OCEAN DRILLING PROGRAM

LEG 115 PRELIMINARY REPORT

MASCARENE PLATEAU - CARBONATE DISSOLUTION PROFILE

Dr. Jan Backman
Co-Chief Scientist, Leg 115
Department of Geology
University of Stockholm
S-106 91 Stockholm
Sweden

Dr. Robert A. Duncan
Co-Chief Scientist, Leg 115
College of Oceanography
Oregon State University
Corvallis, OR 97331

Dr. Andrew H. Macdonald
Staff Scientist, Leg 115
Ocean Drilling Program
Texas A&M University
College Station, TX 77843-3469

Philip D. Rabinowitz
Director
ODP/TAMU

Audrey W. Meyer
Manager of Science Operations
ODP/TAMU

Louis E. Garrison
Deputy Director
ODP/TAMU

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SCIENTIFIC REPORT

The scientific party aboard JOIDES Resolution for Leg 115 of the Ocean Drilling Program consisted of:

Jan Backman, Co-Chief Scientist (University of Stockholm, S-106 91 Stockholm, Sweden)
Robert Duncan, Co-Chief Scientist (Oregon State University College of Oceanography, Corvallis, OR 97331)
Andrew Macdonald, Staff Scientist (Ocean Drilling Program, Texas A&M University, College Station, TX 77840)
Paul Baker (Duke University Department of Geology, Durham, NC 27708)
Alistair Baxter (City of London Polytechnic Geology Department, Bigland Street, London E1 2NG, England)
Anne Boersma (404 RR1 Gate Hill Road, Stony Point, NY 10980)
James Cullen (Salem State College Department of Geological Sciences, Salem, MA 01970)
Andre Droxler (Rice University Department of Geology, P.O. Box 1892, Houston, TX 77251)
Martin Fisk (Oregon State University College of Oceanography, Corvallis, OR 97331)
John Greenough (St. Mary's University Geology Department, Halifax B3H 3C3 Nova Scotia)
Robert Hargraves (Princeton University Department of Geological and Geophysical Sciences, Princeton, NJ 08544)
Peter Hempel (Universitaet Kiel Geol.-Palaeontol. Institut, D-2300 Kiel, Federal Republic of Germany)
Mike Hobart (Lamont-Doherty Geological Observatory, Palisades, NY 10964)
Michael Hurley (Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, England)
David Johnson (Woods Hole Oceanographic Institution, Woods Hole, MA 02543)
Naja Mikkelsen (Geological Survey of Denmark, Thoravej 31, 2400 Copenhagen, Denmark)
Hisatake Okada (Yamagata University Department of Earth Sciences, Yamagata 990, Japan)
Larry Peterson (University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149)
Domenico Rio (University of Parma Department of Geology, Via delle Scienze, 43100 Parma, Italy)
Simon Robinson (University of Liverpool Department of Geography, P.O. Box 147, Liverpool L69 3BX, United Kingdom)
David Schneider (Lamont-Doherty Geological Observatory, Palisades, NY 10964)
Peter Swart (University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149)
Yoshiyuki Tatsumi (Kyoto University Department of Geology and Mineralogy, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606, Japan)
Didier Vandamme (Lab. de Paleomagnetisme, IPGP, 4 place Jussieu, 75252 Paris Cedex 05, France)
Gustavs Vilks (Atlantic Geoscience Centre, Bedford Institute of Oceanography, Box 1006, Dartmouth B2Y 4A2, Nova Scotia)
Edith Vincent (Dept. Geol. Dynamique, UPMC, 4 place Jussieu, 75252 Paris Cedex 05, France)

INTRODUCTION

Leg 115 is the first of a nine-leg program of exploration of the Indian Ocean. Compared with the Atlantic and Pacific ocean basins the Indian Ocean is relatively unexplored; during this multifaceted investigation many fundamental questions will be examined. The scientific objectives of this leg fall into two main subject areas: hotspot volcanism and paleoclimatology.

Hotspots and Plate Tectonics

As the Indian subcontinent moved northward away from Antarctica and Australia from Early Cretaceous time to the present it passed over stationary thermal anomalies in the upper mantle, called hotspots (Morgan, 1981). Excess melting of the mantle peridotite within these hotspot areas led to anomalous volcanism on the overlying plate and hence the formation of lineaments consisting of discrete volcanos and coalesced volcanic ridges. These lineaments record the motion of the plates surrounding the Indian Ocean.

During the voyage from Port Louis, Mauritius to Colombo, Sri Lanka, JOIDES Resolution followed the volcanic trace left by the Reunion hotspot on the African and Indian plates (Figure 1). This presumed volcanic ridge, now covered with a carbonate platform along much of its length, extends northward from the volcanically active island of Reunion, to the inactive and rapidly eroding island of Mauritius, and then on beneath the Soudan, Cargados Carajos and Nazareth banks (Figure 2). The Saya de Malha Bank forms the eastern end of a NW-to-SE-trending ridge which includes the Precambrian granites of the Seychelles Bank. Together these elevated regions form the Mascarene Plateau (Fisher et al., 1967).

Although the Saya de Malha Bank lies adjacent to Nazareth Bank the volcanic rocks of the former erupted much earlier (approximately 30 m.y.), when the Seychelles microcontinent was still adjacent to India, and are probably related to the older Deccan Trap flood basalt volcanism which stretches across much of western India. Reconstruction of the Central Indian Ocean basin during the last 36 m.y. removes the ocean crust created at the Central Indian Ridge and joins the Nazareth Bank to the Chagos Bank (McKenzie and Sclater, 1971). Hence the hotspot trace continues northward past the Chagos Bank along the Maldive Islands, the Laccadive Islands, and into the Deccan Traps in western India.

The drilling plan was to recover volcanic rocks at selected locations along this hotspot lineament to determine the age of volcanism and its petrologic and geochemical character. In the hotspot model, the age of the volcanism should increase northwards, from a 'zero' age at Reunion to about 67 Ma for the basalts of the Deccan Traps (Duncan, 1978, 1981). Radiometric and biostratigraphic dating of basalts and lowermost sediments will provide estimates of the timing of volcanism. In addition, the presumed hotspot would have erupted basalts in various plate tectonic environments: intra-plate oceanic islands, spreading ridge-centered oceanic islands, and continental margin. Potential mantle source regions for magma genesis, then, could vary from hotspot mantle to asthenospheric (MORB) mantle to sub-continental mantle, and basalt compositions should express the relative contributions of these sources through time. Geochemical studies (major and trace elements, and isotopic compositions) will be used to characterize the volcanic rocks and form the basis for comparative studies.

An additional plate-tectonic objective is the definition of true polar wander. Under the premise that hotspots remain stationary in the upper mantle over geologically significant periods of time, all volcanos produced over a given hotspot should give the same magnetic latitude - unless the whole earth has shifted with respect to its axis of rotation. In the latter case a systematic departure of paleolatitudes (determined from paleomagnetic measurements on basalts and sediments) from present hotspot positions will determine the direction and magnitude of this motion, called true polar wander (Hargraves and Duncan, 1973). It is clear that Pacific hotspots have moved 5-10° south during Tertiary time (Gordon and Cape, 1981). If true polar wander is the explanation, we should see a comparable northward shift of hotspots in the Indian Ocean, relative to the geomagnetic axis.

Paleoceanography and Stratigraphy

The seafloor topography east and southeast of the Seychelles Bank in the Indian Ocean provides large bathymetric gradients over a small geographic area; water depths vary by over 4000 m. These conditions are crucial for the study of how biogenically formed carbonate dissolves as a function of increasing water depth. The strong bathymetric contrast ensures that important chemical boundary conditions are present in the water column; e.g., the carbonate compensation depth (CCD) and the lysocline (Broecker and Peng, 1982). Drilling along such a bathymetric gradient ensures that these chemical boundaries are crossed, and the narrow geographic distance ensures that the surface water production of skeletal carbonate is similar throughout the suite of sites.

Both productivity and the subsequent dissolution are closely linked to the evolution of ocean circulation and climate history. The pattern of vertical and horizontal fluxes of water throughout the world ocean determines, by and large, the nutrient concentration in the surface waters and thus the rate by which sediment forming micro-organisms are produced in the mixed layer. The climate, together with the tectonic development of the ocean basin geometry, forms the ultimate driving force for both the shallow and deep ocean circulation.

The main purpose of the Leg 115 paleoceanographic program was to study the interplay between the flux in carbonate production and the dissolution of this material as a function of water depth, as the shallow and deep circulation and the climate evolved through late Cenozoic times. In terms of "deep" water mass changes, it is particularly important to establish how the intermediate and deep water masses responded to:

(1) The Miocene tectonic closing of the Tethyan seaway which connected the low-latitude Indo-Pacific and Atlantic regions.
(2) The formation of a permanent ice cap in Antarctica during middle Miocene times.
(3) The onset of northern hemisphere glacial/interglacial cycles during late Pliocene times.

In terms of shallow water masses, it is desirable to learn how the boundary between the Equatorial Water (monsoon driven, rich in nutrient concentration, low in oxygen) and Central Water (subtropical anticyclonic gyre, low in nutrient concentration, rich in oxygen) masses has fluctuated through time. The Leg 115 sites are aligned along a north-south-trending transect that crosses the transition zone between the Equatorial and Central water masses.

A complementary aspect of carbonate dissolution was addressed by drilling periplatform oozes in the Maldive Islands area. Periplatform sediments deposited within the vicinity of shallow carbonate banks contain large amounts of needle-like fine aragonite and some magnesium calcite in the form of skeletal fragments and micrite, both of which are produced in shallow carbonate environments. Because of their special mineralogy, bank-derived sediments are susceptible to more rapid and shallower dissolution than the calcitic components. Aragonite dissolution cycles have been shown to occur in phase with the late Pleistocene glacial/interglacial cycles (Droxler et al., 1983). The variation through time in the preservation of bank-derived metastable aragonite can therefore be used to model time dependent fluctuations in carbonate saturation levels in intermediate water masses.

Leg 115 recovered the first APC/XCB-cored material from the Indian Ocean. We drilled a total of 22 holes at 12 sites and recovered 3058 m of cored material (Table 1). Moreover, Leg 115 is one of the few legs scheduled to retrieve Cenozoic sediments from the equatorial Indian Ocean. Not surprisingly, much effort will be spent to establish adequate magnetostratigraphic records from these low-latitude sediments and to improve existing correlations between biostratigraphy and magnetostratigraphy.

DRILLING RESULTS

SITES 705 and 706 (Nazareth Bank, Mascarene Plateau)

Site 705 is located on the eastern shoulder of the Mascarene Plateau along the northeastern margin of the Nazareth Bank at a water depth of 2307.5 m on relatively gently sloping terrain. This site is approximately 30 nautical miles (nmi) north and east of shallow water carbonate banks and reefs and is composed predominantly of biogenic sediments, deposited on the volcanic slopes. They are dissected by numerous west-to-east-trending canyons that have cut down through the sediments as deep as 200 m. The intervening sediment highs are characterized by modestly to poorly stratified reflective layers. From survey data the site was located in the center of a 6-nmi-wide sediment lobe, bounded by deep east-trending canyons.

The primary objective at these sites was to drill to basement and recover a sequence of volcanic rocks for radiometric dating, geochemical and petrological analyses, and paleomagnetic studies. These studies will determine the origin of the Mascarene Plateau and affect Cenozoic plate reconstructions for the Indian Ocean. A secondary objective was to use the sediment cores of this southernmost site to monitor time-dependent fluctuations of surface water mass boundaries (Equatorial Water, Central Water), along with carbonate dissolution at this moderately deep location, through the expected Neogene and Paleogene strata.

The sedimentary sequence (0-27.5 mbsf) at Site 705 is composed of a single lithologic unit consisting of homogeneous, coarse-grained foraminifer ooze lacking sedimentary structures. Depositional rates were less than 10 m/m.y. during the past 2.65 Ma, but increased to 11.4 m/m.y. during the early part of the late Pliocene (between 2.65 and 3.00 Ma). These rates further increased to >20 m/m.y. in the lowermost part of the sequence (3.0-3.45 Ma).

Site 706 lies 3 nmi north of Site 705 at a water depth of 2506.5 m. Because of hole instability problems at Site 705, drilling was attempted near the base of a canyon to the north, where seismic records suggested that more consolidated sediments are present. A prominent ledge 35 m above the canyon floor was chosen as the drilling site. The objectives at Site 706 were identical to those at Site 705; however, because the site was located to avoid the upper Neogene coarse-grained foraminifer ooze encountered at Site 705, the paleoceanographic goals could not be achieved completely. A total sediment thickness of about 50 m was estimated from the seismic stratigraphy.

The stratigraphic section at Site 706 consists of loose foraminifer sands, overlying compact calcareous oozes with numerous volcanic ash layers, that overlie breccias of shallow-water limestone and volcanic rock fragments, covering vesicular basalts. The dominant lithologies and age assignments of the stratigraphic sequence are as follows (Figure 3):

0.0-4.0 mbsf:	Coarse calcareous nannofossil-bearing foraminifer ooze of Pleistocene age.
4.0-47.0 mbsf:	Calcareous nannofossil ooze containing numerous volcanic ashes of early Oligocene age.
47.0-47.5 mbsf:	Basalt and shallow-water limestone gravel, breccia containing basalt clasts with sulfide cement of early Oligocene age.
47.5-121.7 mbsf:	Vesicular and massive plagioclase basalt flows of early Oligocene age.

A succession of visually observed lithostratigraphic markers was used to correlate Hole 706A with Hole 706B (Hole 706C was washed down to basement). About 90% of the 47.5 m long sediment sequence was probably deposited in less than 1 million years during the early Oligocene, entirely within Subchron C12R. No biostratigraphic zonal boundary was identified; thus, the shipboard inter-hole correlation is based primarily on lithostratigraphic data. The lithostratigraphic markers consist of three parts: (1) the Pleistocene/ Oligocene unconformity, (2) a sharp change from yellow to green nannofossil ooze 3.5 m below the unconformity, and (3) five prominent ash layers in the green nannofossil ooze. One of these ash layers occurs only in Hole 706B, although the corresponding depth interval was recovered in Hole 706A. The lithostratigraphic markers suggest, however, that a nearly complete composite section was recovered from 0.0 mbsf to 47.0 mbsf.

Shipboard magnetic susceptibility data showed that an unconformity of 2 to 3 m occurs in each of the two holes. This suggests that differential erosion occurred over this small area (10 m spacing) during deposition.

The geologic column at Site 706 begins with a basement of lava flows. These are thin, vesicular flows near the surface which become noticeably more massive with depth. The evidence of chilled margins and thin, baked sediment interbeds suggests that all flows were erupted below sealevel. Some 32 flow units were recognized on the basis of glassy chilled margins. Their mineralogy is dominated by plagioclase and varying amounts of subordinate augite and olivine phenocrysts, suggesting that the basalts can be grouped into two or three magma types. Overlying the basalt is a coarse gravel that includes pebbles of reef limestone of Eocene to Oligocene age, and rounded nodules of pyrite-cemented volcanic sandstone. Delicate, fresh glass shards enclosed in the sulfide attest to the rapid deposition and cementation of this material. The presence of 'framboids' suggests that the pyrite was deposited by sulfur-reducing bacteria.

Lying immediately above the gravel is a 40 m sequence of calcareous nannofossil ooze and chalk interbedded with volcanic ash. These ash layers are generally a few centimeters thick and many contain unaltered shards of glass and fresh crystals of feldspar and pyroxene. Very fine particulate pyrite, which give the ashes a black to dark gray color, is an additional constituent. Several ash layers show signs of bioturbation. There are 4-5 ash layers per meter through this unit, or one event about every 5,000 years, assuming a sedimentation rate of 40 m/m.y. The Oligocene nannofossil ooze and chalk consist almost exclusively of nannofossils (90-100%) with less than 10% foraminifers. Benthic foraminifers indicate that the seafloor was shallower than present by 700-2000 m during early Oligocene times. At about 4 m below the top of this unit there is a distinct color change from buff brown-yellow above to gray-green below, indicating a probable change in oxidation state.

The combined bio- and magnetostratigraphic information obtained from Holes 706A and 706C provide the basis for age estimates of the basalt and lowermost sediment at Site 706. The lower Oligocene nannofossil ooze is uniformly reversely magnetized, and all biostratigraphic indicators are consistent with deposition and magnetization of these sediments during the early portion of Subchron C12R. The basalts, on the other hand, are all normally magnetized, and baked sediments interlayered with the flows contain Ericsonia formosa but no Eocene fauna. This indicates that the volcanic rocks were erupted during Subchrons C13N-1 through C13N-2 (35.3-35.9 Ma; Berggren et al., 1985). Using the extremes of this age range, the minimum volcanic accumulation rate is about 120 m/m.y. If the basalts were magnetized entirely during Subchron C13N-1, this rate would have been greater than 380 m/m.y.

A major hiatus occurs at the top of the nannofossil ooze, where Pleistocene foraminifer sands overlie the lower Oligocene sequence. The Pleistocene unit is about 4 m thick and of uniform age (<85 k.y.). Coarser sediment occurs at the base of this unit, where pebbles of shallow water limestone that were probably eroded from the Nazareth Bank or Saya de Malha Bank were found. Given the location of Site 706 near the base of a major canyon, the uniform age and size sorting of fragments, this unit is interpreted as resulting from a grain flow that traveled eastward down the shoulder of the Mascarene Ridge.

Paleomagnetic measurements on split cores and discrete samples yield a paleolatitude of $30^{\circ} \pm 3^{\circ}$ for sediments recovered from Site 706. This implies that this site was about 9° south of the present location of hotspot activity at Reunion Island. Since the paleolatitude of the Deccan Traps (western India) is in the same range (27° to 30° S; Courtillot et al., 1986), the results imply that the hotspot remained at constant latitude between 67 and 35 Ma, but moved north between 35 Ma and the present (Figure 4).

SITE 707 (Saddle between Seychelles and Saya de Malha Bank, Mascarene Plateau)

Site 707 is located in the western tropical Indian Ocean at a water depth of 1541.4 m. The northwestern part of the Mascarene Plateau stretches 1300 km, from the Seychelles Bank to the Saya de Malha Bank, separating the deep Arabian Sea basin to the north from the deep Mascarene basin to the south (Figure 2). The southward flow of intermediate deep waters across the plateau has scoured a major channel perpendicular to the ridge axis, and Site 707 is located some 6 nmi east of this channel. Small offsets in acoustic basement relief over the region have resulted in sediment-thickness variations between 200 m and 400 m on top of the plateau.

The main objective at this site was to recover a stratigraphically continuous Neogene sediment sequence for paleoceanographic and paleoclimatological studies. As Site 707 is located in comparatively shallow water, dissolution of biogenic carbonate should be minimal. Thus, the accumulation of carbonate sediment at Site 707 can be used as a reference for the true productivity flux of pelagic carbonate in this part of the western Indian Ocean.

A secondary objective was to recover the lowermost sediments and basement to determine the age and nature of the igneous rocks underlying the plateau. Two alternative models are considered: (1) that Precambrian granitic rocks exposed in the Seychelles Islands extend southeast under Site 707 and even as far as the Saya de Malha Bank (the ridge was thus originally a microcontinent piece in the Gondwanan puzzle), or (2) that the basement for the region is made up of basalts equivalent to the Deccan Trap flood basalts of western India, erupted near the Cretaceous/Tertiary boundary when this ridge was part of India.

The lithologic composition and stratigraphic preservation of the sedimentary section at Site 707 show many similarities to DSDP Site 237, located 60 nmi to the northwest. A fairly expanded sequence of upper Neogene sediments overlies condensed sediments of middle Miocene through Oligocene age, which overlie less condensed lower Paleogene sediments showing increased rates of deposition during Paleocene (primarily early Paleocene) times. The basaltic basement contains a few intercalated shallow-water limestones that are virtually unaffected by dolomitization, in contrast to the limestones lying on top of the basement. The dominant lithologies and age assignments of the stratigraphic sequence are as follows (Figure 3):

0.0-151.0 mbsf:	Nannofossil-bearing foraminifer ooze to foraminifer-bearing nannofossil ooze of Pleistocene through early Miocene age.
151.0-213.3 mbsf:	Nannofossil ooze of Oligocene through late Eocene age.
213.3-251.4 mbsf:	Nannofossil ooze and chalk of middle Eocene age.
251.4-280.3 mbsf:	Radiolarian-bearing nannofossil chalk of middle Eocene age.
280.3-375.6 mbsf:	Micritic chalk with interbedded silicified limestone and chert, glauconitic foraminifer limestone, and shallow-water calcareous mudstones, of early Eocene to early Paleocene age.
375.6-443.2 mbsf:	Vesicular to compact, massive porphyritic basalt flows with interbedded shallow-water limestones of early Paleocene age.

Sediments from Holes 707A and 707B are characterized by a gradual downhole increase in nannofossil content. This essentially homogeneous lithology lacks sedimentary structures. The carbonate content is on the average over 90%; the remaining few percent consists mainly of opaline silica. Higher frequency variation in the carbonate content (between 80 and 95%) is confined to two shorter time intervals: after 2.4 Ma and between 5.0 and 6.5 Ma. The shipboard work thus indicates the existence of possible links between carbonate content in this 'shallow' tropical Indian Ocean site and (1) the onset of northern hemisphere glaciations during late Pliocene time and (2) the Messinian event during the latest Miocene.

Due to the high carbonate percentages, the rate of bulk sediment accumulation is practically identical to the rate of carbonate accumulation. It is only during the earliest Pliocene and late Miocene that these rates exceed 1 g/cm^2/1000 years during the past 37 m.y. Assuming that carbonate dissolution has been minimal, the generally low accumulation rates during post-Eocene times presumably reflect the influence of bottom current erosion, rather than subdued productivity of microplankton.

Two erosional horizons of relatively short duration (2 and 1 m.y., respectively) were encountered: one occurring in the later part of the middle Miocene and the other during late Oligocene times. Both are preceded by a stepwise reduction in accumulation, and both may well be associated with glacial events in Antarctica (at 13-14 Ma and 25-26 Ma, respectively; Miller and Fairbanks, 1985). A conspicuous peak value followed immediately by an equally conspicuous trough in both bulk and carbonate sediment accumulation occurs during early Oligocene times (33-35 Ma). These extreme values may coincide in time with the drastic decline in temperature of the early Oligocene deep water masses (4-5°C; Shackleton and Kennett, 1975).

Upper Paleocene to lower Eocene glauconite-bearing foraminifer chalk and limestone are indicative of a shallow, slow deposition environment. Below this we recovered calcareous mudstones and silicified limestones of early Paleocene age. The presence of macrofossils (brachiopods, gastropods) indicates that these sediments were deposited in extremely shallow water.

Basalt was penetrated at a sub-bottom depth of 376 m. Six distinct flow units were recognized within the basalt, on the basis of changes in mineralogy and lithostratigraphic breaks at intercalated macrofossil limestone beds. The basalts are vesicular at the top but become compact downcore. Flow units are thick (one appears to be at least 30 m), generally fine to medium grained, and contain plagioclase, pyroxene, and olivine phenocrysts. The absence of chilled margins and the intercalated sediments indicate extremely shallow water conditions suggesting subaerial or littoral eruptions.

The age of the basalts is constrained biostratigraphically to the middle part of the Paleocene, between anomalies 26 and 28. The basalts are of uniformly reversed polarity, indicating that they were erupted during Subchron C26R or C27R, either between 60.8 and 63.0 Ma or between 63.5 and 64.3 Ma. A tentative biostratigraphic interpretation points to the latter time interval for the basalt eruption. The origin of the southeastern half of the ridge is thus linked with Deccan Trap volcanic activity during the latest Cretaceous-earliest Tertiary time. Plate reconstructions for the early Paleocene place this region adjacent to western India (Figure 5).

SITE 708 (Abyssal plain southwest of Madingley Rise)

Site 708 is located in the western equatorial Indian Ocean at a water depth of 4096.5 m. The Seychelles Bank, which forms the northwestern end of the Mascarene Plateau, descends from water depths of less than 200 m to just over 4000 m along its eastern rim. This transition from bank to abyssal plain occurs over a distance of 60 nmi or less; Site 708 lies 60 nmi north of the Seychelles bank out on the abyssal plain. The undulating basement is completely covered by sediment, and the present seafloor shows a virtually featureless topography. Total sediment accumulation amounts to about 600 m in the basement depressions and half that figure over the basement highs. As the ocean crust was formed during Paleocene times in the area of Site 708 (Schlich, 1982), average sedimentation rates were on the order of 10 m/m.y.

The water depth at Site 708 places it towards the deeper end of the carbonate depth profile. The major objective was to recover a complete Neogene sequence in order to study the time-dependent dissolution of the slowly accumulating pelagic carbonate as a function of water depth. Site 708 was drilled at a depth approaching two critical chemical boundaries in the water column: the lysocline and the CCD. Vertical fluctuations of these boundaries through time thus represent changes in the ocean chemistry, which are largely driven by climate-induced changes in the deep ocean circulation but are also influenced by changes in productivity and the influx of pelagic carbonate. Time-dependent variability in carbonate preservation at Site 708 can thus be used to model the interacting system of carbonate flux/dissolution and climate-induced changes in deep ocean circulation.

Only one hole (708A) was drilled because the cored sediments reveal a history of alternating pelagic and turbidite deposition. About 25% of the recovered sequence consists of turbidites exceeding 0.4 m in thickness. Including thinner turbidites would approximately double the turbidite percentage. The shelf character of the benthic foraminiferal assemblages within the turbiditic sediments indicates that the Seychelles Bank, located some 100 miles to the west, is the most likely and prominent source area.

While the lower boundaries of the turbidites are generally sharp and easily recognized visually, the upper boundaries usually grade into the overlying pelagic ooze. Whole-core volume magnetic susceptibility measurements at 5-cm intervals clearly revealed, however, the upper boundaries of most turbidites due to their higher carbonate content. Most of the variability in the magnetic susceptibility record at Site 708 is caused by the alternating deposits of turbidite and pelagic sediments.

Three major lithologic units were recognized in the pelagic sediments, based on differences in color and lithology (Figure 3):

0-120.6 mbsf: Divided into Subunits 1a and 1b. Subunit 1a (0.0-56.8 mbsf) is dominated by white to light gray foraminifer-bearing nannofossil ooze. The bottom of Subunit 1a coincides with the upper/lower Pliocene boundary. Subunit 1b (56.8-120.6 mbsf) contains sediments that are consistently darker than above and are composed of foraminifer-bearing nannofossil ooze that is sometimes clay-rich. This latter subunit ends in the lower part of the upper Miocene.

120.6-178.2 mbsf: Contains alternating intervals of white nannofossil ooze and dark brown, clay-rich nannofossil ooze. This unit has a low carbonate content and its base occurs in the lower Miocene.
178.2-236.2 mbsf: Sediments dominated by white to pale brown nannofossil ooze and chalk. The oldest sediment is of early Oligocene age.

The time control is based on biostratigraphy since problems with magnetic overprint in the clay-rich (40-70% carbonate) turbidite-free pelagic sediments resulted in uninterpretable magnetostratigraphic signals. On a turbidite-free basis, the biostratigraphy suggests sedimentation rates of 10 m/m.y. from the Pleistocene back to about 9 Ma, followed by a stepwise reduction in rate leading to a hiatus at about 13 Ma. The hiatus has a duration of about 2 m.y.; the average sedimentation rate for the remaining part of the sequence, early Miocene through most of the Oligocene, is estimated to be about 5 m/m.y.

The carbonate content (1 sample/0.75 m) in the pelagic parts of the sequence in late Miocene through Pleistocene times is on the order of 70% (±10%). The middle Miocene is characterized by the most extreme variability, with carbonate values ranging from less than 1% to over 80%, whereas the Oligocene shows the most stable values (around 90%). This general pattern also appears clearly in the colors of the pelagic sediments, ranging from white or gray in the Plio-Pleistocene and Oligocene nannofossil oozes, to dark brown in the middle Miocene clays. The causes of this pattern are at least three-fold: (1) Thermal relaxation and subsidence of the ocean crust have moved the site with time into progressively deeper and more corrosive waters. The higher Oligocene carbonate percentages at Site 708 are thus probably linked to the fact that the location was closer to the ridge crest and thus shallower during those times. (2) The history of carbonate preservation at Site 708 reveals a strong influence of another factor which operates on shorter time scales and which is superimposed on the subsidence effect. This second, and more pronounced, effect presumably reflects changes in the ocean chemistry as induced by the late Neogene climatic evolution. (3) Time-related variations in supply rate of biogenic carbonate from the mixed layer have certainly contributed to the observed pattern of carbonate preservation. The supply rate, however, can be assessed only by study of a (shallow) reference site largely unaffected by dissolution and/or erosion and winnowing.

Bulk and carbonate sediment accumulation rates were calculated on a 'turbidite-free' basis. Although much of the detailed variability should be regarded with caution because of the turbidites, it is clear that the largest differences between bulk and carbonate accumulation rates occurred during late Neogene times, that carbonate accumulation began to approach the bulk figures during early Miocene times and that the Oligocene carbonate rates make up 90% of the bulk accumulation. The middle Miocene gap is partly caused by a hiatus and partly by minimal recovery in two cores.

SITE 709 (Madingley Rise)

Site 709 is located in the western equatorial Indian Ocean at a water depth of 3038.2 m in a small basin near the summit of the Madingley Rise, a regional topographic high between the Carlsberg Ridge and the northern Mascarene Plateau. The irregular basement topography is draped with sediment, varying in thickness from less than 50 m to over 400 m. Site 709 was placed in one of the thicker sedimentary sequences since the primary objective was to study the Neogene history of carbonate preservation at this intermediate depth.

The cored sediments at Site 709 make up a single major lithostratigraphic unit consisting of alternating clay-bearing nannofossil ooze and nannofossil ooze, which is tentatively divided into three subunits on the basis of distinctive correlatable changes in color (Figure 3):

0.0-25.0 mbsf: Buff-colored nannofossil ooze of Pleistocene age.
25.0-100.0 mbsf: Numerous thin greenish-gray nannofossil ooze horizons, spanning approximately 7 m.y., from 1 Ma to about 8 Ma (Pliocene to late Miocene).
100.0-353.7 mbsf: Light gray to white nannofossil ooze and chalk representing the time interval from 8 Ma (late Miocene) to 47 Ma (middle Eocene). The occurrence of more indurated chalk was observed first at about 130 mbsf, and increases with depth.

Numerous ash layers were observed. Two particularly prominent ones bracket the Miocene/Pliocene boundary in all three holes drilled at this site. Sedimentation rates were on the order of 10-12 m/m.y. during Pliocene/ Pleistocene times, slightly higher during the late Miocene; this is then followed by a significant decrease close to the middle/late Miocene boundary that lasts until a middle Miocene hiatus stretching from 11 Ma to about 15 Ma. A stratigraphically disordered sequence characterizes the depth interval immediately below the hiatus. Sediments from the early part of the lower Miocene are intermixed with sediments of late early and early middle Miocene age (11-20 Ma). All three holes penetrated the Oligocene/Miocene boundary. Oligocene sedimentation rates are on the order of 5-6 m/m.y.; these comparatively low rates continue well into the middle Eocene. A four-fold increase in the sedimentation rate occurs at about 46 Ma in Hole 709C.

Volume magnetic susceptibility measurements at 5-cm intervals reveal inconsistencies in the sedimentary section recovered in all three holes. As discussed by Ruddiman et al. (1986), it is difficult to pinpoint the exact causes for such inconsistencies in the hole-to-hole correlation.

Carbonate contents show a component of 'high' frequency variability, based on 1 analysis per 0.75 m. When smoothed, the carbonate curve for the upper Neogene displays a 'cyclic' character. Nevertheless, the influence of a parameter which affects the carbonate record on a 0.4-0.5 m.y. periodicity seems to be present in this sediment sequence. The carbonate content ranges between approximately 88% and 93%, except for some sections of early late Miocene (and Paleogene) age that have carbonate contents of about 84-85%.

Site 709 shows the greatest variability in bulk mass accumulation rates during late Neogene times, where the values range from about 0.4 to 1.8 g/cm^2/1000 years. By assuming a constant input of the noncarbonate fraction in the time interval between 0 and 9 Ma, and using a mean bulk accumulation rate of 1.16 g/cm^2/1000 years, a change in the carbonate mass accumulation of 0.06 g/cm^2/1000 years would explain a 5% amplitude change (88-93%) in carbonate content.

The bulk accumulation rates vary between approximately 0.5 and 0.7 g/cm^2/1000 years from 20 Ma to 46 Ma. The four-fold increase in sedimentation rate at 46 Ma is of course also apparent in the accumulation rates. From the point of view of mass accumulation rates, however, the increase of the noncarbonate fraction is six-fold (from 0.06 to 0.36 g/cm^2/1000 years), using mean carbonate contents of 90.7% (20-46 Ma) and 83.6% (46-47.2 Ma), and mean bulk accumulation rates of 0.59 (20-46 Ma) and 2.22 (46-47.2 Ma) g/cm^2/1000 years. This six-fold increase is probably due to a larger input of siliceous material (radiolarians, diatoms and sponge spicules) and possibly volcanic ash, suggesting that the decrease in carbonate content at about 46 Ma is caused by dilution rather than dissolution.

The mass accumulation rates indicate major differences in depositional modes between the early Miocene-Oligocene (20-36 Ma) and the Eocene (36-46 Ma), despite the fact that a constant sedimentation rate of 5.5 m/m.y. is used as a working hypothesis. The mean carbonate contents are 91.3% (20-36 Ma) and 89.8% (36-46 Ma), respectively, whereas the corresponding bulk accumulation rates are 0.56 and 0.64 g/cm^2/1000 years. Thus the mean noncarbonate fraction accumulated at a rate of 0.05 g/cm^2/1000 years during the later half of the Eocene. The evidence indicates a 25-30% higher mass accumulation rate of the noncarbonate fraction during the Eocene, as compared to the early Miocene-Oligocene interval. The accumulation of carbonate is just over 10% greater during the Eocene (0.57 g/cm^2/1000 years) than during the early Miocene-Oligocene interval (0.51 g/cm^2/1000 years).

SITE 710 (Madingley Rise)

Site 710 is located in the western equatorial Indian Ocean on the central Madingley Rise, a regional topographic high between the Carlsberg Ridge and the northern Mascarene Plateau (Figure 2). Situated at a water depth of 3812 m, near the present-day sedimentary lysocline, Site 710 is ideally suited for a study of the Neogene history of carbonate flux and dissolution. It should also provide information on down-slope transport processes.

Two holes were continuously cored at Site 710. Major lithologies are as follows:

0.0-69.0 mbsf: Unit 1 is divided into two subunits. Subunit 1a consists of light yellowish gray nannofossil ooze containing about 5-10% biogenic silica and about 80% carbonate. Thin (2-5 cm) turbidites consisting of white foraminifer-nannofossil ooze occur occasionally. This subunit is believed to reflect oxidizing conditions. Subunit 1b is distinguished from Subunit 1a by its greenish color, which may reflect more reducing conditions. Quasi-rhythmical changes in color occur throughout Unit 1, probably caused by differential dissolution of the biogenic carbonate. The deepest core assigned to Unit 1 (Core 115-710A-8H) shows signs of slumping. The bio- and magnetostratigraphic records suggest also that the lowermost part of Unit 1 is disturbed. Unit 1 encompasses the interval from the Pleistocene to the upper Miocene (0-8 Ma).

69.0-132.0 mbsf: Unit 2 consists of clay-bearing nannofossil ooze and nannofossil clay. Its upper limit coincides with a marked change in carbonate content, from values around 80% to values around 60%, indicating strong carbonate dissolution.

The carbonate content increases to 70% towards the lower part of Unit 2 (although the entire unit is characterized by strongly variable carbonate percentages). This unit is confined to the Miocene (8-24 Ma), and its lower boundary coincides with the Oligocene/Miocene boundary.

132.0-209.7 mbsf: Unit 3 consists of alternating nannofossil ooze and chalk of Oligocene age (24-33 Ma). The carbonate content is consistently high (90%) although the planktonic foraminifers are largely dissolved.

Site 710 contains the first good magnetostratigraphic record to be obtained during Leg 115, although good magnetostratigraphic control ends at about 22 Ma.

The carbonate content record, based on 1 sample/0.75 m from Hole 710A, contains a 'high' frequency component which, when smoothed, displays a quasi-cyclical character. Dry bulk densities vary from values of 0.7 g/cm^2 to 1.25 g/cm^2, where the highest values are observed in the middle-lower Miocene nannofossil clays. Bulk carbonate and noncarbonate accumulation rates are shown in Figure 6.

In contrast to Site 709, Site 710 exhibited generally lower bulk accumulation rates during the late Miocene through Pleistocene, but proportionally higher accumulation rates of the noncarbonate fraction (Figure 7). This difference is attributed to carbonate dissolution at this deeper site. The early Miocene bulk accumulation is virtually identical at the two sites, yielding values of 0.5-0.6 g/cm^2/1000 years. A 25% difference in bulk accumulation rate, however, exists between the two sites during late Oligocene times (25-33 Ma); the higher rates occur at Site 710. Since the same set of biostratigraphic criteria were used at both sites for deriving age models, the difference is attributed to differences in depositional modes. The average bulk and carbonate accumulation rates are 0.80 and 0.70 g/cm^2/1000 years respectively at Site 710, and 0.56 and 0.52 g/cm^2/1000 years respectively at Site 709 between 25 and 33 Ma. More carbonate was apparently deposited at Site 710 despite the fact that dissolution of carbonate was more intense at this deeper site (88% of the bulk at Site 710 as compared to 93% at Site 709). This depositional pattern suggests that winnowing affected the shallower Site 709, transporting fine grained material downslope to be redeposited on the terrace at Site 710. Why this pattern was confined to the late Oligocene remains to be answered.

SITE 711 (Madingley Rise)

Site 711 is located at a water depth of 4428.2 m on the northern edge of the Madingley Rise, just a few hundred meters above the abyssal plain which separates the Madingley Rise from the Carlsberg Ridge (Figure 1). Site 711 forms the deep end-member of the carbonate bathymetric transect.

Based on differences in biogenic components and carbonate contents, four lithologic units were described from Site 711 (Figure 3):

0.0-17.7 mbsf: Alternating light yellowish clayey nannofossil ooze and dark grayish brown radiolarian-bearing nannofossil clay and nannofossil-bearing clay of late Pliocene through

Pleistocene age. Carbonate content varies between 40 and 60%.

17.7- 68.0 mbsf: Generally carbonate-poor (0-10%) clays. About 25 thin (<30 cm) turbidites occur in this unit, which represents the time from the late/early Pliocene boundary to the earliest Miocene.

68.0-173.0 mbsf: Carbonate-rich (75-90%) sediments that are virtually devoid of foraminifers. The sediments are characterized as nannofossil ooze or clay-bearing nannofossil ooze which, towards the bottom of this unit, becomes more lithified and grades into clay-bearing nannofossil chalk. Two distinct ash layers, 15 cm and 5 cm thick, respectively, occur in the upper Oligocene section. The entire unit represents the time interval from the earliest Miocene through the Oligocene.

173.0-249.7 mbsf: Distinguished from the unit above by the consistent occurrence of radiolarians, which decreases the carbonate values to about 70-80%. A few short intervals within this unit consist of almost pure radiolarian ooze. Unit 4 spans the major part of the middle Eocene (41-50 Ma).

The time control in the upper 104.5 m is based on biostratigraphy and magnetostratigraphy. Below that depth, the time control is based on biostratigraphy. This deep site is characterized by distinctly low sedimentation rates that increase to over 10 m/m.y. in the interval below 200 mbsf. Despite the fact that the middle and lower Miocene sediments are strongly condensed, with an average sedimentation rate of about 2 m/m.y., this sequence appears to represent continuous deposition. Oligocene and late Eocene sedimentation rates are on the order of 6-7 m/m.y. A few distinct dissolution events occur across the middle/upper Eocene boundary, which lower the apparent sedimentation rate to about 4 m/m.y. (between 40 Ma and 46 Ma); thereafter the rates increase to over 13 m/m.y.

Bulk and carbonate accumulation rates at Site 711 clearly display the effects of substantial dissolution. The noncarbonate fraction dominates the bulk accumulation throughout most of the Neogene, but is secondary to the carbonate accumulation rates during Oligocene and Eocene times (except for two short intervals near the middle/late Eocene boundary). The bulk accumulation rates varied between 0.1 and 0.4 g/cm^2/1000 years during the Neogene, increased to about 0.6 g/cm^2/1000 years during the Oligocene and latest Eocene, decreased to 0.3 g/cm^2/1000 years during the early late and late middle Eocene, and finally increased to about 1.2 g/cm^2/1000 years during the early half of the middle Eocene. Assuming that the input of the noncarbonate component was similar over the entire Madingley Rise (Sites 709, 710 and 711) at any given time interval, the general increase in accumulation rate of this component as a function of water depth suggests the influence of down-slope transport processes (Figure 8). The only exception to this pattern is the upper Miocene through Pleistocene intervals at Sites 710 and 711, which show identical non-carbonate accumulation rates.

Site 711 was below the depth of the CCD throughout most of the Neogene. The carbonate-rich Paleogene sediments are virtually devoid of foraminifers, indicating that the site has been below the depth of the foraminifer lysocline since 50 Ma and that nannofossils are generally less susceptible to dissolution than foraminifers.

SITE 712 (Northern margin Chagos Bank)

In the transit from Site 711 to Site 712, JOIDES Resolution crossed the Central Indian Ridge which forms the boundary between the African and Indian plates (Figure 9). This spreading ridge has been active since Chron 13 time (36 Ma), when the Chagos Bank was rifted from the Nazareth Bank and the Ninetyeast Ridge was separated from the Kerguelen hotspot. Before this time the plate boundary spreading system was located farther to the south (McKenzie and Sclater, 1971; Schlich, 1982). The rationale for drilling at the Chagos Bank was to sample hotspot-produced volcanic rocks midway between the Deccan flood basalts and ocean island basalts found on the islands of Reunion and Mauritius.

Site 712 is located on the northern margin of the Chagos Bank at a water depth of 2892.4 m. Shallow water carbonate reefs and banks lie 70 nmi to the south and southwest. An abrupt scarp, probably related to pre-36 Ma transform faulting, drops 3000 m just 30 nmi to the east. In the immediate vicinity of this site is a gently dipping volcanic apron which deepens to the north to a 4500 m channel, dividing the Chagos Bank from the Maldive Islands.

The basement rocks in this region form a series of offset steps, probably resulting from extension and normal faulting. The sediment cover is about 190 m. Hole 712A was terminated in middle Eocene nannofossil oozes and volcanic ashes at 115.3 mbsf.

Major lithologies are as follows (Figure 3):

0.0-58.0 mbsf:	Clay-bearing foraminifer nannofossil ooze with thin turbidites and minor bioturbation of late Pliocene to middle Miocene age; with depth these sediments become more consolidated as foraminifer nannofossil chalks.
58.0-106.0 mbsf:	Essentially no recovery except for drilling rubble, which included coarse fragments of recrystallized limestone. Late Oligocene age.
106.0-115.3 mbsf:	Clay-bearing foraminifer nannofossil chalk with numerous thin interbedded volcanic ash layers. Middle Eocene age.

SITE 713 (Northern margin Chagos Bank)

Site 713 is located 1.6 nmi to the north of Site 712, on the northern margin of the Chagos Bank, at a water depth of 2909.5 m (Figure 9).

Hole 713A recovered basalts of olivine tholeiitic composition, intercalated with nannofossil chalks of early middle Eocene age (47-48 Ma). The basalts vary from thicker (10 m), more vesicular flows at the top, to thinner (1 m), more compact flows with depth. Some 35 separate flow units were distinguished on the basis of sediment interbeds and glassy, chilled margins. The basalts were erupted well below sealevel, but the degree of vesicularity in some of the flows indicates conditions a good deal shallower than the present depth (3000 m). Thermal subsidence considerations (Sclater et al., 1977) predict a depth for this site of about 1000 m at the time of volcanic activity. The benthic foraminiferal assemblage observed between the lava flows indicates a deeper water environment; this conflict, however, is at present unresolved.

A significant amount of well-preserved black volcanic ash was observed that increases towards the base of the sediment column and that is intercalated with the basalt flows. Preliminary examination indicates that these may represent much more evolved magmas than those inferred from the basaltic rocks. The ashes are undoubtedly of local origin, but the variability of the compositions among the fresh glasses will allow a much more complete assessment of the range of volcanic products at this location on the hotspot track.

The major lithologies can be summarized as follows (Figure 3):

0.0-31.0 mbsf: Homogeneous nannofossil-bearing foraminifer ooze to foraminifer-bearing nannofossil ooze of Pleistocene to late Miocene age.

31.0-106.9 mbsf: Foraminifer-bearing nannofossil chalk, clay-bearing in parts, with volcanic ashes increasing in occurrence and thickness with depth. Spectacular bioturbation and small-scale faulting are preserved and clearly seen because of color contrast. Middle Eocene age.

106.9-192.0 mbsf: Vesicular to compact submarine basalts of olivine basalt composition. Flows vary from 1 to 10 m thickness and are interbedded with middle Eocene nannofossil chalks and volcanic ashes.

SITE 714 (East Maldives Ridge)

Site 714 is located at a water depth of 2231.5 m on the eastern shoulder of the Maldives Ridge, which forms part of the aseismic ridge extending northwards from the Chagos Bank to the Laccadive Islands (Figure 9). Seismic profiles from the Maldives Ridge area reveal massive accumulation, on the order of 1 to 1.5 km, of sediments and sedimentary rocks on top of the presumed volcanic basement. Our main purpose was to retrieve a complete upper Neogene sequence of soft aragonite-bearing (periplatform) ooze.

Two holes were continuously cored at Site 714: Hole 714A terminated in foraminifer-nannofossil chalk of late Oligocene age (about 28 Ma) at 233.0 mbsf, whereas Hole 714B ended in foraminifer-bearing nannofossil ooze at 122.6 mbsf at the lower/middle Miocene boundary (about 16 Ma). The depositional history contains a single major hiatus, spanning the time interval from 0.5 to 8.2 Ma (late Pleistocene through late Miocene), but otherwise the sequence is characterized by continuous sediment accumulation. This sequence is both more expanded and more complete than any other lower upper Miocene through lower Miocene sequence recovered during Leg 115. The excellent preservation of foraminifers and calcareous nannofossils in this Miocene section may thus contribute substantially to our understanding of their low latitude intercorrelation during Miocene times. The middle Miocene also contains moderately well-preserved siliceous faunas and floras, which again emphasizes the potential importance of this tropical Indian Ocean sequence for Miocene biostratigraphy and paleoceanography.

The sequence is composed of two lithostratigraphic units, one of which is divided into two subunits (Figure 3):

0.0-19.55 mbsf: Unit 1 consists of upper Pleistocene (0-0.5 Ma) dark greenish-gray clay-bearing foraminifer-bearing nannofossil ooze, grading downhole into a foraminifer-bearing clayey nannofossil ooze. The average carbonate content is 76%.

19.55-120.0 mbsf: Subunit 2a consists of very light greenish-gray lower upper Miocene through middle Miocene (8.2-16 Ma) clay-bearing foraminifer-bearing nannofossil ooze. The carbonate content shows a generally progressive increase from lows of about 81-82% at 9 Ma, to peak values of about 89% at 16 Ma (estimated from mean values in 1 m.y. time increments). The carbonate contents range from 61% to 95%.

120.0-233.0 mbsf: Subunit 2b is compositionally similar to subunit 2a, but is distinguished on the basis of the degree of lithification. Subunit 2a grades into a clay-bearing foraminifer-nannofossil chalk characterizing Subunit 2b. Burrow mottles (moderate) occur throughout Unit 2. The carbonate content of Subunit 2b displays more subtle variations than those observed in Subunit 2a, and no obvious trends are discerned. Apart from a single extreme value of 61% all carbonate contents are in the range between 77% and 93% with an average of 87%.

Since the geomagnetic field intensities are too low to yield a magnetostratigraphic record, we have to rely on the calcareous nannofossil correlation to magnetostratigraphy from Site 710, and apply those results to the material recovered from Site 714. This approach, together with the use of well-calibrated planktonic foraminifer datums from Atlantic and Pacific low latitude regions (Site 710 lay below the foraminifer lysocline as it was during Miocene times), should provide the necessary means for the reconstruction of a highly resolved chronology at Site 714.

The Pleistocene bulk accumulation rate is approximately twice that of the average of the pre-Pleistocene rates. Nevertheless, the Miocene rates were consistently higher than 1 $g/cm^2/1000$ years between 8.2 and 19 Ma, and slightly below that value throughout most of the earliest Miocene and late Oligocene. The accumulation rate of the noncarbonate fraction mimics by and large the changes in bulk and carbonate accumulation, with the highest Miocene values near the middle/upper and lower/middle Miocene boundaries and slightly lower rates during the middle and lower Miocene. Considering the consistently high bulk sediment percentage of nannofossils, winnowing apparently has had little effect on the calculated mass accumulation rates. Provided the age-depth model for Site 714 is accurate, the mass accumulation rates should reflect the true time dependent variability in input of carbonate.

SITE 715 (East Maldives Ridge)

Site 715 is located on the eastern margin of the Maldives Ridge, at a water depth of 2262.3 m (Figure 9). The main objective was to penetrate the supposed basaltic basement underlying the carbonate bank deposits which form the Maldive Islands. This site lies on the Chagos-Maldive-Laccadive Ridge, roughly midway between Site 713 on the Chagos Bank and the southern limit of the Deccan flood basalts of western India (Figure 9). According to the model which attributes this volcanic lineament to India's northward motion over the Reunion hotspot (Morgan, 1981), we expected to find a basalt age of about 55

Ma (Duncan, 1981; Emerick, 1985). The composition of the basalts should also reveal the relative contributions of mantle melts from the hotspot and asthenosphere (MORB) sources.

The best opportunity for drilling to basement appeared to lie at the base of the eastern slope of a narrow peripheral ridge which connects with the main shallow carbonate bank to the west. To the east, the ocean floor drops away to a 2600-m-deep plain containing more than 1 km of mostly hemipelagic deposits derived from the Indian subcontinent (Sclater et al., 1977).

At this site one hole was drilled which penetrated basalt at 211 mbsf and continued a further 77 m into basement. Above the basalt was 100 m of lower Paleogene (Eocene to Paleocene) shallow water limestone. Pelagic nannofossil oozes of Pleistocene to Miocene age lie above the limestone.

The major lithologies identified at Site 715 are (Figure 3):

0.0-104.6 mbsf: Clay-bearing foraminifer-bearing nannofossil oozes, homogeneous greenish-gray, with rare pyrite mottling. Late Pleistocene and middle to early Miocene age.

104.6-211.3 mbsf: Shallow water carbonate sequence, progressing from (1) wackestone, composed of benthic foraminifers, fragments of bivalves, brachiopods, pelecypods, minor hardgrounds and glauconite, that are interpreted as slope deposits; (2) packstone with large intact benthic foraminifers, bryozoans, gastropods, and molluscs, indicating shallower water deposition; to (3) grainstone with solitary and colonial coral fragments and bryozoans, indicating very shallow water and high energy conditions of deposition. Early Paleogene age.

211.3-287.8 mbsf: Subaerially erupted lava flows of olivine basalt composition, fine-grained, plagioclase-phyric, slightly to moderately altered. Flows are 1 to 5 m thick with one limestone interbed (0.5 m thick) and several baked (laterite?) contacts. Overlain by very shallow water reef limestones of early Paleogene age (Paleocene or Eocene).

The uppermost pelagic ooze section was similar to that cored at Site 714, only 3 nmi to the west. A major hiatus of about 14 m.y. exists between the Pleistocene and middle Miocene nannofossil oozes. The next unit down gives a fascinating look at the early stages of reef-building and subsidence of the volcanic edifice in Eocene-Paleocene time. These deposits record a progressive deepening of the site from littoral to bank to slope conditions.

In the basaltic section, we see the final stages of volcanic activity of an oceanic island in early Tertiary time. Subaerially erupted olivine basalts are overlain by a coarse volcanic sandstone of angular and rounded fragments in a carbonate cement which is interpreted as a beach deposit. A later flow is succeeded by a section of intertidal to shallow water coral reef limestones; hence, we have a record of the initial stages of subsidence of the volcano. Some 21 separate flow units have been distinguished in the recovered section, and two distinct magma types have been identified. The upper type is a plagioclase-phyric basalt, while the lower type is a mafic, olivine-rich basalt with slight alkaline character. Flows are vesicular towards the margins and vary from 1 to 5 m in thickness.

Seafloor subsidence curves for the Indian Ocean (Sclater et al., 1977) can be used to indirectly date the volcanic rocks (Figure 10). We know that the basalts were erupted above sealevel and they are now at about 2500 m below sealevel. Thermal subsidence is most rapid for volcanos built on young oceanic lithosphere (i.e., near spreading ridges) and less rapid for volcanos erupted in the interior of old, thick oceanic plates (Crough, 1978). Using the young lithosphere end-member, 2500 m of subsidence would have taken a minimum of about 47 m.y.; a more average range is 55 to 60 m.y. These age estimates are consistent with the shipboard biostratigraphic age for the shallow water limestone.

Paleomagnetic measurements of the uppermost flow show normal polarity; the remainder of the sequence is reversed. The magnetic directions are stable and the site paleolatitude calculated from 15 spot measurements is $26 \pm 5^{\circ}$ S. This result is consistent with the paleolatitude estimates for Sites 706, 707 and the Deccan flood basalts (Courtillot et al., 1986). The measured Site 713 paleolatitude is significantly farther north, which may be due to post-crystallization tectonic movements. We conclude from the paleolatitude study of the four basement sites that there has been significant true polar wander--about 8°--northward for the Reunion hotspot with respect to the geomagnetic pole (=spin axis) and that this motion occurred between 36 Ma and the present.

SITE 716 (Maldives Ridge)

Site 716 is located in the center of the Maldives Ridge at a water depth of 533.3 m. The site lies in flat terrain on a broad, shallow basin which is filled with 1-1.5 km of sediments and sedimentary rocks. The primary objective was to retrieve a complete late Neogene sequence for studies of aragonite-bearing periplatform oozes.

The recovered sequence represents a single lithologic unit from the mudline to 267.4 mbsf, consisting of foraminifer-bearing nannofossil ooze that grades into chalk. Celestite occurs sporadically in the deeper part of the section; this site thus appears to contain a fascinating history of diagenetic processes.

Petrographic observation and XRD analyses indicate that aragonite is present throughout the entire sequence. Although the sequence is consistently dark greenish-gray in color, with shades of paler color towards the bottom of the section, clays are a minor component. The carbonate content is in excess of 95%. Diatoms and radiolarians are virtually absent, and the minor amounts of opaline silica present are from sponge spicules. Paleontological examination suggests that the recovered sequence is stratigraphically continuous and that the deposition occurred in two major regimes. The upper 135 m show two sedimentation rates: 43 m/m.y. during the late Pleistocene (0-0.46 Ma) and 29 m/m.y. during the early Pliocene (0.46 Ma to 4.6 Ma). The second regime, where the sedimentation rate is on the order of 125 m/m.y., ranges from earliest Pliocene to latest Miocene.

It is apparent that the sediments cored at Site 716 offer a unique opportunity for high-resolution studies of the late Neogene which, in turn, should have a profound impact on our understanding of the paleoenvironmental development on both a regional and a global scale.

DISCUSSION

Leg 115 set out to accomplish two major programs. The first was to establish the reality of age-progressive, hotspot-associated volcanism along the Mascarene-Chagos-Maldives lineament and to recover basaltic rocks for geochemical studies of source compositions for mantle melting under the central Indian Ocean basin. The second was to document the Neogene history of carbonate production and dissolution in tropical Indian Ocean waters.

Hotspots and Plate Tectonics

Four sites in Leg 115 recovered basaltic volcanic rocks. Site 706 is located on the northern margin of the Nazareth Bank, Site 707 is located midway between the Seychelles and Saya de Malha Bank, Site 713 is located on the northern margin of the Chagos Bank, and Site 715 lies on the eastern margin of the central Maldives Ridge (Figures 2 and 9). These positions are more or less equally spaced along the lineament and sited to optimize sampling of the hotspot products through time. In addition to the sites we drilled, basalts are exposed at Reunion, Mauritius, and the Deccan Traps, and are available from two industry wells on the Mascarene Plateau, making nine separate sample suites for petrochemical studies. Very shortly, this may be one of the best described hotspot traces known.

Our first objective was to confirm that this ridge system is constructed of oceanic volcanic rocks and that ages really do increase to the north along the submerged portions of the lineament. Biostratigraphic age estimates for the four sites are in good agreement with ages predicted assuming a fixed Reunion hotspot (Duncan, 1981; Morgan, 1981; Emerick, 1985). With further radiometric and biostratigraphic refinement, Site 706 (35 Ma), Site 713 (47 Ma), and Site 715 (55-60? Ma) ages will be used to define poles of rotation for Indian plate motion through the Cenozoic. Figure 5 illustrates one set of working reconstructions based on our preliminary results. A long-standing goal of deep-sea drilling in the Indian Ocean has been to determine the nature and origin of the ridge joining the Seychelles Bank with the Saya de Malha Bank (Fisher, Bunce, et al., 1974). Through drilling to basement at Site 707 we now know that this ridge formed by basaltic volcanism in early Paleocene time (64 Ma), probably as part of the Deccan flood basalt event.

Our shipboard petrochemical studies have identified several important aspects of the basaltic volcanism at the four sites. The shipboard XRF facility generated high-quality major and trace element analyses (81 samples) and greatly assisted our sampling for shore-based studies. At Sites 707 and 715 we intersected subaerially erupted lava flows, while at Sites 706 and 713 the flows were erupted at intermediate water depths. Hence, different positions on the volcanic structures at the given sites were sampled. Although all samples are to some degree affected by secondary alteration, primary mineral and bulk rock compositions can be obtained.

All compositions are basaltic, with plagioclase feldspar dominant in most samples, but olivine important especially in the Site 715 rocks. Major and trace element variation diagrams (e.g., Figures 11-13) point out the general effects of olivine, clinopyroxene, and plagioclase in controlling fractionation at all sites. Figure 13 illustrates an especially interesting aspect of the compositions. The ratio Zr/Nb is not thought to change during mantle melting or crystal fractionation processes because Zr and Nb are both equally incompatible elements. Thus, differences in Zr/Nb reveal differences in mantle source compositions. Intra-plate oceanic island basalts yield low ratios (5 to 10) while spreading ridge (MORB) basalts have high ratios (20 to 30). As the figure shows, Site 715 basalts are indistinguishable from Reunion basalts on this basis, while Site 707 and 713 basalts show more of a MORB contribution. Site 706 basalts are intermediate and similar to some of the Deccan basalts. Isotopic compositions for these basalts will further distinguish likely contributions to the melting, but from our preliminary results it appears that Site 715 may have formed in an intraplate setting, Site 706 closer to a spreading ridge, and Sites 707 and 713 erupted when a spreading segment coincided with the hotspot.

A final objective of the basement drilling along this lineament was to investigate the phenomenon of true polar wander. It now appears from the geometry and age progression of volcanic activity along the Reunion and Kerguelen hotspot traces that these (and other) hotspots have maintained fixed positions relative to one another during the formation of the Indian Ocean. In this case, the hotspots form a reference frame for plate motions and reconstructions. It also follows that every volcano formed over a given hotspot should have the paleomagnetic latitude, <u>unless</u> the hotspot reference frame has moved with respect to the geomagnetic pole (assumed to coincide on average with the earth's spin axis). Any departure from a constant paleolatitude has been interpreted as true polar wander, or motion of the whole earth with respect to its spin axis. Studies of paleolatitudes for the Pacific plate (Gordon and Cape, 1981) have shown true polar wander of about 10° since the Late Cretaceous; that is, central Pacific hotspots have moved south relative to the spin axis. On the opposite side of the globe hotspots should appear to move north over the same period. Our paleolatitude studies (Figure 4) suggest that, indeed, the Reunion hotspot lay 7° farther south than its present position up until at least 35 Ma. No significant polar wander is discerned for the interval from 67 to 35 Ma.

<u>Paleoceanography and Stratigraphy</u>

Modern paleoceanography is based upon the retrieval of complete and virtually undisturbed sediment sections from the ocean floor. An auxiliary demand is that a highly resolved chronology can be established in the recovered sediments. Leg 115 provides the first opportunity for extensive deep sea drilling in the Indian Ocean in which these basic paleoceanographic requirements can be met. The paleoceanographic program of Leg 115 was composed of two independent, but complementary, parts: (1) the carbonate (calcite) dissolution profile along the bathymetric transect, spanning the depth interval from 1541.4 m (Site 707) to 4428.2 m (Site 711), and located in a fairly narrow geographic area on the northern Mascarene Plateau and the Madingley Rise; (2) the aragonite-bearing periplatform oozes (Site 714 at 2231.5 m depth; Site 716 at 533.3 m depth), located on the Maldives Ridge. All but the last two sites were drilled south of the equator. Overriding objectives were to recover complete Neogene sequences from all carbonate dissolution sites, and complete late Neogene sections from the periplatform sites.

Carbonate Dissolution Profile. The shipboard approach to portray the history of carbonate flux and its dissolution at depth was to calculate average mass accumulation rates of both the carbonate and noncarbonate fractions over 1 m.y. time increments for each site. The resulting graphs thus represent the amalgamation of sedimentation rates, as derived from biostratigraphy and magnetostratigraphy, carbonate contents (weight%), analyzed at 0.75 m intervals (except Site 707--0.5 m intervals), and physical properties data (dry bulk density).

The shallow Site 707 was to be used as reference for the other, deeper carbonate sites, as it was anticipated that carbonate dissolution would be negligible. Low-amplitude, but distinct, long-period oscillations in carbonate content occurred through the entire pelagic sequence (0-37 Ma). Winnowing has strongly reduced the accumulation rates, which of course complicates the use of this material to monitor the true carbonate flux. Winnowing is particularly emphasized after 3 Ma, and between 9 and 29 Ma. This implies a depositional history suitable for analysis of the variability of flow strengths of intermediate deep waters across the topographic saddle joining the Seychelles Bank to the Saya de Malha Bank. A trough in accumulation coincides with the early Oligocene deep water event (Shackleton and Kennett, 1975). Likewise, drastic decreases in accumulation close to the Oligocene/Miocene and near the middle/late Miocene boundaries may eventually be linked to glacial episodes in Antarctica (Miller and Fairbanks, 1985). The moderately good preservation of planktonic foraminifers during middle and early Miocene times is in agreement with vigorous bottom currents at Site 707.

Thirty to fifty percent of the sequence recovered at Site 708 (4096.5 m) consists of shallow water calciturbidites, presumably originating from the Seychelles Bank. Calculated on a turbidite-free basis the upper Neogene (0-10 Ma) carbonate accumulation shows three distinct troughs: after 1 Ma, between 3 and 5 Ma, and between 8 and 9 Ma. The middle Miocene interval was lost, in part because of minimal recovery in two consecutive cores and in part due to a hiatus. The lower Miocene-Oligocene rates are conspicuously even, which may partially reflect the influence of a poorly resolved chronology. Foraminiferal preservation is very poor throughout the pelagic sequence at Site 708.

Three sites were drilled from the summit of the Madingley Rise (709) and downslope (710, 711). Dissolution increases with depth, and Sites 709 and 710 share some common features: (1) strong variability in carbonate accumulation during the late Neogene, (2) shallow CCD's during middle and late early Miocene times, and (3) increased carbonate accumulation during earliest Miocene and Oligocene times. Apart from the upper Pliocene-Pleistocene, Site 711 was located below the CCD throughout the Neogene, but was above this chemical boundary during the Oligocene and most of the Eocene (24-49 Ma)--except for a few strong dissolution cycles straddling the middle/late Eocene boundary. Mass accumulation rates of bulk sediment, carbonate and the noncarbonate fraction from Hole 710A (0-33 Ma) are shown in Figure 6.

By comparing the carbonate-free accumulation rates at Sites 709 through 711 and assuming a constant input of this fraction at any given time interval, the effect of downslope transport processes may be discerned. Figure 7 shows the relationship between the shallowest (709) and the next deeper (710) sites: simply expressed, downslope transport of the noncarbonate fraction, from Site 709 to Site 710, occurred throughout their overlapping time intervals. During Oligocene times, the carbonate fraction was also transported to deeper levels. Thus despite the greater dissolution at the deeper Site 710, more carbonate accumulated between 25 and 33 Ma because of the downslope transport processes. Figure 8 shows the carbonate-free relationship between the two deepest sites (710 and 711). Much of the downslope transport of the noncarbonate fraction originating from the most elevated areas of the Madingley Rise apparently was trapped at intermediate deep levels (Site 710) and never reached the base of the rise (711). The only intervals where the carbonate-free accumulation at Site 711 exceeds that at Site 710 are between 13 and 21 Ma, and between 27 and 32 Ma. Some shorter time intervals display even higher noncarbonate input to the shallower of the two sites. These three sites (709-711) also appear to contain carbonate content oscillations of a quasi-cyclical nature (0.4-0.5 m.y. periodicity?).

Once a correction for the subsidence and sediment load is calculated, meaningful reconstructions of the time dependent development of lysocline and CCD positions can be made. Yet the crude estimates of mass accumulation rates and carbonate contents presented above indicate that the later part of the lower Miocene and most of the middle Miocene were periods of intense carbonate dissolution. Pronounced CCD excursions to shallower levels also occurred at about the middle/upper Eocene boundary. Apart from the youngest intervals in the shallowest sites, the preservational states of planktonic foraminifers vary from moderate to very poor.

Periplatform oozes. Site 714 was a disappointment in terms of recovery of aragonite-bearing periplatform oozes (hiatus from 0.5 to 8.2 Ma), but a tremendous and unexpected success in terms of recovery of a unique middle Miocene through upper Oligocene sequence that contains all major pelagic microfossil groups. The preservational states of the calcareous groups are exceptionally good and the sequence is characterized by uncomplicated and relatively high sedimentation rates (10-20 m/m.y.). Site 714 will be an important reference section for middle Miocene through upper Oligocene biostratigraphy and paleoceanography in the tropical Indian Ocean.

Site 716 (533.3 m water depth) was the last site to be drilled during Leg 115, and the available time was too short to allow even routine shipboard analyses to be performed, except for lithostratigraphy and biostratigraphy. The sequence was stratigraphically continuous from the Pleistocene through the upper Miocene, with remarkably high sedimentation rates prior to 4.6 Ma (>100 m/m.y.). Aragonite occurs throughout the sequence, which also contains what seems to be the promise of a fascinating history of diagenetic processes.

Stratigraphy. Combined biostratigraphy and magnetostratigraphy represent the means by which highly resolved chronologies can be obtained in deep sea sediments. Leg 115 experienced a number of problems with the magnetostratigraphic data collection, due to magnetic overprinting. After half the holes were drilled, the problem was traced to the core barrels which, after demagnetization, yielded cores with meaningful magnetostratigraphic results (Sites 710 and 711). The rotary drilled Sites 712, 713 and 715 yielded magnetostratigraphic results from the basalts. The sediments at Site 714, however, were too weakly magnetized to be measured. A few core sections were measured at Site 716, and these appear promising from a magnetostratigraphic point of view.

The magnetostratigraphic results from Site 710 thus offer the first opportunity to directly correlate calcareous nannofossil (planktonic foraminifers are dissolved) datums with Neogene magnetostratigraphy from the tropical Indian Ocean. The results obtained from Site 710 suggest that major revisions have to be made in the calibration between zonal schemes and the geomagnetic polarity record. The range of one critical species (S. heteromorphus) has been changed from 14.4 Ma (last occurrence) and 17.1 Ma (first occurrence) to 13.0 and 18.5 Ma, respectively. This observation, which is corroborated by data from DSDP Leg 94 (Ruddiman, Kidd, Thomas, et al., 1986), has important consequences for lower and middle Miocene biochronology and, hence, for paleoceanographic interpretations focused on that time interval. When these newly derived age estimates are applied to the sequence obtained from Site 714, it becomes apparent that these estimates fit the overall configuration of events much better than previous estimates.

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TABLE 1. SITES DRILLED DURING LEG 115

Hole	Position (Latitude, Longitude)	Water depth (mbsl)**	Penetr. (mbsf)	Recovery (%)	Age of oldest sediment
705					
A	13°10.00'S 61°22.27'E	2307.5	27.5	70.0	Pliocene
706					
A	13°06.86'S 61°22.27'E	2506.5	47.5	82.9	early Oligocene
B	13°06.86'S 61°22.27'E	2507.5	43.7	67.0	early Oligocene
C	13°06.86'S 61°22.27'E	2507.5	121.7*	25.0	early Oligocene
707					
A	7°32.72'S 59°01.01'E	1541.4	213.3	75.1	middle Eocene
B	7°32.72'S 59°01.01'E	1541.4	124.9	77.0	middle Miocene
C	7°32.73'S 59°01.01'E	1541.4	443.7*	35.0	early Paleocene
708					
A	5°27.23'S 59°56.63'E	4096.5	236.2	80.0	early Oligocene
709					
A	3°54.72'S 60°33.16'E	3038.2	203.1	91.0	late Oligocene
B	3°54.72'S 60°33.16'E	3038.2	254.8	92.0	early Oligocene
C	3°54.72'S 60°33.16'E	3038.2	353.7	92.6	middle Eocene
710					
A	4°18.69'S 60°48.76'E	3812.0	209.7	88.0	early Oligocene
B	4°18.69'S 60°48.76'E	3810.5	83.4	71.9	late Miocene
711					
A	2°44.46'S 61°09.75'E	4428.2	249.6	81.6	middle Eocene
B	2°44.47'S 61°09.78'E	4429.7	98.6	90.0	late Oligocene
712					
A	4°12.99'S 73°24.38'E	2892.4	115.3	36.0	middle Eocene
713					
A	4°11.58'S 73°23.65'E	2909.5	191.7	60.0	middle Eocene
714					
A	5°03.69'N 73°46.98'E	2231.5	233.0	83.5	late Oligocene
B	5°03.69'N 73°46.98'E	2231.5	122.6	93.7	early Miocene
715					
A	5°04.89'N 73°49.88'E	2262.3	287.8	48.0	early Eocene(?)
716					
A	4°56.00'N 73°17.01'E	533.3	257.1	102.0	middle Miocene
B	4°56.00'N 73°17.01'E	533.3	264.4	101.0	middle Miocene

* indicates washed intervals: Hole 706C, 0-44.3 mbsf; Hole 707C, 0-183.8 mbsf.
** water depth (mbsl) = DPM depth - 10.5 m.

FIGURE CAPTIONS

Figure 1. The JOIDES Resolution trackline and location of sites drilled during Leg 115, western Indian Ocean.

Figure 2. Bathymetric map of the western Indian Ocean (after Fisher et al., 1971) showing the location of sites drilled during Leg 115 in the vicinity of the Mascarene Plateau. Sites 705 and 706 are on the eastern shoulder of the ridge, at the northeastern margin of the Nazareth Bank. Site 707 lies on the elevated ridge connecting the Seychelles Bank with the Saya de Malha Bank. Site 708 is on the abyssal plain just to the north of the Mascarene Plateau. Sites 709, 710, and 711 are on the Madingley Rise, between the Mascarene Plateau and the Carlsberg spreading ridge.

Figure 3. Geologic columns constructed from lithostratigraphic and biostratigraphic examination of core material recovered during Leg 115.

Figure 4. Paleolatitudes of sites along the Reunion hotspot track. The hotspot has moved about 8^{o} north with respect to the geomagnetic axis between the age of Site 706 (36 Ma) and the present. Prior to 36 Ma all sites seem to have had about the same latitude for volcanic activity. (Site 713 is anomalous and may have experienced post-crystallization tectonic rotation.)

Figure 5. Plate reconstruction for the western Indian Ocean at C29R time (67 Ma), in the hotspot reference frame. Hotspots (Reunion, R; Comores, C; Kerguelen, K; Marion, M) are shown in present coordinates. Deccan Trap volcanic activity occurred as the trailing edge of the Indian plate crossed over the Reunion hotspot. Site 707 basalts show affinities to the Deccan basalts and were probably erupted as part of that volcanic event.

Figure 6. Mass accumulation rates of the noncarbonate fraction (black), carbonate (striped) and bulk sediment (unfilled) from Hole 710A. No data exist between 7.4 and 8.2 Ma (gap in the section).

Figure 7. Comparison of mass accumulation rates of the carbonate-free fractions at the relatively shallower Site 709 (striped) and the relatively deeper Site 710 (unfilled). The gap in the Site 709 record between 11 and 20 Ma is caused partly by a hiatus and partly by the existence of turbidites (no data collected). Note the generally higher accumulation rates at the deeper site, indicating the influence of downslope transport processes.

Figure 8. Comparison of mass accumulation rates of the carbonate-free fractions at the relatively shallower Site 710 (striped) and the relatively deeper Site 711 (unfilled).

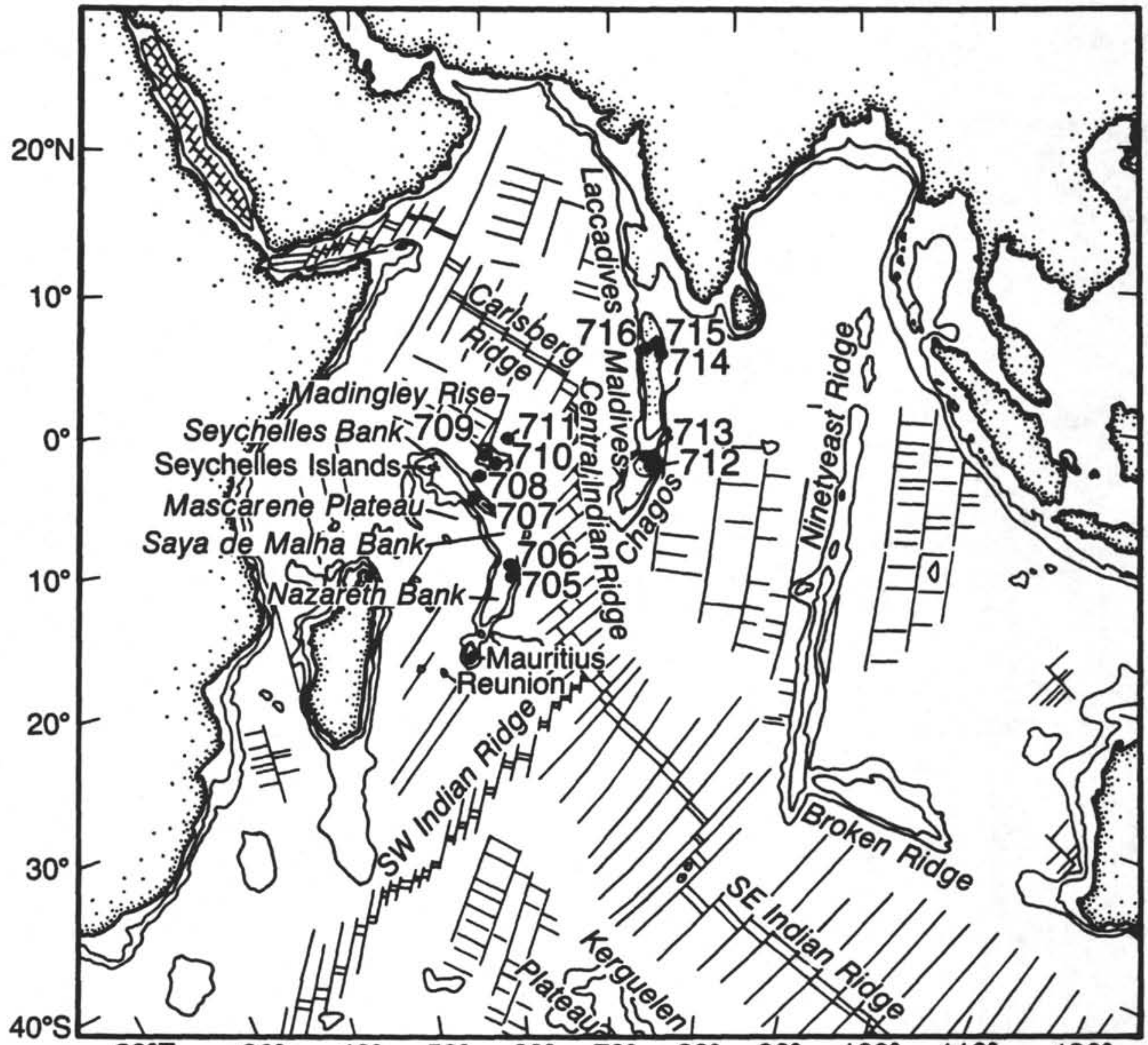
Figure 9. Location of Leg 115 sites drilled in the central Indian Ocean: Sites 712 and 713 are on the northern margin of the Chagos Bank, and Sites 714, 715 and 716 are on the eastern shoulder of the central Maldives Ridge.

Figure 10. Hypothetical thermal subsidence curve for Site 715. The site was at or above sealevel at the time of volcanism and has subsided 2500 m. The estimated basement age is thus about 55 to 60 Ma, which is consistent with our early Paleogene biostratigraphic age estimate and the hotspot-predicted age of 55 Ma.

Figure 11. Variation diagram for SiO_2 vs MgO for Leg 115 basement rocks.

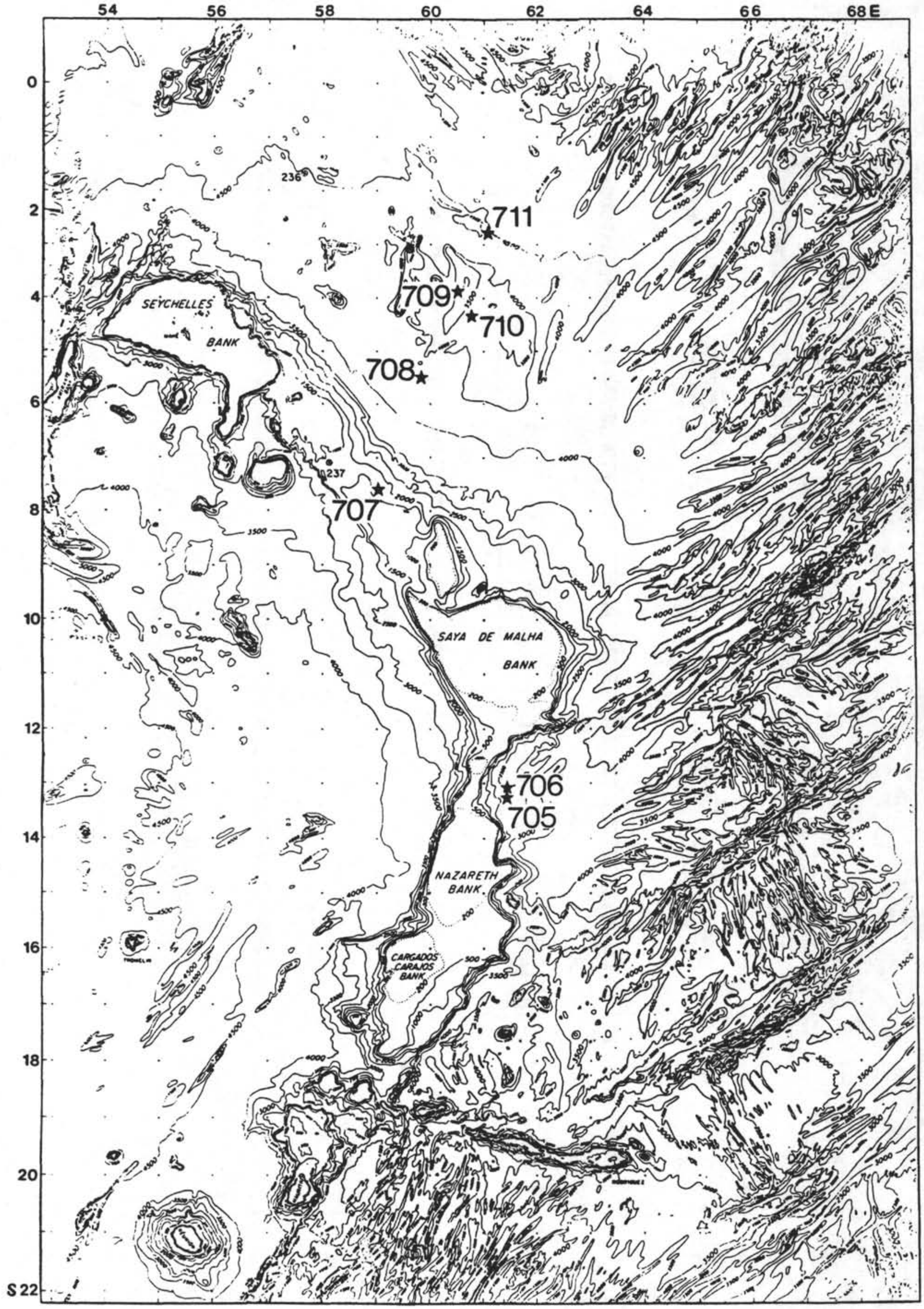
Figure 12. Variation diagram for Cr vs MgO for Leg 115 basement rocks.

Figure 13. Variation diagram for Zr vs Nb for Leg 115 basement rocks. The ratio Zr/Nb is a fingerprint for mantle source composition. The basaltic rocks recovered from this hotspot track have compositions which fall between intraplate oceanic islands and spreading ridge basalts.



20°N
10°
0°
10°
20°
30°
40°S
20°E
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
Laccadives
Maldives
Chagos
Carlsberg Ridge
Central Indian Ridge
Ninetyeast Ridge
Madingley Rise
Seychelles Bank
Seychelles Islands
Mascarene Plateau
Saya de Malha Bank
Nazareth Bank
Mauritius
Reunion
SW Indian Ridge
Broken Ridge
SE Indian Ridge
Kerguelen Plateau
705
706
707
708
709
710
711
712
713
714
715
716

Figure 1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56
58
60
62
64
66
68E
0
2
4
6
8
10
12
14
16
18
20
S22
711
709
710
708
707
706
705
236
237
SEYCHELLES
BANK
SAYA DE MALHA
BANK
NAZARETH
BANK
CARGADOS
CARAJOS
BANK

Figure 2

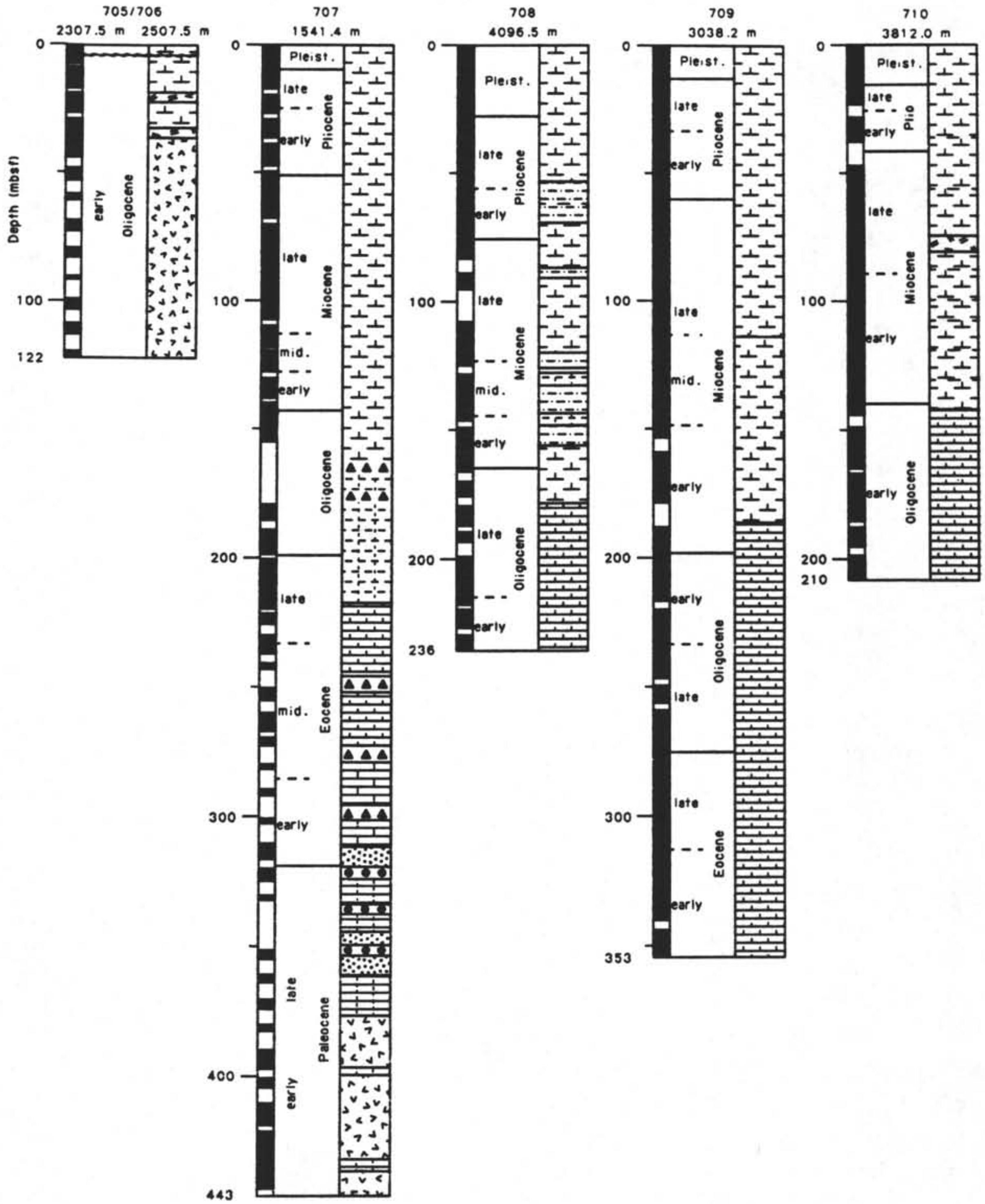
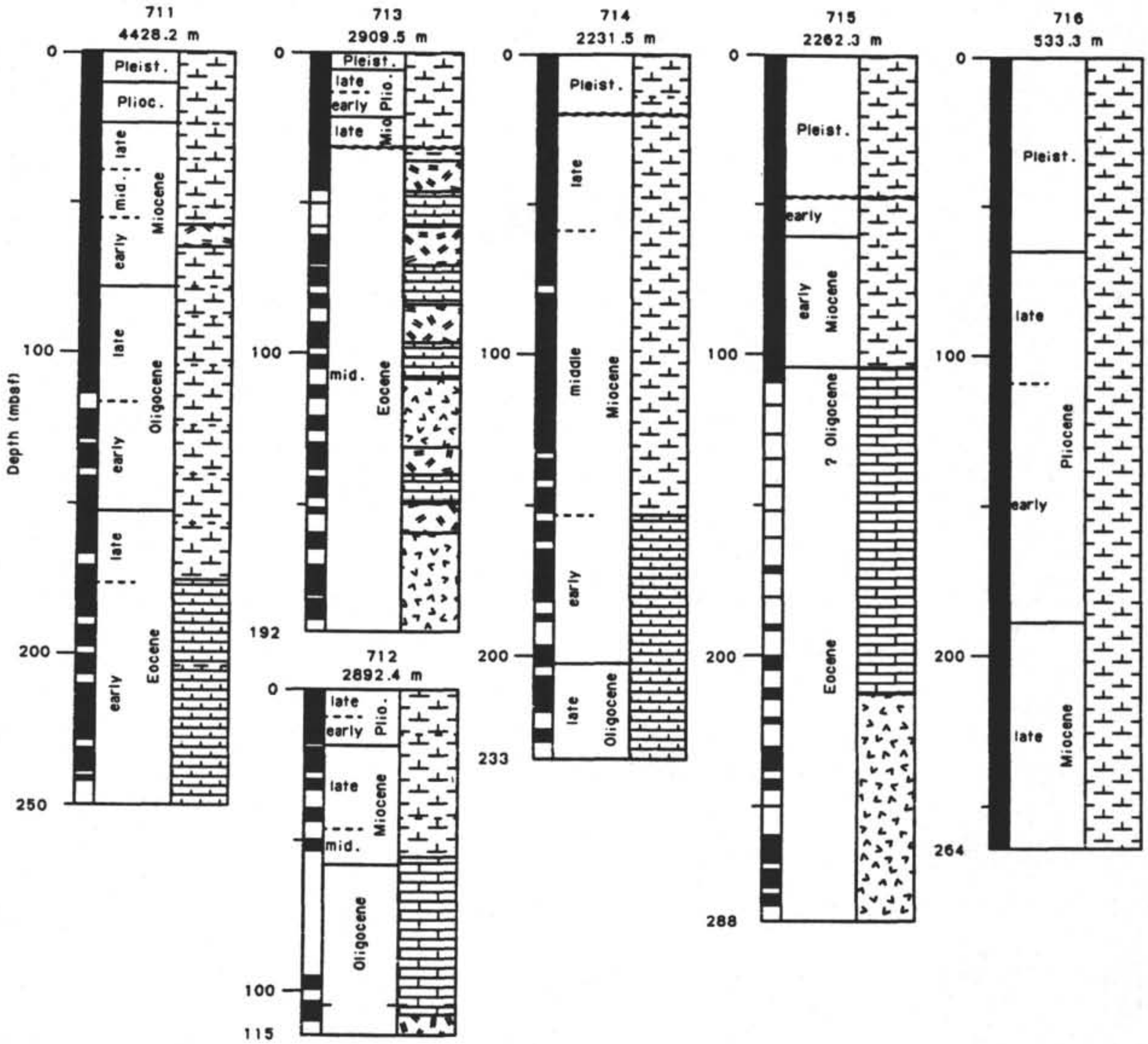

705/706
2307.5 m
2507.5 m
707
1541.4 m
708
4096.5 m
709
3038.2 m
710
3812.0 m
Depth (mbsf)
0
100
122
200
236
300
353
400
443
210
Pleist.
Pliocene
Plio
Miocene
Oligocene
Eocene
Paleocene
late
mid.
early

Figure 3A



711
4428.2 m
713
2909.5 m
714
2231.5 m
715
2262.3 m
716
533.3 m
712
2892.4 m
Depth (mbsf)
0
100
200
250
192
115
233
288
264
Pleist.
Plioc.
Plio.
Mio
Miocene
Oligocene
Eocene
? Oligocene
Pliocene
late
mid.
middle
early

Figure 3B

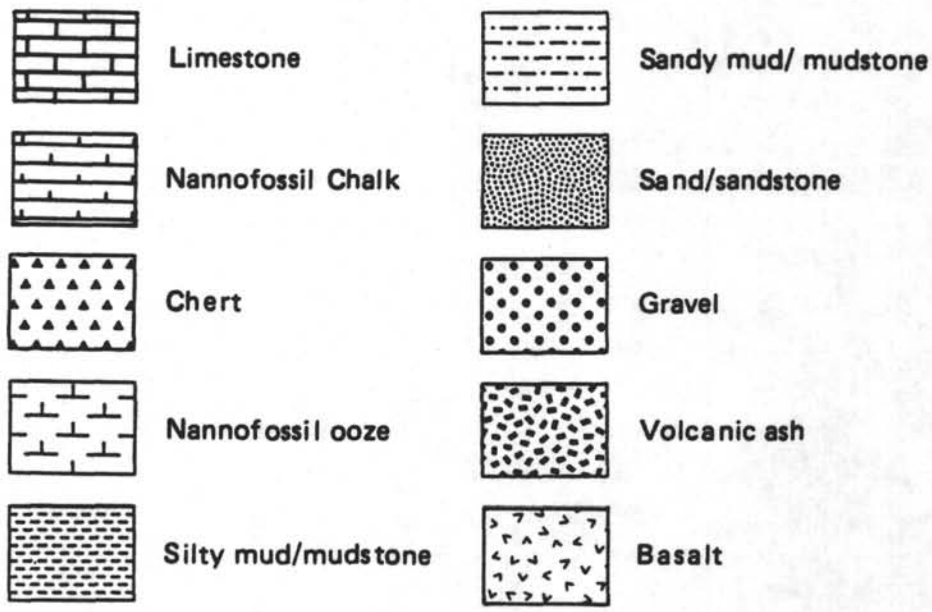
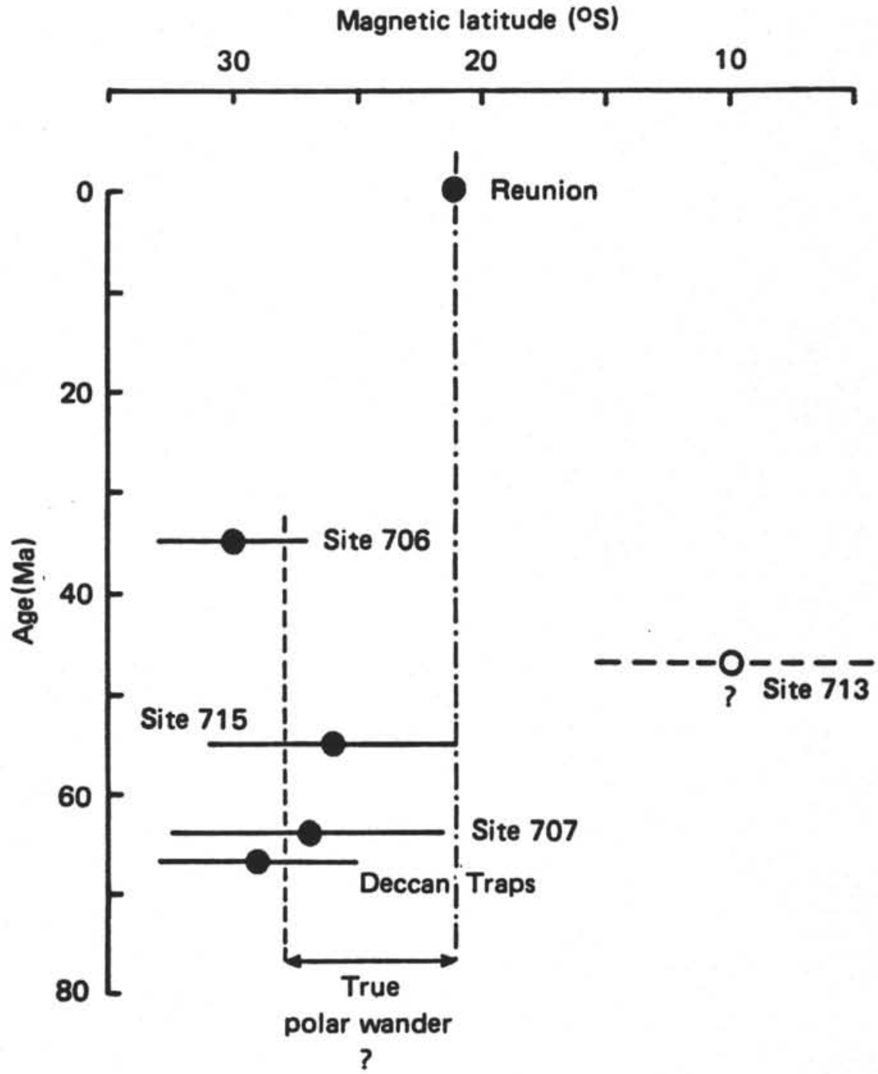

Limestone
Sandy mud/ mudstone
Nannofossil Chalk
Sand/sandstone
Chert
Gravel
Nannofossil ooze
Volcanic ash
Silty mud/mudstone
Basalt

Figure 3C



Magnetic latitude (°S)
30
20
10
0
20
40
60
80
Age (Ma)
Reunion
Site 706
Site 713
?
Site 715
Site 707
Deccan Traps
True
polar wander
?

Figure 4

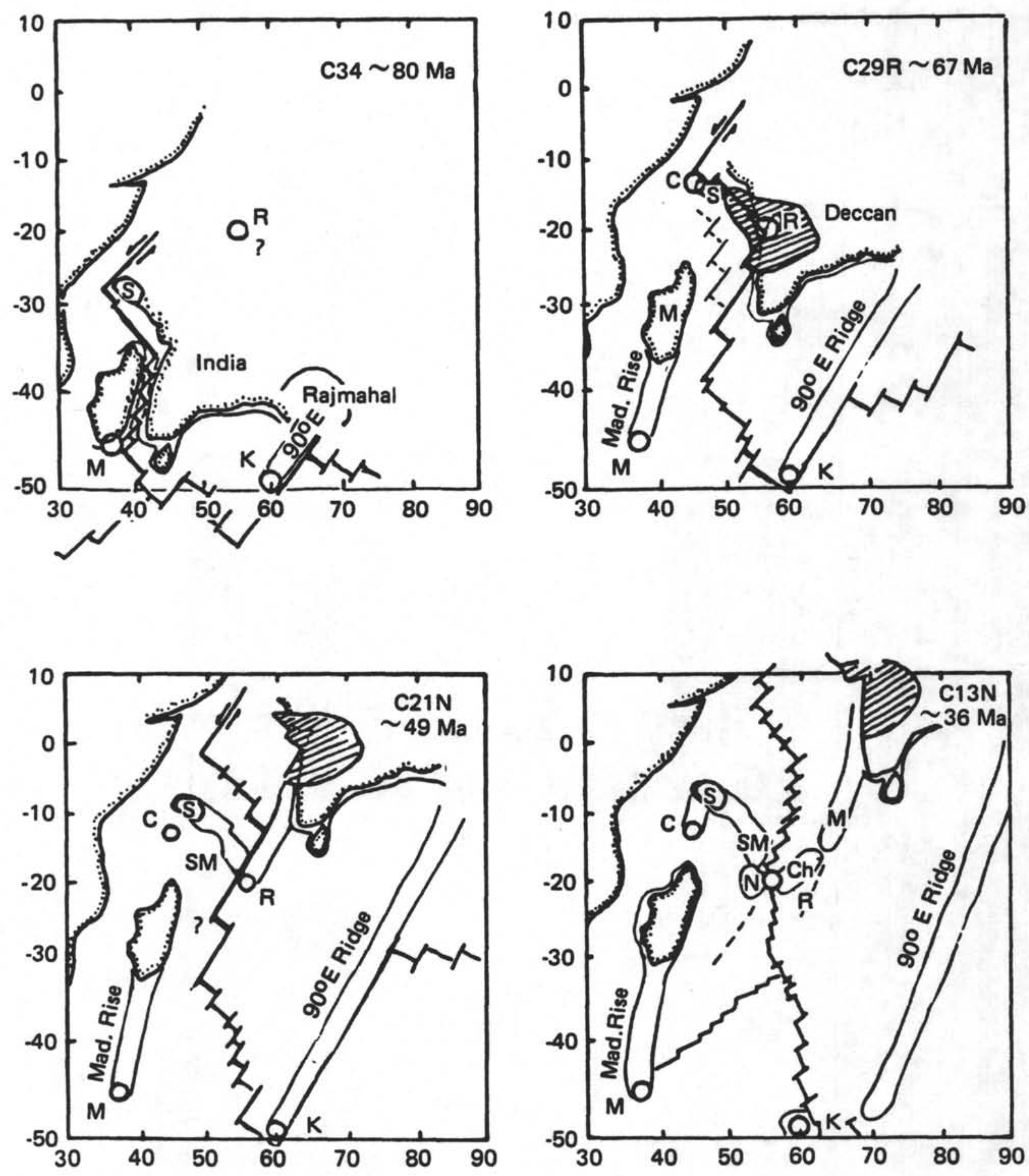

C34 ~80 Ma
R
?
S
India
Rajmahal
90°E
M
K
C29R ~67 Ma
C
S
R
Deccan
M
Mad. Rise
90° E Ridge
K
C21N
~49 Ma
C
S
SM
R
?
Mad. Rise
90°E Ridge
M
K
C13N
~36 Ma
S
C
SM
N
Ch
M
R
Mad.Rise
90° E Ridge
M
K

Figure 5

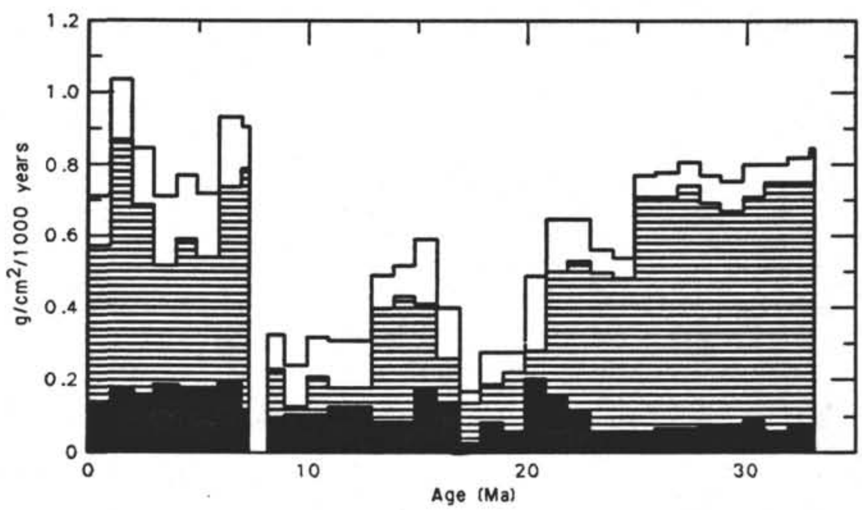


Figure 6

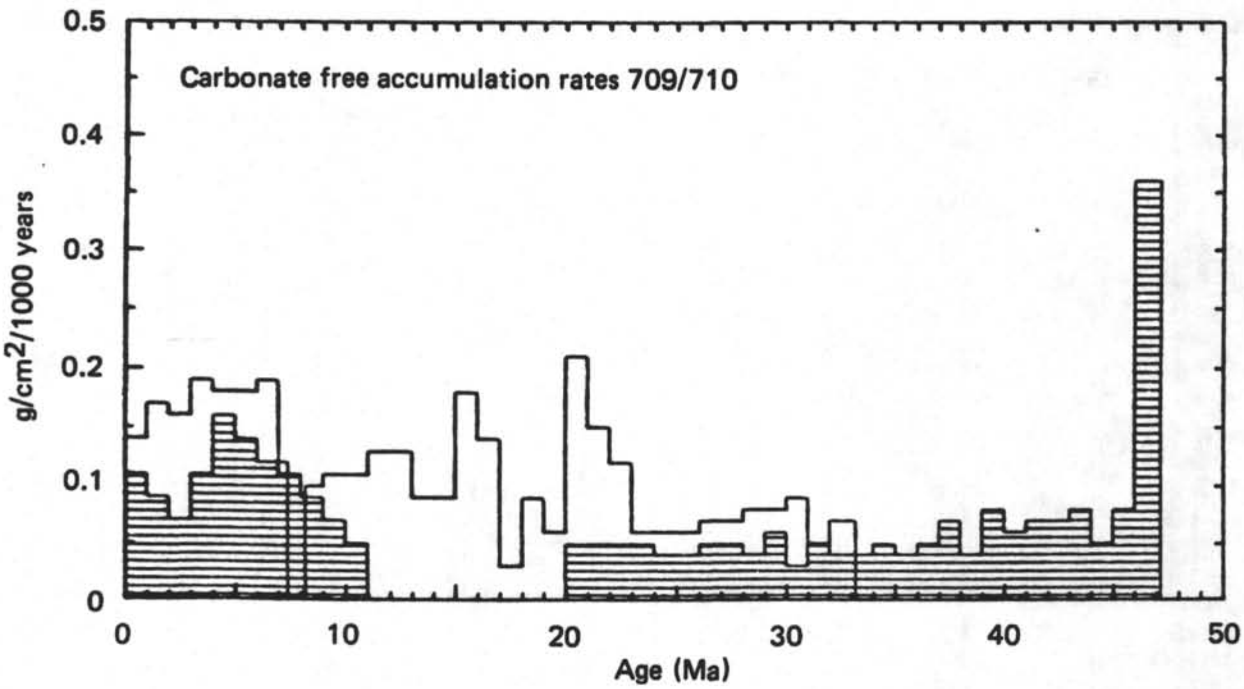

Carbonate free accumulation rates 709/710
g/cm2/1000 years
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
Age (Ma)

Figure 7

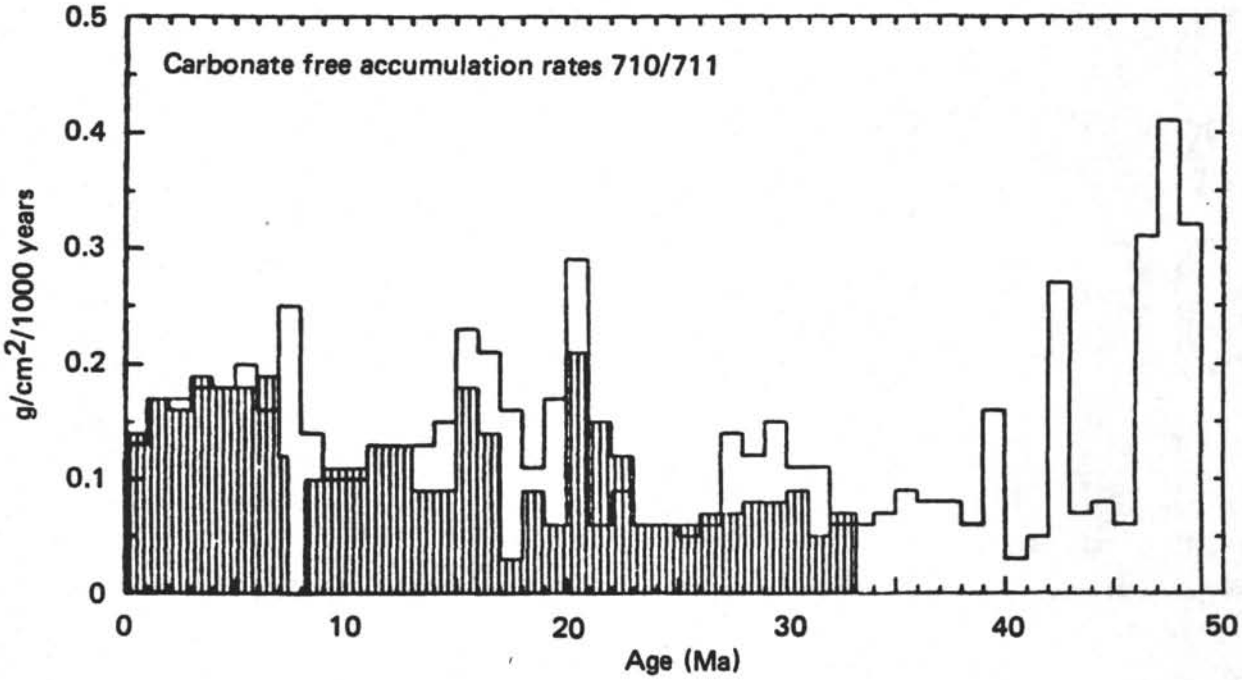

Carbonate free accumulation rates 710/711
0.5
0.4
0.3
0.2
0.1
0
g/cm2/1000 years
0
10
20
30
40
50
Age (Ma)

Figure 8

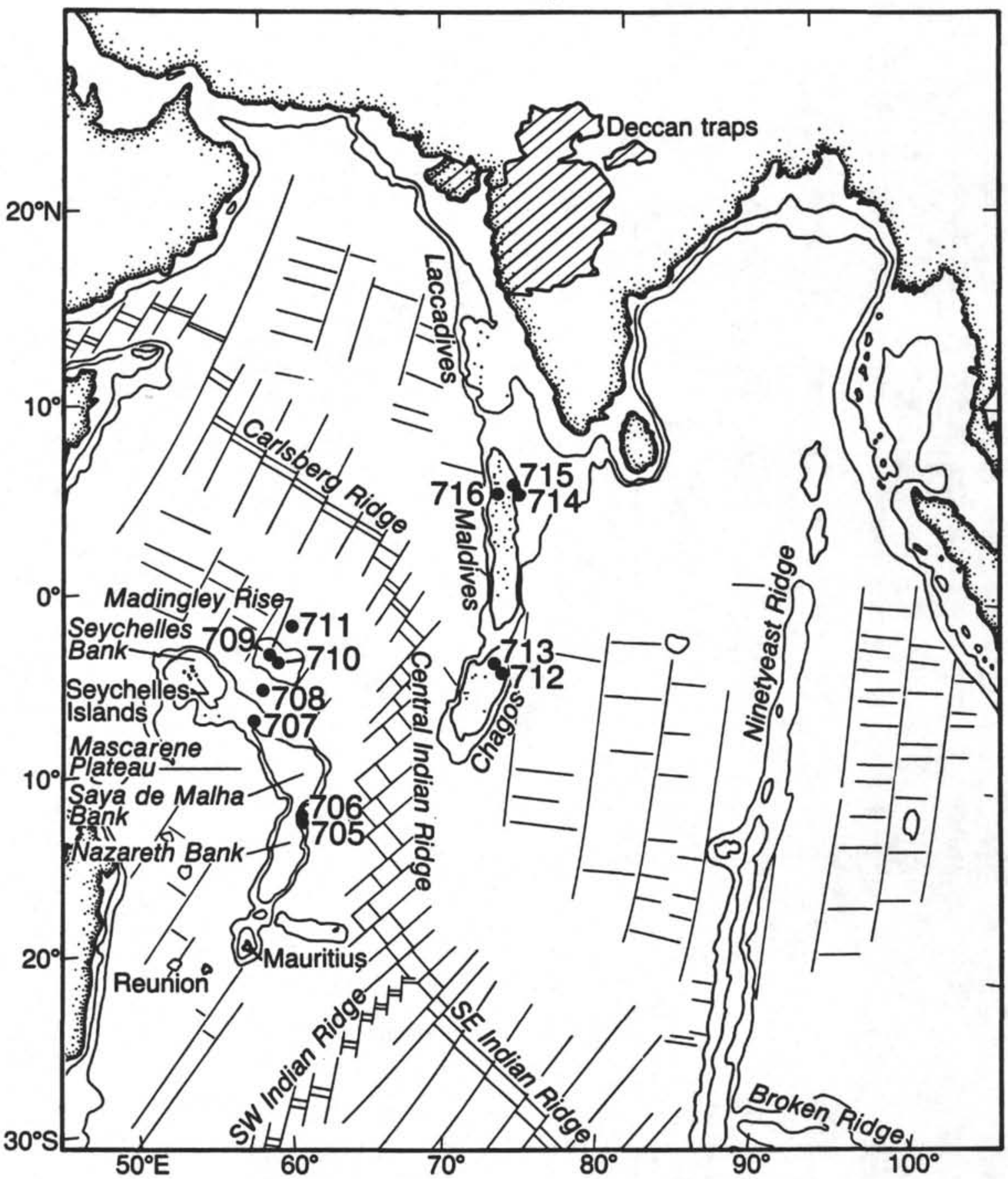

Deccan traps
20°N
10°
0°
10°
20°
30°S
50°E
60°
70°
80°
90°
100°
Laccadives
Carlsberg Ridge
Maldives
715
716
714
713
712
Chagos
Madingley Rise
711
Seychelles Bank
709
710
Seychelles Islands
708
707
Mascarene Plateau
Saya de Malha Bank
706
705
Nazareth Bank
Central Indian Ridge
Ninetyeast Ridge
Mauritius
Reunion
SW Indian Ridge
SE Indian Ridge
Broken Ridge

Figure 9

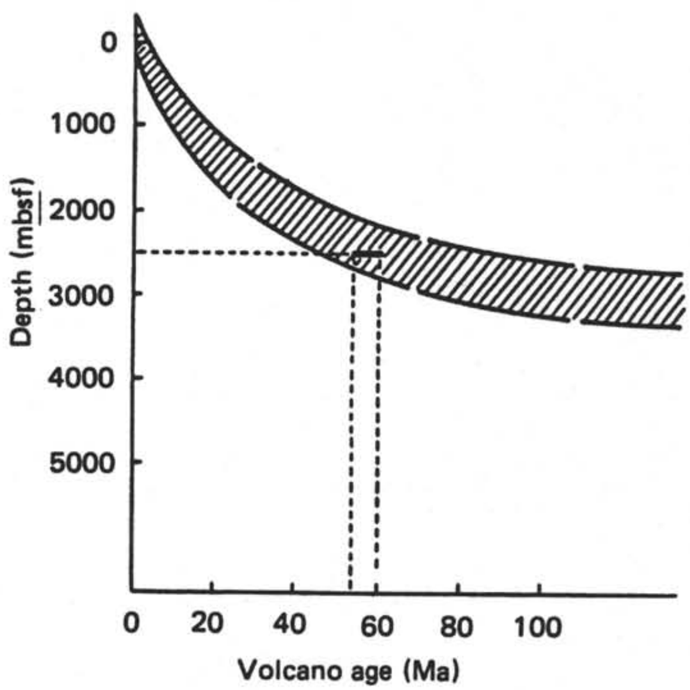

0
1000
2000
3000
4000
5000
Depth (mbsf)
0
20
40
60
80
100
Volcano age (Ma)

Figure 10

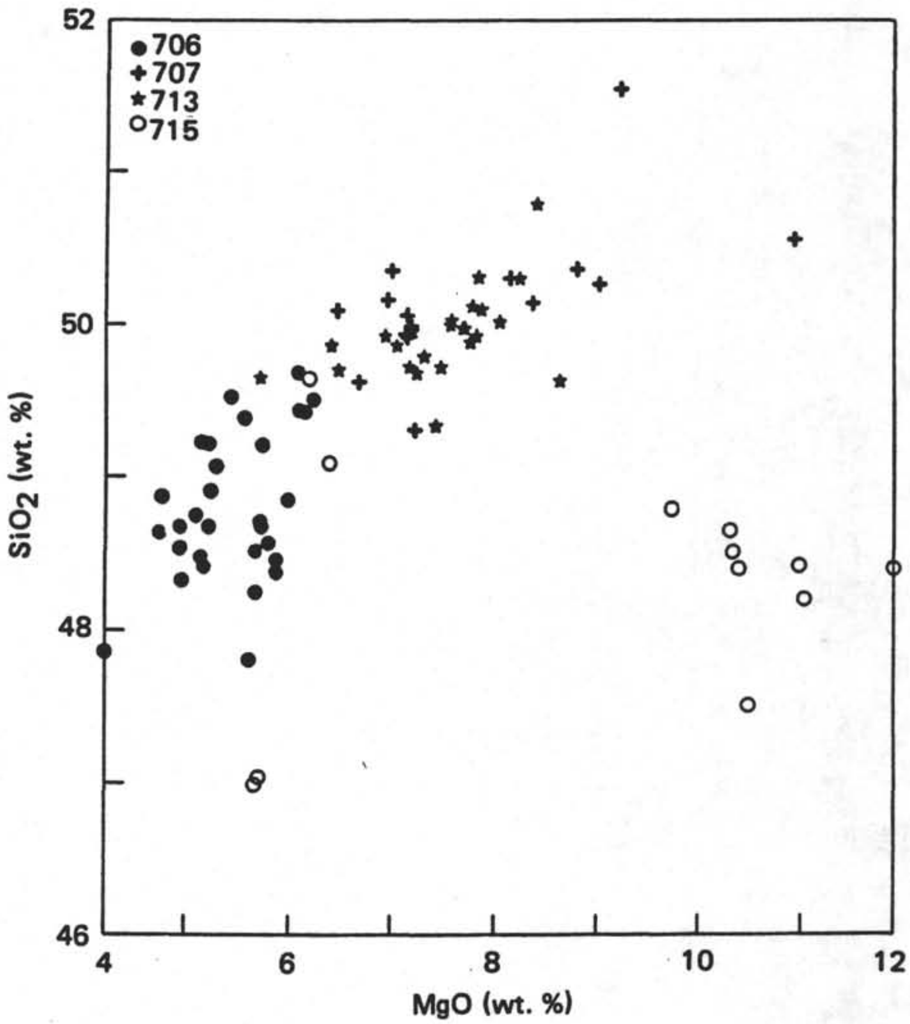


Figure 11

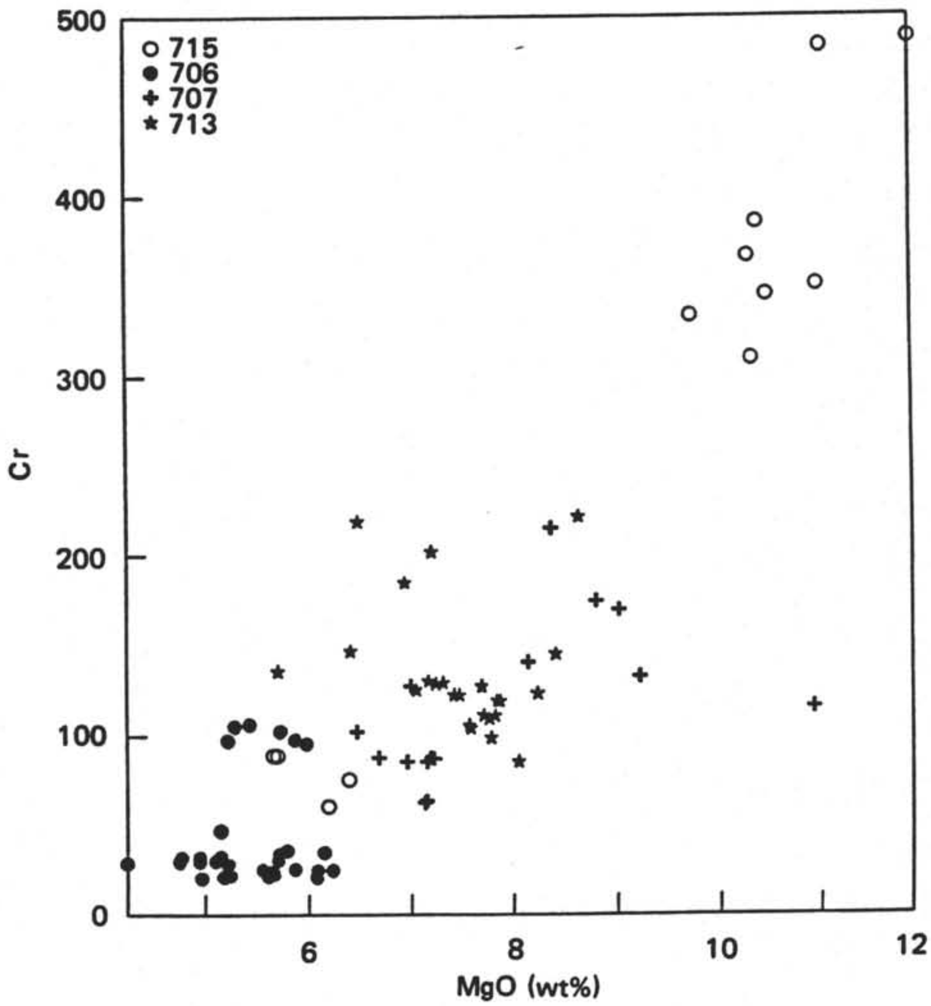


Figure 12

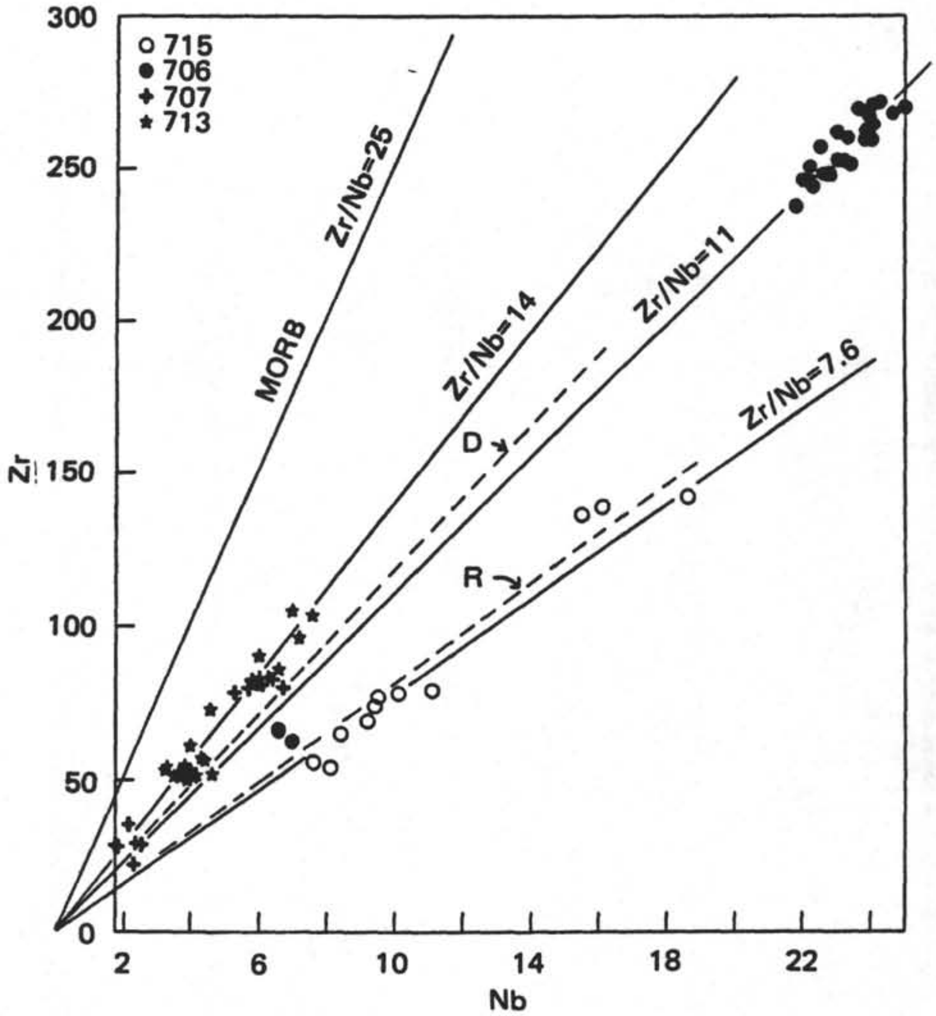

715
706
707
713
MORB
Zr/Nb=25
Zr/Nb=14
Zr/Nb=11
Zr/Nb=7.6
D
R
Zr
Nb
0
50
100
150
200
250
300
2
6
10
14
18
22

Figure 13

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard JOIDES Resolution for Leg 115 were:

Operations Superintendent:	Lamar Hayes
Special Tools Engineer:	Tom Pettigrew
Special Tools Engineer:	Mark Robinson

Other operations and engineering personnel aboard JOIDES Resolution for Leg 115 were:

Schlumberger Logger:	Scott McGrath Schlumberger Offshore 369 Tristar Drive Webster, TX 77598

LEG 115 OPERATIONS

Leg 115 was initially planned to last 42 days with two main programs: penetration and recovery of volcanic basement rocks on the Mascarene Plateau and recovery of complete and undisturbed sediments by Advanced Hydraulic Piston coring (APC) along a paleoceanographic depth transect consisting of four sites.

Mauritius to Site 705 (MP-3)

The anchor was raised at 2115 hr, 19 May, and JOIDES Resolution was under way for Site MP-3. Work on the drilling floor was suspended during transit because of heavy seas.

On the approach to target site MP-3 the seismic equipment was streamed for the pre-site survey and a beacon was dropped at 2100 hr, 21 May, establishing Site 705. A distance of 478 nmi was covered at an average speed of 10.3 kt (including surveying time over target site MP-1) in 46.5 hr.

Hole 705A

As the Bottom Hole Assembly (BHA) was lowered to the seafloor, the drill string was rabbited and downgraded joints were removed.

The mudline was established at 2318 m by drill pipe measurement (DPM), and after recovering three APC cores of foraminifer sand, with the BHA beginning to stick after the second core, it was decided to abandon Hole 705A. Total penetration was 27.5 mbsf with 19.2 m of core recovered, for a recovery of 70%.

Site 705 to Site 706

The BHA was pulled above the mudline 100 m and at 2000 hr, the ship was relocated in the Dynamic Positioning mode 3 nmi NNW of Site 705 to initiate Site 706. A retrievable beacon was dropped at 2320 hr, 22 May, establishing Site 706.

Hole 706A

The BHA was lowered to the seafloor and APC coring commenced with a water core on the first attempt. The second attempt established the mudline at 2517 m (DPM). After 41.1 m of penetration, recovering foraminifer sand and "blue-green" clay, the water sampler temperature probe (WSTP, formerly called PWS) was successfully deployed by free-fall. In Core 115-706A-6H, approximately 10 cm of basalt was recovered at 2564.5 m (47.5 mbsf). With the objectives met, the BHA was pulled clear of the mudline and the ship was offset 10 m south to initiate Hole 706B. Total penetration was 47.5 mbsf with 39.3 m of core recovered, for a recovery of 82.9%.

Hole 706B

The BHA was again lowered to the seafloor and the mudline established at 2518.3 m (DPM). Overlap APC coring to 2541.3 m (23 mbsf) recovered 22.3 m of foraminifer sand and "blue-green" clay for an APC recovery of 99.6%. With penetration falling off, it was decided to change to the Extended Core Barrel (XCB) system.

XCB coring from 2541.3 to 2562.6 m recovered 7.12 m of foraminifer sand and clay for an XCB recovery of 33.4%. On Core 115-706B-7X, 0.52 m of basalt was recovered. With basement reached and the objectives met, the APC/XCB BHA was tripped to change to the Rotary Core Barrel (RCB) system and the ship was offset 20 m north to establish Hole 706C. Total penetration was 43.7 mbsf, recovering 29.4 m of core for a total recovery of 67%.

The experimental XCB shoes with seals (one shoe with 1/4" jets, one with 3/32" jets) were deployed. The experimental shoes presented no problems during retrieval with the sandline. Full cores of sand and clay were recovered. As to improved recovery, the test proved inconclusive due to the morphology of the hole, i.e., sand directly on top of basement. The test was rescheduled for later holes.

Hole 706C

The BHA was lowered to the seafloor (2518 m DPM) and the hole was washed down 44.3 m (2562.3 m) to begin RCB coring. RCB coring advanced the hole to 2639.7 m (121.7 mbsf).

During retrieval of Core 115-706C-4R the drill string became stuck and circulation was lost. It was believed that loose sand and rubble on top of the basalt were falling into the hole, causing the problem. The drill string was worked for 1.5 hr and was finally freed. The core barrel was retrieved and the hole was swept with 30 bbl of mud. The hole was swept after each core barrel retrieved thereafter.

Total depth of penetration was 121.7 mbsf to 2639.7 m, with 77.4 m of basement cored, recovering 19.7 m of basalt for a total recovery of 25%.

Site 706 to Site 707 (CARB-1B)

With the allotted time depleted, the drill string was tripped and the recallable beacon recovered at 2130 hr, 25 May. A course was set for target site CARB-1B, a new site determined by the Co-Chiefs and approved by ODP while enroute.

Target site CARB-1B is located 3 nmi ENE of the original target site, CARB-1. At 0100 hr, 26 May, the ship was under way. The seismic gear was streamed for a presite evaluation and a retrievable beacon dropped at 1300 hr, 27 May, to establish Site 707. The ship was in Dynamic Positioning (DP) mode at 1410 hr.

Hole 707A

The BHA was lowered to the seafloor and the mudline established at 1551.9 m (DPM). The hole was APC cored to 1725.6 m (173.7 mbsf) where penetration and recovery fell off. Orientation instruments were deployed from Core 115-707A-4H at 1577.7 m through Core 115-707A-19H. APC coring recovered 127.7 m of core for an APC recovery of 73.5%.

XCB coring was employed from Core 115-707A-20X at 1725.6 m through Core 115-707A-25X at 1765.2 m (213.3 mbsf), when a hard formation, presumably chert, was encountered. At this point the XCB barrel was retrieved and an amalgamated synthetic diamond cutting shoe was installed. The synthetic diamond cutting shoe was unable to penetrate the hard formation and it was decided to pull clear of the mudline, offset the ship 10 m south and initiate Hole 707B. XCB coring in Hole 707A recovered 32.6 m of core for an XCB recovery of 82.3%. Total penetration was 213 mbsf with 160.3 m of core recovered for a total recovery of 75%.

Hole 707B

At 2005 hr, 27 May, the BHA was again lowered to the seafloor and the mudline established at 1551.9 m (DPM). Hole 707B was APC cored 13 times to 1676.8 m, followed by XCB coring to total depth. Total penetration was 124.9 mbsf to 1765.2 m with 96.1 m of core recovered for a total recovery rate of 77%.

The scientists wanted to double APC core the top 120 m only. With that objective met, the APC/XCB BHA was tripped out and replaced with a standard RCB BHA. The ship was offset 10 m south to initiate Hole 707C.

Hole 707C

The RCB BHA was lowered to the seafloor (1552 m) and the hole was washed down 183.8 mbsf to 1735.8 m. Coring commenced at this depth, with the ultimate objective of penetrating the hard formation encountered in Hole 707B at 1765.2 m (213 mbsf).

At approximately 1764 m (212 mbsf), while drilling in a soupy chalk ooze, the drill string became stuck, presumably by sand falling back into the hole. The drill string was worked for half an hour before it was jarred free. The hard formation, previously found at 213 mbsf in Hole 707B, was never encountered, even though the ship had been offset only 10 m.

Basalt was recovered with Core 115-707C-23R, at 1941 m (389 mbsf). After Core 115-707C-28R at 1995.2 m (443.2 mbsf), the Co-Chiefs decided to stop drilling and prepare to log the hole. Cores 115-707C-25R through 115-707C-28R recovered 31.7 m of basalt (82% recovery), much to the pleasure of the petrologists.

Total penetration was 443.2 mbsf to 1995.2 m. Total cored interval was 259.4 m with 91.3 m of core recovered for a total recovery of 35%.

The first suite of logging tools (DIL-GR-SLT-MCD) was run with no problems. The second suite of logging tools (GST-ACT-CNT-NGT) encountered a bridge at 1945 m. The GST was redeployed and again did not function properly. The GST was retrieved and the third suite of logging tools (LDT-CNL-NGT-GPIT) was deployed. Another bridge was encountered at 1732 m and the logging tools were retrieved and rigged down.

At approximately 0200 hr, 30 May, the ship was heading in DP mode into a half knot current with light winds when it was hit broadside by a ripcurrent moving at approximately 6 kt. The DP system reacted immediately by sounding alarms and bringing on line another skid to supply sufficient power to hold position. The ship was immediately headed into the oncoming ripcurrent and the DP system kept the ship within 91.4 m (6% of water depth) of the hole with no adverse effect on the drill string. The ripcurrent was observed on radar and at first believed to be a rain shower. It was approximately 6 nmi wide and 4 nmi long with an internal current of 3 kt. Another ripcurrent of lesser strength hit the ship at 0300 hr, 31 May, causing the ship to move off position only 46.6 m, or 3% of water depth.

Site 707 to Site 708 (CARB-4)

With all the coring objectives met and logging time depleted, the drill string was tripped out and the beacon recalled and retrieved. The transit to target site CARB-4 was begun at 0330 hr, 2 June. At 1700 hr, 2 June, the recallable beacon was dropped and Site 708 was established. The ship was in DP mode by 1800 hr.

Hole 708A

A typical APC/XCB BHA with 1/2" angled jets in the bit and modified for the XCB with shoe seal system was run to the seafloor. The mudline was established at 4107 m (DPM), and the hole was APC cored eight times to a depth of 4183 m (76 mbsf). APC coring recovered 76.76 m for 100% recovery. The hole was then advanced to 4343.2 m (236.2 mbsf) with 17 XCB cores recovering 112.9 m (71% recovery). At the request of the Co-Chiefs the hole was abandoned. Total penetration was 236.2 mbsf to 4343.2 m with 189.6 m of core recovered for a total recovery of 80%.

Beginning with this site a new "speeded up coring" procedure was used. The new procedure involves leaving the sinker bars in the drill string and pumping them down with the core barrel. This new procedure produced XCB coring wireline trip times approximately 40% less than the time estimates given in the Preliminary Time Estimates for Coring Operations for XCB coring wireline trips.

Site 708 to Site 709 (CARB-2A)

The beacon was recalled and retrieved at 0825 hr and the ship was under way for target site CARB-2A at 1200 hr, 4 June. The presite survey for Site 709 did not look promising to the Co-Chiefs, and after further surveying and approval from ODP, an alternate site was selected approximately 6 nmi north of CARB 2A. The recallable beacon was dropped at 0130 hr, 5 June, establishing Site 709.

Hole 709A

The standard APC/XCB BHA (modified for XCB seal and Monel drill collar) was made up and run to the seafloor. APC coring commenced, with the objective of coring to 250 mbsf, and established the mudline at 3046.9 m (DPM). Orientation instrumentation was deployed beginning with Core 115-709A-4H. Cores 115-709A-18H, 115-709A-19H, and 115-709A-20H had pull-out forces of 20,000 lb. Core 115-709A-21H, after advancing the hole to 3250 m (203.1 mbsf), had a pull-out force of 30,000 lb. The next core barrel could not be retrieved and parted in the attempt.

Total penetration was 203.1 mbsf to 3250 m with 184.7 m of core recovered for a total recovery of 91%.

With coring halted due to the parted core barrel, the hole was filled with heavy mud, the drill string pulled clear of the seafloor and the ship was offset 10 m south to initiate Hole 709B.

Hole 709B

The APC/XCB BHA was lowered back to the seafloor and the mudline established at 3048.7 m (DPM). APC coring advanced the hole to 3235.9 m (187.2 mbsf) with 172.9 m of core recovered (92% recovery). The XCB system was deployed at this point in anticipation of the formation change that stuck the APC barrel in Hole 709A.

The experimental XCB cutting shoe with seal was used to further advance the hole to 3303.5 m (254.8 mbsf). Core quality was excellent with 61.6 m of core recovered for an XCB recovery of 91%. Total penetration was 254.8 mbsf to 3303.5 m with 234.6 m of core recovered for a total recovery of 92%.

With the 250 mbsf objective met, the hole was filled with heavy mud, the drill string was pulled clear of the mudline, and the ship was offset 10 m south to initiate Hole 709C.

Hole 709C

Once again the BHA was lowered to the seafloor and the mudline established at 3048.7 m (DPM). APC coring recovered 100% in 20 cores to a depth of 3237.8 m (189.1 mbsf). The WSTP was successfully deployed by free-falling after Cores 115-709C-11H (3150.9 m, 102.2 mbsf), 115-709C-15H (3189.5 m, 140.8 mbsf), and 115-709C-20H (3237.8 m, 189.1 mbsf). Good water samples and temperature data were gathered. Again, in anticipation of the formation change, the XCB system was deployed at this point.

The XCB core barrel was deployed 17 times, recovering 138.7 m of core while advancing the hole 155 m to 3402.4 m (353.7 mbsf), for an XCB recovery of 89.4%. Total penetration was 353.7 mbsf to 4302.4 m with 327.9 m of core recovered for a total recovery of 93%.

The experimental XCB cutting shoe with seal was used in this hole also. High quality cores were recovered in both the soupy chalk ooze and the firmer chalk sediment below.

Site 709 to Site 710 (CARB-3)

The hole was filled with heavy mud, the beacon recalled and retrieved at 1500 hr, the drill string tripped out, a course was laid for target site CARB-3 and at 1700 hr the ship was under way.

Hole 710A

The same APC/XCB BHA as used on the previous sites was made up and lowered to the seafloor. The mudline was established at 3822.5 m (DPM). APC coring advanced the hole to 3947.4 m (124.9 mbsf) in 13 coring runs. Orientation instruments were deployed beginning with Core 115-710A-4H until the change was made to XCB. APC coring recovered 111.5 m of core (89.2% recovery). When the pull out force reached 30,000 lb, the APC system was replaced with the XCB system.

The XCB system was run nine times, advancing the hole to 4032.2 m (209.7 mbsf), recovering 73.7 m of core for a recovery of 86.9%. Again high quality cores in both soupy chalk ooze and clays were recovered with the experimental XCB cutting shoe with seal.

Total penetration was 209.7 mbsf to 4032.2 m with 185.2 m of core recovered for a total recovery of 88%.

Hole 710B

With the BHA back on bottom the mudline was established at 3821 m (DPM). The APC was deployed nine times to 3904.4 m (83.4 mbsf). With the coring objective met the drill string was tripped out and preparations made to get under way for target site CARB-4B.

Total penetration was 83.4 mbsf to 3904.4 m with 72 m of core recovered for a total recovery of 86%.

Site 710 to Site 711 (CARB-4B)

The beacon was recalled and back on board at 1145 hr, 10 June. The ship was under way at 1500 hr, and was over target site CARB-4B by 2200 hr, after traveling approximately 94 nmi.

Hole 711A

The recallable beacon was dropped at 0030 hr, 11 June, to establish Site 711. The ship was in DP mode at 0130 and the drill string was tripped in. The same APC/XCB BHA used on earlier sites was lowered to the seafloor and the mudline established at 4438.7 m (DPM). The hole was advanced to 4543.2 m (104.5 mbsf) using the APC system, recovering 95.1 m of core for a recovery of 91%. Orientation instrumentation was deployed beginning with Cores 115-711A-4H through 115-711A-11H when the change was made to the XCB.

The hole was advanced to 4688.4 m (249.7 mbsf) using the XCB system, recovering 108.7 m of core for an XCB recovery of 80%. With the objectives met, the drill string was pulled clear of the mudline and the ship offset 10 m south to initiate Hole 711B.

Total penetration was 249.7 mbsf to 4688.4 m with 203.8 m of core recovered for a total recovery of 81.6%.

Hole 711B

The BHA was lowered to the seafloor and the mudline established at 4440.2 m (DPM). The hole was APC cored 11 times to 4538.8 m (98.6 mbsf). The objective of this hole was to APC core the top 100 m of sediments. With the objective met, the drill string was tripped out and the transit to target site CB-1 began.

Total penetration was 98.6 mbsf to 4538.8 m with 88.6 m of core recovered for a total recovery of 90%.

Site 711 to Site 712 (CB-1)

Several attempts to recall the beacon were made but the beacon did not respond. The same recallable beacon had been used since Site 706. With the drill string on board and everything secured, the 445 nmi transit to Site CB-1 (Chagos Bank) was begun at 1200 hr, 13 June.

Site 712 was an alternate site added to the leg when permission to drill in Mauritian territorial waters was rescinded. The survey gear was streamed 2 hr prior to arriving at target site CB-1 to ensure that a complete survey was made. At 2400 hr, 15 June, the beacon was dropped to establish Site 712.

Hole 712A

The objective of Hole 712A was to recover 100 m of basement core. The BHA was lowered to the seafloor and the mudline established at 2902.9 m (DPM). Recovery was good until a chert stringer was encountered at 2941.2 m (38.3 mbsf). The chert stringer was penetrated but recovery dropped off considerably. Virtually no core was recovered from 2960.4 to 2989.3 m, at which time the bit deplugger was dropped. When coring continued, recovery was low and the hole was getting tight. Each time the drill string was picked up, hole was lost and had to be washed back down. Gel/water mud was used to sweep the hole, with little affect. With the hole conditions getting worse it was decided to abandon Hole 712A.

Total penetration was 115.3 mbsf to 3018.2 m with 41.46 m of core recovered for a recovery of 36%.

Site 712 to Site 713

A site was chosen by the Co-Chiefs from seismic survey data, in hopes of finding better drilling conditions. The drill string was pulled 100 m above the seafloor and at 2020 hr, 16 June, the ship was moved 1.6 nmi NNW in DP mode. A beacon was dropped at 2200 hr to establish Site 713.

Hole 713A

The RCB BHA was lowered back to the seafloor and at 2345 hr, 16 June, coring commenced, establishing the mudline at 2920.3 m (DPM). Basalt was encountered at 3027.3 m (107 mbsf). After Core 115-713A-19R, the hole became tight. The drill string was worked, the hole was swept with gel/water mud and coring resumed. While cutting Core 115-713A-20R penetration dropped off to 1 m per hour. With consideration that the hole might be junked with a broken bit, a decision was made to drop a minicone, pull out of the hole and reenter with a diamond bit.

The top of the BHA was pulled to the mudline and at 1900 hr, 18 June, a minicone was deployed. At 1930 hr, the camera was lowered. The minicone was found to be positioned properly in the hole and the BHA was pulled through with no problem. The camera and drill string were tripped out.

The roller cone bit was replaced by the diamond bit and the BHA was lowered back to the seafloor. The camera was lowered to begin reentry. After two hours of searching and one hour of positioning over the cone, the reentry was made. The camera was retrieved, the hole was washed down to bottom at 3103.6 m (183.3 mbsf), with no fill found, and coring resumed.

After 6.9 m of penetration on Core 115-713A-21R, the core barrel had to be retrieved because of jamming. While cutting Core 115-713A-22R penetration slowed to nothing and the pump pressure climbed to 1800 psi. When the bit was picked up off bottom the pump pressure would drop to 250 psi. All indications were that the bit was worn out and further penetration was impossible. The drill string was tripped out and Hole 713A was abandoned. The diamond bit had only penetrated 8.4 m of basalt, recovering 5.2 m of core.

Total penetration was 191.7 mbsf to 3112 m (DPM) with 115 m of core recovered for a recovery of 60%.

Site 713 to the Maldive Islands

With everything secured at 1300 hr, 20 June, the ship was under way to the Maldive Islands. A storm with 35-40 kt winds (gusting to 65 kt) and heavy rain was encountered in the early morning hours on 21 June, and continued throughout the transit to the Maldives. The storm slowed the ship to 9 kt, and arrival at Male in the Maldives was at 1100 hr, 22 June, two hours behind schedule. Due to the high winds and associated seas, the ship was not put into anchorage and remained positioned approximately 1 nmi south of Male in DP mode. Dr. Rabinowitz had made the trip from ODP to Male to secure drilling clearance for two of the Maldive sites. Dr. Rabinowitz, two observers, customs, immigration and security officials from the Maldives came on board at Male.

Maldives to Site 714 (MLD-2)

After a brief visit, the boarding party was put ashore except for the two observers. At 1515 hr, June 22, the ship was under way for Site MLD-2. The presite survey at MLD-2 did not look promising to the Co-Chiefs and surveying continued until an alternate site was found approximately 6 nmi south of MLD-2. Clearance had been given by the Maldivian government to drill anywhere within a 10 nmi radius of the proposed sites. A beacon was dropped at 0230 hr, 23 June, to establish Site 714.

Due to winds gusting to 70 kt, the beacon was temporarily lost as it descended to the bottom. After approximately one hour, the ship was positioned over the beacon and in DP mode at 0355 hr.

Hole 714A

The mudline was established at 2042 m (DPM) and APC coring commenced. The hole was advanced to 2160.4 m (118.4 mbsf) with 115.2 m of core recovered for an APC recovery of 97.2%. The pull-out force for Core 115-714A-13H was 35,000 lb and the decision was made to go to the XCB system. The hole was further advanced to 2275 m (233 mbsf) with twelve XCB coring runs recovering 114.6 m of core for a recovery of 69.2%. Although the XCB shoe seals were worn badly by this point in the leg, they were still used.

Total penetration was 233 mbsf to 2275 m with 194.6 m of core recovered for a total recovery of 83.5%.

Hole 714B

The mudline was established at 2042 m (DPM) and APC coring commenced. The objective of this hole was to double APC the sediments. After 13 APC coring runs with 122.6 m of penetration, the objective was met and the hole was abandoned.

Total penetration was 122.6 mbsf to 2155.6 m with 114.9 m of core recovered for a recovery of 93.7%.

Site 714 to Site 715 (MLD-4)

Once the mudline was cleared at Hole 714B the ship was moved in DP mode 3 nmi north to target site MLD-4, while the drill string was being tripped out. Basement was to be penetrated at MLD-4 so the drill string was tripped to change the BHA. A beacon was dropped at 1600 hr, 24 June, to establish Site 715.

Hole 715A

The RCB BHA was lowered to the seafloor and a water core was brought up in the first attempt to establish the mudline. At 2245 hr, the mudline was established on the second attempt, at 2272.8 m (DPM) and coring continued. The first eleven RCB cores recovered nearly 100% and then fell off drastically while still in sediments. A hard brittle reef limestone was encountered, but only limestone nodules were recovered in the core catcher. Basalt was encountered at 210 mbsf (2483 m). At 230 mbsf (2502.8 m) problems started again and the hole was swept with 20 bbl of mud after each core.

Total penetration was 287.8 mbsf to 2560.6 m with 137.7 m of core recovered for a recovery of 48%.

The BHA was pulled to 70 mbsf and the Schlumberger line was rigged over the crown to begin logging. The first suite of logging tools consisted of DIL-SONIC-GR-CAL. The second suite of logging tools consisted of

GST-ALT-NGT. The third logging tool was an LTD. All three logging runs went to 2556 m and the hole was logged up to the BHA. All three suites of logging tools functioned properly. The logging equipment was rigged down at 0300 hr, 28 June, and the drill string was tripped out.

Site 715 to Site 716 (MLD-1)

Target site MLD-1 was approved by the Maldivian authorities while in Male and was slated for coring only if time permitted. With extra drilling time available, the drill floor was secured, the thrusters were raised and the ship was under way for the 30-nmi WSW transit to target site MLD-1 at 0745 hr, 28 June.

Hole 716A

A standard APC/XCB BHA with the same bit used on the previous holes was lowered to the seafloor and the mudline was established at 543.8 m (DPM). Cores were coming up so fast that two teams of scientists were assigned to describe them, in an effort to keep up. The hole was advanced to 801.5 m (257.7 mbsf) with 27 APC coring runs. With the 250 m penetration objective achieved, the BHA was pulled clear of the mudline and the ship was offset 10 m to initiate Hole 716B.

Total penetration was 257.7 mbsf to 801.5 m with 262.7 m of core recovered for a recovery of 102%.

Hole 716B

The BHA was lowered back to the seafloor and the mudline established at 543.8 m (DPM). Coring continued to 808.2 m (264.4 mbsf) with 28 APC coring runs. Once again when the 250 m penetration objective was met, coring was halted.

Total penetration was 264.4 mbsf to 808.2 m with 267.1 m of core recovered for a recovery of 101%.

Site 716 to Male, Maldive Islands

At 0100 hr, 30 June, the ship was under way for Male to return the two observers. The clock was advanced one hour at the beginning of the transit. After a transit of 58 nmi the ship arrived at Male at 0645 hr. The ship was not anchored and held its position approximately 1 nmi south of the island.

Male, Maldive Islands

While waiting for clearance from the Maldivian officials the drill line was cut and slipped. The platform over the drill line spool was removed and preparations were made to install a new spool in Colombo. The Maldivian immigration and customs officials boarded the ship and clearance was given to sail.

Male to Colombo, Sri Lanka

The immigration and customs officials were put ashore along with the two observers. At 1100 hr, 30 June, the ship was under way for the 422 nmi transit to Colombo, Sri Lanka, ETA 0600 hr, 2 July.

Summation of Leg 115

Leg 115 was a fruitful leg for core recovery. Total core recovered was 3075 m, including 124 m of basement rock, with an overall recovery of 77.7%.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 115

TOTAL DAYS		49.6
TOTAL DAYS IN PORT		6.6
TOTAL DAYS UNDER WAY (INCLUDING SURVEY)		12.8
TOTAL DAYS ON SITE		30.2
TRIP TIME	7.27	
CORING TIME	19.2	
DRILLING TIME	0.2	
LOGGING/DOWNHOLE SCIENCE TIME	1.8	
REENTRY TIME	0.5	
STUCK PIPE TIME	0.1	
OTHER	1.2	
TOTAL DISTANCE TRAVELED (NAUTICAL MILES)		3208.0
AVERAGE SPEED (KNOTS)		10.4
NUMBER OF SITES		12
NUMBER OF HOLES		22
TOTAL INTERVAL CORED (M)		3955.4
TOTAL CORE RECOVERED (M)		3075.2
PERCENT CORE RECOVERED		77.7
TOTAL INTERVALED DRILLED (M)		227.3
TOTAL PENETRATION (M)		4182.7
MAXIMUM PENETRATION (M)		353.0
MAXIMUM WATER DEPTH (M FROM DRILLING DATUM)		4440.2
MINIMUM WATER DEPTH (M FROM DRILLING DATUM)		543.8

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 115

HOLE	LATITUDE	LONGITUDE	DEPTH (M)	NUMBER OF CORES	CORED (M)	RECOVERED (M)	PERCENT RECOVERED	DRILLED (M)	TOTAL PENRT.	TIME ON HOLE	TIME ON SITE
705A	13 10.000 S	61 22.270 E	2318.0	3	27.5	19.16	69.7		27.5	23.00	23.00
706A	13 06.860 S	61 22.270 E	2517.0	6	47.5	39.28	82.7		47.5	11.25	11.25
B	"	"	2518.0	7	43.7	29.44	67.4		43.7	17.00	28.25
C	"	"	"	9	77.4	19.72	25.5	44.3	121.7	45.00	73.25
707A	7 32.731 S	59 01.010 E	1551.9	25	213.3	160.26	75.1		213.3	23.50	23.50
B	"	"	"	13	124.9	96.08	76.9		124.9	16.75	30.25
C	"	"	"	28	259.4	91.33	35.2	183.0	442.4	89.00	129.25
708A	5 27.231 S	59 56.627 E	4107.0	25	236.2	189.65	80.3		236.2	43.50	43.50
709A	3 54.721 S	60 33.156 E	3048.7	21	203.1	184.74	91.0		203.1	29.50	29.50
B	"	"	"	27	254.8	234.56	92.1		254.8	21.00	50.50
C	"	"	"	34	353.7	327.90	92.7		353.7	37.00	87.50
710A	4 18.687 S	60 48.760 E	3822.5	22	209.7	185.20	88.3		209.7	28.25	28.25
B	"	"	3821.0	9	83.4	71.98	86.3		83.4	14.00	42.25
711A	2 44.470 S	61 09.747 E	4438.7	26	249.7	203.81	81.6		249.7	39.00	39.00
B	"	"	4440.2	11	98.6	88.65	90.0		98.6	20.50	59.50
712A	4 12.999 S	73 24.400 E	2902.9	12	115.3	41.46	36.0		115.3	22.25	22.25
713A	4 11.575 S	73 23.650 E	2920.0	20	191.7	114.98	60.0		191.7	85.00	85.00
714A	5 03.688 N	73 46.983 E	2242.0	25	233.0	194.63	83.5		233.0	25.00	25.00
B	"	"	"	13	122.6	114.93	93.7		122.6	12.00	37.00

715A	5 04.894 N	73 49.879 E	2272.8	31	287.8	137.72	47.9		287.8	88.00	88.00
716A	4 55.996 N	73 17.001 E	543.8	27	257.7	262.68	101.9		257.7	11.50	11.50
B	"	"	"	28	264.4	267.07	101.0		264.4	22.75	34.25
	TOTALS			424	3955.4	3075.20	77.7	227.3	4182.7	714.25	714.25

OCEAN DRILLING PROGRAM
BIT SUMMARY
LEG 115

HOLE	MFG	SIZE	TYPE	SERIAL NUMBER	CORED (M)	DRILLED (M)	TOTAL PENET	CUMULATIVE (M)	HOURS THIS HOLE	TOTAL HOURS	CONDITION	REMARKS
705A	SEC	11-7/16	S86F	469675	27.5		27.5	27.50	0.0	0.0	NEW	W/XCB PACK-OFF
706A	SEC	11-7/16	S86F	469675	47.5		47.5	75.00	0.0	0.0	NEW	W/XCB PACK-OFF
B	"	"	"	"	43.7		43.7	118.7	2.0	2.0	"	" "
C	RBI	9-7/8	C4	AT755	77.4	44.3	121.7	240.40	17.0	19.0	T1,B2,I	
707A	SEC	11-7/16	S86F	469675	213.3		213.3	453.70	2.5	4.5	T1,B2,I	W/XCB PACK-OFF
B	"	"	"	"	124.9		124.9	578.60	3.5	8.0	"	" "
C	RBI	9-7/8	C4	AT7756	259.4	183.8	443.2	1021.80	28.5	28.5	T1,B2,I	RELEASED IN HOLE
708A	SEC	11-7/16	S86F	469675	236.2		236.2	1258.00	11.5	19.5	T1,B2,I	
709A	SEC	11-7/16	S86F	469675	203.1		203.1	1461.20	0.5	20.0	T1,B2,I	
B	"	"	"	"	254.8		254.8	1716.00	4.5	24.5	"	
C	"	"	"	"	353.9		353.9	2006.99	5.0	29.5	T1,B3,I	ONE CONE LOOSE
710A	SEC	11-7/16	S86F	469675	209.7		209.7	2216.69	2.0	31.5	T1,B3,I	ONE CONE LOOSE
711A	SEC	11-7/16	S86F	469675	249.7		249.7	2466.39	4.0	35.5	T1,B3,I	ONE CONE LOOSE
B	"	"	"	"	98.6		98.6	2565.00	0.5	36.0	"	" " "
712A	RBI	9-7/8	C4	AT761	115.3		115.3	2680.30	2.0	2.0	N/A	
713A	RBI	9-7/8	C4	AT761	191.7		191.7	2872.00	23.0	25.0	T2,B2,0-1/8	REENTRY
713A	NOR	9-7/8	DIAM	1185	8.4		8.4	8.4	4.5	4.5	80% SALVAGE	CUTTING STRUCTURE RINGED NEAR CORE THROAT; BODY WELDS & MATRIX BONDS FAILING

714A	SEC	11-7/16	S86F	469675	233.0		233.0	3105.00	3.5	43.5	T2,B3,I	
B	"	"	"	"	122.0		122.0	3227.0	0.0	43.5	T2,B3,0-1/8	
715A	RBI	9-7/8	C4	AT755	287.0		287.0	3514.00	21.0	40.0	N/A	RELEASED IN HOLE
716A	SEC	11-7/16	S86F	469675	257.7		257.7	3771.00	0.0	43.5	T2,B3,0-1/8	
B	"	"	"	"	264.4		264.4	4035.00	0.0	42.5	"	

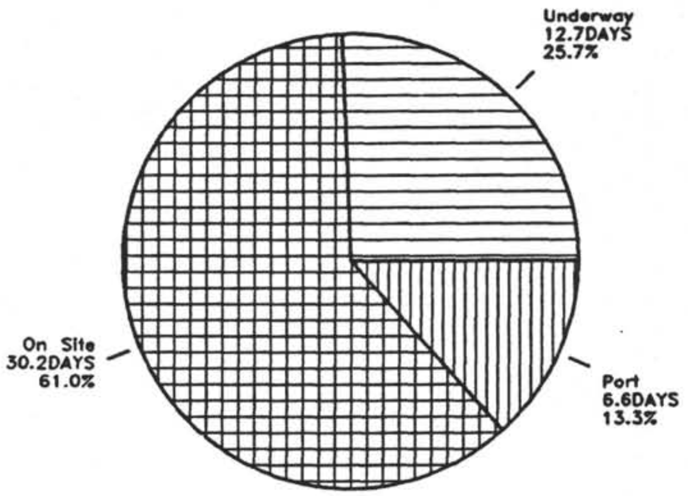
OCEAN DRILLING PROGRAM
BEACON SUMMARY
LEG 115

SITE	MAKER	FREQY KHz	SERIAL NUMBER	SITE TIME HOURS	WATER DEPTH	REMARKS
705	DATASONIC	15.5	369	23.00	2318.0	GOOD SIGNAL
706	DATASONIC	16.5	308	73.75	2518.0	RECALLABLE - RELEASED OK - SURFACED IN 43 MIN.
707	DATASONIC	16.5	308	134.50	1551.9	RECALLABLE - RELEASED ON FIRST ATTEMPT
708	DATASONIC	16.5	308	43.50	4107.0	FAILED TO RELEASE ON FIRST THREE ATTEMPTS - FOURTH TRY RELEASED
709	DATASONIC	16.5	308	87.50	3048.7	RECALLABLE - RELEASED OK - PAINTED BEACON YELLOW
710	DATASONIC	16.5	308	42.25	3822.5	RECALLABLE - RELEASED OK
711	DATASONIC	16.5	308	59.5	4440.2	BEACON FAILED TO RELEASE - LEFT ON SEA FLOOR
712	DATASONIC	15.5	362	60.00	2902.9	SIGNAL OK
713	DATASONIC	14.5	365	109.00	2920.0	SIGNAL OK
714	DATASONIC	15.5	360	27.00	2242.0	SIGNAL OK
715	DATASONIC	16.5	368	88.00	2272.8	SIGNAL OK
716	DATASONIC	15.5	371	3.25	543.8	RAN ON TAUT WIRE - ERRATIC SIGNAL - RETRIEVED
716	DATASONIC	14.5	365	25.00	543.8	SIGNAL OK - RETRIEVED

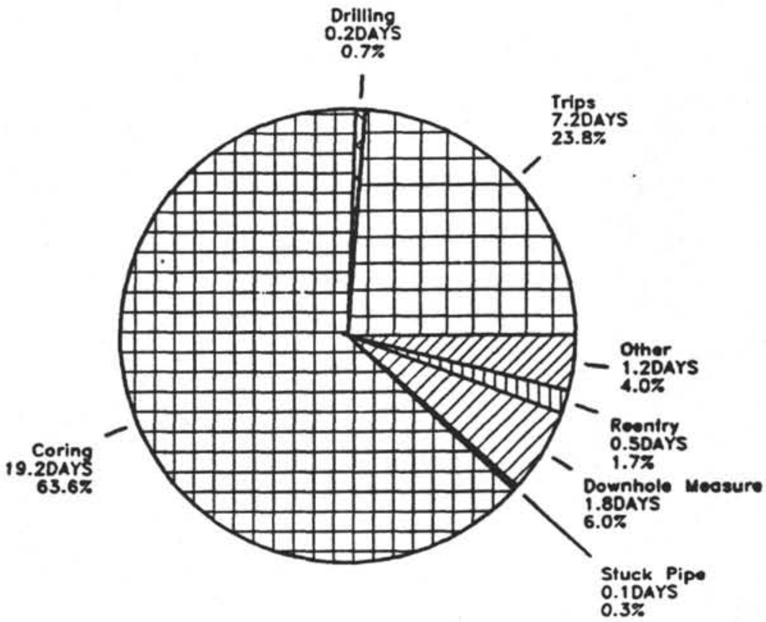
TIME DISTRIBUTION

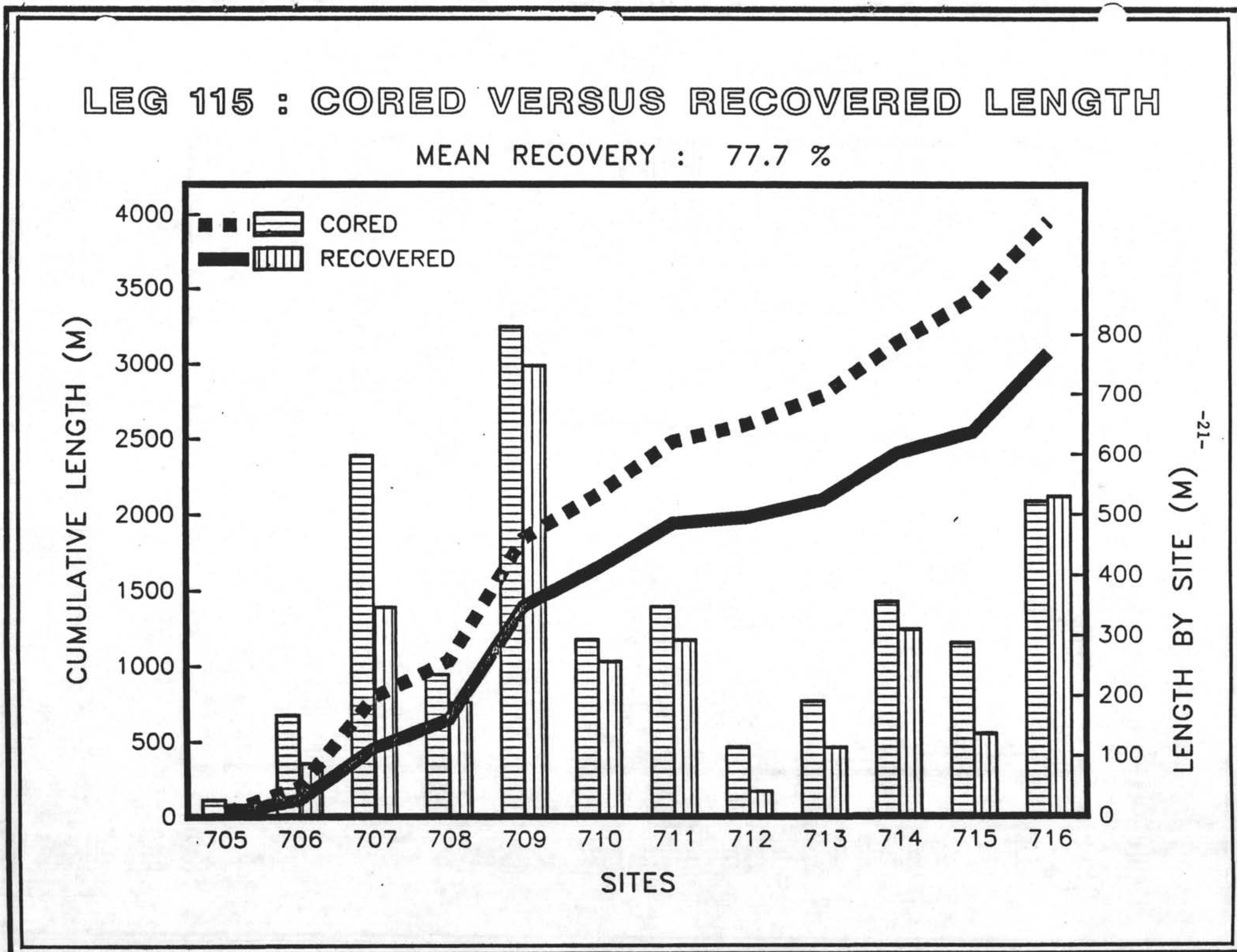
LEG 115

Total Time Distribution

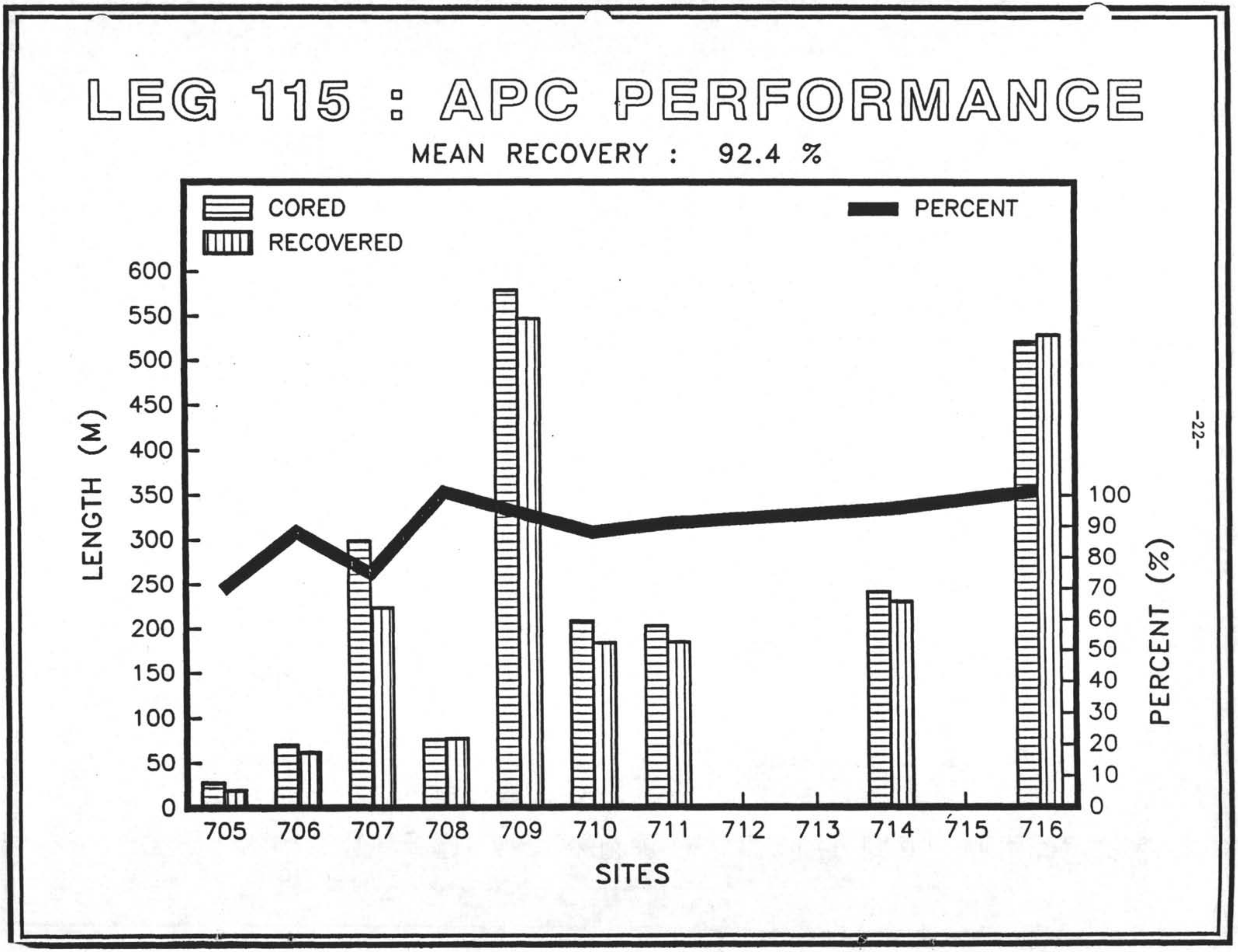


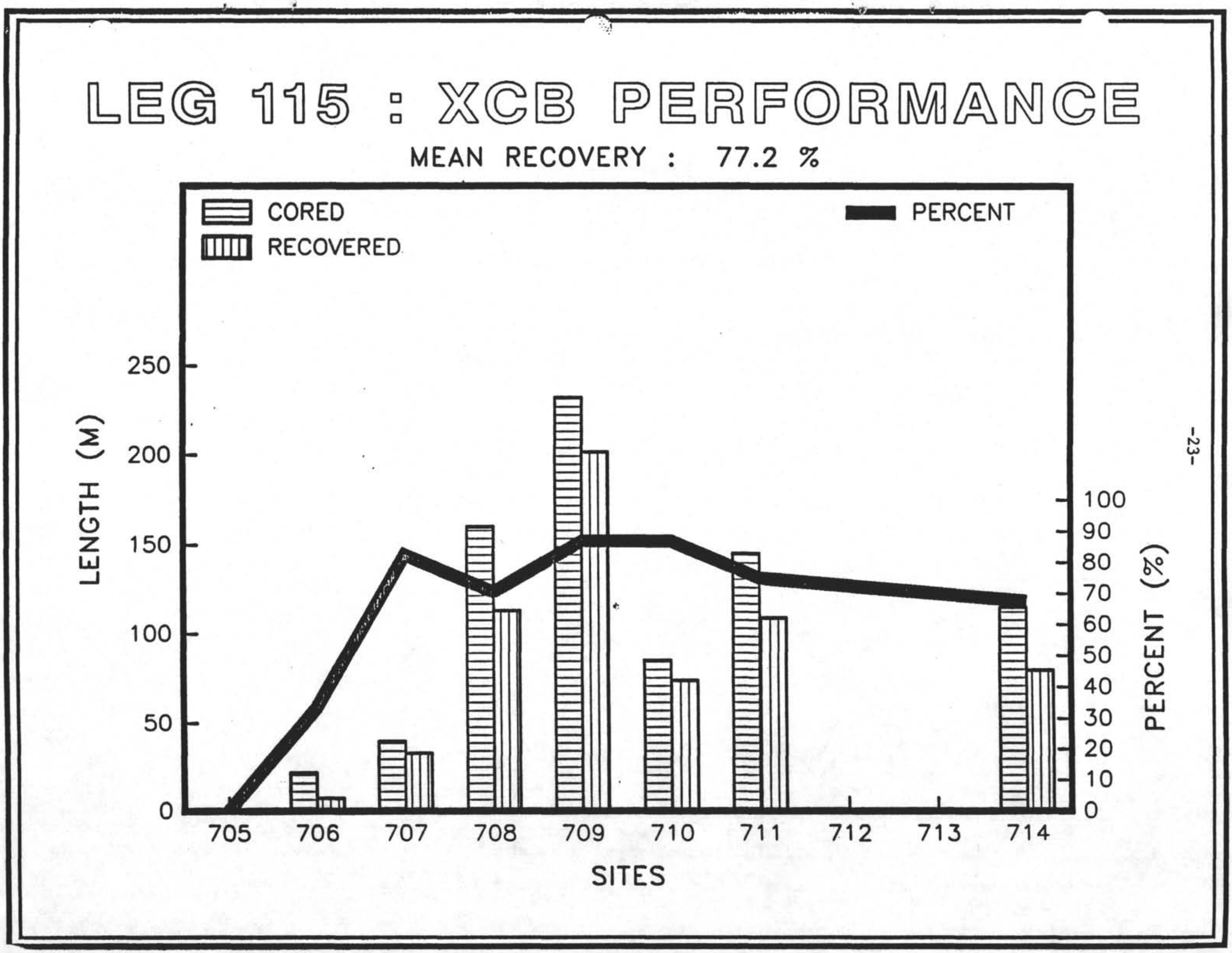
On Site Time Distribution





LEG 115 : CORED VERSUS RECOVERED LENGTH
MEAN RECOVERY : 77.7 %
CORED
RECOVERED
CUMULATIVE LENGTH (M)
4000
3500
3000
2500
2000
1500
1000
500
0
LENGTH BY SITE (M)
800
700
600
500
400
300
200
100
0
705
706
707
708
709
710
711
712
713
714
715
716
SITES


LEG 115 : APC PERFORMANCE
MEAN RECOVERY : 92.4 %
CORED
RECOVERED
PERCENT
LENGTH (M)
600
550
500
450
400
350
300
250
200
150
100
50
0
PERCENT (%)
100
90
80
70
60
50
40
30
20
10
0
705
706
707
708
709
710
711
712
713
714
715
716
SITES



LEG 115 : XCB PERFORMANCE
MEAN RECOVERY : 77.2 %
CORED
RECOVERED
PERCENT
LENGTH (M)
250
200
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
PERCENT (%)
705
706
707
708
709
710
711
712
713
714
SITES

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 115 of the Ocean Drilling Program were:

Laboratory Officer:	Burney Hamlin
Senior Marine Technician:	Brad Julson
Chemistry Technician:	Tamara Frank
Chemistry Technician:	Katie Sigler Tauxe
Computer System Manager:	Larry Bernstein
Curatorial Representative:	Bob Wilcox
Electronics Technician:	Jim Briggs
Electronics Technician:	Dwight Mossman
Photographer:	Stacey Cervantes
X-ray Technician:	Bettina Domeyer
Yeoperson:	Dawn Wright
Marine Technician:	Dan Bontempo
Marine Technician:	Angelo Camerlenghi
Marine Technician:	Henrike Groschel-Becker
Marine Technician:	Jessy Jones
Marine Technician:	John Tauxe
Marine Technician:	John Weisbruch

TECHNICAL REPORT

Portcall

Crossover and freight movement began the morning of 14 May as soon as the onçoming technicians arrived at the ship. Critical parts were removed from the air shipment and repair work on the XRD and SEM started. Both units were soon functioning satisfactorily. A GRAPE wipe test was done for the Radiation Safety office at Texas A&M. The XEROX machines were serviced by a company representative.

The previous legs' cores were offloaded into two 20' refrigerated containers for shipment to the East Coast Repository at L-DGO. There was some question whether dockside work could be accomplished in the two days allotted before the ship was to be moved to anchorage, but all freight movements were accommodated. A 20' container was filled with empty K-boxes, pallets of liner splices and cases of D-tubes for storage until Leg 117. A barrel of our Tanner gas was stored with SEDCO barrels in another container that will also be stored. The iceberg towing line was lowered onto a flatbed trailer and taken to a covered storage. A larger container will be secured, the line placed in it and stored with the other containers.

The dry ice for the frozen shipment arrived but was 1/3 to 1/2 sublimated, a problem the agent acknowledged. For this reason only last leg's foreign destination samples were shipped.

The ship was moved to clear water so that the hull could be cleaned and inspected by a diving team using underwater video and sonic devices. Baker Tools magnafluxed the drill pipe and collars. Water taxi service allowed personnel movement to shore.

Our Zodiac inflatable boat was deployed and circled the ship a few times before going into Port Louis for fuel.

Underway

The ship weighed anchor and sailed 19 May at 2115 for proposed site MP-3. Speeds exceeding 13 knots precluded streaming the seismic gear for this and other transits this leg. Magnetometer and all navigation parameters including our GPS and TRANSIT positions were collected on magnetic tape for approximately 3600 underway miles. The watergun records from the pre-site survey at target site MP-3 compared favorably with the DARWIN's airgun surveys and the water guns were used the remainder of the leg. The banks we passed over on the run to MP-3 were surprisingly shallow.

The seismic gear was deployed over the rest of the proposed drilling areas and sites were selected. It was noted that features we looked for on 10 year old seismic lines sometimes were not recognizable on our records. This was because of the emergence of GPS as a primary navigation aid which we use whenever possible. With this in mind it is easy to understand why survey time has to be extended occasionally and site positions have to be changed.

Core Lab

Activity in the lab reflected the coring mode: hectic with APC coring; a little more relaxed when XCB coring takes over and recovery begins to drop; then, on some of the sites, time for catching up during the rotary coring segments.

A new absolute pressure valve supplied by 2G was installed on the cryogenic magnetometer. Magnetic signatures in the sediment and rocks were recorded routinely using the cryogenic magnetometer, minispin, and susceptibility meter. Split cores were run in the cryogenic magnetometer and loose sediment caused some problems with the conveyor system. Staffing with two paleomagnetists eased the work load on the marine technician assigned to the lab and allowed him to function primarily in core handling.

Physical Properties

The old GRAPE track, used currently with the P-wave logger, failed twice, provoking the technicians to find time to draw up a plan to incorporate the P-wave transducers on to the new GRAPE mechanism. SEDCO's machinists milled core holders and made stand-offs for the source and detector. The ODP ETs rewired the components, techs assembled the transducers on a PVC bracket and modified the program to reflect the new requirements. After fine tuning with real cores, data were successfully collected.

Curatorial

Excellent recovery and high resolution sampling at selected carbonate sites contributed to the large number of samples taken this leg. The four basement sites provided contrast and kept the area very busy.

Almost 3075 meters of cored sediment and rock was recovered, processed and an estimated 20,000 samples taken. The cores and frozen organic samples will stay aboard until the second Colombo portcall before shipment to the ODP repository at Texas A&M. Because of time constraints at the end of the cruise, the cores from the last site will be sampled at the repository.

X-ray Lab

Both X-ray instruments were used regularly throughout the leg. About 250 samples were scanned with the Phillips XRD providing quantitative analyses for quartz, aragonite, dolomite, and calcite. A troublesome board in the PDP11 control computer finally failed near cruise end and terminated the data processing features. A replacement board is on order. Samples could still be scanned using the diffraction control unit and an analog trace generated.

Basalt samples from four holes (706C, 709C, 713A, and 715A) were prepared for XRF analysis. Approximately 90 samples were scanned for major and trace elements. Some sediment samples from Hole 711A were scanned for trace elements.

Petrology Lab

Polished thin sections were prepared from more than 200 billets. The equipment was trouble free though a motor control board was replaced on the Logitech thin section machine.

Scanning Electron Microscope

The SEM was used only for training technicians this leg.

Computer Services

Computer classes were conducted in port and at sea for the scientists with emphasis on CTOS word processing and Picsure graphics software. Few hardware or software problems hampered the use of the system. With more people becoming proficient using CPU intensive graphics programs the concern over slowness has increased, and hard disk space is approaching capacity.

Ship communications were routed from various sources through the yeoperson who made a hardcopy for the Operations Superintendent. The message files were then placed in an account available to the Radio Officer's IBM. After the Radio Officer got an ok'ed hardcopy from the Operations Superintendent, the daily traffic was transmitted. This routine worked well once implemented.

Photo Lab

The photographer and lab were able to accommodate all demands of the cruise. Equipment was maintained as necessary including fixing some small leaks and tolerating the nuisance of rust colored hot tap water and pre-filters. At one point E-6 color chemistry seemed to go astray, but the problem eventually turned out to be the densitometer used to gauge the consistency of the negatives.

Electronics Shop

Competent efforts from the electronics technician kept all labs operating throughout the leg. The usual array of problems ranged from wiring new electrical plugs to mechanical and electronic problems presented by the XRF and Masscomp computers.

Assisting the SEDCO electronics technician gave our ET's a feel for service requirements of the subsea TV camera system during one minicone reentry.

Storekeeper

No problems were noted with our incoming air and surface shipments other than one of the surface containers of mixed operations and logistics supplies arrived with a damaged roof. K-box 3 in that container was received wet but the contents were undamaged. Supplies of D-tubes and liner patches were stored on board as possible and the remainder were left in a shore storage container for future portcalls.

Items in the lower tween and hold storage lockups were re-labeled and straightened.

Gym

The gym was used daily for aerobic exercises, rowing, ping pong and "pumping iron." New resilient deck tile flooring was laid at the beginning of the cruise, and increased everyone's "sureness of footing and spring." The small exercise bike saw many days of use.

Special Projects

With the assistance of the SEDCO Drilling Supervisor, the passageway deck from the core lab entrance to the bridge was cleared of vinyl covered rug and painted. All of the office spaces on the bridge deck were also cleared and painted. The XEROX area and passage to the lounge were also stripped of vinyl covered rug, and beige floor tile was layed.

Lockers were installed in the co-chiefs' cabins and the desks in the co-chiefs' office were augmented with drawer pedestals.

In the X-ray lab sample preparation area, a temporary maple table top was replaced with a white composite laboratory table top more appropriate for the XRF clean area. A file drawer pedestal was installed under the paleo lab's maple work surface.

The ship's welders were able to rehinge a ventilation cover that protruded into a walkway on the aft starboard poop deck. It now lies nearly flat against the bulkhead and out of the way.

The welders' efforts continued in the modification of an area near the generator room into a battery room. It will eventually supply power to the VAX for up to two hours. Additional materials are expected in Colombo to finish the job.

Problems

The lab focsle deck (paleo, petrology, and chemistry) was again much warmer that the rest of the labs and the air delivered was very low in volume. During the few sunny days we enjoyed this leg those stationed in these labs used fans for relief. It is likely that the overcast and cloudy weather experienced this leg kept the area from being intolerable the majority of the time. The wall area over the LAS system in the X-Ray lab is large enough to accommodate another chill water heat exchanger but vented into the chemistry area.

Five-micron water pre-filters are passing rust to the photoprocessor and to the osmotic membrane in the chemistry lab's Barnstead water de-ionizer. The stained filters will be sent to Texas A&M for particle size evaluation. It will be decided there whether the fine rust can be removed with filters, processed out chemically or controlled by adjusting the water pH.

Safety

The **METS** team secured the lab stack during our fire drills and met later to discuss the outcome of the drill. We also undertook a familiarization tour of the labs' electrical panels and water turnoff signs. Color coding lab areas with colors in the electrical panels is planned. Safety equipment was checked and first aid kits resupplied.

The Captain had a section of the emergency guidelines for the computer area re-written for clarity. Compressed air was substituted for HALON and the computer lab fire system tested successfully. The second fire drill in the computer area demonstrated the HALON alarm for all and simulated the team reaction to a larger fire than a waste-can fire.