OCEAN DRILLING PROGRAM

LEG 165 SCIENTIFIC PROSPECTUS

CARIBBEAN OCEAN HISTORY AND THE CRETACEOUS/TERTIARY BOUNDARY EVENT

Dr. Haraldur Sigurdsson
Co-Chief Scientist, Leg 165
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882
U.S.A.

Dr. R. Mark Leckie
Co-Chief Scientist, Leg 165
Department of Geosciences
University of Massachusetts
Amherst, MA 01003
U.S.A.

To Be Named
Staff Scientist, Leg 165
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.

Dr. Paul J. Fox
Director
ODP/TAMU

Dr. Jack Baldauf
Manager
Science Operations
ODP/TAMU

Timothy J.G. Francis
Deputy Director
ODP/TAMU

July 1995

Scientific Prospectus No. 65

First Printing 1995

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. 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)

This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

ABSTRACT

The Caribbean region presents a wide array of geologic problems related to its plate tectonic evolution, the nature of its oceanic crust or basement, ocean and climate history, and the opening and closing of intra-Caribbean and Atlantic-to-Pacific seaways. With the exception of DSDP Site 502, the Caribbean has not been targeted by the Ocean Drilling Program or Deep Sea Drilling Project for more than two decades. A fresh impetus has now been given to Caribbean drilling by the recent discovery of a strewn field of unaltered impact glass spherules or tektites in Haiti and Mexico at the Cretaceous/Tertiary boundary, and the identification of their source in the 180 to 300 km-wide Chicxulub impact crater in the Yucatan.

Leg 165 drilling will address two major themes: the nature of the Cretaceous/Tertiary boundary and the influence of tropical seas on global ocean history and climate evolution. Drilling at five primary sites will provide a unique opportunity to examine nearly 90 m.y. of Earth history, including (1) the K/T boundary impact event, mechanisms of ejecta dispersal, and environmental consequences from aerosols and fallout of ejecta; (2) catastrophic extinction events and biotic recovery; (3) the nature of climate forcing in the pre-Neogene world and tests of climate models with boundary conditions very different from those of today; (4) several episodes of moderate to extreme climatic warmth (early Late Cretaceous, early Eocene, early to mid Pliocene); (5) the evolution of tropical sea surface temperatures and changes in meridional temperature gradients; (6) changes in oceanic circulation and in sources of deep and intermediate water masses through Late Cretaceous and Cenozoic time; (7) the closing of low latitude oceanic gateways, the opening of a major gateway within the Caribbean, and the oceanic and climatic consequences of low latitude tectonics during the late Neogene; (8) tropical climate variability during the late Quaternary; and (9) nature and origin of Caribbean crust.

INTRODUCTION

The Leg 165 drilling program will focus on a broad spectrum of problems relevant to the understanding Earth history, biotic evolution, and the nature of the ocean-climate system. These can be broadly assigned to one of two themes: (1) consequences of the K/T impact and (2) tropical influences on global ocean processes and climate change.

The principal hypothesis put forward to account for the worldwide Cretaceous/Tertiary boundary mass extinctions is the impact of a large bolide on the Earth (Alvarez et al., 1980). The recent discovery of fresh impact glasses at the K/T boundary in the Beloc Formation of Haiti (Sigurdsson et al., 1991a; Izett, 1991), in the Mimbral sequence of northeastern Mexico (Margolis et al., 1991), and at DSDP Sites 536 and 540 in the Gulf of Mexico (Alvarez et al., 1991) provides evidence for a major impact event in the Caribbean region. Geochemical evidence from these glasses also yields constraints for an impact site on continental crust overlain by evaporite-rich sediments (Sigurdsson et al., 1991b), which is consistent with the stratigraphy near the 180 km (Hildebrand et al., 1990) to 300 km (Sharpton et al., 1994) Chicxulub impact crater on the Yucatan Peninsula of Mexico. The discovery of impact glass-bearing deposits in the circum-Caribbean region indicates that sediments within the Caribbean Sea have an excellent potential for yielding K/T boundary layers similar to the rare sections exposed on land. Leg 165 will drill a series of sites in the Caribbean Sea and on the margin of the Yucatan Basin for the purpose of penetrating and recovering the K/T interval (Fig. 1).

In addition to K/T boundary objectives, the Leg 165 drilling program will address diverse aspects of tectonics, paleoceanography, climatology, and evolution in the tropics, thereby providing new information on the role of the tropics in the ocean-climate system through geologic time. The recovery of relatively complete Upper Cretaceous, Tertiary, and Quaternary sedimentary sequences in the Caribbean will greatly advance our knowledge of a wide range of major paleoceanographic and paleoclimatic problems. Chief among these are:

- the nature of climate forcing in the pre-Neogene world in order to test climate models under different boundary conditions:

  a) low latitude sea surface temperatures and changes in equator-to-pole temperature gradients through the late Mesozoic and Cenozoic,
  b) the linkage between greenhouse gases and warm global climates of the past, and
  c) the role of oceanic heat transport during times of moderate to extreme warmth (e.g., Late Cretaceous, early Eocene, and early Pliocene), including a test of the hypothesis of warm saline deep and intermediate water formation in the pre-Neogene record;
- the tropical record of abrupt ocean and climate change (e.g., Paleocene/Eocene boundary, Eocene/Oligocene boundary, Younger Dryas event), including the impact on and response of benthic and planktonic microbiota;
- improving resolution and correlations between calcareous and siliceous plankton biostratigraphy and paleomagnetic stratigraphy, and refining low latitude Upper Cretaceous and Paleogene chronostratigraphy;
- the role of Caribbean tectonics in the evolution of North Atlantic paleoceanography and Northern Hemisphere glaciation during the late Neogene, especially the opening of a major

intra-Caribbean gateway during the middle to late Miocene, and the closing of the Central American Seaway during the late Miocene and Pliocene;
- the history of variations in intermediate and deep water masses in the Caribbean during the late Neogene and Quaternary and implications for global circulation;
- the potential linkages between sub-millennial climatic events of the northern latitudes (e.g., Heinrich events), modes of deep water formation, and variability of tropical climate in the late Quaternary;
- the environmental conditions of anoxic basin development.

The drilling during Leg 165 will also address important problems related to the age and origin of the Caribbean oceanic crust as a large igneous province (LIP) and the nature and origin of the Cayman Ridge.

SCIENTIFIC OBJECTIVES AND METHODOLOGY

The Cretaceous/Tertiary Boundary

Study of the K/T boundary by drilling in the Caribbean region has become even more compelling following the discovery of a thick impact ejecta deposit in Haiti (Hildebrand and Boynton, 1990), the find of unaltered impact glass or tektite spherules in the deposit (Sigurdsson et al., 1991a, 1991b), and the recognition of the Chicxulub crater at the north end of the Yucatan Peninsula of Mexico as the locus of bolide impact (Fig. 2; Pope et al., 1991; Hildebrand et al., 1991). The current debate is now centered on the size of the crater. Sharpton et al. (1994) view the geophysical data and preliminary Pemex drilling results as an indication that the Chicxulub represents a multi-ring impact basin, with a diameter of about 300 km, whereas Hildebrand et al. (1995) have interpreted similar data as indicating that the Chicxulub is a simple impact crater of about 180 km diameter.

The major outstanding issue regarding the K/T boundary event is the exact relationship between the bolide impact and the associated extinctions. This issue relates to bolide size, impact angle, ejecta dispersal, and, perhaps most important, the geochemistry of the impact terrain. It turns out that the Yucatan terrain has geologic features that are likely to have brought about uniquely severe environmental effects from the impact. Evidence from the geochemistry of impact glasses or tektites indicates that two dominant geologic formations were melted: (1) Paleozoic continental crust (producing black, high-silica tektite glasses), and (2) Cretaceous evaporites and carbonates (producing sulfur-rich, high-Ca yellow glasses; Sigurdsson et al., 1991a, 1991b; Koeberl and Sigurdsson, 1992). Drilling in the Caribbean region will have a bearing on a number of problems associated with the K/T boundary event, as discussed below.

Total Ejecta Mass

Ejecta from the bolide impact consists of three principal components: (1) melt ejecta, in the form of impact glass spherules or tektites; (2) gases from vaporized target material, dominantly water, CO_2, and SO_2, which have converted to a stratospheric aerosol; and (3) crustal rock ejecta or "dust," consisting of proximal breccia and distal crystal fallout (shocked quartz, etc.). Estimates of total ejecta mass range from 2 x10^{19} g (Alvarez et al., 1980), to 1.9 x10^{20} g (Roddy et al., 1991), based on the Ir anomaly and crater size. The variation in deposit thickness is best fitted by two linear segments (Fig. 3A), suggesting that the distribution represents two dominant modes of dispersal. In this model, approximately 99% of the ejecta occurs within 1400 km of the impact site (1.2% of the earth's surface), whereas the remaining <1% is distributed over the remaining surface (Fig. 3B). The ejecta fallout loading of solid matter on most of the Earth's surface is thus estimated to be about 0.27 g/cm^2. In comparison, Pollack et al. (1983) adopted a 1 g/cm^2 mass loading of "dust" in their assessment of climatic effects of K/T boundary impact ejecta. These results thus suggest that previous estimates of a high atmospheric mass loading at the K/T boundary due to large amounts of rock "dust" may be high by a factor of 4, and that rock "dust" was therefore probably not a major climate-forcing factor in the wake of the impact.

The proposed Leg 165 drilling will provide much-needed constraints on the solid ejecta mass distribution, as the proposed sites form a transect that crosses the hypothesized transition between the thick proximal ejecta within 1400 km from source, and the thin distal ejecta (Fig. 3A). Drilling will thus contribute to our knowledge of the ejecta dispersal pattern. Most current models assume an axisymmetric distribution of the ejecta blanket deposit, but the recent proposal of Schultz (1994), that the Chicxulub structure represents an oblique impact, implies that the ejecta distribution would be asymmetric. The fan-shaped distribution of proposed drill sites may help address this hypothesis.

Ejecta Dispersal Mechanisms

Studies of the well-preserved and thick (0.5-1 m) Haiti K/T boundary sections indicate that the ejecta deposit consists of three principal units that reflect different depositional processes (Fig. 4).

A basal 20-cm unit is composed of impact glass spherules and their smectite alteration products and is normally graded. The large grain size of glass spherules (up to 8 mm diameter) indicates that they cannot have been transported as fallout from thermal plumes, but rather as ballistic fallout. This basal unit is overlain by a 20-50 cm thick cross-bedded smectite and carbonate-rich unit, which contains large glass spherules as well as sediment rip-up clasts. Sigurdsson et al. (1991a) have interpreted this as a density current deposit or turbidite, which may be related to a giant impact-generated tsunami or seiche event, such as has been proposed for similar debris flow deposits at the K/T boundary in northern Mexico (e.g., Smit et al., 1994). The uppermost unit is a 0.5-2 cm thick reddish-brown smectite layer that contains the iridium anomaly and minute shocked quartz grains. It most likely represents late-stage fallout of aerosols and atmospherically suspended impact “dust.” The proposed drilling will provide additional information on these lithologic units, their grain size and complex depositional mechanisms, and possible facies variations in the ejecta layer as a function of distance from source.

Volatile Components and Extinction Mechanisms

The geochemical evidence from the Haiti impact glasses or tektites, on the nature of the impact terrain, shows that volatile emission from the target rocks was an important feature of the K/T boundary event, and that this feature may account for the uniquely severe environmental effects and high extinction rate that mark this geologic boundary. The high sulfur content (up to 1 wt%), high oxygen fugacity (Oskarsson et al., 1991), and sulfur isotopic composition of the high-Ca yellow impact glasses (Chaussidon and Sigurdsson, 1994) are conclusive evidence of their formation by fusion of evaporite and carbonate in the presence of a silicate melt. The geologic constraints indicate that the impact volatilized sedimentary rocks and pore fluids to produce a large stratospheric vapor plume consisting of the potent brew of CO_2, SO_2, and H_2O in about equal proportions. These inferences are fully supported by the geologic evidence of the Cretaceous stratigraphy of the Yucatan Peninsula, which contains a 3 km-thick succession of evaporite and carbonate sediments at the site of impact (Lopez Ramos, 1981). The atmospheric loading from an impact-generated sulfate aerosol is thus equal to, or possibly greater by an order of magnitude than, the rock “dust” lofted by the impact. It seems very likely that a very large sulfate aerosol must have formed after impact, with major global surface cooling. Because of the prodigious amount of CO_2 released, a number of investigators have proposed a sudden, and even harmful, greenhouse warming at the time of impact. However, as indicated by Pollack et al. (1983), in the presence of a dense stratospheric aerosol, no warming by a greenhouse effect is possible under these conditions, despite the greatly enhanced infrared opacity of the atmosphere.

The proposed Caribbean drilling sites will potentially benefit studies of K/T boundary environmental effects. First, the possibilities of coring through complete K/T boundary sections is likely based on results from DSDP Sites 152 and 146, and these new sequences are likely to yield glass spherules for further geochemical analysis. To date, only the Haiti site and the Mimbral site in Mexico have yielded unaltered glass from the boundary. Additional glass samples are needed for further quantitative evaluation of the possible role of evaporites and carbonate sediments in the formation of the impact melt. Second, the recovered boundary deposit may contain fragmentary ejecta from the impacted terrain, such as carbonates and evaporites, that would help elucidate the proportion of chemical sediments in the impacted region. Third, the added information on the thickness distribution of the impact ejecta deposit will help constrain impact angle and the direction and magnitude of the blast zone (Schultz, 1994). Finally, analyses of microbiota and stable isotopes from well-preserved marine sediments across the K/T boundary will shed light on the environmental changes accompanying the bolide impact.

Cretaceous and Paleogene Ocean and Climate History

Recent findings from late Quaternary ice cores and North Atlantic marine records and studies of the Cenomanian/Turonian, Paleocene/Eocene, and Eocene/Oligocene boundary events indicate that rapid changes in climate and in the mode of deep sea circulation have occurred throughout the late Mesozoic and Cenozoic. What we see in this ancient record is an ocean-climate system that we understand poorly in terms of its natural variability through time, as well as how different forcing mechanisms can yield various feedback responses or threshold events. The tropics hold an important key to understanding how this system operated through time, in defining climate parameters such as deep and surface water temperatures and chemistry, in understanding how the tropical biota responded to changes, in helping to identify causes, rates, and magnitudes of climate change, and in defining the role the ocean plays in mitigating these changes. The ancient record, in particular, provides important insights to the processes of climate change, which, in turn, help to continually improve quantitative models of the ocean-climate system. Elevated levels of CO_2 are suspected to have been a major climate forcing factor during the warmer times of the Late Cretaceous and Paleogene. However, Late Cretaceous and Paleogene stable isotope data have been difficult to reconcile with models of CO_2 forcing. The relative roles of greenhouse gases, latitudinal heat transport, and latitudinal variation in sea surface insolation need to be tested further.

Climate Forcing in the Late Cretaceous and Paleogene

Mid-Cretaceous times, particularly during the late Aptian-earliest Turonian, are believed to have been the warmest of the Cretaceous (Arthur et al., 1987, 1990; Bralower et al., 1993; Huber et al., in press). This warmth has been attributed to heightened plate tectonic activity and elevated levels of CO_2 in the atmosphere (e.g., Barron and Washington, 1985; Larson, 1991). Sea level was very high (Haq et al., 1987), epicontinental seas were widespread, and global ice volume was probably minimal (Barron, 1983). Burial of vast amounts of organic matter during the mid Cretaceous attests to the ample carbon supply and overall warmth of the seas. Because the North and South Atlantic were not yet connected, ocean circulation was dominated by the circum-tropical Tethys Ocean.

In the absence of significant ice and with a different ocean basin configuration, the mode of deep ocean circulation may have been very different from today's thermohaline circulation. Bottom, deep, and/or intermediate water masses may have formed in Tethys, on its adjacent broad shelves or in epicontinental seas, by the sinking of warm saline tropical waters (Arthur and Natland, 1979; Brass et al., 1982; Saltzman and Barron 1982; Wilde and Berry, 1982). This mode of deep water formation is widely suspected to have been an important if not the dominant mode during the mid to Late Cretaceous and during part of the Paleogene (e.g., Arthur et al., 1985; Leckie, 1989; Kennett and Stott, 1990, 1991; Bralower et al., 1993; Huber et al., in press). Warm saline deep water formation is consistent with global circulation modeling of Cretaceous oceans and climate, which suggests strong precession-scale variation in evaporation-precipitation balances over low- and mid-latitude epicontinental seas (Barron et al., 1985; Glancy et al., 1986, 1993; Oglesby and Park, 1989; Park and Oglesby, 1991). Nevertheless, it has yet to be conclusively demonstrated as an important mode of deep water formation during mid- to Late Cretaceous time. Recovery of Cretaceous and Paleogene sequences from the Caribbean will greatly aid in isotopic testing of the hypothesis of warm saline deep and intermediate waters, since this region is likely to have been close to potential sources.

Recent work by Huber et al. (in press) suggests that very warm surface water temperatures persisted in the southern high latitudes from Turonian through early Campanian time. The paleoceanographic conditions of Cretaceous low latitudes, although poorly defined at present, played a very important role in Late Cretaceous climate. Possible causes of the relatively high temperature of polar waters include elevated concentrations of greenhouse gases and increased ocean heat transport from low to high latitudes. The relative importance of these factors can be assessed by isotopic documentation of tropical sea surface temperatures (SSTs; e.g., Crowley and North, 1991). Were levels of atmospheric CO_2 elevated throughout Late Cretaceous time and responsible for warm "greenhouse" climates, including greater tropical warmth, or did a different mode of oceanic circulation transport more heat to the polar regions, resulting in similar or cooler tropical SSTs than modern? The Caribbean seafloor contains Upper Cretaceous sequences that are highly suitable for such documentation.

As shown in Figure 5, Caribbean sediments appear to contain records of Milankovitch-scale sedimentary variation (e.g., DSDP Site 146; J. King and S. D'Hondt, unpublished data). Analysis of sedimentologic and faunal data from these ancient sequences will document the sensitivity of the low latitude ocean to Milankovitch-band forcing and may document the presence of threshold events in Late Cretaceous paleoceanographic and paleoclimatic history. For example, Caribbean drilling can test the hypothesis that expression of a precessional "double-beat" in the mid-latitude South Atlantic resulted from equatorial dominance in mid-latitude Late Cretaceous paleoceanographic records (Park et al., 1993). Caribbean drill sites may also provide suitable sequences for analysis of chronostratigraphically well-constrained stable isotopic trends in the tropical Late Cretaceous ocean, allowing isotopic testing for the global or regional extent of large climate steps in the Late Cretaceous "greenhouse" (e.g., Barrera and Huber, 1990; D'Hondt and Lindinger, 1994).

The first of several major episodes of cooling in the high latitudes began in the mid Maastrichtian (e.g., Barrera, 1994). The late Paleocene witnessed a renewed warming trend that culminated in the early Eocene with the warmest temperatures and highest sea level of the Cenozoic (e.g., Dawson et al., 1976; Haq et al., 1977, 1987; Wolfe, 1985; Rea et al., 1990). Furthermore, $\delta^{18}O$ data indicate that the deep ocean and high-latitude surface oceans were at their warmest Cenozoic values in the early Eocene (e.g., Savin, 1977; Miller et al., 1987; Stott and Kennett, 1990; Zachos et al., 1994). Some $\delta^{18}O$ data suggest that early Eocene low latitude sea-surface waters may have been slightly cooler or saltier than those of present-day equatorial oceans (Fig. 6) (Boersma and Shackleton, 1981; Zachos et al., 1990, 1994). The juxtaposition of data indicating relatively warm high latitude regions and cooler or more saline low latitude regions suggests that early Eocene (and Late Cretaceous) equator-to-pole thermal gradients may have been more heavily affected by latitudinal heat transport and less dependent on atmospheric concentrations of greenhouse gases than present coupled atmosphere-ocean models generally assume (Barron, 1987; Rind and Chandler, 1991). This hypothesis needs to be tested further with additional isotopic data from the low latitudes.

The nature of climatic forcing during times of exceptional high-latitude warmth, such as the Late Cretaceous and early Eocene, and the reasons for subsequent cooling remain uncertain (Zachos et al., 1994). Climate models have been used to test for changes in the effectiveness of meridional heat transport by ocean and atmosphere with changes in paleogeography and oceanic gateways vs. climate forcing by changes in the concentration of greenhouse gases in the atmosphere (Rind and Chandler, 1991; Barron et al., 1993; Sloan et al., 1995). The determination of tropical SSTs will help to test the validity of greenhouse forcing models for times of global warmth. In addition, recovery of relatively complete Cretaceous and Paleogene sequences from the Caribbean would closely constrain the regional presence and timing of gradual and abrupt changes in surface and deep $\delta^{18}O$ and $\delta^{13}C$ trends, and elucidate relationships between tropical climate change and plankton evolution.

Abrupt Climate and Ocean Change in the Pre-Neogene Record

Two episodes of abrupt climate change are prominent features of the Paleogene record: the extreme warming event that occurred near the time of the Paleocene/Eocene boundary, and the abrupt cooling event recorded near the Eocene/Oligocene boundary. Superposed on the warming trend that began in the late Paleocene and culminated in the early Eocene was an abrupt warming in the southern high latitudes during latest Paleocene time (e.g., Miller et al., 1987; Rea et al., 1990; Kennett and Stott, 1990, 1991; Zachos et al., 1993). Both surface and deep water temperatures increased rapidly, perhaps within 10 k.y., coincident with a major extinction event in deep-sea benthic foraminifers (Tjalsma and Lohmann, 1983; Thomas, 1990, 1992). This event has been attributed to a rapid change in the mode of deep ocean circulation. Warm saline deep waters originating in the tropics, much like the circulation pattern suspected for part of the mid- and Late Cretaceous interval, may have caused the warming event and extinctions. But what was (were) the cause(s) of this rapid change in circulation?

The abrupt cooling of deep waters in the earliest Oligocene represents one of the largest cooling steps of the Cenozoic (e.g., Shackleton and Kennett, 1975; Kennett, 1977; Corliss et al., 1984; Keigwin and Corliss, 1986; Miller et al., 1987, 1991; Berggren and Prothero, 1992; Zachos et al., 1993). This event is attributed to the establishment of a large icesheet on Antarctica.

Zachos et al. (1993) suggest that both of these episodes of rapid climate change in the Paleogene represent transient climatic states, sustained briefly by positive feedbacks associated with the abrupt reorganization of ocean and/or atmospheric circulation. Gradual forcing may proceed to a point at which some physical threshold is exceeded and another climate mode, albeit short-lived, replaces the other in a nonlinear response (e.g., Berger, 1982). Other possible examples of abrupt ocean and climate change in the pre-Neogene record are the black shale events ("Oceanic Anoxic Events") of the mid Cretaceous (e.g., Arthur et al., 1987, 1990; Bralower et al., 1993). What role, if any, did the tropical ocean play in the onset or demise of abrupt climatic events, and how did this region respond to rapid changes in global climate and/or oceanic circulation? Excellent recovery of continuous Paleogene and Upper Cretaceous sequences in the Caribbean, at sites with minimal Neogene overburden, is vital to address these types of questions.

Late Cretaceous and Paleogene Chronostratigraphy

The chronostratigraphy of the mid and Upper Cretaceous and Paleogene has been vastly improved over the last two decades because of the utilization of integrated bio- and magnetostratigraphies (e.g., Berggren et al., 1985, and in press; Gradstein et al., 1994; Bralower et al., in press). However, the Cretaceous and Paleogene tropical deep-sea record still lacks the spatial and temporal coverage, core recovery, and paleomagnetic control to assess diachronism of biostratigraphic data or to correlate low latitude sequences at sub-million-year time scales to the relatively well-constrained Tethyan Gubbio sequence (Alvarez et al., 1977; Monechi and Thierstein, 1985; Premoli Silva and Sliter, 1995) and high-latitude sequences (e.g., ODP Sites 689 and 690; Huber, 1990; Stott and Kennett, 1990). The limited chronostratigraphic control, particularly in the Cretaceous, makes it difficult to measure rates of paleoceanographic and paleoecologic change or to correlate between sites. Successful recovery of Upper Cretaceous sequences from this region will provide valuable paleomagnetic and biostratigraphic records for refinement of tropical chronostratigraphy.

Development of relatively high-resolution low-latitude chronostratigraphies may be aided by the presence of Milankovitch-scale sedimentary variations in Upper Cretaceous and Paleogene Caribbean sequences. The recovered Maastrichtian and Paleocene sections at DSDP Sites 146 and 153 in the Caribbean exhibit alternating light and dark intervals (Fig. 5) that closely resemble coeval precessional cycles described from South Atlantic and Indian Ocean sequences (Maurasse, 1973; Borella, 1984; Herbert and D'Hondt, 1990; Huang et al., 1992). Similar Milankovitch-scale variation has been successfully used for high resolution K/T stratigraphy (Herbert and D'Hondt, 1990).

Neogene and Quaternary Ocean and Climate History

The tectonic history of the Caribbean is intimately linked to ocean circulation and late Neogene climate change. Uplift and, during the Pliocene, final emergence of the Isthmus of Panama is the most obvious example. However, the Aves Swell and northern Nicaragua Rise (NNR) may also have acted as important barriers to ocean circulation in the past. The NNR is thought to have been a shallow carbonate platform until the middle Miocene, and its foundering in the late middle Miocene may have initiated the Caribbean Current and thus contributed at that time to the intensification of the Gulf Stream (e.g., Mullins et al., 1980; Droxler et al., 1991). Recovery of cores in the Caribbean basins north and south of the Nicaragua Rise and in present-day channels of the NNR will test Neogene models for surface and deep circulation related to the opening and closure of gateways and shed some light on mixing of the world ocean and regulation of high-latitude climate.

The paucity of Caribbean high-resolution Neogene records stands in stark contrast to other equatorial regions of the world ocean, where ODP drilling has recovered very complete Pliocene-Pleistocene records and has greatly increased our potential for understanding global and regional paleoceanographic and paleoclimatic variation (e.g., Indian Ocean Legs 115-117, 121, Pacific Legs 130 and 138, and Atlantic Legs 108 and 154). Drilling in the Caribbean Sea between roughly 900 and 3300 m water depth will provide new data in the global array of equatorial monitors of surface and deep-water circulation. Such drilling will allow us to address several questions of both regional and global paleoceanographic, paleoclimatic, and paleobiological significance: What is the history of the Caribbean Current? When was it established? How has the strength of its flow related to tectonic events within the Caribbean region? How has Neogene variation in the Caribbean Current influenced the evolution of North Atlantic surface, intermediate, and deep water circulation, and consequently the climate of the North Atlantic Ocean? What has been the evolutionary and ecological response of planktonic biota to the partial demise of the carbonate megabank along the NNR and closure of the Central American Seaway?

Initiation and Evolution of the Caribbean Current

The Caribbean oceanic surface circulation has been significantly modified by two major Neogene tectonic events: 1) foundering of the NNR and the opening of a major intra-Caribbean gateway (Droxler et al., 1992, 1993; Droxler and Burke, 1995); and 2) closure of the Central American

Seaway and the cutoff of the Atlantic-Pacific gateway. The first event, possibly related to a reorganization of the spreading within the Cayman Trough (Droxler et al., 1991), was responsible for the opening of a new gateway for the North Atlantic Western Boundary Current in the middle Miocene through the partial demise of a carbonate megabank that covered the full length of the NNR (Fig. 7). The seaway's opening during the middle Miocene along the NNR is hypothesized to have had a direct impact on the initiation of the "modern" western boundary current with some potential link to the onset of the NADW formation in the late middle Miocene (e.g., Crowley and North, 1991; Wright et al., 1991).

The development of a strong North Atlantic Western Boundary Current in the Caribbean sometime in the middle Miocene is clearly documented in the Gulf of Mexico and in the Straits of Florida. Intensification of the Loop Current/Gulf Stream circulation during the middle Miocene is supported by numerous observations down-current of the Nicaragua Rise and Yucatan Strait (e.g., Gomberg, 1974; Mullins and Neumann, 1979; Mullins et al., 1980; Popenoe, 1985; Austin et al., 1986; Denny, 1992; Denny et al., in press). Drilling downstream of the Nicaragua Rise and on the NNR itself will provide new data on the foundering of the rise, timing of the initiation of the Caribbean Current (and intensification of the Loop Current/Gulf Stream), changes in the strength of the Caribbean Current during the late Neogene, and relationship to changes in conveyor circulation and North Atlantic climate.

Closure of the Central American Seaway

The second tectonic event to significantly change circulation in the Caribbean was the final closure of the Central American Seaway (Isthmus of Panama) in mid-Pliocene time (~ 3.5 Ma) based on nearshore marine records of Costa Rica, western Panama, and Colombia (Duque-Caro, 1990; Coates et al., 1992; Fig. 4). This estimate corresponds quite well with the conclusions of Saito (1976) and Keigwin (1978) based upon biogeographic differences in planktonic foraminifers from both sides of the Central American Seaway. Keller et al. (1989) inferred a slightly younger age for the final closure using faunal evidence which suggests that the surface connection existed until 2.4 Ma. The final closure of the Central American Seaway is expected to have significantly strengthened the Western Boundary Current, diverted northward large volumes of warm and salty waters, and increased the production of NADW (e.g., Raymo et al., 1989; Maier-Reimer et al., 1990).

Closure of the Central American Seaway was accompanied by changes in coiling directions in planktonic foraminifers, temporary disappearance of certain foraminifers from the Atlantic Ocean, and initial appearance of several new species, which are largely restricted to the Atlantic Basin (e.g., Ericson and Wollin, 1956; Saito, 1976; Keigwin, 1978, 1982; Keller et al., 1989; Jones, in press). Neogene sequences to be collected on Leg 165 will help to further document changes in planktonic assemblages that accompanied the formation of distinct Caribbean water masses and to test relationships between oceanographic history and the disappearance and repopulation of plankton in the Atlantic during glacial and interglacial stages.

History of Deep and Intermediate Waters in the Caribbean

The presence of relatively shallow sills separating the major basins in the Caribbean makes each basin a sensitive monitor for the history of intermediate waters in the open Atlantic Ocean. Because different parts of the Caribbean Sea are silled at depths that presently range from 1400 to 1800 m, sediments deposited in the deep Caribbean basins below, at, and several hundred meters above sill depths are thought to record variations in the flux and mixture of both Antarctic Intermediate Water (AAIW) and Upper North Atlantic Deep Water (UNADW). Outside the Caribbean, at the latitude of the Lesser Antilles, UNADW today ranges in water depths from 800 to 1100 m, and AAIW, 1200 to 2000 m (Bainbridge, 1981). The relative proportions of these source waters in the low latitudes of the western North Atlantic can be monitored by studying carbonate preservation and other geochemical proxies of deep water character (e.g., $\delta^{13}C$, Cd/Ca) in the Caribbean basins (Fig. 8).

There is excellent agreement between appearances and disappearances of *Globorotalia tumida* and Caribbean records of carbonate dissolution (Fig. 8D). The Atlantic reappearance of *G. tumida* during the last deglaciation has been related to the renewed surface water connection between the Indian and Atlantic oceans through the Agulhas and Benguela currents at ~ 9 ka (Jones, in press). Gordon et al. (1992) suggested that salt and heat acquired during this transit may “pre-condition” the Atlantic for NADW formation. Thus, there may be a direct link between the presence of *G. tumida* in the Caribbean and the onset of upper layer return flow of the thermohaline circulation cell (Jones, in press). Haddad (1994) documented evidence for such a link based on the preservation of metastable carbonates on the Nicaragua Rise: low influx of AAIW corresponds to low concentration of *G. tumida,* good preservation of metastable carbonates, and low production of NADW, whereas high flux of AAIW corresponds to high concentrations of *G. tumida*, poor preservation of metastable carbonates, and high production of NADW. Analyses of late Neogene Caribbean records across the 900-3300 m water depth range represented by the primary drill sites should document paleoceanographic linkages between Caribbean surface water flow and rates of NADW formation, and intermediate water mass history. In turn, this will shed important light on our understanding of how Caribbean tectonics has influenced the global “conveyer belt” of surface and deep ocean flow, and hence the evolution of Neogene climate.

Late Quaternary Tropical Climate Variability

Information on rates and magnitudes of tropical climate change is greatly lacking on interannual to millennial time scales. Annually laminated, high deposition rate sediments of the anoxic Cariaco Basin will provide an important late Quaternary record of tropical ocean and climate variability on these sub-Milankovitch time scales (Hughen et al., in press). The Cariaco Basin is well situated to record in its sediments a detailed history of trade wind-induced coastal upwelling and fluvial discharge from northern South America, phenomena both related to past changes in the strength and position of the Intertropical Convergence Zone (ITCZ). The basin’s location also makes it highly suitable for recording surface ocean changes that result from changes in the Atlantic’s thermocline conveyor circulation. By their varved nature, the sediments of the Cariaco Basin offer the prospect of examining how short-term climate sensitivity responds to past changes in large-scale global boundary conditions. The record to be obtained will also provide a well-constrained basis for theoretical and temporal linkage of tropical paleoclimate events and processes of other regions (e.g., Laurentide meltwater events and the Younger Dryas cold event in the North Atlantic Basin).

Recent studies have documented considerable sub-Milankovitch scale variability in climatic and paleoceanographic records of glacial stages. Bond et al. (1993) identified a succession of SST oscillations in the North Atlantic during the last glaciation. These cycles culminated in very cold events marked by layers of ice-rafted debris (Heinrich layers) that can be correlated over much of the North Atlantic. It has been suggested that the Heinrich events resulted from catastrophic collapse of the Laurentide ice sheet (Lehman, 1993), which, in turn, caused cessation of deep water (lower NADW) formation in the North Atlantic (Bond et al., 1993; Keigwin and Lehman, 1994). These changes in deep water formation rate should have affected the Caribbean region because of its location and role with respect to the interhemispheric exchange of surface and deep water as part of the three-dimensional circulation of the Atlantic. Data already available from the Cariaco Basin suggest that changes in upwelling, SST, and regional rainfall/runoff patterns are linked to high latitude events through changes in the strength of the ocean conveyor (Peterson et al., 1994; in prep.). Successful recovery of sediments with high accumulation rates (>6 cm/k.y.) at other Caribbean sites may also shed light on these relationships.

Relationships between Environmental Change and Sedimentary and Geochemical Properties in Modern and Cretaceous Anoxic Basins

Drilling of annually laminated Cariaco Basin sediments will also allow documentation of relationships between environmental change and sedimentary and geochemical properties in modern large anoxic basins. This basin may provide an analogue for the older anoxic basins of the Caribbean Plate. Late Cretaceous black shales are known from the Venezuela Basin (DSDP Site 146; Edgar, Saunders, et al., 1973) and from marine sequences of northern South America (Colombia and Venezuela; e.g., Macellari and de Vries, 1987; Tribovillard et al., 1991). Deposition of these black shales is likely to have been largely controlled by Caribbean tectonics. During the Cretaceous and Paleogene, this region was marked by a large “Cretaceous basalt province” and island arc complexes that were at least locally subaerially exposed (e.g., Escalante, 1990; Lundberg, 1991). As likely barriers to regional deep-water flow and possible causes of extensive Cretaceous upwelling in this region, they undoubtedly affected regional paleoceanographic conditions. At present, our understanding of both the arc complexes and the black shales is derived primarily from land-based Central American outcrops. Therefore, the causes of black shale deposition in the Caribbean during Late Cretaceous time remain enigmatic due to the complex regional tectonic history, post-depositional diagenesis of land-based outcrops, and our incomplete understanding of relationships between oceanographic conditions and the sedimentary geochemistry of Holocene analogs, like the Cariaco Basin. Additional offshore records in the Caribbean can be used to test possible relationships between regional Cretaceous paleogeography, black shale deposition, and paleoceanographic conditions (including water mass characteristics and productivity; e.g., Arthur et al., 1990; Arthur and Sageman, 1994).

Caribbean Tectonics and the Nature of Crust in the Region

The Caribbean Crust as a Large Igneous Province (LIP)

Large oceanic plateaus have long remained curious enigmas within the general understanding of ocean crust formation. Recent ODP drilling in the Indian and Pacific oceans has documented the volcanic origin of the Kerguelen (Legs 119 and 120) and Ontong Java (Leg 130) plateaus. These huge provinces (10 million km^3) appear to be formed over brief periods of intense volcanism (e.g., Tarduno et al., 1991) and are likely to be the oceanic equivalents of continental flood basalt provinces. Development of these provinces may be caused by the massive, initial eruptive phase of plumes rising from the deep mantle (Richards et al., 1989; Courtillot and Besse, 1987; Larson, 1991). A better understanding of large igneous provinces (LIPs) carries implications for crustal accretion, global elemental fluxes, and mantle composition and circulation.

Early marine geophysical surveys in the Caribbean led to the recognition that a large area was underlain by anomalously thick oceanic crust (e.g., Officer et al., 1957). In an effort to explain the large thickness of crust and corresponding great depth to the Moho (up to 16 km below sea level) it was proposed that the Caribbean was an area of extensive intrusion by primary basaltic magma. A conspicuous feature of the Caribbean crust is the existence of laterally extensive acoustic reflectors which show up on seismic profiles in the Colombia and Venezuela basins. Two prominent horizons, A" and B", have been mapped out by numerous workers and sampled during early DSDP drilling. On DSDP Leg 15, horizon B" was sampled at five drill sites with recovery of only about 15 m of basement. The samples consist of basalt and diabase whose mineralogy and geochemical characteristics are distinct from those of MORB (Edgar, Saunders, et al., 1973). This discovery led to the recognition of a Coniacian to early Campanian flood basalt event within the Caribbean, of great extent (600,000 km^2) and exceptional thickness (up to 20 km), and showed that the top of the plateau is the widespread smooth B" seismic reflector.

Plate reconstructions indicate that original Caribbean oceanic crust was formed along one of the spreading centers in the Pacific (Fig. 9; Burke et al., 1978; Duncan and Hargraves 1984; Burke, 1988; Donnelly et al., 1989). These authors speculate that voluminous volcanism associated with the onset of the Galapagos hot spot may have created the Caribbean oceanic plateau as the Jurassic Farallon plate passed eastward over the hot spot. Further evidence that the Caribbean crust represents a LIP comes from the dating of on-land igneous sections that are thought to represent tectonized peripheral parts of the oceanic plateau. These sections have been recognized in Haiti, Curacao, western Colombia, and Costa Rica. ^{40}Ar-^{39}Ar incremental heating experiments and the Re-Os isochron method show contemporaneous volcanism at all sites during the period 88-89 Ma. These dates are similar to the biostratigraphic ages (Turonian-Coniacian) obtained from DSDP Leg 15 sediments (Sites 146, 150, 151, and 153) which directly overlie the igneous rocks of unit B". The limited duration, generally synchronous nature, and widespread distribution of this dating suggest that volcanism may have occurred over a relatively brief period, but with great intensity, and that it influenced a very large area.

Additional evidence for the LIP character of the Caribbean can be found in the geochemistry of the basaltic rocks from the interior and margins of the province. The predominant magma type of both the on-land and drilled sections is tholeiitic in major element composition and exhibits flat REE patterns. These are similar to other oceanic plateau basalts from the Ontong Java Plateau and the Nauru Basin. Other less abundant types of magma include LREE-enriched alkali basalts from Haiti, Costa Rica and DSDP Site 151, and MgO-rich basalts, picrites, and komatiites found in western Colombia, Curacao, and Costa Rica. The isotopic signature of basalts from the Dumisseau Formation in Haiti and from Gorgona are similar to the plume-related basalts of the Galapagos (Figs. 10 and 11), thus providing additional support for the origin of the Caribbean LIP in the Galapagos area with subsequent eastward migration and insertion in its present position between North and South America. The high-MgO rocks from the circum-Caribbean are particularly interesting in that they indicate eruption temperatures of up to 1500°C and could be associated with as much as 50% partial melting of the mantle. Although their stratigraphic position is uncertain, there is some indication that they erupted early in the event. Such large degrees of melting, once thought to be restricted to Precambrian times, may be indicative of the early stages of flood basalt events.

There is now considerable evidence in support of the hypothesis that large areas of the Caribbean, as delineated by the presence of layer B", represent a LIP, and drilling during Leg 165 at proposed sites S-6 and S-3B will help to elucidate the nature of this important province. It is hoped that this drilling will indicate the age and basalt compositional patterns of the province and help provide a link to tectonized crustal sections of the plateau exposed subaerially along its margins. At this time, nothing is known about the plateau basalts in the large western region (Colombia Basin), where proposed site S-6 is located.

Nature of the Cayman Ridge

The Cayman Ridge forms a major structural feature that separates the Cayman Trough from the Yucatan Basin. While the Yucatan Basin is quite likely to be floored by oceanic crust, judging from magnetic anomalies and other geophysical data, the origin and age of the crustal basement forming the Cayman or Camaguey Ridge are important and unsolved problems. The Cayman Ridge has become an isolated structural high due to two major tectonic events: the opening of the Yucatan Basin and the Cayman Trough transform fault. The left-lateral strike-slip of the northern Caribbean Plate boundary at a rate of about 2 cm/yr along the Cayman Trough has resulted in displacement of about 1200 km along the plate boundary. The complement of the Cayman Ridge is therefore not to be found in the Nicaragua Rise to the south, but rather in the Greater Antilles to the east. The relatively shallow depth (3 km) and thick crust of the Cayman Ridge (17 to 20 km; Ewing et al., 1960; Bowin, 1968, 1976; Dillon et al., 1972; Rosencrantz, 1990) are consistent with the idea that it may represent a Late Cretaceous island arc complex, as supported by radiometric ages of granodiorites and amphibolites dredged from the north wall of the Cayman Trench (Perfit and Heezen, 1978). Dredging at higher levels in the trench wall shows that these plutonic basement rocks are overlain by Late Cretaceous and Paleocene volcanics and carbonates.

Proposed site S-2B on Leg 165 is the first attempt at deep-sea drilling in the region of the Cayman Ridge and Yucatan Basin. Results from this site not only will address the age and nature of the ridge basement but will also have a bearing on the age and opening of the Yucatan Basin to the west.

Regional Geology of Drilling Targets

Cayman Ridge and Yucatan Basin

The Caribbean region to be studied during Leg 165 covers a great variety of structural and geologic terrains that can be divided into six principal areas (Fig. 12). The Yucatan Basin is perhaps the least known of these regions. It is divided into the Yucatan Plain to the west and northwest, and the Camaguey Ridge and Cayman Ridge complex to the southeast. The latter includes the location of Leg 165 proposed site S-2B and alternate site S-2C (Fig. 1). A number of seismic refraction, gravity, and magnetic studies have explored the nature and origin of the Yucatan Basin (Ewing et al., 1960; Edgar et al., 1971; Bowin, 1976; Hall and Yeung, 1980; Yeung, 1981; Rosencrantz, 1990). The relatively deep (4.5 km) basin that forms the Yucatan Plain is most likely underlain by oceanic crust, produced by Late Cretaceous to Eocene back-arc spreading behind the Cuban arc (Pindell and Dewey, 1982; Holcombe et al., 1990). A tentative age of 72 to 51 Ma has been assigned to the magnetic lineations in the basin (Yeung, 1981). By comparison, the Camaguey/ Cayman Ridge region is relatively shallow (3 km) and underlain by thick crust that probably originated as a volcanic arc complex, judging from outcrops in the north wall of the Cayman Trough (Perfit and Heezen, 1978; Holcombe et al., 1990). Basement ages of the Camaguey/ Cayman Ridge are unknown but are probably mid to Late Cretaceous.

Only the surficial sediments are known in the Yucatan Basin. The Yucatan Plain is covered by turbidites of terrigenous sands and muds (0.5 to 1.5 sec thick; Dillon and Vedder, 1973), while the Camaguey/Cayman Ridge is isolated from the influx of terrigenous sediments and is covered by pelagic ooze and chalk.

Nicaragua Rise

The Nicaragua Rise extends eastward across the Caribbean, from Honduras to Jamaica. It includes Leg 165 primary proposed site NR-1/2 (Pedro Channel) on the northern Nicaragua Rise and alternate site NR-4 (Walton Basin) (Fig. 1). The Rise is capped by a number of prominent shallow-water carbonate banks, including the Pedro Bank and the Rosalind Bank. Based on the relatively great crustal thickness (20 km) of the Rise, outcrops in the south wall of the Cayman Trough, and evidence from several deep wells, the crust is most likely made up of Cretaceous to Early Tertiary volcanic island arc complexes (Case, 1975; Perfit and Heezen, 1978; Holcombe et al., 1990).

Sediment cover on the rise is principally Paleocene to Miocene limestone, marl, and siltstone, reflecting depositional environments ranging from nearshore to biogenic carbonate deposition (Arden, 1975; Holcombe et al., 1990). Shallow carbonate sedimentation characterized the rise from late Eocene to middle Miocene time, forming a continuous carbonate platform. In the middle Miocene, this platform was segmented into a series of smaller banks as a result of strike-slip movement at the Caribbean plate boundary to the north. The easternmost portion of the megabank was uplifted to form Jamaica. Since the segmentation, shallow carbonate sedimentation has continued on the elevated portions of the rise, whereas deep-water periplatform oozes were deposited in the surrounding seaways and basins.

Lower Nicaragua Rise

Three of the Leg 165 proposed sites are located on the lower Nicaragua Rise, primary proposed site S-3B and alternate sites S-5/NR-8 and S-3C (Fig. 1). This region of highly variable relief has a complex history, involving extensive deformation, including faults, ridges, troughs and young volcanoes (La Providencia and San Andres islands). On the basis of the overall depth of the Rise and on evidence from seismic refraction and drilling, the crust has been regarded as of oceanic origin, similar to that in the Colombia Basin to the south (Ewing et al., 1960; Edgar et al., 1971; Holcombe et al., 1990). It was probably formed in the Pacific Ocean during the Mesozoic as an oceanic plateau, and is thus of fundamentally different character than the Nicaragua Rise. The highly disturbed character of this province may be due to wrench faulting between the stable Nicaragua Rise to the northwest and the Caribbean Basin crust to the south.

Sediment cover of the Rise is dominantly pelagic carbonates, with minor amounts of clay, judging from DSDP Site 152 along the Hess Escarpment on the southeast end of the Rise (Edgar, Saunders, et al., 1973). The sediment record extends from the Campanian to at least mid Tertiary, and includes the important basin-wide seismic reflector A”, which correlates with an Eocene chert and chalk sequence.

Colombia Basin and Beata Ridge

The southern part of the Caribbean, including the Colombia Basin and Beata Ridge, is underlain by oceanic crust of Cretaceous or possibly Late Jurassic age. In the 3 to 4.3 km deep Colombia Basin the crust has typical oceanic seismic velocities. However, it is up to twice as thick as typical oceanic crust (up to 18 km; Ewing et al., 1960), although it is thinner in the western part (Houtz and Ludwig, 1977). The widespread seismic reflector B” correlates with the top of the Cretaceous basalt flow and sill complex (Bowland and Rosencrantz, 1988). Primary proposed site S-6 is located on an unnamed rise in the central Colombia Basin (Fig. 1).

The sedimentary succession in the Colombia Basin is very thick, 1 to 3 s on regional seismic reflection profiles (about 1 to 4 km), and thickening to >6 s beneath the Magdalena Fan to the southeast (Bowland, 1993). Thick turbidites dominate much of the basin sedimentation, derived from the Colombian Andes to the south. In the western part of the basin, sediments were previously sampled by drilling on a knoll at DSDP Site 154, recovering upper Miocene to Pliocene terrigenous deposits, containing turbidites, overlain by Pliocene and younger pelagic foraminifer-bearing nannofossil marls (Saunders et al., 1973). A marked decrease in the deposition of terrigenous sediments is apparent with time. A similar lithology was recovered by drilling of the more elevated DSDP Site 502 on the Mono Rise, except that turbidites were absent (Prell et al., 1982). We anticipate that proposed site S-6 is similarly out of reach of near-bottom sediment transport and the turbidite wedge. Seismic horizon A” is present in the central part of the Colombia Basin, and thus in the region of proposed site S-6 (Bowland, 1993). The interval beneath A” is believed to be mainly Upper Cretaceous and Lower Tertiary pelagic limestone, chalk, chert, and clay deposited in an open marine environment (Bowland, 1993).

Venezuela Basin

The deep (3 to 5 km) Venezuela Basin is underlain by igneous oceanic crust throughout, marked by the seismic horizon B”. In the western region, the B” horizon is a smooth surface, whereas in the eastern part the B” horizon has the rough surface character more characteristic of normal oceanic crust (Diebold et al., 1981; Diebold and Driscoll, 1995). Northeast trending magnetic anomalies in the basin have been interpreted as reflecting crustal accretion at a spreading ridge, between 127 and 155 Ma (Ghosh et al., 1984). Leg 165 alternate sites S-7 and S-7A are located in the Venezuela Basin (Fig. 1).

The outer margins of the basin are dominated by thick, turbidite-filled abyssal plains, which have not been penetrated by deep-sea drilling (Holcombe et al., 1990). On the other hand, DSDP drill sites in the interior of the basin have recovered a thick succession of pelagic sediments (DSDP Sites 29, 146, 149, and 150; Bader et al., 1970; Edgar, Saunders, et al., 1973). Upper Cretaceous limestone and marls containing basaltic ash overlie the igneous basement, but at DSDP Site 153 the Upper Cretaceous sediments include carbonaceous clays, which imply euxinic conditions and restricted circulation during early evolution of the basin. Paleocene limestones and clays are overlain by lower Eocene cherts and hard siliceous limestone, which mark seismic horizon A”. Miocene to Oligocene deposits are foraminiferal-nannofossil chalks and clays. Holocene to Miocene deposits are foraminiferal-nannofossil chalk oozes, marl oozes, and clays.

Cariaco Basin

Several small basins occur in the boundary zone between the Caribbean Plate and the South American Plate. The Cariaco Basin at the Venezuelan margin is an area of fault-controlled recent sedimentation, a pull-apart basin (Schubert, 1982) defined by the right-lateral strike-slip between the two plates (Moron-Sebastian-El Pilar fault). Rates of slip along these faults are on the order of 12 to 50 mm/yr, leading to a 25 to 100 km offset, which formed the Cariaco Basin in 2 m.y. (Mann et al., 1990; Ladd et al., 1990). The underlying basement is thought to be a complex mixture of metamorphosed slices or nappes of both plates, including ophiolite and metamorphic rocks of sedimentary and volcanic origin.

DSDP Leg 15 cored Site 147 in the Cariaco Basin to a depth of 189 m (Edgar, Saunders, et al., 1973). Sediments from this site and from nearby piston cores indicate an upper anoxic unit up to

10 m thick consisting of annually laminated (Hughen, et al., in press), grayish-green silty clays. This unit, the base of which has been radiocarbon dated at 12.6 ka (Peterson et al., 1991), overlies a bioturbated unit of yellowish-brown silty clays clearly deposited under oxic seafloor conditions. Laminated, anoxic sediments return at the base of long piston cores at ~26 ka, a point in time that places this event near the end of δ^{18}O Stage 3. Previous drilling at Site 147 suggests that most of the older sedimentary sequence was similarly deposited under anoxic conditions. The lack of bioturbation that results from anoxic depositional conditions, coupled with the high sedimentation rates (30 to 100 cm/k.y.), will allow for reconstruction of a unique and detailed record of climate change and paleoceanographic conditions during the late Quaternary. Primary proposed site CB-1A will be drilled to a depth of 180 m at the location of Site 147 (Fig. 1).

DRILLING STRATEGY

Leg 165 will follow a drilling strategy that will provide a transect of APC, XCB, and rotary cores of Cretaceous to Cenozoic sedimentary deposits across the northern and western Caribbean, and the Cariaco Basin of offshore Venezuela. All sites will be single APC cored to refusal (approximately 150-200 mbsf). The Cariaco Basin proposed site CB-1A will be triple APC/XCB cored to 180 mbsf.

For the Cretaceous/Tertiary objectives, the distribution of sites will provide information on variation of the thickness, grain size, and lithology of the impact ejecta deposit from proximal (S-2B; ~400 km paleodistance from Chicxulub) to distal areas, with distal sites fanning out from southwest to southeast of the crater. During rotary drilling of the relatively thin K/T boundary deposit, we propose to enhance core recovery by drilling only half a core barrel before core recovery in this drilling interval, in order to prevent core loss.

Rotary coring into the igneous basement at several of the primary sites will provide important information about the composition, age, and character of the basaltic rocks that underlie the sediments of the Caribbean and contribute to its anomalous crustal thickness. These samples are critical for an evaluation of the Caribbean basement as a large igneous province (LIP) that was transported from the Pacific.

The primary site on the northern Nicaragua Rise will be drilled to the level of an inferred drowned megabank to reconstruct the history of subsidence. The overlying sediments will provide a record of the development of the Caribbean current and its intensification as the Isthmus of Panama formed and the Central American Seaway closed.

In the shallow drilling (~180 m) proposed in the Cariaco Basin, a continuous, high-resolution record of sedimentation during the late Quaternary is sought. The most complete core recovery will be obtained here by triple, overlapping APC coring.

Logging Plan

To achieve the three objectives of Caribbean paleoceanography (late Mesozoic-early Cenozoic climate variability of tropical oceans, ejecta dispersal and biotic consequences associated with the K/T boundary impact, and high-resolution variability of Quaternary tropical oceans and climate), downhole measurements will comprise an important component of the proposed science because core recovery in the deepest sediments, those representing the late Mesozoic-early Cenozoic transition, is likely to be low.

Standard logs are to be run in high-resolution mode (1-in. sampling) and some intervals could be logged several times. Log measurements will not be required at proposed site CB-1A in the Cariaco Basin because of shallow penetration depth.

The Cretaceous and Cenozoic sedimentary record in this region is dominated by Milankovitch-scale bedding cycles that will be used for chronostratigraphic purposes; integration of core and log measurements (formation microscanner (FMS), natural gamma, magnetic susceptibility (GHMT)) of these bedding cycles will be an important science objective of Leg 165. The K/T boundary is expressed as a well-defined lithologic change over 1 to 2 m (normally graded ejecta overlain by clay layer), which can be resolved by both standard and higher-resolution log measurements. A special strategy will be applied in the logging of the K/T boundary section, to get a very high resolution of a relatively thin deposit (1 to 2 m) of distinct lithology, compared to other sediments. Because the K/T boundary deposit will be geochemically distinct from the surrounding sediments, we propose to use the geochemical log to define the boundary better, in case of poor core recovery. We also anticipate that the boundary deposit has a characteristic high magnetic susceptibility, and thus will show up as a distinct peak on the GHMT log. If the K/T boundary ejecta deposit has physical properties that are sufficiently different from the background sediments, the FMS will give a resistivity image of the formation. It will also allow us to look at the orientation of the formation contacts and any fabric that might exist in the formation.

This leg may provide an excellent opportunity to use core and log data integration as a means to reconstruct continuous, detailed records of regional lithologic variability and paleomagnetic stratigraphy since the late Mesozoic.

Human Hazards

A deep-sea cable lies about 6 nmi southeast of proposed site S-6, and a deep-sea cable lies 7 nmi north of proposed site NR-4. The precise locations of these cables have been established with the collaboration of the Underwater Systems Division of AT&T, and are deemed not to present a problem for drilling operations . No obstructions have been observed in the vicinity of the other sites.

Hydrocarbon Occurrence

Hydrocarbons will be monitored routinely during all drilling operations, as dictated by ODP general procedures. Within the region of interest to Leg 165, the only area known to contain “shows” of hydrocarbons is in the vicinity around the Cariaco Basin (proposed site CB-1A). There have been no reported shows in the basin itself. The Cariaco Basin and surrounding shelves cover an area of 23,000 km^2. Sediment thickness in the basin is up to 6.2 km, ranging from Cretaceous to Holocene in age. The oil shows in the region have been observed in Miocene to Pliocene sediments, with sandstone reservoirs and possible Miocene source rocks. Total potential petroleum reserves and resources in the surrounding area are estimated as 90 million bbl of oil and 1 to 2000 bcf of gas (Morris et al., 1988). No hydrocarbons were encountered in the drilling of DSDP Site 147 in this basin. Bacterially produced methane is present in the organic-rich sediments of the anoxic Cariaco Basin. The basin is currently anoxic below a water depth of about 300 m. It is anticipated that the presence of methane will cause problems in initial core handling as a result of gas expansion upon the cores’ arrival at the surface.

Weather and Currents

The Caribbean hurricane season is from June to November, whereas Leg 165 is scheduled from 24 December 1995 to 18 February 1996. Weather conditions generally should be very good in the region. At most sites the surface currents range from 0.4 to 1.2 statute mi/hr and should pose no problems to drilling operations.

SAMPLING OF CRITICAL INTERVALS

One of the major objectives of Leg 165 is the recovery of the K/T boundary deposit in the Caribbean. In view of its scientific importance, the K/T boundary must be regarded as a critical interval in the sediments cored during this leg, and sampled accordingly. This critical interval is the boundary deposit itself, which may be up to 1 or 2 m thick, and the sediments 3 m above and below the boundary deposit. In addition to its biostratigraphic identification, the boundary can be defined by geochemical means. Such an identification of the boundary is important for the scientific goals of the leg. This will be done on board the vessel by analysis of a suite of trace elements that are diagnostic of the boundary impact ejecta (altered impact glass and aerosol fallout). Samples for onboard XRF analysis of trace elements will be routinely taken at close spacing from the sediment throughout this critical interval, as well as in the K/T boundary deposit itself. This sampling for onboard XRF analysis will be done at primary proposed sites S-2B, S-6, and S-3B, or at their back-up sites.

X-Ray Fluorescence Laboratory

The analysis of trace elements by XRF methods is required during the cruise. This will involve both freeze-dried and powdered sediment samples of approximately 10 cc, as well as samples of basement or igneous rocks.

IMPACT OF JANUS TESTING ON LEG 165 CRUISE PARTICIPANTS

ODP and Tracor have been mandated by the JOIDES panels to begin the testing of specific components of the new JANUS database system in the shipboard environment on Leg 165. Other components are scheduled to be tested on subsequent legs until full implementation is achieved. During Leg 165 the cooperation of the technical staff and scientific party members will be requested at times during the cruise to enter duplicate data and provide feedback to Tracor representatives on the look and feel and ease of use of the new database interface. The Tracor representatives will also be available to help with duplicate data entry. While every effort will be made to minimize the impact on the scientific party, it is imperative that this testing be performed on schedule. It should be remembered that the data entered into the new database are strictly for test purposes and not for scientific use.

Hardware

Space will be required in the core entry area for the installation of a PC and bar code printer. This system will be used for the entry of CORELOG data into the new ORACLE database. In addition, a PC and bar code printer will be required near the sampling area for sample data entry into the new database, and another PC near the description table to add sub-section data (this information will be used in a new depth calculation scheme). In some cases, it may be possible to use existing hardware in the Core Laboratory areas to run the new programs, to conserve space and minimize the impact of JANUS-related testing on Leg 165.

Software

The CORELOG, SAMPLE, and LEG/SITE/HOLE & DRILLING data entry portions of the new database will be ready for testing on Leg 165. In addition, Tracor will be ready to test programs they are developing to grab flat file data output from the MST system and the thermal conductivity, sonic velocity, shear strength, and pycnometer instruments.

ACKNOWLEDGMENTS

We offer a special thanks to Steve Carey, Steve D’Hondt, Andre Droxler, Larry Peterson, Dick Norris, and Tim Bralower for their contributions to this prospectus.

LEG 165 OPERATING TIME ESTIMATES
PRIMARY PROPOSED SITES

Proposed site	Position (Latitude) (Longitude)	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Downhole Measurements (days)	Transit Time* (days)	Remarks
Transit: Miami to S-2B						1.48	
S-2B (United Kingdom)	19°29.1'N 82°55.6'W	3177	855	8.6	2.3		
Transit: S-2B to S-6						1.79	
S-6 (Colombia)	12°43.2'N 78°46.2'W	2811	1335	18.7	4.3		Free Fall Funnel Option = 15.5 days
Transit: S-6 to Kingston						1.21	Possible Observer Transfer #1
Transit: Kingston to NR-1/2						0.77	
NR-1/2 (Honduras)	16°33.2'N 79°52.0'W	910	650	4.0	1.9		
Transit: NR-1/2 to S-3B						1.10	
S-3B (Jamaica)	15°45.4'N 74°54.6'W	3322	470	4.9	2.0		
Transit: S-3B to Caracas						2.22	Possible Observer Transfer #2
Transit: Caracas to CB-1A						0.32	
CB-1A (Venezuela)	10°42.5'N 65°10.5'W	892	180	2.1	0.0		Triple APC only
Transit: CB-1A to San Juan						1.73	
TOTAL ESTIMATED DAYS	**59.4**			**38.3**	**10.5**	**10.6**	
TOTAL AVAILABLE DAYS	**56.0**						

Shortfall: <3.4>

* All transit times based on 11.0 kt

In case of time savings, high priority will be given to double APC at primary sites.

LEG 165 OPERATING TIME ESTIMATES
ALTERNATE AND BACK-UP SITES

Proposed site	Position (Latitude) (Longitude)	Water Depth (m)	Penetration (mbsf)	Drilling Operations (days)	Downhole Measurements (days)	Remarks
NR-4	17°22.8'N 77°42.5'W	850	400	2.5		1st Alternate
S-2C	19°20.6'N 83°06.0'W	3120	870	9.4		Back-up to proposed site S-2B
S-3C	15°57.6'N 74°39.0'W	3382	540	5.8		Back-up to proposed site S-3B
S-7	15°07.2'N 69°22.8'W	3949	760	10.0		2nd Alternate
S-7A	14°58.8'N 68°54.0'W	4110	760	10.2		Alternate to proposed site S-7
S-5/NR-8	15°00.0'N 77°40.8'W	2080	1125	12.1		3rd Alternate

REFERENCES

Alvarez, W., Arthur, M.A., Fischer, A.G., Lowrie, W., Napoleone, G., Premoli Silva, I., and Roggenthen, W.M., 1977. Type section for the Late Cretaceous-Paleocene geomagnetic reversal time scale. *Geol. Soc. Am. Bull.*, 88:367-389.

Alvarez, L.W., Alvarez, W., Asaro, F., and Michel, H.V., 1980. Extraterrestrial cause for the Cretaceous/Tertiary extinction. *Science*, 208:1095-1108.

Alvarez, W., Smit, J., Asaro, F., Lowrie, W., Margolis, S., Claeys, P., Kastner, M., and Hildebrand, A., 1992. Proximal impact deposits at the Cretaceous-Tertiary boundary in the Gulf of Mexico: a restudy of DSDP Leg 77 sites 536 and 540. *Geology*, 20(8):697-700.

Arden, D., 1975. The geology of Jamaica and the Nicaragua Rise. *In* Nairn, A.E.M., and Stehli, F.G. (Eds.), *The Ocean Basins and Margins*, vol. 3, The Gulf of Mexico and the Caribbean, 617-661.

Arthur, M.A., Dean, W.E., and Schlanger, S.O., 1985. Variations in the global carbon cycle during the Cretaceous related to climate, volcanism, and changes in atmospheric CO_2. *In* Sundquist, E.T., and Broecker, W.S. (Eds.), *The Carbon Cycle and Atmospheric* CO_2*: Natural Variations from the Archean to Present.* Am. Geophys. Union Monogr., 32:504-529.

Arthur, M.A., and Natland, J.H., 1979. Carbonaceous sediments in the North and South Atlantic: the role of salinity in stable stratification of Early Cretaceous basins. *In* Talwani, M., Hay, W., and Ryan, W.B.F. (Eds.), *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*. Am. Geophys. Union, Maurice Ewing Ser., 3:375-401.

Arthur, M.A., Schlanger, S.O., and Jenkyns, H.C., 1987. The Cenomanian-Turonian Oceanic Anoxic Event, II, paleoceanographic controls on organic matter production and preservation. *In* Brooks, J., and Fleet, A. (Eds.), *Marine Petroleum Source Rocks*. Geol. Soc. London, Spec. Publ. 24, 399-418.

Arthur, M.A., Jenkyns, H.C., Brumsack, H.-J., and Schlanger, S.O., 1990. Stratigraphy, geochemistry, and paleoceanography of organic-carbon rich Cretaceous sequences. *In* Ginsburg, R.N., and Beaudoin, B. (Eds.), *Cretaceous Resources, Events and Rhythms*, Dordrecht: Kluwer, 75-119.

Arthur, M.A., and Sageman, B.B., 1994. Marine black shales: depositional mechanisms and environments of ancient deposits. *Annu. Rev. Earth Planet. Sci.*, 22:499-551.

Austin, J.A., Schlager, W., Palmer, A.A., et al., 1986. *Proc. ODP, Init. Repts.*, 101: College Station, TX (Ocean Drilling Program).

Bader, R.G., et al., 1970. *Initial Reports DSDP*, 4: Washington D.C. (U.S. Govt. Printing Office).

Bainbridge, A., 1981. GEOSECS Atlantic Expedition, Hydrographic Data, 1: Washington, D.C. (U.S. Government).

Barrera, E., 1994. Global environmental changes preceding the Cretaceous-Tertiary boundary: early-late Maastrichtian transition. *Geology*, 22:877-880.

Barrera, E., and Huber, B.T., 1990. Evolution of Antarctic waters during the Maastrichtian; foraminifer oxygen and carbon isotope ratios, Leg 113. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 813-827.

Barron, E.J., 1983. A warm, equable Cretaceous: the nature of the problem. *Earth Sci. Rev.*, 19:305-338.

Barron, E.J., 1987. Eocene equator-to-pole surface ocean temperatures: a significant climate problem? *Paleoceanogr.*, 2(6):729-740.

Barron, E.J., Arthur, M.A., and Kauffman, E.G., 1985. Cretaceous rhythmic bedding sequences; a plausible link between orbital variations and climate. *Earth Planet. Sci. Letters*, 72:327-340.

Barron, E.J., Peterson, W.H., Pollard, D., and Thompson, S.L., 1993. Past climate and the role of ocean heat transport: model simulations for the Cretaceous. *Paleoceanogr.*, 8:785-798.

Barron, E.J., and Washington, W.M., 1985. Warm Cretaceous climates, high atmospheric CO_2 as a plausible mechanism. *In* Sundquist, E.T., and Broecker, W.S. (Eds.), *The Carbon Cycle and Atmospheric* CO_2*: Natural Variations from the Archean to Present*. Am. Geophys. Union Monogr., 32:546-553.

Berger, W.H., 1982. Climate steps in ocean history; lessons from the Pleistocene. *In* National Research Council Geophysics Study Committee, *Climate in Earth History*: Washington, D.C. (Natl. Acad. Press), 43-54.

Berggren, W.A., Kent, D., Flynn, J.J., and Van Couvering, J.A., 1985. Cenozoic geochronology. *Geol. Soc. Am. Bull.*, 96:1407-1418.

Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M.-P., in press. A revised Cenozoic geochronology and chronostratigraphy. *In* Berggren, W.A., Kent, D.V., and Hardenbol, J. (Eds.), *Geochronology, Time Scales and Global Stratigraphic Correlations: A Unified Temporal Framework for Historical Geology*. Soc. Econ. Paleont. Min. Spec. Vol. 54.

Berggren, W.A., and Prothero, D.R., 1992. Eocene-Oligocene climatic and biotic evolution: an overview. *In* Prothero, D.R., and Berggren, W.A. (Eds.), *Eocene-Oligocene Climatic and Biotic Evolution*. Princeton (Princeton Univ. Press), 1-28.

Boersma, A., and Shackleton, N.J., 1981. Oxygen- and carbon-isotope variations and planktonic-foraminifer depth habitats, Late Cretaceous to Paleocene, Central Pacific, Deep Sea Drilling Project Sites 463 and 465. *In* Thiede, J., Vallier, T.L., et al., *Init. Repts. DSDP*, 62: Washington (U.S. Govt. Printing Office), 513-526.

Bond, G.C., Broecker, W., Johnsen, S., McManus, J., Labeyrie, L., Jouzel, J., and Bonani, G., 1993. Correlations between climate records from North Atlantic sediments and Greenland ice. *Nature*, 365:143-147.

Borella, P.E., 1984. Sedimentology, petrology, and cyclic sedimentation patterns, Walvis Ridge transect, Leg 74, Deep Sea Drilling Project. *In* Moore, T.C., Jr., Rabinowitz, P.D., et al., *Init. Reports DSDP*, 74: Washington (U.S. Govt. Printing Office), 645-662.

Bowin, C.O., 1968. Geophysical study of the Cayman Trough. *J. Geophys. Res.*, 73:5159-5173.

Bowin, C.O., 1976. *The Caribbean: Gravity Field and Plate Tectonics*. Geol. Soc. Am. Spec. Paper 169, 79 p.

Bowland, C.L., 1984. Seismic stratigraphy and structure of the western Colombian Basin, Caribbean Sea [M.S. thesis]. University of Texas, Austin, TX.

Bowland, C.L., 1993. Depositional history of the western Colombian Basin, Caribbean Sea, revealed by seismic stratigraphy. *Geol. Soc. Am. Bull.*, 105:1321-1345.

Bowland, C.L., and Rosencrantz, E., 1988. Upper crustal structure of the western Colombian Basin, Caribbean Sea. *Geol. Soc. Am. Bull.*, 100:534-546.

Bralower, T.J., Leckie, R.M., and Sliter, W.V., in press. An integrated Cretaceous microfossil biostratigraphy. *In* Berggren, W.A., Kent, D.V., and Hardenbol, J. (Eds.), *Geochronology, Time Scales and Global Stratigraphic Correlations: A Unified Temporal Framework for Historical Geology*. Soc. Econ. Paleont. Min. Spec. Vol. 54.

Bralower, T.J., Sliter, W.V., Arthur, M.A., Leckie, R.M., Allard, D., and Schlanger, S.O., 1993. Dysoxic/anoxic episodes in the Aptian-Albian (Early Cretaceous). *In* Pringle, M.S., Sager, W.W., Sliter, W.V., and Stein, S. (Eds.), *The Mesozoic Pacific: Geology, Tectonics, and Volcanism.* Am. Geophys. Union, Geophys. Monogr. 77, 5-37.

Brass, G.W., Southam J.R., and Peterson, W.H., 1982. Warm saline bottom water in the ancient ocean. *Nature*, 296:620-623.

Burke, K., 1988. Tectonic evolution of the Caribbean. *Annu. Rev. Earth Planet. Sci.*, 16:201-230.

Burke, K., Fox, P.J., and Sengor, A.M.C., 1978. Buoyant ocean floor and the evolution of the Caribbean. *Jour. Geophys. Res.*, 83:3949-3954.

Case, J.E., 1975. Geophysical studies in the Caribbean Sea. *In* Nairn, E.M., and Stehli, F.G. (Eds.), *The Ocean Basins and Margins*, Vol. 3, The Gulf of Mexico and the Caribbean, 107-180.

Chaussidon, M., and Sigurdsson, H., 1994. Sulfur isotope study of high-Ca impact glasses from the K/T boundary. New developments regarding the K/T Event and other catastrophes in Earth history. LPI Contribution, 825:21-22 [Abstract].

Coates, A.G., Jackson, J.B.C., Collins, L.S., Cronin, T.M., Dowsett, H.J., Bybell, L.M., Jung, P., and Obando, J.A., 1992. Closure of the Isthmus of Panama: the near-shore marine record of Costa Rica and western Panama. *Geol. Soc. Am. Bull.*, 104:841-828.

Corliss, B.H., Aubry, M.-P., Berggren, W.A., Fenner, J.M., Keigwin, L.D., Jr., and Keller, G., 1984. The Eocene/Oligocene boundary event in the Deep Sea. *Science*, 226:806-810.

Courtillot, V., and Besse, J., 1987. Magnetic field reversals, polar wander and core-mantle coupling. *Science*, 237:1140-1147.

Crowley, T.J., and North, G.R., 1991. *Paleoclimatology*: New York (Oxford University Press).

Dawson, M.R., West, R.M., Langston, W., Jr., and Hutchinson, J.H., 1976. Paleogene terrestrial vertebrates: northernmost occurrence, Ellesmere Island, Canada. *Science*, 192:781-782.

Denny, W.M., 1992. Seismic stratigraphy and geologic history of mid-Cretaceous through Cenozoic rocks, southern Straits of Florida [M.S. thesis]. University of Texas at Austin, Austin, TX.

Denny, W.M., Austin, J.A., and Buffler, R.T., in press. Seismic stratigraphy and geologic history of mid-Cretaceous through Cenozoic rocks, Southern Straits of Florida. *AAPG Bull.*

D’Hondt, S., and Lindinger, M., 1994. A stable isotopic record of the Maastrichtian ocean-climate system: South Atlantic DSDP Site 528. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 112:363- 378.

Diebold, J.B., and Driscoll, N.W., 1995. Geophysical investigations of the Caribbean; Cruise summary EW-9501. Lamont-Doherty Earth Observatory, 41 pp.

Diebold, J.B., Stoffa, P.L., Buhl, P., and Truchan, M., 1981. Venezuela Basin crustal structure. *J. Geophys. Res.*, 86:7901-7923.

Dillon, W.P., Vedder, J.G., and Graf, R.J., 1972. Structural profile of the northwestern Caribbean. *Earth Planet. Sci. Letters*, 17(1):175-180.

Dillon, W.P., and Vedder, J.G., 1973. Structure and development of the continental margin of British Honduras. *Geol. Soc. Am. Bull.*, 84:2713-2732.

Donnelly, T.W., 1989. Geologic history of the Caribbean and Central America. *In* Bally, A.W., and Palmer, A.R. (Eds.), *The Geology of North America - An Overview*, Geology of North America, A: Geol. Soc. Am., 299-321.

Droxler, A.W., and Burke, K., 1995. Cenozoic gateway opening and closing in the Caribbean: control on inter-oceanic and inter-hemispheric exchange of water masses between the Atlantic and Pacific Oceans? *Eos*, Trans. Am. Geophys. Union, 76, Suppl. 53 [Abstract].

Droxler, A.W., Cunningham, A., Hine, A.C., Hallock, P., Duncan, D., Rosencrantz, E., Buffler, R., and Robinson, E., 1992. Late middle(?) Miocene segmentation of an Eocene-early Miocene carbonate megabank on the northern Nicaragua Rise tied to the tectonic activity at the North America/Caribbean plate boundary zone. *Eos*, Trans. Am. Geophys. Union, 73, Suppl. 43:299 [Abstract].

Droxler, A.W., Haddad, G.A., Buffler, R.T., Rosencrantz, E., Norris, R.D., Peterson, L.C., Hine, A.C., Hallock, P., and Mascle, A., 1993. Neogene drilling transects in the Caribbean. ODP Proposal #408-Add2.

Droxler, A., Hine, A.C., Hallock, P., Buffler, R., Rosencrantz, E., and Mascle, A., 1991. Northern Nicaragua Rise drilling proposal: testing two new interpretations. ODP Proposal #408.

Duncan, R.A., and Hargraves, R.B., 1984. Plate tectonic evolution of the Caribbean region in the mantle reference frame. *In* Bonini, W.E., Hargraves, R.B., and Shagam, R. (Eds.), *The Caribbean-South American Plate Boundary and Regional Tectonics*. Geol. Soc. Am. Mem., 162: 81-94.

Duque-Caro, H., 1990. Neogene stratigraphy, paleoceanography and paleobiogeography in northwest South America and the evolution of the Panama Seaway. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 77:203-234.

Edgar, N.T., Ewing, J.I., and Hennion, J., 1971. Seismic refraction and reflection in Caribbean Sea. *AAPG Bull.*, 55:833-870.

Edgar, N.T., Saunders, J.B., et al., 1973. *Initial Reports DSDP*, 15: Washington D.C. (U.S. Government Printing Office) , 1137 pp.

Ericson, D.B., and Wollin, G., 1956. Correlation of six cores from the equatorial Atlantic and the Caribbean. *Deep-Sea Res.*, 3:104-125.

Escalante, G., 1990. The geology of southern Central America and western Colombia. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 201-230.

Ewing, J., Antoine, J., and Ewing, M., 1960. Geophysical measurements in the western Caribbean Sea and in the Gulf of Mexico. *J. Geophys. Res.*, 65:4087-4126.

Ghosh, N., Hall, S.A., and Casey, J.F., 1984. Seafloor spreading magnetic anomalies in the Venezuela Basin. *In* Bonini, W.E., et al. (Eds.), *The Caribbean-South American Plate Boundary and Regional Tectonics*. Geol. Soc. Am. Memoir, 162:65-80.

Glancy, T.J., Jr., Arthur, M.A., Barron, E.J., and Kauffman, E.G., 1993. A paleoclimate model for the North American Cretaceous (Cenomanian-Turonian) epicontinental sea. *In* Caldwell, W.G.E., and Kauffman, E.G. (Eds.), *Evolution of the Western Interior Basin*. Spec. Pap. Geol. Assoc. Can., 39:219-241.

Glancy, T.J., Barron, E.J., and Arthur, M.A., 1986. An initial study of the sensitivity of modeled Cretaceous climate to cyclical insolation forcing. *Paleoceanogr.*, 1:523-537.

Gomberg, D., 1974. Geology of the Portales Terrace. Florida Science, 37 (Suppl. 1):15.

Gordon, A.L., Ray, F.W., Smethie, W.M., Jr., and Warner, M.J., 1992. Thermocline and intermediate water communication between the South Atlantic and Indian oceans. *J. Geophys. Res.*, 97:7223-7240.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J., and Huang, Z., 1994. A Mesozoic time scale. *J. Geophys. Res.*, 99(B12):24,051-24,074.

Haddad, G. A., 1994. Calcium carbonate dissolution patterns at intermediate water depths of the tropical oceans [Ph.D. dissert.]. Rice Univ., Houston, TX.

Hall, S.A., and Yeung, T., 1980. A study of magnetic anomalies in the Yucatan Basin. *Trans. Ninth Caribbean Geol. Conf.*, 519-526.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235:1156-1166.

Haq, B.U., Premoli Silva, I., and Lohmann, G.P., 1977. Calcareous plankton biogeographic evidence for major climatic fluctuations in the Early Cenozoic Atlantic Ocean. *J. Geophys. Res.*, 82:3861-3876.

Herbert, T.D., and D'Hondt, S.L., 1990. Precessional climate cyclicity in Late Cretaceous-early Tertiary marine sediments: a high resolution chronometer of Cretaceous-Tertiary boundary events. *Earth Planet. Sci. Lett.*, 99(3):263-275.

Hildebrand, A.R., and Boynton, W.V., 1990. Proximal Cretaceous-Tertiary boundary impact deposits in the Caribbean. *Science*, 248:843-847.

Hildebrand, A.R., Kring, D.A., Boynton, W.V., Penfield, G.T., and Pilkington, M., 1990. Cretaceous/Tertiary boundary impact site(s) between the Americas. *Geol Soc. Am. Abstr. Progr. 1990 Annu. Mtg.*, 22:280 [Abstract].

Hildebrand, A., Penfield, G.T., Kring, D.A.M., Pilkington, A., Camargo Z., Jacobsen, S.B., and Boynton, W.V., 1991. Chicxulub crater: a possible Cretaceous/ Tertiary boundary impact crater on the Yucatan peninsula, Mexico. *Geology*, 19:867-871.

Hildebrand, A.R., Pilkington, M., Connors, M., Otiz-Aleman, C., and Chavez, R.E., 1995. Chicxulub crater size and structure as revealed by horizontal Bouger gravity gradients and cenote distribution. *26th Ann. Lunar and Planet. Sci. Conf. Abstr.*, NASA, Houston, TX, 603-604 [Abstract].

Hildebrand, A.R., and Stansberry, J.A., 1992. K/T boundary ejecta distribution predicts size and location of Chicxulub crater. *23rd Ann. Lunar and Planet. Sci. Conf. Abstr.*, Houston, TX, 537-538 [Abstract].

Holcombe, T.L., Ladd, J.W., Westbrook, G., Edgar, N.T., and Bowland, C.L., 1990. Caribbean marine geology: ridges and basins of the plate interior. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 231-260.

Houtz, R.E., and Ludwig, W.J., 1977. Structure of Colombia Basin, Caribbean Sea from profiler-sonobuoy measurements. *J. Geophys. Res.* 82:4861-4867.

Huang, Z., Boyd, R., and O'Connell, S., 1992. Upper Cretaceous cyclic sediments from Hole 762C, Exmouth Plateau, Northwest Australia. *In* von Rad, U., Haq, B.U., et al., *Proc. ODP, Sci. Results*, 122: College Station, TX (Ocean Drilling Program), 259-277.

Huber, B.T., 1990. Maastrichtian planktonic foraminifer biostratigraphy of the Maud Rise (Weddell Sea, Antarctica): ODP Leg 113 Holes 689B and 690C. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results,* 113: College Station, TX (Ocean Drilling Program), 489-513.

Huber, B.T., Hodell, D.A., and Hamilton, C.P., in press. Mid- to Late Cretaceous climate of the southern high latitudes: stable isotopic evidence for minimal equator-to-pole thermal gradients. *Geol. Soc. Am. Bull*.

Hughen, K., Overpeck, J.T., Peterson, L.C., and Anderson, R., in press. An analysis of varves and their palaeoclimatic significance in sediments of the anoxic Cariaco Basin, Venezuela. *In* Kemp, A.E.S. (Ed.), *Palaeoclimatology and Palaeoceanography from Laminated Sediments*. Geol. Soc. London Spec. Pub.

Izett, G.A., 1991. K/T boundary tektites from near Beloc, Haiti. *22nd Ann. Lunar and Planet. Sci. Conf. Abstr*., 625-626 [Abstract].

Jones, G.A., in press. Timing of the Holocene repopulation of the Atlantic Ocean by *G. menardii* and *G. tumida* and implications for surface watermass paleoceanography. *Deep-Sea Res.*

Keigwin, L.D., Jr., 1978. Pliocene closing of the Isthmus of Panama, based on biostratigraphic evidence from nearby Pacific Ocean and Caribbean Sea cores. *Geology*, 6:630-634.

Keigwin, L.D., Jr., 1982. Isotopic paleoceanography of the Caribbean and east Pacific: role of Panama uplift in late Neogene time. *Science,* 217:350-353.

Keigwin, L.D., Jr., and Corliss, B.H., 1986. Stable isotopes in late middle Eocene to Oligocene foraminifera. *Geol. Soc. Am. Bull.*, 97:335-345.

Keigwin, L.D., and Lehman, S.J., 1994. Deep circulation linked to Heinrich Event 1 and Younger Dryas in a mid-depth North Atlantic core. *Paleoceanogr.*, 9:185-194.

Keller, G., Zenker, C.E., and Stone, S.M., 1989. Late Neogene history of the Pacific-Caribbean gateway. *J. South Am. Earth Sci.*, 2:73-108.

Kennett, J.P., 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic ocean, and their impact on global paleoceanography. *J. Geophys. Res.*, 82:3843-3860.

Kennett, J.P., and Stott, L.D., 1990. Proteus and Proto-Oceanus: ancestral Paleogene oceans as revealed from Antarctic stable isotopic results; ODP Leg 113. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 865-880.

Kennett, J.P., and Stott, L.D., 1991. Abrupt deep-sea warming, paleoceanographic changes and benthic extinctions at the end of the Paleocene. *Nature*, 353:225-229.

Koeberl, C., and Sigurdsson, H., 1992. Geochemistry of impact glasses from the K/T boundary in Haiti: relation to smectites, and a new type of glass. *Geochim. Cosmochim. Acta*, 56:2113-2129.

Ladd, J.W., Holcombe, T.L., Westbrook, G.K., and Edgar, N.T., 1990. Caribbean marine geology: active margins of the plate boundary. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 261-290.

Larson, R.L., 1991: Latest pulse of earth: evidence for a mid-Cretaceous superplume. *Geology*, 19, 547-550.

Leckie, R.M., 1989. A paleoceanographic model for the early evolutionary history of planktonic foraminifera. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 73:107-138.

Lehman, S.J., 1993. Climate change; ice sheets, wayward winds and sea change. *Nature*, 365:108-110.

Lopez Ramos, E., 1981. Geologia de Mexico, Tomo III. (2nd ed.): Mexico City (Univ. Nac. Auton. Mex.).

Lundberg, N., 1991. Detrital record of the early Central American magmatic arc: petrography of intraoceanic forearc sandstones, Nicoya Peninsula, Costa Rica. *Geol. Soc. Am. Bull.*, 103:905-918.

Macellari, C.E., and de Vries, T.J., 1987. Late Cretaceous upwelling and anoxic sedimentation in northwestern South America. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 59:279-292.

Mahoney, J.J., 1987. An isotopic survey of Pacific oceanic plateaus: implications for their nature and origin. *In* Keating, B.H., et al. (Eds.), *Seamounts and Islands*, AGU Monograph, 43:207-220.

Maier-Reimer, E., Mikolajewicz, and Crowley, T., 1990. Ocean general circulation model sensitivity experiment with an open Central American Isthmus. *Paleoceanogr.*, 5:349-366.

Mann, P., Schubert, C., and Burke, K., 1990. Review of Caribbean neotectonics. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 307-338.

Margolis, S., Claeys, P., Alvarez, W., Montanari, A., Swinburne, N., Smit, J., and Hildebrand, A., 1991. Tektite glass from the Cretaceous-Tertiary boundary, proximal to the proposed impact crater in northern Yucatan, Mexico. *Geol. Soc. Am. Abstr.*, A421 [Abstract].

Maurasse, F., 1973. Sedimentary structures of Caribbean Leg 15 sediments. *In* Edgar, N.T., Saunders, J.B., et al., *Init. Reports DSDP*, 15: Washington (U.S. Govt. Printing Office), 833-846.

Miller, K.G., Berggren, W.A., Zhang, J., and Palmer-Julson, A.R., 1991. Biostratigraphy and isotope stratigraphy of upper Eocene microtektites at Site 612: how many impacts? *Palaios*, 6:17-38.

Miller, K.G., Janecek, T.R., Katz, M.E., and Keil, D.J., 1987. Abyssal circulation and benthic foraminiferal changes near the Paleocene/Eocene boundary. *Paleoceanogr.*, 2(6): 741-761.

Monechi, S., and Thierstein, H.R., 1985. Late Cretaceous-Eocene nannofossil and magnetostratigraphic correlations near Gubbio, Italy. *Mar. Micropaleontol.*, 9:419-440.

Morris, A.E.L., Taner, I., Meyerhoff, H.A., and Meyerhoff, A.A., 1990. Tectonic evolution of the Caribbean region; alternative hypothesis. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 433-457.

Mullins, H.T., and Neumann, A.C., 1979. Geology of the Miami Terrace and its paleoceanographic implications. *Mar. Geol.*, 30:205-232.

Mullins, H.T., Neumann, A.C., Wilber, R.J., Hine, A.C., and Chinburg, S.J., 1980. Carbonate sediment drifts in the northern Straits of Florida. *AAPG Bull.*, 64:1701-1717.

Officer, C.B., Ewing, J.I., Edwards, R.S., and Johnson, H.R., 1957. Geophysical investigations in the eastern Caribbean: summary of 1955 and 1956 cruises. *In* Ahrens, L.H., Press, F., Ramhana, K., and Runcorn, S.K. (Eds.), *Physics and Chemistry of the Earth*, Vol. 3, Pergamon Press, New York, 17-109.

Oglesby, R., and Park, J., 1989. The effect of precessional insolation changes on Cretaceous climate and cyclic sedimentation. *J. Geophys. Res.*, 94:14,793-14,816.

Oskarsson, N., Steinberg, M., Pradel, P., Helgason, O., Sigurdsson, H., and D’Hondt, S., 1991. Oxygen isotope variation, Mossbauer spectra or iron oxidation and volatile content of tektite glasses from the Cretaceous-Tertiary boundary, Haiti. *22nd Ann. Lunar and Planet. Sci. Conf. Abstr.*, 1009 [Abstract].

Park, J., D'Hondt, S.L., King, J.W., and Gibson, C., 1993. Late Cretaceous precessional cycles in double time; a warm-Earth Milankovitch response. *Science*, 261:1431-1434.

Park, J., and Oglesby, R.J., 1991. Milankovitch rhythms in the Cretaceous; a GCM modelling study. *Global Planet. Change*, 4:329-355.

Perfit, M.R., and Heezen, B.C., 1978. The geology and evolution of the Cayman Trench. *Geol. Soc. Am. Bull.*, 89:1155-1174.

Peterson, L.C., Lin, H.-L., Overpeck, J.T., and Murray, D.W., 1994. Synchronous climate change in the North Atlantic and circum-Caribbean regions: the conveyor belt connection. *Eos*, Trans. Am. Geophys. Union, 75(15), Suppl. 56.

Peterson, L.C., Overpeck, J.T., Kipp, N.G., and Imbrie, J., 1991. A high-resolution late Quaternary upwelling record from the anoxic Cariaco Basin, Venezuela. *Paleoceanogr.*, 6:99-119.

Pindell, J.L., and Barrett, S.F., 1990. Geologic evolution of the Caribbean region: a plate-tectonic perspective. *In* Dengo, G., and Case, J.E. (Eds.), *The Caribbean Region*, Geology of North America, H: Geol. Soc. Am., 405-432.

Pindell, J., Cande, S., Pitman, W., Rowley, D., Dewey, J., Labrecque, J., and Haxby, W., 1988. A plate-kinematic framework for models of Caribbean evolution. *Tectonophysics*, 155:21-138.

Pindell, J., and Dewey, J.F., 1982. Permo-Triassic reconstruction of western Pangea and the evolution of the Gulf of Mexico/Caribbean region. *Tectonics*, 1:179-212.

Pollack, J.B., Toon, O.B., Ackerman, T.P., McKay, C.P., and Turco, R.P., 1983. Environmental effects of an impact-generated dust cloud: Implications for the Cretaceous-Tertiary extinctions. *Science*, 219:287-289.

Pope, K.O., Ocampo, A.C., and Duller, C.E., 1991. Mexican site for K/T impact crater? *Nature*, 351:105.

Popenoe, P., 1985. Cenozoic depositional and structural history of the North Carolina margin from seismic stratigraphic analyses. *In* Poag, C.W. (Ed.), *Geologic Evolution of the United States Atlantic Margin*: New York (Van Nostrand Reinhold), 125-187.

Prell, W.L., Gardner, J.V., Adelseck, C.G., Blechschmidt, G., Fleet, A.J., Keigwin, L.D., Jr., Kent, D.V., Ledbetter, M.T., Mann, U., Mayer, L.A., Riedel, W.R., Sancetta, C.A., Spariosu, D.J., and Zimmerman, H.B., 1982. Site 502: Colombia Basin, western Caribbean Sea. *In* Prell. W.L., Gardner, J.V., et al., *Initial Reports DSDP*, 68: Washington D.C. (U.S. Govt. Printing Office), 15-162.

Premoli Silva, I., and Sliter, W.V., 1995. Cretaceous planktonic foraminiferal biostratigraphy and evolutionary trends from the Bottaccione section, Gubbio, Italy. *Palaeontographia Italica*, 82:1-89.

Raymo, M.E., Ruddiman, W.F., Backman, J., Clement, B.M., and Martinson, D.G., 1989. Late Pliocene variation in Northern Hemisphere ice sheets and North Atlantic deep water circulation. *Paleoceanogr.*, 4:413-446.

Raymo, M.E., Ruddiman, W.F., Shackleton, N.J., and Oppo, D.W., 1990. Evolution of Atlantic-Pacific $\delta^{13}C$ gradients over the last 25 m.y. *Earth Planet. Sci. Letters*, 97:353-368.

Rea, D.K., Zachos, J.C., Owen, R.M., and Gingerich, P.D., 1990. Global change at the Paleocene/Eocene boundary: climatic consequences of tectonic events. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 79:117-128.

Richards, M., Duncan, R.A., and Courtillot, V.E., 1989. Flood basalts and hot-spot tracks; plume heads and tails. *Science*, 246:103-107.

Rind, D., and Chandler, M., 1991. Increased ocean heat transports and warmer climate. *J. Geophys. Res.*, 96 (D4):7437-7461.

Roddy, D.J., Schmitt, R.A., and Shuster, S.H., 1991. Asteroid and comet impacts on continental and oceanic sites. *22nd Ann. Lunar and Planet. Sci. Conf. Abstr.*, 1129-1130 [Abstract].

Rosencrantz, E., 1990. Structure and tectonics of the Yucatan Basin (Caribbean Sea) as determined from seismic reflection studies. *Tectonics*, 9:1037-1059.

Saito, T., 1976. Geologic significance of coiling direction in the planktonic foraminifer. *Pulleniatina*. *Geology*, 4:305-309.

Saltzman, E.S., and Barron, E.J., 1982. Deep circulation in the Late Cretaceous; oxygen isotope paleotemperatures from *Inoceramus* remains in DSDP cores. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 40:167-181.

Saunders, J.B., Edgar, N.T., Donnelly, T.W., and Hay, W.W., 1973. Cruise synthesis. *In* Edgar, N.T., et al., *Initial Reports DSDP*, 15: Washington D.C. (U.S. Govt. Printing Office), 1071-1111.

Saunders, J.B., Bernoulli, D., Mueller-Merz, E., Oberhaensli, H., Perch-Nielsen, K., Riedel, W.R., Sanfilippo, A., and Torrini, R., Jr., 1984. Stratigraphy of the late middle Eocene to early Oligocene in the Bath Cliff section, Barbados, West Indies. *Micropaleontology*, 30(4):390-425.

Savin, S.H., 1977. The history of the earth's temperature during the past 100 million years. *Annu. Rev. Earth Planet. Sci.*, 5:319-355.

Schubert, C., 1982. Origin of Cariaco Basin, southern Caribbean Sea. *Mar. Geol.*, 47(3-4):345-360.

Schultz, P.H., 1994. Visualizing the nature and consequences of the Chicxulub impactor: clues from Venus. New developments regarding the K/T event and other catastrophes in Earth history. LPI Contribution, 825:104-106 [Abstract].

Sen, G., Hickey-Vargas, R., Waggoner, D.G., and Maurasse, F., 1988. Geochemistry of basalts from the Dumisseau Formation, southern Haiti; implications for the origin of the Caribbean Sea crust. *Earth Planet. Sci. Letters*, 87:423-437.

Shackleton, N.J., and Kennett, J.P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analysis in DSDP sites 277, 279, and 280. *In* Kennett, J.P., Houtz, R.E., et al., *Initial Reports DSDP*, 29: Washington D.C. (U.S. Govt. Printing Office), 743-755.

Sharpton, V.L., Marin, L.E., and Schuarytz, B.C., 1994. The Chicxulub multi-ring impact basin: evaluation of geophysical data, well logs, and drill core samples. New developments regarding the K/T Event and other catastrophes in Earth history. LPI Contribution, 825:108-110 [Abstract].

Sigurdsson, H., D’Hondt, S., Arthur, M.A., Bralower, T.J., Zachos, J.C., Fossen, M., and Channell, J.E.T., 1991a. Glass from the Cretaceous-Tertiary boundary in Haiti. *Nature*, 349:482-487.

Sigurdsson, H., Bonté, Ph., Turpin, L., Chaussidon, M., Metrich, N., Steinberg, M., Pradel, Ph., and D’Hondt, S., 1991b. Geochemical constraints on source region of Cretaceous/Tertiary impact glasses. *Nature*, 353:839-842.

Sloan, L. Cirbus, Walker, J.C.G., and Moore, T.C., Jr., 1995. Possible role of oceanic heat transport in early Eocene climate. *Paleoceanogr.*, 10:347-356.

Smit, J., Roep, T.B., Alvarez, W., Claeys, P., Montanari, S., and Grajales, M., 1994. Impact-tsunami-generated clastic beds at the K/T boundary of the Gulf coastal plain; a synthesis of old and new outcrops. New developments regarding the K/T Event and other catastrophes in Earth history. LPI Contribution, 825:117-119 [Abstract].

Speed, R.C.,1987. Caribbean Geological Evolution. Report of a workshop to define Caribbean geological problems, needed investigations, and initiatives for ocean drilling: Washington, D.C. (Joint Oceanographic Institutions Inc.), 211 pp.

Stott, L.D., and Kennett, J.P., 1990. Antarctic Paleogene planktonic foraminifer biostratigraphy: ODP Leg 113, Sites 689 and 690. *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 549-569.

Tarduno, J.A., Sliter, W.V., Kroenke, L., Leckie, M., Mayer, H., Mahoney, J.J., Musgrave, R., Storey, M., and Winterer, E.L., 1991. Rapid formation of Ontong Java Plateau by Aptian mantle plume volcanism. *Science*, 254:399-403.

Thomas, E., 1990. Late Cretaceous through Neogene deep-sea benthic foraminifers (Maud Rise, Weddell Sea, Antarctica). *In* Barker, P.F., Kennett, J.P., et al., *Proc. ODP, Sci. Results*, 113: College Station, TX (Ocean Drilling Program), 571-594.

Thomas, E., 1992. Cenozoic deep-sea circulation: evidence from deep-sea foraminifera. *In* Kennett, J.P., and Warnke, D.A. (Eds.), *The Antarctic Paleoenvironment: A Perspective on Global Change*. Am. Geophys. Union Antarct. Res. Ser., 56:141-165.

Tjalsma, R.C., and Lohmann, G.P., 1983. Paleocene-Eocene bathyal and abyssal benthic foraminifera from the Atlantic Ocean. *Micropaleontology, Spec. Publ.,* 4:1-90.

Tribovillard, N.-P., Stehan, J.-F., Manivit, H., Reyre, Y., Cotillon, P., and Jautee, E., 1991. Cretaceous black shales of Venezuelan Andes: preliminary results on stratigraphy and paleoenvironmental interpretations. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 81:313-321.

Wilde, P., and Berry, W.B.N., 1982. Progressive ventilation of the oceans: potential for return to anoxic conditions in the post-Paleozoic. *In* Schlanger, S.O., and Cita, M.B. (Eds.), *Nature and Origin of Cretaceous Carbon-Rich Facies*: Academic Press (New York), 209-224.

Wolfe, J.A., 1985. Distribution of major vegetational types during the Tertiary. *In* Sundquist, E.T., and Broecker, W.S. (Eds.), *The Carbon Cycle and Atmospheric* CO_2*: Natural Variations from the Archean to Present*: Am. Geophys. Union Monogr., 32:357-376.

Wright, J.D., and Miller, K.G., 1993. Southern Ocean influences on Late Eocene to Miocene deep-water circulation. *In* Kennett, J.P., and Warnke, D.A. (Eds.), *The Antarctic Paleoenvironment: A Perspective on Global Change.* Am. Geophys. Union Antarct. Res. Ser., 60:1-25.

Wright, J.D., Miller, K.G., and Fairbanks, R.G., 1991. Evolution of modern deepwater circulation: evidence from the Late Miocene Southern Ocean. *Paleoceanogr.*, 6:275-290.

Yeung, T.C., 1981. A study of magnetic anomalies in the Yucatan Basin. [M.S. Thesis]. Univ. Houston, Houston, TX.

Zachos, J.C., Berggren, W.A., Aubry, M.-P, and Mackensen, A., 1990. Isotope and trace element geochemistry of Eocene and Oligocene foraminifers from Site 748, Kerguelen Plateau. *In* Wise, S.W., Jr., Schlich, R., et al., *Proc. ODP, Sci. Results,* 120: College Station, TX (Ocean Drilling Program), 839-854.

Zachos, J.C., Lohmann, K.C., Walker, J.C.G., and Wise, S., 1993. Abrupt climate change and transient climates during the Paleogene: a marine perspective. *J. Geol.*, 101:191-213.

Zachos, J.C., Stott, L.D., Lohmann, K.C., 1994. Evolution of Early Cenozoic marine temperatures. *Paleoceanogr.*, 9:353-387.

Figure 1: Location of primary and alternate sites in the Caribbean, to be drilled during ODP Leg 165.

Figure 2: Paleogeographic plate-tectonic reconstruction of the Caribbean region at Cretaceous/Tertiary boundary time, based on the Paleocene (ca. 59 Ma) reconstruction of Pindell and Barrett (1990). The figure shows the location of the Chicxulub impact crater, and the important K/T boundary impact deposits in Beloc, Haiti, and Mimbral, Mexico. Also shown are the approximate locations of the Leg 165 sites, which will recover the K/T boundary ejecta deposit.

Figure 3 A: The global thickness distribution of the K/T boundary ejecta deposit (data from Hildebrand and Stansberry, 1992). The thickness distribution can best be represented as a two-segment plot, in the form of ln (-thickness) vs. Square root of isopach area. An assumption is made that the thickness isopachs are circular in shape. The intersection of the two segments is at a distance of 1400 km from the Chicxulub impact crater.

Figure 3B: Distribution of the K/T boundary impact fallout on the Earth. The vast majority of the ejecta is within a 1400 km radius of the Chicxulub crater, or on 1.2% of the Earth’s surface. The distal ejecta fallout represents an atmospheric mass loading of about 0.27 g/cm^2.

Figure 4: Stratigraphic relations and carbonate abundance in the K/T boundary impact deposit in the Beloc region in Haiti. The deposit consists of three units: (1) impact glass fallout (tektite fall unit); (2) impact glass gravity flow with carbonate clasts and carbonate matrix (turbidite?); (3) interbedded smectite (altered glass) and carbonate unit, with a thin (<1 cm) iridium-rich layer at the top, which contains shocked quartz grains. On the left of the figure is the bulk carbonate variation in the boundary deposit and adjacent Tertiary and Cretaceous sediments. Vertical scale in centimeters.

Figure 5: Magnetic susceptibility record of upper Maastrichtian cores 15 and 16 from DSDP Site 146 (unpubl. data from J. King and P. Gangemi). The low magnetic susceptibility values correspond to intervals of lighter colored sediment, and high values correspond to relatively dark sediment intervals.

Figure 6: High- to low-latitude surface water $\delta^{18}O$ gradients of (A) the late Eocene and early Oligocene, and (B) the early Eocene. Note the low apparent gradients in both the Eocene and early Oligocene oceans, relative to Holocene gradients. Also note the relatively low values at low latitudes in the late Eocene and early Oligocene. With the exception of one early Eocene sample

from poorly recovered Site 152 sediments, none of these data are from the Caribbean. Only two other samples between 0° and 30°N are from the greater Atlantic region, one from the early Oligocene and one from late Eocene (both in the Gulf of Mexico at 20°N; from Zachos et al., 1990).

Figure 7: Simplified paleoreconstructions of the Caribbean (after Pindell et al., 1988), showing the timing of proposed megabank foundering and the resultant current regimes from Oligocene to the present (based on model of Droxler et al., 1992).

Figure 8: Metastable $CaCO_3$ composite dissolution index (CDI) for Nicaragua Rise cores CH8802-75 and CH8802-73 (Haddad, 1994), compared to (A) percentage of foraminifer fragments and (B) benthic foraminiferal $\delta^{13}C$ from the deep Venezuela Basin. Similarities between these records suggest that Caribbean carbon chemistry has been similar from the base of the thermocline to abyssal depths during the last 250 k.y. (C) shows good correlation between the shallow intermediate water CDI record and % NADW (Raymo et al., 1990). High NADW formation corresponds to high AAIW flux into the North Atlantic and Caribbean and poor carbonate preservation. Low NADW formation corresponds to low AAIW flux into the Caribbean and good carbonate preservation. (D) shows that reduced southern source upper water layer advection into the Caribbean during periods of good carbonate preservation is also suggested by the near inverse correlation between *G. menardii-tumida* abundance and the CDI.

Figure 9: Plate tectonic evolution of the Caribbean region, assuming a Galapagos hot-spot source for the Caribbean large igneous province (Duncan and Hargraves, 1984). Upper figure shows the configuration of the region at 80 Ma, with the oceanic plateau formed at the Galapagos hot spot (solid circle) shown in stippled pattern. Arrows indicate plate motion vectors. The lower figure shows the configuration at 60 Ma, where CA is the Central America arc, G is the Galapagos hot spot, and S is the Sala y Gomez hot spot.

Figure 10: Neodynium and strontium isotopic data on Leg 15 basalts from the Caribbean oceanic plateau (G. Waggoner in Speed et al., 1987), the Dumisseau Formation in Haiti (Sen et al., 1988), the Galapagos hot spot basalts (K. Harpp, unpubl., 1990), and other oceanic plateau basalts (Mahoney, 1987). The correspondence in radiogenic isotope character of the Caribbean plateau basalts and the Galapagos hot spot supports the idea of a common mantle source, and a source of the Caribbean oceanic plateau from the Galapagos hot spot.

Figure 11: The isotopic ratios $^{207}Pb/^{204}Pb$ (upper) and $^{208}Pb/^{204}Pb$ (lower) in basalts and komatiites from circum-Caribbean regions (Dumisseau Formation, Haiti, and Gorgona Island), in relation to the isotopic fields for Galapagos hot spot and East Pacific Rise (EPR) basalts.

Figure 12: Caribbean physiographic provinces discussed in the text.

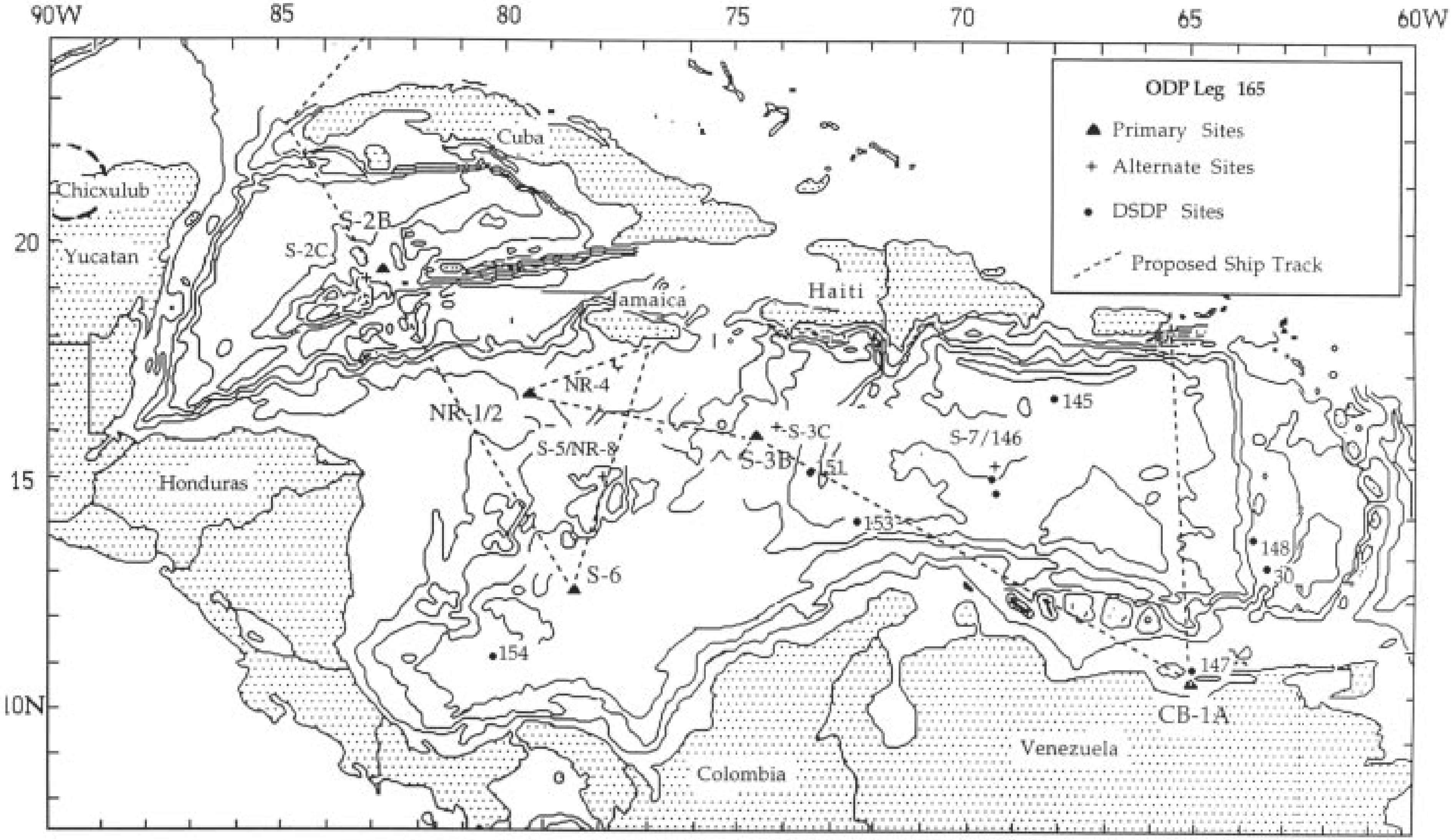


Figure 1: Location of primary and alternate sites in the Caribbean, to be drilled during ODP Leg 165.

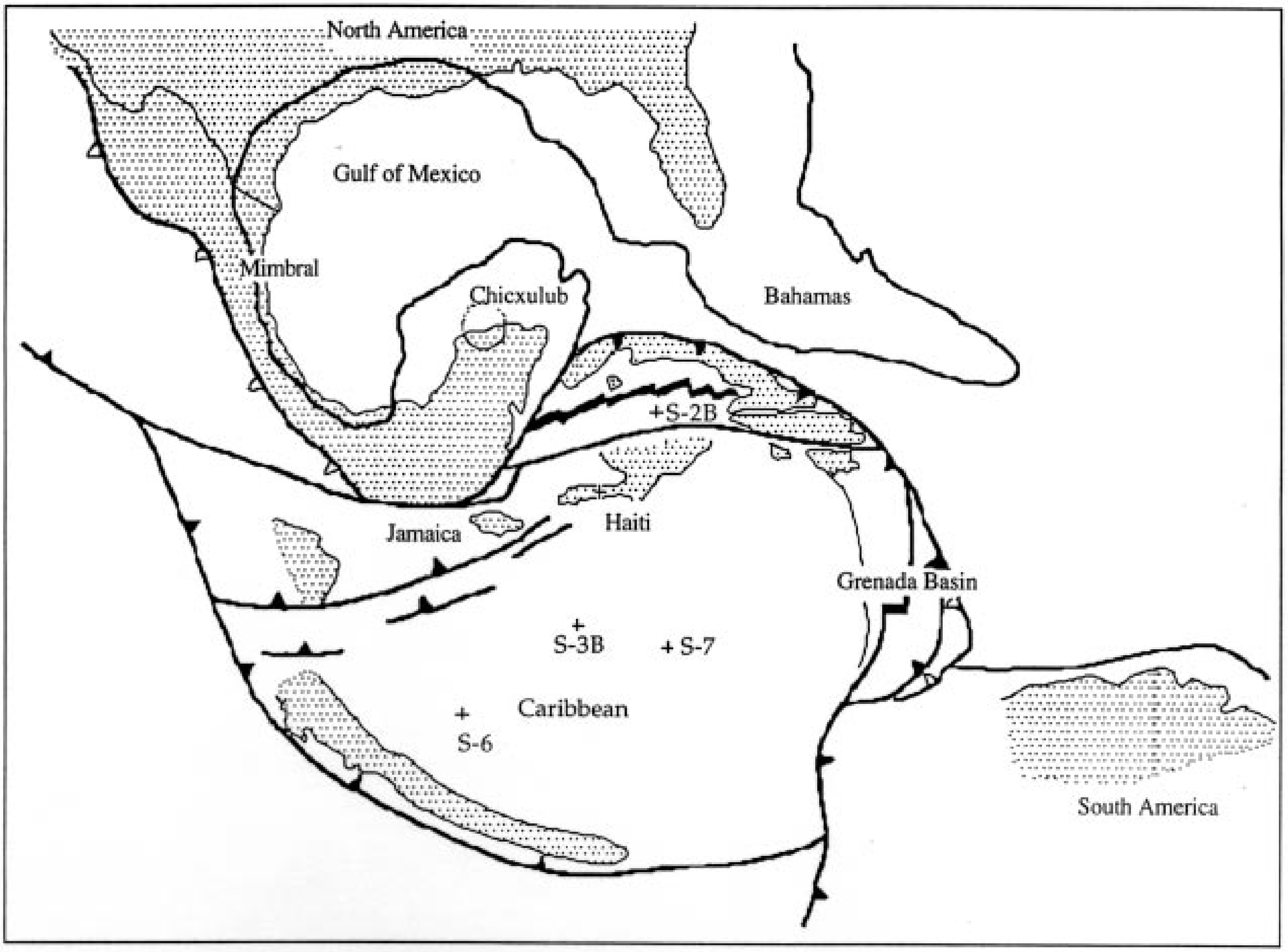


Figure 2: Paleogeographic plate-tectonic reconstruction of the Caribbean region at Cretaceous/Tertiary boundary time, based on the Paleocene (ca. 59 Ma) reconstruction of Pindell and Barrett (1990). The figure shows the location of the Chicxulub impact crater, and the important K/T boundary impact deposits in Beloc, Haiti and Mimbral, Mexico. Also shown are the approximate locations of the Leg 165 sites, which will recover the K/T boundary ejecta deposit.

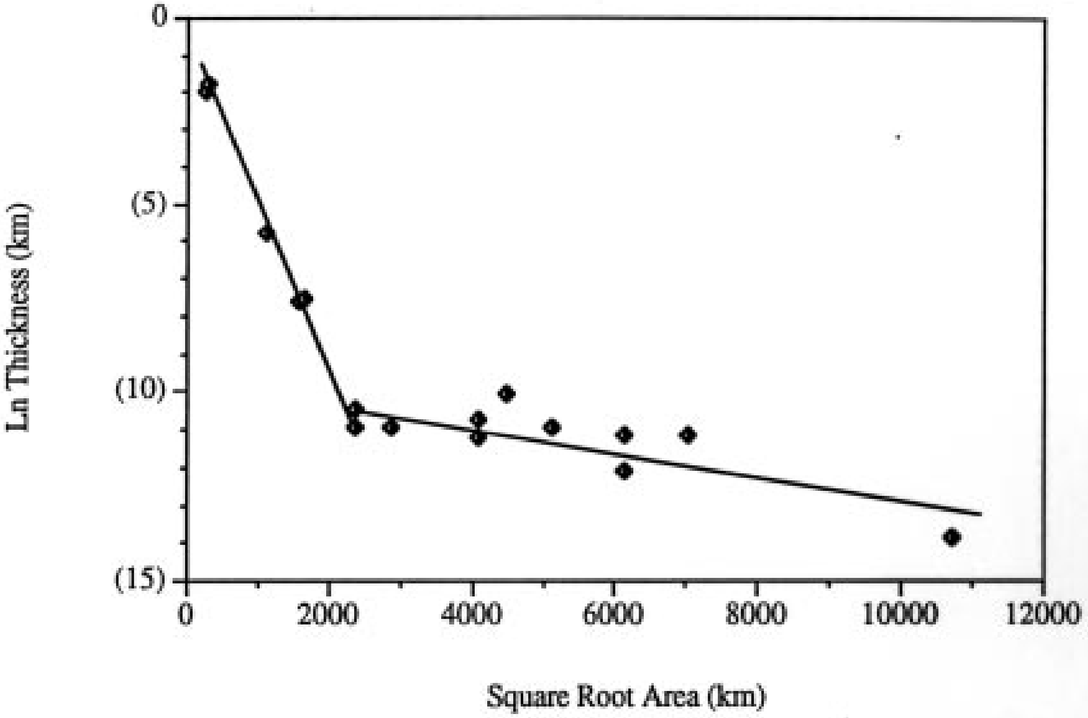


Figure 3 A: The global thickness distribution of the K/T boundary ejecta deposit (data from Hildebrand and Stansberry, 1992). The thickness distribution can best be represented as a two-segment plot, in the form of ln (-thickness) vs. square root of isopach area. An assumption is made that the thickness isopachs are circular in shape. The intersection of the two segments is at a distance of 1400 km from the Chicxulub impact crater.

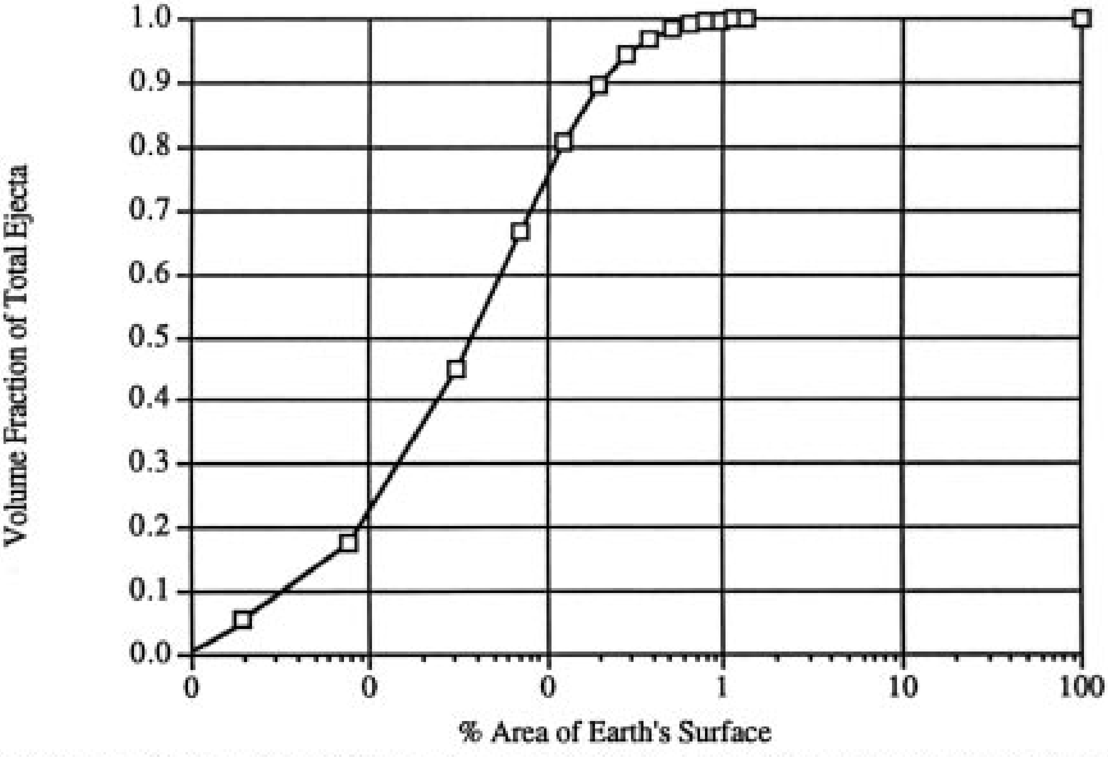


Figure 3B: Distribution of the K/T boundary impact fallout on the Earth. The vast majority of the ejecta is within a 1400 km radius of the Chicxulub crater, or on 1.2% of the Earth's surface. The distal ejecta fallout represents an atmospheric mass loading of about 0.27 g/cm^2.

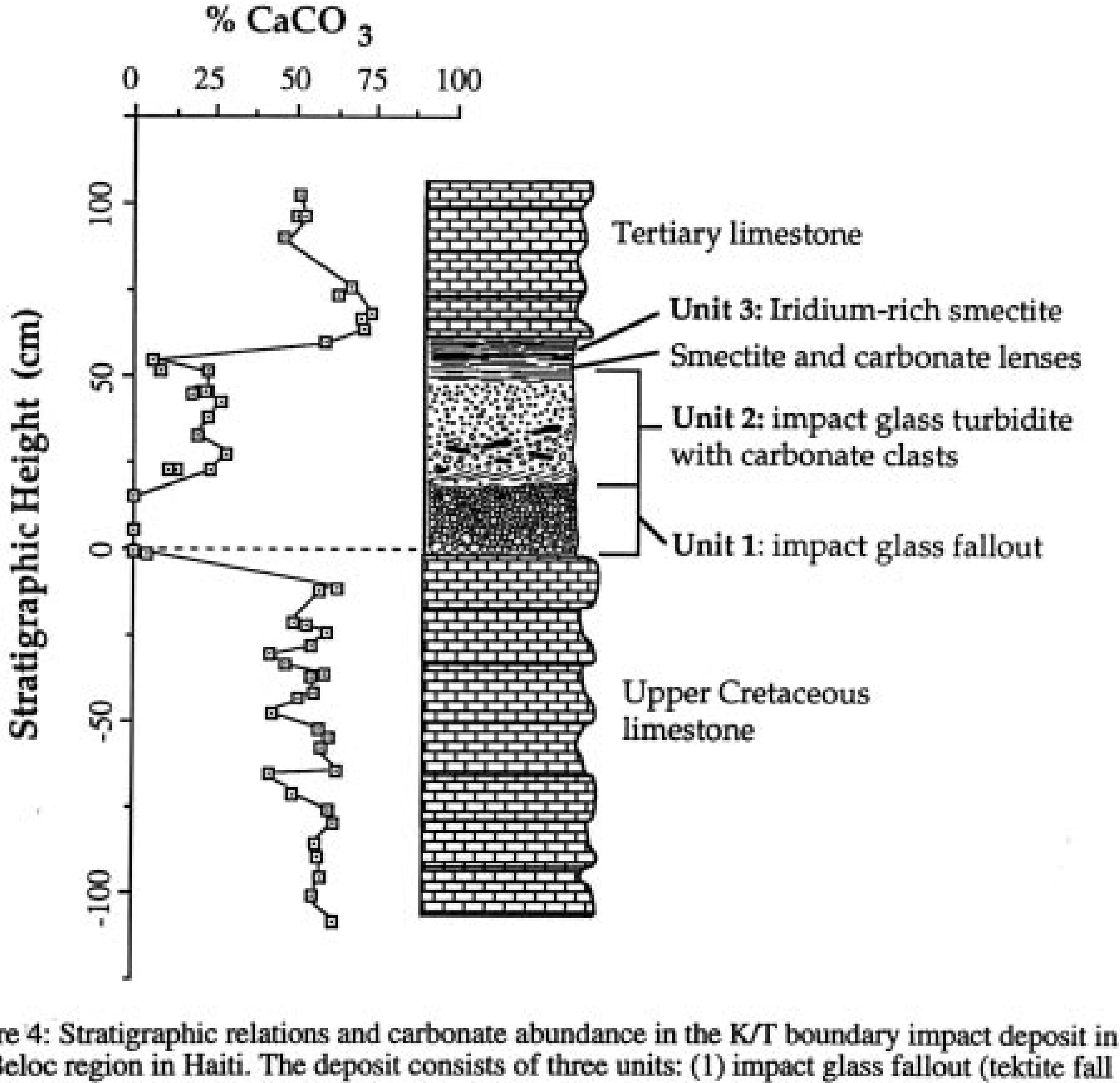


Figure 4: Stratigraphic relations and carbonate abundance in the K/T boundary impact deposit in the Beloc region in Haiti. The deposit consists of three units: (1) impact glass fallout (tektite fall unit); (2) impact glass gravity flow with carbonate clasts and carbonate matrix (turbidite?); (3) interbedded smectite (altered glass) and carbonate unit, with a thin (<1 cm) iridium-rich layer at the top, which contains shocked quartz grains. On the left of the figure is the bulk carbonate variation in the boundary deposit and adjacent Tertiary and Cretaceous sediments. Vertical scale in centimeters.

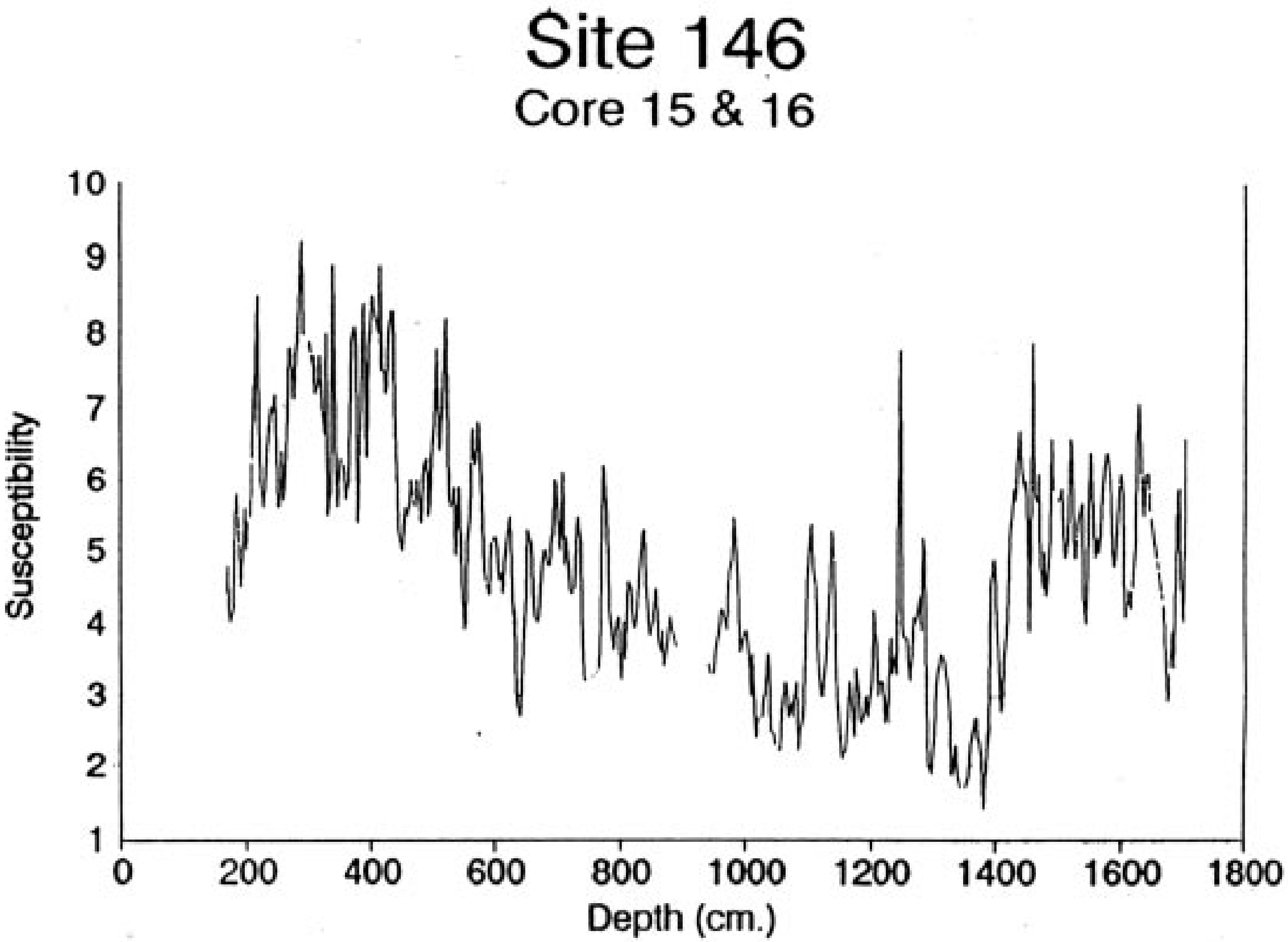


Figure 5: Magnetic susceptibility record of upper Maastrichtian cores 15 and 16 from DSDP Site 146 (unpubl. data from J. King and P. Gangemi). The low magnetic susceptibility values correspond to intervals of lighter colored sediment, and high values correspond to relatively dark sediment intervals.

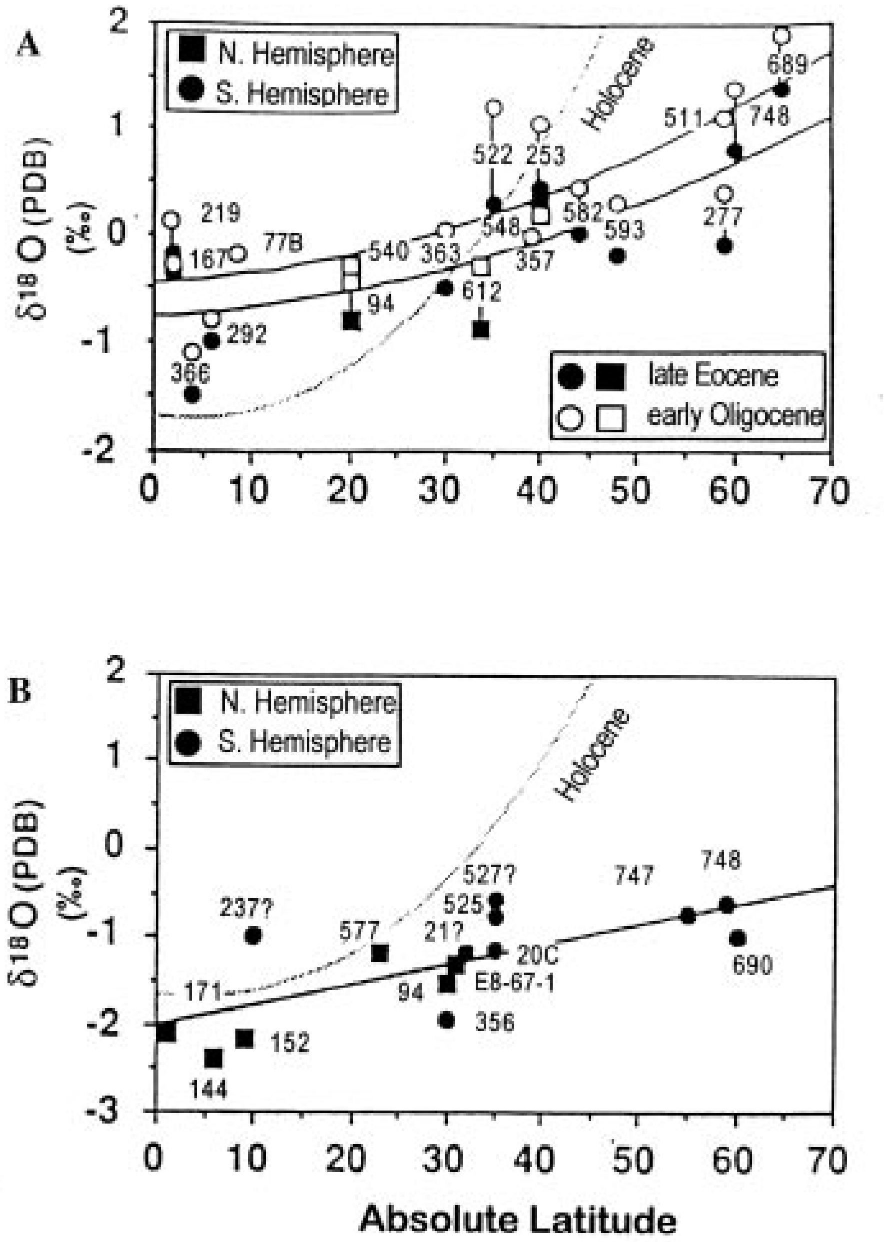


Figure 6: High- to low-latitude surface water $\delta^{18}O$ gradients of (A) the late Eocene and early Oligocene, and (B) the early Eocene. Note the low apparent gradients in both the Eocene and early Oligocene oceans, relative to Holocene gradients. Also note the relatively low values at low latitudes in the late Eocene and early Oligocene. With the exception of one early Eocene sample from poorly recovered Site 152 sediments, none of these data are from the Caribbean. Only two other samples between 0° and 30°N are from the greater Atlantic region, one from the early Oligocene and one from late Eocene (both in the Gulf of Mexico at 20°N; from Zachos et al., 1990).

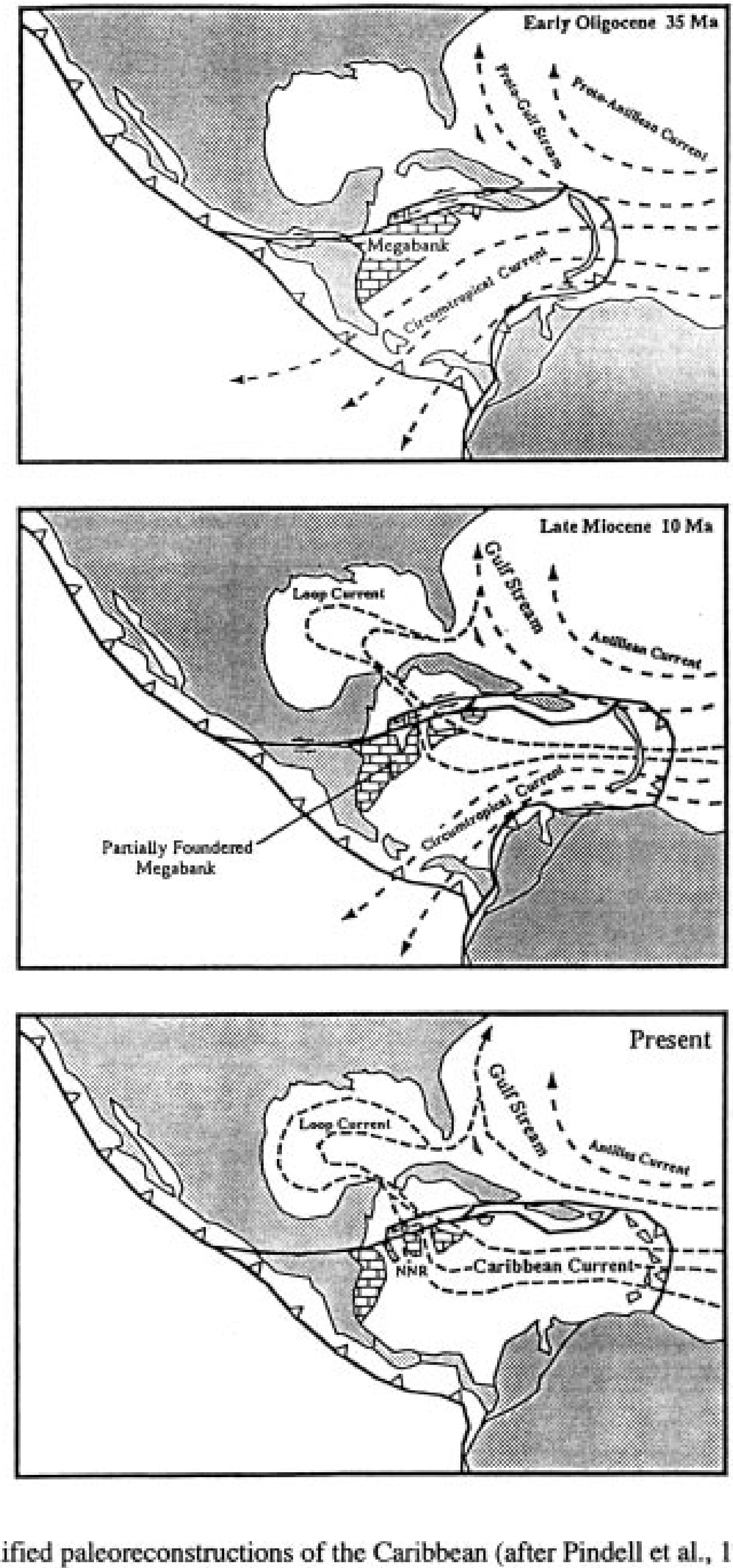


Figure 7: Simplified paleoreconstructions of the Caribbean (after Pindell et al., 1988), showing the timing of proposed megabank foundering and the resultant current regimes from Oligocene to the present (based on model of Droxler et al., 1992).

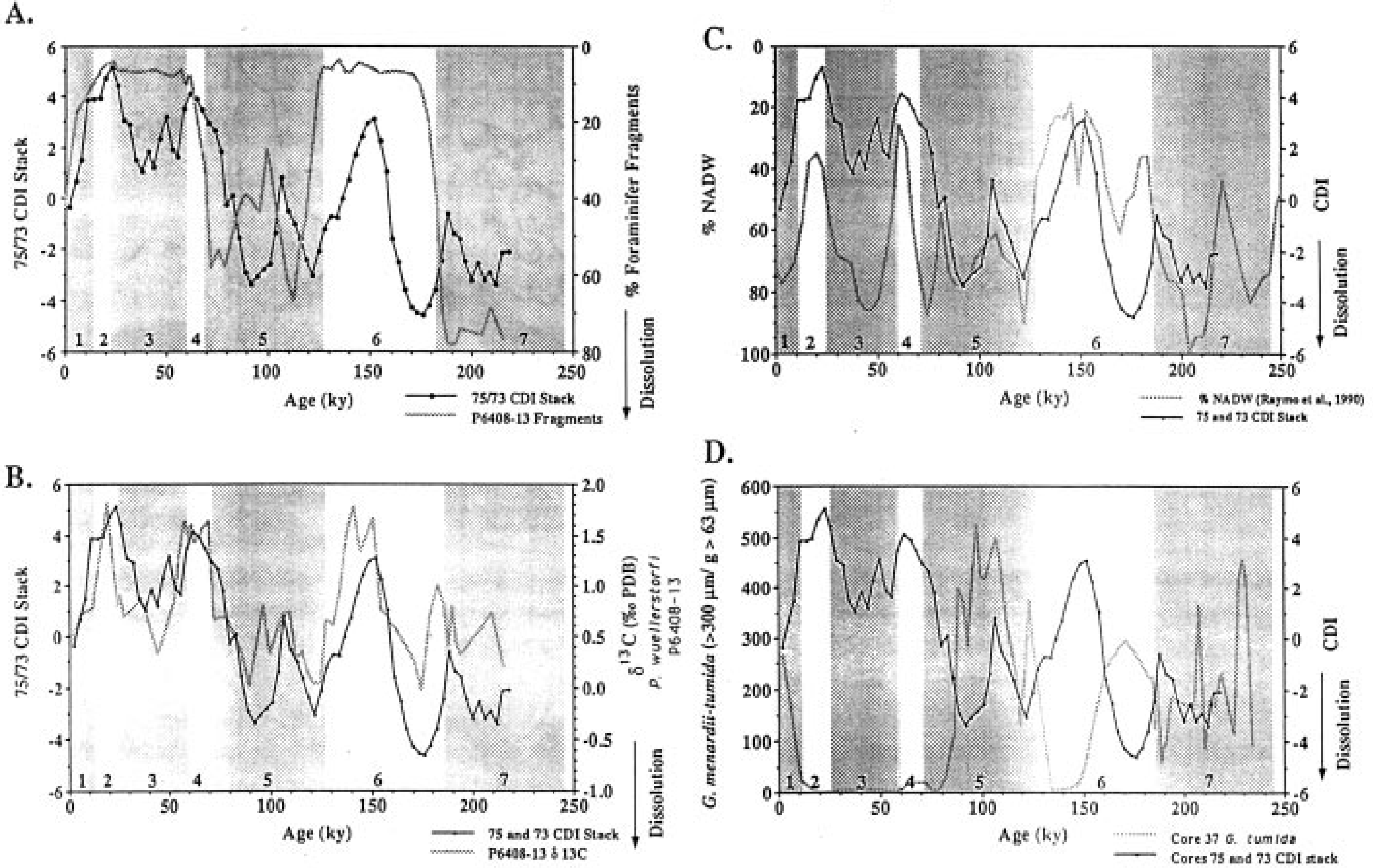


Figure 8: Metastable $CaCO_3$ composite dissolution index (CDI) for Nicaragua Rise cores CH8802-75 and CH8802-73 (Haddad, 1994), compared to (A) percentage of foraminifer fragments and (B) benthic foraminiferal $\delta^{13}C$ from the deep Venezuela Basin. Similarities between these records suggest that Caribbean carbon chemistry has been similar from the base of the thermocline to abyssal depths during the last 250 k.y. (C) shows good correlation between the shallow intermediate water CDI record and % NADW (Raymo et al., 1990). High NADW formation corresponds to high AAIW flux into the North Atlantic and Caribbean and poor carbonate preservation. Low NADW formation corresponds to low AAIW flux into the Caribbean and good carbonate preservation. (D) shows that reduced southern source upper water layer advection into the Caribbean during periods of good carbonate preservation is also suggested by the near inverse correlation between *G. menardii-tumida* abundance and the CDI.

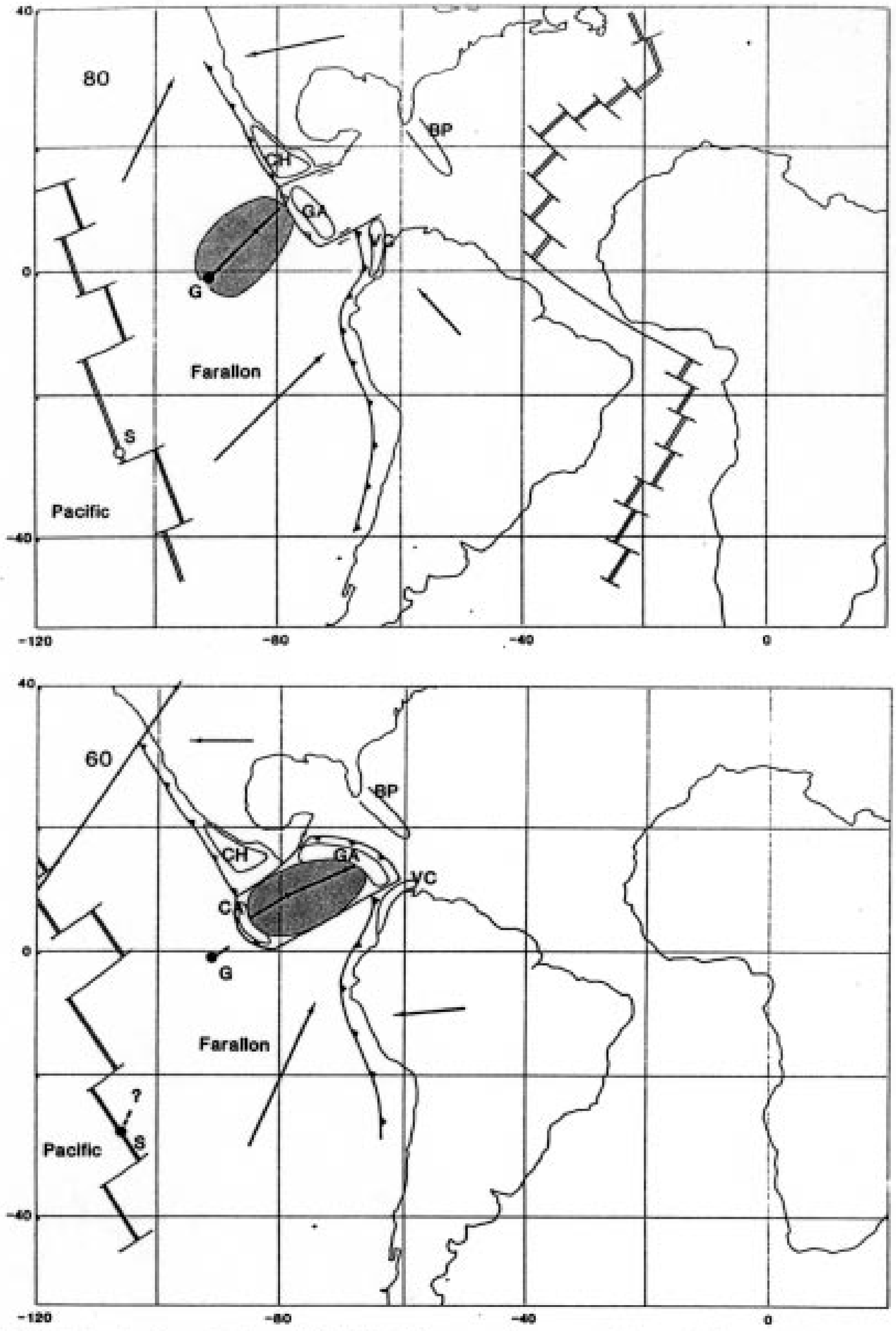


Figure 9: Plate tectonic evolution of the Caribbean region, assuming a Galapagos hot-spot source for the Caribbean large igneous province (Duncan and Hargraves, 1984). Upper figure shows the configuration of the region at 80 Ma, with the oceanic plateau formed at the Galapagos hot spot (solid circle) shown in stippled pattern. Arrows indicate plate motion vectors. The lower figure shows the configuration at 60 Ma, where CA is the Central America arc, G is the Galapagos hot spot, and S is the Sala y Gomez hot spot.

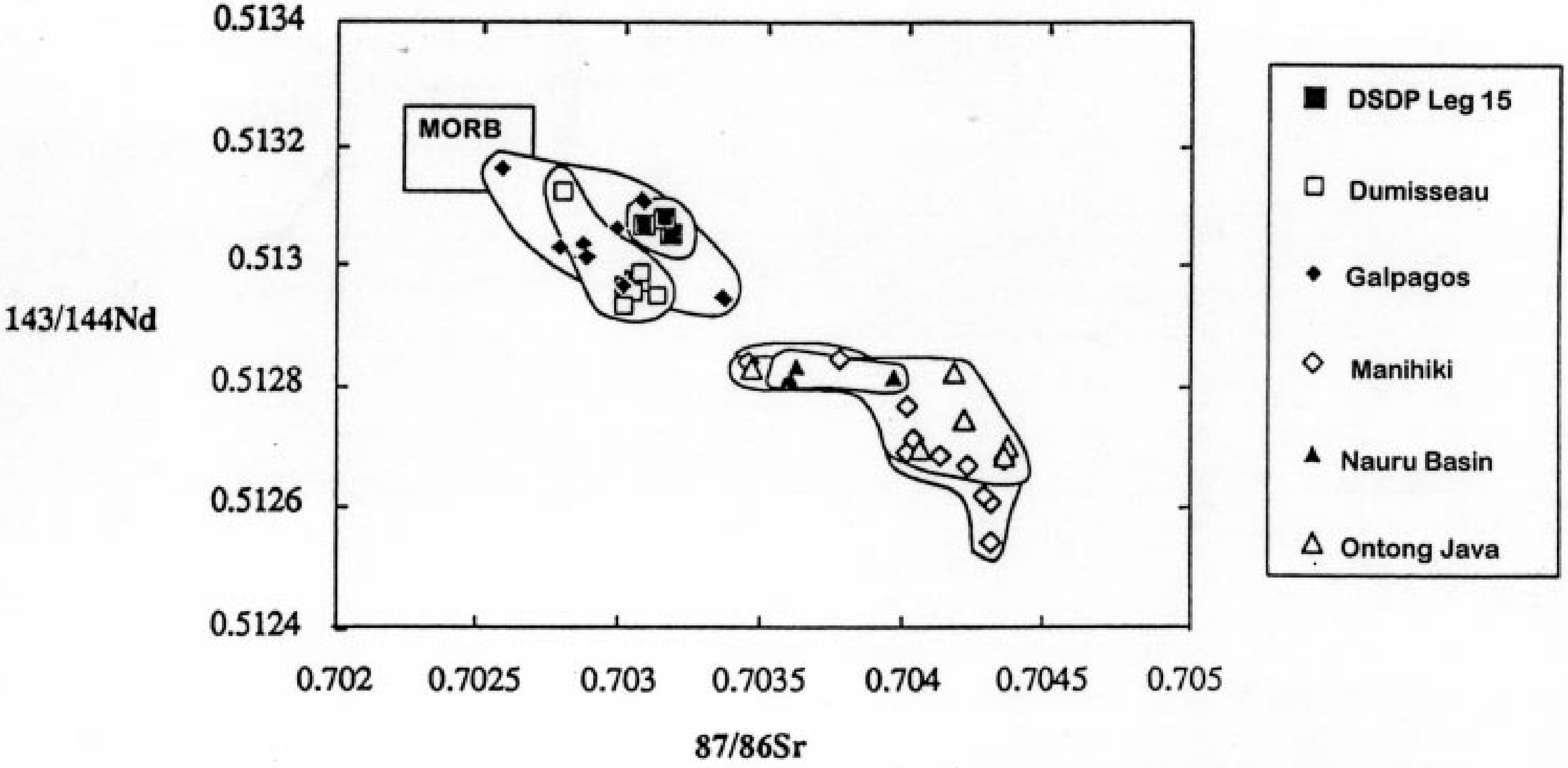


Figure 10: Neodynium and strontium isotopic data on Leg 15 basalts from the Caribbean oceanic plateau (G. Waggoner in Speed et al., 1987), the Dumisseau Formation in Haiti (Sen et al., 1988), the Galapagos hot spot basalts (K. Harpp, unpubl., 1990), and other oceanic plateau basalts (Mahoney, 1987). The correspondence in radiogenic isotope character of the Caribbean plateau basalts and the Galapagos hot spot supports the idea of a common mantle source, and a source of the Caribbean oceanic plateau from the Galapagos hot spot.

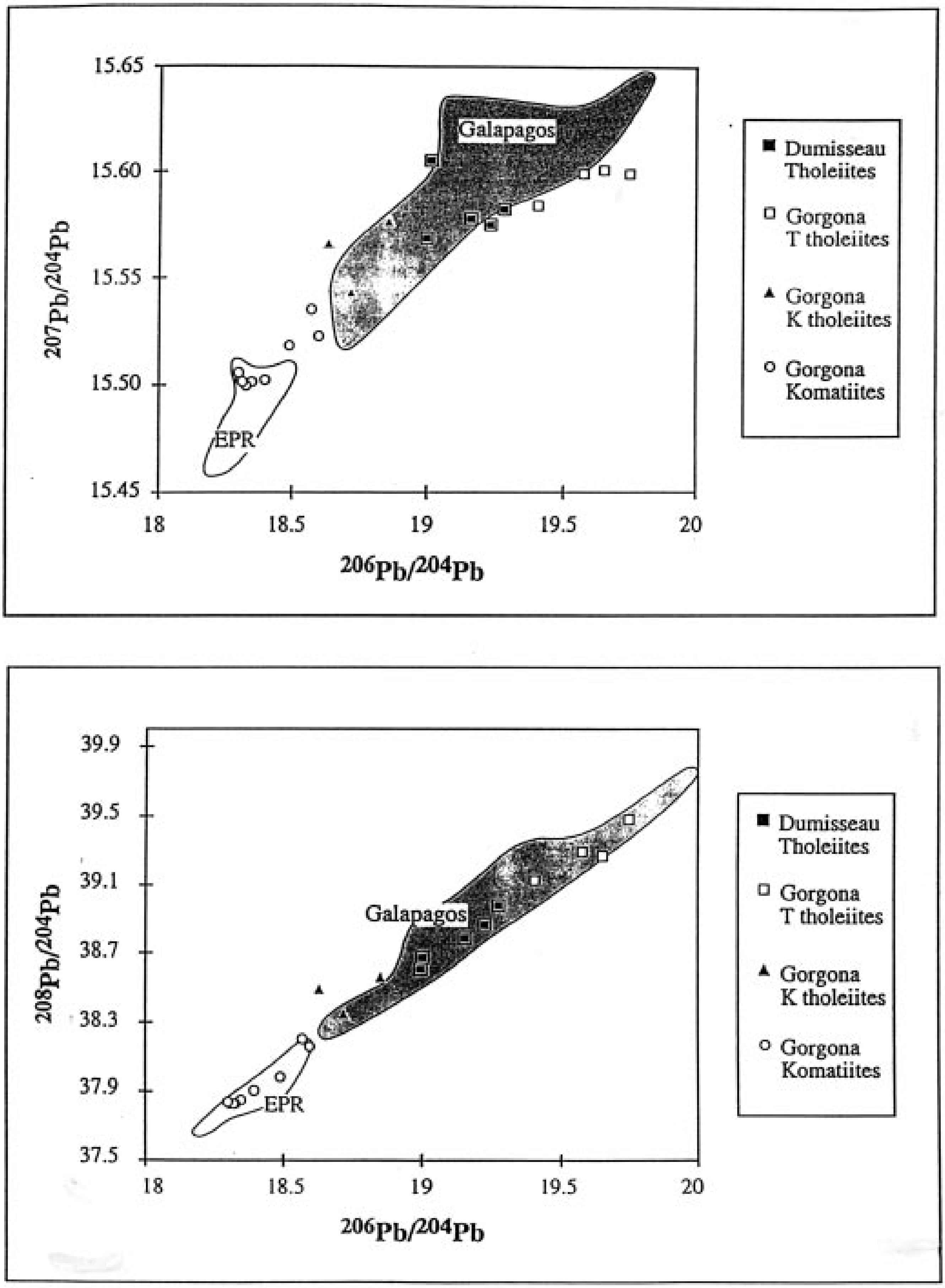


Figure 11: The isotopic ratios $^{207}Pb/^{204}Pb$ (upper) and $^{208}Pb/^{204}Pb$ (lower) in basalts and komatiites from circum-Caribbean regions (Dumisseau Formation, Haiti, and Gorgona Island), in relation to the isotopic fields for Galapagos hot spot and East Pacific Rise (EPR) basalts.

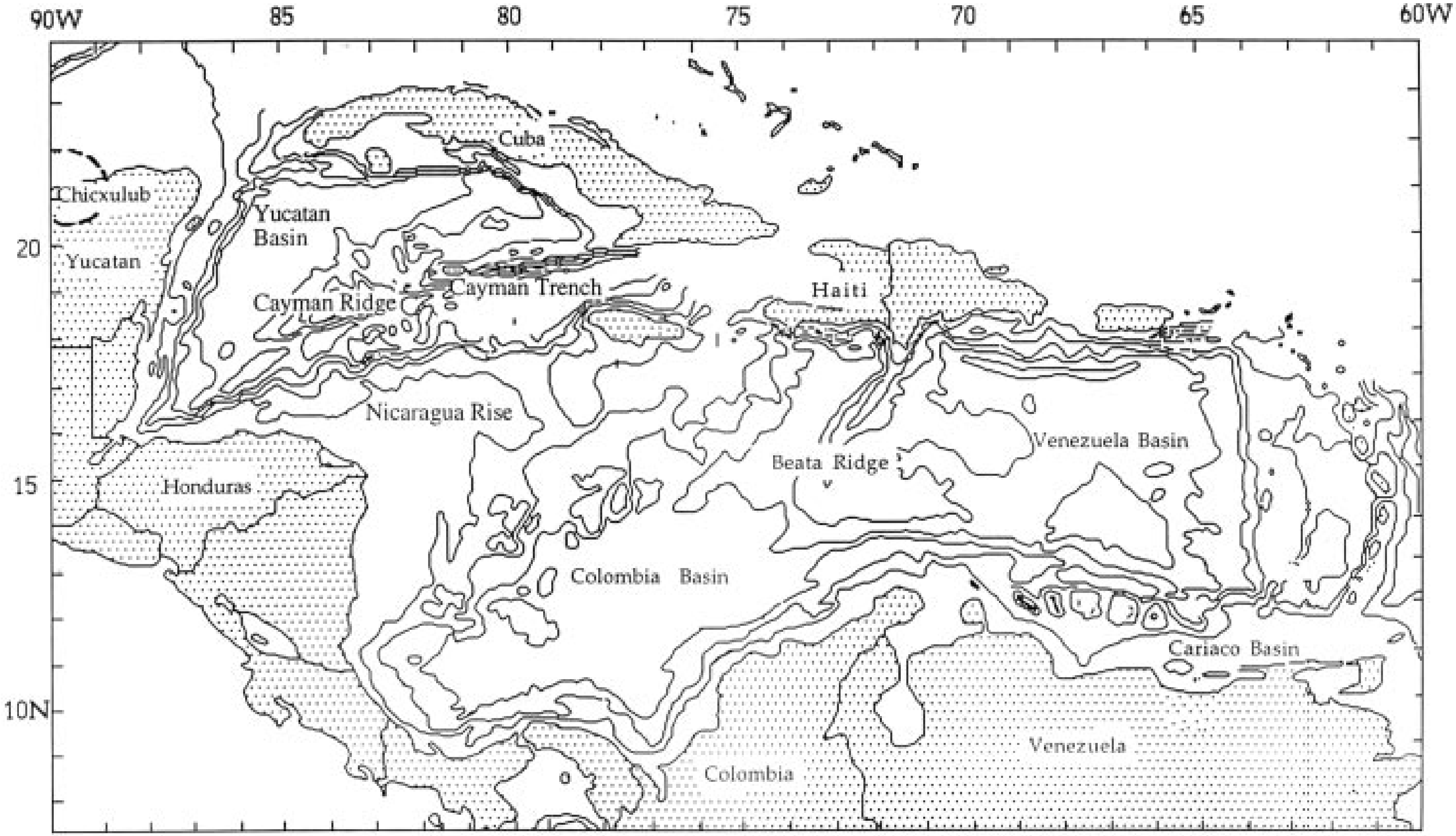


Figure 12: Caribbean physiographic provinces discussed in the text.

SITE SUMMARIES

PROPOSED PRIMARY SITES

Site: S-2B (Cayman Ridge)

Priority: 1

Position: 19°29.1'N, 82°55.6'W

Water Depth: 3177 m

Sediment Thickness: 845 m (approved to a depth of 855 mbsf)

Seismic Coverage: SCS lines E9417-13 and E9417-16; SP 320 on SCS Line E9417-13

Objectives:

(1) Determining processes of impact deposition at a K/T boundary sequence relatively proximal to the Yucatan Peninsula.
(2) Late Cretaceous(?) and Paleogene tropical ocean and climate history.
(3) Isotopic and microfaunal/floral documentation of regional paleoceanographic conditions before and after middle Miocene(?) subsidence of the northern Nicaragua Rise (i.e., the Neogene initiation and evolution of the Caribbean Current downstream of the Nicaragua Rise).
(4) Assessing the history of Atlantic intermediate waters in the Yucatan Basin.
(5) Age and nature of the Cayman Ridge basement.

Drilling Program: Hole A: APC to refusal, XCB to total depth (basement). Hole B (if necessary): wash-down, RCB to basement; 10 m penetration of basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, hemipelagic clay, chalks, marls, cherts, and basalts.

Site: S-6 (unnamed rise, Colombia Basin)

Priority: 1

Position: 12°43.2'N, 78°46.2'W

Water Depth: 2811 m

Sediment Thickness: 1313 m (approved to a depth of 1335 mbsf)

Seismic Coverage: UTIG MCS line CT1-12A; SCS RC-1201; SP 4780 on UTIG MCS Line CT1-12A

Objectives:

(1) Recovery of a K/T sequence distal from the Chicxulub crater and on a different tangent to the crater than other K/T sequences (for testing the direction of the K/T impact and types of emplacement processes associated with the impact).

(2) Late Cretaceous and Paleogene tropical ocean and climate history.

(3) Recovery of an extended sequence for high-resolution chronostratigraphy of the low latitude Late Cretaceous.

(4) Recovery of Paleogene and Neogene sediments that, at shallower sub-bottom depths, will be appropriate for stable isotopic reconstruction of low latitude paleoceanographic conditions and events, including the Miocene and Pliocene transition from seawater flow westward through the Central American Seaway to the present post-closure situation of northward flow through the Yucatan channel.

(5) To determine impact of the carbonate megabank partial drowning and Caribbean Current initiation, possibly during middle to late Miocene, on the sedimentation in upcurrent adjacent basins still open to the low latitude eastern Pacific Ocean.

(6) To determine the impact of closure of the Central American Seaway on the pelagic sedimentation especially due to the isolation of the Colombia basin from the low latitude eastern Pacific Ocean and the general strengthening of the Caribbean current.

(7) Relatively high-resolution analysis of tropical climate variability and Late Quaternary NAIW history.

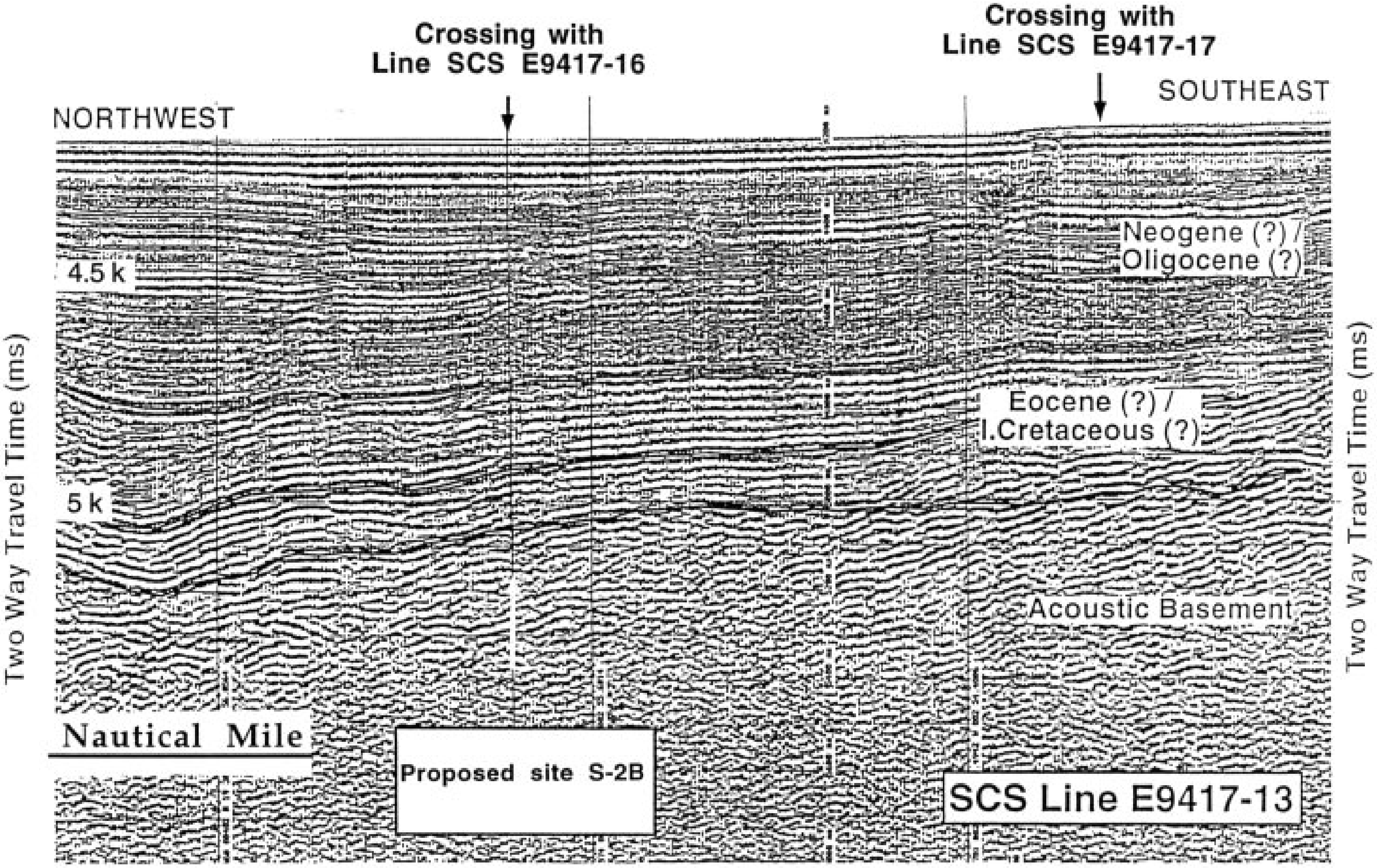
(8) Documentation of Atlantic intermediate water history in the Colombia Basin.

Drilling Program: Hole A: APC to refusal, XCB to refusal. Hole B: drill ahead to approximately 600 m, set reentry cone and case hole, RCB to basement; 10 m basement penetration.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, hemipelagic clay, chalks, marls, cherts, and basalts.

Human Hazards: A NE-SW-trending cable lies 6 nmi southeast of the site (see chart INT 402 DMA 1985). A letter from AT&T Underwater Systems confirms that the site is at a safe distance from the cable.


Crossing with
Line SCS E9417-16
Crossing with
Line SCS E9417-17
NORTHWEST
SOUTHEAST
4.5 k
5 k
Two Way Travel Time (ms)
Neogene (?) /
Oligocene (?)
Eocene (?) /
l.Cretaceous (?)
Acoustic Basement
Two Way Travel Time (ms)
Nautical Mile
Proposed site S-2B
SCS Line E9417-13

GRAPHIC SUMMARY, SITE S-2B

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			
0 m	Seafloor	Holocene Neogene Section	1.6 km/s	Foram-Nanno Chalk/ooze, Marl and Clay	Pelagic above CCD	Neogene section ?	Relatively thick and undisturbed Neogene section?
432 m	A "?	E. - Eocene	2.5 km/s	Siliceous Limestone, Chalk, Chert Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone			This level is marked by a prominent basin-wide reflector.
657 m							
845 m	Acoustic basement	> L. Cretaceous	> 4.5 km/s	Igneous rocks?	Oceanic Plateau Basalt ?		Rosencrantz (1990) has estimated a Late Cretaceous age for the basement, by comparison with igneous rocks exposed in the north wall of the Cayman Trench.

Site: S-6 (unnamed rise, Colombia Basin)

Priority: 1

Position: 12°43.2'N, 78°46.2'W

Water Depth: 2811 m

Sediment Thickness: 1313 m (approved to a depth of 1335 mbsf)

Seismic Coverage: UTIG MCS line CT1-12A; SCS RC-1201; SP 4780 on UTIG MCS Line CT1-12A

Objectives:

(1) Recovery of a K/T sequence distal from the Chicxulub crater and on a different tangent to the crater than other K/T sequences (for testing the direction of the K/T impact and types of emplacement processes associated with the impact).
(2) Late Cretaceous and Paleogene tropical ocean and climate history.
(3) Recovery of an extended sequence for high-resolution chronostratigraphy of the low latitude Late Cretaceous.
(4) Recovery of Paleogene and Neogene sediments that, at shallower sub-bottom depths, will be appropriate for stable isotopic reconstruction of low latitude paleoceanographic conditions and events, including the Miocene and Pliocene transition from seawater flow westward through the Central American Seaway to the present post-closure situation of northward flow through the Yucatan channel.
(5) To determine impact of the carbonate megabank partial drowning and Caribbean Current initiation, possibly during middle to late Miocene, on the sedimentation in upcurrent adjacent basins still open to the low latitude eastern Pacific Ocean.
(6) To determine the impact of closure of the Central American Seaway on the pelagic sedimentation especially due to the isolation of the Colombia basin from the low latitude eastern Pacific Ocean and the general strengthening of the Caribbean current.
(7) Relatively high-resolution analysis of tropical climate variability and Late Quaternary NAIW history.
(8) Documentation of Atlantic intermediate water history in the Colombia Basin.

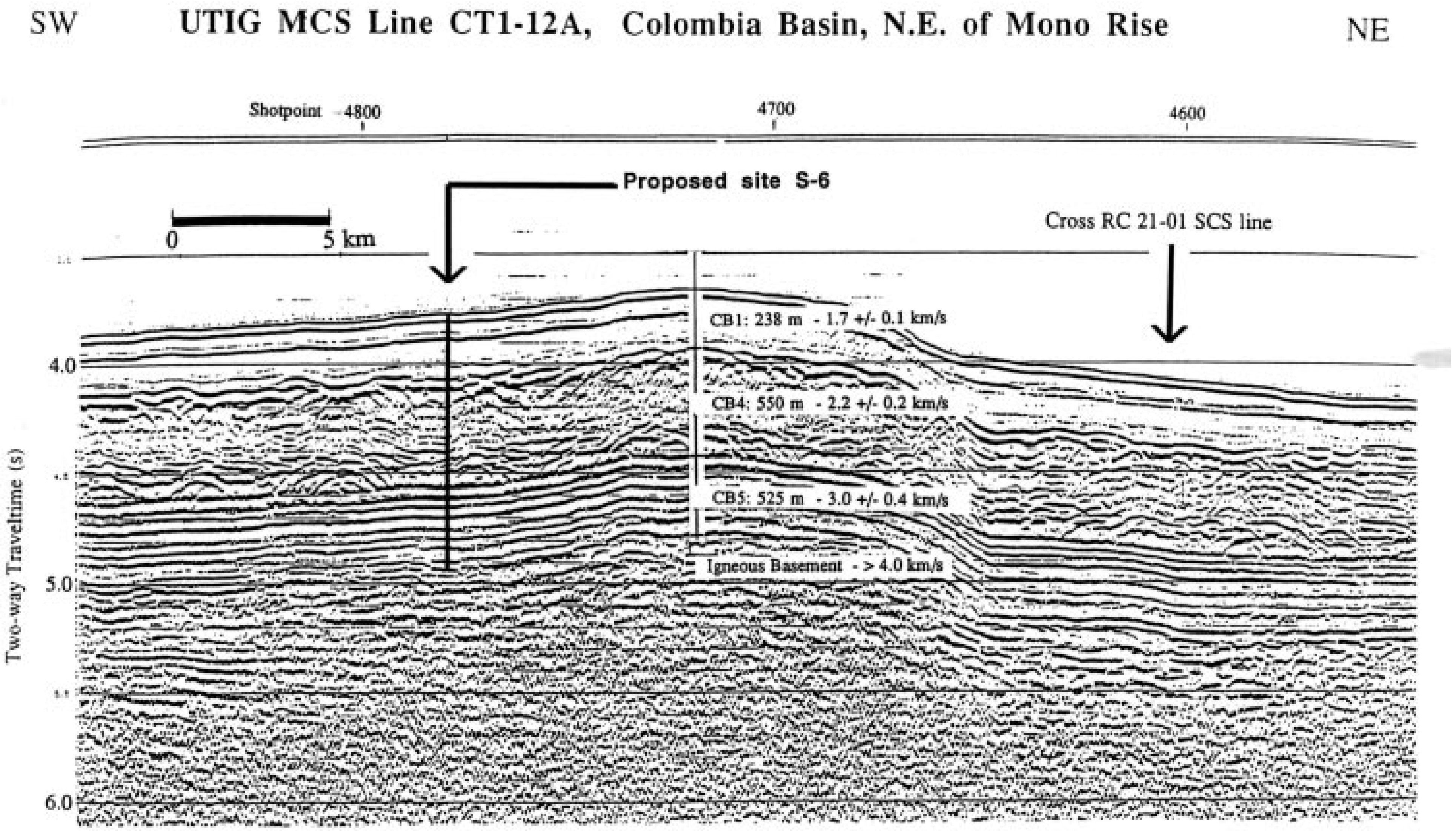
Drilling Program: Hole A: APC to refusal, XCB to refusal. Hole B: drill ahead to approximately 600 m, set reentry cone and case hole, RCB to basement; 10 m basement penetration.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, hemipelagic clay, chalks, marls, cherts, and basalts.

Human Hazards: A NE-SW-trending cable lies 6 nmi southeast of the site (see chart INT 402 DMA 1985). A letter from AT&T Underwater Systems confirms that the site is at a safe distance from the cable.

UTIG MCS Line CT1-12A, Colombia Basin, N.E. of Mono Rise



Seismic units CB1, CB4, CB5 and interpretations modified from Bowland, C.L., and Rosencrantz, E., GSA Bull. v. 100, p534-546, April 1988; Bowland, C.L., GSA Bull. v. 105, p1321-1345, October 1993.

CB1: Foram/Nanno Ooze, Calcareous Clay, Pelagic Drape, Miocene - Holocene, Sampled at DSDP 154 & 502.

CB4: Hemipelagic clay, Siliceous & Calcareous Ooze, M. Eocene - Miocene, Sampled at DSDP 502.

CB5: Indurated Chalk, Chert, Siliceous Clay - L. Cretaceous - Eocene. Comparable to A" to B" interval in the Venezuela Basin sampled at DSDP Sites, 146, 150, 151, 152.

Igneous Basement: Oceanic Plateau, L. Cretaceous, Comparable to Horizon B" in the Venezuela Basin sampled at DSDP Sites, 146, 150, 151, 152.

GRAPHIC SUMMARY, SITE S-6

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			
0 m	Seafloor Seismic Unit **CB1** Bowland, 1993	Holocene	1.7 km/s	Foram-Nanno ooze, Calcareous clay		23.8	Seismic units CB1, CB4, CB5 from Bowland, C.L.,1993, GSA Bull. V. 105, p1321-1345.
238 m	Seismic Unit **CB4** Bowland, 1993	Miocene	2.2 km/s	Hemipelagic clay Siliceous/calcareous Ooze	Pelagic drape deposited on basement high above CCD	13.8	
788 m	Seismic Unit **CB5** Bowland, 1993	M. Eocene	3.0 km/s	Chalk, Chert, Siliceous clay		13.8	Comparable to seismic reflection A" in the Venezuela Basin.
1313 m		L. Cretaceous	> 4.0 km/s	Igneous Basement	Oceanic Plateau Basalt - (88 Ma?)		Comparable to seismic reflection B" in the Venezuela Basin correlating to the top of L. Cretaceous Basalts sampled during DSDP Leg 15.

Site: NR-1/2 (Pedro Channel, northern Nicaragua Rise)

Priority: 1

Position: 16°33.2'N, 79°52.0'W

Water Depth: 910 m

Sediment Thickness: 600 m (approved to a depth of 650 mbsf)

Seismic Coverage: SCS lines CH9204-30 and CH9204-05; SP 1495 on SCS line CH9204-30

Objectives:

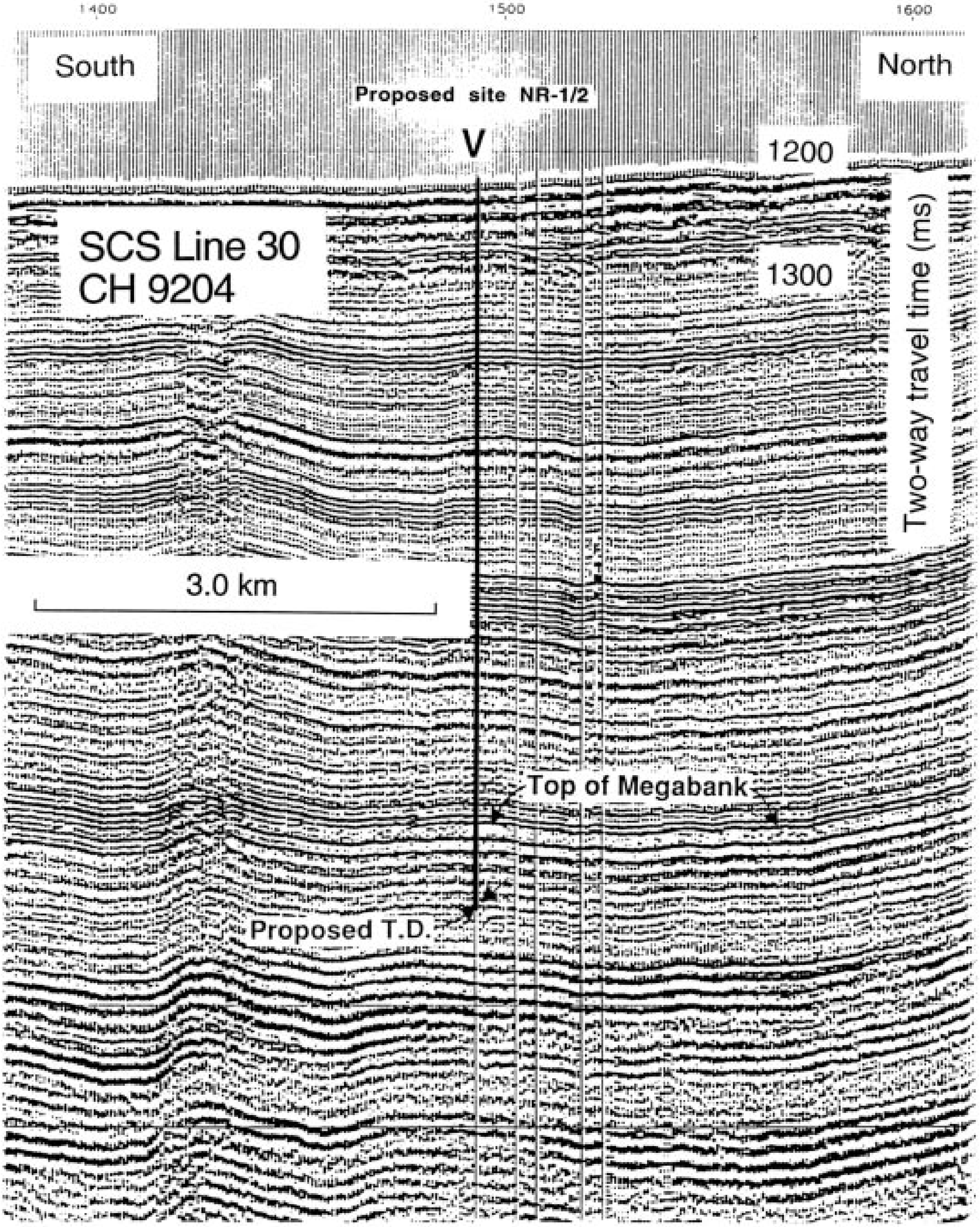
1) Estimate the timing (possibly middle Miocene?) for the formation of Pedro Channel by drilling in the transition from periplatform sediments to the underlying shallow water limestones (i.e., the upper part of the drowned megabank). Seaways formed by the partial drowning of the carbonate megabank covering the northern Nicaragua Rise during the Oligocene and early Miocene (Pedro Channel and Walton Basin; NR-1/2 and alternate site NR-4), are part of a major gateway opening along the Nicaragua Rise for the Caribbean Current. The formation of these seaways has therefore played a significant role in the establishment of the modern Western Boundary Current in the North Atlantic Ocean.

2) Unravel the history of the Caribbean Current across the northern Nicaragua Rise by drilling the sedimentary periplatform sequence overlying the drowned parts of the megabank. In addition to the widening and deepening of the newly formed northern Nicaragua Rise seaways, variations of the Caribbean Current strength since the late Miocene would also be related to the gradual shoaling and ultimate closure of the Central American Seaway in the mid Pliocene (Coates et al., 1992). The drilling strategy is to penetrate the most continuous periplatform section, first to develop late Neogene litho- and chronostratigraphies, and then to analyze the direct influence of the Caribbean Current on the sediment deposition. By drilling this sedimentary sequence, features in the high-resolution seismic lines away from NR-1/2 (e.g., as major erosion, tectonic displacement) could be placed within a chrono- and lithostratigraphic framework.

Drilling Program: Hole A: APC to refusal, XCB to total depth (carbonate platform). Hole B (if required): wash-down, RCB to total depth. Time permitting, a second APC-only hole will be drilled.

Logging and Downhole Operations: Four runs with the quad combo-tool string, geochemical tool string, GHMT magnetic logging tool, and FMS. Core orientation on Hole A.

Nature of Rock Anticipated: Periplatform oozes and lithified neritic carbonates.


1400
1500
1600
South
North
Proposed site NR-1/2
V
1200
1300
Two-way travel time (ms)
SCS Line 30
CH 9204
3.0 km
Top of Megabank
Proposed T.D.

GRAPHIC SUMMARY, SITE NR-1/2

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. rate of sediment accumulation (m/My)*	*Comments*
0 m	Seafloor	Holocene					
		Pleistocene to Pliocene		Periplatform ooze	Shallow basin		Sedimentary sequence formed as a result of drowning of carbonate megabank.
550 m		Mid-Miocene?					
				Lithified neritic carbonates	Carbonate bank		

Site: S-3B (lower Nicaragua Rise, near DSDP Site 152)

Priority: 1

Position: 15°45.4'N, 74°54.6'W

Water Depth: 3322 m

Sediment Thickness: 460 m (approved to a depth of 470 mbsf)

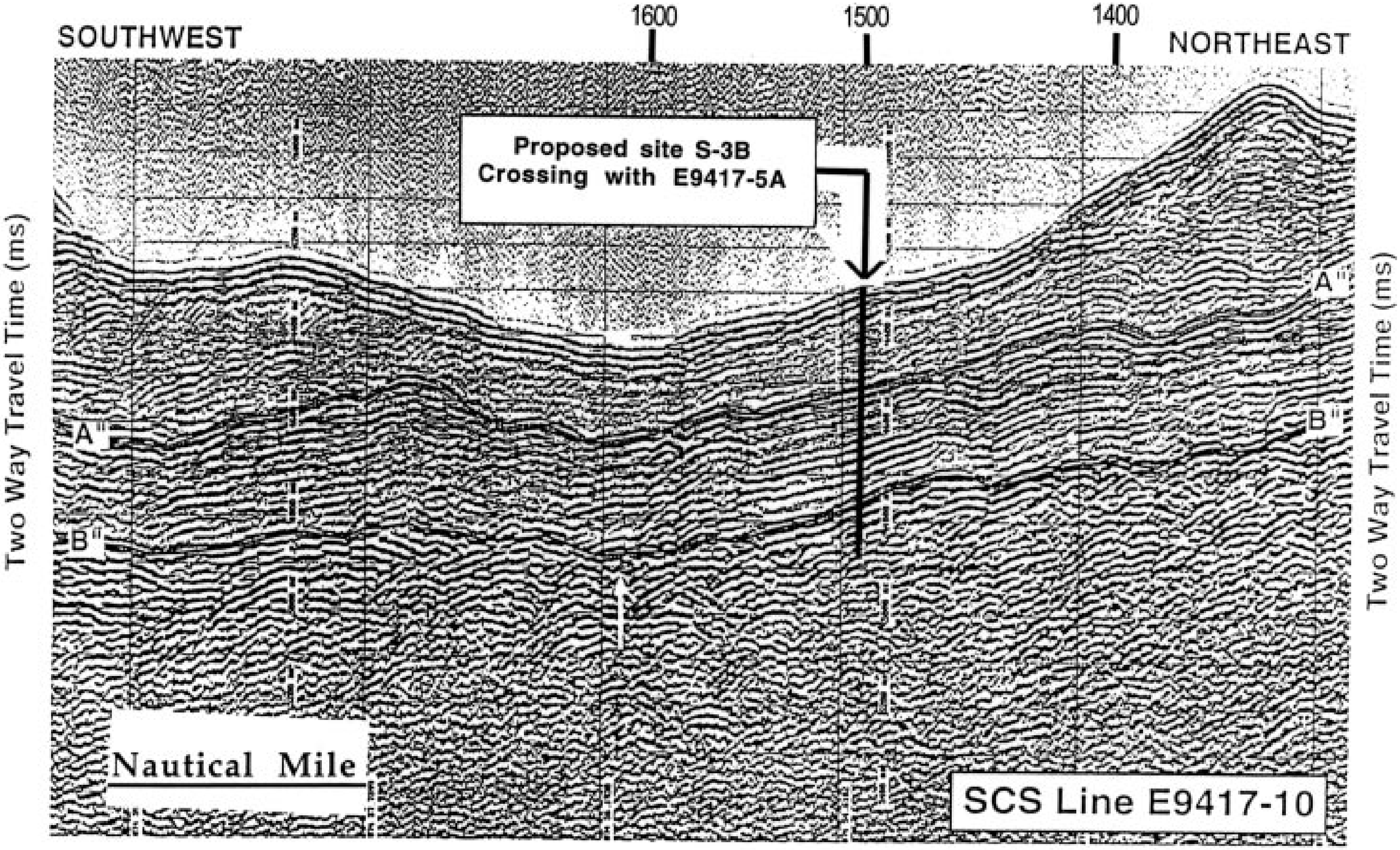
Seismic Coverage: SCS lines E9417-10 and E9417-5A; SP 1500 on SCS Line E9417-10

Objectives:
(1) Recovery of a relatively undisturbed high-resolution, deep-water K/T sequence.
(2) Cretaceous and Paleogene sediments suitable for isotopic reconstruction of low latitude surface water temperatures (e.g., for determining latitudinal gradients in Late Cretaceous and assessing the relative importance of greenhouse gas concentrations (i.e., atmospheric CO_2) and latitudinal heat transport to Late Cretaceous climate).
(3) Development of high-resolution low latitude Late Cretaceous and Paleogene chronostratigraphy.
(4) Assessment of low latitude paleoceanographic changes that have taken place from Late Cretaceous to Holocene times.

Drilling Program: Hole A: APC to refusal, XCB/MDCB to basement; 10 m basement penetration.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS in K/T boundary interval.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, chalks, marls, cherts, and basalts.


SOUTHWEST
1600
1500
1400
NORTHEAST
Proposed site S-3B
Crossing with E9417-5A
Two Way Travel Time (ms)
Two Way Travel Time (ms)
A"
B"
A"
B"
Nautical Mile
SCS Line E9417-10

GRAPHIC SUMMARY, SITE S-3B

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			Depths, velocities, and accumulation rates are from DSDP Leg 15 Init. Repts. For Site 152, 18 nmi northeast of S-3.
0 m	Seafloor	Holocene Incomplete Neogene Section	1.6 km/s	Foram-Nanno Chalk/ooze, Marl and Clay	Pelagic above CCD	Incomplete Neogene section ?	Discontinuous reflections.
160 m	A"	E. - Eocene	2.5 km/s	Siliceous Limestone, Chalk, Chert Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone		8-31	A" is a prominent basinwide reflection appearing continuous and time synchronous.
460 m	B"	Campanian - Maas.	> 4.5 km/s	Interlayered Basalt and Foram Limestone	Oceanic Plateau Basalt - interlayered sediment		B" is a high-amplitude, flat-lying (smooth) basinwide reflection correlating to the top of L. Cretaceous basalts sampled during DSDP Leg 15.

Site: CB-1A (Cariaco Basin, DSDP Site 147)

Priority: 1

Position: 10°42.5'N, 65°10.5'W

Water Depth: 892 m

Sediment Thickness: 1500 m (approved to a depth of 180 mbsf)

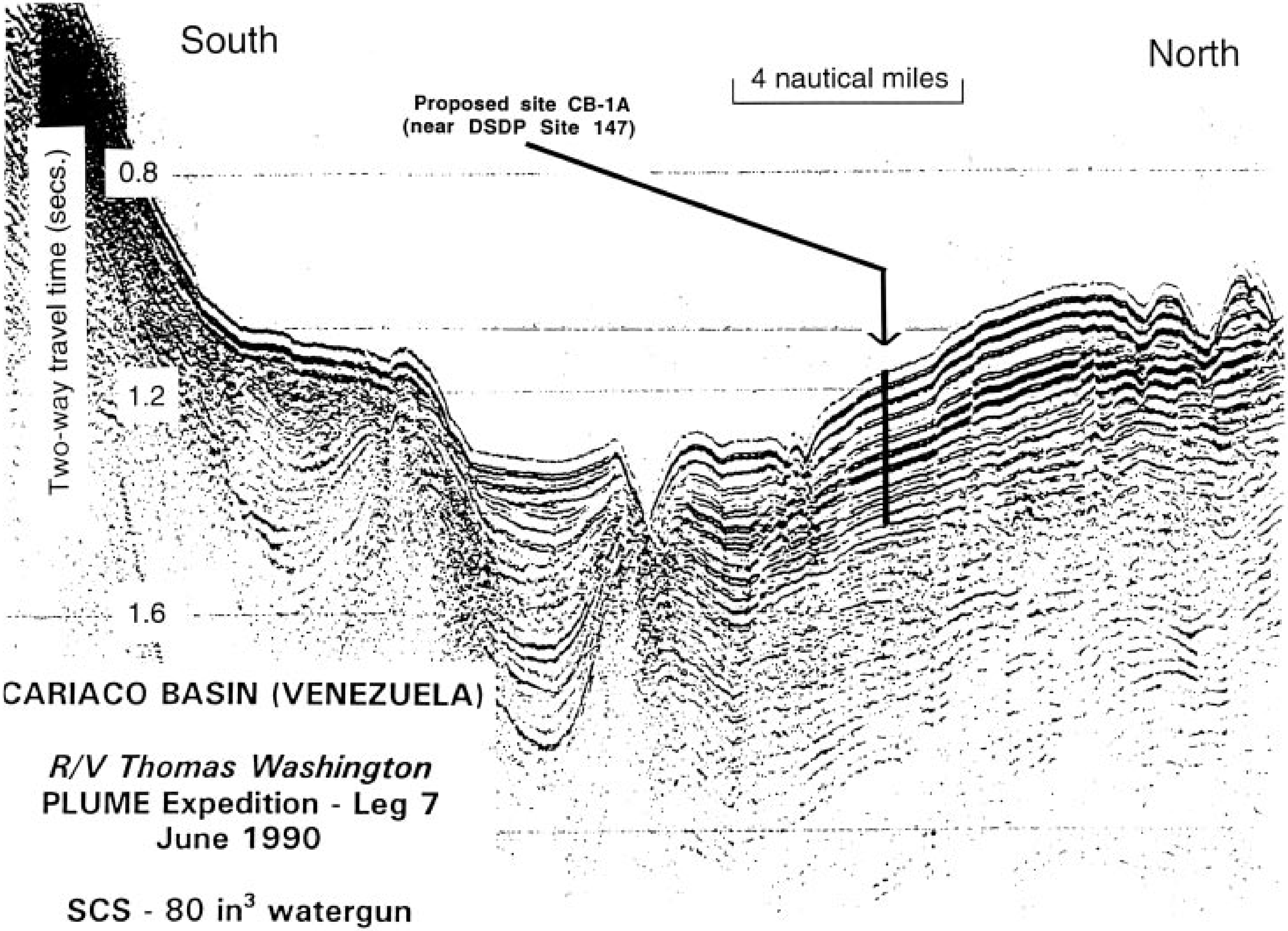
Seismic Coverage: SCS survey from PLUME Leg 07, lines K1-J1 and W1-X1

Objectives: Extremely high-resolution records for studying
(1) Rates and magnitudes of tropical Atlantic climate change at interannual to millennial time scales over the late Quaternary (including late Quaternary variability in tradewind intensity and position of the intertropical convergence zone).
(2) Relationships between Cariaco Basin ventilation and paleoclimatic and paleoceanographic change in the late Quaternary.
(3) Relationships between environmental change and sedimentary and geochemical properties in modern large anoxic basins.
(4) A downstream link to paleoceanographic objectives of Amazon Fan drilling (Leg 155). Re-drilling of DSDP Site 147 (Leg 15).

Drilling Program: Triple APC/XCB to 180 mbsf.

Logging and Downhole Operations: Core orientation on Hole A and Hole B.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, hemipelagic silts and clays, chalks, marls.



CARIACO BASIN (VENEZUELA)

R/V Thomas Washington
PLUME Expedition - Leg 7
June 1990

SCS - 80 in^3 watergun

GRAPHIC SUMMARY, SITE CB-1A

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
0 m	Seafloor	Holocene					
				Bluish Clays	Anoxic basin		Varved sediments.
		Pleistocene		Marl ooze			This is re-drilling of DSDP Site 147.
			1.5				
						40	
200 m		Pliocene?		Dolomite			

SITE SUMMARIES

PROPOSED SECONDARY SITES

(No prioritization of sites should be inferred)

Site: NR-4 (Walton Basin, northern Nicaragua Rise)

Priority: 2

Position: 17°22.8'N, 77°42.5'W

Water Depth: 850 m

Sediment Thickness: 350 m (approved to a depth of 400 mbsf)

Seismic Coverage: SCS lines CH0288-31 and CH 0288-36; SP 800 on SCS line CH0288-31

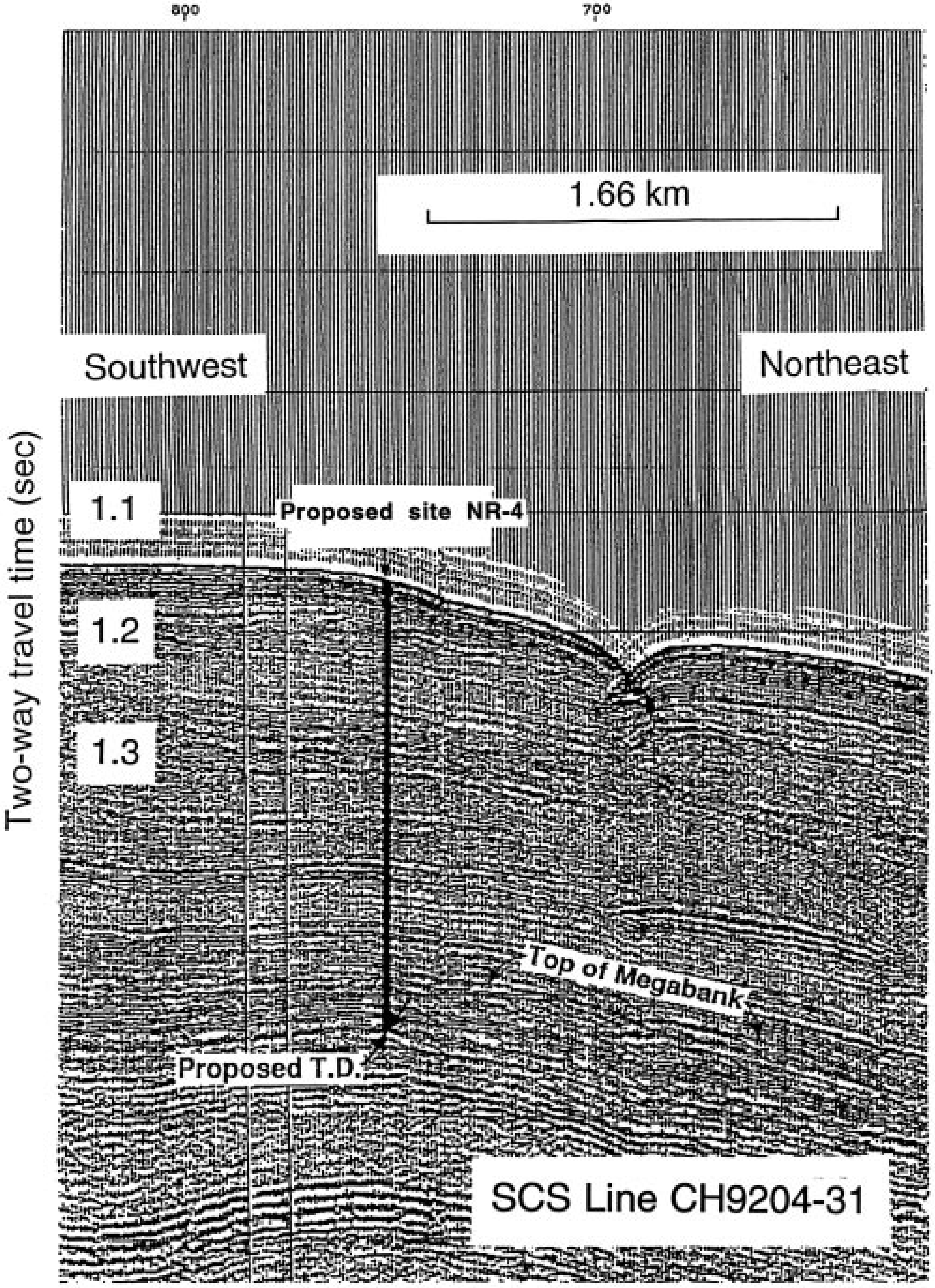
Objectives: To closely date the middle Miocene(?) submergence of the Walton Basin, the second prominent gateway for Caribbean Current flow over the northern Nicaragua Rise (for closer estimation of the timing of Caribbean Current initiation, since it should resolve any possible diachroneity in subsidence of the Pedro Channel and Walton Basin). The comparisons between proposed sites NR-1/2 and NR-4 are essential to estimate the possible diachronous formation of Pedro Channel and Walton Basin through partial drowning of the megabank, in addition to the differences and similarities in the history of the Caribbean Current between both basins (see Droxler et al., 1993). Otherwise, its late Neogene and Quaternary paleoceanographic utility should be similar to that of proposed site NR-1.

Drilling Program: Hole A: APC to refusal, XCB to total depth (carbonate platform). Hole B (if required): wash-down, RCB to total depth.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and FMS.

Nature of Rock Anticipated: Periplatform oozes and lithified neritic carbonates.

Human Hazards: A SE-NW-trending Jamaica-Cayman undersea cable lies 7 nmi north of this site (chart INT 402 DMA 1985). A letter from Captain Glyn Wrench, of Cable and Wireless Marine Ltd., confirms that the cable is 10 km from the site, and that drilling at this site “would not cause a problem” in connection with the cable (3/20/95).


800
700
1.66 km
Southwest
Northeast
Two-way travel time (sec)
1.1
1.2
1.3
Proposed site NR-4
Top of Megabank
Proposed T.D.
SCS Line CH9204-31

GRAPHIC SUMMARY, SITE NR-4

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. rate of sediment accumulation (m/My)*	*Comments*
0 m	Seafloor	Holocene					
		Pleistocene to Pliocene	1.6	Periplatform ooze	Shallow basin	20	Sedimentary sequence formed as a result of drowning of carbonate megabank.
350 m		Mid-Miocene?					
			2.5	Lithified neritic carbonates	Carbonate bank		

Site: S-2C (Cayman Ridge)

Priority: 2 (alternate to proposed site S-2B)

Position: 19°20.6'N, 83°06.0'W

Water Depth: 3120 m

Sediment Thickness: 855 m (approved to a depth of 870 mbsf)

Seismic Coverage: SCS lines E9417-18 and E9417-16; SP 500 on SCS line E9417-16

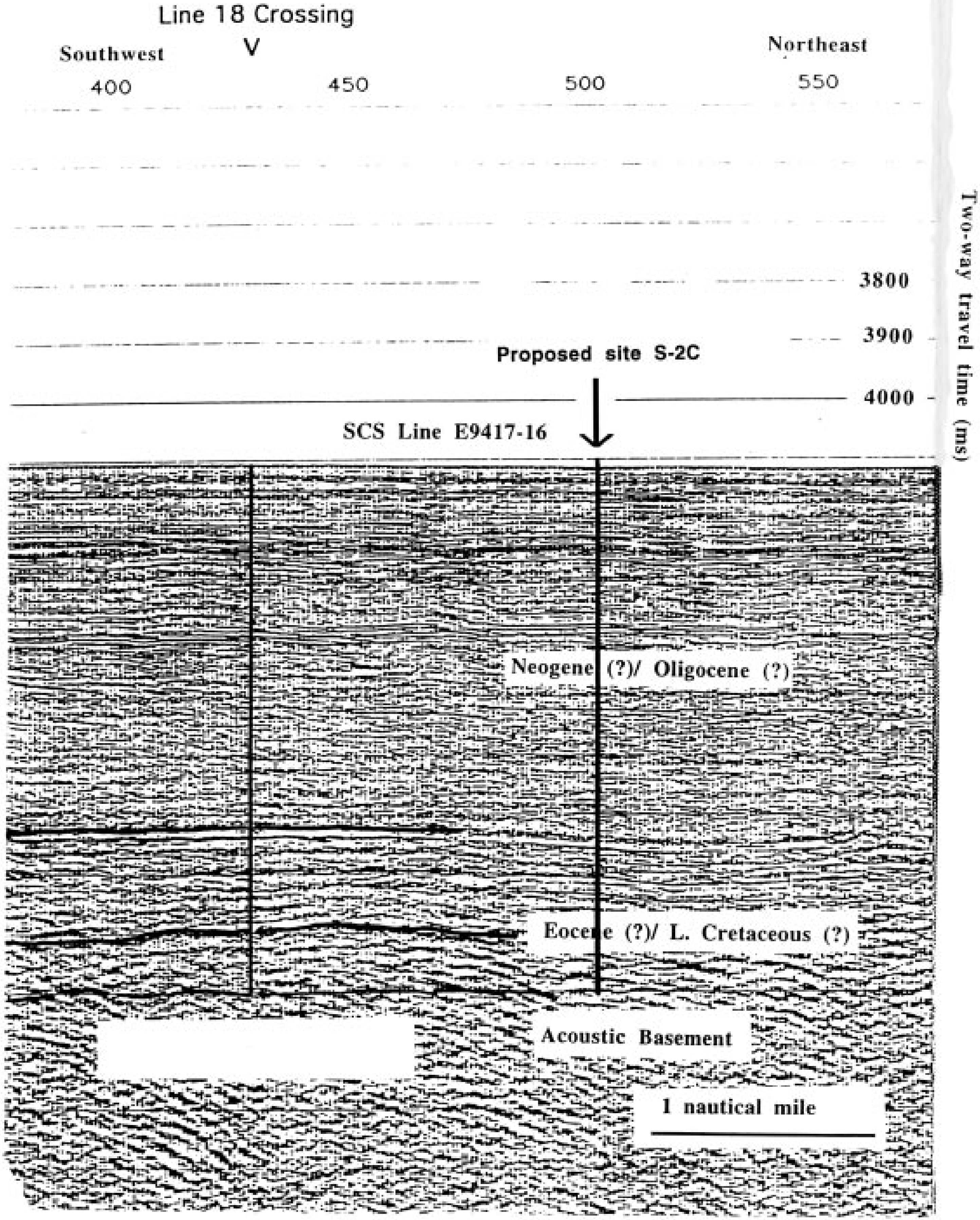
Objectives:

(1) Determining processes of impact deposition at a K/T boundary sequence relatively proximal to the Yucatan Peninsula.
(2) Isotopic and microfaunal/floral documentation of regional paleoceanographic conditions before and after middle Miocene(?) subsidence of the northern Nicaragua Rise (i.e., the Neogene initiation and downstream evolution of the Caribbean Current downstream of the Nicaragua Rise).
(3) Assessing the history of Atlantic intermediate waters in the Yucatan Basin.
(4) Age and nature of the Cayman Ridge basement.

Drilling Program: Hole A: APC to refusal, XCB to total depth (basement). Hole B (if necessary): wash-down, RCB to basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval. Core orientation on Hole A.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, hemipelagic clay, chalks, marls, cherts, and basalts.


Line 18 Crossing
V
Southwest
Northeast
400
450
500
550
3800
3900
4000
Two-way travel time (ms)
Proposed site S-2C
SCS Line E9417-16
Neogene (?)/ Oligocene (?)
Eocene (?)/ L. Cretaceous (?)
Acoustic Basement
1 nautical mile

GRAPHIC SUMMARY, SITE S-2C

Sub-bottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Ave. Rate of sediment accumulation (m/My)	Comments
			1.51	(water)			
0 m	Seafloor	Holocene Neogene Section	1.6 km/s	Foram-Nanno Chalk/ooze, Marl and Clay	Pelagic above CCD	Neogene section ?	Relatively thick and undisturbed Neogene section?
480 m	A "?	E. - Eocene	2.5 km/s	Siliceous Limestone, Chalk, Chert			This level is marked by a prominent basinwide reflector.
730 m				Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone			
855 m	Acoustic basement	> L. Cretaceous	> 4.5 km/s	Igneous rocks?	Oceanic Plateau Basalt?		Rosencrantz (1990) has estimated a Late Cretaceous age for the basement, by comparison with igneous rocks exposed in the north wall of the Cayman Trench.

Site: S-3C (lower Nicaragua Rise, near DSDP Site 152)

Priority: 2 (alternate to proposed site S-3B)

Position: 15°57.6'N, 74°39.0'W

Water Depth: 3382 m

Sediment Thickness: 521 m (approved to a depth of 540 mbsf)

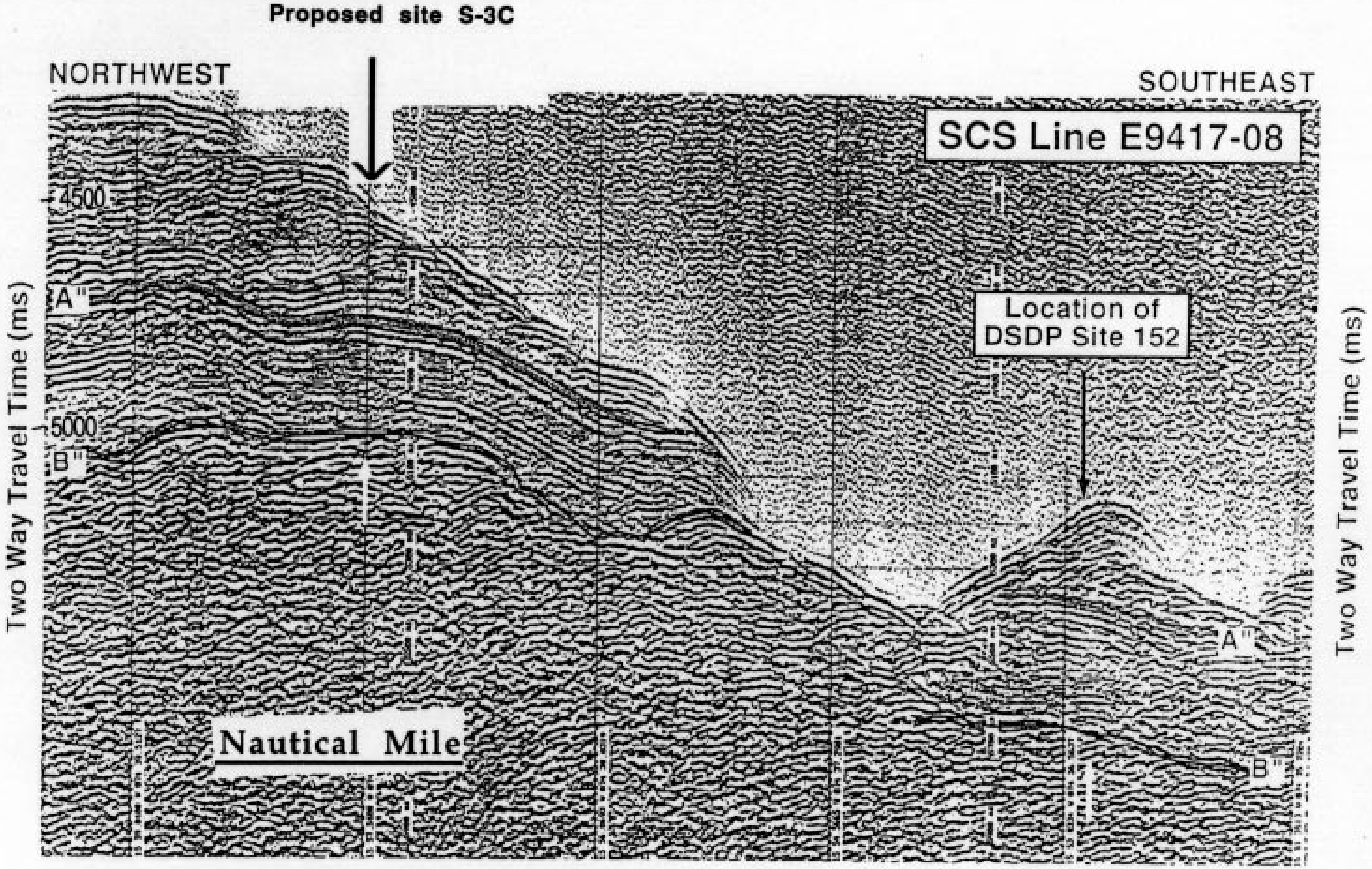
Seismic Coverage: SCS line E9417-08; SP 500 on SCS line E9417-08

Objectives:
(1) Recovery of a relatively undisturbed high-resolution, deep-water K/T sequence.
(2) Cretaceous and Paleogene sediments suitable for isotopic reconstruction of low latitude surface water temperatures (for determining latitudinal gradients in Late Cretaceous sea-surface temperature and assessing the relative importance of greenhouse gas concentrations (i.e., atmospheric CO_2) and latitudinal heat transport to Late Cretaceous climate).
(3) Development of high-resolution low-latitude Cretaceous and Paleogene chronostratigraphy.
(4) Assessment of low latitude paleoceanographic changes that have taken place from Late Cretaceous to Holocene times.

Drilling Program: Hole A: APC to refusal, XCB/MDCB to basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS in K/T boundary interval.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, chalks, marls, cherts, and basalts.


Proposed site S-3C
NORTHWEST
SOUTHEAST
SCS Line E9417-08
4500
A"
5000
B"
Two Way Travel Time (ms)
Location of DSDP Site 152
Two Way Travel Time (ms)
A"
B"
Nautical Mile

GRAPHIC SUMMARY, SITE S-3C

Sub-bottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Ave. Rate of sediment accumulation (m/My)	Comments
0 m	Seafloor		1.51	(water)			Depths, velocities, and accumulation rates are from DSDP Leg 15 Init. Repts. For Site 152, 5.4 nmi northwest of S-3A.
		Holocene Incomplete Neogene Section	1.6 km/s	Foram-Nanno Chalk/ooze, Marl and Clay	Pelagic above CCD	Incomplete Neogene section ?	Discontinuous reflections.
208 m	A "	E. - Eocene		Siliceous Limestone, Chalk, Chert			A" is a prominent basinwide reflection appearing continuous and time synchronous.
			2.5 km/s	Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone		8-31	
521 m	B "	Campanian - Maas.					
			> 4.5 km/s	Interlayered Basalt and Foram Limestone	Oceanic Plateau Basalt - interlayered sediment		B" is a high-amplitude, flat-lying (smooth) basinwide reflection correlating to the top of L. Cretaceous basalts sampled during DSDP Leg 15.

Site: S-7 (Venezuela Basin, near DSDP Sites 146/149)

Priority: 2

Position: 15°07.2'N, 69°22.8'W

Water Depth: 3949 m

Sediment Thickness: 738 m (approved to a depth of 760 mbsf)

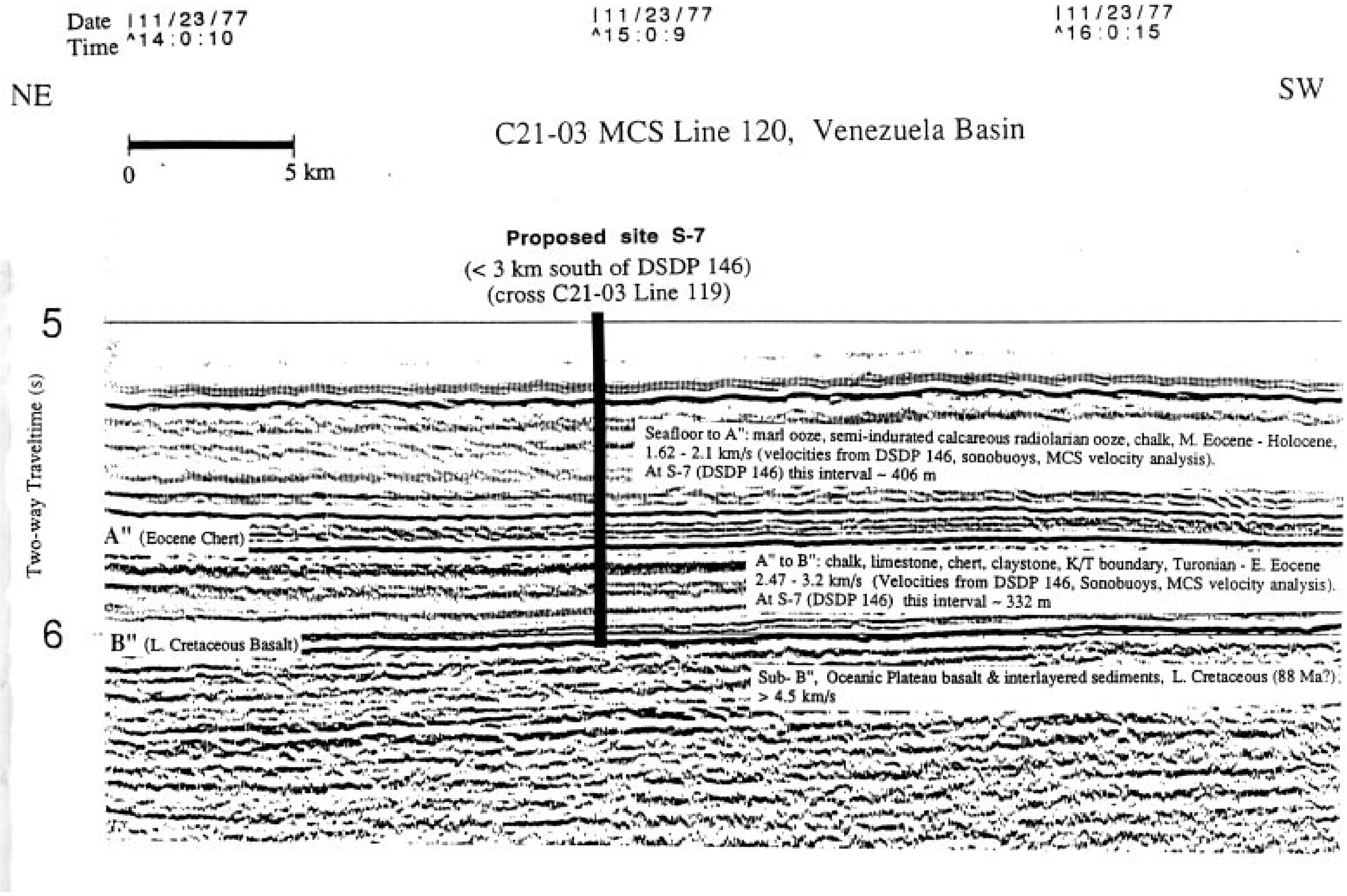
Seismic Coverage: MCS lines C21-03-119 and 120

Objectives:
(1) Recovery of a K/T sequence distal from the proposed Chicxulub impact site.
(2) Recovery of sequences suitable for documenting low latitude paleoceanographic trends and events of the Cretaceous and Paleogene.
(3) Recovery of relatively deep water (3750 m) sediments for documentation of deep and intermediate Caribbean watermass response to Neogene and Quaternary variations in the ocean-climate system.

Drilling Program: Hole A: APC to refusal, XCB/MDCB to refusal. Hole B: wash-down, RCB to basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, chalks, marls, cherts, and basalts.



Seafloor to A": marl ooze, semi-indurated calcareous radiolarian ooze, chalk, M. Eocene - Holocene, 1.62 - 2.1 km/s (velocities from DSDP 146, sonobuoys, MCS velocity analysis). At S-7 (DSDP 146) this interval ~ 406 m

A" to B": chalk, limestone, chert, claystone, K/T boundary, Turonian - E. Eocene 2.47 - 3.2 km/s (Velocities from DSDP 146, Sonobuoys, MCS velocity analysis). At S-7 (DSDP 146) this interval ~ 332 m

Sub- B", Oceanic Plateau basalt & interlayered sediments, L. Cretaceous (88 Ma?): > 4.5 km/s

GRAPHIC SUMMARY, SITE S-7

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			
0 m	Seafloor	Holocene		Foram-Nanno Chalk/ooze, Marl and Clay		9.5	Stratigraphy based on drilled sequence at DSDP Site 146. Flat-lying semi-continuous reflections.
200 m	- - - - - -	E. Miocene	1.62 km/s	Rad. - Nanno Chalk Semi-indurated Rad. Ooze	Open ocean pelagic above CCD	6.2	
406 m	A "	E. - M. Eocene	2.47 km/s	Chert/Limestone/Chalk Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone		9.7	A" is a prominent basinwide reflection appearing continuous and time synchronous.
738 m	B "	Turonian-Coniacian	> 4.5 km/s	Dolorite Sill & Limestone	Oceanic Plateau Basalt - interlayered sediment (88 Ma?)		B" is a high-amplitude, flat-lying (smooth) basinwide reflection correlating to the top of L. Cretaceous basalts sampled during DSDP Leg 15.

Site: S-7A (Venezuela Basin, near DSDP Sites 146/149)

Priority: 3 (alternate to proposed site S-7)

Position: 14°58.8'N, 68°54.0'W

Water Depth: 4110 m

Sediment Thickness: 738 m (approved to a depth of 760 mbsf)

Seismic Coverage: UTIG MCS line VB-1-SA and VB-3-N; 8 km SSW of 15.05°N, 68.90°W, on seismic line VB-1-SA, to a new location at 14.98°N, 68.90°W

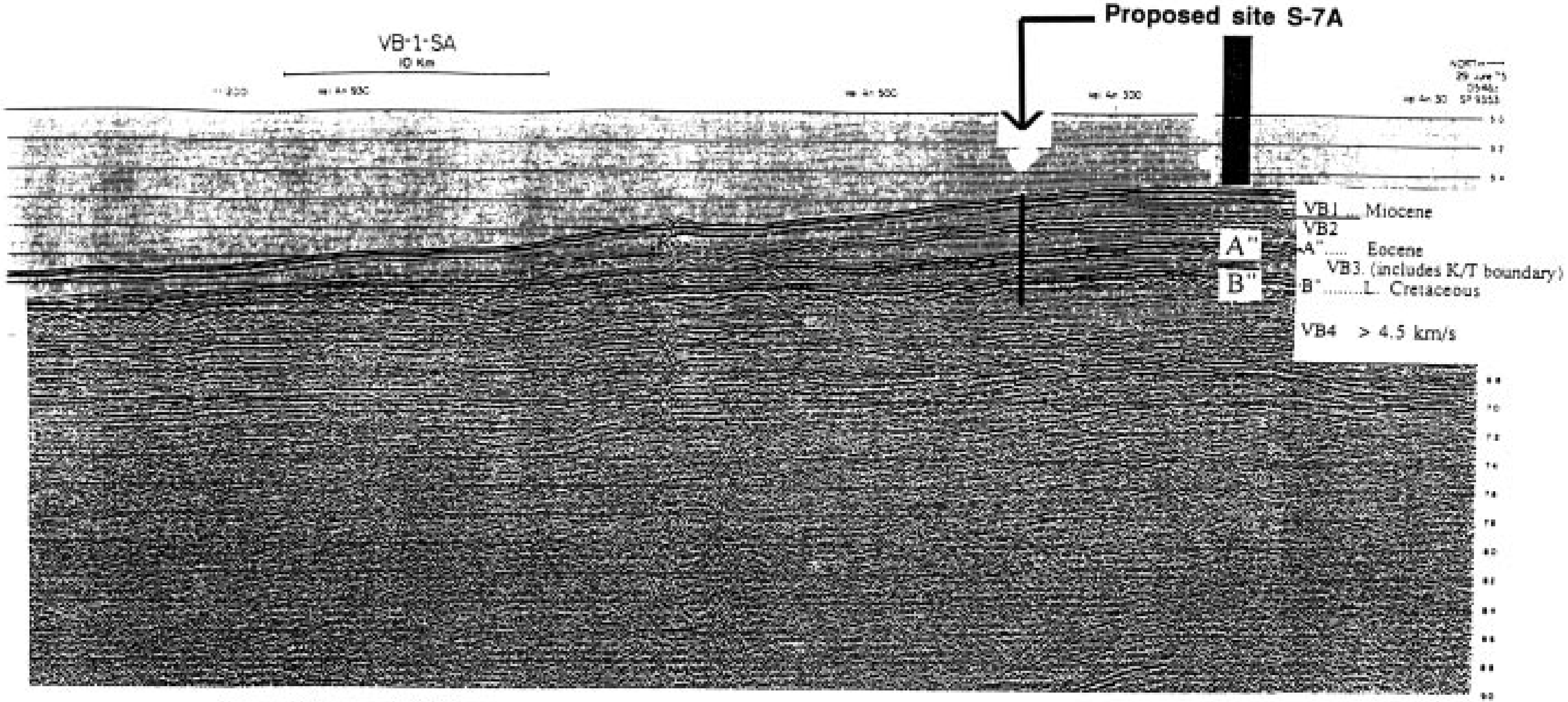
Objectives:

(1) Recovery of a K/T sequence distal from the proposed Chicxulub impact site.
(2) Recovery of sequences suitable for documenting low latitude paleoceanographic trends and events of the Cretaceous and Paleogene.
(3) Recovery of relatively deep water (3750 m) sediments for documentation of deep Caribbean watermass response to Neogene and Quaternary variation in the ocean-climate system.

Drilling Program: Hole A: APC to refusal, XCB/MDCB to refusal. Hole B: wash-down, RCB to basement.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, chalks, marls, cherts, and basalts.



Interpretations modified from:
Ladd and Watkins, Marine Geology, v35, p 21-41, 1980.

VB1: Chalk and Marl Ooze, E. Miocene - Holocene, Sampled at DSDP 146

VB2: Semi-indurated Calcareous Radiolarian Ooze, Chalk, M. Eocene - E. Miocene,
1.6 - 2.1 km/s (Velocities from DSDP 146, Sonobuoys, MCS velocity analysis).
At Site 7A this interval ~ 310 m

VB3: A"-B" interval, Includes K/T Boundary, Chalk, Limestone, Chert, Coniacian - E. Eocene, Sampled at DSDP 146
2.5 - 3.2 km/s (Velocities from DSDP 146, Sonobuoys, MCS velocity analysis).
At Site 7A this interval ~ 240 m

VB4: Sub- B", Oceanic Plateau, L. Cretaceous, Sampled at DSDP 146

GRAPHIC SUMMARY, SITE S-7A

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. Rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			
0 m	Seafloor	Holocene	1.62 km/s	Foram-Nanno Chalk/ooze, Marl and Clay	Open ocean pelagic above CCD	9.5	Stratigraphy based on drilled sequence at DSDP Site 146. Flat-lying semi-continuous reflections.
200 m	- - - - - - -	E. Miocene		Rad. - Nanno Chalk Semi-indurated Rad. Ooze Chert/Limestone/Chalk		6.2	
406 m	A"	E. - M. Eocene	2.47 km/s	Siliceous Claystone Nanno Chalk Chert Radiolarian Limestone		9.7	A" is a prominent basinwide reflection appearing continuous and time synchronous.
738 m	B"	Turonian-Coniacian	> 4.5 km/s	Dolorite Sill & Limestone	Oceanic Plateau Basalt - interlayered sediment (88 Ma?)		B" is a high-amplitude, flat-lying (smooth) basinwide reflection correlating to the top of L. Cretaceous basalts sampled during DSDP Leg 15.

Site: S-5/NR-8

Priority: 2 (alternate to proposed site S-6)

Position: 15°00.0'N, 77°40.8'W

Water Depth: 2080 m

Sediment Thickness: 1105 m (approved to a depth of 1125 mbsf)

Seismic Coverage: UTIG MCS line CT1-28B, SP 4500

Objectives:

(1) Recovery of a distal high resolution K/T sequence located along a trajectory path suitable for testing the direction of the K/T impact and evaluating the different types of emplacement processes associated with particle dispersal by the impact.

(2) Cretaceous and Paleogene ocean climate history.

(3) Neogene carbonates suitable for documenting the “upstream” history of the Caribbean Current before, during, and after subsidence of the Northern Nicaragua Rise and closure of the Isthmus of Panama.

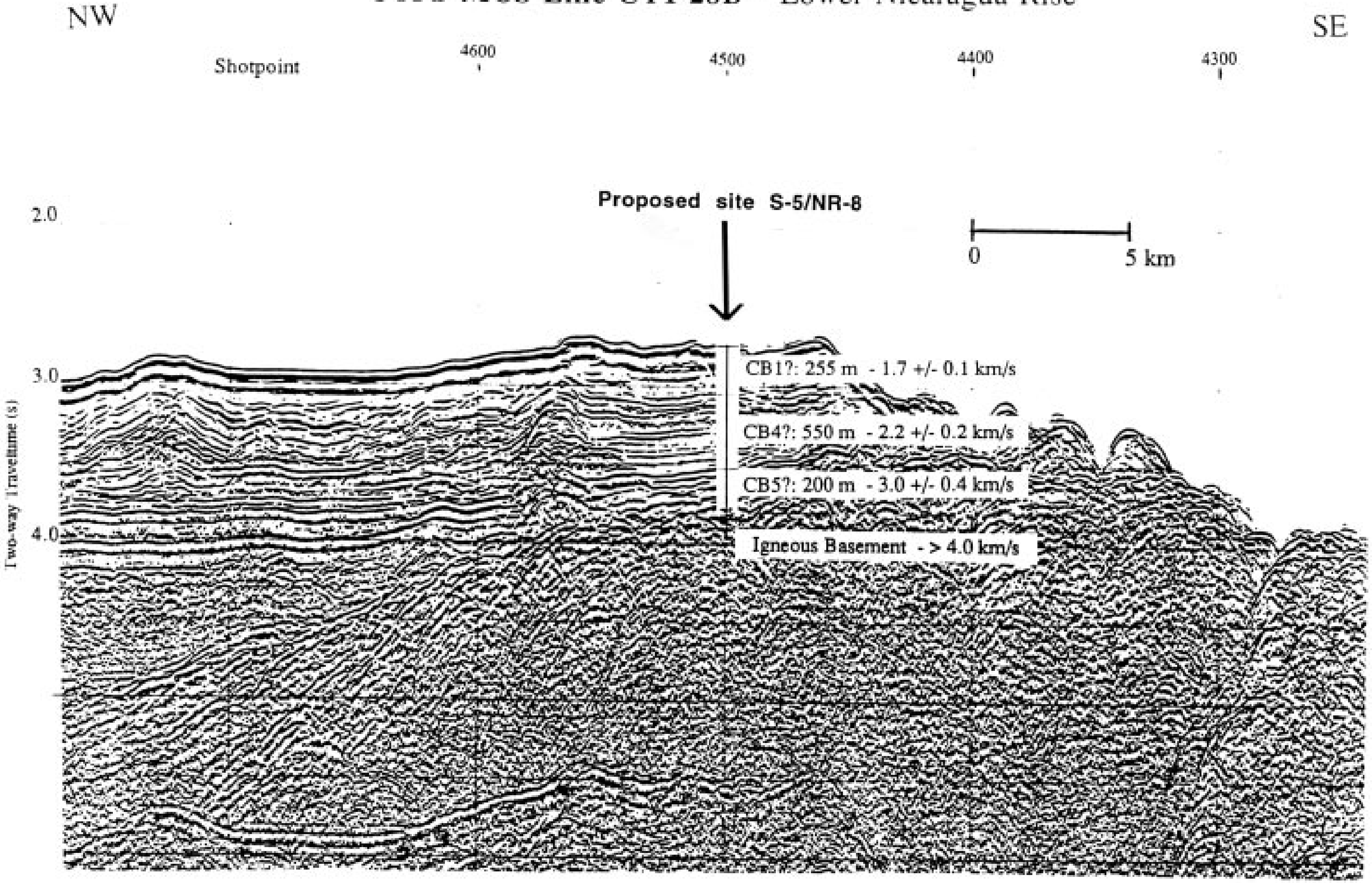
Drilling Program: Hole A: APC to refusal, XCB to refusal. Hole B: wash-down, RCB to total depth.

Logging and Downhole Operations: Four runs with the quad-combo tool string, geochemical tool string, GHMT magnetic logging tool, and multiple passes of FMS through K/T boundary interval.

Nature of Rock Anticipated: Nannofossil foraminiferal ooze, chalks, marls, cherts, and basalts.

Human Hazards: A N-S-trending cable lies 31 nmi to the east of the site (chart INT 402 DMA 1985).

UTIG MCS Line CT1-28B - Lower Nicaragua Rise



GRAPHIC SUMMARY, SITE S-5/NR8

Sub-bottom depth (m)	*Key reflectors, Unconformities, faults, etc*	*Age*	*Assumed velocity (km/sec)*	*Lithology*	*Paleo-environment*	*Ave. rate of sediment accumulation (m/My)*	*Comments*
			1.51	(water)			Sediments and basement have not been sampled.
0 m	Seafloor Seismic Unit **CB1?** Bowland, 1993	Holocene	1.7 km/s	Foram-Nanno ooze, Calcareous clay		23.8	**Tentative Correlation** with Seismic units CB1, CB4, CB5 from Bowland, C.L.,1993, GSA Bull. V. 105, p1321-1345.
255 m	Seismic Unit **CB4?** Bowland, 1993	Miocene?	2.2 km/s	Siliceous/calcareous Ooze	Pelagic drape deposited on basement high above CCD	13.8	
805 m	Seismic Unit **CB5?** Bowland, 1993	M. Eocene?	3.0 km/s	Chalk, Chert, Siliceous clay		13.8	Seismic reflection A" is not readily identified on the lower Nicaragua Rise.
1105 m		L. Cretaceous	> 4.0 km/s	Igneous Basement	Oceanic Plateau Basalt (88 Ma?)		Comparable to seismic reflection B" in the Venezuela Basin in that it correlates to the top of igneous basement.

SCIENTIFIC PARTICIPANTS

OCEAN DRILLING PROGRAM LEG 165

Co-Chief Scientist:

R. Mark Leckie
Department of Geosciences
University of Massachusetts
Amherst, Massachusetts 01003
U.S.A.
E-mail: mleckie@eclogite.geo.umass.edu
Work Phone: (413) 545-1948
Fax: (413) 545-1200

Co-Chief Scientist:

Haraldur Sigurdsson
Graduate School of Oceanography
University of Rhode Island
Narragansett, Rhode Island 02882-1197
U.S.A.
E-mail: haraldur@gsosun1.gso.uri.edu
Work Phone: (401) 792-6596
Fax: (401) 792-6811

Staff Scientist:

TBN
Ocean Drilling Program
Texas A&M Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
Fax: (409) 845-0876

Sedimentologist:

Steven N. Carey
Graduate School of Oceanography
University of Rhode Island

South Ferry Rd.
Narragansett, Rhode Island 02882-1197
U.S.A.
E-mail: scarey@gsosun1.gso.uri.edu
Work Phone: (401) 792-6209
Fax: (401) 792-6811

Sedimentologist:
Pierre Cotillon
Université Lyon I
Centre des Sciences de la Terre
43 Bd. du 11 novembre
69622 Villeurbanne Cedex
France
Work Phone: (33) 72 44 82 46
Fax: (33) 72 44 83 82

Sedimentologist:
André W. Droxler
Department of Geology & Geophysics
Rice University
P.O. Box 1892
Houston, Texas 77251
U.S.A.
E-mail: andre@geophysics.rice.edu
Work Phone: (713) 527-4885
Fax: (713) 285-5214

Sedimentologist:
Gerald Haug
Geologisch-Paläontologisches Institut
Universität Kiel
Olshausenstr. 40
D-24118 Kiel
Federal Republic of Germany
E-mail: gh@gpi.uni-kiel.de
Work Phone: (49) 431 880 2866
Fax: (49) 431 880 4376

Sedimentologist:
Maria Mutti
E.T.H. - Zurich
Geological Institut
Sonneggstr. 5
CH 8092 Zurich
Switzerland
E-mail: maria@erdw.ethz.ch
Work Phone: (41) 1 632 3673
Fax: (41) 1 632 1080

Sedimentologist:
Richard B. Pearce
Department of Oceanography
The University
Highfield, Southampton S017 1BJ
United Kingdom
E-mail: rbp@soton.ac.uk
Work Phone: (44) 1703-59-3275
Fax: (44) 1703-59-3059

Sedimentologist:
Larry C. Peterson
Rosenstiel School of Marine & Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
U.S.A.
E-mail: petersonl@rcf.rsmas.miami.edu
Work Phone: (305) 361-4692
Fax: (305) 361-4632

Sedimentologist:
Hiroyoshi Sano
Department of Earth & Planetary Sciences
Kyushu University
Faculty of Science 33
Hakozaki, Fukuoka 812-12
Japan

E-mail: sano@planet.geo.kyushi-u.ac.jp
Work Phone: (81) 92-641-1101 ext. 4303
Fax: (81) 92-671-1666

Physical Properties Specialist: Andrew Cunningham
Department of Geology & Geophysics
Rice University
MS-126
6100 South Main
Houston, Texas 77005-1892
U.S.A.
E-mail: andyc@geophysics.rice.edu
Work Phone: (713) 527-4880
Fax: (713) 285-5214

Physical Properties Specialist: Ida L. Lind
Danmarks Tekniske Højskole
Instituttet for Geologi og Geoteknik
Bygning 204
DK-2800 Lvngbv.
Denmark
Work Phone: (45) 45 936 266
Fax: (45) 42 885 935

Physical Properties Specialist: Ursula Röhl
Bundesanstalt für Geowissenschaften und Rohstoffe
Postfach 51 01 53
Stilleweg 2
D-30631 Hannover
Federal Republic of Germany
E-mail: roehl@gate1.bgr.d400.de
Work Phone: (49) 511-643-2795
Fax: (49) 511-643-2304

Paleomagnetist:
Bruno Galbrun
Département de Géologie Sédimentaire
Université Pierre et Marie Curie
Case 117
4 Place Jussieu
F-75252 Paris Cedex 50
France
Work Phone: (33) 1 44 27 50 41
Fax: (33) 1 44 97 38 31

Paleontologist (nannofossils):
Timothy Bralower
Department of Geology
University of North Carolina
Chapel Hill, North Carolina 27599-3315
U.S.A.
E-mail: tjbralow@email.unc.edu
Work Phone: (919) 962-0704
Fax: (919) 966-4519

Paleontologist (nannofossils)
Koji Kameo
Technical Research Center
Teikoku Oil Co., Ltd.
9-23-30, Kita-karasuyama
Setagayaku
Tokyo, 157
Japan
Work Phone: (81) 3-3326-9441

Paleontologist (foraminifers):
William P. Chaisson
290 Laburnam Crescent
Rochester, New York 14620
U.S.A.
E-mail: 71024.617@compuserve.com
Home Phone: (716) 461-3563
Fax: n/a
After October 1, 1995

Paleontological Research Institution
1259 Trumansburg Road
Ithaca, New York 14850
U.S.A.
E-mail: 71024.617@compuserve.com
Work Phone: (607) 273-6623
Fax: (607) 273-6620

Paleontologist (foraminifers):
Steven L. D’Hondt
Graduate School of Oceanography
University of Rhode Island
Narragansett Bay Campus
Narragansett, Rhode Island 02882
U.S.A.
E-mail: dhondt@gsosun1.gso.uri.edu
Work Phone: (401) 792-6808
Fax: (401) 792-6811

Palynologist:
Florin-Alexandru Neumann
Department of Geology
University of Toronto
Earth Sciences Centre
22 Russell St.
Toronto, Ontario M5S 3B1
Canada
E-mail: florin@quartz.geology.utoronto.ca
Work Phone: (416) 978-0658
Fax: (416) 978-3938

Inorganic Geochemist:
Richard W. Murray
Department of Earth Sciences
Boston University
Boston, Massachusetts 02215
U.S.A.
E-mail: rmurray@crsa.bu.edu

Work Phone: (617) 353-6532
Fax: (617) 353-3290

Inorganic Geochemist: D. Graham Pearson
Department of Geological Sciences
Durham University
South Road
Durham DH1 3LE
United Kingdom
E-mail: d.g.pearson@durham.ac.uk
Work Phone: (44) 191-376-6701
Fax: (44) 191-376-2510

Organic Geochemist: Timothy W. Lyons
Department of Geological Sciences
University of Missouri, Columbia
101 Geological Sciences Building
Columbia, Missouri 65211
U.S.A.
E-mail: geoltl@showme.missouri.edu
Work Phone: (314) 882-6328
Fax: (314) 882-5458

JOIDES Logging Scientist: Lewis J. Abrams
Department of Geology
University of Puerto Rico
P.O. Box 5000
Mayaguez, Puerto Rico 00681-5000
U.S.A.
E-mail: lew@bigwavbe.upr.clu.edu
Work Phone: (809) 832-4040, ext. 3587
Fax: (809) 265-3845
LDEO Logging Scientist: Gilles Pierrard
Institut Mediterraneen de Technologie
Technopole de Chateau Gombert
13451 Marseille Cedex 20

France
E-mail: pierrard@imtmer1.imt-mrs.fr
Work Phone: 33-91-05-45-01
Fax: 33-91-05-43-43

Database Engineer: TBN

Schlumberger Engineer: Richard Sammy
Schlumberger Offshore Services
369 Tristar Dr.
Webster, Texas 77598
U.S.A.

Operations Manager: Mike Storms
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: storms@nelson.tamu.edu
Wk. Phone: (409) 845-2101
Fax: (409) 845-2308

Laboratory Officer: Burney Hamlin
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: hamlin@nelson.tamu.edu
Work Phone: (409) 845-5716
Fax: (409) 845-2380

Assistant Laboratory Officer/
Marine Laboratory Specialist (X-ray): Don Sims
Ocean Drilling Program
Texas A&M University Research Park

1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: sims@nelson.tamu.edu
Work Phone: (409) 845-2481
Fax: (409) 845-2380

Marine Laboratory Specialist/
Curatorial Representative:
Lorraine Southey
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: southey@nelson.tamu.edu
Work Phone: (409) 845-4822
Fax: (409) 845-2380

Marine Computer Specialist/System Manager:
Matt Mefferd
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: mefferd@nelson.tamu.edu
Work Phone: (409) 862-4847
Fax: (409) 845-4857

Marine Computer Specialist/System Manager:
Terry Klepac
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: klepac@nelson.tamu.edu
Work Phone: (409) 862-4849
Fax: (409) 845-4857

Marine Laboratory Specialist (Storekeeper): John Dyke
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: dyke@nelson.tamu.edu
Work Phone: (409) 845-2480
Fax: (409) 845-2380

Marine Laboratory Specialist (X-ray): Mary Ann Cusimano
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: maryann@nelson.tamu.edu
Work Phone: (409) 845-2480
Fax: (409) 845-2380

Marine Laboratory Specialist (Chemistry): Phil Rumford
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: rumford@nelson.tamu.edu
Work Phone: (409) 845-2483
Fax: (409) 845-2380

Marine Laboratory Specialist (Chemistry): Chieh Peng
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547

U.S.A.
E-mail: chieh@nelson.tamu.edu
Work Phone: (409) 845-2480
Fax: (409) 845-2380

Marine Laboratory Specialist (Paleomagnetics): Edwin Garrett
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: garrett@nelson.tamu.edu
Work Phone: (409) 845-2481
Fax: (409) 845-2380

Marine Laboratory Specialist (Physical Properties): Taku Kimura
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: taku@nelson.tamu.edu
Work Phone: (409) 845-2483
Fax: (409) 845-2380

Marine Laboratory Specialist (Photography): Roy Davis
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: photo@nelson.tamu.edu
Work Phone: (409) 845-8482
Fax: (409) 845-4857
Marine Laboratory Specialist (Underway): Dennis Graham
Ocean Drilling Program

Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: graham@nelson.tamu.edu
Work Phone: (409) 845-8482
Fax: (409) 845-2380

Marine Laboratory Specialist
(Downhole Measurements):
Gus Gustafson
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
Work Phone: (409) 845-8482
Fax: (409) 845-2380

Marine Laboratory Specialist
(Temporary):
TBN
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.

Marine Electronics Specialist:
Eric Meissner
Ocean Drilling Program
Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
E-mail: meissner@nelson.tamu.edu
Work Phone: (409) 845-8482
Fax: (409) 845-2380

Marine Electronics Specialist:
Dwight Mossman
Ocean Drilling Program

Texas A&M University Research Park
1000 Discovery Drive
College Station, Texas 77845-9547
U.S.A.
Work Phone: (409) 845-8482
Fax: (409) 845-2380