Backman, J., Duncan, R. A., et al., 1988
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1. INTRODUCTION[1]

Shipboard Scientific Party[2]

Leg 115 is the first of a nine-leg program of exploration of the Indian Ocean. Previous drilling by the Deep Sea Drilling Program (DSDP), Legs 22 through 29 (1972–73), resulted in the first detailed information about the geologic and oceanographic history of this major region of the oceans. Compared with the Atlantic and Pacific Ocean Basins, however, the Indian Ocean is still relatively unexplored. During this multifaceted investigation, we hoped to examine many fundamental questions. The scientific objectives of this leg fell into two main subject areas: hotspot volcanism and paleoceanography.

HOTSPOTS AND PLATE TECTONICS

An extraordinary feature of the Indian Ocean is the large number of elevated plateaus and ridges scattered throughout the basin. Scientists have ascribed the origins of these ridges to continental fragments, ancient island arcs, and volcanic activity associated with either fracture zones in the ocean crust or stationary hotspots. The Seychelles Bank, at the northwestern end of the Mascarene Plateau, is composed of late Precambrian granitic rocks which are intruded by late Cretaceous/early Tertiary basaltic dikes (Baker and Miller, 1963). From the arcuate shape of the combined Mascarene and Seychelles Plateaus, Meyerhoff and Kamen-Kaye (1981) proposed that these were underlain by a Paleozoic island arc.

Drilling on Leg 115 at two sites and industrial drilling at two other sites have recovered Tertiary-age basalts, which appear from preliminary analyses to exhibit only ocean-island to mid-ocean-ridge chemical characteristics. Available age constraints from Leg 115 shipboard biostratigraphic data and published radiometric dating of the subaerial basaltic lavas show a clear and systematic decrease in age from the north to the south along the ridge, which supports the theory of an origin by hotspot activity rather than by sporadic or synchronous volcanism along a transform fault, as suggested by McKenzie and Sclater (1971).

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, 1972). Excess melting of the upper mantle peridotite within these hotspot areas led to anomalous volcanism on the overlying plate and, hence, the formation of lineaments consisting of discrete volcanoes and coalesced volcanic ridges. These lineaments record the motion of the plates surrounding the Indian Ocean.

Morgan (1981) proposed that young volcanic activity at the island of Réunion is the present manifestation of a stationary hotspot which produced the island of Mauritius, the volcanic ridge underlying much of the Mascarene Plateau, the Chagos Bank, the Maldive and Laccadive Islands, and the massive flood basalt volcanism of the Deccan Traps, western India (Fig. 1). The primary evidence for this hypothesis is that the geometry of these volcanic islands and submarine (presumed volcanic) ridges is consistent with northward motion of the Indian plate, followed by northeastward motion of the African plate, over a fixed melting anomaly at the location of Réunion during Tertiary time (Morgan, 1981; Duncan, 1981). In addition, this volcanic trail is parallel with the Ninetyeast Ridge, another submarine lineament linked to hotspot activity (now centered near the Kerguelen Islands, Antarctic plate), and the two may record the northward motion of India during the opening of the Indian Ocean.

Until Leg 115, however, the only accessible sampling locations along the proposed Réunion hotspot track were the young volcanic islands at the southern end and the Deccan flood basalts at the northern end. The reality of the hotspot model remained to be tested by sampling intervening submarine sites as part of the Ocean Drilling Program. During Leg 115, we recovered volcanic rocks by drilling at four sites along this trace. Biostratigraphic age estimates from sediments intercalated with and directly overlying the basaltic rocks confirm that volcanic activity progressed to the south through Tertiary time and are consistent with a stationary Réunion hotspot (Fig. 2).

We designed the route of Leg 115 so that we could sample the presumed volcanic rocks underlying the carbonate platform which forms the Mascarene Plateau and the Chagos-Maldive-Laccadive Ridge system (Fig. 1). Following the cessation of eruptive activity, volcanoes were eroded to sea level (if emergent) and subsided as the oceanic lithosphere adjusted to the weight of the new load. In tropical latitudes, carbonate reefs have grown fast enough to keep pace with the subsidence of the basement rocks and have maintained a platform near sea level. The carbonate sediments covering the central portions of the Mascarene Plateau are 1–2 km thick (Meyerhoff and Kamen-Kaye, 1981); consequently, we positioned the drilling sites on the shoulder of the ridge to penetrate the volcanic rocks through principally pelagic sediments.

During the voyage from Port Louis, Mauritius, to Colombo, Sri Lanka, *JOIDES Resolution* followed the presumed volcanic trace left by the Réunion hotspot on the African and Indian plates (Fig. 1). This volcanic ridge, now covered with a carbonate platform along much of its length, extends northward from the volcanically active island of Réunion, to the inactive and rapidly eroding island of Mauritius, and then on beneath the Soudan, Cargados Carajos, and Nazareth Banks (Fig. 3). The Saya de Malha Bank forms the eastern end of the northwest-trending ridge that 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 the Nazareth Bank, the volcanic rocks of the former erupted much earlier (at approximately 62 Ma at Site 707), when the Seychelles microcontinent was still adjacent to India, and are probably related to the late Cretaceous–early Tertiary Deccan flood basalt volcanism which stretches across much of western India. Reconstruction of the central Indian Ocean basin for 36 Ma removes the ocean crust created at the Central Indian Ridge and joins the Nazareth Bank to the Chagos Bank (McKenzie and Sclater,

[1] Backman, J., Duncan, R. A., et al., 1988. *Proc. ODP, Init. Repts.* 115: College Station, TX (Ocean Drilling Program).

[2] Shipboard Scientific Party is as given in the list of Participants preceding the contents.

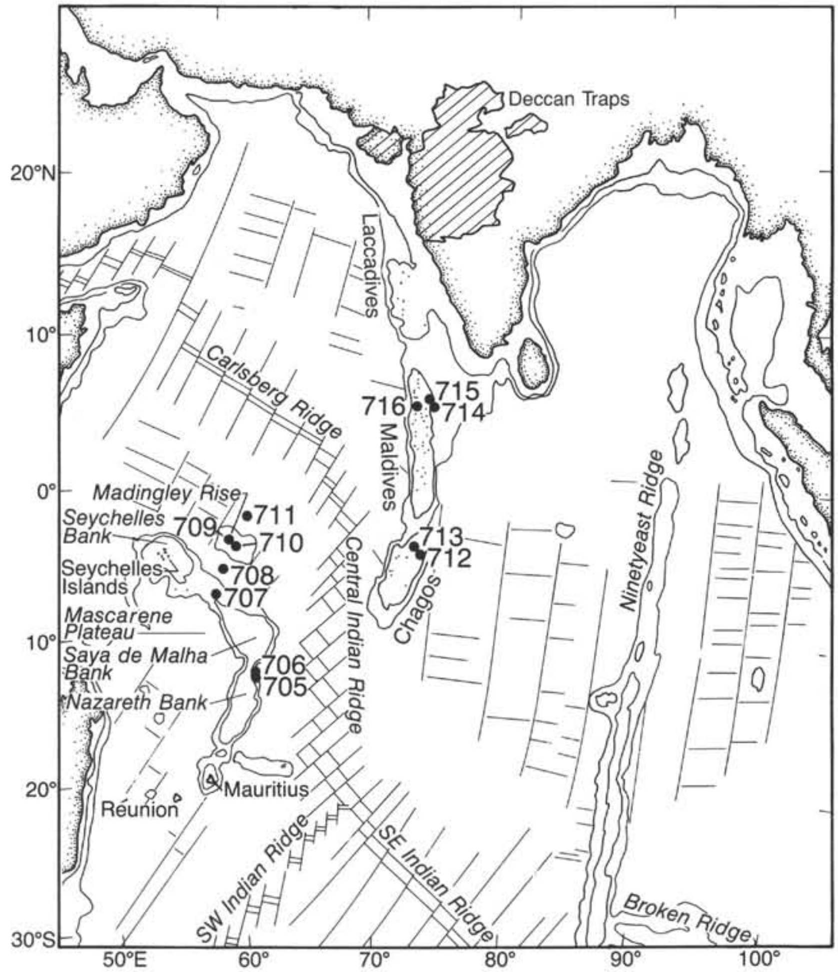

Figure 1. Major bathymetric features of the central Indian Ocean are shown by 2- and 4-km depth contours. Leg 115 drilled into volcanic rocks at Sites 706 and 707 (Mascarene Plateau), Site 713 (Chagos Bank), and Site 715 (Maldives Ridge). These sites are part of a volcanic trail that links present-day hotspot activity near Réunion Island with the Deccan flood basalt volcanism erupted at the Cretaceous-Tertiary boundary.

1971). Hence, the hotspot trace continues northward through the Chagos Bank along the Maldive Islands, the Laccadive Islands, and into the Deccan Traps in western India.

The drilling program planned 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 northward, from a "zero" age at Réunion 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. Basaltic rocks have also been sampled at several other locations along this hotspot track.

Industry Wells on the Mascarene Plateau

Meyerhoff and Kamen-Kaye (1981) have described the stratigraphy of two test wells drilled by Texaco, Inc., in 1975 on the Saya de Malha Bank and Nazareth Bank, Mascarene Plateau (Fig. 3). At the northern site (SM-1), 2400 m of upper Paleocene to Quaternary, neritic to shallow-water carbonate rocks overlie a section of basaltic rocks at least 830 m thick. This is an extremely valuable site as it represents a very deep penetration and complete sampling of one ancient location of the hotspot. If the Saya de Malha Bank does correspond to the western extension of the Deccan flood basalts, then we might expect to match some of the downsection compositional variations reported for the volcanic section in western India (e.g., Beane et al., 1986). At the Nazareth Bank site (NB-1), drilling reached a total depth of 1700 m, the lower 160 m of which were basalts and trachytic rocks (Meyerhoff and Kamen-Kaye, 1981). The overlying sedimentary sequence was Eocene to Pliocene shallow-water carbonates.

The Deccan Flood Basalts

At the northern end of the proposed Réunion hotspot lineament is the remarkable volcanic province of the Deccan flood basalts, covering over 500,000 km^2 of west and central India. In places the basalts form sequences more than 2000 m thick. Prior to erosion 1.5 million km^3 of basalt originally may have erupted here. It appears that the Deccan volcanism was the first manifestation of the Réunion hotspot (although earlier formed volcanic centers may have occurred to the north and are now hidden in the suture zone between India and Asia).

Excellent summaries of the stratigraphy and geochemical composition of the Deccan basalts have appeared recently (Beane et al., 1986; Mahoney, 1987; Cox and Hawkesworth, 1985). Published radiometric dates on the flows vary from 102 to 30 Ma, but the thickest sections were apparently erupted in a much more restricted period, from 66 to 60 Ma (Kaneoka, 1980; Courtillot et al., 1986). Magnetostratigraphic data (summarized in Courtillot et al., 1986) have been used to argue that the entire sequence was erupted over two reversals of the magnetic field. (The majority of the flows are reversely magnetized, and a short normal section occurs at the bottom and at the top.) In this case the whole eruptive history would cover only 1–2 m.y.

The conflict over the absolute age and age range of the Deccan basaltic volcanism is important in the context of the hotspot model and the position of India relative to the Réunion hotspot in the late Cretaceous and early Tertiary. Of enormous recent interest is the relationship of events at the time of the Cretaceous-Tertiary boundary. While there are many persuasive arguments that meteorite impact led to climate deterioration and the demise of many faunal groups at this time (Alvarez et al., 1980), an alternative position is that catastrophic volcanic eruptions injected dust and gases into the atmosphere in sufficient rates to cause the required climate change (Officer and Drake, 1983).

The proposed volcanic catastrophe is, in fact, the Deccan flood basalts. This second model works, however, only if it can be shown that the volcanism corresponded exactly with the Cretaceous-Tertiary boundary and occurred over a short period (1–2 m.y. rather than 5–10 m.y. or more). Correlating the Deccan basalts precisely with the Cretaceous-Tertiary boundary, of course, may also link the volcanism to the site of meteorite impact (Hartnady, 1986; Courtillot et al., 1986).

The Rodrigues Ridge

The Rodrigues Ridge is a puzzle. It is known to be volcanic from recent surveying and dredging (*Darwin* 21/87 Site Survey cruise for Leg 115) and rises from abyssal depths to near sea level at several locations and above at its eastern end (Rodrigues Island). This narrow, linear volcanic ridge is perpendicular to the Mascarene Plateau and intersects the latter about 200 km north of Mauritius (Fig. 3). The trend of the ridge does not have any apparent relationship with transform faults or magnetic anomalies produced at the Central Indian Ridge. Its relationship to the Réunion hotspot track is unknown, although several possibilities exist.

Morgan (1978) proposed that the Rodrigues Ridge, and similar features such as the Darwin-Genovesa Island lineament north of the Galapagos Islands, result from "channeled" asthenospheric flow from a hotspot to a nearby spreading ridge. The trend of the Rodrigues Ridge in his model is determined by the vector addition of the African plate motion over the hotspot and the relative motion of the spreading ridge away from the plate. If this is true, there should be a clear age progression from west (old) to east (young) along the ridge.

The trend of the Rodrigues Ridge is also subparallel with magnetic anomalies associated with Paleogene seafloor spreading (prior to the present Central Indian Ridge). It may then represent a young reactivation of a spreading-ridge segment by the passage of the plate over the hotspot, although it is unclear why this particular area was vulnerable while others were not. The ages along the ridge should be synchronous and mark the time that the hotspot passed the intersection point (about 16 Ma). Another possibility is that the ridge is due to a separate hotspot, younger and weaker than the Réunion hotspot. The west-northwest volcanic trend is not quite that expected from the most recent west to east motion of the Somali plate over hotspots in the region (Emerick and Duncan, 1982). If this were the case, however, the ages should progress from west (young) to east (old) in an opposite sense to Morgan's (1978) model.

The Mascarene Islands: Réunion, Mauritius, and Rodrigues

The volcanic islands of Réunion, Mauritius, and Rodrigues (collectively called the Mascarene Islands) lie between 19° and 22°S and between 55° and 64°E (Fig. 3). These islands sit at the southern end of the volcanic lineament and are the most recent expression of the hotspot activity. McDougall (1971) determined the timing of the volcanism on the three islands (shown in Fig. 4).

Réunion Island rises 7000 m from an ocean floor of Paleocene age (Chron 27 = 63 Ma). Its highest elevation is 3069 m above sea level. Two volcanoes make up the island: (1) Piton des Neiges is inactive and forms the northwest two-thirds of the island, and (2) Piton de la Fournaise forms the southeastern part of the island and is one of the most productive volcanoes in the world. The centers of the two volcanoes are 30 km apart. The oldest rocks found on the island are about 2 Ma. Piton des Neiges has not been active for 70,000 years, and the shield volcano is rapidly eroding into steep valleys and cirques. Active for 360,000 years, Piton de la Fournaise is being built on the flank of Piton des Neiges in much the same way as Kilauea is forming on the flank of Mauna Loa.

The rocks of Réunion are primarily basalts that are transitional between tholeiites and alkali basalts of Hawaii. The last stage of volcanism on Piton des Neiges erupted lavas of basaltic to quartz-trachytic composition. The lavas are quartz-normative with only a few exceptions. Lavas from Piton de la Fournaise are similar to those of Piton des Neiges and are mostly olivine basalts, but plagioclase-phyric lavas, hawaiites, and ankaramites also occur.

Mauritius was built by perhaps three eruptive episodes (Fig. 4), the first of which was the most voluminous. This earliest phase of volcanism consists primarily of olivine basalts and oceanites like the main phase of volcanism at Réunion. The second episode of activity is distinctly alkalic with highly magnesian (9–13 wt%) alkali olivine basalts, basanites, and nephelinites. The third episode is primarily alkali-olivine basalt and is similar in many ways to the first phase.

The origin of the "rejuvenescent" phases of volcanism is perplexing in view of the hotspot model. Given that the ages of the initial (main) shield-building phase of the islands show a progression consistent with African (Somali) plate motion over a stationary hotspot (Emerick and Duncan, 1982), it is unclear how the later stages of volcanism at Mauritius were triggered. If Morgan's (1978) channeled asthenospheric flow model is viable, melts can appear several hundred kilometers "downstream" from the hotspot. A continuous, rather than punctuated, volcanic history might be expected, however. Alternatively, extensional stresses that develop in the loaded and reheated oceanic plate may have facilitated the later volcanism.

Rodrigues Island lies about halfway between the Central Indian Ridge and Mauritius, at the eastern end of the Rodrigues Ridge. It rises only a few hundred meters above sea level and is composed of olivine basalts erupted about 1.5 Ma. Chemically these basalts are not significantly different from the older series lavas on Mauritius or the differentiated lavas of Piton des Neiges on Réunion (Baxter et al., 1985). The lavas of Rodrigues, however, are distinguished by ubiquitous coarse-grained inclusions and megacrysts, including plagioclase (as long as 5 cm), kaersutite, magnetite, hercynite, augite, and apatite, probably derived from a layered plutonic body beneath the volcano.

A major objective of Leg 115, then, was to obtain volcanic basement samples to test whether or not the age of volcanic activity increased to the north along this series of lineaments, in accord with the prediction of the hotspot model. It appears that this has been clearly confirmed. The four new sites drilled to basement during Leg 115, together with the industry wells, dredged sites, and subaerial basalt occurrences produce an extremely detailed sampling of the volcanic products of hotspot activity along this line province. Following radiometric and biostratigraphic age estimates for the age of volcanism at the various sites, we expect to develop a refined history of Indian and

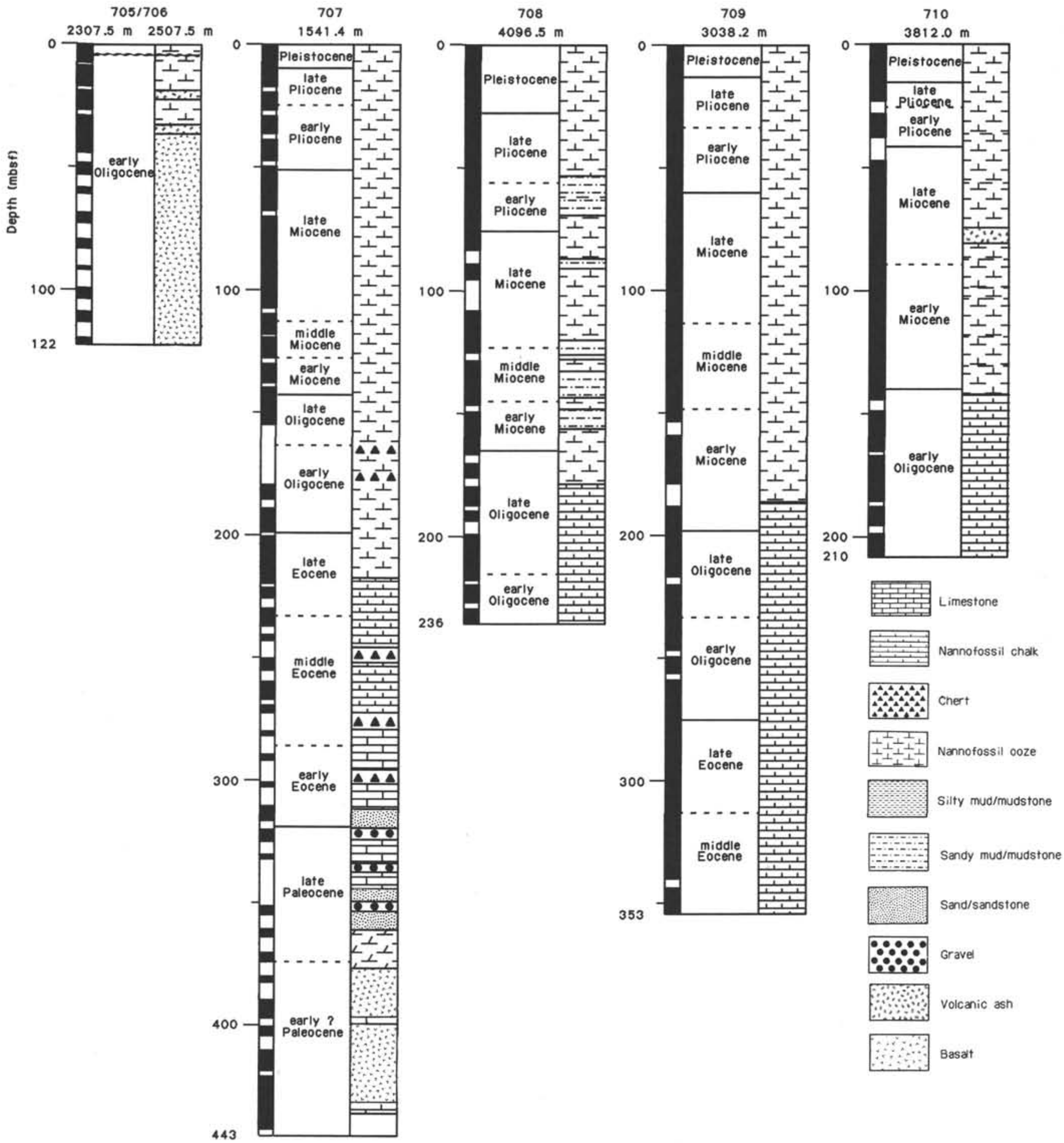

Figure 2. Geologic columns constructed from lithologic and biostratigraphic examination of core material recovered during Leg 115. Locations of drilling sites are shown in Figure 1.

African plate motions for Tertiary time, relative to the hotspot reference frame.

We can also investigate the proposition that the Réunion hotspot has been stationary with respect to other prominent hotspots in the region. To do this we use African plate motion over hotspots in the South Atlantic from well-documented volcanic lineaments, such as the Tristan da Cunha hotspot and its trace, the Walvis Ridge (O'Connor and Duncan, 1984), and add to that the relative motion of the Indian plate away from the African plate for the last 100 m.y. (e.g., Norton and Sclater, 1979). The result is a predicted trail of the Réunion and Kerguelen hotspots, fixed in their present coordinates, which can be directly compared with the actual ridges and age estimates from sample sites (Fig. 5). The geometry of both hotspot tracks is very well

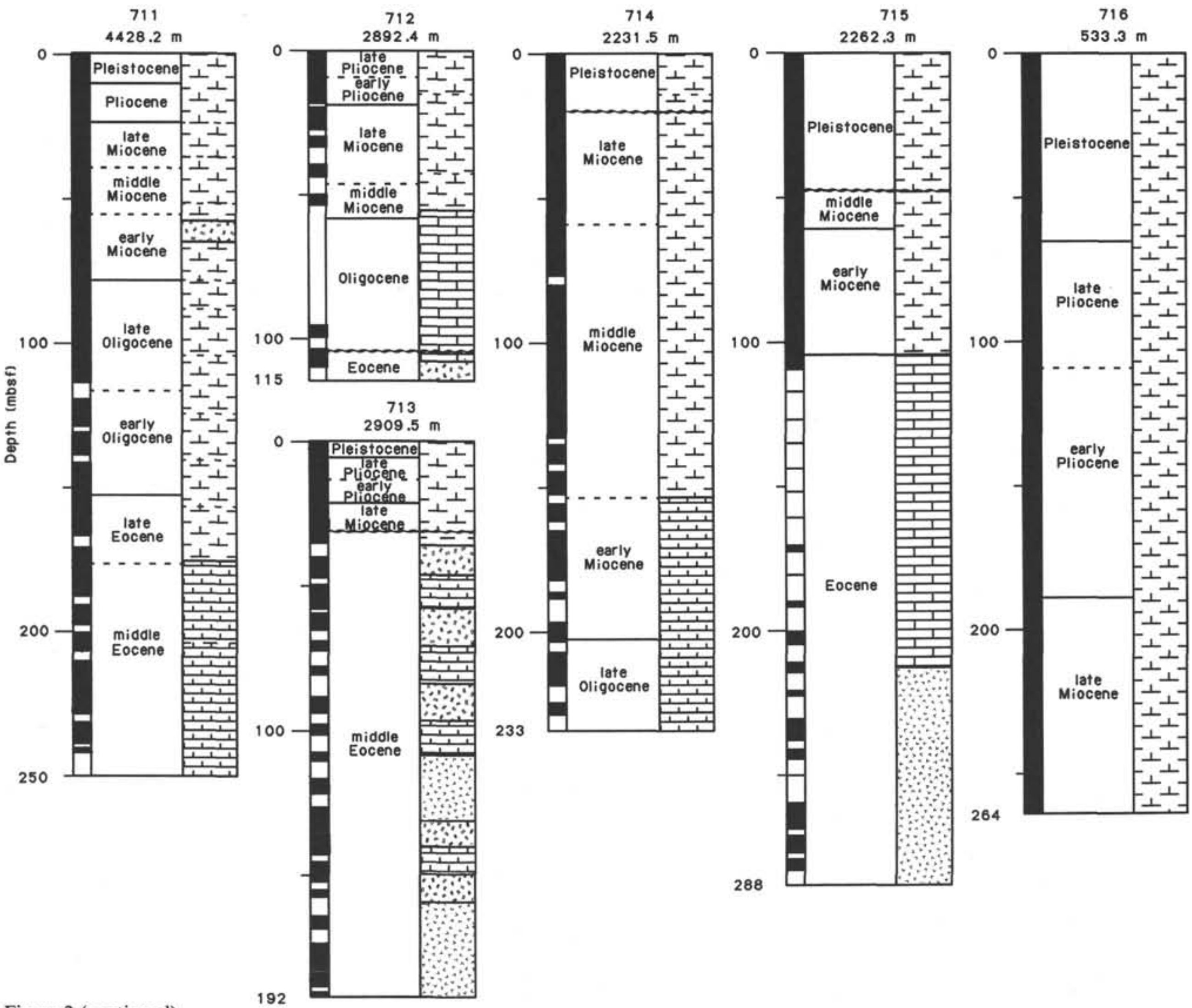

Figure 2 (continued).

matched, and the new age estimates from the drilling sites are in excellent agreement with those predicted by the stationary hotspot model. Drilling at additional sites along the Ninetyeast Ridge (Leg 121) will provide further documentation of volcanic ages.

An additional objective of Leg 115 was to sample a wide distribution of basalts from along the hotspot track for geochemical studies. The presumed hotspot would have erupted basalts in various plate tectonic environments: intraplate 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 mid-ocean ridge basalt (MORB) mantle to subcontinental mantle, and basalt compositions should express the relative contributions of these sources through time. We will use geochemical studies (major and trace elements and isotopic compositions) to characterize the volcanic rocks and to form a basis for comparative studies.

An example of such geochemical variations is illustrated in Figure 6, from shipboard X-ray fluorescence (XRF) analyses. Here, basalts from Site 715 are most similar to basalts erupted recently at Réunion, while those from Site 706, 707, and 713 show evidence of magma mixing between hotspot and MORB mantle end-members. We will integrate these and other geochemical data with plate reconstructions to estimate the environment of volcanic activity at discrete times along this hotspot track.

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 volcanoes 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 has been proposed 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 OF THE EQUATORIAL INDIAN OCEAN

Background

We have developed our knowledge of pre-Pleistocene paleoceanography and stratigraphy in the tropical Indian Ocean on the basis of material which was cored by DSDP Legs 22 through

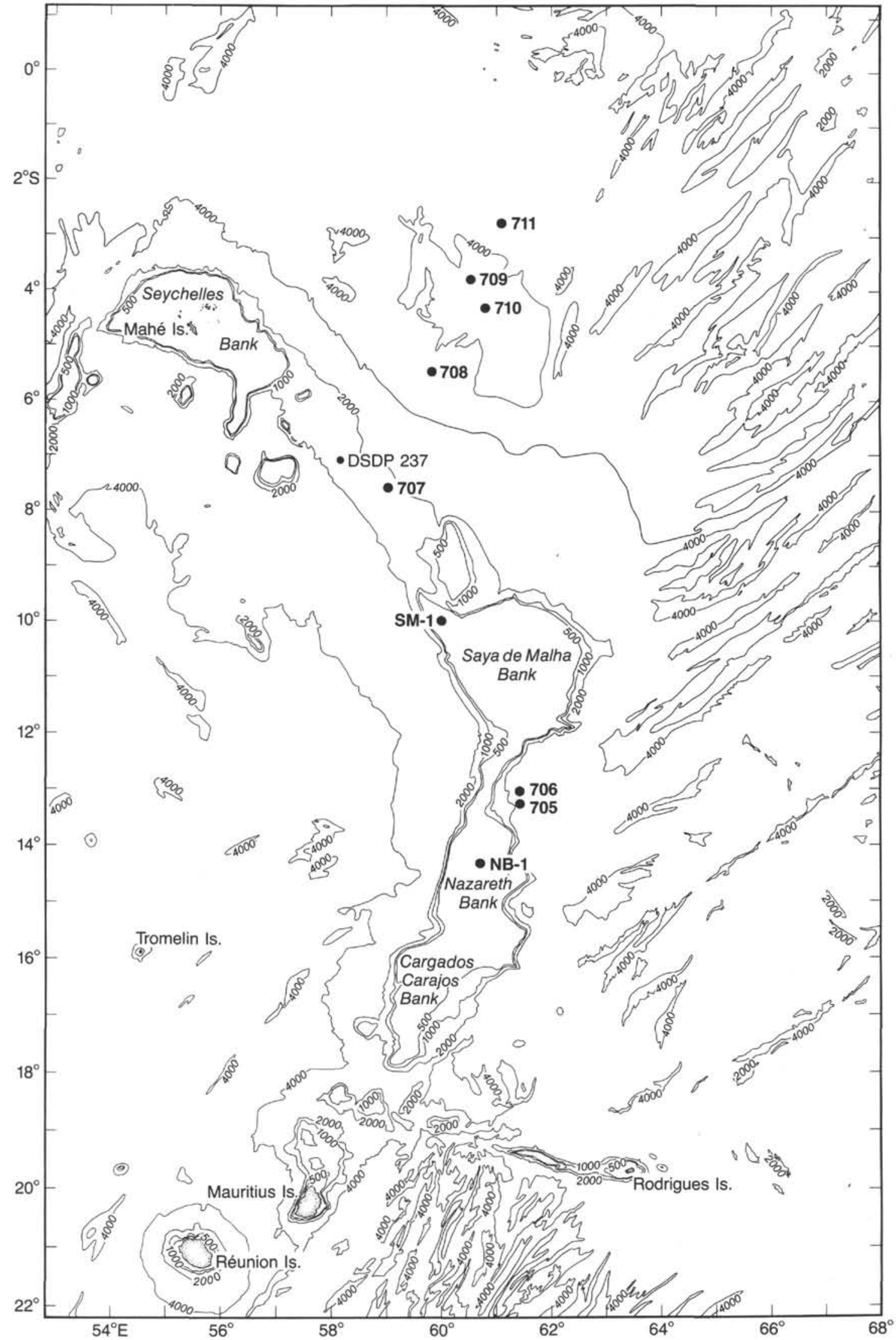

Figure 3. Bathymetric features of the Mascarene Plateau, showing the locations of Leg 115 drilling sites in the western Indian Ocean (after Fisher, Bunce, et al., 1974).

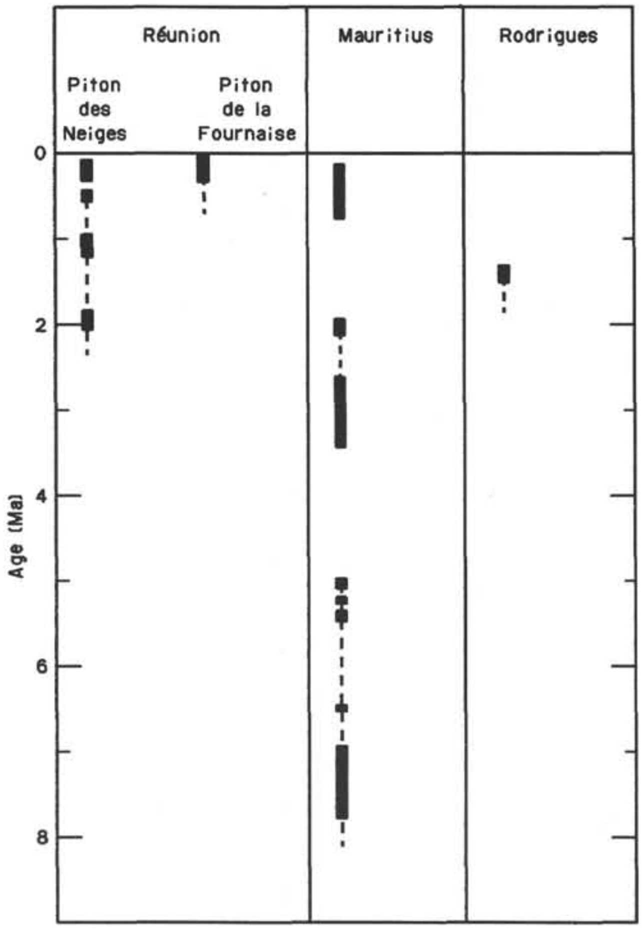

Figure 4. K-Ar ages of lavas from the Mascarene Islands (from McDougall, 1971).

25 in 1972. Heirtzler et al. (1977) have summarized the major results of these four cruises. Much of this DSDP material is of poor quality in light of modern standards and new scientific developments, because deep-sea drilling employed only the conventional rotary coring device 15 years ago. The coring process, in particular, severely disturbed the softer sediments, which in turn negatively affected recovery percentages. There were 17 DSDP sites drilled within 10° latitude north and south of the Indian Ocean equator, achieving an average recovery only slightly in excess of 50%.

Modern attempts to understand ocean history require close to 100% recoveries of penetrated sediment sections and core material that is virtually undisturbed by the coring process. We have learned during the last decade that forces operating on time scales on the order of 10^4–10^5 years are key elements in the evolution of the ocean environment. The DSDP responded to this requirement of improved core quality by developing the hydraulic piston corer (HPC/APC) in the late 1970's. Greatly improved sediment recovery rates since that time have made detailed reconstructions of the ocean paleoenvironment and its changes over tens of millions of years possible.

In this context an increasing emphasis was put on drilling strategies that sampled sediment sections along environmental gradients. Examples include DSDP Legs 85, 86, 90, and 94 with latitudinal gradients in the Atlantic and Pacific Ocean basins and DSDP Legs 72 and 74 with bathymetric gradients in the Atlantic Ocean. Paleoenvironmentally oriented ODP cruises have continued this approach, and Leg 115 contained the first program for APC-coring along a bathymetric transect in the tropical Indian Ocean. This transect will ultimately form part of a global network of depth transects that will enable us to examine the earth's carbonate budget and reconstruct its paleoceanographic history through the Cenozoic.

We chose additional sites on Leg 115 to allow complementary studies of sedimentation, dissolution, and diagenesis in periplatform sediments and to provide materials for detailed biostratigraphic and magnetostratigraphic studies.

History of Sedimentation and Carbonate Dissolution

The construction of well-constrained models of the deep-sea sediment budget and its changes through time and space are of critical importance if we are to understand the history of both global climate and ocean circulation. Furthermore, we can establish such models only by quantifying the processes which control the sediment budget. The accumulation of pelagic carbonate sediments in open-ocean environments is primarily dependent on (1) the rate of production of foraminifers and calcareous nannoplankton and (2) the rate of dissolution of these components at depth. The productivity is determined by the availability of nutrients which, in turn, depends on the rates of supply of these elements from continental runoff and ocean circulation (e.g., vertical mixing, upwelling).

In general, the rate of dissolution of calcium carbonate is a function of the degree of calcite saturation in seawater at the sediment/water interface. Averaged globally, the degree of calcite saturation varies in order to balance the total carbonate budget. The oceanic circulation, and the underlying causes for its development and change, is therefore a key factor among the dissolution-related parameters (for data and reviews of factors controlling the deep-sea carbonate sediment budget, see, e.g., Sliter et al., 1975; Broecker and Peng, 1982; Morse, 1983; Moore, Rabinowitz, et al., 1984).

Far less is currently known about the history of carbonate accumulation and dissolution in the Indian Ocean than in the other major ocean basins. Using conventional piston cores, Peterson and Prell (1985) studied in detail the late Pleistocene record of dissolution in the equatorial Indian Ocean. On much longer time scales, however, the record of carbonate distribution and preservation is poorly known. Figure 7 shows the best available reconstruction of carbonate-compensation depth (CCD) variations in the Indian Ocean, compiled from facies data from previous DSDP sites (Sclater et al., 1977). Unfortunately, of the sites used to construct this figure, many did not reach basement, and only a small subset have an adequate sediment record.

The principal objective of the carbonate-dissolution transect drilled during Leg 115 centered on the collection of materials from which we could study the interplay between the flux in carbonate production at the ocean's surface and the dissolution of this material as a function of water depth, as the shallow and deep circulation and the climatic systems evolved through late Cenozoic times. Thus, drilling in the tropical Indian Ocean was aimed at significantly increasing our knowledge of the sediment-circulation-climate system on both a regional and global scale.

The key to achieving our major objective was to obtain a tightly spaced transect of continuous late Cenozoic sediments from sites spanning a wide range of water depths. The requirements for such a transect also included the following:

1. location of the sites in a small geographic area to ensure that the pelagic rain to all sites is similar;
2. location of the shallowest site well above the depth of the calcite saturation horizon to ensure that little or no carbonate dissolution has occurred;
3. a wide depth range for the sites so that a wide range of calcite saturation levels are represented, and location of the sites

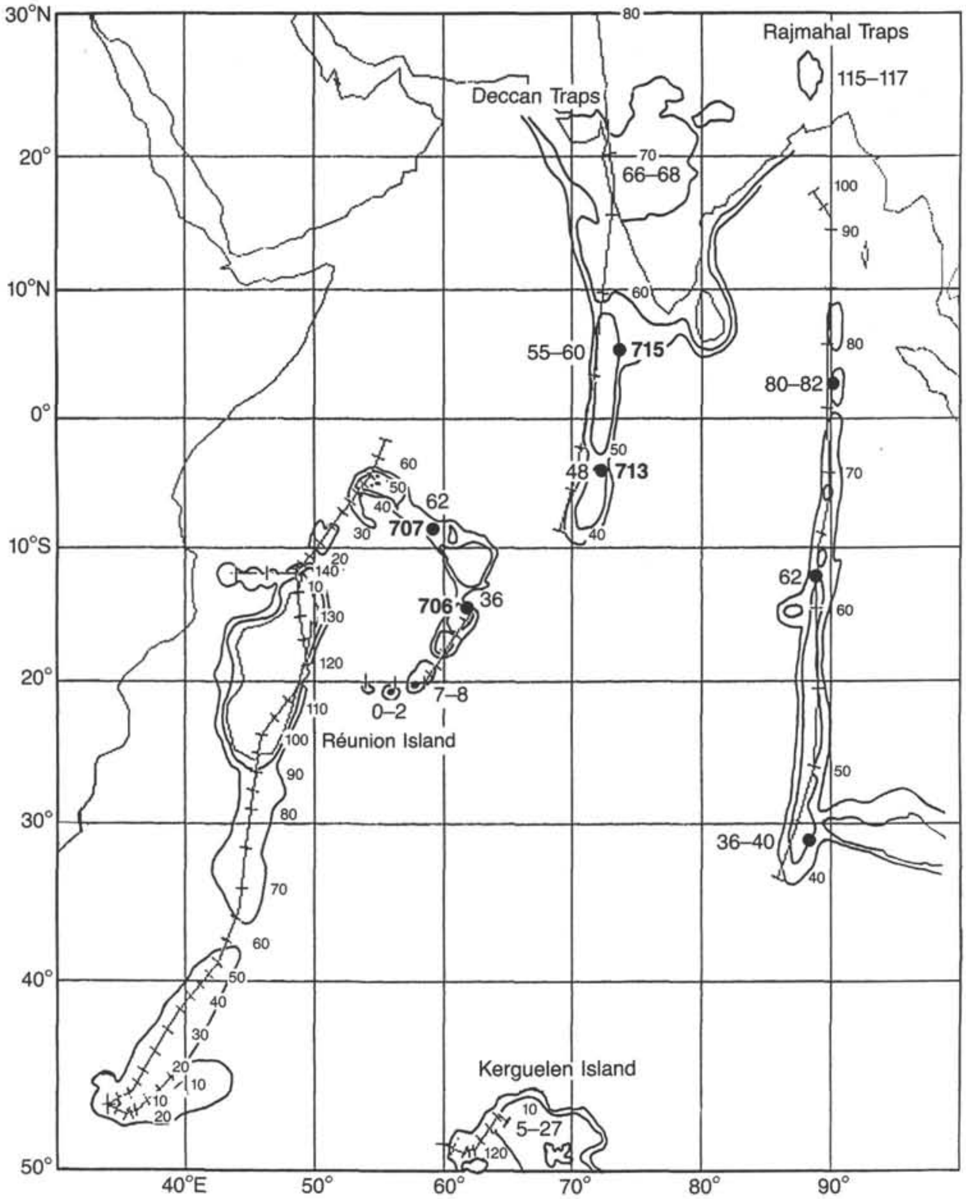

Figure 5. Computer-modeled hotspot tracks are calculated assuming hotspots are stationary. The predicted trails are determined from African plate motion over South Atlantic hotspots (O'Connor and Duncan, 1984) and relative motion between the Indian and African plates. These compare well with the actual lineaments and documented ages (Ma) of volcanic activity along the Réunion hotspot (McDougall, 1971; Courtillot et al., 1986) and Kerguelen hotspot (Watkins et al., 1974; Lameyre et al., 1976; Duncan, 1978) tracks. Numbers are ages in millions of years. Sites 706, 707, 713, and 715 shown.

both above and within present and past lysoclines and spanning present and past water-mass boundaries; and

4. location of the sites in an area with reasonably high sedimentation rates to ensure that high-resolution studies are possible (aiming for sample intervals <10 k.y.).

The seafloor topography east of the Seychelles–Saya de Malha platform in the tropical Indian Ocean provides a large depth range (>4000 m) within a small geographic area and thus fulfills these requirements. Leg 115 drilled five sites (Sites 707–711) in this region (Fig. 3) which will allow us to address a number of questions related to the evolution of the late Cenozoic carbonate system.

We would like to know, for example, how the carbonate system of the tropical Indian Ocean varied in response to changing climatic boundary conditions, changing glaciation levels, and changing deep-ocean circulation. Related questions include: How has surface productivity varied in response to climate and to the evolving physical geometry of the northern Indian Ocean? How do the sediments reflect the variation and interaction between surface production of biogenic carbonate and its dissolution at depth?

Differences in sediment accumulation rates along the recovered depth transect should be controlled mainly by the input of biogenic carbonate and its dissolution at depth. The input of biogenic silica and its dissolution at depth will, of course, also influence the sediment accumulation rates, although to a considerably lesser extent. A third factor which has to be accounted for is the deposition of inorganic materials (e.g., clay minerals).

When we consider that the supply of biogenic carbonate is dominant, and that the sum of all three components should be virtually identical over the entire study area at any given time, it

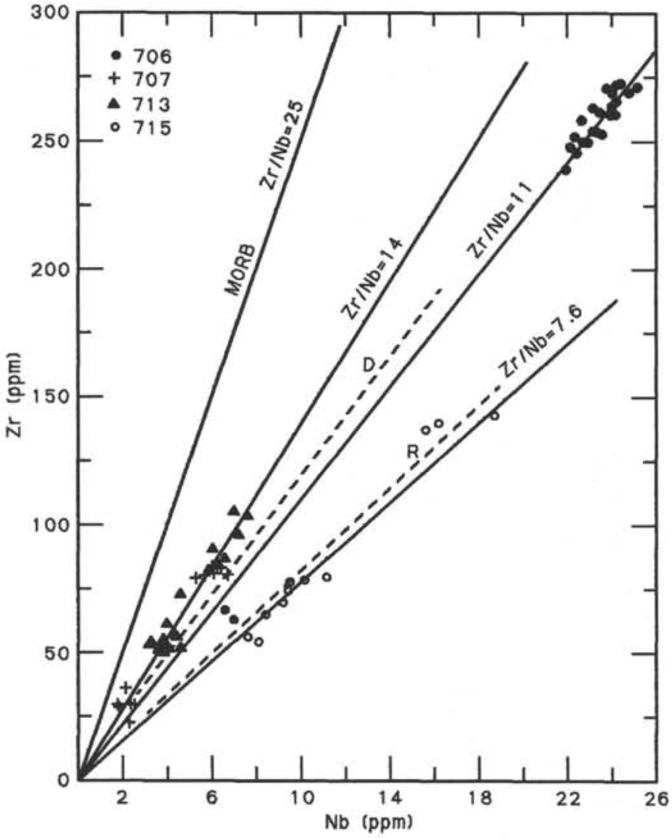

Figure 6. Variation diagram for Zr vs. Nb for Leg 115 basaltic rocks. The Zr/Nb ratio is an indicator of mantle-source composition. The basalts recovered from submarine sites along this hotspot track have compositions which fall between intraplate oceanic islands and spreading-ridge basalts. Shown for comparison are average values for basalts from Réunion (R; Fisk et al., 1988) and the Deccan Traps (D; Cox and Hawkesworth, 1985).

is the increasing carbonate dissolution with depth that will produce the major differences in sediment accumulation rates. The only other major factor creating differences in those rates is the effect of erosion and/or winnowing, as induced by the time-dependent intensity of near-bottom currents. Therefore, it is critically important to quantify the downslope-transport processes. Considerable post-cruise effort is planned to document the various processes which have affected the regional sediment budget in the late Cenozoic.

Aragonite Dissolution and Periplatform Sedimentation (Maldive Islands)

Drilling periplatform oozes in the Maldive Islands area will also treat the complementary aspect of carbonate dissolution. Periplatform sediments deposited exclusively within the vicinity of shallow carbonate banks are unique environments in which to study climatically induced fluctuations in carbonate saturation levels within intermediate-depth water masses. Besides calcitic nannoplankton and foraminifers, as well as aragonitic pteropods, the periplatform carbonate oozes contain large amounts of fine, needlelike aragonite and some magnesium calcite in the form of skeletal fragments and micrite, both of which are produced in shallow-water carbonate environments. Because of their special mineralogy (aragonite and magnesium calcite), bank-derived sediments are susceptible to more rapid and shallower dissolution than calcitic components like coccoliths and foraminifers.

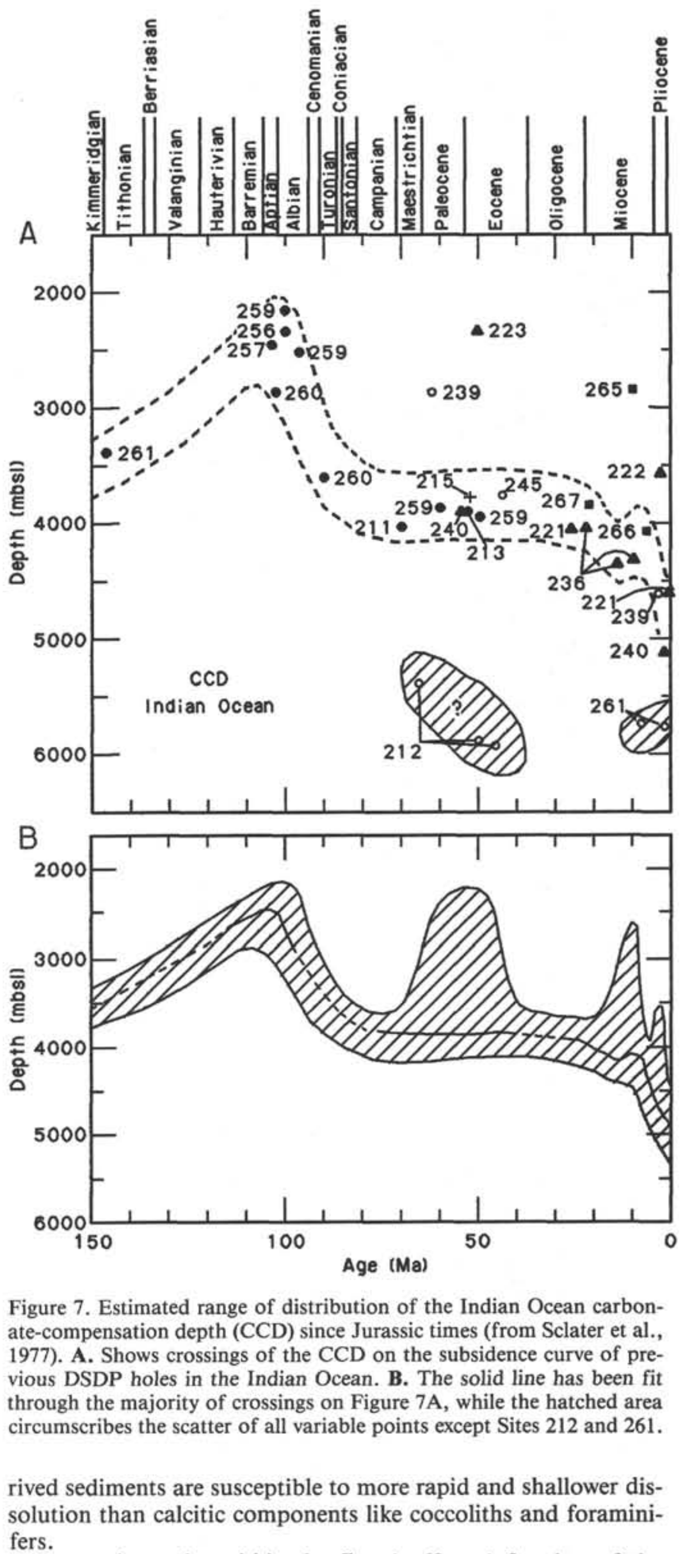

Figure 7. Estimated range of distribution of the Indian Ocean carbonate-compensation depth (CCD) since Jurassic times (from Sclater et al., 1977). **A.** Shows crossings of the CCD on the subsidence curve of previous DSDP holes in the Indian Ocean. **B.** The solid line has been fit through the majority of crossings on Figure 7A, while the hatched area circumscribes the scatter of all variable points except Sites 212 and 261.

Aragonite cycles within the fine (<62 μm) fraction of the Bahamian periplatform ooze 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-depth water masses.

The Neogene carbonate sections drilled at sites near the Maldive Islands will be studied to address the following major objectives:

1. to derive a detailed oxygen and carbon isotope stratigraphy for the Neogene and to test the integrity of correlations between aragonitic variation in the periplatform ooze and the Pleistocene oxygen isotope record,
2. to determine the interaction between sea-level fluctuations and carbonate off-bank transport and to test the highstand carbonate theory (high sedimentation rates and high turbidite deposition during interglacials) established in the Bahamas, and
3. to decipher the effects of diagenesis on metastable aragonite and magnesium calcite.

Evolution of Shallow- and Deep-Water Circulation in the Northwestern Indian Ocean

Because the Indian Ocean has a unique geometry (no northern ocean) and a strong monsoonal circulation in the tropical atmosphere and ocean, some of the water masses and circulation patterns are distinctly different from those in the Atlantic and the Pacific. We can trace the evolution of this system through the study of benthic faunas, which reflect deep-water circulation changes, and planktonic faunas and floras, which reflect surface-water changes. In addition, by studying gradients in $\delta^{18}O$ and $\delta^{13}C$ values, we can compare vertical and horizontal circulation patterns to other oceanic basin sites.

Leg 115 sediments will provide a basis for a study of the biotic, chemical, and sedimentologic responses to the physical evolution of the northern Indian Ocean and to the global evolution of climate. Moreover, Leg 115 is one of the few legs in the current phase of the Indian Ocean drilling by ODP that will recover Cenozoic sediments from the equatorial Indian Ocean. Not surprisingly, we will expend much effort on developing paleoceanographic records which reflect temporal changes in the near-surface and deep-water environment.

Stratigraphy

Accomplishing the paleoceanographic objectives put forward for Leg 115 will ultimately depend on the chronologic control that we can achieve. For example, meaningful models of how the sediment budget varies over time or as a function of bathymetry require that we determine the precise rate by which the different sediment components accumulate.

The collection of (late) Cenozoic APC material from the carbonate depth transect and Maldive Islands sites will make possible the development of a high-resolution biostratigraphy (based on calcareous and siliceous microfossils) for the low-latitude Indian Ocean. There is still room for much improvement regarding the precise sequencing of, or relative distance between, biostratigraphic species events, both within and between microfossil groups. Once we establish adequate magnetostratigraphic polarity records, we can then transform the biostratigraphic information, via direct correlation, into an accurate magnetobiochronology (see Plate 1, back pocket).

Although scientists have expended much effort to establish high-quality magnetostratigraphic records from deep-sea sediments, we still do not possess a single continuous Miocene record from a low-latitude environment. This lack of an adequate magnetobiochronologic record makes it difficult to assess the rates of many of the important processes which characterized the development of the Miocene deep-sea environment. Therefore, we will deal with this particularly conspicuous problem in our drilling program at the equatorial Indian Ocean sites. The recovery of a series of APC-cored sections from a relatively small area is ideal for this purpose because it should assure the recovery of the complete magnetobiostratigraphic section.

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