes in climate and oceanography coincide with often-drastic changes in the Earth's biota. Some of these events, such as the Cretaceous/Tertiary (K/T) extinction and the late Eocene tektite layers, are associated with the impacts of extraterrestrial objects, like asteroids or meteorites, whereas other events, including the benthic foraminifer extinction in the late Paleocene and the mid-Maastrichtian extinction events, are probably related to intrinsic features of the Earth's climate system. Two of the critical intervals, the early Eocene and the late Albian, are characterized by unusually warm climatic conditions when the Earth is thought to have experienced such extreme warmth that the episodes are sometimes described as "super greenhouse" periods. The major objectives of Leg 171B were to recover records of these critical boundaries, or intervals, at shallow burial depth where microfossil and lithologic information would be well preserved, and to drill cores along a depth transect where the vertical structure of the oceans during the boundary events could be studied. The recovery of sediments characterized by cyclical changes in lithology in continuous Paleogene or Mesozoic records would help to establish the rates and timing of major changes in surface and deep-water hydrography and microfossil evolution.

Accordingly, five sites were drilled down the spine of the Blake Nose, a salient on the margin of the Blake Plateau where Paleogene and Cretaceous sediments have never been deeply buried by younger deposits (Figs. 1–3). The Blake Nose is a gentle ramp that extends from ~1000 to ~2700 m water depth and is covered by a drape of Paleogene and Cretaceous strata that are largely protected from erosion by a thin veneer of manganiferous sand and nodules. We recovered a record of the Eocene period that, except for a few short hiatuses in the middle Eocene, is nearly complete. The continuous expanded records show Milankovitch-related cyclicity that provides the opportunity for astronomical calibration of at least parts of the Eocene time scale, particularly when combined with an excellent magnetostratigraphic record and the presence of abundant calcareous and siliceous microfossils. The chemistry of the well-preserved calcareous microfossils will be used to document climate variability when the Earth's climate switched from a greenhouse to an icehouse state.

During Leg 171B, we recovered a suite of critical events in the Earth's history that includes the late Eocene radiolarian extinction, the late Paleocene benthic extinction, the Cretaceous/Tertiary (K/T) extinction, the mid-Maastrichtian event, and several episodes of organic-rich sedimentation in the Albian warm period. Unlike most regions of the Atlantic where calcareous fossils have been severely dissolved just above the extinction horizon, the upper Paleocene benthic foraminifer extinction occurs within an expanded interval of calcareous sediments. The K/T boundary was recovered at three sites, each within a biostratigraphically and magnetostratigraphically complete sequence that includes the earliest part of the Cenozoic recovery from the Late Cretaceous extinction. We managed to recover three copies of the boundary interval at one site in a section that includes a 10- to 17-cm-thick spherule bed, a rusty brown limonitic layer, a dark gray clay bed (planktonic foraminifer Zone Pα), and white ooze that also represents planktonic foraminifer Zone Pα.

Our strategy was to drill multiple holes at each site to recover complete sedimentary sequences by splicing multisensor track (MST) or color records. This method has become routine after development during ODP Legs 138 and 154. In all of the Leg 171B holes drilled using the advanced hydraulic piston corer and the extended core barrel, we had very high recovery, which was a prerequisite to obtaining the necessary complete sections. The initial results of Leg 171B are discussed below in the context of shipboard observations that provide the framework for post-cruise investigations.

LITHOSTRATIGRAPHY

The sedimentary record at the Blake Nose consists of Eocene carbonate ooze and chalk that overlie Paleocene claystones, as well as Maastrichtian and upper Campanian chalk (Fig. 4). In turn, Campanian strata rest unconformably upon Albian to Cenomanian claystone and clayey chalk that appear to form a conformable sequence of clinoforms. A condensed section of Coniacian–Turonian nannofossil chalks, hardgrounds, and debris beds is found between Campanian and Cenomanian rocks on the deeper part of the Blake Nose. The contact between the upper and lower Albian appears to be disconformable, whereas the lower Albian/Aptian contact may be complete. Albian claystones are interbedded with Barremian periplatform debris, which shows that the periplatform material is reworked. The entire mid-Cretaceous and younger sequence rests on a Lower Cretaceous, and probably Jurassic, carbonate platform that is more than 5 km thick in the region of the Blake Nose.

The middle to upper Eocene is exposed on the seafloor across much of the Blake Nose. The unconsolidated oozes are protected from erosion by a layer of manganese sand and nodules that are as much as ~3 m thick in places. The manganiferous sand is composed largely of Pleistocene–Holocene planktonic foraminifers, but in the shallower parts of the Blake Nose, mixed assemblages of Oligocene to middle Miocene foraminifers are present. Bivalves and gooseneck barnacle plates are mixed in the sand.

The Eocene sequence consists largely of green siliceous nannofossil ooze and chalk. The upper part of the sequence is typically light yellow, and the color change to green sediments below is very sharp. This color change is diachronous and probably relates to a diagenetic front produced by flushing the sediment with seawater, but it does not seem to have altered the microfossil preservation or sediment composition. Planktonic foraminifers, radiolarians, and calcareous nannofossils are well preserved throughout most of the middle Eocene, but calcareous fossils are more overgrown in the lower middle Eocene and lower Eocene. A distinct feature of the Eocene sequence is a high number of vitric ash layers that we found at every site. The ash layers

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[2]Shipboard Scientific Party is given in the list preceding the Table of Contents.

Prior Chapter Contents Next Chapter

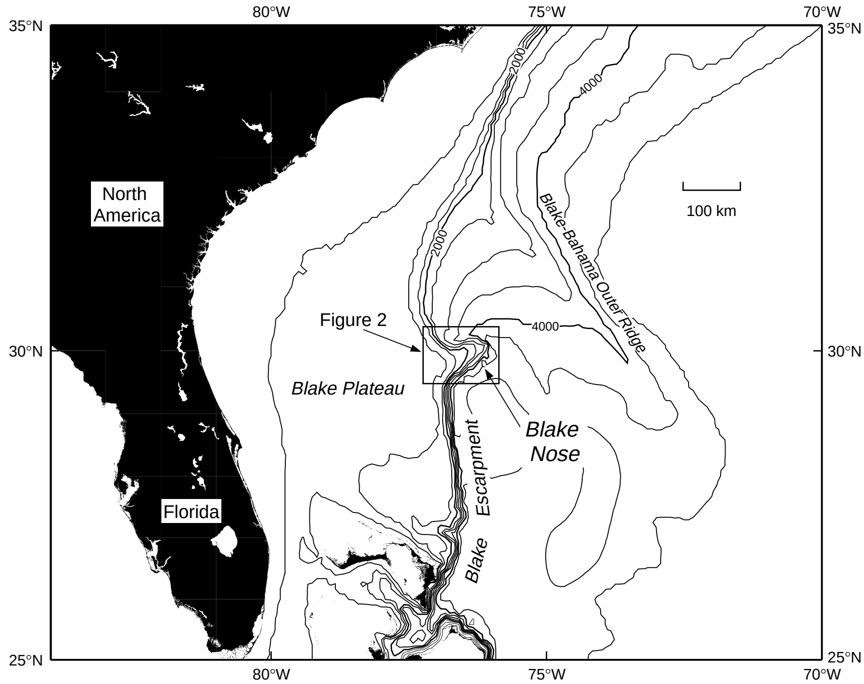

Figure 1. Location of ODP Leg 171B Blake Nose paleoceanographic drilling transect.

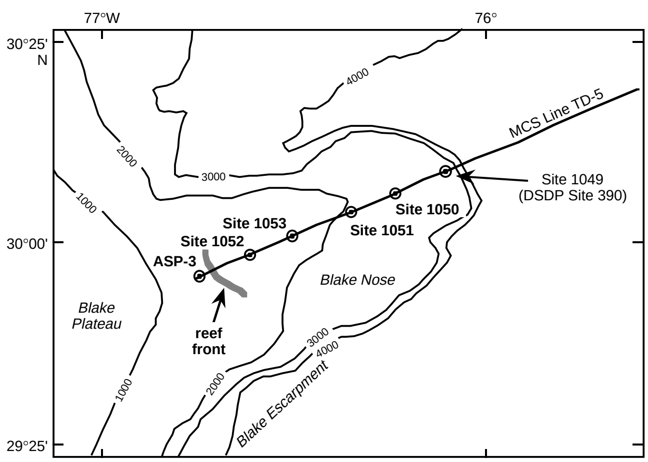

Figure 2. Map of the Blake Nose in the western North Atlantic Ocean showing the locations of drilling sites and the multichannel seismic Line TD-5 (also see Fig. 3). Bathymetry is in meters.

serve as excellent correlation markers between the sites and will be used as anchor points within the cyclostratigraphic record.

The cyclostratigraphic record, based on the color and MST data, is well developed at Site 1052, the shallowest site. The upper middle to upper Eocene record displays clear cyclical color changes, which have been used to splice the records of the individual holes into a composite (Fig. 5). The Milankovitch-controlled cycles will be used to recalibrate the late middle Eocene and late Eocene time scales. Radiometric dates on the ashes and dating by astronomical tuning will produce an integrated time scale to recalibrate the biomagnetostratigraphy and biostratigraphy. The Eocene cyclostratigraphy is less well developed at the sites downdip from Site 1052, although a splice for most of the record has been produced at each site. Color cycles are well developed for the Paleocene and early Eocene and will help calibrate the biomagnetostratigraphy and biostratigraphy of those intervals as well as aid in intersite correlation (Figs. 6, 7). The color changes also were used to construct a spliced record from the three holes at Site 1049 in the Cretaceous part of the section.

The Paleocene and lower Eocene are relatively clay rich compared with the middle and upper Eocene. The upper Paleocene contains chert or hard chalk, and preservation of most fossil groups is moderate to poor. The lower Paleocene is typically an olive green, clay-rich nannofossil chalk or ooze. Calcareous microfossils are typically very well preserved, whereas siliceous components are nearly absent. The sequence is biostratigraphically complete, except for a possible unconformity in the upper Paleocene where nannofossil Zone CP5 is missing at some sites. The Danian part of the sequence thickens upslope from about 20 m at Site 1049 (2656 meters below sea level [mbsl]) to about 80 m at Site 1052 (1300 mbsl). Clay-rich nannofossil chalk and ooze continue into the uppermost Maastrichtian. The K/T boundary consists of a 9- to 17-cm graded bed of green spherules capped by fine-grained, rusty brown grains that are overlain by dark gray clay of the earliest Danian at Site 1049. This succession is interpreted as fallout from the Chicxulub impact structure on the Yucatan Peninsula and the succeeding deposition of lowermost Danian sediment following the K/T extinction event. Notably, neither of the two K/T boundary sections drilled updip of Site 1049 has well-developed ejecta beds between early Danian (foraminifer Zone Pα) and latest Maastrichtian (*Micula prinsii* Zone) deposits. Either the spherules at these sites were slumped into deeper water very shortly after deposition, or turbidites carrying the ejecta debris bypassed the upper slope and deposited at least part of their load near the tip of the Blake Nose.

Notably, the Maastrichtian sections at Sites 1049, 1050, and 1052 are disturbed by slumping. Most of the section consists of gray nannofossil ooze or chalk. Laminations are well preserved, but burrowing is not evident, presumably because the sediment was partially liquified during slumping. However, it seems that relatively little, if any, of the Maastrichtian section has been lost because the sequence is biostratigraphically complete and in the correct stratigraphic order. It is possible that the slumping was associated with the large-magnitude earthquake produced by the Chicxulub impact. At Site 1052, the middle Maastrichtian contains a large slump that lies between light

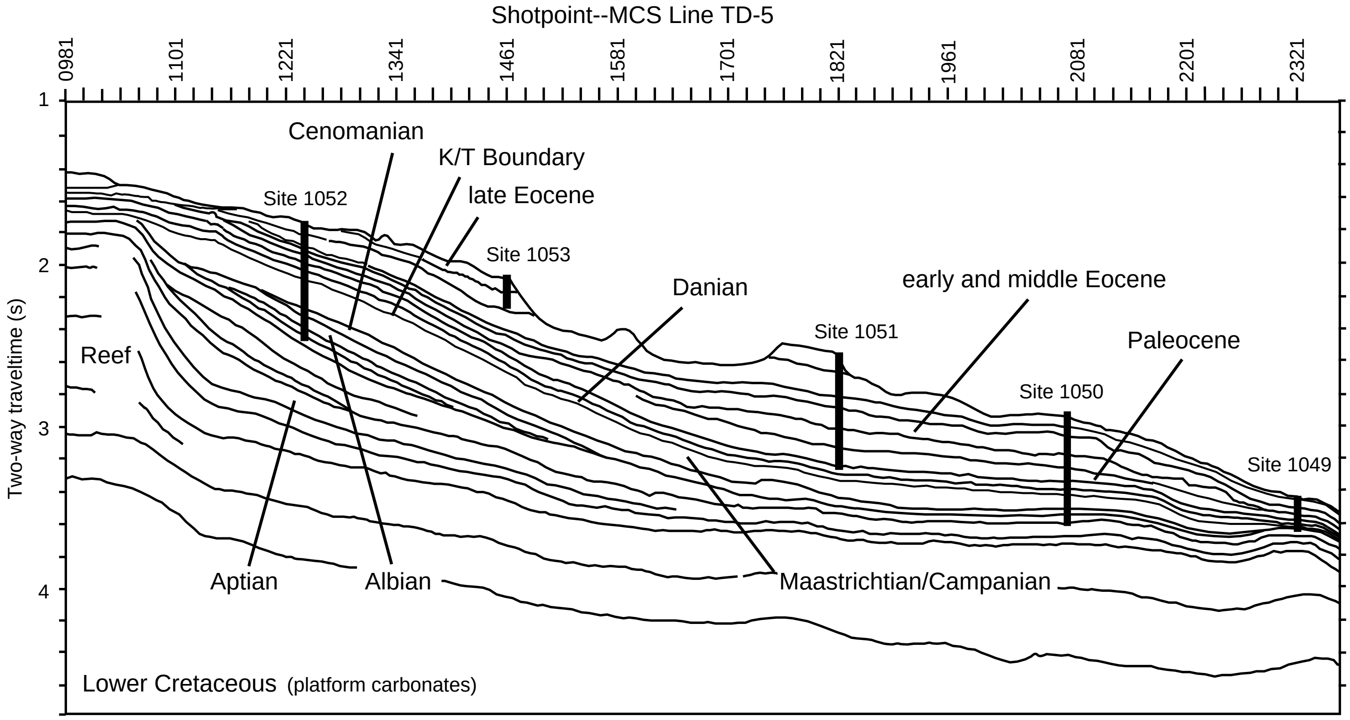

Figure 3. Seismic interpretation of multichannel seismic Line TD-5 across the Blake Nose showing the major reflectors, their ages, and locations of drilling sites. Location of seismic line is shown in Figure 2.

gray, burrowed chalk above and the more weakly burrowed, greenish gray chalk below.

The Maastrichtian unconformably overlies white ooze containing nannofossil and planktonic foraminifers characteristic of the upper Campanian at Site 1049. A somewhat thicker sequence of upper Campanian strata is present at Site 1050; this sequence overlies a highly condensed section of Coniacian–Turonian hardgrounds that is only about 9 m thick. Updip, at Site 1052, Campanian nannofossils are mixed into the lower Maastrichtian chalk, which rests directly upon the Cenomanian. Evidently, some upper Campanian–Turonian sediments were deposited on the Blake Nose but were largely eroded before deposition of the Maastrichtian.

Cenomanian chalk and claystone are present only in a thin wedge on the upper part of the Blake Nose, but they thicken considerably down the slope. Seismic data and Leg 171B drilling results suggest that the Cenomanian sequence expands significantly near the center of the Blake Nose, where it reaches about 70 m in thickness and then thins again at the tip of the Blake Nose. Most of the Cenomanian deposits at Site 1050 are slumped black shales and gray claystones. Cenomanian strata are completely absent from the section at Site 1049, which is drilled on a small paleo-high near the northeast tip of the Blake Nose.

The seismic profile of multichannel seismic Line TD-5 shows that the Cenomanian–Albian sequence consists of two sets of clinoforms built over, and to the northeast of, a buried reef complex (see Fig. 3, “Introduction” chapter, back-pocket foldout, this volume). The lower Cenomanian is on top of a thick package of upper Albian clinoforms, and the two appear to be conformable. Within the clinoform stack, the Cenomanian includes dominant dark olive-gray, calcareous silty claystone to clay-rich siltstone and contains very well–preserved calcareous microfossil assemblages. The sediment color varies from an olive gray to black, and darker intervals are rich in clay and fine silt.

Cenomanian sediments rest upon upper Albian clinoforms. There are two clinoform sequences built out in front of the Aptian reef. Both sets of clinoforms thicken seaward of the northwest–southeast-trending reef front. The upper clinoform set was partly drilled at Site 1052 and proved to consist of alternating green claystone, silty claystone, green laminated claystone, and thin beds of cross-bedded, mixed siliceous and calcareous grainstone. The laminated green claystones are rich in humic organic matter and occur in 0.5- to 1.5-m-thick sequences interbedded with thin limestone beds that are poor in organic matter. Age-equivalent strata in Europe are known as Oceanic Anoxic Event (OAE) 1d and consist of a series of laminated beds deposited within oxygen-depleted waters. The upper Albian section appears to overlap the top of the Aptian reef and pinches out entirely near the toe of the Blake Nose. Near the bottom of Hole 1052E, the Albian sequence becomes dominated by slightly to moderately bioturbated, dark olive-gray, sandy siltstones probably deposited in middle- or outer shelf environments. These sandstones were probably deposited near storm wave base, as suggested by the occurrence of well-sorted grainstone and sedimentary structures associated with sand waves. Apparently, the entire upper Albian clinoform stack represents a deepening-upward package.

This clinoform sequence overlaps a second clinoform sequence that probably is represented by lower Albian and upper Aptian variegated claystones recovered at Site 1049 and at Deep Sea Drilling Project Site 390. The lowermost Albian at Site 1049 contains a 46-cm-thick black shale containing as much as 11.5% marine organic matter. This black shale section is correlative with the OAE 1b—a black shale sequence known from European sections. The upper Aptian section is interbedded with periplatform carbonates that either were eroded from the reef complex to the west or were deposited at the same time as the reef system.

INTERSTITIAL WATERS

Interstitial waters were analyzed at every site across the Blake Nose depth transect. The results are consistent with the biogenic and

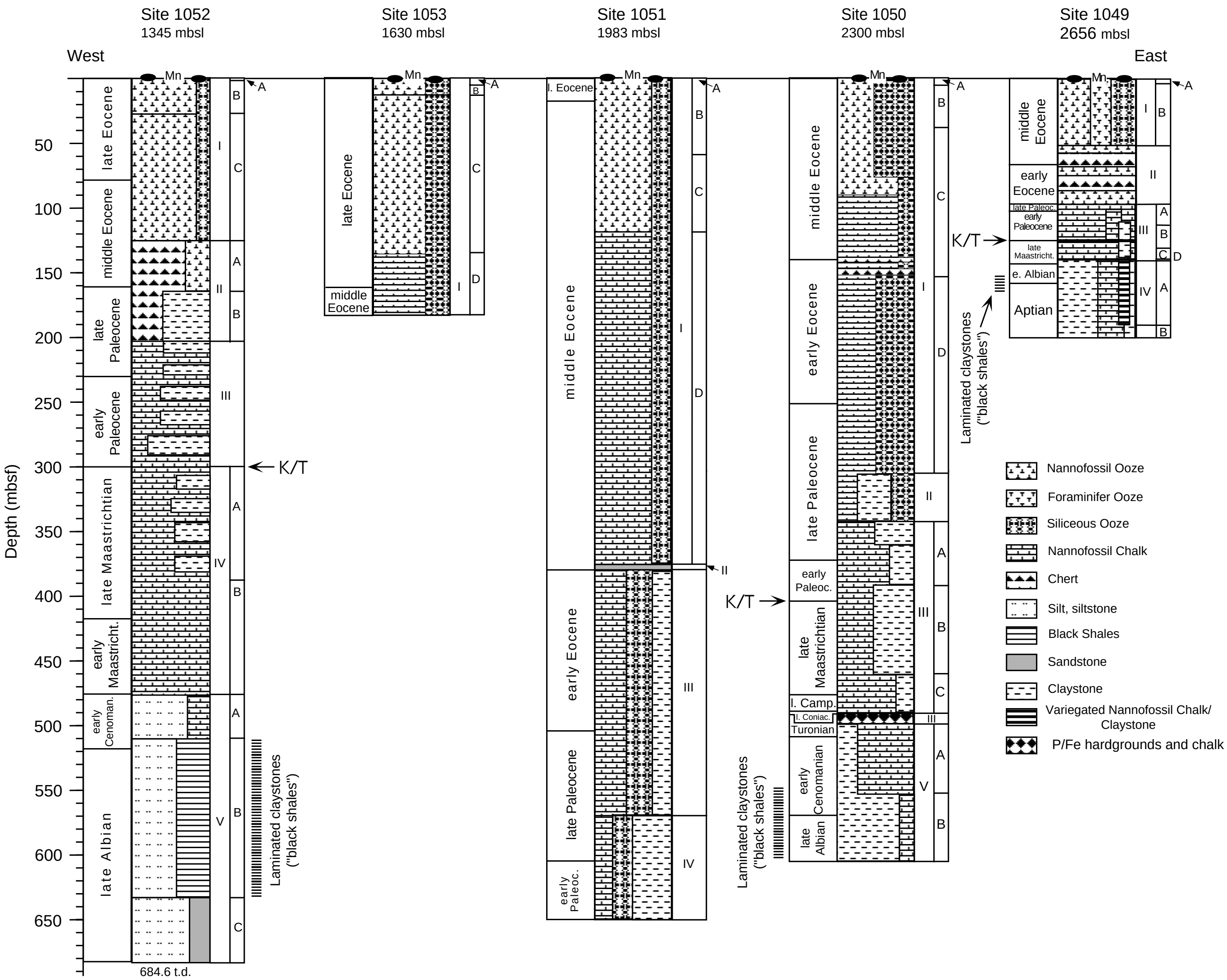

Figure 4. Stratigraphic summary of Sites 1049–1053 along the drilling transect.

volcaniclastic nature of generally organic, carbon-poor sediments and extreme depth (>5 km) to basement.

Elevated silica concentrations in the pore waters are consistent with a significant alteration of biogenic and volcaniclastic siliceous sediments, particularly in the lower Eocene and Paleocene sequences. Excellent preservation of radiolarians around ash layers, especially at Site 1051, may indicate that the volcaniclastics are the more important of these two silica sources in the Blake Nose area.

Volcaniclastics are dispersed throughout the section and also seem to be the dominant control of the pore-water calcium and magnesium concentration depth gradients. Formation of authigenic dolomite is an additional control, especially at Site 1052. Calcium and magnesium gradients are weak in the Blake Nose relative to many deep-sea sequences where gradients are often controlled by seawater-basalt interaction in the underlying upper oceanic crust. The weakness of these gradients at the Blake Nose is consistent with the extreme depth (>5 km) of basement in this area.

General increases with depth in strontium concentrations and calculated Sr/Ca values at all of the Blake Nose sites are consistent with the recrystallization of biogenic carbonate in the sediment column and alteration of volcaniclastics.

Perhaps the most remarkable results from the interstitial pore waters at the Blake Nose are the extreme concentrations of lithium (as much as 20 times that of seawater; Fig. 8). Extreme distance from the basement and the shape of the pore-fluid lithium profiles suggest that the pore waters' source of lithium is within the sedimentary column and that high concentrations are most likely caused by alteration of the volcaniclastics.

ANOXIC EVENTS

Finely laminated sediments occur periodically throughout the mid-Cretaceous section drilled during Leg 171B. One of our goals was to recover laminated deposits along a depth transect to study the vertical extent of disaerobic waters in the Cretaceous Atlantic. Our results suggest a marked difference in character between laminated sediments taken from the shallow and deep ends of the Blake Nose.

The upper Albian section at the upper end of the Blake Nose consists partly of dark green laminated claystones that alternate with lighter colored limestones. We observed 15 cycles of light-colored, strongly bioturbated, coarse-grained clayey limestones with moder-

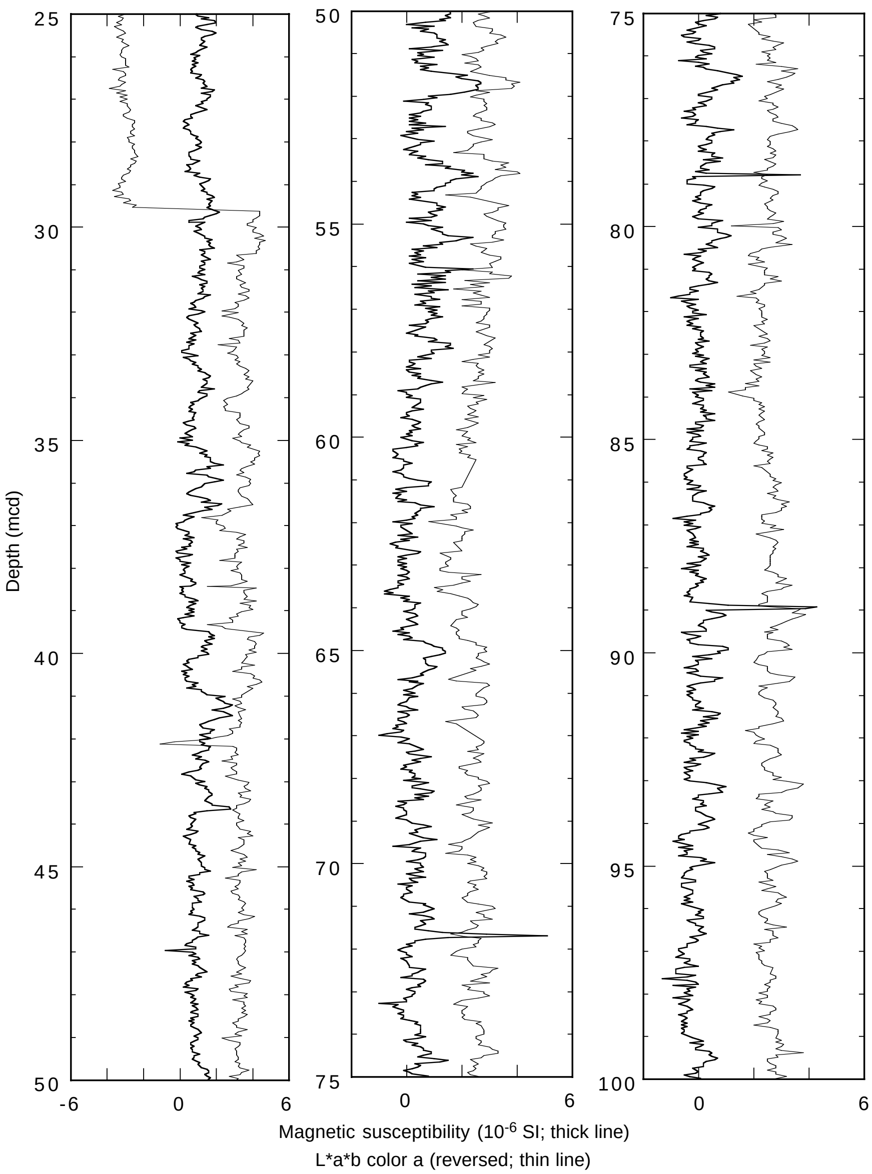

Figure 5. Susceptibility (thick line) and color (thin line) in a series of 25-m panels that cover the upper 100 m of the middle–upper Eocene section recovered at Site 1052. Both measurements show variability with a wavelength of about 1 m that probably reflects variations in the Earth-Sun orbital geometry, which will be investigated in post-cruise work.

ately bioturbated silty claystones and dark laminated claystones. The organic carbon content of the laminated beds is <1%, and the kerogen is of terrestrial origin. These laminated deposits are part of a deepening-upward cycle from strata deposited near storm wave base to sediments deposited near the shelf-slope break. The pervasive lamination of the deeper water part of the sequence suggests that the top of the disaerobic zone impinged upon the margin near the depth of storm wave base. The interval where the laminated, dark gray sediments occur is time equivalent to similar sediments deposited during OAE 1d found in Tethyan deposits (Fig. 9). The widespread occurrence of the cyclic alternation of dark laminated claystones and limestones indicates that environmental conditions were similar throughout the Tethys and the young Atlantic basin.

Although this is not the deep-water equivalent of the laminated claystones found updip on the Blake Nose, the early Albian black shale (OAE 1b) probably reflects the relative clastic starvation of the deep-water seaward edge of the Blake Escarpment, compared with the shallower areas that represent the ancient shelf and shelf-slope break (Fig. 9). The abundance of marine organic matter suggests that the black shale is the distal equivalent of more terrigenous sediments presumably present in a clinoform stack that overlaps the reef complex on the Blake Plateau. The black shale may represent a relatively brief period during which anoxic conditions extended well down into intermediate water masses, because most upper Aptian and lower Albian sediments at the seaward end of the Blake Nose are not organic rich.

MID-MAASTRICHTIAN DEEP-WATER REVERSAL

The Maastrichtian was a time of global cooling that marked the end of the Cretaceous greenhouse climate. Widespread geochemical and biological shifts, including extinction among rudistid and inoceramid bivalves, seem to be concentrated in the middle of the Maastrichtian. It has been proposed that rudists thrived in a hypersaline "Supertethyan" province and that inoceramids thrived at bathyal depths where the bottom water was warm and saline (e.g., MacLeod and Huber, 1996). Extinction among both groups could be explained by reorganization of Maastrichtian oceans, with temperature differences replacing salinity differences as the dominant force driving cir-

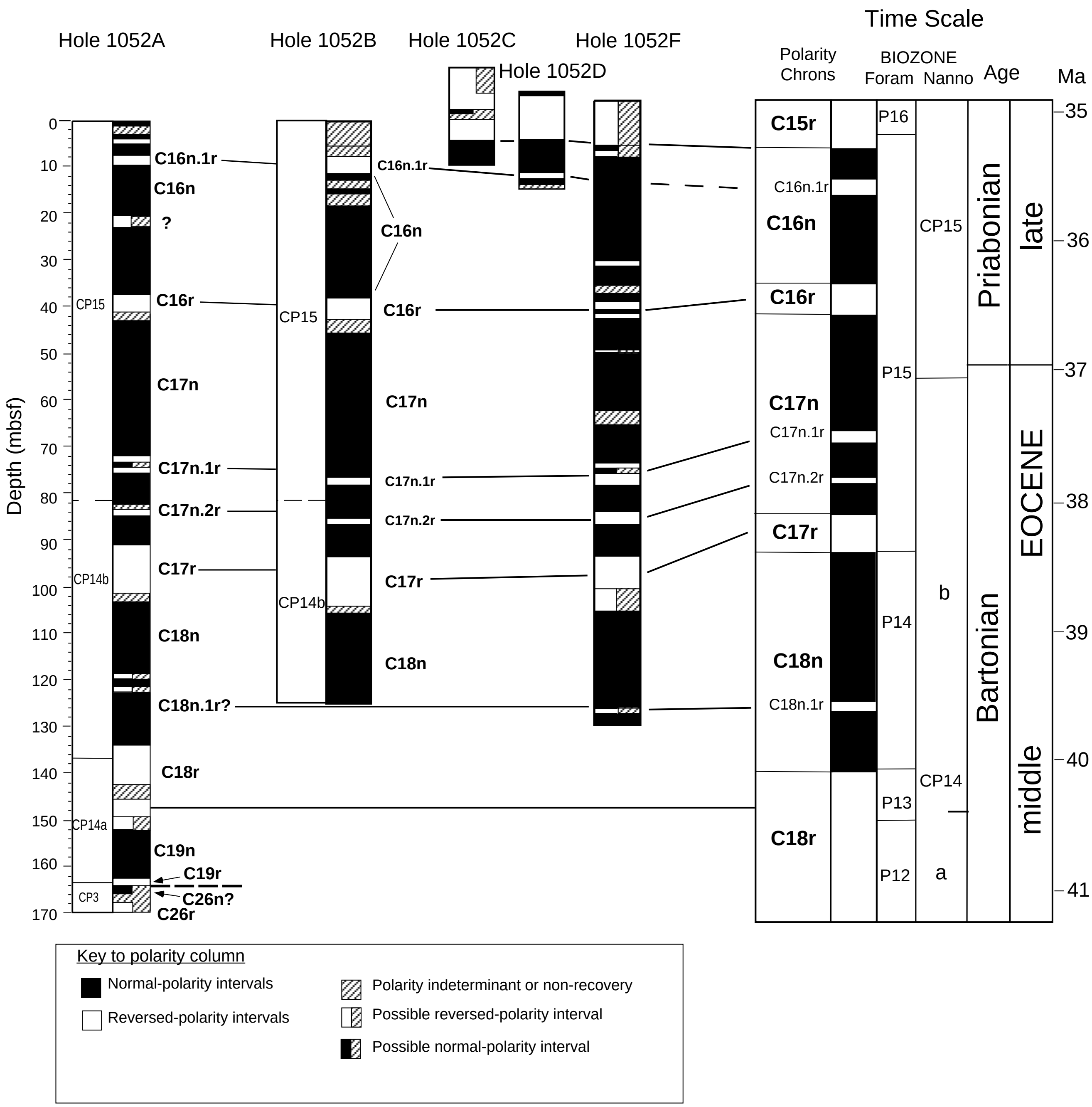

Figure 6. Magnetostratigraphy of Site 1052 during the middle and late Eocene. This site has a very well–defined magnetostratigraphy that we will attempt to calibrate, in terms of absolute duration of the various chrons, using cyclostratigraphy (see Fig. 5) for this site.

culation. A reversal in deep-ocean circulation patterns would affect many paleoclimatologic and paleoecologic variables such as latitudinal heat transport, benthic carbon budgets, and deep-ocean ventilation. Although some data support each of these propositions (e.g., MacLeod and Huber, 1996), there remain more predictions than demonstrations of the ocean circulation hypothesis.

Lower and upper Maastrichtian sediment was recovered at Sites 1049, 1050, and 1052. The observed distribution of inoceramid shell fragments in foraminifer residues indicates that the disappearance of inoceramids at Site 1052 falls within an ~40-m interval of good to excellent recovery. The ichnofabric switches from dominantly laminated, or slightly bioturbated, to thoroughly bioturbated across the interval; this result is consistent with increasing ventilation of the bottom waters and with a change in bottom-water circulation patterns. On the other hand, the abundance of organic carbon is lower in the less bioturbated intervals, raising the possibility that food supply, rather than benthic oxygenation, might have limited the activity of (pre-extinction) burrowing organisms. Detailed documentation of the relationship among paleontologic, geochemical (including stable isotopes), and sedimentologic data at this and the other sites along the

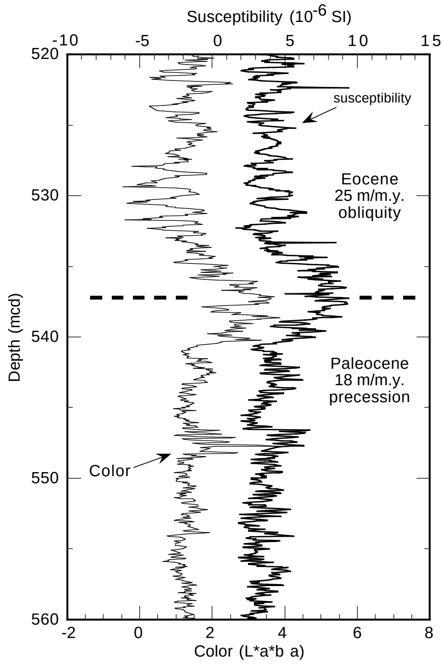

Figure 7. Susceptibility and color through a Paleocene interval at Site 1049 that displays what may be a precessional orbital cycle.

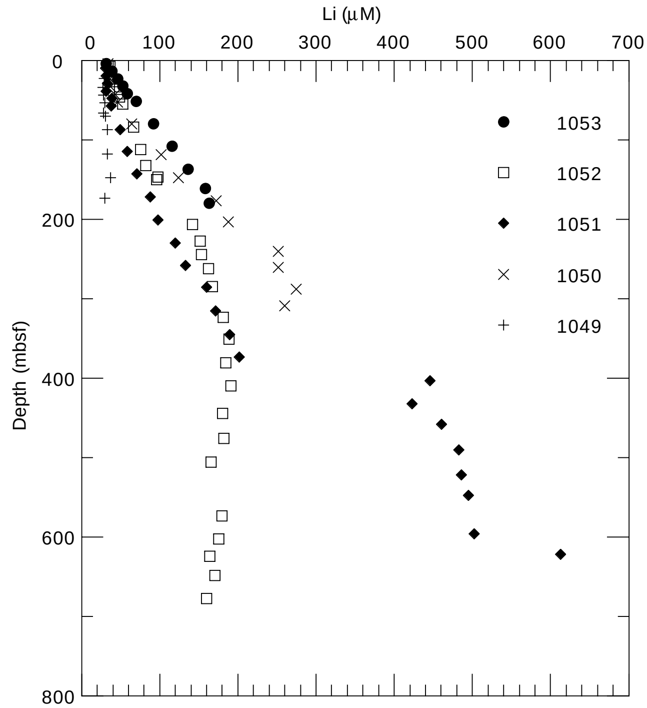

Figure 8. Lithium concentrations within pore waters vs. depth at all sites.

Blake Nose transect will provide the best data currently available to test paleoceanographic change during the last 5 m.y. of the Cretaceous period.

K/T BOUNDARY

A complete K/T boundary interval was recovered from Holes 1049A, 1049B, and 1049C (Fig. 10); a partial K/T boundary section was recovered from Hole 1052E. The spherule bed is 17, 9, and 10 cm thick in Holes 1049A, 1049B, and 1049C, respectively. With the exception of the apparent compression in Holes 1049B and 1049C, the boundary interval seems to be virtually undisturbed and exhibits the same stratigraphic sequence in each hole (Fig. 10). The lowest bed is a graded, faintly laminated layer consisting almost entirely of green spherules that range in size from 2 to 3 mm at the base to <1 mm at the top. This spherulitic layer is capped by a 3-mm-thick orange limonitic layer that contains flat goethite concretions. The limonitic layer is overlain by 3–7 cm of dark, burrow-mottled clay, which represents the Pα foraminifer Biozone. The final bed in the sequence is a 5- to 15-cm-thick, white foraminifer–nannofossil ooze that contains a Zone Pα foraminifer assemblage. The K/T boundary sections at Site 1049 are complete and thus excellent for studying the response of marine biota to the effects of the extraterrestrial event. For instance, because the planktonic foraminifers are extremely well preserved, they are ideal for stable isotope studies that we hope will reveal the chain of climate events caused by the impact.

PALEOCENE/EOCENE BOUNDARY

Upper Paleocene sections are frequently interrupted by a clay bed or are characterized by a sudden switch from carbonate deposition to siliceous deposition that has been related to a short-lived intensification of low-latitude deep-water production. There is also geochemical evidence for the rapid release of buried gas hydrates, including the potent greenhouse gas, methane, that may explain the extreme warmth of the early Eocene. Unfortunately, the changes in type of sedimentation and the frequent unconformities in the upper Paleocene have inhibited study of this “super greenhouse” event. A complete, or nearly complete, upper Paleocene carbonate sequence that should help resolve many of the issues concerning the biochronology and geochemistry of this period was recovered during Leg 171B.

The uppermost Paleocene at Site 1051 consists of color-banded, greenish nannofossil chalk that contains moderately to poorly preserved foraminifers and calcareous nannofossils. Nonetheless, species are sufficiently well preserved that it will be possible to construct a detailed biochronology. The material is suitable to produce a detailed carbon isotope profile from the late Paleocene to early Eocene. Such a profile can be used to test the gas-hydrate hypothesis for upper Paleocene warming and to facilitate the correlation of Site 1051 with other localities around the globe. Finally, the sequence displays pronounced cyclic sedimentation of dark green and pale green alternations that may reflect orbital cycles. In conjunction with the magnetostratigraphy for this site, the color cycles should help produce a very detailed chronology of the duration of the thermal maximum.

GEOLOGIC HISTORY OF THE BLAKE NOSE

The Blake Nose is composed largely of Jurassic to mid-Cretaceous carbonate platform deposits. The platform rests on basement rocks formed by intrusion and volcanism through attenuated continental crust during the rifting stage of the Atlantic. As much as 10 km of carbonates accumulated in this area. By Barremian–Aptian time, the reef tract stepped back 40–50 km from the Early Cretaceous margin and formed a long tract of coral-rudist reefs such as the one evident in seismic profiles in the shallow subsurface at the head of the Blake Nose (Fig. 3).

The reef tract ceased growth during the late Aptian, at which time periplatform debris was no longer delivered to the outer edge of the

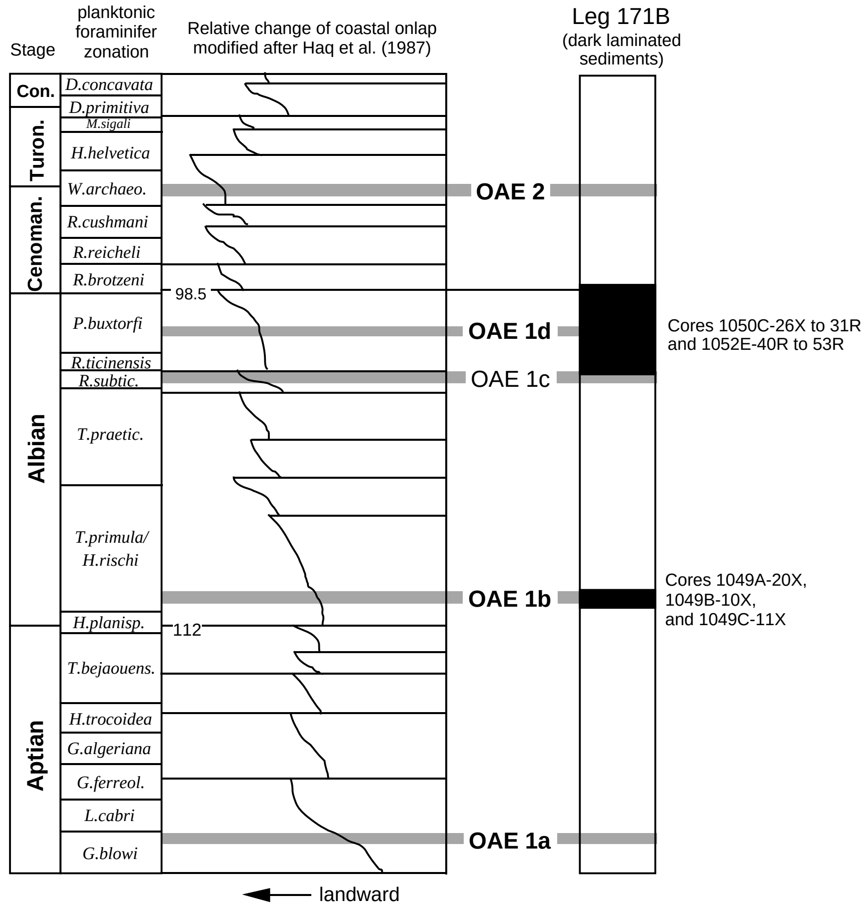

Figure 9. The stratigraphic position of dark gray laminated sediments recovered at Sites 1049, 1050, and 1052 in relation to the onlap curve of Haq et al. (1987).

Blake Nose and the deposition of green and red variegated clays began. These nannofossil clays must have been deposited at a depth of at least 1500 m, because the top of the Aptian reef to the west does not appear to have been subaerially eroded and, hence, was probably near or below wave base. Aptian clinoforms are built out in front of the reef and also partly overlap the reef top. The nature of these rocks is not known, except where they have been recovered in deep-water facies at Site 1049. At least part of the clinoform sequence is probably correlative with the black shale of latest Aptian age found at Site 1049, suggesting that the disaerobic conditions associated with the organic-rich sediments extended to a water depth of at least 1500 m.

The lower Albian sequence at Site 1049 contains a number of hardgrounds and firmgrounds, suggesting that there were periods of nondeposition or erosion within the sequence. Some of these short hiatuses may correlate with the tops of deepening-upward sequences within the Aptian clinoform stack that are similar to deepening-upward sequences within the overlying upper Aptian clinoforms. Additionally, some truncated clinoforms within the Aptian sequence are visible on seismic reflection profile TD-5, and these may correlate with nondeposition or erosion surfaces near the toe of the Blake Nose. Unfortunately, the entire mid-Cretaceous section at Site 1049 is so condensed that it is difficult to unambiguously correlate reflectors updip into the various clinoform wedges, and, in any event, the Aptian–lower Albian section does not produce strong reflectors, except within the clinoform stack.

Upper Aptian and lower Albian strata are overlapped unconformably by a second major clinoform wedge of late Albian age. These clinoforms are composed mostly of micaceous claystones that are interbedded with mixed carbonate and terrigenous grainstones near the base of the stack that pass upward into cyclic, limestone-laminated, dark green claystones. The lower part of the clinoform sequence was probably deposited near storm wave base because the sands are well washed and exhibit sedimentary structures indicative of megaripples or sand waves. The upper part of the sequence was apparently deposited in deeper water, perhaps near the shelf-slope break, as it contains few, if any, sand layers and no evidence of substantial bottom-current activity. Presently, the top of the clinoform sequence is located about 500 m below the top of the adjacent reef. Decompaction of the clay-rich strata in the Albian clinoforms by 60%–80% suggests that these sediments were deposited at ~100- to 200-m water depth if the top of the reef was at sea level. The presence of Albian marine rocks landward of the Blake Nose suggests that the Blake Plateau also was submerged and implies that the clinoform sequence was deposited at even greater depths than estimated above.

Clinoforms within the upper Albian sequence pinch out against a surface of erosion or nondeposition that is overlain by lower Cenomanian strata. There is little time missing across this hiatus at Site 1052, which is close to the center of the upper Albian clinoform stack, and judging from the planktonic foraminifer or nannofossil biochronologies, there is no discernible hiatus. If a hiatus does exist, it probably represents a reduction in sediment supply to the slope either because of a sea-level rise that trapped sediment inshore or a diversion of sediment to some other location on the slope. The Cenomanian is absent from most of the Blake Plateau, suggesting that it may not have been deposited there. Alternatively, the Cenomanian may have been removed by later erosion and was preserved only on the upper slope. In any case, the downdip pinch-out of Cenomanian strata in the middle of the Blake Nose is evidence that the Cenomanian recovered at Site 1052 was a relatively deep-water deposit near the most seaward extent of deposition. Deep-water conditions

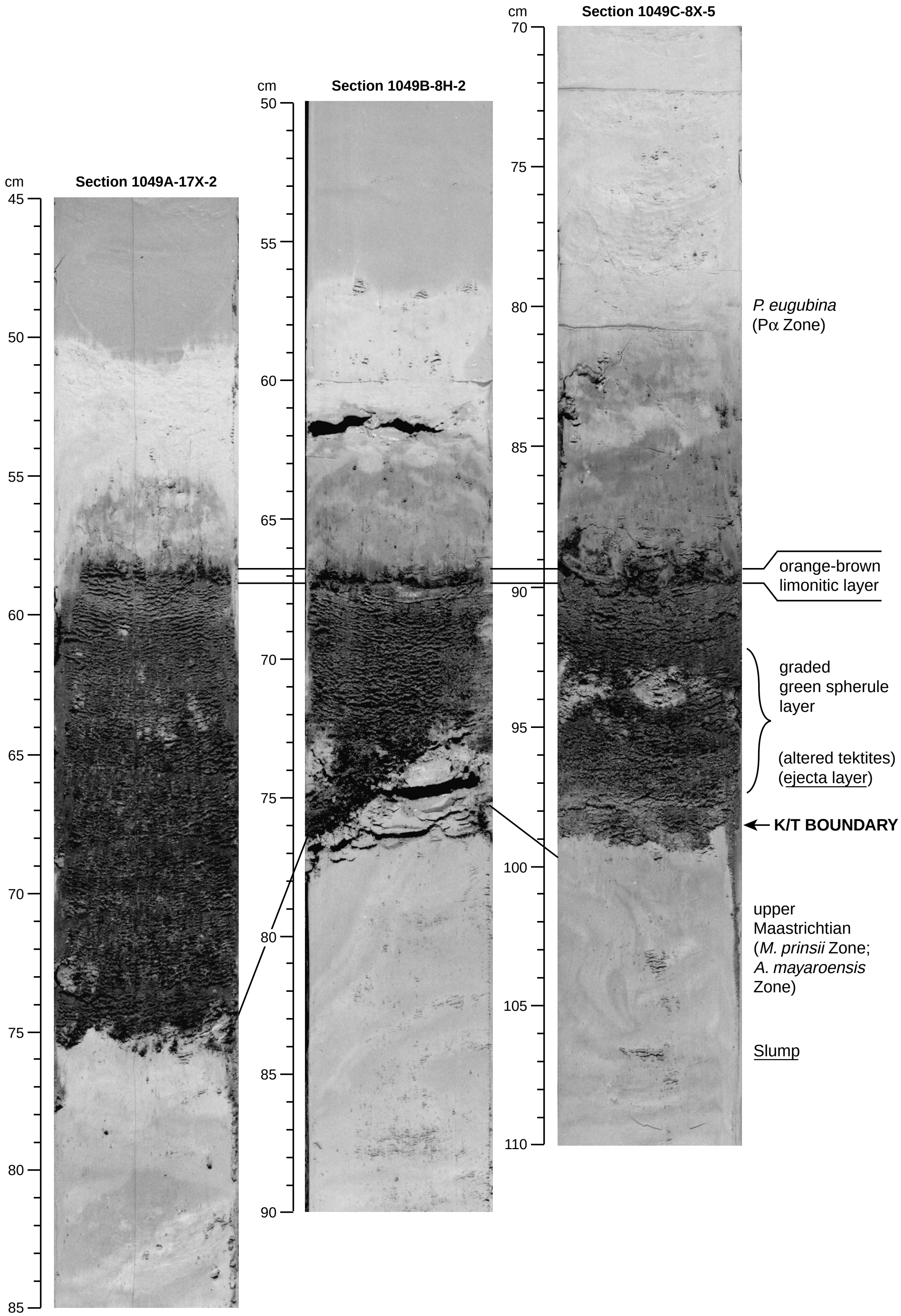

Figure 10. Compilation of the three K/T boundary sections recovered at Site 1049.

are supported by the presence of rich assemblages of planktonic foraminifers including the keeled rotaliporids that are rare or absent in epicontinental seas and shallow-shelf strata.

There is a widespread major unconformity above the Cenomanian on the Blake Nose from which upper Cenomanian to lower Campanian strata were largely removed. A thin section of Turonian and Coniacian is present as a series of manganiferous hardgrounds, beds of rip-up debris, and red nannofossil chalks. A very thin sequence of upper Campanian foraminifer ooze is present at Sites 1049 and 1050, but no sediment of corresponding age has been recovered from the shallower parts of the slope. However, the Maastrichtian sequence contains numerous slumps, including one at the Maastrichtian/Cenomanian contact at Site 1052, and it is possible that Campanian sediments were removed from the area at Site 1052 by downslope transport. Despite the slumping, much of the Maastrichtian appears to be present as a drape of nannofossil chalk and ooze. The preserved record has a well-developed color banding that may record orbital cycles. The sequence also appears to preserve an expanded record of the mid-Maastrichtian, and changes in bioturbation intensity and the abundance of inoceramid prisms suggest that the biological crisis recognized in low-resolution sections from other parts of the globe are probably preserved at the Blake Nose, as well.

The end of the Cretaceous and earliest events of the Cenozoic are well preserved on the Blake Nose. We recovered a thick spherule bed that presumably represents the ejecta debris from the Chicxulub crater only at Site 1049. Nonetheless, the K/T boundary sections drilled at all of the Blake Nose sites preserve the early Danian biozones and the nannofossil markers for the latest Maastrichtian (see “Lithostratigraphy” section, this chapter). Hence, we succeeded in coring the boundary beds along a depth transect and made possible for the first time studies of the boundary beds and events over a 1300-m gradient in water depth.

Deposition of a nearly uniform drape of pelagic sediment continued into the Paleocene. The Danian is unusually thick on the Blake Nose relative to most sites in the deep sea, and the claystone has preserved the calcareous microfossils very well. Paleocene strata are the first to preserve geochemical and lithologic evidence for abundant volcanic ash on the Blake Nose, a trend that continued throughout the Eocene. The upper part of the Paleocene is increasingly siliceous, and chert stringers are present where the Paleocene beds thin toward the landward and seaward ends of the Blake Nose.

By the latest Paleocene, deposition was concentrated into a major clinoform stack that reached its greatest thickness near the center of the Blake Nose transect. At least two hiatuses are present in this sequence. One is within the uppermost Paleocene sequence and occurs close to the late Paleocene “Thermal Maximum,” when the deep oceans appear to have abruptly warmed for a few 100,000 yr. However, the hiatus is either absent or very short near the center of the clinoform stack where the Paleocene/Eocene transition is biostratigraphically complete. A second hiatus is present near the lower Eocene–middle Eocene transition where an ~2-m.y. interval in the Eocene record is absent. The middle Eocene hiatus is present across the entire Blake Nose and is represented by foraminifer packstones, grainstones, chert, and green clay. The hiatus cuts out the top of the Paleocene through the lower middle Eocene on the upper part of the Blake Nose, where foraminifer packstones and nannofossil claystones contain highly mixed assemblages within a stratigraphic interval only about 5 m thick.

Sedimentation apparently backstepped up the slope of the Blake Nose during the middle and late Eocene. Upper middle Eocene siliceous nannofossil oozes and chalks are thickest at Sites 1051 and 1053, which are probably close to the depocenter of these units. Indeed, analysis of the compaction state of the sedimentary sections at Sites 1050 and 1049 suggests that these areas probably were never buried by more than 100–150 m of sediment. This observation implies that the middle and upper Eocene thinned toward the tip of the Blake Nose. The updip continuation of the middle and upper Eocene has been removed almost completely by erosion, making it difficult to estimate how much Eocene strata were originally deposited there. However, our ability to piston core 140 m of Eocene section at Site 1053 further suggests that the sediment was not compacted by burial beneath a thick blanket of younger sediments.

It is probably no coincidence that the youngest Eocene sediments are of latest Eocene age. The Oligocene is associated with widespread hiatuses in the North Atlantic Ocean. The Gulf Stream assumed its present course for the most part in the Oligocene and cut into the surface of the Florida Straits and the Blake Plateau. A highstand of sea level in the late Oligocene shifted sedimentation from the shelf to the coastal plain, starving the outer shelf and slope landward of the Blake Escarpment. In the Blake Basin, Oligocene cooling at high latitudes intensified the southward flow of deep water along the Blake Escarpment and formed the widespread A^u seismic reflector that represents an unconformity distributed over most of the western North Atlantic. Erosion of the base of the Blake Escarpment occurred during the Oligocene as well, and large blocks of debris are present on the northwest and southeast slopes of the Blake Nose. In contrast, the northeastern tip of the Blake Nose has likely experienced relatively little erosion. Not only are there no slump blocks at the base of the escarpment in this area, but all sedimentary sequences younger than the late Aptian appear to thin considerably or pinch out there. It appears that although there has not been substantial erosion of the plateau in this area, the northwestern and southeastern sides have experienced considerable erosion. Indeed, the Aptian reef is exposed in the escarpment on both sides of the Blake Nose. If the reef tract stepped back a similar distance all along the Blake Plateau during the Aptian, more than 70 km of the escarpment must have been eroded to the south and north of the Blake Nose to create the present bathymetry.

A remaining issue is why the Blake Nose exists as a submarine feature in the first place. Erosion of coastal cliffs often produces sharp headlands where hard formations locally slow down the rate of erosion. This analogy may also explain the origin of the Blake Nose if the tip of this feature is composed of more resistant rocks than the remainder of the Blake Escarpment. At present, there are no data to address the relative erosion-resistance of points along the Blake Escarpment. However, it may not be a coincidence that the Blake Spur Fracture Zone clips the northeastern tip of the escarpment at the Blake Nose. It may be that mineralization associated with the fracture zone has reduced the rate of erosion of the plateau at this point.

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Prior Chapter Contents Next Chapter