OCEAN DRILLING PROGRAM

LEG 154 PRELIMINARY REPORT

CEARA RISE

Dr. William B. Curry
Co-Chief Scientist, Leg 154
Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
U.S.A.

Dr. Nicholas J. Shackleton
Co-Chief Scientist, Leg 154
Godwin Laboratory
University of Cambridge
Free School Lane
Cambridge CB2 3RS
United Kingdom

Dr. Carl Richter
Staff Scientist, Leg 154
Ocean Drilling Program
Texas A&M University Research Park
College Station, Texas 77845-9547
U.S.A.

Philip D. Rabinowitz
Director
ODP/TAMU

Jack Baldauf
Manager
Science Operations
ODP/TAMU

Timothy J.G. Francis
Deputy Director
ODP/TAMU

April 1994

Preliminary Report No. 54

First Printing 1994

Distribution

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77845-9547, U.S.A. In some cases, orders for copies may require payment for postage and handling.

DISCLAIMER

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program is provided by the following agencies:

Canada/Australia Consortium for the Ocean Drilling Program
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Français de Recherche pour l'Exploitation de la Mer (France)
Ocean Research Institute of the University of Tokyo (Japan)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Greece, Iceland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey)

SCIENTIFIC REPORT

The following scientists were aboard *JOIDES Resolution* for Leg 154 of the Ocean Drilling Program:

William B. Curry , Co-Chief Scientist (Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.)

Nicholas J. Shackleton, Co-Chief Scientist (Godwin Laboratory, University of Cambridge, Free School Lane, Cambridge CB2 3RS, United Kingdom)

Carl Richter, Staff Scientist (Ocean Drilling Program, Texas A&M University Research Park, 1000 Discovery Drive, College Station, Texas 77845-9547, U.S.A.)

Jan E. Backman (Department of Geology and Geochemistry, Stockholm University, S-106 91 Stockholm, Sweden)

Franck Bassinot (Centre des Faibles Radioactivites (CFR), Domaine du CNRS, Avenue de la Terrasse BP 1, 91198 Gif-sur-Yvette, France)

Torsten Bickert (Fachbereich Geo, Universität Bremen, 28334 Bremen, Federal Republic of Germany)

William P. Chaisson (290 Laburnam Crescent, Rochester, New York 14620, U.S.A.)

James L. Cullen (Department of Geological Sciences, Salem State College, Salem, Massachusetts 01970, U.S.A.)

Peter deMenocal (Lamont-Doherty Earth Observatory, Palisades, New York 10964, U.S.A.)

Lee Ewert (Borehole Research, Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, United Kingdom)

Jens Grützner (GEOMAR, Research Center for Marine Geosciences, Wischhofstrasse 1-3, 24148 Kiel 14, Federal Republic of Germany)

Teresa King Hagelberg (Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882, U.S.A.)

Gretchen Hampt (Earth Sciences Board, University of California, Santa Cruz, Santa Cruz, California 95064, U.S.A.)

Sara E. Harris (College of Oceanic and Atmospheric Sciences, Ocean Administration Building 104, Oregon State University, Corvallis, Oregon 97331, U.S.A.)

Timothy D. Herbert (Scripps Institution of Oceanography, Geological Research Division, La Jolla, California 92093-0215, U.S.A.)

David McCullough Dobson (Department of Geological Sciences, University of Michigan, 1006 C.C. Little Building, Ann Arbor, Michigan 48109-1063, U.S.A.)

Kate Moran (Atlantic Geoscience Centre, Bedford Institute of Oceanography, Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada)

Masafumi Murayama (Ocean Research Institute, University of Tokyo, 1-15-1 Minamidai Nakano-ku, Tokyo 164, Japan)

David W. Murray (Department of Geological Sciences, Brown University, Box 1846, Providence, Rhode Island 02912-1846, U.S.A.)

Paul N. Pearson (Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom)

Isabella Raffi (Facoltà di Scienze, #MM.FF.NN., Università di Chieti, c/o Villa Cybo, 00040 Castelgandolfo, Italy)

David A. Schneider (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.)

Ralf Tiedemann (GEOMAR, Institute for Marine Geosciences, Wischhofstrasse 1-3, 24148 Kiel, Federal Republic of Germany)

Jean-Pierre Valet (Institut de Physique du Globe, Géomagnetisme et Paléomagnetisme, 4 Place Jussieu, Tour 14-24, 2° étage, 75252 Paris Cedex 05, France)

Graham P. Weedon (School of Geological Science, University of Luton, Park Square, Luton, Bedfordshire, LU1 3JU, United Kingdom)

Hisato Yasuda (Department of Geology, Kochi University, Kochi 780, Japan)

James C. Zachos (Earth Sciences Board, Earth and Marine Science Building, University of California, Santa Cruz, Santa Cruz, California 95064, U.S.A.)

ABSTRACT

The Ceara Rise in the western equatorial Atlantic provides an ideal target for constructing a bathymetric transect of drill sites. It is located in the main flow path of the two principal water masses in the oceans. Mixing between these water masses creates the initial chemical and physical properties for deep water in the eastern basins of the Atlantic and for the Indian and Pacific oceans. Therefore it is imperative to understand the history of deep-water circulation and chemistry in this region in order to evaluate the changes in deep-water chemistry and carbonate preservation that are observed in other ocean basins.

The objective of Leg 154 was to construct a transect of coring sites distributed down the northeastern flank of Ceara Rise from 2901 to 4373 m. Several questions of paleoceanographic significance can be addressed by a depth transect of this type:

1. What was the history of deep-water flow in the Atlantic during the Cenozoic? What has been the relationship between deep-water circulation, chemistry, and Earth's climate?

2. What was the history of carbonate production and dissolution in the equatorial Atlantic during the Cenozoic? How have changes in carbonate production and dissolution been affected by changes in deep circulation and in Earth's climate?

3. What has been the Cenozoic history of surface water and climate in the tropics? How have the $\delta^{13}C$ of nutrient-depleted surface water and oceanic $\Delta\delta^{13}C$ varied throughout the Cenozoic?

The sediments recovered by Leg 154 span the last 55 m.y. and are suitable for depth transect reconstructions for a variety of temporal resolutions. When compared to similar depth transects in the Indian and Pacific oceans, the Ceara Rise depth transect will help to constrain the Cenozoic history of deep-water circulation and chemistry. The sites will prove to be an extremely valuable resource for paleoceanographic studies for many years to come.

INTRODUCTION

During the last decade, a coring and drilling strategy has been employed by the Ocean Drilling Program to recover bathymetric transects of advanced piston cores (APC) and extended core barrel (XCB) cores in order to reconstruct the Cenozoic history of deep water chemistry, carbonate production and dissolution, and deep-water circulation. It invokes the same successful strategy used during pioneering Deep Sea Drilling Project (DSDP) transects for reconstructing Neogene and Paleogene sedimentation history (e.g., DSDP Leg 74) and for reconstructing late Quaternary deep-water chemistry and sedimentation history (Johnson, 1984; Curry and Lohmann, 1982, 1983, 1985, 1986, 1990; Peterson and Prell, 1985a, 1985b; Jones et al., 1984; Farrell and Prell, 1989, for example).

The reasons for invoking the depth transect strategy lie in the interaction between the carbonate chemistry of deep water and the underlying sediment lithology. The bathymetric distribution of physical and chemical properties in the ocean results from large-scale circulation processes and imparts lithological changes in sediments and chemical variability in the benthic microfossils preserved in the sediments. For instance, the net flow of deep water from the Atlantic to the Pacific Ocean and the mineralization of organic carbon cause variations in the preservation of calcium carbonate that are recorded in the sediments; the Pacific Ocean today is much more corrosive to carbonate and has a different carbon chemistry than the Atlantic as a direct result of the modern circulation pattern. These gradients show up in the carbonate content of the sediments and in the carbon isotopic chemistry of benthic micro-organisms. By reconstructing past gradients in both the depth distribution of the carbonate facies and the chemistry of benthic-dwelling microfossils, we are able to infer the history of deep-water chemistry and circulation in the geological record. This approach works well in depth transects because carbonate dissolution is depth dependent and because bathymetric gradients of deep-water chemistry are important clues to water-mass origin and flow direction.

A basic assumption of the research strategy is that the principal source of carbonate in the sediments is from surface-water production, with little or no downslope or lateral input. If true, then carbonate accumulation in the least dissolved, shallowest sites approximates the carbonate productivity of the overlying surface waters. For sites located close together the vertical input rate of carbonate in all sites in the bathymetric transect should be equal. Then the difference in carbonate accumulation between shallow and deep sites is a quantitative indicator of the amount of carbonate lost to dissolution. These mass balances of carbonate supply and burial provide the means to reconstruct past carbonate productivity and dissolution. With the same bathymetric transects, gradients in deep-water chemistry can be inferred from the chemistry of benthic microfossils. Thus, from a single suite of cores located on the slopes of an aseismic rise, we can determine past changes in carbonate productivity, carbonate dissolution, and important features of deep-water chemistry and circulation.

The purpose of Leg 154 was to sample a bathymetric transect in the western equatorial Atlantic at the Ceara Rise (Fig. 1) in order to complement the global array of depth transects that has been acquired during the last decade (ODP Leg 108, eastern equatorial Atlantic; Leg 113, Maud Rise; Leg 115, Madingley Rise; Leg 117, Owen Ridge; Leg 130, Ontong Java Plateau; and Leg 145, Detroit Seamount) to fully evaluate the Cenozoic history of deep-water chemistry. In addition, Ceara Rise is located beneath the warm surface waters of the western tropical Atlantic, making it ideal for reconstructing the history of tropical sea-surface temperatures, the evolution of tropical calcareous microfossils, and the chemistry of nutrient-depleted surface waters.

Deep-water circulation in the Atlantic (and to a great extent in the world ocean) is controlled by the mixing between deep-water masses in the western basins of the South Atlantic and southern ocean. The Atlantic contains the source regions for the two major water masses in the deep oceans today, and in the past this ocean likely contained the source area for other water masses. Mixing between water masses in the South Atlantic and southern ocean produces the initial chemical and physical characteristics of the deep water that flows through the Indian Ocean and into the Pacific. Thus no reconstruction of Cenozoic deep-water circulation and chemistry can be complete without a full understanding of the history of deep-water circulation in the western Atlantic. On the basis of location, present oceanographic setting, and continuity of high sedimentation rates, the Ceara Rise certainly provides one of the best target locations for reconstructing this paleoceanographic history.

Drilling strategy

Leg 154 followed a drilling strategy that resulted in a depth transect of APC, XCB, and RCB cores for the sedimentary sequences deposited during the Cenozoic at Ceara Rise. Five sites were chosen at approximately 300-m depth increments down the gentle slopes of the northeast face of Ceara Rise (Figs. 1 and 2). All five sites obtained APC/XCB cores down into the Miocene section: Sites 925 through 929, located at about 3041, 3598, 3315, 4012, and 4356 m, respectively. Deeper penetration was planned at three of the sites (925, 926, 929) in order to provide a depth transect which would span the period since the early Oligocene. Drilling near to basement (0.9 to 1.3 s below the seafloor) was planned at Sites 925 and 929. Slow rates of penetration limited recovery, so the oldest sections date to the middle Eocene at Site 925; on the other hand the importance of the Oligocene section encouraged us to extend a fourth site into the Oligocene (Site 928); Site 929 extended into the Paleocene.

The goal of the drilling was to obtain the most complete sections possible for the drilled intervals; thus all five sites included triple, overlapping APC coring to refusal. Below APC depths, the choice of XCB or RCB depended on the observed recovery. The work aboard ODP Leg 138 had shown that it was possible to plan drilling and shipboard work to be able to document truly complete recovery of the stratigraphic section at each site before proceeding to the next, at least for the part of the section that can be cored with the APC. With high-resolution downhole logs and continuous data on cores (magnetic susceptibility, GRAPE density, color, natural gamma) Leg 154 attempted to extend this capability through the Paleogene. Since the sites cored on Leg 154 were all from a small geographical area, we expected also to be able to demonstrate high-resolution correlations between the sites using high-resolution biostratigraphy, magnetostratigraphy, and core and downhole-logging data. Composite depth sections for the Leg 154 sites extend continuous records back to at least the late Miocene (~7 Ma) with confident site to site correlations of orbital scale variability throughout, despite the fact that we were unable to determine magnetostratigraphy.

RESULTS

Site 925

Site 925 (proposed site CR-1) is situated on the shallowest part of the Ceara Rise (Fig. 2) and will provide the reference section for the study of the paleoceanography of the western equatorial Atlantic Ocean. The upper 350 m of section, cored in three parallel holes to ensure completeness, comprises a truly continuous sequence of pelagic foraminiferal and nannofossil ooze grading to chalk at the base, covering the last 16 m.y. without any break. Figure 3 shows lithology, biostratigraphic age constraints, reflectance, susceptibility, carbonate content, bulk density, and natural gamma radiation for the upper 200 m. Preservation of calcareous microfossils is generally very good to excellent, and numerous high-resolution studies will be possible in these sediments. Below this a 400-m-thick sequence of lower Miocene and Oligocene greenish, rhythmically bedded chalk was recovered with the RCB. Again, the preservation of calcareous microfossils is very good, although the sediments become progressively more lithified with burial depth. In general, recovery was high in this sequence, and the downhole logs provide continuity over the inter-core gaps. In the upper and middle Eocene part of the section the sediment grades toward a hard limestone with pervasive recrystallization; drilling was terminated at the point where it was judged that the sediments offered few opportunities for paleoceanographic investigations. Pore-water studies provide additional evidence that significant recrystallization is proceeding in the deepest part of the section.

The warm western areas of the tropical oceans are generally considered to represent the regions of most rapid evolution in marine plankton, and this belief is supported by the calcareous microfossils (foraminifers and calcareous nannofossils) recovered at Site 925. Preservation is excellent, providing ideal material for detailed taxonomic and ecological studies. An added attraction of the sequence is its proximity to many of the classic localities from which many of the species of Neogene tropical foraminifers were first described. Site 925 offers the continuity and temporal control that is invariably lacking in the classic land sections.

The primary lithostratigraphic units for the sedimentary sequence are defined on the basis of data obtained from eight sources: (1) smear slide examination, (2) visual observation of color, (3) percent carbonate measurements, (4) degree of sediment lithification, (5) magnetic susceptibility measurements, (6) reflectance spectrophotometry measurements, (7) particle grain-size analysis, and (8) X-ray diffraction analysis. Two gradational boundaries dividing three units were subsequently identified at levels where distinct changes in one or more of the above data are observed.

Unit I (0-135 mbsf) consists of lower Pliocene to Holocene alternating nannofossil clay and clayey nannofossil ooze. Unit II (135 to 290 mbsf) consists of middle Miocene to lower Pliocene nannofossil ooze with clay and foraminifers. Unit III (290-930 mbsf) consists of middle Eocene to middle Miocene nannofossil limestone and chalk with foraminifers and clay. More subtle changes in lithologic character occur within the three lithostratigraphic units and provide the basis for dividing each unit into a series of subunits.

During the last 16 m.y. of global climatic deterioration, sedimentation rates have gradually increased from a low of about 10 m/m.y. during the middle Miocene to about 33 m/m.y. during the Pleistocene (Fig. 4). This increase is chiefly accounted for by an increasing flux of terrigenous material that presumably originated in the Amazon River; indeed, during the Pleistocene the biogenic carbonate flux actually decreased.

A composite section has been constructed on the basis of magnetic susceptibility and color reflectance data that will enable high-resolution sampling to be carried out with maximum efficiency and minimum waste of samples. Figure 5 shows spliced magnetic susceptibility and reflectance records for the upper 200 meters composite depth. The composite section also enables us to generate accurate spliced records of natural gamma-ray emission, GRAPE density, and P-wave velocity. These records will be valuable both as means for correlating core and downhole-log data, and proxies of sediment lithology.

Even without any sophisticated age model development, the relationship between the visually striking sedimentary cycles that pervade the succession and orbital cycles can be demonstrated by spectral analysis. Despite the lack of a paleomagnetic record from Sites 925 through 929, we anticipate that the temporal refinement that will result from calibrating the lithological cycles to orbital cycles will provide unique data on biogenic and lithogenic sedimentary fluxes to the top of the Ceara Rise over the past 40 m.y. and the erosional history caused by changes in deep-water circulation and chemistry.

Site 926

Site 926 (proposed site CR-3) is situated at an intermediate depth (3597 m) on a plateau on the southern flank of the Ceara Rise (Fig. 2). The upper 350 m of section, cored in three parallel holes to ensure completeness, comprises a truly continuous sequence of pelagic foraminiferal and nannofossil ooze grading to chalk at the base, covering the last 16 m.y. without any break. Preservation of calcareous microfossils is generally very good to excellent, and numerous high-resolution studies will be possible in these sediments. Below this a 400-m-thick sequence of lower Miocene and Oligocene greenish rhythmically bedded chalk was recovered with the XCB. Again the preservation of calcareous microfossils is very good, although the sediments become progressively more lithified with burial depth. In general, recovery was high in this sequence and the downhole logs provide continuity over the inter-core gaps.

Although calcium carbonate and terrigenous clay are the major constituents of the sediment recovered at Site 926, significant quantities of biogenic silica are present in the lower Miocene sediments (Fig. 6). This accounts for the significant peak in the concentration of Si in the pore waters both at Site 926 and at Site 925, where only trivial quantities of biogenic silica remain in the sediment (Fig. 6). A second feature of the pore-water profile at both Sites 926 and 925 is the unusually high concentration of lithium.

The warm western areas of the tropical oceans are generally considered to represent the regions of most rapid evolution in marine plankton, and this idea is supported by the calcareous microfossils (foraminifers and calcareous nannofossils) recovered at Site 926. Preservation is generally excellent apart from the middle Miocene section in which carbonate dissolution has affected the foraminiferal assemblages, providing ideal material for detailed taxonomic and ecological studies. An added attraction of the sequence is its proximity to many of the classic localities from which many of the species of Neogene tropical foraminifers were first described. Site 926 offers the continuity and temporal control that is invariably lacking in the classic land sections. The sediments adjacent to the Oligocene/Miocene boundary are thicker than at Site 925, suggesting that there may have been a brief, undetected hiatus at Site 925.

During the last 16 m.y. of global climatic deterioration, sedimentation rates have gradually increased from a low of about 12 m/m.y. in the middle Miocene to about 33 m/m.y. during the Pleistocene (Fig. 7). This increase is chiefly accounted for by an increasing flux of terrigenous material that presumably originated in the Amazon River; indeed during the Pleistocene the biogenic carbonate flux actually decreased, as was observed at Site 925. But the late Neogene increase in sedimentation rate is not solely the result of increased terrigenous supply. During the Miocene episodes of severe dissolution caused the lysocline to shoal to depths shallower than 3600 m, reducing sedimentation rates at Site 926 by about 25%. During the early Miocene, where siliceous microfossils were present in the sediments, sedimentation rates at Site 926 exceeded those at Site 925 by 8%.

A composite section has been constructed, on the basis of magnetic susceptibility and reflectance data, that will enable high-resolution sampling to be carried out with maximum efficiency and minimum waste of samples. The composite section will also enable us to generate accurate spliced records of natural gamma-ray emission, GRAPE density, and P-wave velocity. These records will be valuable both as means for correlating core and downhole-log data, and proxies of sediment lithology.

The spliced records of magnetic susceptibility and color reflectance can readily be correlated cycle by cycle with those generated for Site 925 over the whole of the Pleistocene and Pliocene and sections of the Miocene. With further work these detailed correlations will be possible over most if not all of the sections recovered. Thus, despite the lack of a paleomagnetic record at either Site 925 or Site 926, it is clear that we have the ability to make extremely detailed comparisons between erosional and biological fluxes to the seafloor at these sites on the Ceara Rise for the past 29 m.y.

In addition to the high-resolution records that have already been obtained by analysis of the sediment recovered at Site 926, the downhole logs at the site have provided invaluable information both at low and high resolution. For example, the downhole natural gamma log (also recorded in the MST-track natural gamma measurements) shows a significant change in sediment composition at about 8 Ma. At high resolution, both the natural gamma record and the resistivity record show a distinct cyclicity with a 1.0- to 1.3-m wavelength through the upper Oligocene and lower Miocene part of the sediment column that unambiguously matches the cyclicity observed in the cores recovered. This part of the section was recovered in a single hole (926B), and it is extremely valuable to have accurately determined the length relationship between the cycles observed in the recovered cores and the wavelength actually present in the sediment. In the siliceous sediments recovered in the eastern equatorial Pacific, cores recovered using the XCB were sometimes stretched by up to 50% (Hagelberg et al., 1992), but it is evident that in the chalks recovered at Site 926 the sediment was recovered at true scale.

Site 927

Site 927 (proposed site CR-2) is the second shallowest member of the bathymetric transect of sites drilled on the Ceara Rise, located on a plateau at 3319 m below sea level (Fig. 2). Site 927 is the member of the depth transect that is closest to the Amazon River. The location is shallow enough to preclude extremes of dissolution caused by shoaling of the lysocline, at least during the upper Pleistocene interval, but several episodes of severe dissolution affected intervals within the middle and late Miocene.

The upper 270 mbsf of sediment was recovered with three overlapping APC/XCB sections (Fig. 8 shows the upper 200 m), and continuity of the sediment section was documented down to approximately 270 mbsf. The upper 210 m of pelagic drape appears to represent continuous, uninterrupted deposition of a nannofossil clay and clayey nannofossil ooze (Fig. 8). This interval corresponds to the last 7 m.y. Below 210 mbsf (within the upper Miocene), several slides and slumps interrupt the continuity of the sediment record. Hole 927C was washed to 358 mbsf so that the entire cored section could be logged; a very scientifically valuable logging operation was performed.

The same lithostratigraphic units observed at Sites 925 and 926 are present at this site (see Site 925, above, for description). Because of the site's close proximity to the Amazon Fan, Unit I is thicker and lower in carbonate content than at the previous two sites. The changes in sedimentation rate observed at Site 927 (Fig. 9) suggest that an increase in terrigenous input, presumably due to increased erosion in the Amazon drainage basin, began about 8 Ma; the terrigenous input has steadily increased since that time. This increase in sedimentation rates is most obvious when Site 927 is compared with Site 926, the site farthest from the Amazon Fan (Fig. 9). The noncarbonate accumulation rate at Site 927 has increased by a factor of 4 during the last 7 m.y. During this interval the carbonate accumulation rate decreased by about 25% both at Site 927 and at the more southerly Sites 925 and 926. In addition to the increase in terrigenous sedimentation between 7 and 8 Ma, a change in the mineralogy of the terrigenous component from a dominantly kaolinite-rich clay assemblage to an illite-rich clay assemblage is documented by the downhole-logging data. Together, these changes suggest that hemipelagic deposition began here in the late Miocene, when there was a change in the nature of weathering in the Amazon drainage basin. The result was a large change in mineralogy and a greatly increased flux of terrigenous components to Ceara Rise.

Site 927 also contains clear evidence for rhythmic sedimentation that is largely controlled by the precession cycle of orbital forcing. The variations in lithology, exhibited by the changes in magnetic susceptibility, color reflectance, and natural gamma radiation (Fig. 8), result from changes in the relative proportions of terrigenous material and biogenic carbonate. For the Pliocene to Holocene interval, there is little evidence for carbonate dissolution. Consequently, the rhythmic changes in lithology must result from high-frequency changes in dilution of the carbonate by Amazon terrigenous material. Whether these changes in lithology result primarily from eustatic sea level or from climatological changes in South America remains to be determined.

Site 927 also contains clear evidence for a middle Miocene hiatus spanning the interval between 13 and 15 Ma (Fig. 9). The reasons for this hiatus are not yet clear. One goal of Leg 154 was to determine the regional and bathymetric extent of Miocene hiatuses at Ceara Rise. The occurrence of this hiatus at Site 927, which is located between Sites 925 and 926 in the depth transect, shows that the occurrence and duration of Miocene hiatuses is not simply depth dependent. The sediments from the three shallowest sites of the depth transect suggest that certain intervals within the Miocene experienced episodes of severe dissolution that contributed to the lower accumulation rates and thinning of the sediment section. However, the absence of sediments dating from 13 to 15 Ma at Site 927 suggests that changes in the deep-water circulation may have eroded sediments during that interval of time.

Site 928

Situated on the northern flank of the Ceara Rise, at a depth of 4012 m (Fig. 2) that is only around 100 m above today's carbonate lysocline, Site 928 (proposed site CR-4) will provide valuable material for the study of the paleoceanography of the western equatorial Atlantic Ocean for the past 31.5 m.y. The upper 180 m of the section, cored in three parallel holes to ensure completeness, comprises a continuous sequence of pelagic foraminiferal and nannofossil ooze grading to clay at the base, covering about the last 10 m.y. The Pliocene-Pleistocene section is clearly complete, but the stratigraphy of the upper Miocene section is complicated by the presence of redeposited material although a complete sequence of nannofossil datums was recovered. The average accumulation rate through the late Miocene part of the section was 8 m/m.y., but about 25% of the section is made up of material that originally accumulated higher on the Ceara Rise, so that the average pelagic sedimentation rate at the site was probably about 6 m/m.y. Preservation of calcareous microfossils is generally very good to moderate, but never bad enough to prejudice the quality of the biostratigraphic age control. Below this a 200-m-thick sequence of lower Miocene and Oligocene greenish rhythmically bedded chalk was recovered with the XCB in Hole 928B. Again, the preservation of calcareous microfossils is very good, although the sediments become progressively more lithified with burial depth. At about 433 mbsf in the Oligocene part of the section there is a significant hiatus where the record for about 28.5 to 27.1 Ma is lacking. In general, recovery was high in this sequence and the good downhole log provides continuity over the inter-core gaps.

At Site 928 it was not until after 6 Ma that sedimentation rates increased, as compared to the low rates that prevailed during the middle and late Miocene. During the Pliocene, rates increased to 30 m/m.y. and then increased again during the Pleistocene to about 36 m/m.y. (Fig. 10). This increase is chiefly accounted for by an increasing flux of terrigenous material that is supplied by the Amazon River. However, the delayed rise in sedimentation rate in the late Miocene compared to the shallower Ceara Rise sites is due to the fact that the CCD was evidently close to the water depth of this site until the latest Miocene, so that almost no carbonate accumulated; even in the early Pliocene, carbonate dissolution probably took a significant proportion of the biogenic flux. During the early Oligocene, sedimentation rates were almost as high as in the Pleistocene, providing an excellent component of a depth transect for high-resolution investigations of Oligocene paleoceanography.

A composite section has been constructed on the basis of magnetic susceptibility and reflectance data that will enable high-resolution sampling to be carried out with maximum efficiency and minimum waste of samples. The composite section also enabled us to generate accurate spliced records of natural gamma-ray emission, GRAPE density, and P-wave velocity. These records are valuable both as means for correlating core and downhole-logging data, and proxies of sediment lithology (Fig. 11). As at other Ceara Rise sites, the downhole spectral gamma log provides information on changes in clay mineralogy, and analyses of a few selected samples from Hole 928A has confirmed the suggestion that at about 8 Ma kaolinite was replaced by illite as the dominant clay mineral. The late Neogene increase in terrigenous sedimentation and the change in clay mineralogy both suggest that the Amazon drainage basin experienced a change in weathering at about 8 Ma.

Site 929

Situated on the northern flank of the Ceara Rise at a depth of 4356 m, Site 929 (proposed site CR-5) is located below today's carbonate lysocline, and was close to the CCD as recently as the last glacial maximum. It is the deepest member of the Ceara Rise depth transect cored during Leg 154 and the site most likely to have been affected by dissolution in the past. Thus, it is the site best located for the purpose of quantifying past rates of dissolution. Site 929 also provided the longest stratigraphic section recovered during Leg 154, with a virtually complete section to the base of the Eocene.

Even at this depth, calcareous microfossils were present through most of the section cored. Red clay was encountered in the lower Pliocene and within several intervals of the Miocene. Recovery of this clay was difficult, particularly its upper part, so that the generation of a composite section was only fully successful down to a depth of about 140 mcd. This upper section was cored in triplicate to provide sufficient material for detailed, high-resolution paleoceanographic investigations over the complete depth transect through the upper Neogene. Despite the reduced carbonate contents caused by more intense dissolution at this site than at Sites 925 to 928, the high-resolution lithological cycles that were monitored by MST and reflectance data can be correlated in detail without difficulty to the records from these shallower sites. Sporadic distinct, thin distal turbidites containing quartz and feldspar and clearly originating in the Amazon are confined to glacial stages of the past million years. Although displaced material also occurs intermittently deeper in the section, as is to be expected at this location, it originated in all other cases at shallower depths on Ceara Rise rather than in the Amazon fan.

Below the highly dissolved Miocene sediments, an almost continuous sequence through the entire Oligocene and Eocene and into the upper Paleocene was recovered. The Paleogene sequence is remarkably homogeneous, being characterized throughout by cyclic alternations of darker and paler greenish gray chalks and clays grading into limestone and claystone. In the Paleocene there apparently was a significant change to a more uniform lithology lacking obvious cyclicity; unfortunately, only five cores were recovered from this section. Preservation of calcareous microfossils varies with carbonate content but is good enough to provide excellent age control in this tropical sequence. Both the Oligocene sequence that was cored with the XCB, and the Eocene that was cored with the RCB, had good recovery of over 70%; the sedimentary cyclicity was successfully documented by magnetic susceptibility and natural gamma radiation measured on the MST and by color measured using the hand-held spectrophotometer. In order to further test the value of the natural gamma tool, which is a relatively recent addition to the multisensor track (MST), the Pleistocene section of Hole 929D was analyzed in high resolution with long-enough counting times (100 s) to permit the information provided by the discrete energy channels to be exploited.

The sedimentation-rate variability at Site 929 parallels the changes observed in other Ceara Rise site locations (Fig. 12). A late Neogene increase in overall sedimentation rate was caused by an increase in the terrigenous mass accumulation rate at about 8 Ma. This increase correlates with a change in the clay mineralogy from kaolinite to illite dominance as recorded in the Th/K ratio recorded in downhole-logging data. Terrigenous sedimentation increased most markedly after about 5 Ma. Carbonate accumulation decreased overall throughout the late Neogene, a change that reflects the decrease in carbonate productivity observed at the shallow sites.

Very low sedimentation rates are recorded in the autochthonous Miocene section. The widespread occurrence of red clays and several sections barren of calcareous microfossils attest to the shoaling of the CCD at this time. These red clays correlate with a nearly identical section observed at the deeper sites of Leg 108 (Ruddimann, Sarnthein, Baldauf et al., 1988). Higher sedimentation rates and orbitally induced rhythmic sedimentation are recorded in the lower Miocene, Oligocene, and upper Eocene sections at Site 929 that were induced by orbital-scale changes in carbonate productivity and dissolution. Middle and lower Eocene sedimentation rates are highly variable; a part of this variability can be accounted for by variations in carbonate content of the sediments, but further work is required to explain all of the variations.

CONCLUSION

The primary goal of Leg 154 was to provide the opportunities for late Neogene paleoceanographic reconstruction. Shipboard work has cleared the way for this endeavor to proceed immediately. Composite sections generated for all five sites enable any time interval to be selected and covered at a chosen sampling interval at all sites over a water depth range of 1.3 km. Fluxes of the various sedimentary components can be examined in relation to surface productivity, terrigenous input (from the Amazon) through vertical and advective transport, and carbonate dissolution. Gradients in nutrient tracers such as ^{13}C, Cd, and Ba in foraminiferal tests may be determined. By coordinating the initial exploitation of the material available from these sites so as to minimize complications that arise from poor inter-laboratory calibration, it should be possible for the first time to make confident estimates of changes in vertical benthic ^{18}O gradients. This will of course pave the way for making more reliable statements regarding changes in inter-oceanic gradients in deep water, making use of ODP sites that have been drilled elsewhere.

The sections recovered during Leg 154 will also provide an excellent opportunity to determine how ocean chemistry changed in association with the growth of Antarctic glaciation. Sites 925, 926, 928, and 929 all recovered sediments coeval with the middle Oligocene increase in ^{18}O while Sites 925, 928, and 929 recovered sediments coeval with the early Oligocene ^{18}O event. There is also a good opportunity to add to our understanding of Paleogene sedimentary budgets; the shallowest and deepest members of the transect (925 and 929), separated vertically by 1300 m, both extend to the middle Eocene (Site 929 provides information from the Paleocene) and, although the Eocene sediments are moderately lithified, the biostratigraphic age control by nannofossils is still very good. Benthic foraminifers appear to be sufficiently well preserved to provide valuable faunal, isotopic and geochemical data that will help us to unravel the complexities of Eocene and Oligocene deep water circulation.

REFERENCES

Curry, W.B., and Lohmann, G.P., 1982. Carbon isotopic changes in benthic foraminifera from the western South Atlantic: Reconstruction of glacial abyssal circulation patterns. *Quat. Res.,* 18:218-235.

Curry, W.B., and Lohmann, G.P., 1983. Reduced advection into Atlantic Ocean deep eastern basins during last glaciation maximum. *Nature,* 306:577-580.

Curry, W.B., and Lohmann, G.P., 1985. Carbon deposition rates and deep water residence time in the equatorial Atlantic Ocean throughout the last 160,000 years. *In* Sundquist, E., and Broecker, W. (Eds.), *The Carbon Cycle and Atmospheric* CO_2*: Natural Variations, Archean to Recent.* AGU, Geophys. Monogr. Ser., 32:285-301.

Curry, W.B., and Lohmann, G.P., 1986. Late Quaternary carbonate sedimentation at the Sierra Leone Rise (eastern equatorial Atlantic Ocean). *Mar. Geol.,* 70:223-250.

Curry, W.B., and Lohmann, G.P., 1990. Reconstructing part particle fluxes in the tropical Atlantic Ocean. *Paleoceanogr.,* 5:487-505.

Farrell, J.W., and Prell, W.L., 1989. Climatic change and $CaCO_3$ preservation: An 800,000 year bathymetric reconstruction from the central equatorial Pacific Ocean. *Paleoceanogr.,* 4:447-466.

Hagelberg, T., Shackleton, N.J., Pisias, N., and Shipboard Scientific Party, 1992. Development of composite depth sections for Sites 844 through 854. *In* Mayer, L.A., Pisias, N.G., Janecek, T.R., et al., *Proc. ODP, Init. Repts.*, 138: College Station, TX (Ocean Drilling Program), 79-85.

Johnson, D.A., 1984. The Vema Channel: Physiography, structure, amd sediment-current interactions. *Mar. Geol.,* 58:1-34.

Jones, G.A., Johnson, D.A., and Curry, W.B., 1984. High-resolution stratigraphy in late Pleistocene/Holocene sediments of the Vema Channel. *Mar. Geol.,* 58:59-87.

Peterson, L.C., and Prell, W.L., 1985a. Carbonate dissolution in Recent sediments of the eastern equatorial Indian Ocean: Preservation patterns and carbonate 1088 above the lysocline. *Mar. Geol.,* 64:259-290.

Peterson, L.C., and Prell, W.L., 1985b. Carbonate preservation and rates of climate change: An 800 kyr record from the Indian Ocean. *In* Sundquist, E., and Broecker, W. (Eds.), *The Carbon Cycle and Atmospheric CO_2: Natural Variations, Archean to Recent.* AGU, Geophys. Monogr. Ser., 32:251-269.

Ruddiman, W.F., Sarnthein, M., Baldauf, J., et al., 1988. *Proc. ODP, Init. Repts.,* 108: College Station, TX (Ocean Drilling Program).

FIGURES

Figure 1. Location of the Ceara Rise in the Atlantic Ocean, showing its location with respect to the South American coast and the Amazon Fan. Bathymetry in meters. Dots are site and contingency site locations.

Figure 2. Perspective view of Ceara Rise from the northwest and southeast, which points out the steep slopes on the southwest margin and gentle dips on the northeast flank. The prominent platform tops of the rise are usually shallower than 3200 m. Several of these platforms were selected for shallow coring sites (Sites 925, 926, and 927). The deeper coring sites of the bathymetric transect (Sites 928 and 929) fall on the gently sloping northeast flank.

Figure 3. Upper 200 m of the master column for Site 925, showing the complete stratigraphic sequence recovered from the four holes, lithology, reflectance (550 nm), magnetic susceptibility (instrument units), carbonate concentration, bulk density, and natural gamma-ray intensity.

Figure 4. Plot of sedimentation rates on the mcd scale vs. age at Site 925.

Figure 5. Spliced records of magnetic susceptibility (top) and reflectance (bottom) from the upper 200 meters composite depth (mcd) of Site 925. Holes are 925A (large dashed line), 925B (small dashed line), 925C (dotted line), and 925D (solid line).

Figure 6. Calcium carbonate content vs. age for Site 926 (left) and Site 925 (center), and pore-water silica profiles vs. age for the two sites (right).

Figure 7. Plot of sedimentation rates at Site 926 on the mcd depth scale vs. age.

Figure 8. Upper 200 m of the master column for Site 927, showing the complete stratigraphic sequence recovered from three holes, lithology, reflectance (550 nm), magnetic susceptibility (instrument units), carbonate concentration, bulk density, and natural gamma-ray intensity.

Figure 9. Plots of sedimentation rates at Site 927 on the mcd depth scale vs. age (left) and the difference in development of sedimentation rates at Sites 926 and 927 (right). The change in rate between 7.3 and 8.4 Ma probably marked the initiation of the still-ongoing uplift of the Andes.

Figure 10. Plot of sedimentation rates at Site 928 on the mcd depth scale vs. age.

Figure 11. Total gamma-ray radiation and Th/K ratio from Hole 928B. Lithologic units and subunits are shown on the right side. Note the decreased Th/K ratio near the Subunit IIA/IIB boundary.

Figure 12. Plot of sedimentation rates at Site 928 on the mcd depth scale vs. age.


Study Area

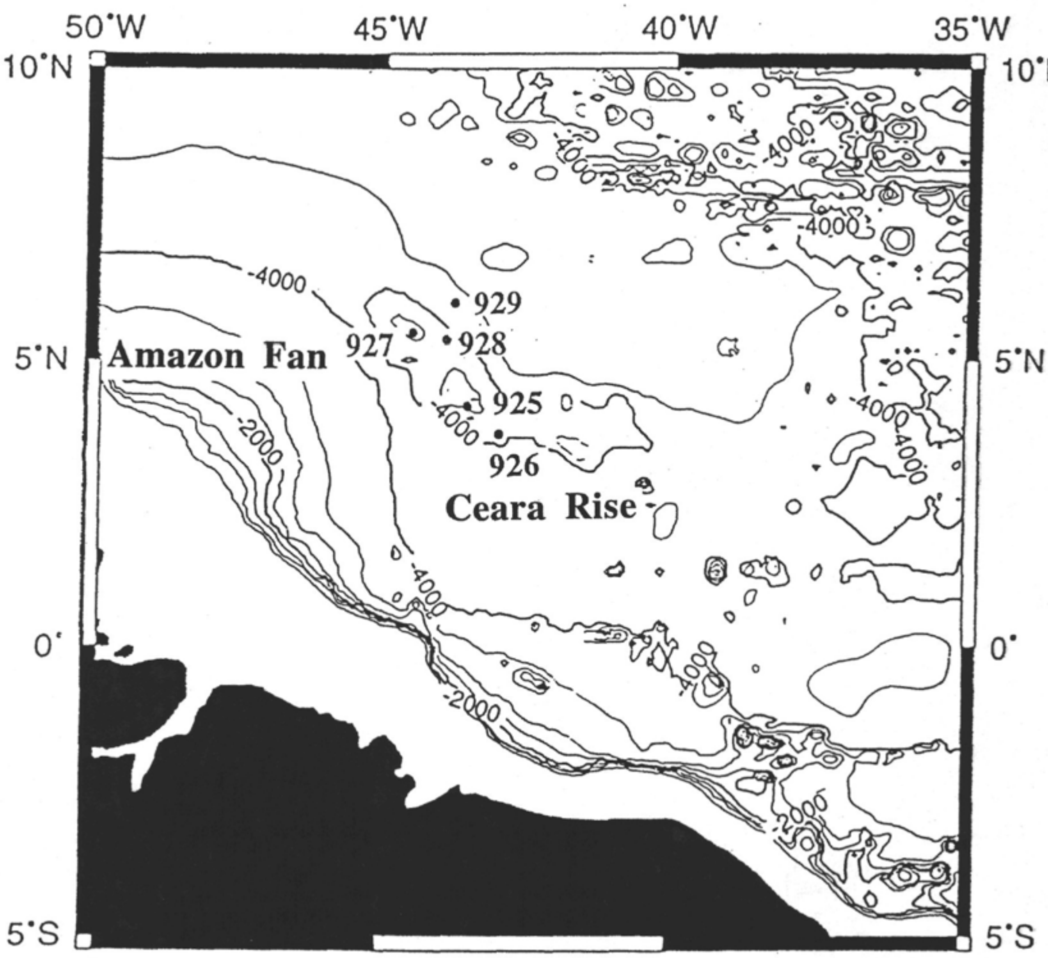

50°W
45°W
40°W
35°W
10°N
5°N
0°
5°S
-4000
-2000
929
927
928
925
926
Amazon Fan
Ceara Rise

Figure 1

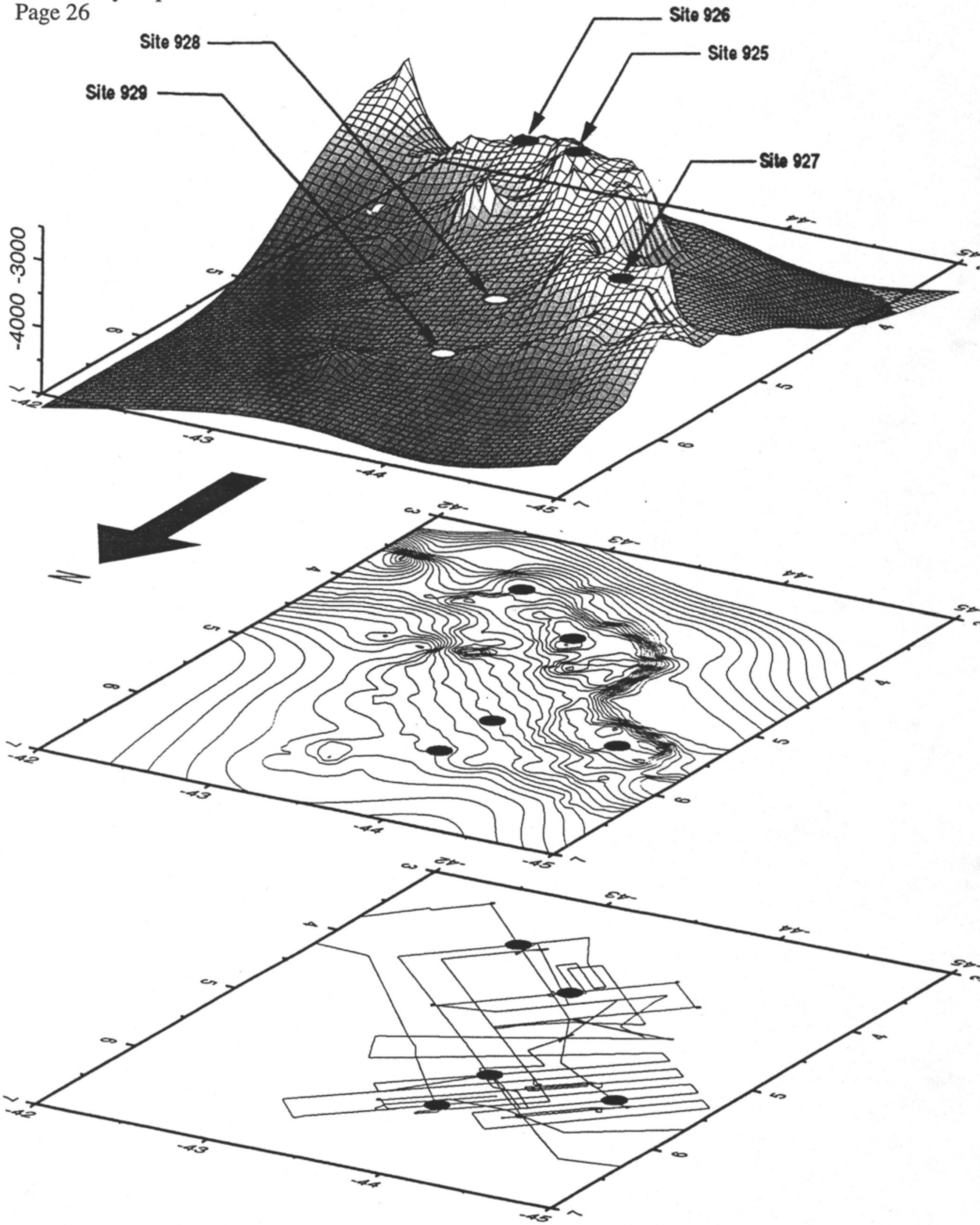


Figure 2

Leg: 154 Master Column Site: 925

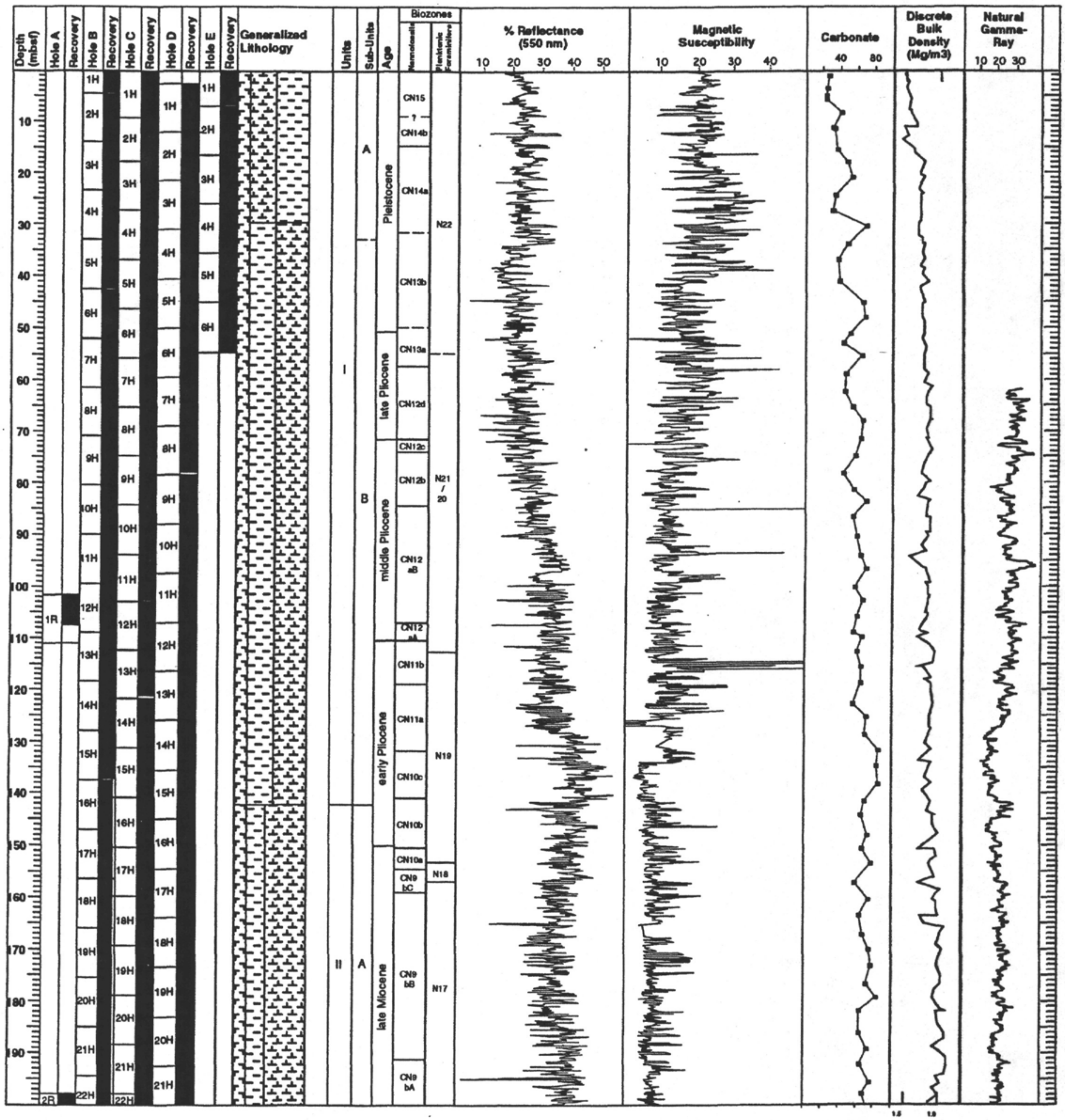


Figure 3

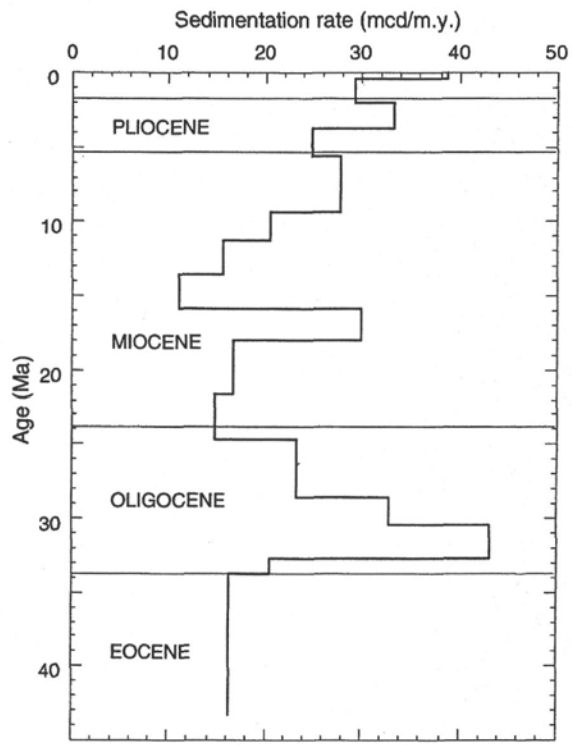

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
Age (Ma)
0
10
20
30
40
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE

Figure 4

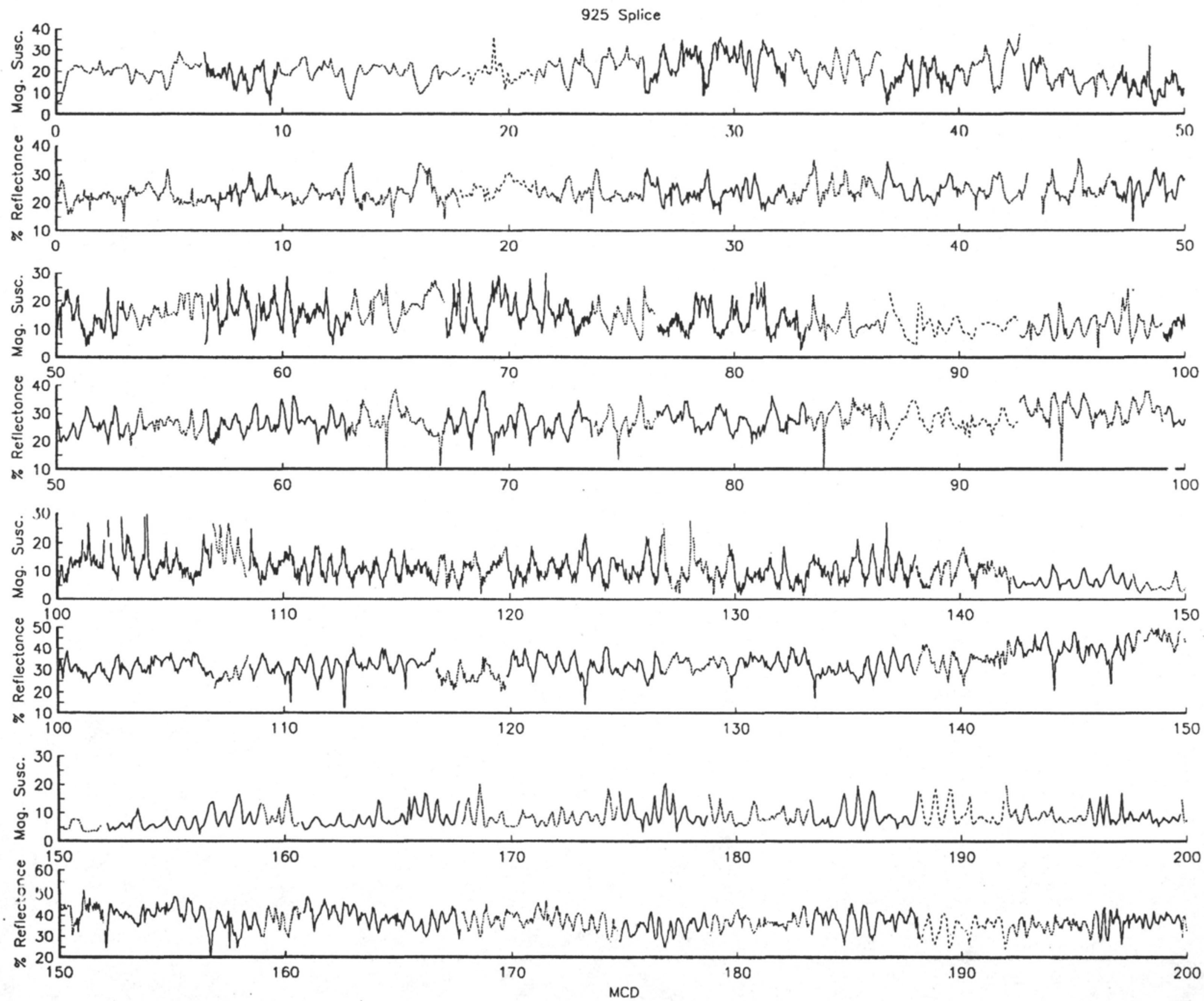


Figure 5

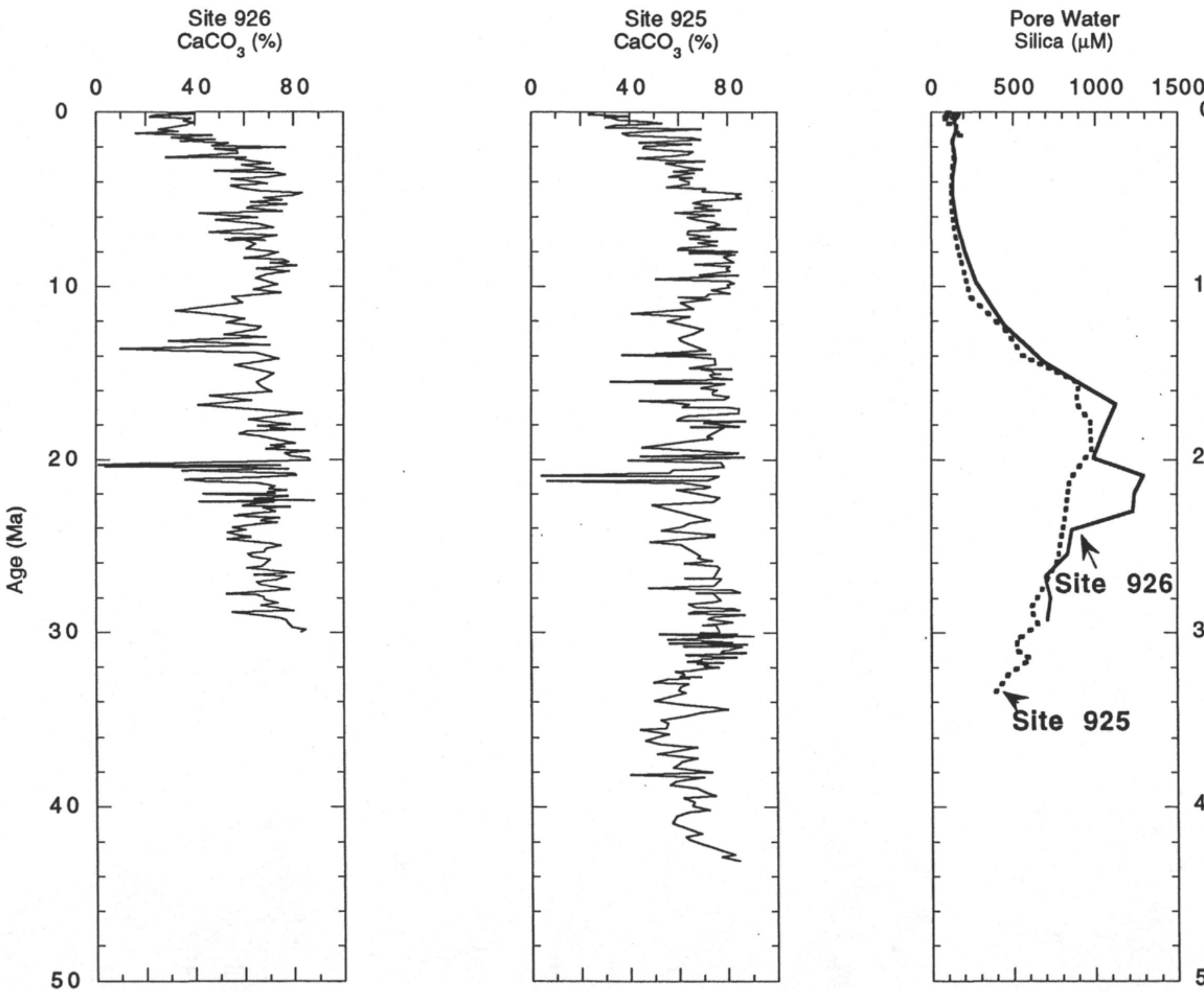

Site 926
CaCO3 (%)
Site 925
CaCO3 (%)
Pore Water
Silica (µM)
Age (Ma)
Site 926
Site 925
0
40
80
500
1000
1500
10
20
30
40
50

Figure 6

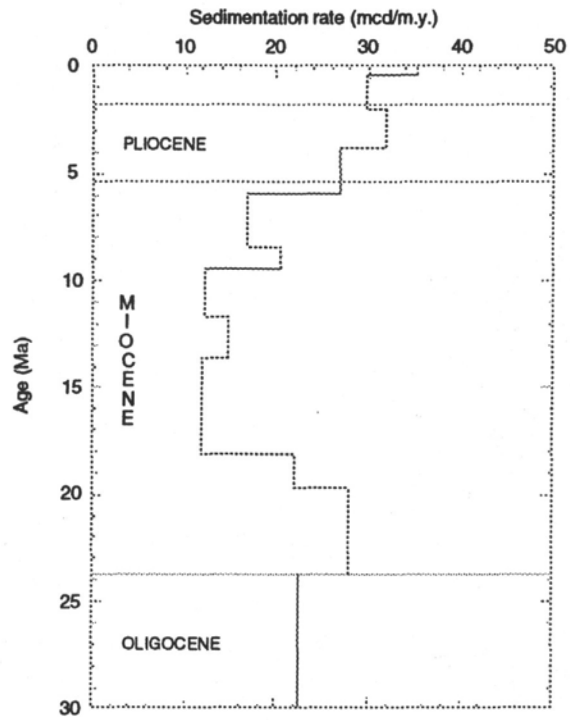

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
Age (Ma)
0
5
10
15
20
25
30
PLIOCENE
MIOCENE
OLIGOCENE

Figure 7

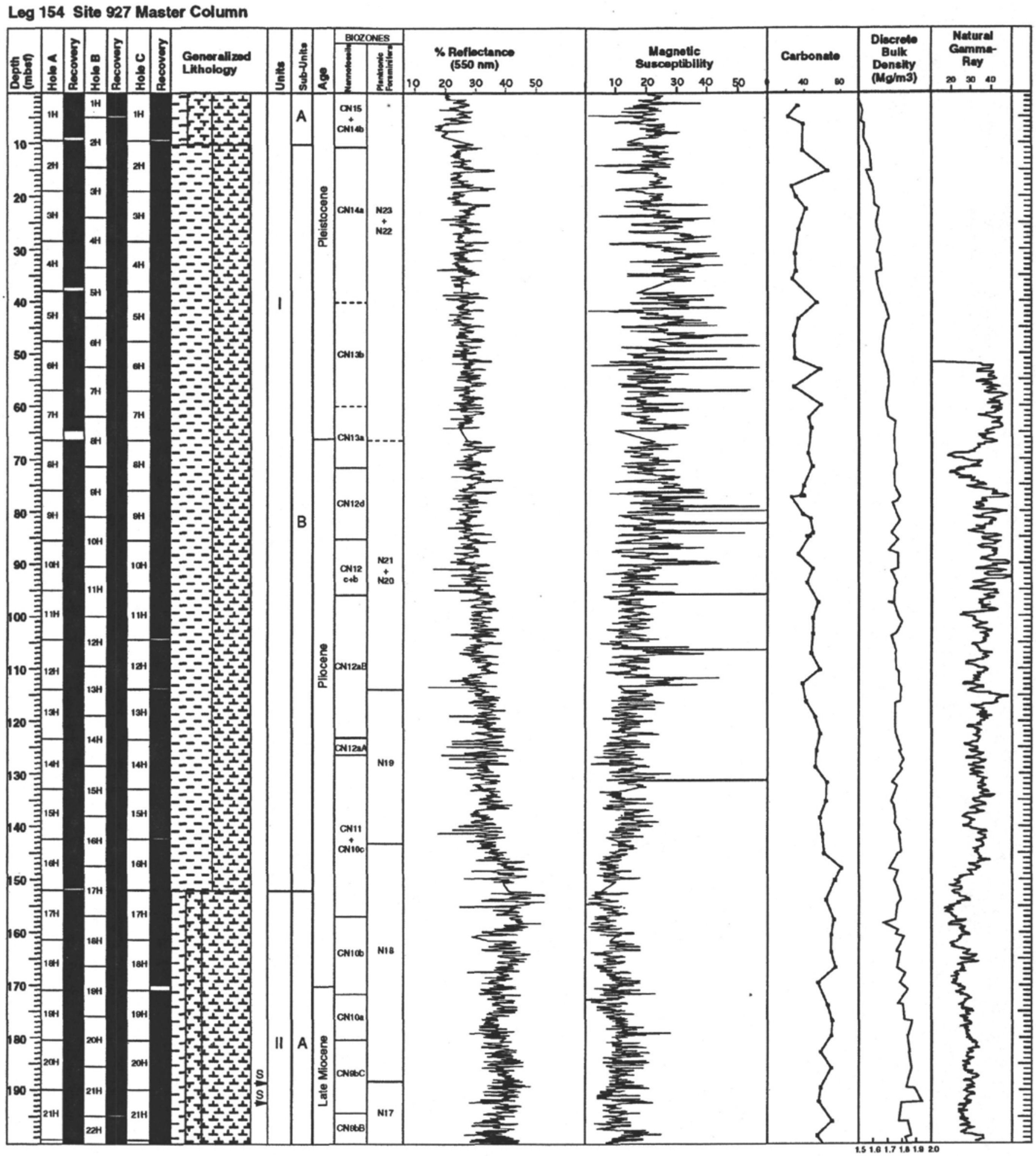

Leg 154 Site 927 Master Column
Depth (mbsf)
Hole A
Recovery
Hole B
Recovery
Hole C
Recovery
Generalized Lithology
Units
Sub-Units
Age
BIOZONES
Nannofossils
Planktonic Foraminifera
% Reflectance (550 nm)
Magnetic Susceptibility
Carbonate
Discrete Bulk Density (Mg/m3)
Natural Gamma-Ray
Pleistocene
Pliocene
Late Miocene
CN15 + CN14b
CN14a
CN13b
CN13a
CN12d
CN12 c+b
CN12aB
CN12aA
CN11 + CN10c
CN10b
CN10a
CN9bC
CN9bB
N23 + N22
N21 + N20
N19
N18
N17

Figure 8

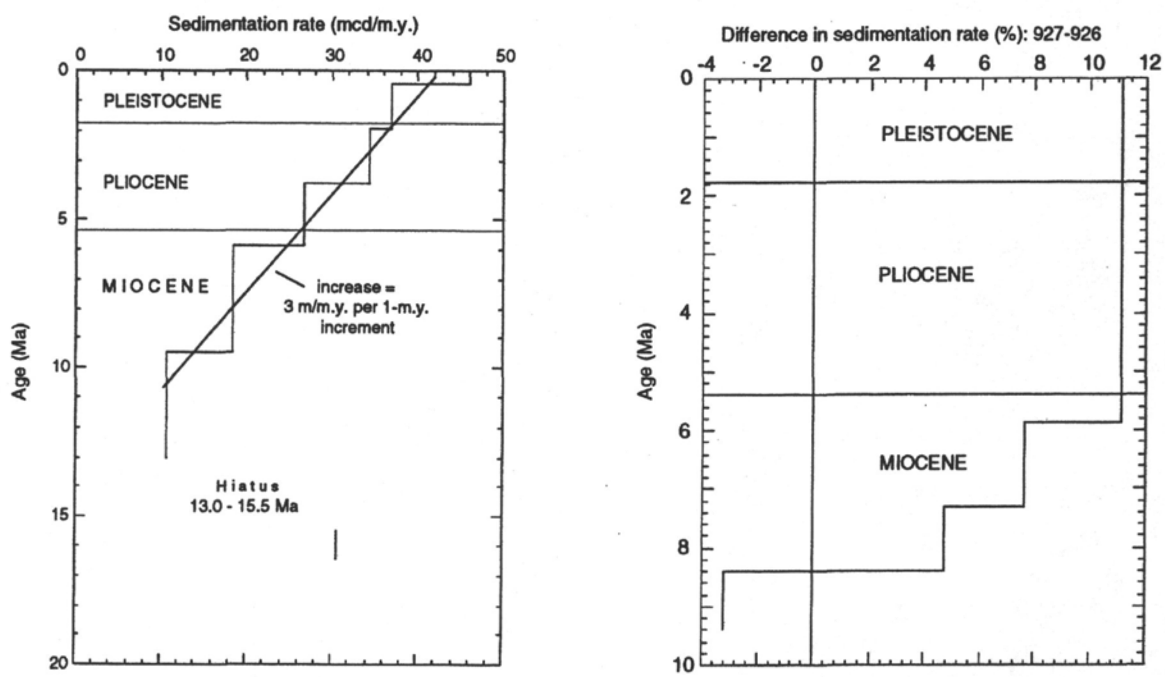

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
5
10
15
20
Age (Ma)
PLEISTOCENE
PLIOCENE
MIOCENE
increase =
3 m/m.y. per 1-m.y.
increment
Hiatus
13.0 - 15.5 Ma
Difference in sedimentation rate (%): 927-926
-4
-2
0
2
4
6
8
10
12
0
2
4
6
8
10
Age (Ma)
PLEISTOCENE
PLIOCENE
MIOCENE

Figure 9

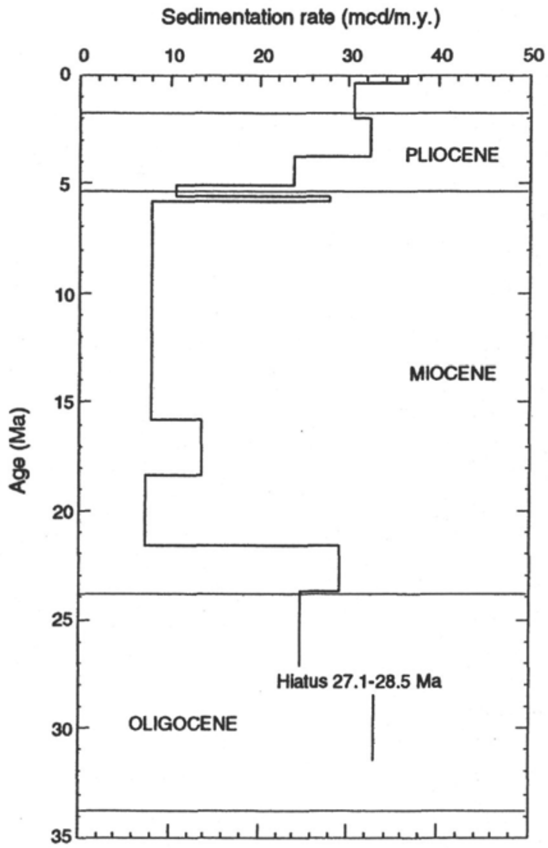

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
5
10
15
20
25
30
35
Age (Ma)
PLIOCENE
MIOCENE
OLIGOCENE
Hiatus 27.1-28.5 Ma

Figure 10

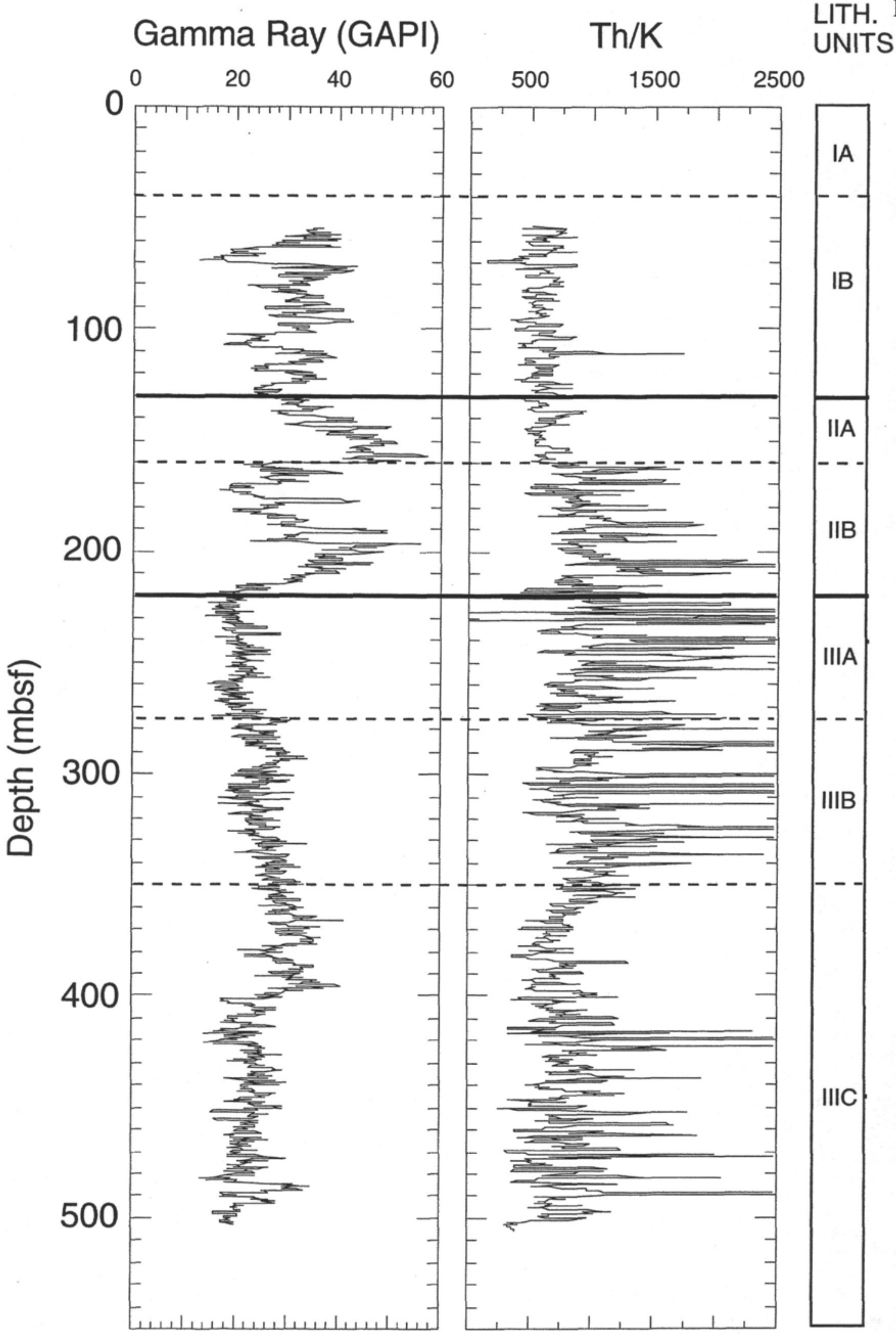

Gamma Ray (GAPI)
Th/K
LITH. UNITS
0
20
40
60
500
1500
2500
0
100
200
300
400
500
Depth (mbsf)
IA
IB
IIA
IIB
IIIA
IIIB
IIIC

Figure 11

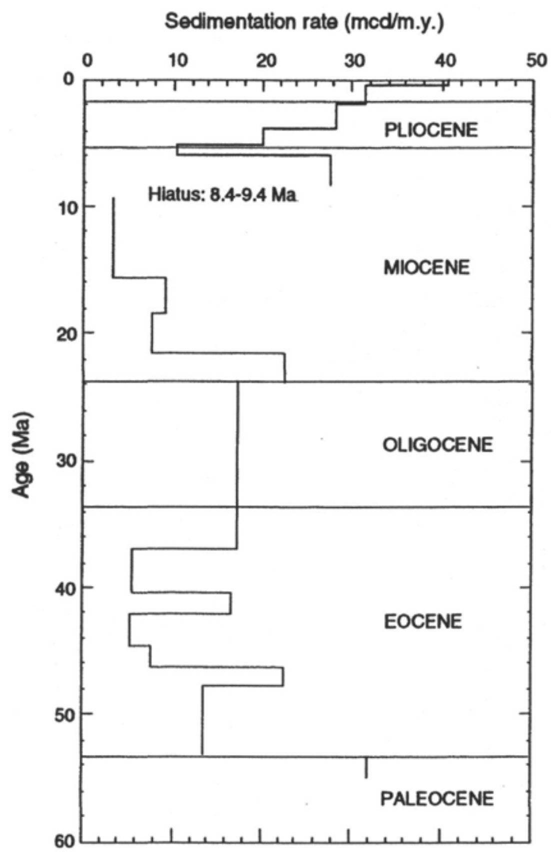

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
10
20
30
40
50
60
Age (Ma)
PLIOCENE
Hiatus: 8.4-9.4 Ma
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE

Figure 12

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 154 were:

Operations Superintendent:	Glen Foss
Schlumberger Engineer:	Karl Pohl

BARBADOS, PORT CALL

The official beginning of ODP Leg 154 came at 0730 hr (local time) on 24 January 1994 with the first mooring line in Bridgetown Harbor, Barbados. A conflict with heavy cruise ship traffic for dock space had been anticipated, so every effort had been made to compress required port call activities into a three-day period, minimize shipments, and defer work items until the Leg 155 port call. During an intense two working days, all crew-change and freight loading/off-loading activities were completed. In addition, 1100 MT (metric tons) of fuel and 700 MT of drill water were taken on, and a diver inspection of the doppler pit log installation was conducted. Jobs that could be continued with the ship at anchor were begun. After less than 36 hr in port, *JOIDES Resolution* was required to vacate her berth inside the breakwater to accommodate an arriving cruise vessel. Arrangements had been made for a berth at a fuel-loading pier outside the protected harbor, and attempts were made to moor to it. Unfortunately, surge conditions were unfavorable and the construction of the pier was incompatible with that of the vessel. Risk of damage to the ship and/or injury to personnel was too great, and the ship was forced to move to anchorage outside the harbor.

Repairs to the main engine seawater circulating line were required before the vessel could leave port, with 4 hr the estimated time with the main engines disabled. Good seamanship precluded lying at anchor without propulsion power available for emergency situations, so it was necessary to delay the work until a dockside berth again was available. Routine maintenance continued at the anchorage and some port call jobs continued, including subcontractor radiographic inspection of the rig's high-pressure circulating manifold. At 2045 hr on 27 January, after 48 hr at anchor, the ship moved back into the harbor. While repairs in the engine room were in progress, more drill water was loaded. The final mooring line was cast off at 2145 hr on 28 January.

TRANSIT FROM BARBADOS TO SITE 925

The *JOIDES Resolution* departed Bridgetown Harbor, Barbados, at 2145 hr on 28 January 1994. Outside the lee of the island, stiff trade winds from forward of the beam along with an opposing current were encountered. Transit speed was held below 10 kt for the first day. After a transit of 30 hr, the vessel reversed course and returned to Barbados to evacuate a crew member. The ship again departed Barbados for the Ceara Rise operating area at 0530 hr on 31 January. Speed was held to about 9 kt the first day out by opposing wind and currents. The wind held fairly constant at 25-30 kt for the entire transit, but variable currents caused the ship's speed to vary between 9 and 12 kt. On 4 February the ship reached the Ceara Rise operating area and proceeded directly to the geographic coordinates of proposed site CR-1. Speed was reduced for the final 8 nmi, and the towed magnetometer was recovered. At 1615 hr the ship passed over the site, and a positioning beacon was launched. Water depth per precision depth recorder (PDR) was 3040 m from sea level.

Hole 925A

For the first RCB hole a prototype drag-type core bit was chosen in an attempt to optimize core recovery and quality. The bit featured a polycrystalline diamond compact (PDC) cutting structure and Amoco-designed anti-whirl construction.

In an attempt to determine the water depth by "feeling for bottom" and noting contact by a deflection of the rig's weight indicator, the top drive was deployed, and the bit was lowered without circulation or rotation. The bit passed the PDR depth of 3051 m below driller's datum at 0330 hr on 5 February, but no positive weight indication was observed, even after the bit had been lowered to 26 m below the PDR depth. The mud pump was started and a momentary increase in pressure indicated that sediment had been plugging the bit nozzles. No definite indication of contact with the soft seafloor had been detected, and a seafloor depth of 3053 m (2 m below PDR depth) was assigned on the basis of experience in similar areas. Rotation and circulation then began, and the 9-7/8" hole was drilled to 102 mbsf, where the inner core barrel was exchanged for a clean one. Spot cores were taken at approximately 100, 200, and 300 mbsf. Sediment properties and core quality were suitable for the initiation of continuous RCB coring from 300 mbsf. The nannofossil chalk proved to be excellent material for coring and well-suited to penetration by the PDC bit. Coring continued with a high rate of penetration (ROP) with excellent core quality and a good recovery percentage. Core recovery statistics were held down only by a tendency for core to escape the core catchers occasionally, in lengths from 1 or 2 m to the full core length of 9.5 m. Below about 690 mbsf, the rate of penetration (ROP) fell sharply from about 30 m/hr to about 6 m/hr and then to less than 3 m/hr. Core 154-925A-49R was recovered after 8.5 m had been cut to check for jammed core or any signs of bit failure. An excellent 7.1-m core was recovered, which was not jammed and had an increased diameter over preceding cores. Circulating pressure and drill string torque were normal, so another inner barrel was pumped into place. After 145 min of coring time on Core 154-925A-50R, only 1 m had been cored despite all efforts to vary coring parameters and dislodge a possible clay ball from the bit. Coring operations were suspended in Hole 925A due to the unacceptable rate of progress.

The top drive was secured, and the bit was tripped to 150 mbsf while a free-fall reentry funnel (FFF) was prepared for launch. A delay of 2-3/4 hr ensued while the FFF was installed around the drill string in the moonpool, dropped, and allowed to fall into place at the seafloor. The pipe trip then continued, and the bit arrived on the drill floor at 0900 hr on 8 February. Suspicions of a balled bit were confirmed when about 30% of the bit's face area was found to be packed with clayey chalk to a depth that prevented the cutters from making contact with the formation. The buildup apparently was the result of the plugging of three circulation jets underlying the balled areas.

Hole 925B

An APC/XCB bottom-hole assembly (BHA) was made up, with a 10-1/8" PDC bit. At 1715 hr Hole 925B was spudded with a "mud-line" APC core. The seafloor interface was recovered, and seafloor depth was established at 3052.0 m from driller's datum. Continuous APC coring then commenced, with magnetic orientation begun on Core 154-925B-3H. Coring conditions were excellent in the nannofossil ooze. Full stroke was achieved easily, and pullout force was negligible to about 280 mbsf. Though pressure indications were questionable on the final three cores, full core barrels were recovered. Coring was terminated when an overpull of 140,000 lb was required to withdraw Core 154-925B-34H. The drill string then was pulled clear of the seafloor, ending Hole 925B.

Hole 925C

The ship was offset 20 m to the north, and the APC system again was deployed. The initial core measured depth to seafloor at 3051.5 m. Core orientation began on the first core, and the break between core intervals was offset 3 m downward to facilitate recovery of a complete section. Coring performance and results were virtually identical to those of Hole 925B. APC coring was suspended after Core 154-925C-34H (at 321.5 mbsf). The coring mode was switched to XCB, and 4 additional cores were taken to drilling target at 360 mbsf. Coring results also were good with the XCB, and over 94% average recovery was achieved. A "wiper trip" was made to 73 mbsf and back to total depth. No drag or hole fill was encountered. The hole was swept with 30 bbl of mud, and a go-devil was pumped down to open the lockable float valve (LFV), before the bit was pulled to logging depth at 88 mbsf.

Hole 925C Logging Operations

Logging operations began at 0900 hr on 11 February. The initial tool combination was the Quad combination tool, combining the seismic stratigraphy and lithoporosity suites. Multiple passes were made in the upper hole interval first to ensure both normal and high-resolution coverage of that important section. When the tool was lowered to total depth, it encountered 9 m of hole fill. Upon completion of the log run from 351 to 358 mbsf, the tool string was recovered and replaced with the magnetic susceptibility tool. A susceptibility log was recorded from about 30 m off total depth to 88 mbsf. The final log was the formation microscanner (FMS), which found fill at about the same depth and logged the interval from about 330 mbsf to the beginning of enlarged hole at about 108 mbsf. When all logging tools had been rigged down, the bit was pulled above the seafloor, ending Hole 925C at 0530 hr on 12 February.

Hole 925D

The vessel was offset 20 m to the west. The APC then was deployed, and preparations were made to spud the final hole of the triplicate APC effort. The first core was "shot" from 3054 m for purposes of overlapping core intervals. Cores were oriented from Core 154-925D-1H, and the experimental "slim-nose" catcher shoe was used for all cores. Plans included "pushing" the APC system beyond the depth reached by it in Holes 925B and 925C in an attempt to compare RCB, XCB, and APC cores over the same stratigraphic interval. The slim-nose catcher sub had been used on Cores 154-925C-32H and -34H. It was noted that overpull was considerably less on both of those cores than on the intervening Core 154-925C-33H. As coring in Hole 925D approached the depth of refusal for the earlier holes, it appeared that the new shoe did, indeed, reduce the force required to withdraw the corer. Overpull did not exceed 40,000 lb until Core 154-925D-37H, which reached the depth objective for the hole (354 mbsf). No further cores were attempted, and the bit was pulled clear of the seafloor.

Hole 925E

The ship was moved 40 m east of Hole 925D and 20 m east of Hole 925B. Hole 925E was spudded with an oriented seafloor core at 1800 hr on 13 February. The recovered core length indicated the seafloor depth to be 3052.5 m from driller's datum. The primary objective of Hole 925E was to recover the uppermost 50 m of the section for geochemical whole-round sampling. Six oriented cores were taken to 54.5 mbsf in less than 5 hr to complete the shallow coring program at Site 925.

Hole 925A (return)

The ship was relocated to Hole 925A. A mechanical bit release (MBR) and a long-toothed roller-cone bit were installed on the BHA used earlier in Hole 925A. After 50 min of automatic station keeping (ASK) positioning, a successful reentry was made at 1220 hr on 14 February.

Minor drag was noted in the upper portion of the hole as the drill string was lowered. A fairly solid obstruction was met at about 190 mbsf. At that point the trip was stopped for recovery of the camera, and the circulating head was installed on the drill pipe. Upon resumption of the trip, the bit was circulated past the bridge without difficulty. About 35 m of fill was found in the hole, and the top drive was picked up for completion of the trip. With circulation and rotation, the hole was cleaned easily to total depth. Continuous RCB coring resumed at 1545 hr. From the outset, core quality was excellent and approached that produced by the PDC bit. Recovery was even better, apparently because less core was being dropped through the core catchers. The ROP was disappointing, however, averaging around 8 m/hr. Below 855 mbsf, the penetration rate fell to about 5.5 m/hr and eventually to less than 4 m/hr. Coring was terminated at 930.4 mbsf, and preparations were made for logging. A wiper trip was made to about 200 mbsf, and 10 m of fill material was flushed from the hole with drilling mud.

Second Logging Operation in Hole 925A

When the bit and associated components had been released at total depth, the end of the pipe was pulled to logging depth at 212 mbsf. The Quad combination logging tool string was assembled and run into the hole. An obstruction at 438 mbsf stopped the tool, however, and the bridge could not be cleared. The upper portion of the hole was logged up to the end of the pipe, and logging tools were recovered. The drill string was lowered past the obstruction in the hope that the hole would be open to total depth below it. Pump circulation was used on the final stand, and no weight resistance was noted.

The second attempt with the Quad combination entered open hole but met another bridge at 497 mbsf. Again the hole was logged up to pipe, and the tool string was recovered. It was decided that the side entry sub (SES) could be used effectively to assist logging tools past the unstable hole intervals. With the end of the drill string pulled back to 265 mbsf, the SES was made up into the string, and again the Quad combo tool string was deployed. The drill string was lowered to 794 mbsf before the logging tool was run into open hole. The tool reached hole fill only 23 m off total depth, and a good log was recorded from that depth. The caliper log revealed three short intervals between 450 and 507 mbsf in which the hole diameter was several centimeters less than bit size. The Quad combo was exchanged for the FMS tool, and FMS data were recorded from 887 to 230 mbsf. Time allotted for logging had expired, so the logging tools were rigged down and the drill string was recovered.

One of the two positioning beacons was recovered routinely during the trip, but the other failed to surface after an indicated release. At 0545 hr on 19 February, *JOIDES Resolution* departed Site 925.

SITE 926

The transit from Site 925 to Site 926 covered about 50 nmi at an average speed of 10 kt. *JOIDES Resolution* was navigated directly to the site coordinates of proposed site CR-3 with neither a departure nor an arrival survey. After the transit of 5 hr, the final approach was made from a way point about 1.5 nmi to the southwest so that steerage way could be maintained directly into the prevailing wind and current. An acoustic beacon was launched at 1045 hr (local time) on 19 February.

Hole 926A

The PDC core bit used for APC/XCB coring at Site 925 again was chosen for Site 926. The BHA was shortened by two drill collars so that logs could be recorded to shallower depth in the critical late Neogene section. Hole 926A was spudded at 2315 hr on 19 February with a "mud-line" APC core. Water depth was found to be 3597 m. Coring proceeded with continuous cores and orientation from Core 154-926A-3H.

Incomplete stroke indication began with Core 154-926A-27H at about 250 mbsf and continued through Core 154-926A-35H with the exception of -31H and -32H, which indicated full stroke. Incomplete recovery and a catastrophic liner failure on Core 154-926A-35H prompted the declaration of APC refusal. The drill string then was pulled clear of the seafloor for a repeat of the APC section.

Hole 926B

The ship was moved 30 m west by ASK offsets, the top drive and APC system were deployed, and Hole 926B was spudded at 1200 hr on 21 February. To provide overlapping core intervals, the seafloor core was actuated from 3 m deeper than Core 154-926A-1H. Core orientation began with the initial core and continued for all APC cores.

Incomplete stroke began with Core 154-926B-26H. One additional APC core was taken, also with incomplete stroke, to 254 mbsf. Coring then continued in the XCB mode to 605.7 mbsf, where the target depth was reached. Core recovery was 94% in the XCB interval, and core quality was good, with the exception of considerable "biscuiting" in the clay-rich zones.

Logging at Hole 926B

Preparations for logging included a wiper trip to 70 mbsf, flushing the hole with drilling mud, and deployment of a go-devil to open the lockable float valve (LFV) before the bit was positioned at logging depth.

With the bit positioned at 81 mbsf for logging, the Quad combination tool string was made up, with the exception of the neutron porosity module, and run into the hole. A good log was recorded up from apparent hole fill at 22 m above total depth. The tool encountered resistance at the bit and could not be pulled back inside the drill string until pump circulation was initiated. Apparently, either the LFV had not been locked open by the go-devil, or passage of the logging tool had somehow unlocked it. When the logging tool had been recovered and rigged down, three stands of drill pipe were added to put the bit below the largest diameter washed-out hole, and a second go-devil was deployed. The GHMT magnetic log was run after the pipe had been raised back to logging depth. The tool found a solid obstruction at 440 mbsf, and the log was recorded up from that depth. The geochemical combination was the third tool string run. Again the tool set down at

440 mbsf. After a good log had been recorded up to the drill pipe, that tool also was stopped at the bit. Pump circulation did not solve the problem, but after about an hour of repeated attempts, the tool was pulled inside the pipe and recovered.

Logging time was running out, and the risk of losing or damaging the FMS tool was considered unacceptable, so logging operations were halted. The tools were rigged down, and the bit was pulled above the seafloor to end operations at Hole 926B.

Hole 926C

After a 30-m offset to the south, the APC was deployed, and Core 154-926C-1H was "shot" from 3610 m below driller's datum. Water depth was assumed to be 3597 m as at the other two holes. All APC cores were oriented. Because of fracturing disturbance noted in earlier holes, the switch to XCB coring was made after Core 154-926C-26H, well before either overpull or penetration refusal. XCB coring then continued, with over 93% average recovery, to 398 mbsf. Allotted time had expired, and scientific objectives had been fulfilled. The drill string was tripped after Core 154-926C-42X had been recovered.

At 1600 hr on 27 February, the drilling assembly was on deck, the beacons had been recovered, and preparations were in progress for departure.

SITE 927

The northwestward transit of 144 nmi from Site 926 to Site 927 (proposed site CR-2) was completed in 13 hr at an average speed of 10.9 kt. *JOIDES Resolution* was navigated directly to the site coordinates of the proposed site with neither a departure nor an arrival survey. An acoustic beacon was launched at 0545 hr (local time) on 28 February 1994.

Hole 927A

Hole 927A was spudded at 1200 hr with an APC core "shot" from 5 m above the PDR depth of 3330 m. The core barrel was filled to the top with sediment, but the uppermost material was judged to have come from at or near the seafloor. Seafloor depth was set at 3325 m, and APC coring continued, with orientation beginning on Core 154-927A-3H.

Core-liner failures and fracturing of chalk core increased with depth. After Cores 154-927A-30H and -31H failed to stroke completely, refusal was declared at 312.5 mbsf. The top drive was set back, and the drill string was pulled clear of the seafloor at 1545 hr on 1 March.

Hole 927B

The ship was offset 20 m to the north, and an oriented "mud-line" APC core fixed the seafloor depth at 3326.5 m from driller's datum. Continuous coring proceeded through Core 154-927B-28H, where the scientific objective was declared satisfied. Total depth was 261.5 mbsf and was well short of physical APC refusal. The bit was pulled clear of the seafloor, ending Hole 927B. Three times during the coring of Hole 927B, radical current shifts caused ASK excursions of about 3% of water depth.

Hole 927C

Hole 927C was spudded, after an additional 20-m north offset, with an oriented seafloor core. Seafloor depth was set at 3328 m from driller's datum on the basis of core recovery. After Core 154-927C-3H had been recovered, the bit was raised in anticipation of another ASK excursion from a strong rip current that was being plotted on the radar screen. Operations were halted for 1/2 hr while the rip current passed the vessel, but the maximum excursion was less than 2% of water depth. Continuous coring then resumed.

The coring mode was switched to XCB after Core 154-927C-24H because of APC-induced fracturing in chalk cores. Coring objectives were satisfied after four XCB cores to 267 mbsf. Hole 927C was drilled ahead to a total depth of 358 mbsf to assure logging of the total section with the long Quad combination tool, the only logging tool that was scheduled. Hole conditions had been good and time was limited, so the customary wiper trip and mud sweep were forgone. After 15 min of extra water circulation at total depth, the bit was pulled to logging depth at 73 mbsf, and the logging tools were rigged. Hole conditions were found to be excellent, and a good log was recorded from just 4 m off total depth.

When the logging tools had been secured, the pipe was tripped, and both positioning beacons were recovered. *JOIDES Resolution* departed Site 927 at 1130 hr on 4 March.

SITE 928

The *JOIDES Resolution* moved 45 nmi westward from Site 927 to 928 (proposed Site CR-4). Opposing trade winds held the average transit speed to 9.0 kt. Again the route was direct except that the final approach was made from a way point about 1.5 nmi downwind. A positioning beacon was launched at 1630 hr (local time) on 4 March.

Hole 928A

Assembly of the BHA began immediately and concurrently with the lowering of hydrophones and thrusters. A seafloor APC core determined the depth to be 4022 m from driller's datum, 5 m shallower than the PDR depth. Core orientation began with Core 154-928A-3H, and continuous APC cores were taken to 208 mbsf. Incomplete stroke was indicated in a stiff nannofossil clay lithology on 6 of the final 7 cores. Complete or near-complete recovery was achieved (but a considerable amount of flow-in was found later when the cores were opened). A catastrophic liner failure and incomplete stroke on Core 154-928A-22H signaled APC refusal. Maximum overpull was 40,000 lb on the final three cores. Coring then continued in XCB mode to 246.7 mbsf, where scientific objectives were satisfied. The bit was pulled clear of the seafloor at 0015 hr on 6 March to end Hole 928A.

Hole 928B

A 20-m south offset was entered into the ASK system, and Hole 928B was spudded with an oriented APC core. Core recovery showed the seafloor depth to be 4023.5 m. Continuous oriented APC cores were taken to 137 mbsf, where a switch to XCB coring was requested on the basis of APC performance in Hole 928A.

The first two XCB cores were disappointing in that only 90 cm of core was recovered in total. It was considered possible that core was being washed away, but the third core achieved full recovery with only a slight reduction in pump rate. It is more likely that an obstruction in the lockable float valve (LFV) or bit was cleared by the third XCB attempt. Good to excellent core recovery and quality then prevailed as continuous XCB cores were taken to 532 mbsf. At about 500 mbsf, the average rate of penetration (ROP) dropped sharply from over 30 m/hr to about 11 m/hr. The reduced rate of progress prompted the decision to terminate coring operations.

Logging operations at Hole 928B

A drilling-mud sweep was circulated before the bit was pulled to logging depth at 80 mbsf, and logging tools were rigged. The wiper trip was deleted because of good hole conditions and limited operating time. A single logging run was made with the Quad combination tool string, with the compensated neutron porosity tool (CNT-G) module omitted. The logging tool was successful in passing some diameter restrictions in the hole between 390 and 490 mbsf, and a good log was recorded from just a few meters off the bottom of the hole. Upon completion of the logging operations, the bit was raised above the seafloor for a final hole at Site 928.

Hole 928C

After a 20-m west positioning offset, Hole 928C was spudded at 0145 hr on 9 March with the bit at 4024 m (just below the seafloor) to provide stratigraphic overlap. Continuous oriented APC cores were taken from the seafloor to 152.5 mbsf, where Core 154-928C-16H failed to give complete-stroke indication. Four XCB cores completed the hole to 181.5 mbsf, where the scientific depth objective was reached. The drill string and positioning beacons then were recovered for the move to Site 929.

SITE 929

The final drill site of Leg 154 lay on the lower northeast flank of the Ceara Rise only 32 nmi north of Site 928. *JOIDES Resolution* navigated to the geographic coordinates of proposed site CR-5, and a positioning beacon was launched at 0500 hr (local time) on 10 March.

Hole 929A

Hole 929A began with a "mud-line" APC core that determined seafloor depth to be 4369 m from driller's datum. APC coring then continued, with core orientation beginning on Core 154-929A-3H. Sediments were more clay-rich than at the sites higher on the Ceara Rise, and were consequently less amenable to APC coring. Good results were obtained through Core 154-929A-13H, but a catastrophic liner failure on Core 154-929A-14H caused severe damage to the core, and incomplete APC stroke on Core 154-929A-15H resulted in several meters of flow-in material.

The XCB system produced good core quality and a high rate of penetration (ROP), so coring continued through the drillable nannofossil clay and chalk section. Below 500 mbsf, ROP fell sharply, and core began to jam the XCB barrel. When Cores 154-929A-55X and -56X recovered a total of only 1.5 m, it was considered to be XCB refusal. Coring was terminated at 527.5 mbsf, and the bit was pulled above the seafloor.

Hole 929B

After a 20-m offset to the east, the APC coring system was deployed, and the first core found the seafloor at 4367 m. Continuous oriented APC cores were taken to 123.5 mbsf. The coring mode then was switched to XCB to avoid a serious liner failure such as occurred on Core 154-929A-14H and apparently was lithology-induced.

Eleven XCB cores completed penetration to the scientific objective at 229 mbsf. Unfortunately, most of Cores 154-929B-15X and -16X were lost when sticky clay held the core-catcher mechanisms open. Again, the BHA was withdrawn from the hole for a respud.

Hole 929C

The vessel was offset 20 m south of Hole 929B for the third member of the triple-APC set. The initial core was started at 4370 m, 3 m below the seafloor depth of Hole 929B to maintain stratigraphic overlap. Oriented APC cores were taken to 126.5 mbsf, where coring again shifted to XCB mode to avoid problems with the stiff, marly clay. The initial XCB core, 154-929C-14X, again was lost through the core catchers, but nearly full recovery was achieved on Cores 154-929C-15X and -16X to complete the coring objective.

Hole 929D

The final APC penetration of the voyage was a scheduled 50-m hole to be dedicated to geochemical studies in the same manner as Hole 925E. After the seafloor had been cleared, the ship was offset 20 m west so that undisturbed sediment would be cored. An oriented mud-line core shot from 4365 m recovered nearly 7 m of core, so seafloor depth was set at 4367.5 m. An additional five oriented APC cores reached total depth at 54.5 mbsf.

A round trip of the drill string then was required for the installation of an RCB BHA for Hole 929E. While the BHA was being converted, it was given its once-per-leg electromagnetic inspection to check for crack and faults in the connections. The bit arrived on deck at 0330 hr on 15 March.

Hole 929E

With a roller-cone bit and standard RCB BHA installed, the drill string was tripped to the seafloor. Hole 929E was spudded with no change in ASK offsets from Hole 929D and drilled to 471.5 mbsf with no cores taken. The clay-rich interval from about 130 to 230 mbsf caused some problems with low ROP, high torque, and high circulating pressure. Those were attributed to a "clay ball" on the BHA and eventually disappeared as drilling continued in the chalk interval.

High torque persisted through Core 154-929A-9R, and Cores -7R and -9R had anomalously low ROP. A short trip was considered necessary to "clean up" the hole. The short trip was effective, as all parameters were normal and ROP, core recovery, and core quality all were favorable in clayey nannofossil limestone. The penetration rate began to increase below 700 mbsf on the final day of coring as the clay content of the nannofossil chalk decreased. The sediment became so soft near the total depth of 809 mbsf that core recovery became sporadic and the average recovery fell sharply. Time allotted for coring expired at 0400 on 19 March, and preparations began for the logging program.

The first logging tool to be run was the Quad combination string with the neutron porosity tool removed. The drill string was lowered into the hole while the logging tool was run down the pipe. Solid resistance was met at 712 mbsf, and the pipe could be advanced no farther with the application of weight and circulation only. A log was recorded up from 692 mbsf as the drill string preceded the tool up the hole. In addition to many washed-out intervals, the caliper log revealed hole restrictions at all depths where drilling and tripping problems had been experienced. The restrictions, attributed to swelling clay, were especially numerous above 220 mbsf. When the Quad combination tool had been rigged down, time remained for only a short logging run with the geochemical combination tool. The SES again was used to place the logging tool below the upper restricted intervals, and the section from 580 to 108 mbsf was logged before it was necessary to recover the tool and rig down.

With the SES removed from the string, the pipe was pulled clear of the seafloor. At that point, the trip was interrupted to replace the upper guide horn assembly and to perform the required slip-and-cut operation on the drilling line. The drill string and positioning beacons then were recovered, and the BHA was disassembled for transit. *JOIDES Resolution* departed Site 929 for Barbados at 0900 on 21 March.

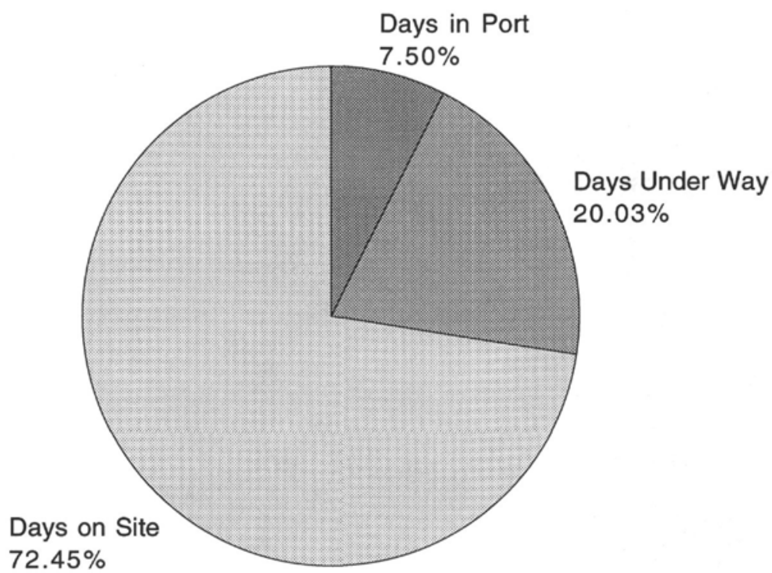
OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 154

Total Days (24 January 1994-25 March 1994)	59.9
Total Days in Port	4.5
Total Days under Way	12.0
Total Days on Site	43.4

Trip Time	5.97
Coring Time	27.95
Drilling Time	0.76
Logging/Downhole Science Time	6.95
Reentry & Related Time	0.21
Stuck Pipe and Hole Trouble Time	0.51
Mechanical Downtime (Contractor)	0.07
Mechanical Downtime (ODP)	0.42
Other	0.60

Total Distance Traveled (nautical miles)	2988
Average Speed (knots)	10.6
Number of Sites	5
Number of Holes	19
Number of Reentries	1
Total Interval Cored (m)	6161.0
Total Core Recovery (m)	5808.3
Percent Core Recovery	94.3
Total Interval Drilled (m)	854.2
Total Penetration (m)	7015.2
Maximum Water Depth (m from drilling datum)	4369.0
Minimum Water Depth (m from drilling datum)	3051.5

Leg 154 Time Distribution



TECHNICAL REPORT

The following ODP Technical and Logistics personnel were aboard *JOIDES Resolution* for Leg 154 of the Ocean Drilling Program:

Laboratory Officer:	Bill Mills
Assistant Laboratory Officer/Underway Geophysics:	Dennis Graham
Assistant Laboratory Officer:	Don Sims
Marine Computer Specialists/System Managers:	Cesar Flores Matt Mefferd
Marine Laboratory Specialist/Yeoperson:	Michiko Hitchcox
Marine Electronics and Downhole Tool Specialists:	"Buddy" Davidson Eric Meisner
Marine Laboratory Specialist/Photography:	Roy Davis
Marine Laboratory Specialist/Curatorial:	Jerry Bode Lorraine Southey
Marine Laboratory Specialist/Chemistry:	Chieh Peng Philip Rumford
Marine Laboratory Specialist/X-ray:	Mary Ann Cusimano
Marine Laboratory Specialist/Thin Section:	"Gus" Gustafson
Marine Laboratory Specialist/Physical Properties:	Taku Kimura
Marine Laboratory Specialist/Paleomagnetics:	Peter Solheid
Marine Laboratory Specialist/Storekeeper:	John Dyke

SCIENTIFIC OBJECTIVES OF LEG 154

The object of Leg 154 was to study the history of deep-water circulation and chemistry in the western equatorial Atlantic. This information is of great importance in understanding the Earth's past climate. The Ceara Rise was chosen because it is located in the main flow path of two principal water masses as well as for its topographic expression that will allow for a depth transect of sites distributed down the northwestern flank from 2901 to 4373 m. Leg 154 cored 5 sites (19 holes) to complete the bathymetric transect. A total of 5808.3 m of core was recovered, setting a new record that surpassed the previous record (5537 m) held by Leg 138.

GENERAL LEG INFORMATION

The *Joides Resolution* departed Bridgetown, Barbados, on 29 January 1994, with a crew of 108 (47 scientists and technicians). Leg 154 ended in Bridgetown, Barbados, on 25 March 1994 for a total of 55 days at sea.

PORT CALL, BARBADOS

On 24 January 1994, the *Joides Resolution* docked in Bridgetown, Barbados, ending Leg 153. On the same morning the Leg 154 crew arrived and began crossovers.

The cruise ships have priority for berths over other types of shipping activities, which left only the 24th and 25th to complete our shipment and bunkering activities before having to vacate our berth. We completed all of our work in time, but due to critical repairs in the engine room we were unable to sail that evening. We attempted to berth at the fuel dock outside the harbor to complete repairs but the surge was too strong, and we were forced to anchor offshore and wait for a berth inside the harbor.

On the evening of the 27th we were able to dock within the harbor and begin repairs. The *JOIDES Resolution* departed Bridgetown, Barbados on 29 January 1994, with a crew of 108 (47 scientists and technicians). Early in the morning of the 30th we reversed course to return a crew member. Finally, on the 31st, we headed for our first site on the Ceara Rise.

UNDERWAY ACTIVITIES

Technicians routinely collected bathymetric, magnetic, and navigational data on all transits. No seismic surveys were conducted during this leg. All sites were located by GPS coordinates only, using the site-survey geophysical data.

LABORATORY ACTIVITIES

The pace of core recovery was not overwhelming but was consistently high, offering little or no breaks. Two additional technicians were staffed, but only one was able to make it to the ship. The loss of this technician and an injury to another placed a greater burden on the remaining staff. Fortunately, several of our labs saw little or no use during the leg (thin section, fantail, down hole tools, and X-ray labs), slightly easing the burden placed on the technicians.

The core/sedimentology, paleontology, physical properties, chemistry, and photo laboratories carried the majority of the work load. The paleomagnetics lab was expected to be another major contributor to this leg's science. Unfortunately, the sediments were magnetically soft and completely magnetized by the drill string, making them useless for any type of magnetic analysis other than susceptibility. Regardless of this, the majority of the piston cores were oriented with the tensor tool in the hope that shore-based magnetic analysis would be able to glean some results.

The main emphasis in laboratory activity was to take high-resolution measurements so that the holes cored at each site could be integrated into a single composite section. The composite section would then be correlated to the logging results. This would allow the results of all the various scientific studies to be correlated on the basis of a common depth scale called meters composite depth (mcd). The majority of the high-resolution sampling was deferred to shore, where the mcd scale will be used to define the sampling intervals.

The composite section was determined using the susceptibility record from the multisensor track (MST) and color reflectance.

This leg saw the first heavy use of the Minolta Color Spectrophotometer. The Alan Mix's color scanner was scheduled to be used during this leg but was not available. Originally, the Minolta Spectrophotometer was purchased to assist the sedimentologists with determining the Munsell color value. Using LabView software, a computerized data-acquisition system was developed. Over 150,000 data points and Munsell and L*a*b* color values were collected using this system.

Other than routine hydrocarbon monitoring, the chemistry lab activities were devoted to inorganic analysis of the sediments and interstitial waters. A large number of carbonate samples were analyzed, and the data used to calibrate the reflectance and susceptibility records. A special high-density water-analysis study was conducted at two sites, as well as routine water sampling.

Four successful heat-flow measurements were made with the Adara system.

LEG 154 Lab Statistics

SAMPLES

Total number:	20,497

PHYSICAL PROPERTIES LAB

MST(includes Susceptibility, GRAPE, P-wave, and Nat. Gamma):	5800 m scanned
Index Properties:	2,985
Velocity:	3,000
Resistivity:	4,000
Strength:	700
Thermal Conductivity:	36

DOWNHOLE TOOLS LAB

In situ temperature:	4

THIN SECTION LAB

Thin sections:	8

CHEMISTRY

Carbon-Carbonate:	899
Interstitial water analysis:	171
Headspace (GC):	260

X-RAY LAB

XRD:	78

PALEOMAGNETICS LAB

discrete:	348

UNDERWAY GEOPHYSICS

Magnetics and Bathymetrics:	27 nmi

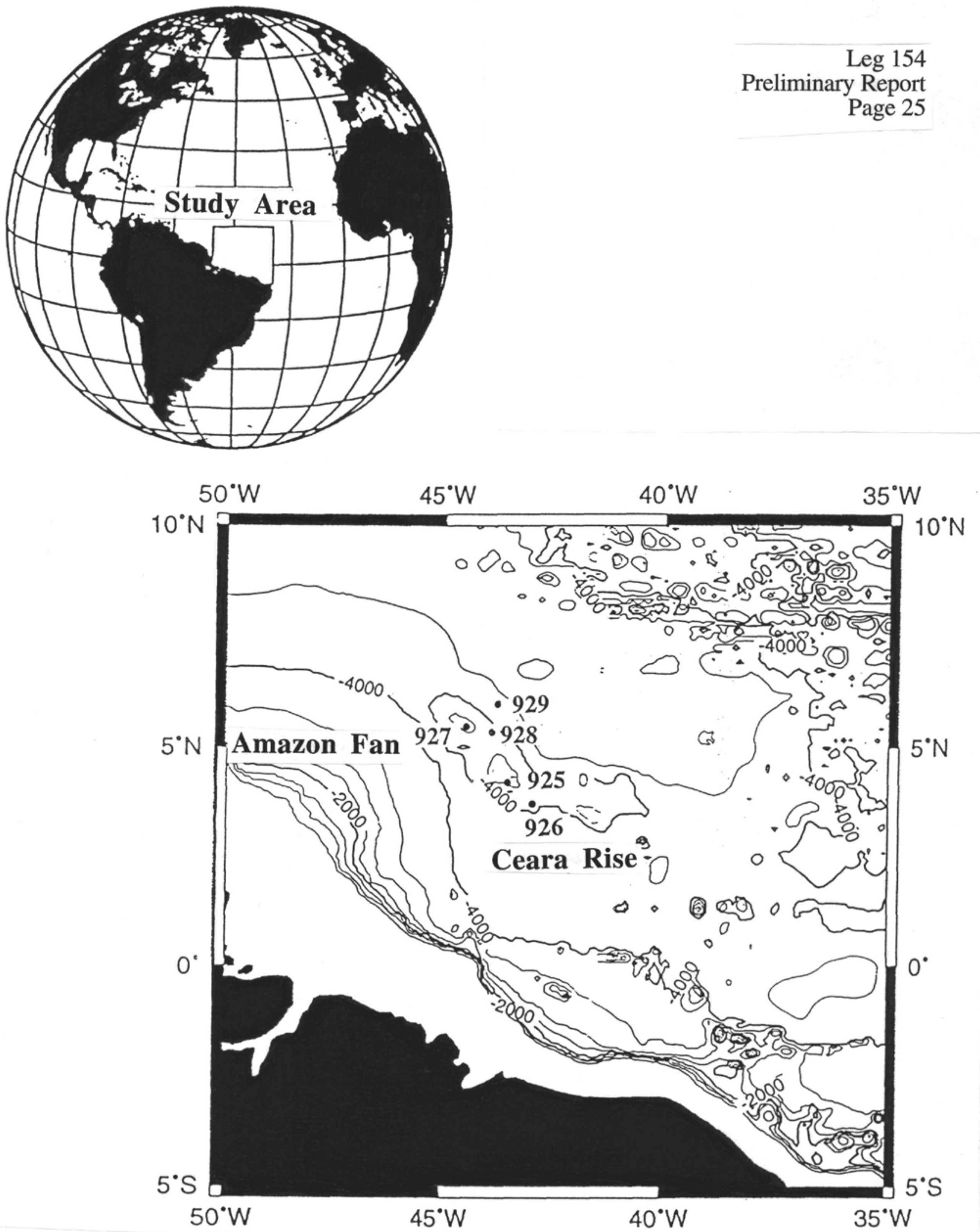

Study Area
50°W
45°W
40°W
35°W
10°N
5°N
0°
5°S
-4000
-2000
929
928
927
925
926
Amazon Fan
Ceara Rise

Figure 1

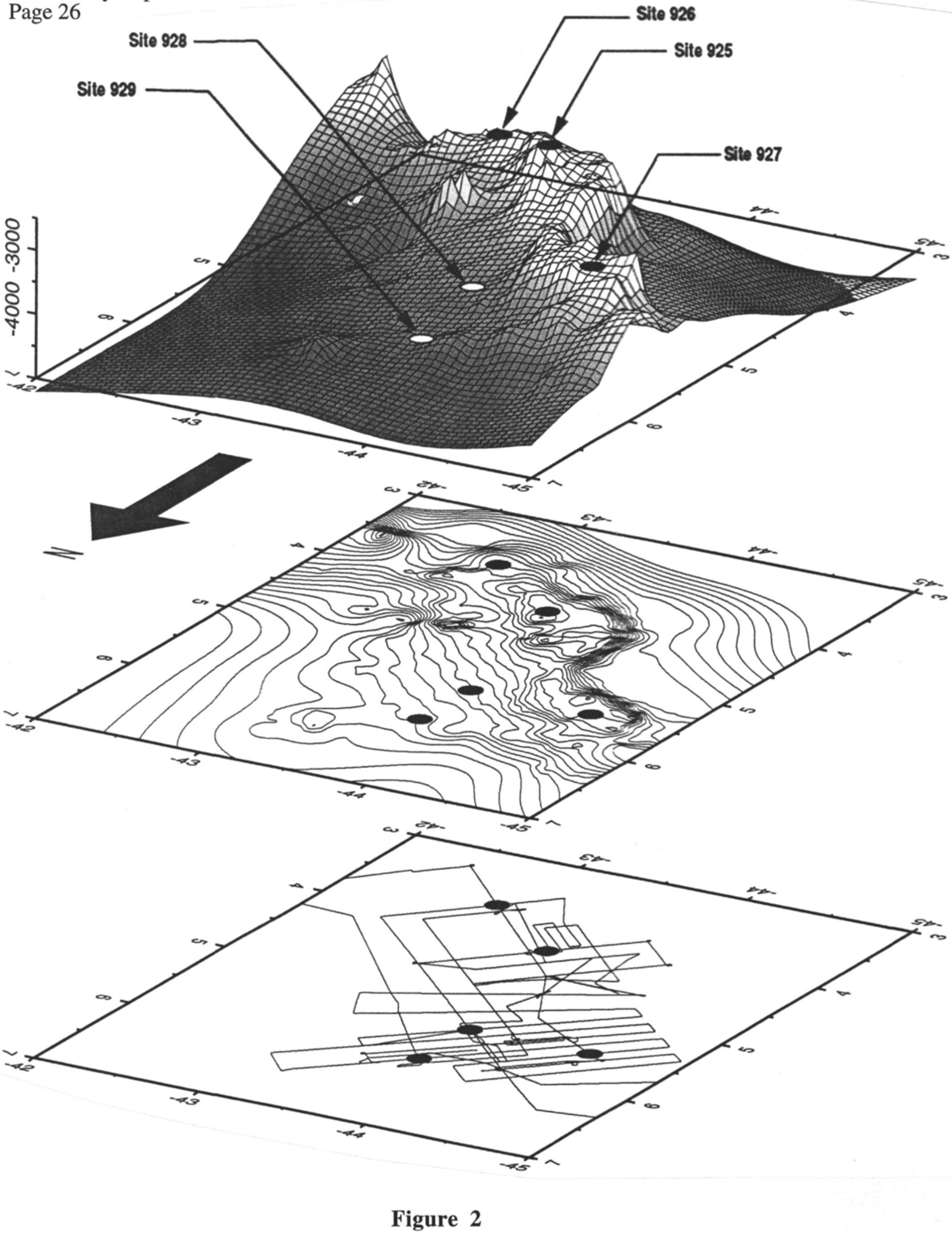


Figure 2

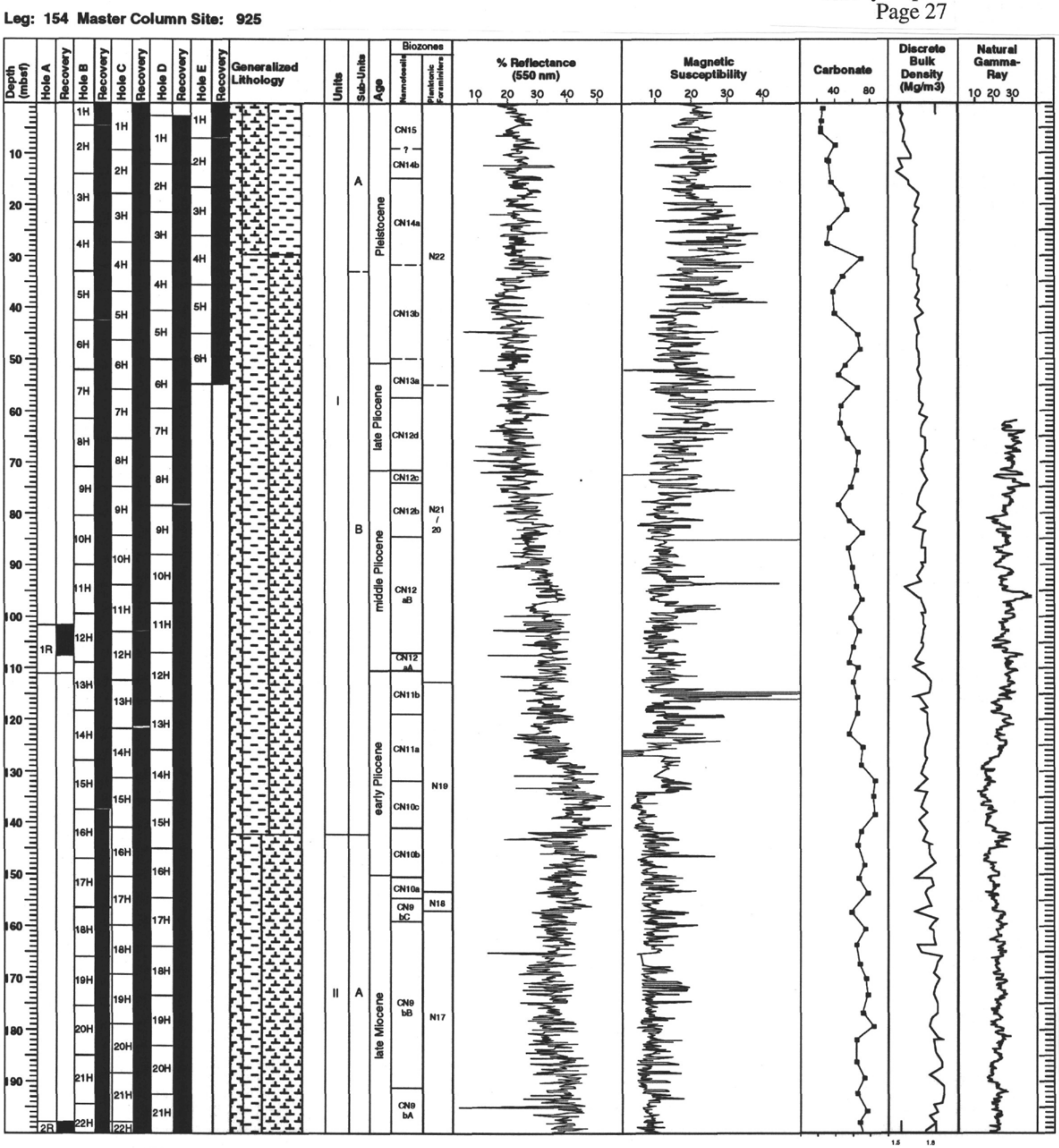

Leg: 154 Master Column Site: 925
Depth (mbsf)
Hole A
Recovery
Hole B
Hole C
Hole D
Hole E
Generalized Lithology
Units
Sub-Units
Age
Biozones
Nannofossils
Planktonic Foraminifers
% Reflectance (550 nm)
Magnetic Susceptibility
Carbonate
Discrete Bulk Density (Mg/m3)
Natural Gamma-Ray
Pleistocene
late Pliocene
middle Pliocene
early Pliocene
late Miocene
CN15
CN14b
CN14a
CN13b
CN13a
CN12d
CN12c
CN12b
CN12 aB
CN12 aA
CN11b
CN11a
CN10c
CN10b
CN10a
CN9 bC
CN9 bB
CN9 bA
N22
N21 / 20
N19
N18
N17

Figure 3

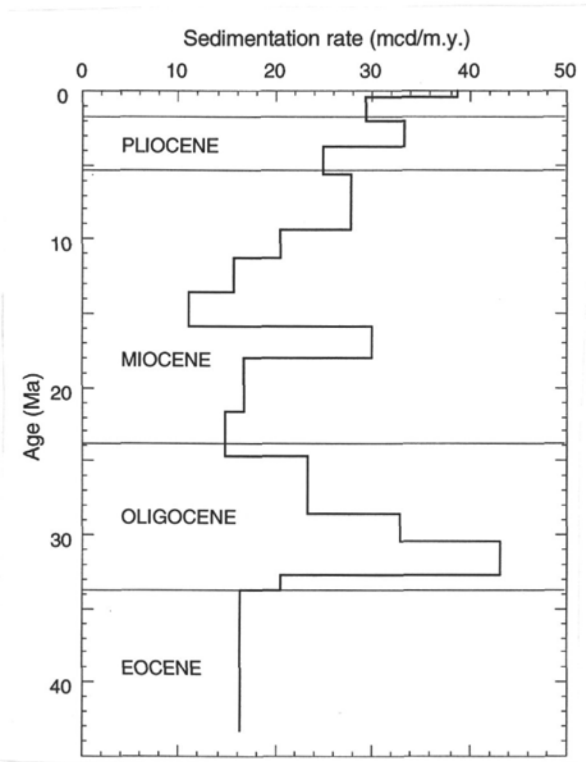

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
10
20
30
40
Age (Ma)
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE

Figure 4

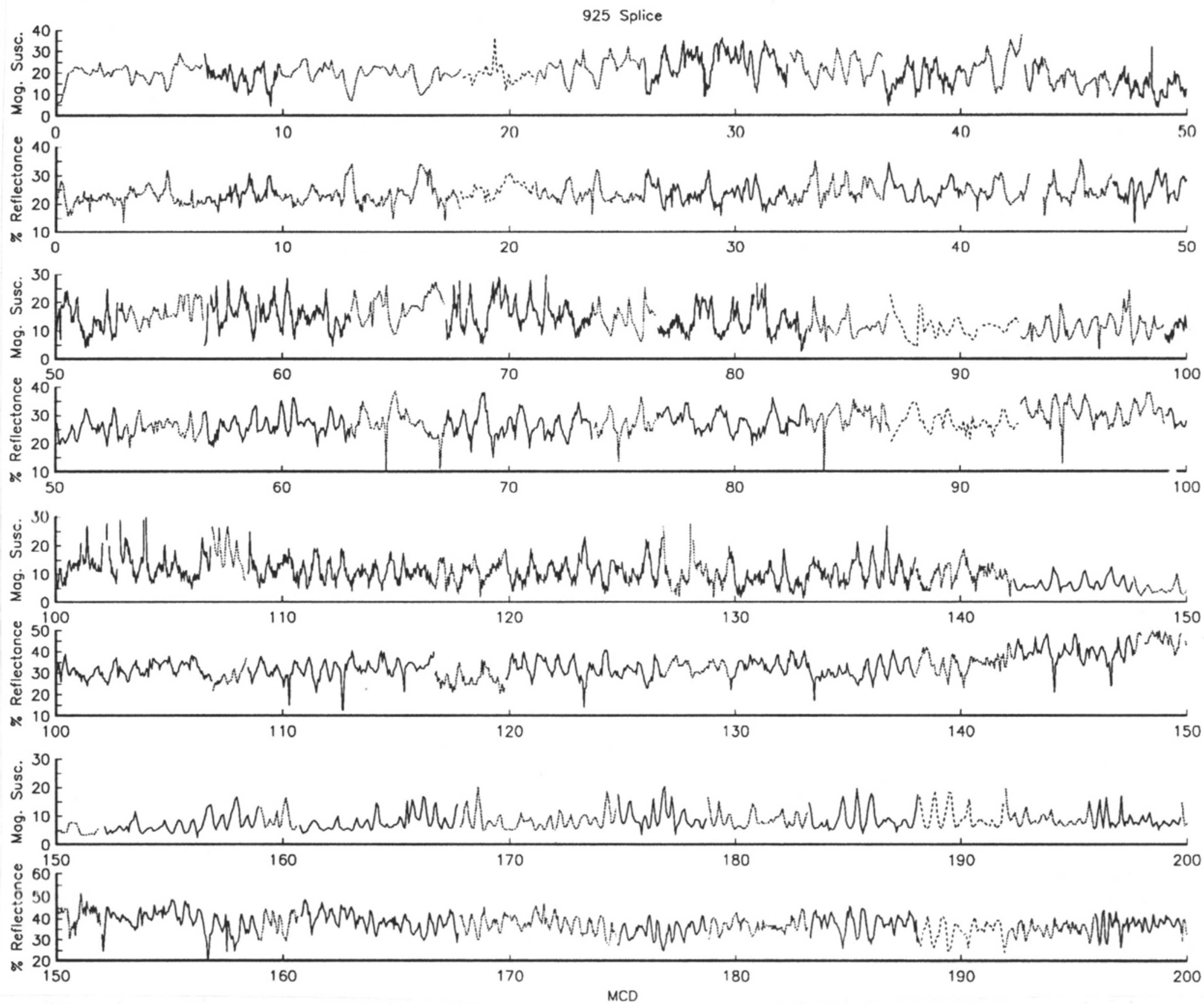


Figure 5

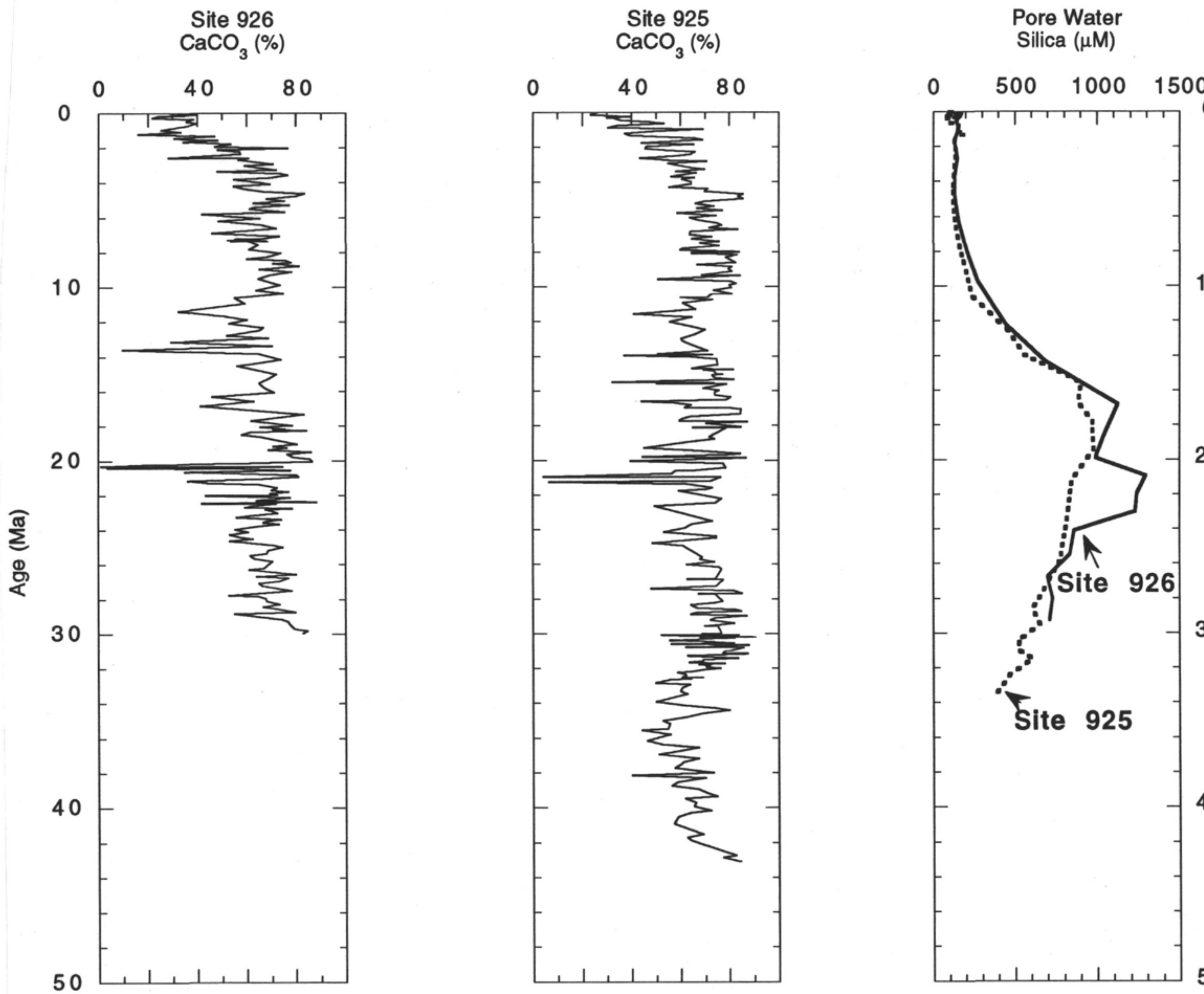

Site 926
$CaCO_3$ (%)
0 40 80
Site 925
$CaCO_3$ (%)
0 40 80
Pore Water
Silica (µM)
0 500 1000 1500
Age (Ma)
0 10 20 30 40 50
Site 926
Site 925

Figure 6

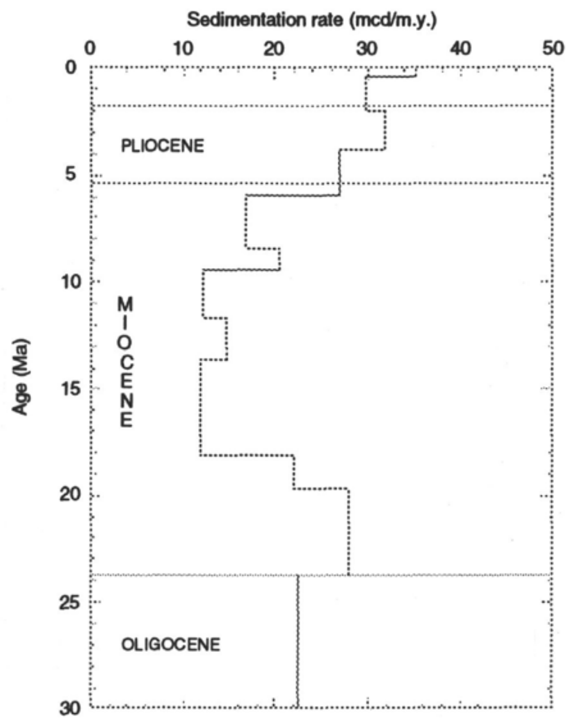

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
5
10
15
20
25
30
Age (Ma)
PLIOCENE
MIOCENE
OLIGOCENE

Figure 7

Leg 154 Site 927 Master Column

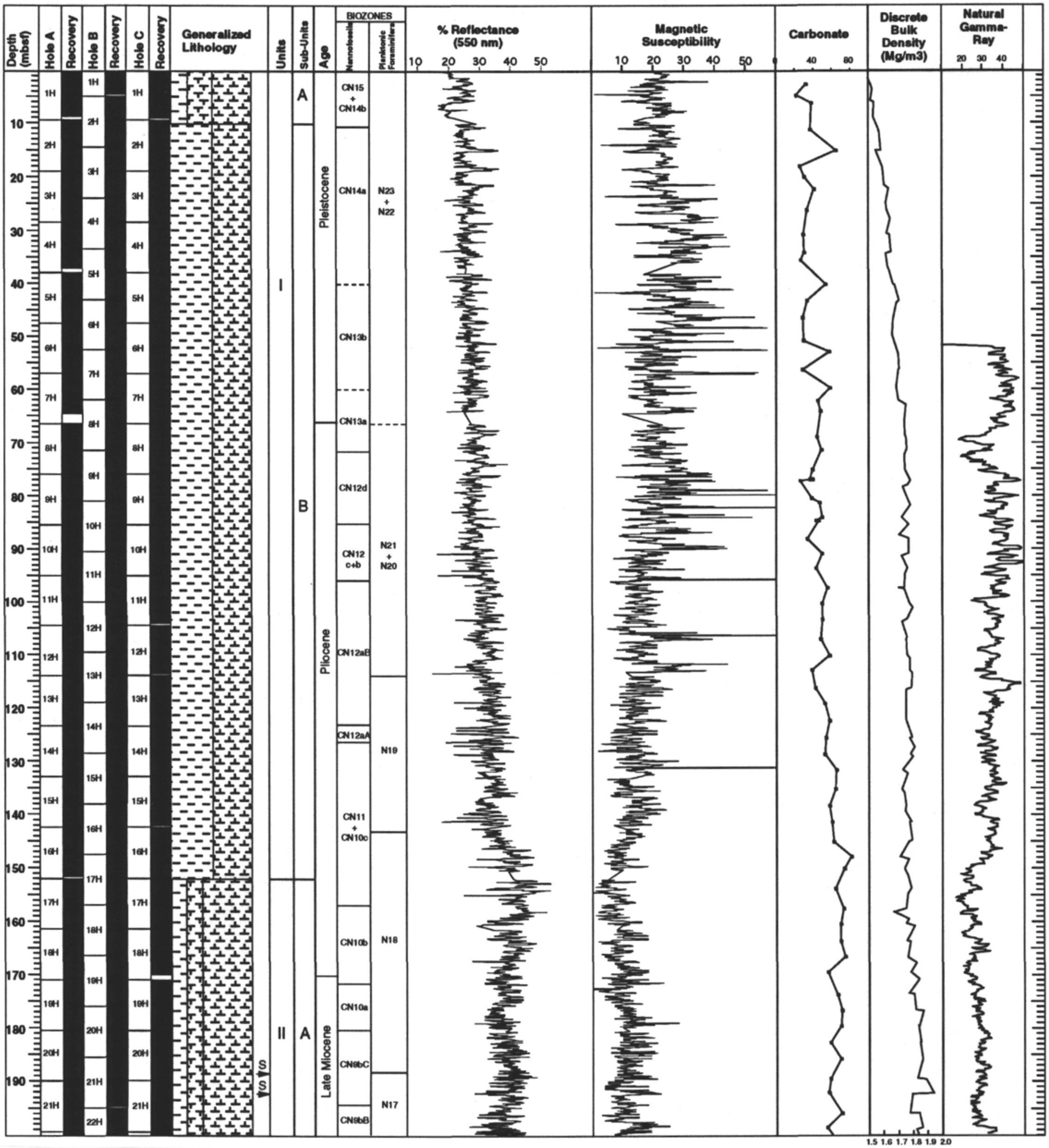


Figure 8

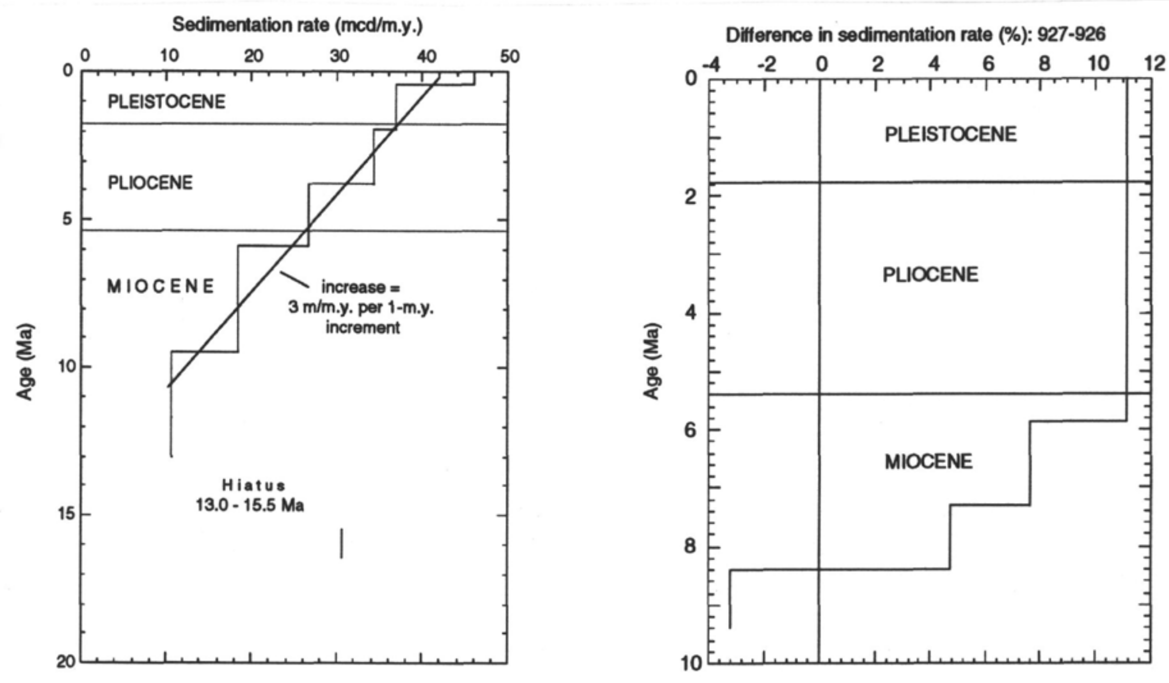

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
5
10
15
20
Age (Ma)
PLEISTOCENE
PLIOCENE
MIOCENE
increase =
3 m/m.y. per 1-m.y.
increment
Hiatus
13.0 - 15.5 Ma
Difference in sedimentation rate (%): 927-926
-4
-2
0
2
4
6
8
10
12
0
2
4
6
8
10
Age (Ma)
PLEISTOCENE
PLIOCENE
MIOCENE

Figure 9

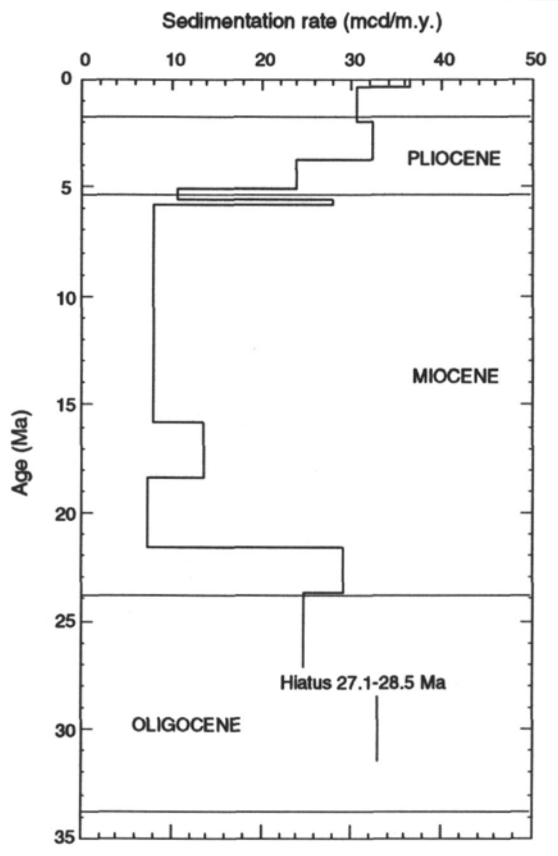

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
5
10
15
20
25
30
35
Age (Ma)
PLIOCENE
MIOCENE
OLIGOCENE
Hiatus 27.1-28.5 Ma

Figure 10

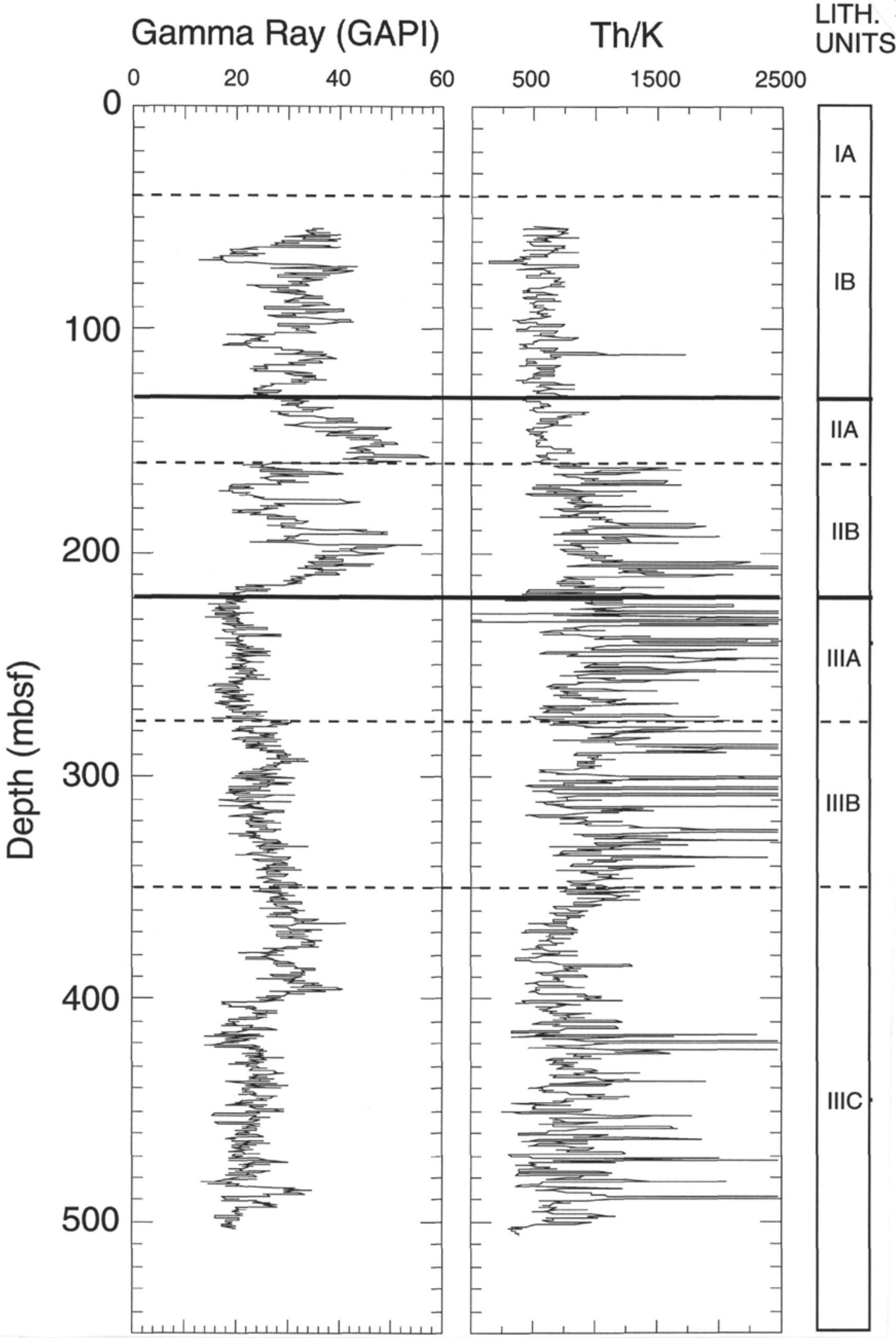

Gamma Ray (GAPI)
0
20
40
60
Th/K
500
1500
2500
LITH.
UNITS
Depth (mbsf)
0
100
200
300
400
500
IA
IB
IIA
IIB
IIIA
IIIB
IIIC

Figure 11

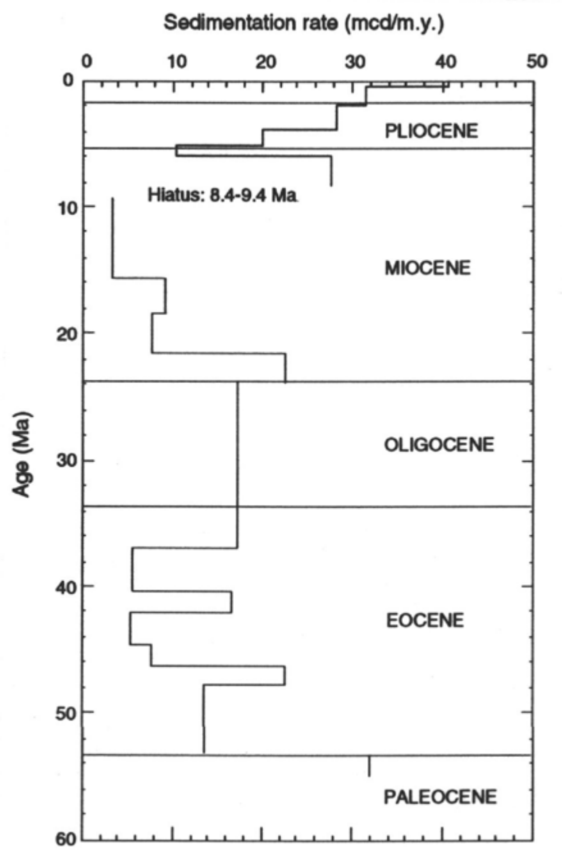

Sedimentation rate (mcd/m.y.)
0
10
20
30
40
50
0
10
20
30
40
50
60
Age (Ma)
PLIOCENE
Hiatus: 8.4-9.4 Ma
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE

Figure 12