OCEAN DRILLING PROGRAM

LEG 117 PRELIMINARY REPORT

OMAN MARGIN/NEOGENE PACKAGE

Warren L. Prell
Co-Chief Scientist, Leg 117
Geology Department
Brown University
324 Brook Street
Providence, RI 02912

Nobuaki Niitsuma
Co-Chief Scientist, Leg 117
Institute of Geosciences
Shizuoka University
Oya, 422, Shizuoka
Japan

Kay-Christian Emeis
Staff Scientist, Leg 117
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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D I S C L A I M E R

SCIENTIFIC REPORT

The scientific party aboard JOIDES Resolution for Leg 117 of the Ocean Drilling Program consisted of:

Warren L. Prell, Co-Chief Scientist (Geology Department, Brown University, Providence, RI)
Nobuaki Niitsuma, Co-Chief Scientist (Institute of Geosciences, Shizuoka University, Shizuoka, Japan)
Kay-Christian Emeis, ODP Staff Scientist (Ocean Drilling Program, Texas A&M University, College Station, TX)
David Anderson (Geology Department, Brown University, Providence, RI)
Ross Barnes (Rosario Geoscience Associates, Anacortes, WA)
Roman A. Bilak (103-1001 14th Ave, SW, Calgary, Alberta, Canada)
Jan Bloemendal (Graduate School of Oceanography, University of Rhode Island, Narragansett, RI)
Cynthia J. Bray (Department of Geological Sciences, Cornell University, Ithaca, NY)
William H. Busch (Department of Geology and Geophysics, University of New Orleans, New Orleans, LA)
Steven C. Clemens (Geology Department, Brown University, Providence, RI)
Pierre Debrabant (Laboratoire de Dynamique Sedimentaire et Structurale, Universite de Lille - Flandres Artois, Villeneuve D'Ascq, France)
Peter de Menocal (Lamont-Doherty Geological Observatory, Palisades, NY)
H. Lo Ten Haven (Institute of Petroleum and Organic Geochemistry, KFA Juelich GmbH, Juelich, Federal Republic of Germany)
Akira Hayashida (Laboratory of Earth Science, Faculty of Engineering, Doshisha University, Kyoto, Japan)
J. Otto R. Hermelin (Department of Geology, University of Stockholm, Stockholm, Sweden)
Richard Jarrard (Lamont-Doherty Geological Observatory, Palisades, NY)
Ahmed Nasser Khalfan Al-Thobbah (Ministry of Petroleum and Minerals, Muscat, Sultanate of Oman)
Lawrence A. Krissek (Department of Geology, Ohio State University, Columbus, OH)
Dick Kroon (Geomarine Center, Vrije Universiteit, Amsterdam, the Netherlands)
David M. Murray (Geology Department, Brown University, Providence, RI)
Catherine Nigrini (510 Papyrus Drive, La Habra Heights, CA)
T. F. Pedersen (University of British Columbia, Vancouver, B. C., Canada)
Werner Ricken (Institut fuer Geologie und Palaeontologie, Universitaet Tuebingen, Tuebingen, Federal Republic of Germany)
Graham B. Shimmield (Grant Institute of Geology, University of Edinburgh, Edinburgh, Scotland, United Kingdom)
Stacia A. Spaulding (University of Nebraska, Lincoln, NE)
Zaher Khalid Sulaiman Al-Sulaiman (Ministry of Petroleum and Minerals, Muscat, Sultanate of Oman)
Toshiaki Takayama (Department of Geology, College of Liberal Arts, Kanazawa University, Kanazawa, Japan)
Graham P. Weedon (Department of Earth Sciences, University of Cambridge, Cambridge, United Kingdom)

INTRODUCTION

Leg 117 of the Ocean Drilling Program devoted 56 days (23 August - 18 October, 1987) to drilling at twelve sites in the northwest Arabian Sea (Figure 1). The immediate goal was to recover continuous and expanded sedimentary sections that were deposited since the Miocene under the influence of high biological productivity and high accumulation rates in one of the most fertile sectors of the world ocean - the area of monsoonal upwelling off Arabia.

As with all upwelling systems, the monsoon-driven upwelling of the western Arabian Sea is characterized by the advection of relatively cold, nutrient-rich water upward into the nutrient-depleted euphotic zone. The water ascends from depths of up to several hundred meters and supports very high rates of carbon fixation by photosynthesis. Sedimentary basins underlying these persistent upwelling cells often preserve records of the biologic and oceanographic conditions prevailing at the time of deposition in the form of biogenic and organic-rich sediments. Biogenic sedimentary components, especially microfossils and organic matter, can be used to decipher past changes in water temperature, nutrient composition, intensity of upwelling, and the duration of upwelling over time scales ranging to millions of years. Sedimentary sections under upwelling areas thus constitute prime targets for paleoceanographic and paleoclimatic research, and have frequently been targets of past scientific ocean drilling.

In contrast to other prominent upwelling systems, which often are located in eastern boundary currents (i.e., on western boundaries of continents) and are caused by large-scale and persistent atmospheric and oceanographic circulation, the upwelling system off Arabia lies within a western boundary current (i.e., off the eastern coast of Arabia) and has a strong seasonal variability. The seasonal nature of the upwelling in the Arabian Sea is driven by the large-scale atmospheric phenomenon of the southwest monsoon.

At present, the near-surface winds over the Arabian Sea typically change direction from southwesterly to northeasterly on a seasonal basis. During the winter, cooling over Asia develops a high-pressure cell that leads to a northeasterly wind flow from Asia over the Arabian Sea. During the summer months, this pattern is reversed because summer heating and ascending air masses create an intense low pressure cell centered around 30°N over the Tibetan Plateau (Figure 2). The pressure gradient between the low-pressure zone over Asia and a high-pressure zone over the southern Indian Ocean drives winds of considerable force in a generally southwest to northeast direction. Winds parallel to the coast of Somalia (Africa) and Arabia cause offshore flow of surface waters during the summer monsoon, and thus force deeper, nutrient-rich and cold water to well up along a broad stretch from the coast to Owen Ridge (Prell and Streeter, 1982). The wind speed and the duration of the southwest monsoon determine the strength and duration of the upwelling events, and sediments on the slope of the Arabian peninsula and on offshore ridges in turn accumulate the biogenic record of the upwelling. The climatic and erosional history of Asia and Africa during the Neogene may depend to a large extent on the strength and variations of the seasonal monsoon; these changes are potentially encoded in the sedimentary records and may be deciphered from sediments recovered during Leg 117.

General atmospheric circulation models (e.g., Hahn and Manabe, 1975) have shown that one driving force for the summer monsoon is closely linked to the altitude of the Himalayan-Tibetan Plateau. The simulations predict that monsoonal strength should have increased in response to Himalayan uplift. If these predictions are correct, then the long-term pattern (several m.y.) of Himalayan uplift should be manifested in a general increase in the amount and possibly in the character of sediment produced by monsoon-driven upwelling. To test this prediction independently, the uplift and erosional history of the Himalayas and their fluvial systems can be compared to the depositional histories of the Indus and the Ganges/Brahmaputra deep-sea fans. Such a comparison, however, assumes that the tectonically induced supply of sediment is one factor that determines the rate of deep-sea fan growth. ODP Leg 116 studied sedimentation on the Bengal Fan (J. R. Cochran, D.A.V. Stow, et al., in prep.; Leg 116 Initial Report). Leg 117 drilled a single site on the Indus Fan to test the coincidence of Himalayan uplift events and increased rates of deposition on the fan. Variations in the strength of the monsoon were to be identified and dated using sites on the Owen Ridge and the Oman margin.

Relatively short (<20 m) records of sedimentary conditions (and climatic change) had previously been established for the last 500 k.y. by conventional gravity cores and piston cores. The character of the biogenic and isotopic record from this time span varies with frequencies expected from the Milankovitch mechanism, i.e., periodicities of 400, 100, 41, 23, and 19 k.y. due to changes in Earth's orbit around the sun. Many changes in Earth's climate at these periods are thought to be driven largely by periodic variations in insolation. To prove unambiguously that insolation changes caused by orbital variations force changes in monsoonal intensity, longer high-resolution records of monsoon-related sedimentation were needed.

An ideal drilling target to meet the needs for continuous Neogene to Holocene sediment sections with high sedimentation rates was identified in the northwest Indian Ocean off Oman and on the Owen Ridge. Sedimentation rates range from 40 m/m.y. on the Owen Ridge to 200 m/m.y. on the Oman margin, and thus provide excellent temporal resolution. The sediments on the margin are deposited in rapidly subsiding slope basins at water depths of 200-1500 m that lie within a pronounced mid-water oxygen-minimum zone (OMZ). The depletion of dissolved oxygen in that sector of the seafloor where the OMZ impinges on the margin may favor preservation of sedimentary components and of primary sedimentary features by curbing bioturbation.

A further incentive for drilling off Oman is the presence of the Owen Ridge, a tectonic feature that parallels the Arabian coast approximately 320 km offshore. It constitutes an ideal drilling target for the recovery of undisturbed high-resolution pelagic sediment sections, because the ridge is elevated some 2000 m above the surrounding seafloor and thus has been well removed from any allochthonous sedimentary input from the margin. At the same time it is positioned at the distal end of the upwelling-related productivity zone. Sediments on the ridge accumulate at about 40 m/m.y. and provide long-term records of the influence of upwelling-driven production. The Owen Ridge sediments also provide the opportunity to identify spatial variations in the response of oceanographic processes to atmospheric and orbital forcing.

The specific problems to be addressed during ODP Leg 117, as stated in the pre-cruise planning phase, were the following:

- What is the history of Neogene monsoonal upwelling as recorded in sediments of the northern Indian Ocean? How did sedimentation under the centers of monsoonal upwelling vary in response to changing radiation budgets and to the Neogene tectonic evolution of Central Asia?

- How did monsoon intensity and glacio-eustatic sea level fluctuations affect the productivity and sedimentary facies of organic-rich biogenic and eolian sediments on the Arabian margin?

- What is the history of the oxygen-minimum zone variations on the Arabian continental margin, and to what extent did it control diagenesis in suboxic and anoxic sediments deposited in the depth zone where it impinges on the margin?

- What indicators of past variations in deep circulation can be extracted from the sediments on the Oman margin, and can they be applied to trace influences from marginal basins such as the Red Sea and the Persian Gulf?

- What is the tectonic history of the Owen Ridge, and what is the origin and nature of basement on the Oman margin?

- How does the Indus Fan record the uplift of the Tibet-Himalayan complex and changes in continental erosion rates or eustatic sea level?

In order to address these questions, three operational areas were identified in the northwest Indian Ocean and drilled during Leg 117 (Figure 1 and Table 1). The areas differ in their prevalent depositional environment and can be grouped into the three operational areas, treated here as the "Ridge Sites" (Sites 721, 722, and 731), the "Margin Sites" (Sites 723 through 730), and the solitary "Fan Site" (Site 720). After a chronological account of the main drilling results and findings for each site, the results of shipboard work will be discussed in the regional contexts of the three study areas.

DRILLING RESULTS

Note: Water-depth measurements cited in this part of the Preliminary Report are based on sonic measurements ("PDR depths"), and differ from the drill-pipe measurements used in the Operations part of this Preliminary Report.

Fan Site 720: 16°07.796'N, 60°44.621'E. Water depth 4037.5 m

Site 720 is located approximately 360 km south-southwest of DSDP Site 222 (Figure 1). The site lies on the western edge of the Indus Fan, near the boundary between the middle and the lower fan. Sediment thickness at Site 720 is greater than 2000 m, and the basement here is thought to occur in magnetic anomaly 25 (chron C25), which indicates a Paleocene age of about 60 Ma. The site is about 5 km east of a meandering channel that is approximately 1.5 km wide, 50 m deep, and has a levee elevation of about 30 m above the surrounding seafloor. The location of Site 720 was selected to avoid channel deposits, thereby maximizing the opportunity to collect a relatively continuous depositional record that can be related to Himalayan uplift and sea level changes. The principal objectives of Site 720 were (1) to recover a continuous upper Neogene section of fine-grained overbank deposits from the mid-fan region of the western Indus Fan; (2) to identify the depositional facies, their compositions, and their accumulation rates for comparison to other Indus Fan (DSDP Leg 23; Whitmarsh, Weser, Ross et al., 1974) and Bengal Fan (ODP Leg 116) sites; and (3) to interpret the depositional history of the Indus Fan sediments in terms of uplift of the source region (the Himalayas), changes in sea level, and changes in climate, oceanographic circulation, and weathering processes.

One advanced hydraulic piston core (APC)/extended core barrel (XCB) hole was drilled at this site. Hole 720A consists of three APC cores that penetrated to 28.6 mbsf with a recovery of 28.4 m (99%) and 40 XCB cores that penetrated from 28.6 mbsf to 414.3 mbsf with a recovery of 60.9 m (16%). The hole was terminated due to poor recovery and the section was logged successfully with the DIT/LSS/GR combination until the logging tool was lost.

The stratigraphic section recovered at Site 720 is Pleistocene in age and has been divided into two major lithologic units (Figure 3). Unit I (0.0-17.22 mbsf) is composed of nannofossil ooze and foraminifer-bearing nannofossil ooze that is characteristic of pelagic deposition. Unit II (17.22-414.3 mbsf) is composed of a wide range of lithologies, including interbedded silty clay, silt, silty sand, sand, and scattered nannofossil ooze; this unit is characteristic of turbiditic deposition. Within Unit II, three facies are identified that represent intervals characterized by (1) high abundance of pelagic (nannofossil) components, (2) fining-upward clastic sequences with a wide variety of bed thicknesses (<2 cm to >50 cm), and (3) fining-upward clastic sequences with coarse-grained bases >5 cm thick. The fan sediments contain relatively high concentrations (averaging approximately 0.4%) of organic carbon that is derived mostly from terrestrial sources. They are characterized also by complete sulfate reduction below 50 mbsf, which is largely a function of rapid sedimentation. Traces of dolomite occur throughout the sequence and are thought to reflect both detrital sources and precipitation in situ.

Biostratigraphic and magnetostratigraphic data from the pelagic intervals indicate sedimentation rates of about 500 m/m.y. for the Pleistocene turbidite sequence and about 30 m/m.y. for the pelagic intervals. The transition from predominantly turbiditic to pelagic deposition is estimated to have occured at approximately 0.6 Ma. During the Pleistocene, the rates of turbidite deposition appear to be generally related to changes in sea level, with higher rates observed during or shortly after low sea level stands. However, the pelagic section of lithologic Unit I does not contain turbidites deposited during low stands of sea level known to have occurred during that interval. The temporary lack of terrigenous influx to the site is probably related to distributary channel switching away from the site, rather than to a general decrease in turbidite deposition on the Indus Fan. The very high rates of Pleistocene turbidite deposition (more than twice the rates found by ODP Leg 116 on the distal Ganges Fan) are consistent with rapid uplift and erosion in the Indus source area, but the lack of a longer record prevents any observations concerning longer term relations between the rates of uplift and sedimentation on the Indus Fan at Site 720.

Ridge Sites

Site 721: 16°40.636'N, 59°51.879'E. Water depth 1944.8 m

Site 721 is located on the Owen Ridge in the western Arabian Sea (Figure 1). The Owen Ridge is an asymmetric, northeast-southwest-trending ridge that dips steeply to the east and gently to the west.

The main scientific objective for drilling Site 721 and closely related Site 722 on the Owen Ridge was to recover a continuous upper Neogene section of pelagic sediments from the crest of the Owen Ridge. These sediments were expected to yield records of long-term (10^5 to 10^6 yr) and short-term (10^4 to 10^5 yr; i.e., corresponding to Milankovitch frequencies) variations in the biotic, sedimentologic, and chemical responses of the depositional system to changes in monsoonal circulation.

The biotic and geologic records, which are essentially high-resolution time series, will be used to test hypotheses of orbital forcing (by changes in solar radiation) and orographic forcing (by uplift of mountains) of monsoon intensity through Neogene time by examining sediments deposited under the upwelling regime. Once the age and depositional environment of the sediments have been established, the records will also be used to reconstruct the carbonate budget and uplift history of the Owen Ridge.

Site 721 consisted of three holes. Hole 721A drilled 9 APC cores that penetrated to 86.4 mbsf with 89.3 m recovery (103%). Hole 721B was drilled to a total depth of 424.2 mbsf with 9 APC and 35 XCB cores and an average recovery of 80%. Hole 721C penetrated to 138 mbsf with 9 APC and 5 XCB cores; recovery was excellent (96%).

The section penetrated at Site 721 ranges from early Miocene to Holocene in age and has been divided into four major lithologic units (Figure 4). Unit I (0.0-261.6 mbsf) consists exclusively of alternating light and dark layers of foraminifer-bearing nannofossil ooze to foraminifer-nannofossil ooze and nannofossil ooze of late Pleistocene to mid-late Miocene age. Radiolarian and foraminiferal assemblages indicative of upwelling predominate in this interval. The sediments of this unit record cyclic changes in color, bulk density, carbonate content, and especially magnetic susceptibility. Preliminary analysis of over 20,000 magnetic susceptibility measurements from all three holes revealed cycles approximately 1 m in length. According to a preliminary age-depth model, this corresponds to a periodicity of approximately 25 k.y. This cyclicity is likely to reflect both changes in oceanic productivity and/or preservation, and changes in the input of eolian material.

Lithologic Unit II (261.6-311.4 mbsf) is composed of upper Miocene foraminifer-nannofossil chalk and ooze (Subunit IIa) that grades downsection to siliceous nannofossil chalk and ooze (Subunit IIb) of middle Miocene age. In contrast to the Pliocene-Pleistocene section of Unit I, biogenic opal is an abundant component, and both diatoms and radiolarians are preserved in the sediments. Microfossil assemblages generally are characterized by the lack of typical tropical species and the dominance of cool-water assemblages. Sedimentation rates are about 50 m/m.y. through much of lithologic Unit II, but decrease to approximately 20 m/m.y. in the uppermost part of the upper Miocene. The data clearly indicate that the monsoonal upwelling system was active in the late Miocene. Due to the uncertain and truncated occurrence of middle Miocene strata at Site 721, the onset of monsoon upwelling as early as middle Miocene cannot be proven.

Nannofossil chalk of early Miocene age makes up lithologic Unit III (311.4-340.7 mbsf). Silica preservation is poor in the carbonate-rich chalks (80-90% $CaCO_3$). A hiatus (from nannofossil zone NN9 to NN5) was recognized at about 311.4 mbsf, and separates Unit II from Unit III.

The basal lithologic Unit IV (340.7-424.2 mbsf) is characterized by turbiditic sequences that contrast with the dominantly pelagic facies of the overlying units. Basal calcareous silty clay and clayey siltstone of early Miocene age grades into clay-bearing nannofossil chalk. Preservation of planktonic calcareous and opaline tests is poor, and benthic foraminifers from upper and middle bathyal depths are absent. The upsection increase in pelagic sediment is related to the uplift of the Owen Ridge with coarse-grained lower Miocene turbidite sequences deposited prior to uplift. During the uplifting phase, increasingly finer grained turbidites were deposited at the site; these are interbedded with pelagic carbonates. The source of the fine mud turbidites is unknown.

Site 722: 16°37.312'N, 59°47.755'E. Water depth 2027.8 m

The two holes drilled at Site 722 had the same objectives as those at Site 721; because of the proximity of the two sites (8 km distance) and similar seismic structures, the sedimentary sequences are comparable but more complete here than at Site 721.

Site 722 consisted of two holes. Hole 722A recovered 9 APC cores that penetrated to 86.5 mbsf with 88.6 m recovery (102%) and 20 XCB cores that penetrated an additional 193.3 m with a recovery of 137.4 m (71%). Total depth and percentage of recovery for Hole 722A were 280.0 mbsf and 80%. Hole 722B was drilled to a total depth of 565.6 mbsf with 10 APC and 49 XCB cores that had an average recovery of 68% (APC had 103% and XCB had 61%).

The section penetrated at Site 722 ranges from early Miocene to late Pleistocene in age and has been divided into four major lithologic units (Figure 5):

Unit I (0.0-221 mbsf) consists exclusively of alternating light and dark layers of foraminifer-bearing nannofossil ooze to foraminifer-nannofossil ooze, and nannofossil ooze of late Pleistocene to late Miocene age. Radiolarian and foraminiferal assemblages indicative of upwelling occur throughout this interval. The sediments of this unit (like those of Site 721) reveal strong cyclic changes in color, bulk density, carbonate content, and particularly well in magnetic susceptibility. Preliminary analysis of magnetic susceptibility data shows that correlations can be made both between holes (at Site 722) and between sites (722 and 721) with a precision approaching 10 cm. The magnetic susceptibility data exhibit a complex variability composed of periodicities (estimated by power spectra analysis) that include the principal Milankovitch frequencies. Preliminary XRD and chemical analyses show that high susceptibility values are correlated with increased quartz and dolomite abundances, low total carbonate content, and darker sediment color. This association of characteristics appears to indicate that changes in the input of eolian material cause the variations in susceptibility. Sedimentation rates in lithologic Unit I range from 20 m/m.y. to about 45 m/m.y. and are lowest in the uppermost part of the upper Miocene and the lower Pliocene (similar to Site 721). As at Site 721, these data clearly indicate that the monsoonal upwelling system has been active since the late Miocene.

Lithologic Unit II (221.0-343.4 mbsf) is composed of foraminifer-bearing, radiolarian-bearing, diatomaceous, and diatomaceous-marly nannofossil chalk of latest middle Miocene and late Miocene age. Biogenic opal is an abundant component, and its abundance is the major difference between lithologic Units I and II. The physical properties of this interval show low density and high porosity because of the admixture of siliceous microfossils. Possible dewatering structures were noted near the base of lithologic Unit II. The sediments at Site 722 encompass sediments of late Miocene age that were lost by slumping at Site 721.

Lithologic Unit III (343.4-411.1 mbsf) is composed primarily of white nannofossil chalk of middle Miocene age. Silica preservation is poor in the carbonate-rich chalks but increases rapidly, along with upwelling faunas of planktonic foraminifers, in the uppermost part of the middle Miocene. The middle Miocene interval missing at Site 721 (from calcareous nannofossil zone NN9 to NN5) is present at Site 722. Thus, the onset of silica preservation and upwelling faunas is recorded in the uppermost middle Miocene sediments at Site 722.

Lithologic Unit IV (411.1-565.1 mbsf) is early and middle Miocene in age. It is characterized by turbidites of silty clay that grade upward to nannofossil chalk on the scale of decimeter-thick beds, and that grade downsection to silty clay beds with coarse bases and disseminated charcoal and pyrite. Preservation of planktonic calcareous and opaline tests is poor, and benthic foraminifers are sparse in Unit IV. The trend from turbiditic to increasingly pelagic deposition is related to the uplift of the Owen Ridge.

Site 722 provides an excellent record of the onset and evolution of monsoonal upwelling from the late middle Miocene to the Pleistocene. This sequence should provide insights into the influences of orbital changes and the uplift of the Himalayas on monsoon-related upwelling and eolian sedimentation on the Owen Ridge.

Margin Sites

A series of eight sites (723-730) is located in the northwest Arabian Sea on the continental margin off Oman. The water depths range from 300 to 1500 m, thereby including the complete vertical extent of a pronounced mid-water oxygen-minimum zone. The sites were located so as to recover sediments from slope basins formed by narrow half-grabens in what is presumed to be ophiolitic basement, similar to that exposed on the island of Masirah (Moseley and Abbot, 1979).

Two of the sites (726 and 729) were targeted to drill pre-Neogene sediments and basement rocks on the horst structures, presumably formed by basement ridges, that subdivide the margin into horsts and grabens. Eolian components and biogenic material produced in association with coastal upwelling are deposited in the slope basins at high rates (40-200 m/m.y.). The sediments were expected to record changes in sedimentation and oceanographic/atmospheric circulation in considerable detail because of impeded benthic activity where the OMZ intersects the slope. The objective of drilling in the basins was to sample these continuous and expanded sections of upper Miocene to Holocene sediments.

Site 723: $18^{\circ}03.079'$N, $57^{\circ}86.561'$E. Water depth 807.8 m

Three holes were drilled at Site 723. Hole 723A reached a total depth of 432.3 mbsf, and Hole 723B was drilled to a total depth of 429.0 mbsf; recovery averaged 68% and 73%, respectively. In both holes, nine APC cores from the uppermost sequence yielded 104% recovery because of severe gas expansion that adversely affected core integrity in both APC and XCB mode. Hole 723B was successfully logged through the bit with the lockable flapper valve, and three logging tool combinations obtained excellent results. Eight APC cores to a total depth of 76.8 mbsf were recovered from Hole 723C.

The section penetrated at Site 723 ranges from latest Pliocene (calcareous nannofossil zone NN18 and the lower part of zone NN19) to Pleistocene and possibly Holocene (calcareous nannofossil zone NN21). Age control was provided mainly by calcareous nannoplankton and paleomagnetic horizons. Only one lithologic unit was recognized at Site 723 (Figure 6).

The lithologic unit comprises three interbedded sedimentary facies. Facies 1, which forms more than 99% of the section at Site 723, is green to olive green foraminifer-bearing marly nannofossil ooze and calcareous clayey silt. Calcium carbonate and organic carbon contents of this facies vary between 40%-70% and 1%-7%, respectively. Faunal and floral indicator species show that monsoonal upwelling was persistent, but variable, throughout the time of deposition. The sedimentation rate is consistently high (approximately 200 m/m.y.) and the section appears to be continuous. Both magnetic susceptibility and downhole logs show cyclic variability that may reflect climate-related changes in upwelling and eolian input to the depositional system.

Facies 2 consists of cemented dolomite beds and stringers that contain foraminifer molds and tests, well-preserved trace fossils, and primary laminations. Dolomites were recovered from five intervals below 260 mbsf, in beds that range from 30 cm to 1 cm thickness; some are laminated. Colors vary from pale green to olive green. Additional dolomite layers were not recovered by coring but were recognized from downhole logs.

Facies 3 is a laminated facies and rarely occurs in beds exceeding a few centimeters in thickness. The parallel laminae that form these beds are 0.1-1 mm thick. Light-colored laminae are accumulations of nannofossils or diatoms, while dark-colored layers are organic-rich clayey silt. The monospecific assemblages of nannofossils and diatoms in the light laminae suggest that they were deposited during blooms of relatively short duration (<1 year), and that bioturbation was inhibited. Facies 3 occurs in close association with facies 2.

Chemical compositions of interstitial waters and gas at Site 723 support the interpretation that diagenetic cementation of dolomites is related to an unusual subsurface hydrological regime in the slope basin. Alkalinity reached a maximum of >100 mmol/L, causing severe core expansion, while chlorinity decreased by 30 mmol/L. The unusually high and persistent increase in alkalinity and the dolomite precipitation below 260 mbsf are both caused by a concomitant increase in sulfate below the zone of sulfate depletion. Profiles of increased sulfate, decreased chloride, and, to some extent, increased calcium at total depth are attributed to advective flow of relatively fresh water that has incorporated dissolved gypsum and/or anhydrite from an evaporitic source.

Site 724: 18°27.713'N, 57°47.147'E. Water depth 592.8 m

Site 724 is located on the seaward flank of the slope basin drilled at Site 723. Eolian components and biogenic material produced by coastal upwelling are deposited here at lower rates than in the southern part of the basin. Like the sediments recovered from the center of the OMZ at Site 723, the sediments here were expected to record changes in sedimentation and oceanographic/atmospheric circulation in considerable detail because of impeded benthic activity. The objective of Site 724 was to identify temporal fluctuations in the OMZ in addition to sampling another section of upper Neogene to Holocene sediments influenced by coastal upwelling.

Three holes were drilled at Site 724. Hole 724A consisted of five APC cores averaging 100.7% recovery to a total depth of 44.5 mbsf. Holes 724B and 724C drilled to total depths of 257.7 and 252.4 mbsf, respectively, in APC and XCB modes, with recoveries of 82% and 96%. Gas expansion again affected core quality adversely.

The section penetrated at Site 724 ranges from latest early Pliocene to Holocene in age, and only one lithologic unit was recognized (Figure 7). The unit comprises green to olive green calcareous clayey silt high in organic carbon. Interbedded in the section below Core 117-724B-18X are decimeter-scale beds of laminated diatomaceous clayey silt which are correlatable to similar beds previously recognized at Site 723. Faunal and floral indicator species show that monsoonal upwelling was persistent throughout the time of deposition. Pronounced spikes of cold-water nannoplankton and of radiolarians occur in the uppermost Pliocene. Distinctly greater dissolution of planktonic foraminifers was recognized in the laminated intervals. The sedimentation rate is 80 m/m.y. and the section appears to have been continuously deposited. Both magnetic susceptibility and downhole logs show cyclic variability that may reflect climate-related changes in the depositional system dominated by upwelling and eolian input.

Chemical compositions of interstitial waters and gas do show the unexpected subsurface source of sulfate inferred at Site 723, but diagenetic effects of organic matter degradation by sulfate reduction are much less obvious at Site 724. No diagenetic dolomite was encountered, and gas pockets contained mainly methane. Increased amounts of propane suggest thermogenic origin of part of the gas.

Site 725: 18°29.200'N, 57°42.030'E. Water depth 311.5 m

Site 725 is located on the landward flank of the slope basin that had been drilled previously at Sites 723 and 724. Biogenic material produced by coastal upwelling, eolian components, and clastic material from the neighboring wide shelf are deposited here at lower rates than in the center of the basin. The intention of drilling Site 725 was to trace the fluctuations in the upper boundary of the OMZ through time and to evaluate these fluctuations with regard to changes in the monsoon and in eustatic sea level.

Three holes were drilled at Site 725. Hole 725A consisted of only one APC core of 4.5 m length. Hole 725B was drilled in XCB mode to Core 117-725B-10X (0.0-93.8 mbsf) and was abandoned because of low recovery (11%). Hole 725C cored three APC cores and 14 XCB cores to a total depth of 162.8 mbsf with an average recovery of 60%.

The section penetrated at Site 725 ranges in age from Pleistocene to Holocene and has been subdivided into three lithologic units (Figure 8). Unit I comprises foraminifer-rich calcitic sandy silt to calcitic marly calcareous ooze, calcitic marly nannofossil ooze, and nannofossil-rich sand, silt, or clay. It is considered to be a hemipelagic facies dominated by input of detrital calcite and biogenic sediments from coastal upwelling. Organic carbon content is relatively low (<2%).

Unit II is composed of diatomaceous clayey silt and diatomaceous mud intercalated with calcitic marly nannofossil ooze and calcitic sand, silt, and clay. Diatom-rich beds form laminae on a sub-centimeter scale and are dominated by frustules of two diatom species. The unit is believed to indicate suboxic depositional conditions. Organic carbon content increases steadily toward the bottom of the hole and averages 2% in Unit II.

Unit III is similar to Unit I and is composed of nannofossil-rich calcitic sand, silt, and clay and calcitic marly nannofossil ooze. All units were found to contain <2% authigenic dolomite and traces of apatite and fish scales. The organic carbon content of Unit III averages 3%. The sedimentation rate of the section recovered at Site 725 is constant at about 120 m/m.y.

As at previously drilled sites on the margin, pronounced spikes of cold-water nannoplankton and of radiolarians occur in the sediments at Site 725. In contrast to the other sites, these occurrences are confined to the calcareous nannofossil zone NN19 (Pleistocene). They do, however, appear to coincide with the laminated sediments of lithologic Unit II.

Chemical compositions of interstitial waters and gas do not show the subsurface source of sulfate inferred at Sites 723 and 724, and diagenetic reactions are less obvious in the relatively organic-lean sediments at this site. Even though dolomite was encountered in trace amounts throughout the cores, the extent of dolomitization was low. Gas pockets contained mainly methane but showed increasing (up to 270 uL/L) ethane and propane concentrations at the base of the cored section. This is believed to be an indication of thermal hydrocarbon generation at depth.

<u>Site 726</u>: 17°48.945'N, 57°22.200'E. Water depth 331.5 m

Site 726 is located in the northwest Arabian Sea and was the third shallow drilling target (with Sites 724 and 725) of a depth transect of sites across the Oman continental margin. Site 726 is located on what was assumed to be a pre-Neogene basement high. This location is landward of a slope basin similar to that previously drilled at Sites 723, 724, and 725. The main objective at Site 726 was to identify the nature and age of lithologies that underlie the hemipelagic sediments deposited on the margin since at least the middle Miocene. Further objectives of drilling at Site 726 were to trace fluctuations in the upper boundary of the OMZ since the Pliocene and to provide a nearshore record of changes in circulation, biogenic productivity, and eustatic sea level, for comparison with deeper margin records.

One hole was drilled at Site 726 to a total depth of 186.3 mbsf. Recovery from six APC cores was 103% (Cores 117-726A-1H to 117-726A-6H, 0.0-54.1 mbsf), while recovery from 117-726A-7X to 117-726A-22X was 40.7% in dolomitized shallow-water limestones.

The section has been divided into two lithologic units, separated by a pronounced hiatus spanning the time from the Eocene to the late Miocene; the units differ considerably in lithologic character (Figure 9).

Unit I (0.0-131.1 mbsf) is subdivided into two subunits. Subunit Ia comprises sediments similar to those found at other sites, i.e., phosphorite-bearing nannofossil-rich calcitic silty clay to clayey silt typical of the deposits underlying highly productive upwelling cells. The sedimentation rate for Subunit Ia (calcareous nannofossil zones NN21 to NN19) was established as 40 m/m.y. Subunit Ib is similar to Subunit Ia, but lag deposits of sand-sized foraminifers, phosphatic grains, and fish teeth and bones are commonly intercalated in the hemipelagic sequence. The sandy layers are interpreted as indicators of current winnowing. The frequency of the lag deposits decreases upsection, which may indicate a progressive deepening of the site toward the present. In agreement with the expected effects of the recurrent winnowing, the section is compressed in Subunit Ia and ranges from calcareous nannofossil zones NN19 to NN10; the average sedimentation rate of Subunit Ib is 10 m/m.y.

Lithologic Unit II was only sparsely recovered from 131.1 mbsf to total depth, and consisted of nummulite and oncolite limestone of Eocene(?) age with variable dolomite and calcite cementation. These shallow-water sediments appear to correspond to limestone occurrences described from the Arabian peninsula and the island of Masirah, where similar deposits overlie ophiolitic basement. The base of the recovered section may be slightly silicified.

Paleontological investigation revealed two major hiatuses at Site 726. The first separates lower upper Pliocene from Pleistocene hemipelagic sediments, while the second separates Eocene limestones from upper Miocene transgressive biogenic and eolian upwelling deposits.

The first hiatus, which represents tha late Pliocene and the Pleistocene, truncates an interval where the presence of radiolarians and diatoms indicates influences of either colder water or water of different nutrient composition at Site 726. The faunal/floral change appears to be coeval with similar occurrences at Sites 723 and 724, which were expanded and in deeper water. Sediments containing cold-water calcareous nannofossils predate the occurrence of opaline plankton and are confined to the Pliocene and upper Miocene sequence.

Poor sediment recovery in the variably indurated limestone and dolostone of Unit II precluded continuous interstitial-water sampling and impeded sampling for interstitial gas.

Site 727: 17°46.096'N, 57°35.216'E. Water depth 914.8 m

The positions of Sites 723 and 727 correspond to the central depth of the pronounced oxygen-minimum zone that impinges on the Oman continental margin beneath its zone of high biogenic productivity. Site 727 was located in the southern part of a slope basin formed by a narrow half-graben in rock assumed to be ophiolitic basement. Eolian components and biogenic material produced by coastal upwelling are deposited here at high rates (100 m/m.y.). The objectives at Site 727 were to obtain a record complementing the continuous and expanded sections of upper Neogene to Holocene sediments previously recovered at Site 723, to trace the imprint of the OMZ through time, and to investigate diagenetic sedimentary processes.

Two holes were drilled at Site 727. Hole 727A reached a total depth of 182.4 mbsf and Hole 727B was drilled to a total depth of 27.1 mbsf; recovery averaged 102% and 103%, respectively. Hole 727B was drilled to ensure that a continuous record of the Pleistocene and Holocene was recovered.

The section penetrated at Site 727 ranges from latest Pliocene to Holocene in age. Age control was provided mainly by calcareous nannoplankton and paleomagnetic horizons. Only one lithologic unit was recognized at Site 727 (Figure 10).

The lithologic unit comprises homogeneous green to olive green foraminifer-bearing marly nannofossil ooze and calcareous clayey silt. Calcium carbonate and organic carbon contents of this facies vary from 40% to 70% and 1% to 7%, respectively. Faunal and floral indicator species show that monsoonal upwelling was persistent throughout the time of deposition, although variability of water temperature and nutrient composition may have modified the assemblages. The sedimentation rate is consistently lower than at Site 723 (approximately 100 m/m.y. vs. 200 m/m.y.), but the section from Site 727 appears to have been continuously deposited. Magnetic susceptibility measurements show downhole variability that may reflect climate-related changes in upwelling and eolian input to the depositional system.

Faunal assemblages are characterized by the highest abundances of benthic foraminifers observed at any of the sites drilled during Leg 117. Nannofloral assemblages are dominated by cold-water species around the Pliocene/Pleistocene boundary. The calcareous nannoplankton assemblage has low diversity, and radiolarians and diatoms were not found.

Chemical compositions of interstitial waters and gas show some indication of sub-bottom supply of sulfate, but diagenetic remineralization appears to be dominated by fermentation reactions and methanogenesis. As noted at previous sites on the margin, Site 727 showed a strong increase in ethane and propane with depth.

Site 728: 17°40.790'N, 59°49.553'E. Water depth 1427.8 m

The position of Site 728 corresponds to the depth where the lower, ill-defined part of the pronounced mid-water OMZ intersects the Oman continental margin. The first objective at Site 728 was to recover a sedimentary section deposited near the lower boundary of the OMZ. The second objective of drilling at Site 728, in conjunction with drilling at Sites 726, 727, and 729, was to investigate the tectonic history of adjacent ophiolite blocks by coring the sediments in the two half-graben basins between three of these blocks. The third objective was to provide a record complementary to the continuous and expanded sections of upper Neogene to Holocene sediments recovered previously at other sites on the Oman margin.

Two holes were drilled at Site 728, and Hole 728A was successfully logged with two tool combinations. Hole 728A was drilled to total depth of 346.8 mbsf, with an unprecedented recovery of 99% from 36 cores (9 APC and 27 XCB cores). The hole was successfully logged through the lockable flapper valve with the DIT/BHC/GR/CAL combination from 80 mbsf to total depth during the first run, and with the GST/CNT/NGT combination in the second run. After logging Hole 728A, Hole 728B was spudded and cored to 347.7 mbsf with an overall recovery rate of 100%.

One lithologic unit was recognized in the section cored at Site 728, and encompasses sediment deposited since the late Miocene (Figure 11). Lithologic Unit I was subdivided into three subunits. Subunit Ia (0-10 mbsf) is composed of Holocene to upper Pleistocene foraminifer ooze to marly calcareous ooze, with common bivalve and gastropod debris. Subunit Ib (10-320 mbsf) is of late Pleistocene to latest Miocene age, and consists of marly nannofossil ooze that grades into chalk at about 200 mbsf. Siliceous microfossils are preserved but comprise <10% of the sedimentary components. Subunit Ic (320-347.7 mbsf total depth) is composed of nannofossil chalk and marly nannofossil chalk, which are interbedded with diatomaceous nannofossil chalk of distinctly different color. The age of this subunit is late Miocene.

An important finding at Site 728 is siliceous microfossils throughout much of the recovered section. Radiolarians are common from Core 117-728A-9H (85.7 mbsf) to total depth, and diatoms are present also. Nannofossil floras have low diversity but are well preserved. *Coccolithus pelagicus*, a cold-water nannofossil, is present in unusually high numbers from 48.6 to 58.1 mbsf (lowest Pleistocene). Benthic foraminifers are abundant to approximately 170 mbsf, and the ratio of planktonic to benthic foraminifers is very high in this interval. The ratio decreases from about 100% to <10% below 170 mbsf. This change suggests that Site 728 was located in <350 m water depth during the late Miocene and the early Pliocene and quickly subsided to the present water depth of 1428 m.

A zone of high organic carbon concentrations was recognized at 80-110 mbsf. This zone coincides with maxima in alkalinity and uranium concentrations from logs, as well as with the depletion of interstitial sulfate and a minimum in dissolved calcium concentration. All of these variations are explainable as a result of the increased organic carbon and its diagenesis.

Site 729: 17°38.715'N, 57°57.221'E. Water depth 1398.8 m

Site 729 is located at a water depth of 1400 m on the Oman margin. Site 729 differs from the other seven sites drilled on the Arabian margin in that it is located on a basement block of presumed ophiolitic origin. Adjacent ridges of ophiolite blocks confine a series of slope basins at various depths on the section of the margin investigated, and Neogene sections in these basins have been a prime target of drilling during Leg 117. The primary objective at Site 729 was to recover the oldest sediments on one of the blocks and to correlate them with acoustically similar rocks overlying other horst structures. A second objective was to penetrate to the underlying basement and to verify the nature and possibly the age of underlying obducted oceanic crust.

One hole was drilled by rotary coring at Site 729. After initially good recovery in Pleistocene sediments to 26.3 mbsf, only fragments of Miocene(?) shallow-water limestone were recovered in 9 successive cores. Because hole conditions deteriorated rapidly, it was decided to abandon Hole 729A at a depth of 109.1 mbsf and turn to more promising drilling targets.

The sediments recovered at Site 729 were subdivided into two lithologic units (Figure 12). Unit I (0.0-26.3 mbsf) consists of marly foraminifer nannofossil ooze of Pleistocene age. Unit II, which was sparsely recovered from 26.3 to 109.1 mbsf, is believed to be composed of oncolith-bearing nummulitic shallow-water limestones of Miocene(?) age; the limestones are uncemented and brittle. Failure to recover any coherent portion of Unit II from the interval 26.3-109.1 mbsf and fear of drilling complications led to the decision to abandon Site 729 without reaching basement.

Site 730: 17°38.885'N, 57°42.519'E. Water depth 1065.8 m

Site 730 was the last site drilled on the Oman continental margin and was added to the operations schedule after Site 729 was abandoned because of poor hole conditions. Like Sites 723 and 727, Site 730 is located near the bottom of the pronounced oxygen-minimum zone that impinges on the margin; it is positioned to the east of a ridge of presumed ophiolitic basement that separates the upper and lower sedimentary basins. Sediments in the upper basin, which were drilled only 6 km to the west at Site 727, onlap eastward onto the ridge and have been thinned and tilted by tectonic movement of the ridge. East of the basement ridge, seismic reflection profiles reveal a prominent unconformity that truncates eastward-dipping beds. We moved upsection on the dipping reflectors (eastward) and cored through the unconformity to recover older strata than those cored previously at Site 727. The ages of the sediments and the hiatuses encountered, and the evolution of the sediment facies, were expected to be useful in reconstructing the subsidence, erosional, and tectonic histories of the slope basins and the prominent basement ridges.

One hole was drilled at Site 730 in APC and XCB coring mode. Hole 730A reached a total depth of 403.9 mbsf and recovered 80% of the section cored. The hole was abandoned because the core barrel parted during retrieval of Core 117-730A-43X.

The sediments at Site 730 range from Holocene to late early Miocene in age and have been divided into three lithologic units (Figure 13). Unit I is a marly nannofossil ooze and extends to 36.8 mbsf. No siliceous fossils occur in this unit. A major hiatus, spanning nannofossil zones NN21 to NN10, was found in Core 117-730A-2H; the hiatus separates lithologically similar sediments of Pleistocene and late Miocene age. The rate of sedimentation in the interval above the hiatus was established as 40 m/m.y.

Lithologic Unit II comprises marly nannofossil ooze and diatomaceous silty clay of middle Miocene age, and extends downsection to Core 730A-20X (191.2 mbsf). Diatom frustules and radiolarians are abundant in lithologic Unit II but they begin to decrease in abundance below 191 mbsf and completely disappear in Unit III. Lithologic Unit III is dominated by foraminifer-nannofossil chalk and constitutes the remainder of the section recovered at Site 730. The oldest sediment is late early Miocene (calcareous nannofossil zone NN4) in age. Lithologic Unit III is dominated by slump beds 10-200 cm thick. Recumbent folds and high-angle faults are visible as offsets of bioturbation traces and color laminations. Throughout Site 730 the occurrence of siliceous microfossils coincides with poor preservation of planktonic and benthic foraminifers, which are progressively recrystallized with depth.

Chemical compositions of interstitial waters and gas show no indication of a sub-bottom supply of sulfate, and diagenetic reactions appear to be dominated by carbonate cementation and methanogenesis. The lithologic contrast between Units II and III is clearly shown by a decrease in organic carbon content, which declines from values above 2% in lithologic Unit II to values less than 1% in Unit III. The decline in organic matter abundance is balanced by a significant increase in carbonate minerals that account for up to 95% of the constituents in some lower Miocene samples.

<u>Site 731</u>: 16°28.229'N, 59°42.149'E. Water depth 2365.9 m

Site 731 is located on the Owen Ridge in the western Arabian Sea. The Owen Ridge is an asymmetric, northeast-southwest-trending ridge approximately 300 km off Oman, that dips steeply to the east and gently to the west.

The first major scientific objective for drilling at Site 731 was to recover a continuous Neogene sequence of pelagic sediments from the crest of the Owen Ridge. These sediments were expected to record long-term and short-term variations in the biotic, sedimentologic, and chemical response of the depositional system to the initiation of, and changes in, the monsoonal circulation system. The second major objective was to penetrate and possibly recover a thick sequence of turbiditic sediments in order to reconstruct the tectonic history of the Owen Ridge and the adjacent Owen Basin.

Site 731 consisted of three holes. Hole 731A began with seven APC cores, which penetrated to 67 mbsf with 102% recovery, and continued in XCB mode to the total depth of 409 mbsf, with 88% recovery. Hole 731B was washed to 408 mbsf, and 5 XCB cores were then recovered from 408.7 to 457.1 mbsf with a low recovery rate (15%) in sandy turbiditic material. Because of time limitations, Hole 731C was washed and cored in RCB mode through the pelagic cover and alternately washed and cored in the upper Oligocene and Miocene turbidites, with the objective of penetrating the thick turbidite sequence and reaching pre-Miocene strata. In spite of the rapid penetration rates, coring had to be suspended at a total depth of 994.2 mbsf in turbiditic sediments of late Oligocene/Miocene(?) age. Recovery in Hole 731C averaged 31%.

The section penetrated at Site 731 is equivalent to those at Sites 721 and 722. Sediments range from late Oligocene/early Miocene(?) to late Pleistocene in age and have been divided into four major lithologic units (Figure 14).

Unit I (0.0-146.5 mbsf) consists of alternating light and dark layers of foraminifer-nannofossil ooze, marly nannofossil ooze, and nannofossil ooze of late Pleistocene to late Miocene age. This unit was subdivided into two subunits based on the occurrence (in Subunit Ia) or the absence (in Subunit Ib) of opaline material. As at Sites 721 and 722, the sediments reveal strong cyclicity that is indicated by changes in color, bulk densitiy, carbonate content, and particularly well in magnetic susceptibility of whole-round cores. Hiatuses were recognized at 97 mbsf and 117 mbsf, which correspond to late Pliocene and early Pliocene to middle late Miocene ages, respectively.

Lithologic Unit II (146.5-240.9 mbsf) is composed of alternations of nannofossil ooze, diatomaceous marly nannofossil ooze, and minor nannofossil-rich diatomaceous mud of late Miocene age. Biogenic opal is abundant, and its abundance is the major difference between lithologic Units I and II.

Cyclicity persists in the interbedded nannofossil chalk and marly nannofossil chalk of lithologic Unit III (240.9-320.1 mbsf). Lithologic Unit IV (320.1-994.2 mbsf) is made up primarily of turbidites. In the upper 40 m of Unit IV, these are composed of silty clay that grades upward to nannofossil chalk in decimeter-scale beds. Downsection, the turbidites are almost barren silty clay, clayey silt, silt, and sand of early Miocene to Oligocene(?) age. Mud turbidites of 5-10 cm thickness are abundant and are stacked into beds of 2-3 m thickness. The mixed turbidite/carbonate transition zone between Units IV and III occurs at 320.1-359.5 mbsf, and may record the time when the ridge was uplifted above the influence of turbidites and above the lysocline. This latter boundary is indicated by deteriorating preservation of planktonic calcareous and opaline tests and the upsection abundance of benthic foraminifers in Unit III. The trend from turbiditic to increasingly pelagic deposition is related to the uplift of the Owen Ridge.

Hole 731C was logged with two tool combinations under good conditions in the 994-m hole. Log quality is excellent and will provide insight into lithologic changes in the long and sparsely recovered turbiditic Unit IV.

Site 731 and nearby Sites 721 and 722 provide an excellent record of the onset and evolution of monsoonal upwelling from the late middle Miocene to the Plio-Pleistocene. This sequence should provide insights into the relationships of orbital changes and the uplift of the Himalayas to the history of monsoon-related upwelling and eolian sedimentation on the Owen Ridge, as well as information on the tectonic history of the Owen Ridge and the evolution of the Owen Basin.

SUMMARY AND CONCLUSIONS

Two of the three morphologically distinct areas that were investigated during Leg 117 share a common tectonic and depositional history for the geological interval investigated by drilling. Oman margin and Owen Ridge sites are to some extent comparable in pre-middle Miocene facies recovered at Sites 721, 722, 731, and 730. In post-middle Miocene time, the margin and the ridge were hemipelagic and pelagic depocenters, respectively, for sediments produced by the same dominant processes. Both accumulated mixtures of eolian, clastic, and biogenic components originating from the adjacent African(?) and Arabian land masses and from a highly productive upwelling center off Oman. Connections between the sedimentary history of the Indus Fan site (720) and the paleoceanographic and geological history of the Oman margin (Sites 723-730) and the Oman Ridge (Sites 721 and 722) are not easily made, given the preliminary nature of our data. While we will try to point out similarities between sections recovered on the margin and those obtained from the ridge, Site 720 on the Indus Fan stands alone and will be discussed separately.

The Mid-Indus Fan, Site 720

The depositional history at Site 720 has been dominated by turbidite deposition, with brief interludes that are characterized by a relative increase in pelagic components. The deposition of the pelagic beds clearly reflects a decrease in clastic influx to the site rather than an increase in pelagic sedimentation rate. A decrease in clastic influx could be caused by local, regional, or global mechanisms. For example, high stands of sea level could reduce the clastic flux to the entire fan. This pattern is observed in the Holocene sediments of the Indus Fan, which are foraminiferal marls and oozes (Kolla and Coumes, 1987). High sea-level conditions favor the deposition of thin pelagic interbeds with great lateral extent on the fan. Therefore, the ages of pelagic interbeds within a generally clastic fan sequence should be coincident with, and controlled by, sea-level and climate variations. A more localized mechanism that favors sedimentation of predominantly pelagic deposits on elevated levees on the fan is the abandonment of an active channel. This mechanism only affects the levees of the active channel but would allow pelagic sediments to accumulate over several sea-level cycles. Turbidite deposition would resume when the channel became active or another channel migrated into the area. The timing of channel switching and abandonment, although difficult to establish precisely, may also be related to increased clastic influx during low or falling sea level. These mechanisms may act separately or in combination to produce the sequence of pelagic intervals observed at Site 720.

In this summary of the depositional history at Site 720, we use the term "bed" to refer to individual turbidites as observed in the lithologic logs. The term "sequence" refers to larger scale trends, such as fining, that are observed in the logging data and in the seismic sections. Here, we combine the lithologic, logging, and seismic information to interpret the evolution of depositional environments at Site 720.

The lower part of the section (390-290 mbsf, seismic unit C) is of early Pleistocene age and contains no pelagic interbeds. It is mostly composed of thinly to thickly bedded muddy and sandy turbidites that form upward-fining sequences of relatively uniform thickness. This association is characteristic of active overbank deposition and minor channel migration over an extended period of time. A sharp transition to finer grained and more pelagic deposition (Core 177-720A-30X, 277-290 mbsf) probably indicates a major shift in the distributary channel, and may be related to differential tectonic motion between the Owen Ridge and the Indus Fan. On the basis of sedimentation rates in similar sediments of lithologic Unit I, this quiescent interval of pelagic deposition may have lasted as long as 300,000 yr.

The lower Pleistocene pelagic interval of Core 117-720A-30X (about 1.19 Ma) is overlain by sandy thick-bedded turbidites that form both fining- and coarsening-upward sequences. These sequences occur from about 277 to 188 mbsf in seismic units B-2 and B-3. The turbiditic interval is interrupted by at least four pelagic intervals; these are observed in the log data, but were not recovered in the cores. We interpret this interval to represent intermittent deposition of unchannelized sheet sands with occasional quiescent periods of pelagic deposition.

The interval from 188 to 103 mbsf (seismic unit B-1) is characterized by turbidites of variable thickness, numerous thin pelagic intervals, and generally increasing clay content upsection. This interval contains the two large upward-fining sequences observed in the log data. The facies observed indicate that turbidite deposition was dominated by large overbank events or sheet flows of thick sands, alternating with normal overbank-levee processes that primarily deposit mud turbidites. The upsection increase in clay content could indicate alternatively that the size and frequency of the turbidite events were waning.

The upper 100 mbsf at Site 720 (seismic unit A) is characterized by further channel switching and abandonment of active channels, resulting in several pelagic intervals intercalated with turbiditic sediments. This seismic unit (A) thickens toward the Owen Ridge and shows abundant buried channels that indicate a rapid infilling over the past 0.7 m.y. The most recent transition from predominantly turbiditic to pelagic deposition (lithologic Unit I) occurred at about 0.6 Ma (14 mbsf). On most submarine fans, late Pleistocene rates of turbidite deposition are generally related to changes in sea level; higher rates are generally observed during low sea level stands. However, pelagic Unit I at Site 720 does not contain turbidites. Therefore, the temporary lack of terrigenous influx to the site is probably related to switching of the distributary channel away from the site rather than to a general decrease in turbidite deposition on the Indus Fan.

The high rates (>500 m/m.y.) of Pleistocene turbidite deposition on the Indus Fan are more than double the rates found by Leg 116 on the distal Ganges Fan. These rapid accumulation rates are consistent with accelerated uplift and erosion in the Indus source area. However, the lack of a longer record precludes any observations concerning longer term relations between the rates of uplift and sedimentation on the Indus Fan at Site 720.

Owen Ridge Sites 721, 722, 731

Neogene sediments have been deposited well above the carbonate lysocline and beyond the zone of lateral bottom transport from continental margins since the Owen Ridge was uplifted. The detailed biotic, chemical, and sedimentologic records obtained from these sediments will be used to test the hypothesis that much of the short-term variability (10^3 yr) in monsoonal upwelling is forced by changes in solar radiation related to variations in the shape of Earth's orbit (the Milankovitch mechanism). Long-term trends in intensity of the monsoon caused by the uplift of the Himalayas may also be imprinted on the long paleoenvironmental record from the ridge. In addition, the age and character of the sediments obtained from the Owen Ridge will be used to reconstruct its depositional and uplift history.

The preliminary shipboard findings at Sites 721, 722, and 731 pertinent to the above objectives have included

- the recovery of a complete if composite upper Miocene to Holocene stratigraphic section;
- the recognition of siliceous facies in the lower upper Miocene;
- the recognition of first "upwelling" faunas in the middle upper Miocene;
- the clear definition of sedimentary cycles that are characterized by changes in sediment color, magnetic susceptibility, and physical properties. The cycles have distinct periodicities that are consistent with the Milankovitch frequencies, and individual cycles can be correlated in detail between holes;
- observations that high accumulation rates in the late Miocene were followed by low rates in the early Pliocene and increasing rates during the Plio-Pleistocene;
- the finding that turbidite deposition on the ridge crest ceased in the early to middle Miocene;
- the observation that high abundances of marine-derived organic carbon of relatively pristine character occur in dark parts of the sedimentary cycles.

The major themes included in interpreting the depositional history of the Owen Ridge are the uplift history, the onset and preservation of bio-siliceous sedimentation and the appearance of distinct upwelling faunas, and the patterns of high-frequency variability in sediment component abundances. We briefly address these themes below.

Uplift of the Owen Ridge

The uplift history of Owen Ridge is indicated by lithofacies changes, i.e., by the gradual transition from a turbiditic facies to a pelagic facies in the latest early Miocene, as well as by phases of non-deposition or erosion. The lower Miocene sections at Sites 721, 722, and 731 are characterized by silty turbidites that grade upward to muddy turbidites. These sediments are typically poor in organic carbon and carbonate, and preliminary mineralogical analyses suggest a sediment source similar to that of the Indus Fan. Planktonic fossils are poorly preserved, and opaline silica is sparse. These sequences were deposited in an active, deep-water turbidite depositional environment before the Owen Ridge was uplifted. In the upper part of lithologic Unit IV, the grain size of basal layers decreases and finer grained muddy turbidites are intercalated with pelagic nannofossil chalks. This trend of finer, more distal(?), and fewer turbidites is also shown by decreases in magnetic susceptibility, bulk density, and P-wave velocity. We interpret these fining-upward sequences as indicators of progressive uplift of each site above the surrounding seafloor. The upper limit of the turbiditic sequence is marked by a prominent seismic reflector that can be mapped over much of the Owen Ridge and in the adjacent Owen Basin.

The lower middle Miocene deposits recovered on the Owen Ridge were entirely dominated by nannofossil chalk that is characterized by high average carbonate content (76%) and poor opal preservation. Thus, by this time, the Owen Ridge sites had been uplifted well above the influence of turbidite deposition and were accumulating pelagic sediments. However, much of the middle Miocene section is missing at Site 721, and several tens of meters of siliceous nannofossil oozes and chalks -- comprising the sediments of middle to late Miocene age -- are locally disturbed by slumping. The failure of the sediments and the resulting slump deposits may be related to the inclination caused by the uplift of the Owen Ridge, but the specific events cannot yet be attributed to a discrete uplift phase. Another phase of uplift, indicated by low accumulation rates (see below) may have occurred in the early Pliocene.

The onset of upwelling faunas and opal deposition

The first indication of enhanced productivity over the Owen Ridge was the appearance of the siliceous facies in the middle late Miocene. Both radiolarians and diatoms appeared at this time, but the species represented are tropical. At the same time, organic carbon concentrations increase from values below 1% to almost 2.0%. Preliminary analyses indicate that the earliest phase of opal accumulation on the ridge is not associated with significantly higher accumulation rates; the upper middle to lower upper Miocene reflects bulk accumulation rates on the order of 1-2 $g/cm^2/k.y.$, which increased to 6 $g/cm^2/k.y.$ by the latest Miocene. Organic carbon accumulation rates doubled from 30 mg to 70 mg $C/cm^2/k.y.$, at the same time. The organic carbon increase was accompanied by abundant and well-preserved planktonic foraminifer and nannofossil assemblages. The late Miocene was clearly a time of higher pelagic flux to the depositional centers on the ridge (Figure 15).

The first indication of upwelling is in middle Miocene sediments and is marked by the appearance of a radiolarian assemblage that contains typical tropical species, but younger radiolarian faunas contain more robust, cool-water forms and lack many tropical forms. A distinctive upwelling planktonic foraminiferal fauna appeared in the early late Miocene with the simultaneous appearance of Globorotalia bulloides, G. menardii, and G. tumida, and the Neogloboquandrina lineage of acostaensis and dutertrei at the boundary between lithologic Units II and I. Finally, in the early Pliocene, cold-water forms of calcareous nannoplankton appeared at Owen Ridge. This sequence of assemblages may indicate an ecologic response to the evolution of monsoonal upwelling. However, detailed study of the faunal and floral variations will be needed to establish the oceanographic significance of this sequence.

The accumulation rates associated with the appearance of upwelling faunas clearly indicate that the monsoonal upwelling system was active in the late Miocene. However, other areas of the world ocean also indicate high accumulation rates in the late Miocene (Prell, Gardner, et al., 1982; Theyer et al., 1985). Thus, the question of global vs. regional causes of high productivity must be considered for the western Arabian Sea before the apparent upwelling phase of the late Miocene can be attributed solely to the monsoonal mechanism. The long-term increase in carbonate-accumulation rates from the late Pliocene to the Holocene may reflect further increases in the intensity of monsoon-driven upwelling and eolian transport in response to continued uplift of the Himalayas. This long-term trend would be consistent with the gradual modification of surface boundary conditions by tectonic mechanisms rather than by the short-term orbital mechanism (Prell and Kutzbach, 1987).

Short-term variability and sedimentary cycles

Light-dark couplets of sediments alternate over intervals of about 1 m in sediments of late Miocene to Pleistocene age and are the most conspicuous expression of sedimentary cycles in the cores from the Owen Ridge. The alternations in color are paralleled by changes in organic carbon and carbonate content, in physical properties, and most conspicuously, in magnetic susceptibility.

Dominant periodicities were revealed when an age model derived from paleomagnetic measurements was applied to the magnetic-susceptibility data set. Power spectra of susceptibility fluctuations through time appeared to yield pronounced periodicities near 400, 41, 23, and 19 k.y.; a 100-k.y. periodicity was recognized in some intervals. The periodicities match those expected for the Milankovitch mechanism, one of the major suspected driving forces of monsoonal variability. We emphasize that the observed periodicities are not unique to the monsoon mechanism, and that the age model used is a rather crude approximation, but we are at the same time confident that the sediment cycles represent fluctuations in the production and preservation of opal, carbonate, and organic carbon, and the input of eolian material.

The Oman Margin Sites 723, 724, 725, 726, 727, 728, 729, and 730

Three themes will be addressed in this preliminary summary of drilling results from the Oman margin. These three have been chosen from a variety of interesting topics, because they are likely to give the reader an impression of the general characteristics of the sedimentary environment.

The first theme concerns the tectonic evolution of the depositional environment and the effect of margin adjustment on sediment types and accumulation rates. We attempt here to show similarities between the sediments of the Owen Ridge and the Oman margin, and to outline disparities that result from the tectonic differentiation that occurred in the early late Miocene. Secondly, the sedimentary facies deposited under the highly productive monsoonal upwelling regime will be highlighted, and the application of facies evolution in the late Tertiary and Quaternary to paleoclimatic and paleoceanographic models will be discussed. Finally, some of the diagenetic processes recognized in these sediments with high organic carbon contents will be discussed. All of the conclusions drawn in the following paragraphs are preliminary and reflect our understanding on the basis of limited analyses.

Summary of stratigraphic results and sedimentation rates

The comparison of biostratigraphic datums with magnetostratigraphic horizons provided ages for biostratigraphic zonations for the last 8 m.y. The relation between biostratigraphic datum levels of nannofossils, radiolarians, and planktonic foraminifers will be combined in a stratigraphic standard. From the preliminary stratigraphy, sedimentation rates have been compiled for individual sites (Figure 15).

The rate of sedimentation is strongly influenced by the tectonic setting, which reflects both local and regional tectonic events. Some parallel changes in the rates of sedimentation are recognized on the Owen Ridge and on the Oman margin, even though sedimentation on the margin is up to four times faster than on the ridge.

One of the most obvious phases of sedimentation is the interval of turbidite emplacement that was recognized on both the margin and the ridge during the late Oligocene(?) to the middle Miocene. At the Owen Ridge, turbidites probably were derived from the nascent Indus Fan. Turbiditic sediments of early Miocene age on the margin are different in composition, and appear to have been derived increasingly from shallow-water foraminiferal sands. Sedimentation rates exceeded 50 m/m.y. on both the ridge and the margin in the middle Miocene to the early middle Miocene.

A phase of hemipelagic and pelagic sedimentation is recognized by nannofossil chalks that were deposited at rates of less than 20 m/m.y. on the Owen Ridge, while high rates of 55 m/m.y. persisted on the Arabian margin in the middle Miocene. A tentative explanation for the facies change is that the Owen Ridge was uplifted above the influence of turbidity flows, and crossed the lysocline in the early middle Miocene. Chalks deposited in slope basins show cyclicity in carbonate content and color.

Significant differences in sedimentation on the margin and the ridge began in the latest Miocene, at approximately 6 Ma. Sedimentation rates on the margin decreased to about 10 m/m.y. between 7 and 5 Ma (Sites 726 and 728), but increased to values exceeding 100 m/m.y. at Sites 728 and 724 from 5 to 3.5 Ma (Figure 15). On the Owen Ridge the rate of sedimentation was strongly reduced and hiatuses developed, perhaps in response to accelerated uplift. Since that time the rate of sedimentation was not uniform in the sites studied on the ridge, and mass wasting, slumping, and submarine slides affected the sequence here, ending a time of high sedimentation rates during the late Miocene.

The depositional centers on the margin changed from outer slope to proximal basins in the middle Pliocene, at about 3.5 Ma, judging from the increase in sand-sized detrital material in the cores and from the effect of the OMZ. The proximal slope basins subsided continuously and accumulated thick sequences at rates approaching 200 m/m.y. from the middle Pliocene to the Holocene.

Biostratigraphic notes (Figure 16)

Three of the sites drilled on the Oman margin (723, 725, and 727) contain expanded Pleistocene sections, and one site (724) contains expanded Pleistocene and uppermost Pliocene sediments. Radiolarian occurrences in all of these sites are sporadic, and biosiliceous components are generally absent. Calcareous nannofossils are abundant, but exhibit low species diversity throughout these sites. Planktonic foraminifers are abundant in the Pleistocene sections, but decline in abundance and preservation near the Plio-Pleistocene boundary (Site 723). Benthic foraminifers are abundant and highly diverse in these relatively shallow margin sites. The presence of shallow-water benthic foraminifers in the lowermost part of Site 724 indicates that the site has subsided several hundreds of meters since the late Pliocene.

Three additional margin sites (726, 729, and 730) have short Pleistocene sequences, with a hiatus underlain by lower upper Miocene sediments (730), upper Miocene(?) limestone (729), or Pliocene and upper Miocene sediments and a second hiatus to Eocene limestone (726). Radiolarians are present in the upper Miocene and Pliocene sediments only. Both planktonic foraminifers and calcareous nannofossils are abundant and well preserved in the Pleistocene sections, but are rare or absent in the limestone sections. At Site 730 planktonic foraminifers are less abundant in the upper and middle Miocene, but are abundant again in the lower Miocene; calcareous nannofossils are poorly preserved in the same lower Miocene section.

The remaining Oman margin site (728) contains a relatively short Pleistocene sequence and an expanded lower Pliocene and upper Miocene sequence. Radiolarians are common and well preserved in the lower Pliocene and upper Miocene sections. Planktonic foraminifers are abundant and well preserved in the Pleistocene section, but rare in the Pliocene and Miocene sections. Calcareous nannofossils are abundant throughout, but are marked by low species diversity. The benthic foraminiferal fauna shows that this site was located in the neritic zone (less than 300 m deep) in the late Miocene and has since been subsiding to its present water depth of 1400 m.

Magnetostratigraphic notes

The major factor limiting the quality and resolution of the paleomagnetic data collected during Leg 117 was the consistently very low natural remanent magnetization intensities. With the exception of samples from the turbidite sequences at Sites 720, 722, and 731, the intensities after alternating-field demagnetization were almost always less than 1 mA/m; they also tended to decrease with depth, so that reliable paleomagnetic data usually could be obtained only from the uppermost 200-300 mbsf. These problems are partially offset by the unusually detailed between-hole and between-site correlations (unique in the history of ocean drilling) made possible by the whole-core susceptibility data. In some cases these correlations will enable us to transfer reversal boundaries (and other stratigraphic datums) from one site to another. For example, the boundary between Chrons C1 (Brunhes) and C1r (Matuyama), and the upper boundary of Subchron C1r-1 (Jaramillo), are clearly distinguished at Site 727. By means of susceptibility correlations it is possible to transfer these datums to Site 728, where they are not resolved clearly, and to Site 724, where they are not resolved at all.

Sites 724, 727, and 728 have the best reversal stratigraphies of the margin sites. At Site 724 we recognized six polarity transitions back to Chron C2A (Gauss); at Site 727 three transitions were recognized back to the middle of Chron C1r (Matuyama); and at Site 728 thirteen transitions were recognized back to the base of Chron C3. Site 728 is perhaps the most interesting section, where we think it is possible to recognize the four Subchrons within Chron C3 (Cochiti, Nunivak, Sidufjall, and Thvera); this part of the section may prove to be particularly useful for refining correlations with biostratigraphy.

Evolution of monsoonal upwelling and sedimentary facies on the Oman margin

The sites drilled on the margin fall into two broad categories: those drilled to recover Neogene sedimentary sections from two half-graben structures between basement ridges (Sites 723, 724, 725, 727, 728, 730), and those situated on the basement ridges to establish the age and nature of pre-Neogene strata underlying this portion of the margin (Sites 726, 729).

The oldest sediments recovered are shallow-water limestones and dolomitized limestones of Paleogene age. These sediments were recovered from the two sites drilled on basement ridges, and in both cases they were unconformably overlain by hemipelagic sediments with compositions characteristic of an upwelling influence. Because age assignments are tentative at this time, and because recovery of the limestones was limited at both sites, we refrain from analyzing this facies in detail. The implications of this facies for regional tectonic evolution in pre-Miocene time await future interpretation.

The oldest Neogene lithology on the margin is nannofossil chalk with as much as 95% $CaCO_3$, which makes up the oldest hemipelagic and possibly turbidite deposits recovered at Site 730. Marly nannofossil ooze, silty calcareous ooze with variable detrital components, and opal-bearing to opal-rich calcareous ooze account for most of the lithologic variations through the remainder of the Neogene sequence. Organic carbon always exceeds 0.5% by weight, and is particularly enriched in opal-bearing and laminated intervals.

Shipboard analysis of sediments recovered during ODP Leg 117 considered the distribution and preservation states of different microfossil groups (planktonic and benthic foraminifers, calcareous nannofossils and radiolarians) through time at the various sites. We learned that variable upwelling conditions have existed from some time in the middle Miocene to the Holocene. As expected, the onset of monsoon-driven upwelling is difficult to identify exactly, because the various planktonic groups require distinct ecological conditions and the different preservation states of the microfossils in the sediments may obscure the signal.

Despite these potential complications, opal production increased substantially at all sites in the middle Miocene Diartus petterssoni zone, indicating increasing productivity in the surface waters during that time. Planktonic foraminifers experienced a concomitant reduction in abundance, suggesting that carbonate dissolution may have been triggered by enhanced organic carbon production and/or environmental changes in the OMZ. However, Globigerina bulloides, a key upwelling species, invaded the area somewhat earlier in the middle Miocene and is present in Zone N11. The combined record of the radiolarians and the planktonic foraminifers, therefore, indicates that increased productivity in the surface waters began in the middle Miocene.

Calcareous nannofossil species diversities in low-latitude areas and this area were compared for each nannofossil zone. This rough estimate showed that sediments of early middle Miocene age (zone NN5) contain about 88% of the total number of species expected to be found in tropical areas. This species diversity gradually decreased through time, and the nannofossil assemblages become remarkably less diverse in sediments younger than 9.5 Ma (early late Miocene; Zone NN9). This pattern of low diversity continued through the late Miocene to the early Pliocene (Zone NN12); after that time the diversity was around 50%, and diversity increased slightly in younger sediments. Based on this rough estimate, the calcareous nannoflora were apparently affected by upwelling slightly later, i.e., in the early late Miocene, than the planktonic foraminifers and the radiolarians.

Upwelling conditions continued during the Pliocene; the calcareous microfossils generally show moderate to poor preservation especially at the Oman margin sites, while radiolarians and diatoms are common and well preserved. Throughout this area, the Pliocene calcareous nannofosssil zonal marker species, Amaurolithus tricorniculatus and Ceratolithus rugosus, are missing, and other species of these genera are rare. Upwelling conditions are probably responsible for very low numbers of these tropical species. In contrast, Coccolithus pelagicus, which is considered a typical cold-water species, is present in unusually high abundance in uppermost Pliocene to lowermost Pleistocene sediments.

An environmental change occurred in the early Pleistocene, and is recorded by an increase in foraminifer abundance and a decrease in the abundance of siliceous microfossils. Organic carbon values in the sediments decrease at the same time. These changes may indicate lower production rates of organic carbon because of decreased upwelling intensity. Preservation conditions for calcareous material may have improved also because of a less intense OMZ or a change in bottom-water circulation.

More detailed microfossil abundance data, including dissolution indices, will be combined with stable-isotope studies of planktonic and benthic species to further assess the hypotheses described above.

Effects of the oxygen-minimum zone on sediment facies

Lithologic change on the margin is believed to reflect, in part, the oceanographic feature of the oxygen minimum zone, which presently extends from approximately 200 m to 1500 m water depth. Approximately synchronous occurrences of millimeter-scale laminations were recognized at several different sites (see Figure 17). These are considered among the most interesting and significant signals of different sedimentary (and environmental) conditions on the Oman margin in the Neogene. The most prominent occurrence of laminations coincides with opaline silica preservation in the late Pliocene and near the Pliocene/Pleistocene boundary, and preliminary correlations suggest that this occurrence of laminated intervals may be coeval over much of the margin.

A fundamental premise in using the laminated intervals to trace the OMZ is the interpretation that laminations imply deposition during a period of bottom-water oxygen depletion to levels below 0.2 mL O_2/L. According to Demaison and Moore (1980), this level is a minimum for maintaining bioturbation. Laminated sediments also record/require temporally varying sediment input, such as expected in a seasonal upwelling setting. The preservation of laminations deposited over several input cycles indicates the absence of benthic organisms for a considerable period of time, because laminated intervals must be thicker than the range of subsequent soft-sediment bioturbation for any laminations to be preserved.

The rates of primary productivity during present-day upwelling off Arabia are greater than 500 mg C m^{-2} d^{-1}, as compared to 100-150 mg over much of the world ocean (Romankevich, 1984). High productivity is one of the main factors that acts to establish a pronounced mid-water OMZ on the margin. The OMZ, in turn, may be one of the most important factors controlling the facies that are deposited. The concept of an oxygen-minimum control has been used extensively to explain various occurrences of organic-rich sediments in the geological past (e.g., von Stackelberg, 1972; Thiede and van Andel, 1977; Jenkyns, 1981). In his paper on oxygen minima, Wyrtki (1962) points out that biochemical processes (the bacterial remineralization of organic matter produced in the euphotic zone) are responsible for the existence of oxygen minima, while circulation controls the position of this zone. In brief, the oxygen minimum occurs in the upper part of a water column that lacks advective recharge of dissolved oxygen (either by the lack of horizontal advection or by the existence of a suboxic to anoxic condition for the water in general). This oxygen-deficient layer is sandwiched between the mixed layer of atmospheric gas exchange and biogenic productivity, and deeper layers of moderately high oxygen content (about 3 mL O_2/L; Wyrtki, 1973). The upper part of the OMZ, which often is relatively immobile and coincides with a density boundary, is an oxygen sink, because bacterial remineralization consumes dissolved oxygen more rapidly than it can be replaced by diffusion from above or below. According to Wyrtki (1962), OMZ will develop at the upper boundary of the central layer, because bacterial remineralization (and oxygen consumption) decreases exponentially with depth.

The above discussion demonstrates that oxygen content in the OMZ over the continental slope is strongly influenced by advection of deep water toward the surface. Other factors, such as the rate of organic matter production in the euphotic zone, certainly play important roles as well. From our preliminary analyses the role of input and the degree of bacterial remineralization appear to be minor, because the quality and quantity of organic matter that reached the seafloor during most of the depositional history as investigated by Leg 117 appear to provide and abundant substrate for vigorous bacterial activity. We can deduce the bacterial activity from the results of pore water geochemistry, as will be discussed later. Higher productivity, caused by more intense upwelling or some other mechanism, may result in an expansion of the oxygen minimum; it may, on the other hand, increase oxygen inflow by more vigorous deep water advection. This problem will be described in more detail below. The rate of oxygen consumption and the rate of horizontal or vertical advection of oxygen into the oxygen minimum determine the spatial extent of the oxygen minimum and its oxygen concentration. The effects of more vigorous vs. less vigorous advection of oxygenated water are shown schematically in Figure 18. Figure 18 depicts a transect across a continental margin underlying highly productive upwelling waters, similar to the situation the Oman margin, and highlights possible facies patterns and oceanographic phenomena.

A brief overview of northern Indian Ocean oceanography

If advection of intermediate water is assumed to influence the extent of the OMZ, then possible sources of that water must be identified. Wyrtki (1973) summarized circulation in the Indian Ocean, and described the northern Indian Ocean as filled essentially with a homogeneous high-salinity water mass termed the Northern Indian Ocean Intermediate Water. An intermediate layer extends from about 800 to 1200 m depth; it is partly composed of waters flowing out of the Red Sea, and is possibly underlain by a branch of oxygen-rich Antarctic Intermediate Water, which creates a salinity minimum in mid-water. These water masses form a tongue of relatively oxygenated water (about 3 mL/L) within the oxygen-poor (<1 mL/L) main water masses at depth. The deep water of the Indian Ocean originates from North Atlantic Deep Water, but this oxygen-rich (>5 mL/L) water probably never reaches the northwest Indian Ocean.

The development of laminations and enhanced preservation of organic carbon and opal may be connected with mechanisms of productivity, circulation, and water-mass dynamics of the northern Indian Ocean. We speculate that no oxygenated water was advected to the slope during an extended period at the Pliocene/Pleistocene boundary. This proposal may imply the following:

- Higher productivity may have resulted in increased oxygen consumption rates and depletion of the dissolved seawater oxygen in an expanded and intensified oxygen-minimum zone.

- Laminated intervals may be developed during a weaker monsoon. At present, relatively oxygen-rich water is advected to the slope basins, because the midwater isopycnals slope upward at the Arabian margin during upwelling. This occurs because surface waters are driven offshore during upwelling, and the deep water adjusts to maintain hydrostatic balance. The dynamic topography over the surface of the Indian Ocean is approximately 1.5 m at present. Because density differences are reduced at depth in the ocean, the surface topography would produce an inclination of several hundred meters at the lower boundary of the OMZ. If the dynamic topography of the Indian Ocean were decreased because of lower monsoonal wind strenth, the topography at the base of the oxygen minimum would decrease and deep oxygenated water would not be advected onto the slope. The oxygen minimum would then expand and intensify in response to decreased advection of dissolved oxygen.

- Decreased advection of Red Sea Water into the oxygen-minimum zone of the Arabian Sea possibly is responsible for extended anoxia during specific time intervals, because it forms the critical Indian Ocean Intermediate Water.

- Episodic influx of highly saline water into the steep slope basins could create anoxic conditions similar to those present in the Orca Basin, the Tyro Basin, and some of the deeps of the Red Sea.

The frequent coincidence of opal preservation with laminations and high organic carbon may represent a productivity signal preserved in the sediments, but may also be an effect of the conspicuous lack of bioturbation. Lack of benthic mixing creates flat diffusion gradients, which would reduce opal dissolution. If sedimentation rates are sufficiently high, so that sediments are rapidly buried, then the flat diffusion gradients would inhibit silica loss to undersaturated bottom waters.

Summary of diagenetic processes observed on the Oman margin

Organic matter remineralization proceeds by microbial degradation reactions that utilize a characteristic sequence of oxidants or electron acceptors in order to derive the greatest free energy yield per mole of carbon consumed. In many pelagic sediments oxygen is the primary oxidant, and the organic matter decomposition is dominated by aerobic or sub-oxic processes, including denitrification and the participation of ferric and manganic oxyhydroxides, where the limiting factor is the amount of organic substrate. However, in the organic-rich continental margin sediments drilled off the Oman margin the diagenetic regime is overwhelmingly controlled by anaerobic processes involving the reduction of seawater sulfate, which is used as the primary electron acceptor, and methanogenic decarboxylic reactions at greater depth. In this situation carbon is often no longer a limiting factor, and hence the microbial reactions appear to be influenced by sediment accumulation rates, organic matter type, and supply of electron acceptors. Since virtually all the sites drilled (except Site 726) display pronounced sulfate consumption, those factors which influence the rate of diffusion and advection of this oxidant are of prime importance. Concurrent with the process of anaerobic degradation of the marine organic matter is the diagenetic alteration and reprecipitation of carbonate phases including calcite, dolomite, and phosphorite; dissolution of biogenic siliceous debris; and fixation of such redox-sensitive metals as sulfides (e.g., Fe in pyrite) or organo-complexes (U in organic-rich sediments). The salient details of these diagenetic reactions provide a unique record with which to document the input variations and burial transformations of organic matter and associated sediment in the northwest Arabian Sea from the Eocene to the present day.

Sulfate reduction and methanogenesis

The profiles of sulfate concentration measured at both the Oman Margin and Owen Ridge sites clearly show that consumption of this oxidant is sluggish, often continuing to depths in excess of 100 mbsf. This result was not expected, as the average organic carbon content of these sediments ranges from 2 to 5 wt% and accumulation rates are on the order of 80-150 m/m.y. Previous studies of sulfate reduction and utilization in coastal and hemipelagic sediments (Berner, 1981; Reimers and Suess, 1983) have indicated that sulfate is often exhausted at considerably shallower depths (5-50 mbsf). ODP Leg 112 examined sulfate reduction off the Peruvian margin and found a typical sulfate reduction gradient of 15 mmol/L/10m which is significantly higher than the gradients measured on the Oman margin. While sulfate consumption at both upwelling margins appears to be influenced by bulk sediment accumulation rates, rather than organic carbon content, water depth or proximity to the OMZ, the difference by a factor of 2-4 in the sulfate reduction gradients between the two margins indicates that another primary control probably exists. At present, we consider that the **type** of organic matter may be critical in this context. The upwelling sediments off Oman are unusual in that biogenic carbonate detritus dominates over siliceous material, and that planktonic foraminifers and diatoms appear to be mutually exclusive throughout the upwelling record.

In the deeper sedimentary sections drilled on the Oman margin, methane was found to increase after complete consumption of interstitial sulfate. The source of this methane appears to result from microbial decarboxylation (Claypool and Kaplan, 1974) of carbonate ions. At Site 723, alkanes of higher atomic weight were measured, suggesting that thermal diagenetic reactions may be occurring, although heat-flow measurements made on the Oman margin suggest that no unusual thermal gradients are present, with the possible exception of Site 726. The production of methane at depth has the added effect of maintaining high concentrations of ammonia (40 mmol/L) and thus alkalinity (100 mmol/L) in the interstitial waters; the latter may have an important role in carbonate diagenesis (see below).

At the northern margin sites (723, 724 and 725) the source of sulfate may not be strictly from overlying seawater via diffusion. The profiles measured indicate that measurable sulfate exists below a subsurface minimum or the point of complete seawater sulfate consumption. We attribute these deeper sulfate concentrations to the occurrence of a subsurface brine of unusual composition, enriched in sulfate and depleted in chloride.

The distribution of other metabolites resulting from the breakdown of the organic matter warrants attention. The concentrations of ammonia and phosphate in the interstitial waters are always markedly less than estimated from reaction stoichiometry assuming complete sulfate consumption and Redfield-type organic matter. We believe that ion exhange reactions at clay lattice sites may influence the ammonia budget, while phosphatization and apatite precipitation make an efficient sink for dissolved phosphate.

Carbonate Diagenesis

The anaerobic diagenetic regime of the Oman margin and Owen Ridge is highly suitable for the precipitation of "organic" dolomites and phosphorites. During sulfate reduction, variations in the concentration of calcium, magnesium, and alkalinity indicate that carbonate precipitation reactions are occurring. Often, rapid consumption of magnesium ions is observed at the Oman margin sites with concurrent small increases in calcium concentrations. The Mg/Ca ratio also drops sharply at this depth. These changes in pore water chemistry often occur within the zone of sulfate reduction, which is still open to diffusional contact with overlying seawater, but well above any influence that the alteration of basaltic or mafic-type basement may have on the pore-water chemistry (commonly the concurrent depletion of magnesium and elevation of calcium; Gieskes, 1981).

Documentation of dolomite formation takes several forms. At shallow depths (10-100 mbsf), disseminated, euhedral, limpid rhombs were clearly observed in smear slides. No evidence of transport attrition was visible. At greater depths the quantity of euhedral dolomite increased, although the distribution became patchy. Finally, at Site 723, well-lithified stringers or beds of dolomite were recovered, ranging up to 2 m in thickness. The composition of this carbonate is almost pure stoichiometric dolomite. These observations attest to the ongoing process of dolomite formation at the Oman margin that results from a sequence of diagenetic reactions. Stable-isotope geochemistry of carbon and oxygen will probably document a polyphase depositional history for the dolomite stringers.

From these observations a tentative model for the early diagenetic formation of dolomite at the Oman margin may be proposed. During sulfate reduction alkalinity increases to a point where dolomite solubility is exceeded and, as precipitation commences, the magnesium concentration and Mg/Ca ratio drop sharply. Note that the seawater Mg/Ca ratio is >5, the theoretical stability limit for dolomite vs. calcite precipitation. The isotopic carbon-13 signature in the precipitated dolomite will be light (-25 delta ^{13}C) within this zone of sulfate reduction. Diffusional contact with overlying seawater will continue to supply magnesium for the dolomitization reaction and sulfate for alkalinity production. A slowing of bulk sediment accumulation rate and/or surface sediment bioturbation will facilitate this supply process. Depending on the particular reaction chemistry, calcium ions will be contributed to solution during alteration of any precursor carbonate present, further decreasing the Mg/Ca ratio. The surfaces of such euhedral dolomites often show step-surface dislocations at kink points, indicating their slow growth from slightly supersaturated solutions (Shimmield and Price, 1984). With continued burial, these dispersed euhedral dolomite rhombs become nucleation centers for more massive dolomitization. Such massive dolomite will probably be characterized by heavy (+15 delta ^{13}C) carbon resulting from the preferential reduction of isotopically light CO_2 during methanogenesis. Thus, a study of the isotopic compositional zoning of the dolomite stringers should reveal the true history of dolomite diagenesis on the Oman margin. The distribution of authigenic dolomite may be controlled by the organic matter content, sediment lithology, and bulk sediment accumulation rate. The stringers may be preferentially formed in the organic-rich, slowly accumulating sediments of the margin that are slightly coarser or have suitable carbonate substrates to initiate dolomite precipitation.

The diagenetic history of dolomitization observed here suggests that the hypothesis of Baker and Kastner (1981), regarding the necessity for complete sulfate depletion before dolomitization can commence, may be untenable. It is clear from the studies of Leg 117 interstitial-water chemistry that magnesium depletion relative to calcium occurs well within the zone of sulfate occurrence. This reaction is confirmed by smear-slide observations of euhedral dolomite. The presence of sulfate, or other large anions, may retard dolomite precipitation from a suitable solution, but the primary requirement for dolomite formation in hemipelagic or shelf sediments appears to be a high organic-matter content coupled with a relatively slow sediment accumulation rate.

Phosphorites

The occurrence of phosphorites or phosphatization on the Oman margin appears to take three distinct forms. First, fish teeth and scales are composed of apatite. Second, nodular aggregates of phosphorite (up to 5 cm diameter) occur, commonly in lag deposits (e.g., Site 726). These aggregates are dark in color and have various degrees of induration. Some have been bored by small serpulids or gastropods, but none have the characteristic patina of the California Borderland nodules found on bank tops near or within the top of the OMZ. Third, and perhaps quantitatively most important, a variety of pellet-like clasts (1-2 mm diam.) were found in sieved residues. These "pellets" display a variety of honey-brown to black colors, the lighter hues possibly reflecting a younger age. X-ray diffraction analysis reveals that this material is almost pure carbonate fluorapatite (francolite).

The phosphorus is almost certainly derived from organic-matter breakdown during anaerobic burial diagenesis. Low phosphate concentrations within the interstitial waters attest to prolific diagenetic reaction. It is possible that the phosphorite precipitates after dolomite, as magnesium has been shown to inhibit apatite precipitation (Burnett, 1977). The nodular phosphorites become concentrated during winnowing of the seafloor sediment and may indicate times when the upwelling-driven countercurrent coincided in depth with the upper shelf and slope. The "pellet" phosphorite may be forming *in situ* in sediment lying within the zone of sulfate reduction where organic matter remineralization is greatest. Slow accumulation rates may be important in this respect. Carbonate fluorapatite is also known to precipitate preferentially on calcite substrates (Leckie and Stumm, 1972) such as foraminifer tests. Studies of Holocene phosphatization off Baja California (Jahnke et al., 1983; Shimmield, unpub. data) indicate that precipitation occurs in organic-rich sediments (5-7 wt% C_{org}) at times when the sediment supply dropped and/or the sediment porosity increased. It is evident that such events represent non-steady-state conditions and are probably most likely to occur in organic-rich shallow water sediments, probably near the top of the OMZ. Uranium-series age dating of the phosphorite material may give a good indication as to whether the phosphorite is *in situ* (concurrent age with the bulk sediment accumulation rate) or a winnowed lag deposit (discordant age). No phosphorite was found in the deeper water sites on the Owen Ridge as would be predicted by the above model.

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TABLE 1: SITES DRILLED DURING LEG 117

Hole	Position	Water Depth (m)	Drilled (m)	Recovery (%)	Nature and Age of Oldest Sediment
720A	16°07.796'N 60°44.621'E	4037.5	414.3	21	Turbiditic sand, silt, mud/ Pleistocene
721A	16°40.636'N 59°51.879'E	1944.8	86.4	103	Nannofossil ooze and chalk/ late Pliocene
721B	16°67.776'N 59°86.450'E	1944.8	424.2	80	Siltstone, claystone, mudstone/ early Miocene
721C	16°67.776'N 59°86.450'E	1944.8	138.0	96	Nannofossil ooze/ early Pliocene
722A	16°37.312'N 59°47.755'E	2027.8	280.0	80.7	Nannofossil ooze/ late Miocene
722B	16°62.180'N 59°79.528'E	2027.8	565.1	68	Silty claystones/ early Miocene
723A	18°03.079'N 57°86.561'E	807.8	432.3	68	Dolomite biscuits/ late Pliocene
723B	18°03.079'N 57°86.561'E	807.8	429.0	73	Nannofossil clayey silt/ late Pliocene
723C	18°03.079'N 57°86.561'E	807.8	76.8	107	Nannofossil clayey silt/ Pleistocene
724A	18°27.713'N 57°47.147'E	592.8	44.5	100	Foraminifer nannofossil ooze/ Pleistocene
724B	18°27.713'N 57°47.147'E	592.8	257.7	82.9	Calcareous clayey silt/ early Pliocene
724C	18°27.713'N 57°47.147'E	592.8	252.4	96	Calcareous clayey silt/ early Pliocene
725A	18°29.200'N 57°42.030'E	311.5	4.5	100	Nannofossil-foraminifer sandy silt/ Pleistocene
725B	18°29.200'N 57°42.030'E	311.5	93.8	11	Foram-rich calcitic sandy silt/ Pleistocene
725C	18°29.200'N 57°42.030'E	311.5	162.8	60	Nannofossil-rich calcitic sand, silt, clay/ Pleistocene
726A	17°48.945'N 57°22.200'E	330.8	186.3	59	Limestone/ Eocene
727A	17°46.096'N 57°35.216'E	914.8	182.4	102	Calcareous clayey silt/ late Pliocene
727B	17°46.096'N 57°35.216'E	914.8	27.1	103	Calcareous clayey silt/ late Pleistocene
728A	17°40.790'N 57°49.553'E	1427.8	346.4	99	Foraminifer-nannofossil ooze/ late Miocene
728B	17°40.790'N 57°49.553'E	1427.8	347.7	100	Claystone/ late Miocene
729A	17°38.715'N 57°57.221'E	1398.8	109.1	29	Limestone/ Eocene
730A	17°38.885'N 57°42.519'E	1065.8	403.9	80	Foram-nannofossil chalk/ late early Miocene
731A	16°28.229'N 59°42.149'E	2365.8	409.0	88	Turbiditic mudstone to sandstone/ early Miocene
731B	16°28.229'N 59°42.149'E	2365.8	457.1*	15	Turbiditic mudstone to sandstone/ early Miocene
731C	16°28.229'N 59°42.149'E	2365.8	994.2*	31	Turbiditic mudstone to sandstone/ early Miocene

Total drilled: 7125.2 m. Total cored: 5875.5 m. Total recovery: 4367.2 m.

* = washed and spot-cored in turbiditic sequence

FIGURE CAPTIONS

Figure 1: Location of sites drilled during Leg 117 in the NW Indian Ocean (inset). The sites are arranged in depth transects across the Owen Ridge and the Oman continental margin. Note the depths of Sites 723-730, which correspond to the depth of the pronounced oxygen-minimum zone in mid-water.

Figure 2: Mechanisms and boundary conditions for the monsoonal circulation in the NW Indian Ocean after Prell and Streeter (1982). SST = Sea surface temperatures. mb = atmospheric pressure in millibars. Figures 2A and 2B show sea-surface temperatures in °C. Shaded areas indicate extent of the elevated Tibetan/ Himalayan Plateau. Cross-hatched region is area of monsoonal upwelling off Arabia.

Figure 3: A. Standard ODP lithologic symbols.
B. Lithologic summary, Hole 720A. Lithologies inferred between recovered intervals. T = turbidites, P = pelagic intervals. P* = pelagic intervals inferred from downhole logging data, but not recovered.

Figure 4: Lithologic summary, Hole 721B.

Figure 5: Lithologic summary, Hole 722B.

Figure 6: Lithologic summary, Site 723.

Figure 7: Lithologic summary, Hole 724B.

Figure 8: Lithologic summary, Hole 725C.

Figure 9: Lithologic summary, Hole 726A.

Figure 10: Lithologic summary, Hole 727A.

Figure 11: Lithologic summary, Hole 728A.

Figure 12: Lithologic summary, Hole 729A.

Figure 13: Lithologic summary, Hole 730A.

Figure 14: Lithologic summaries, Holes 731A,B,C.

Figure 15: Age versus depth curves of all sites drilled during Leg 117 on Owen Ridge. Circled numbers to the left of upper axes denote (1) nannofossil data in the Pleistocene/Pliocene, (2) radiolarian zones, (3) calcareous nannofossil zones, (4) magnetic reversal zones, and (5) biologic marker horizons.

Figure 16: Biostratigraphic summary, Leg 117.

Figure 17: Summary diagram of sediment facies and composition on the Oman margin. See text for explanation.

Figure 18: Summary diagram of possible relationship between the extent of the oxygen-minimum zone and sedimentary facies on the Oman margin. See text for explanation.

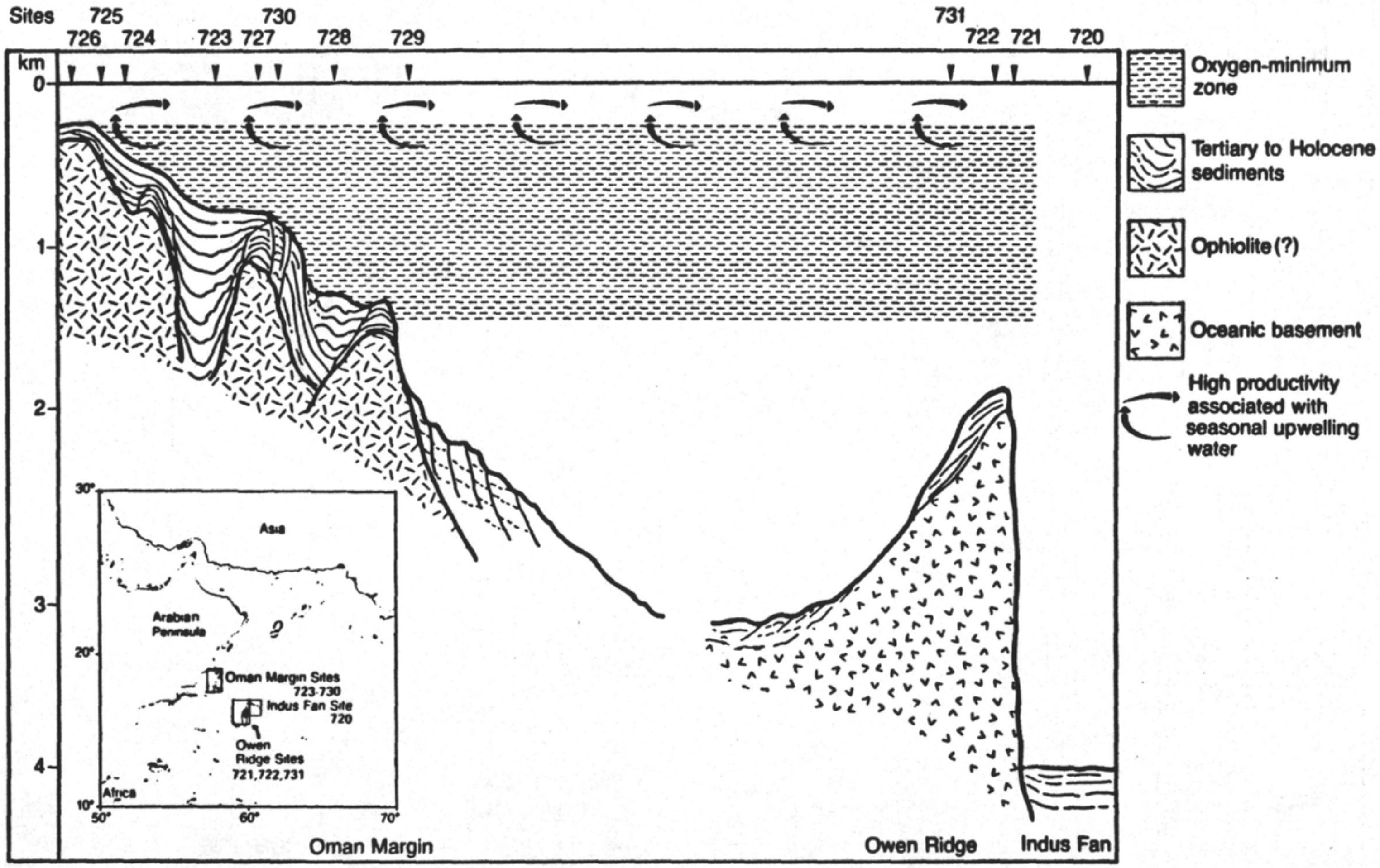

Sites
725
730
731
726 724
723 727
728
729
722 721
720
km
0
1
2
3
4
Oxygen-minimum zone
Tertiary to Holocene sediments
Ophiolite (?)
Oceanic basement
High productivity associated with seasonal upwelling water
Asia
Arabian Peninsula
Oman Margin Sites 723-730
Indus Fan Site 720
Owen Ridge Sites 721,722,731
Africa
30°
20°
10°
50°
60°
70°
Oman Margin
Owen Ridge
Indus Fan

Figure 1.

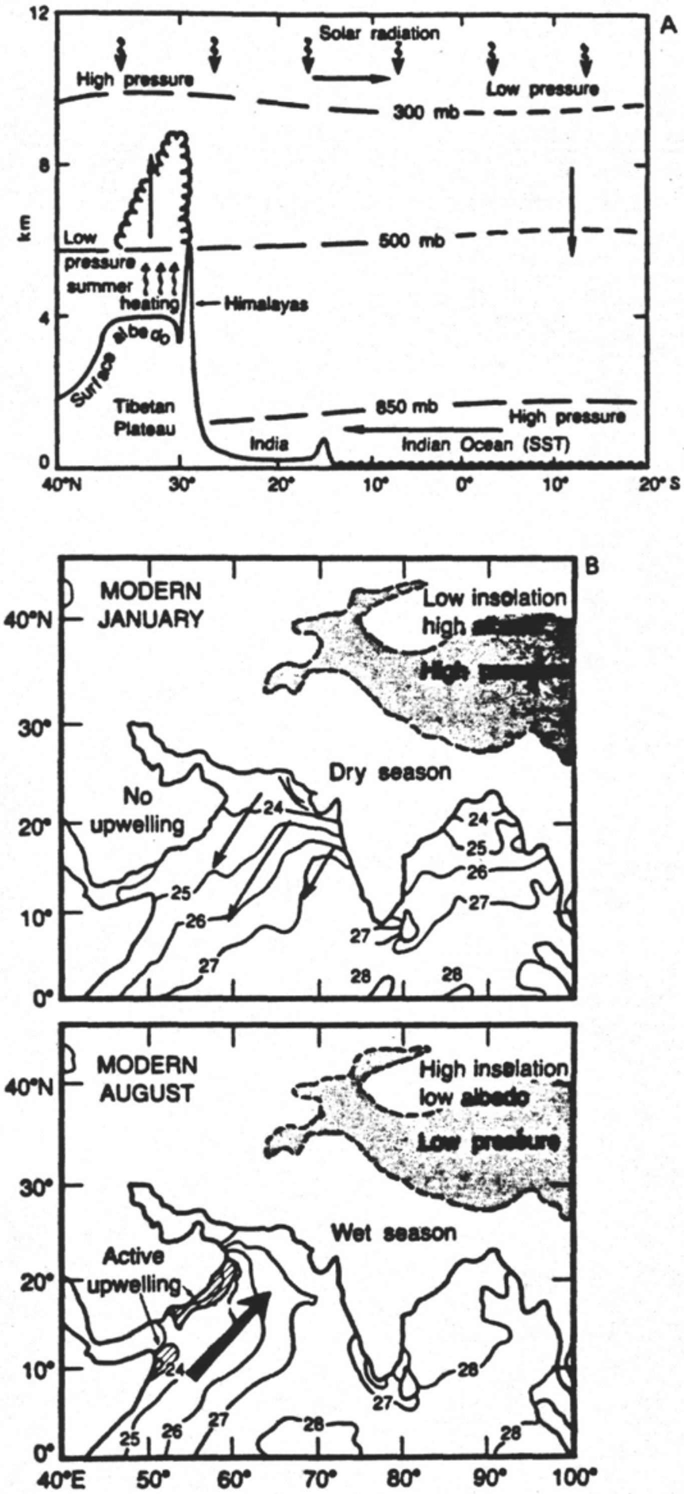

A
Solar radiation
High pressure
Low pressure
300 mb
500 mb
850 mb
km
Low pressure
summer heating
Himalayas
Surface albedo
Tibetan Plateau
India
Indian Ocean (SST)
High pressure
40°N
30°
20°
10°
0°
10°
20° S
B
MODERN JANUARY
Low insolation
high
Dry season
No upwelling
24
25
26
27
28
MODERN AUGUST
High insolation
low albedo
Low pressure
Wet season
Active upwelling
40°E
50°
60°
70°
80°
90°
100°

Figure 2.

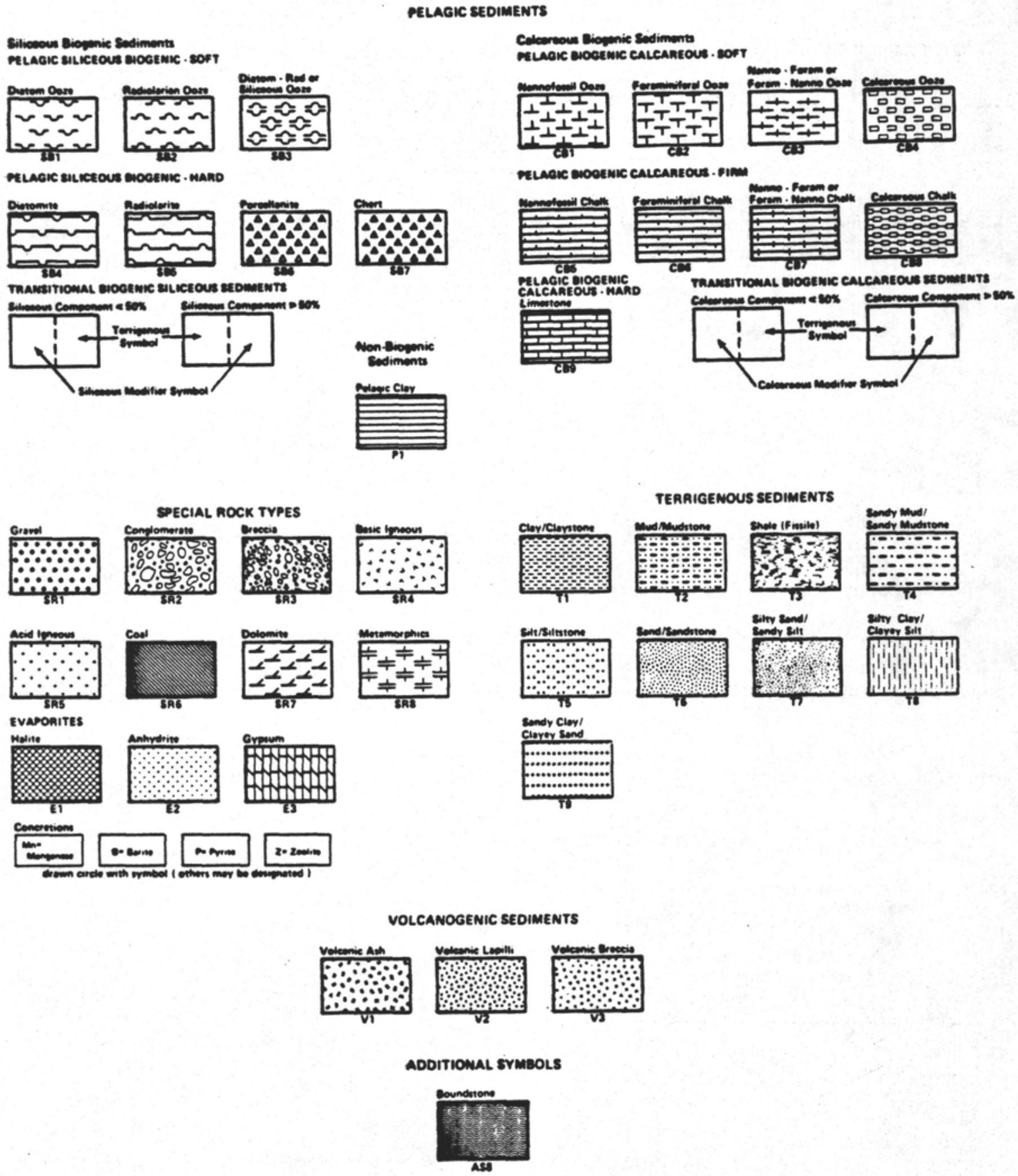

PELAGIC SEDIMENTS
Siliceous Biogenic Sediments
PELAGIC SILICEOUS BIOGENIC - SOFT
Diatom Ooze
SB1
Radiolarian Ooze
SB2
Diatom - Rad or Siliceous Ooze
SB3
PELAGIC SILICEOUS BIOGENIC - HARD
Diatomite
SB4
Radiolarite
SB5
Porcellanite
SB6
Chert
SB7
TRANSITIONAL BIOGENIC SILICEOUS SEDIMENTS
Siliceous Component < 50%
Siliceous Component > 50%
Terrigenous Symbol
Siliceous Modifier Symbol
Calcareous Biogenic Sediments
PELAGIC BIOGENIC CALCAREOUS - SOFT
Nannofossil Ooze
CB1
Foraminiferal Ooze
CB2
Nanno - Foram or Foram - Nanno Ooze
CB3
Calcareous Ooze
CB4
PELAGIC BIOGENIC CALCAREOUS - FIRM
Nannofossil Chalk
CB5
Foraminiferal Chalk
CB6
Nanno - Foram or Foram - Nanno Chalk
CB7
Calcareous Chalk
CB8
PELAGIC BIOGENIC CALCAREOUS - HARD
Limestone
CB9
TRANSITIONAL BIOGENIC CALCAREOUS SEDIMENTS
Calcareous Component < 50%
Calcareous Component > 50%
Terrigenous Symbol
Calcareous Modifier Symbol
Non-Biogenic Sediments
Pelagic Clay
P1
SPECIAL ROCK TYPES
Gravel
SR1
Conglomerate
SR2
Breccia
SR3
Basic Igneous
SR4
Acid Igneous
SR5
Coal
SR6
Dolomite
SR7
Metamorphics
SR8
EVAPORITES
Halite
E1
Anhydrite
E2
Gypsum
E3
Concretions
Mn= Manganese
B= Barite
P= Pyrite
Z= Zeolite
drawn circle with symbol (others may be designated)
TERRIGENOUS SEDIMENTS
Clay/Claystone
T1
Mud/Mudstone
T2
Shale (Fissile)
T3
Sandy Mud/ Sandy Mudstone
T4
Silt/Siltstone
T5
Sand/Sandstone
T6
Silty Sand/ Sandy Silt
T7
Silty Clay/ Clayey Silt
T8
Sandy Clay/ Clayey Sand
T9
VOLCANOGENIC SEDIMENTS
Volcanic Ash
V1
Volcanic Lapilli
V2
Volcanic Breccia
V3
ADDITIONAL SYMBOLS
Boundstone
AS8

Figure 3A.

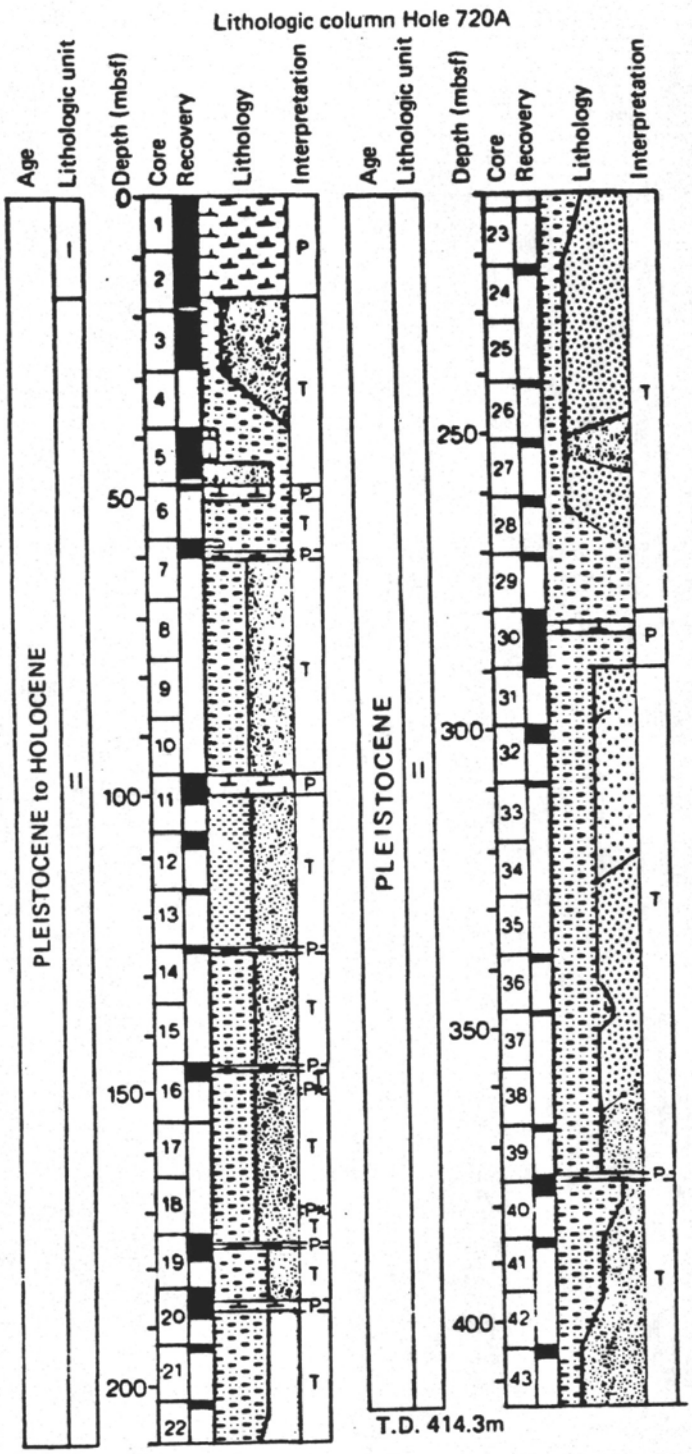

Lithologic column Hole 720A
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
Interpretation
PLEISTOCENE to HOLOCENE
PLEISTOCENE
I
II
0
50
100
150
200
250
300
350
400
P
T
T.D. 414.3m

Figure 3B.

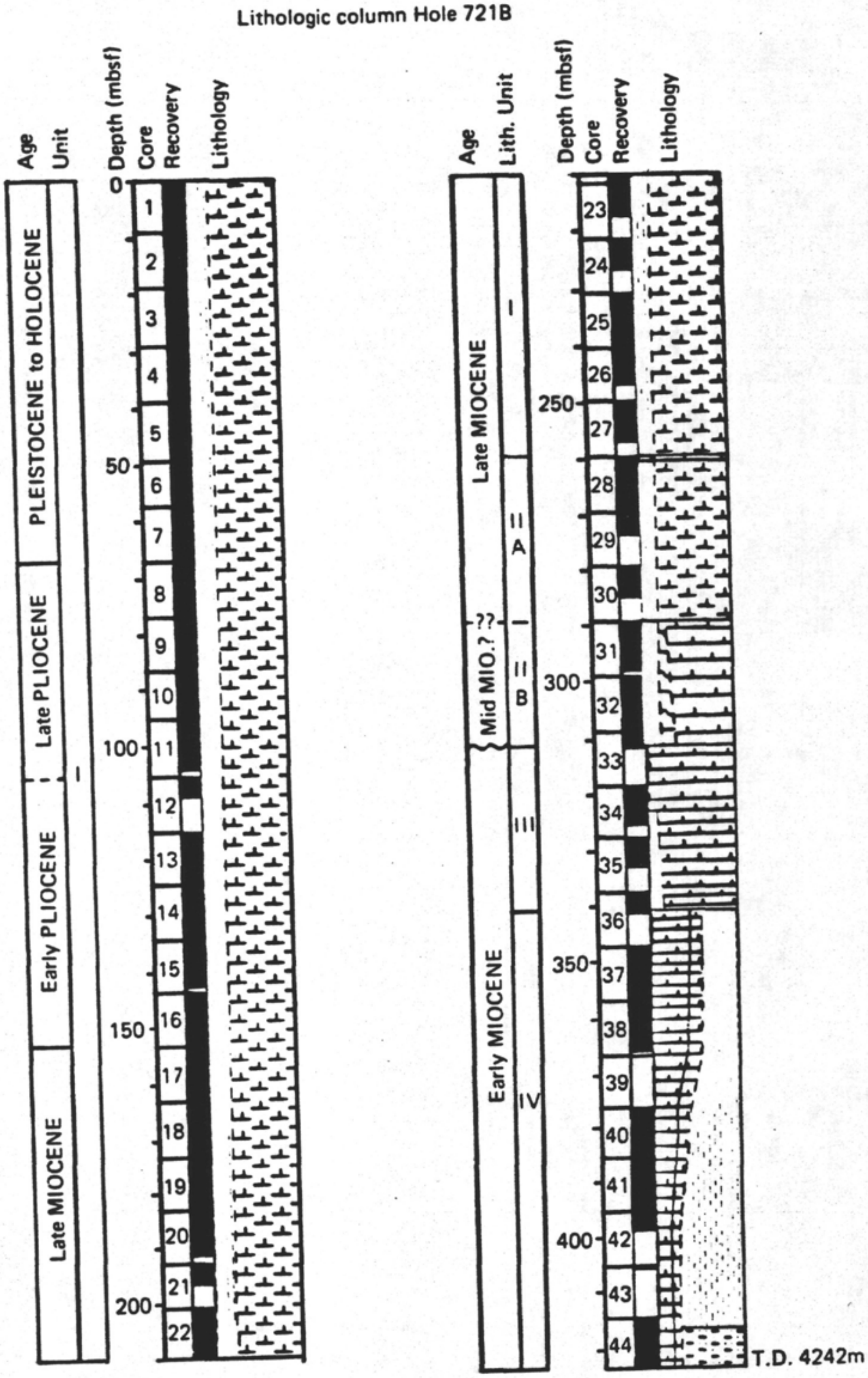

Lithologic column Hole 721B
Age
Unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE to HOLOCENE
Late PLIOCENE
Early PLIOCENE
Late MIOCENE
I
0
50
100
150
200
Lith. Unit
Late MIOCENE
Mid MIO.?
??
Early MIOCENE
II A
II B
III
IV
250
300
350
400
T.D. 4242m

Figure 4.

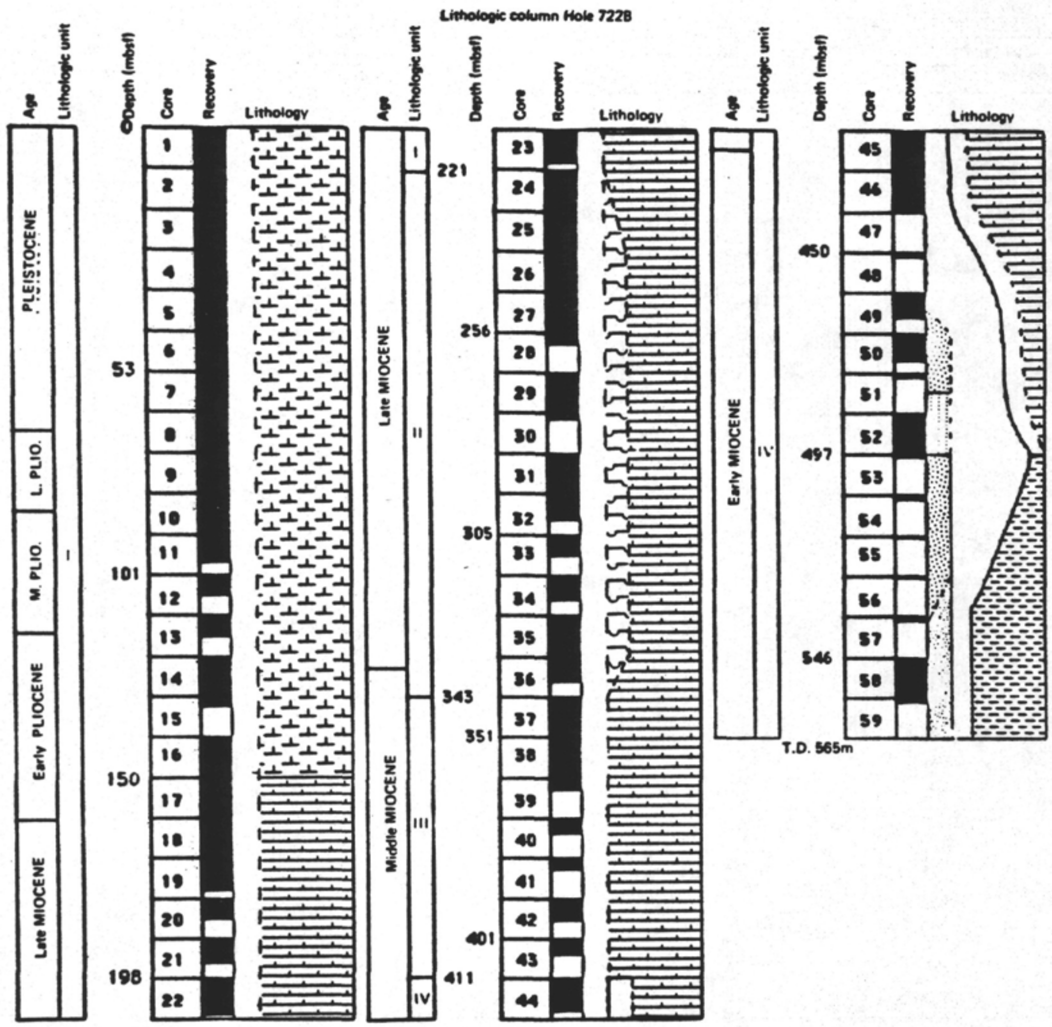

Lithologic column Hole 722B
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE
L. PLIO.
M. PLIO.
Early PLIOCENE
Late MIOCENE
Middle MIOCENE
Early MIOCENE
I
II
III
IV
53
101
150
198
221
256
305
343
351
401
411
450
497
546
T.D. 565m

Figure 5.

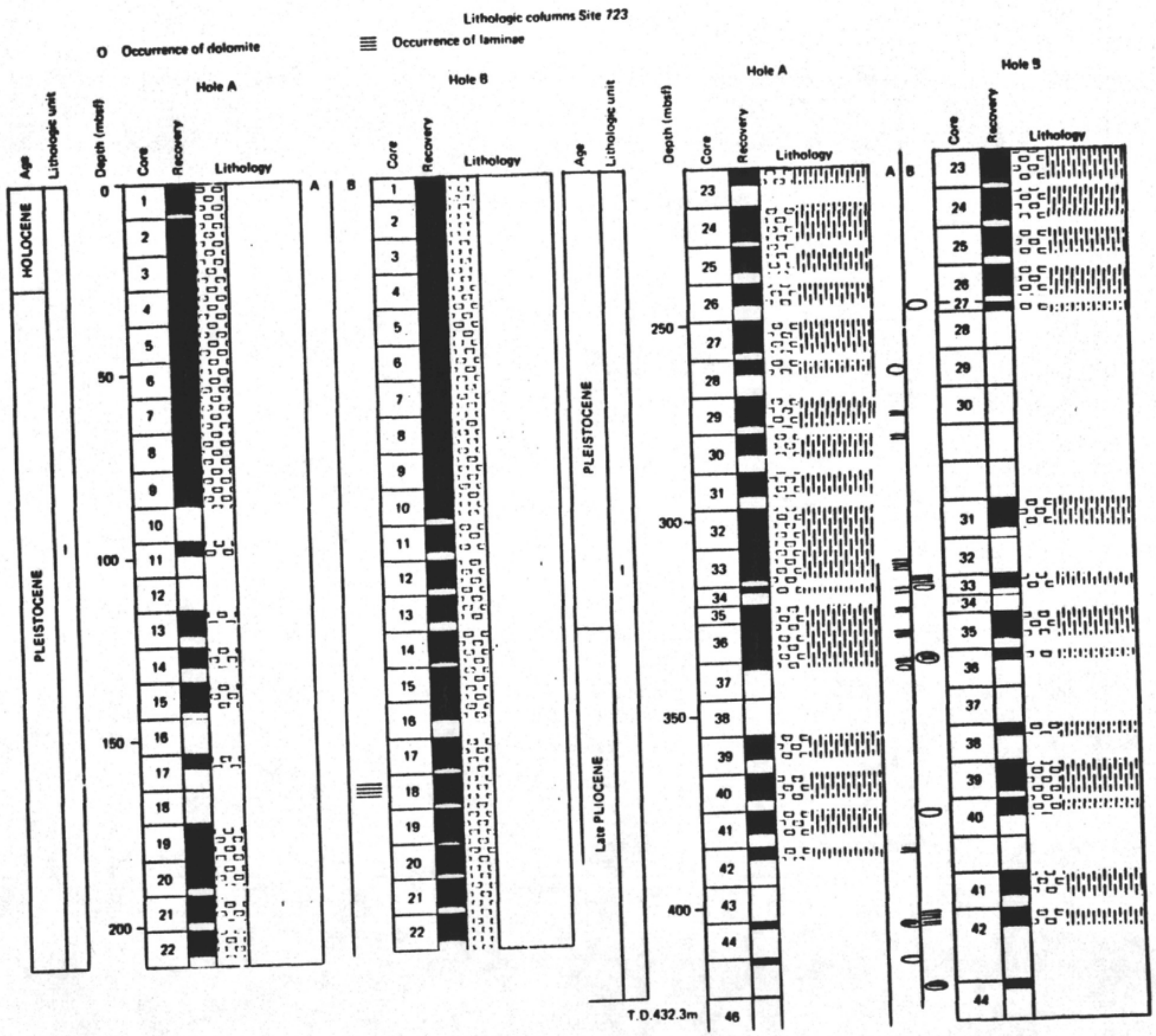

Lithologic columns Site 723
O Occurrence of dolomite
Occurrence of laminae
Hole A
Hole B
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
HOLOCENE
PLEISTOCENE
Late PLIOCENE
I
A
B
T.D.432.3m

Figure 6.

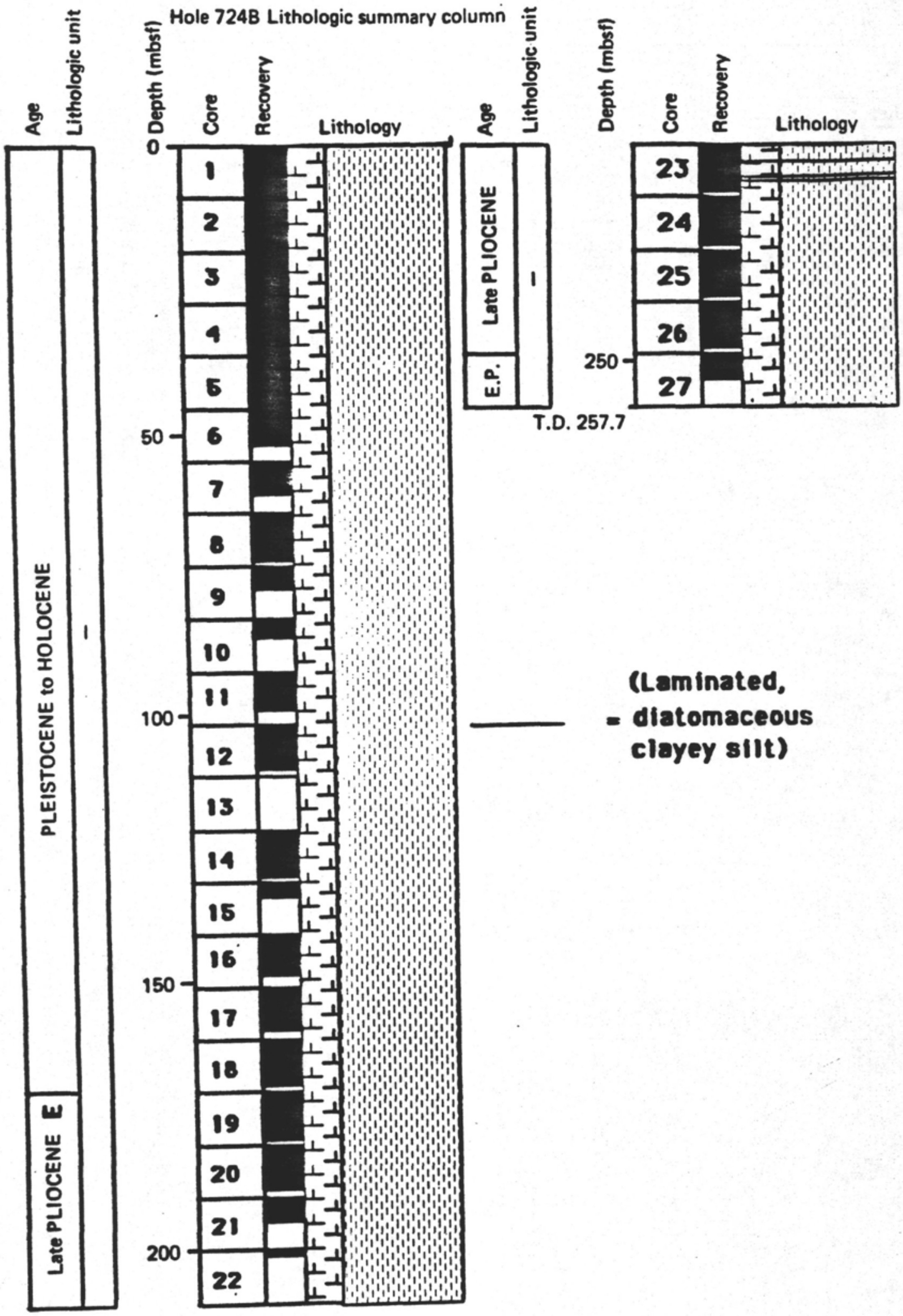

Hole 724B Lithologic summary column
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE to HOLOCENE
Late PLIOCENE
E
I
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Late PLIOCENE
E.P.
250
23
24
25
26
27
T.D. 257.7
(Laminated,
= diatomaceous
clayey silt)

Figure 7.

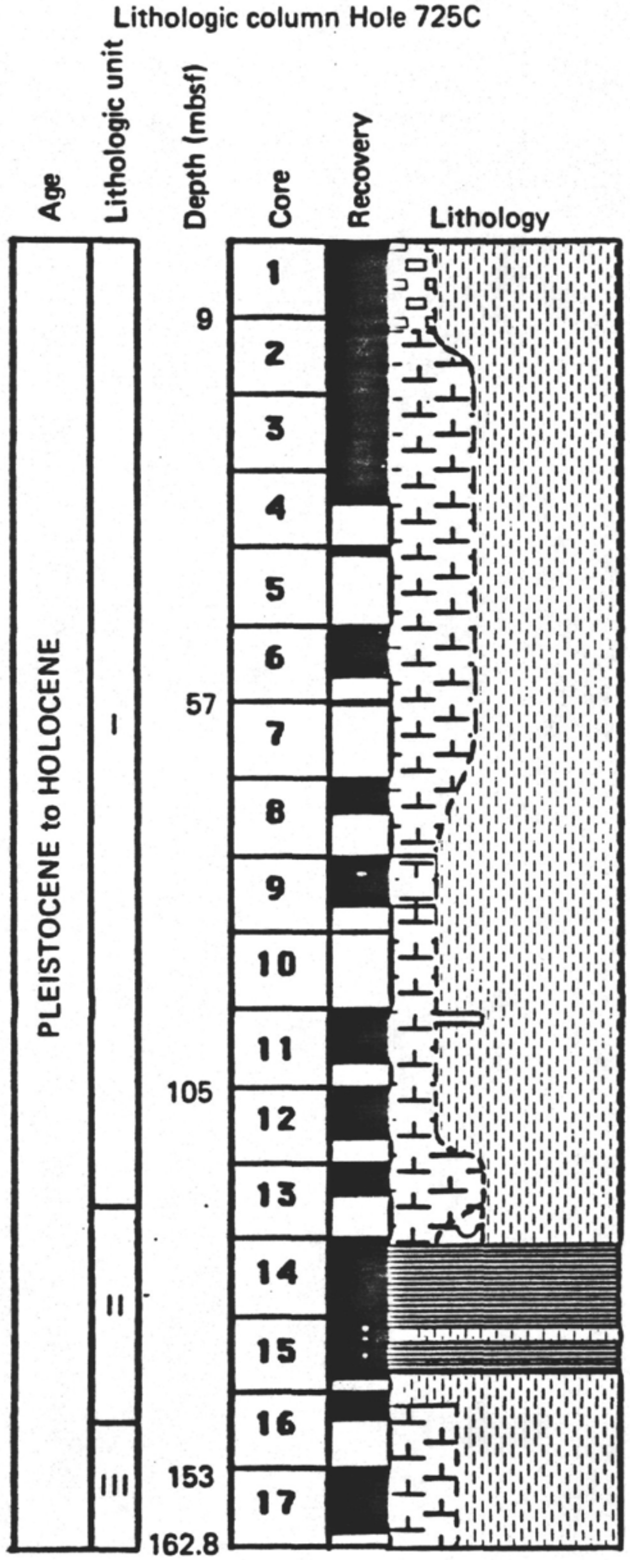

Lithologic column Hole 725C
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE to HOLOCENE
I
II
III
9
57
105
153
162.8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Figure 8.

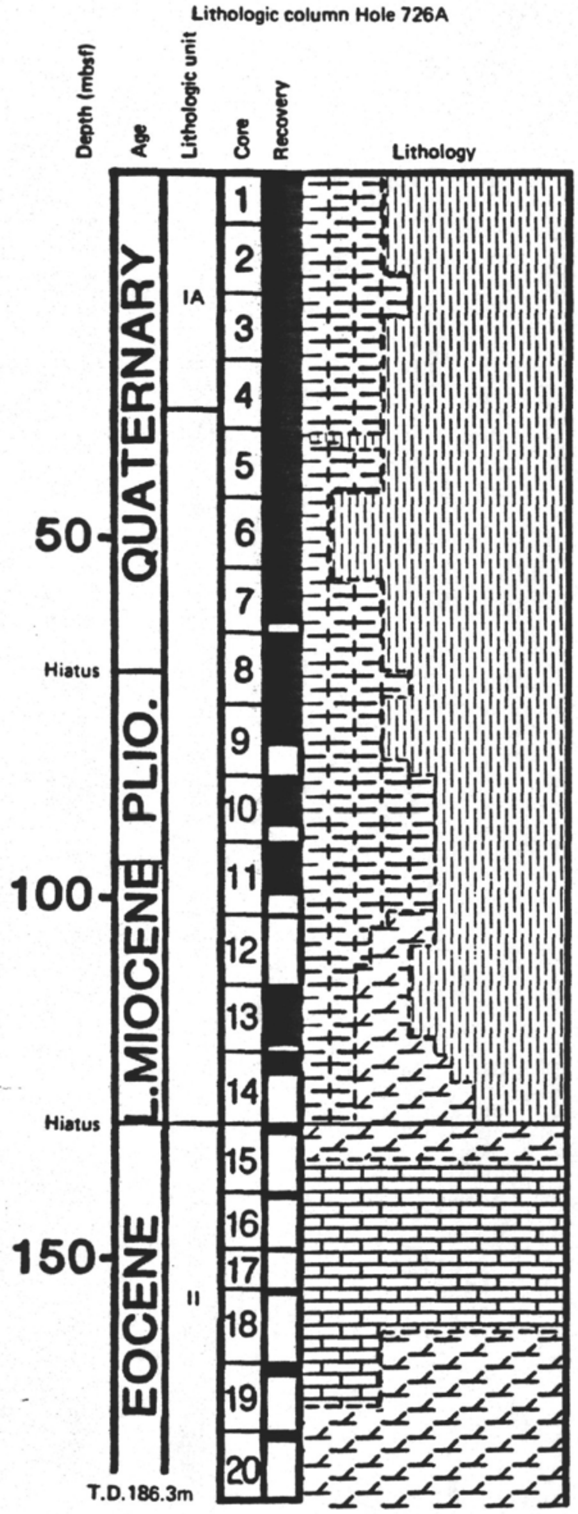

Lithologic column Hole 726A
Depth (mbsf)
Age
Lithologic unit
Core
Recovery
Lithology
50
100
150
Hiatus
Hiatus
T.D.186.3m
QUATERNARY
PLIO.
L.MIOCENE
EOCENE
IA
II
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Figure 9.

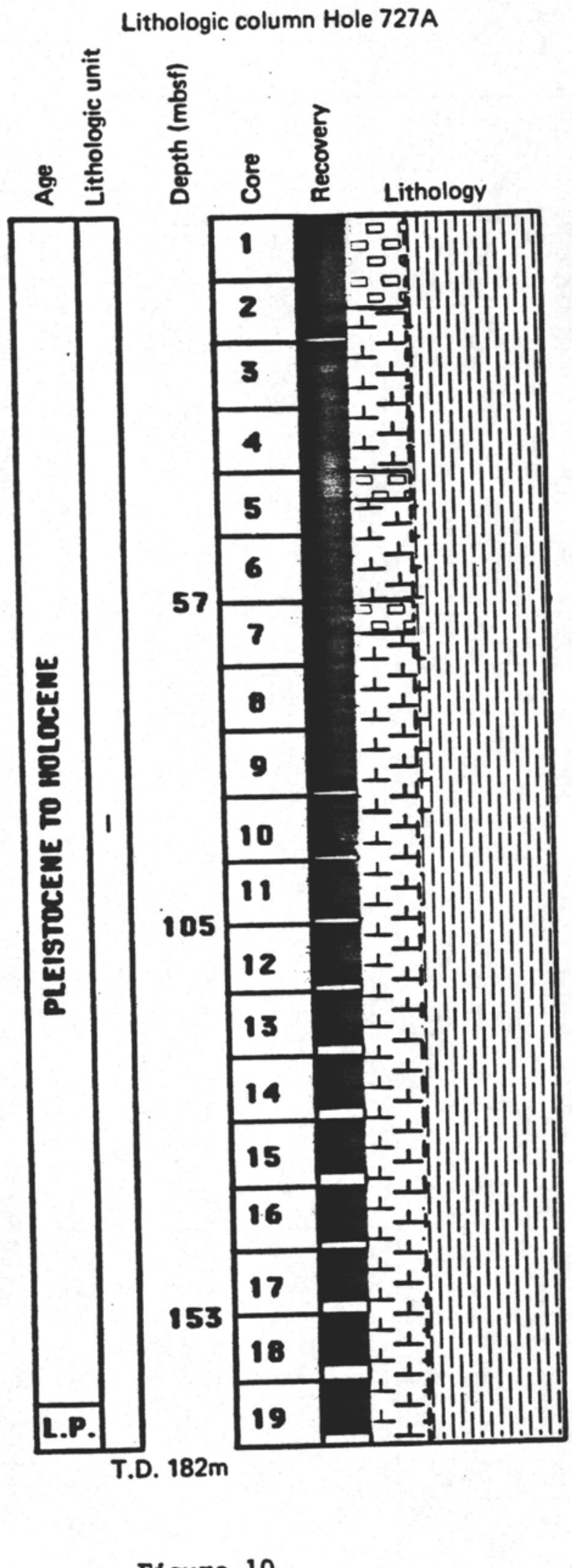

Lithologic column Hole 727A
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE TO HOLOCENE
L.P.
I
57
105
153
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
T.D. 182m

Figure 10.

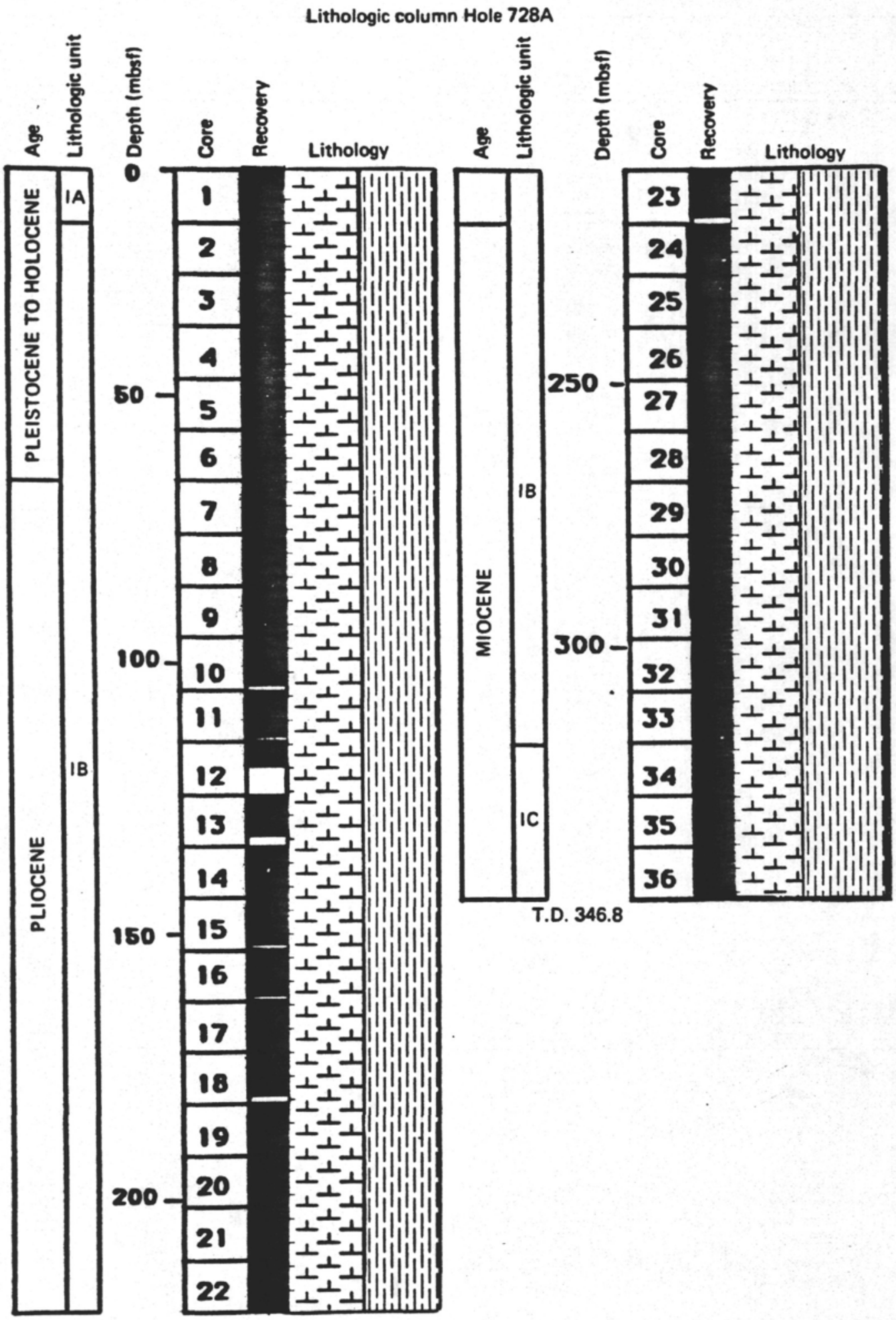

Lithologic column Hole 728A
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE TO HOLOCENE
PLIOCENE
IA
IB
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
MIOCENE
IB
IC
250
300
23
24
25
26
27
28
29
30
31
32
33
34
35
36
T.D. 346.8

Figure 11.

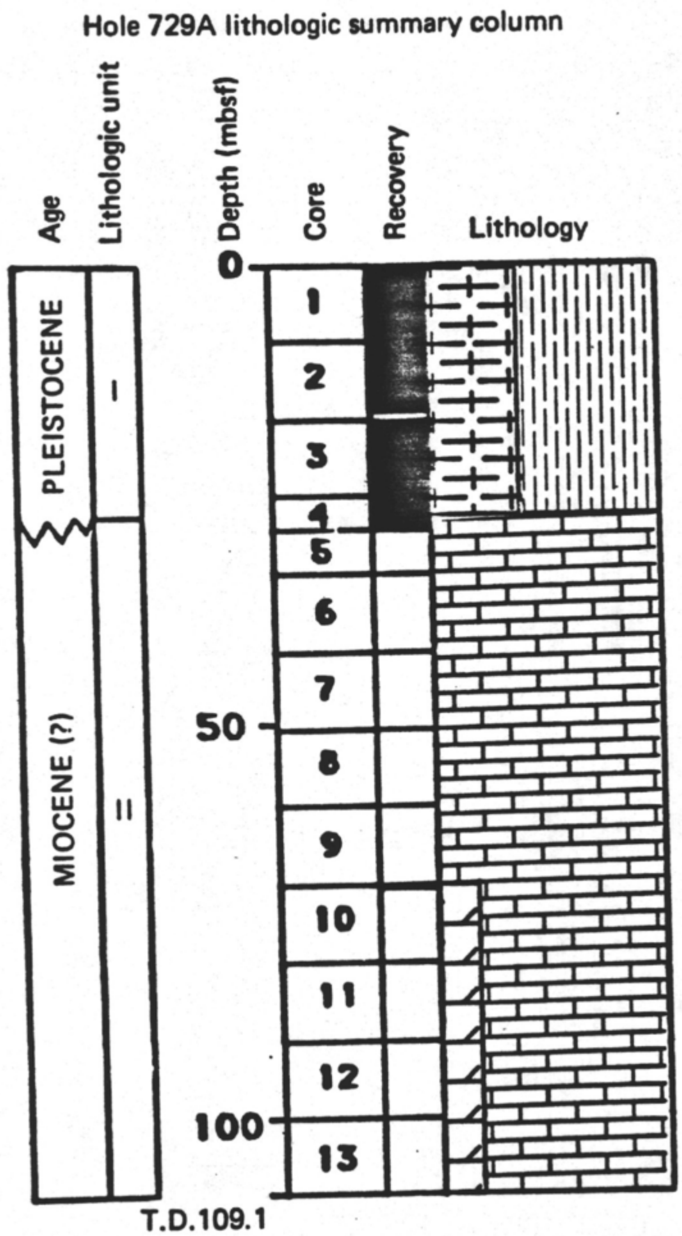

Hole 729A lithologic summary column
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE
MIOCENE (?)
I
II
0
50
100
1
2
3
4
5
6
7
8
9
10
11
12
13
T.D.109.1

Figure 12.

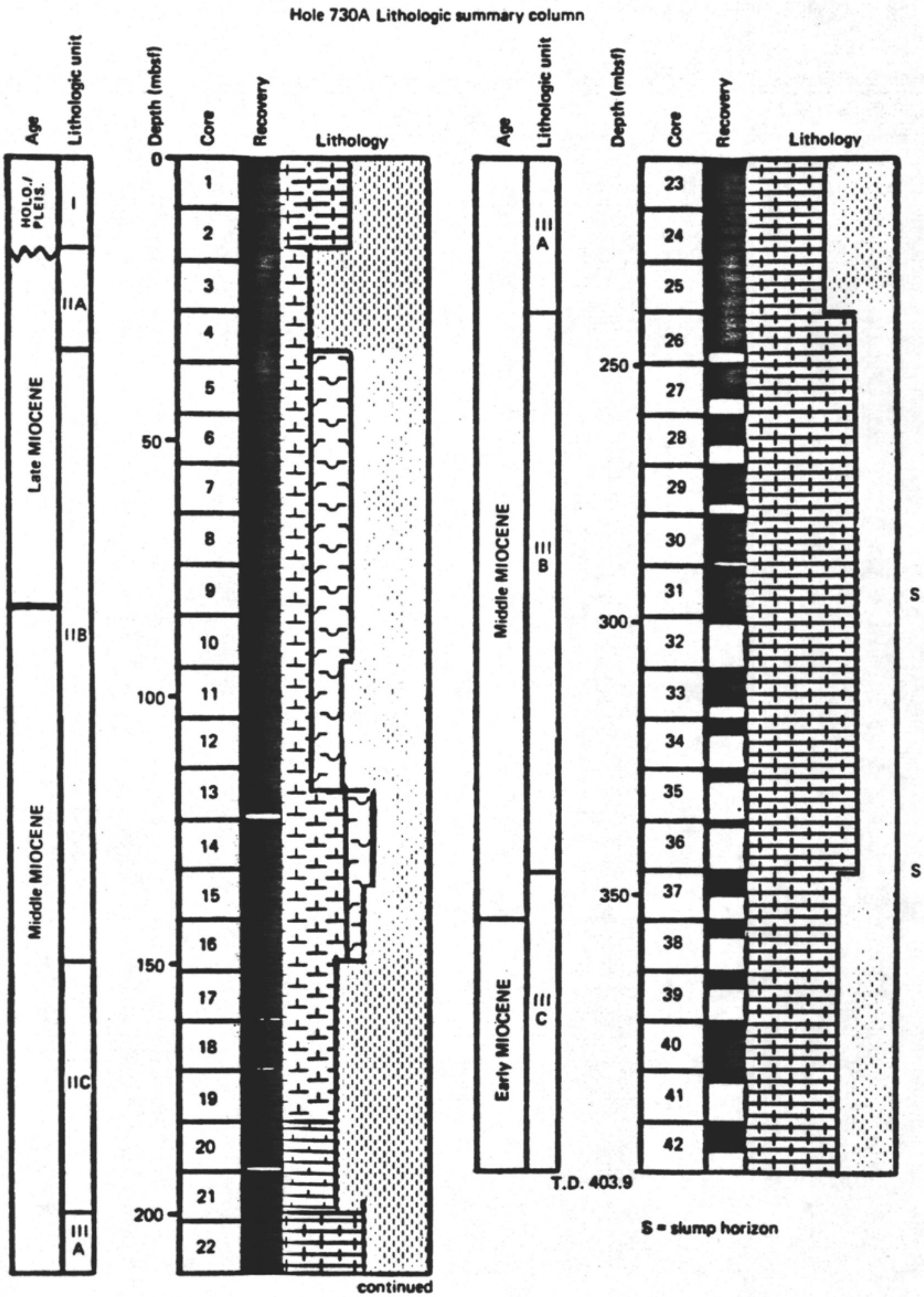

Hole 730A Lithologic summary column
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
HOLO./PLEIS.
I
IIA
Late MIOCENE
IIB
Middle MIOCENE
IIC
III A
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
continued
III A
Middle MIOCENE
III B
Early MIOCENE
III C
250
300
350
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
T.D. 403.9
S
S
S = slump horizon

Figure 13.

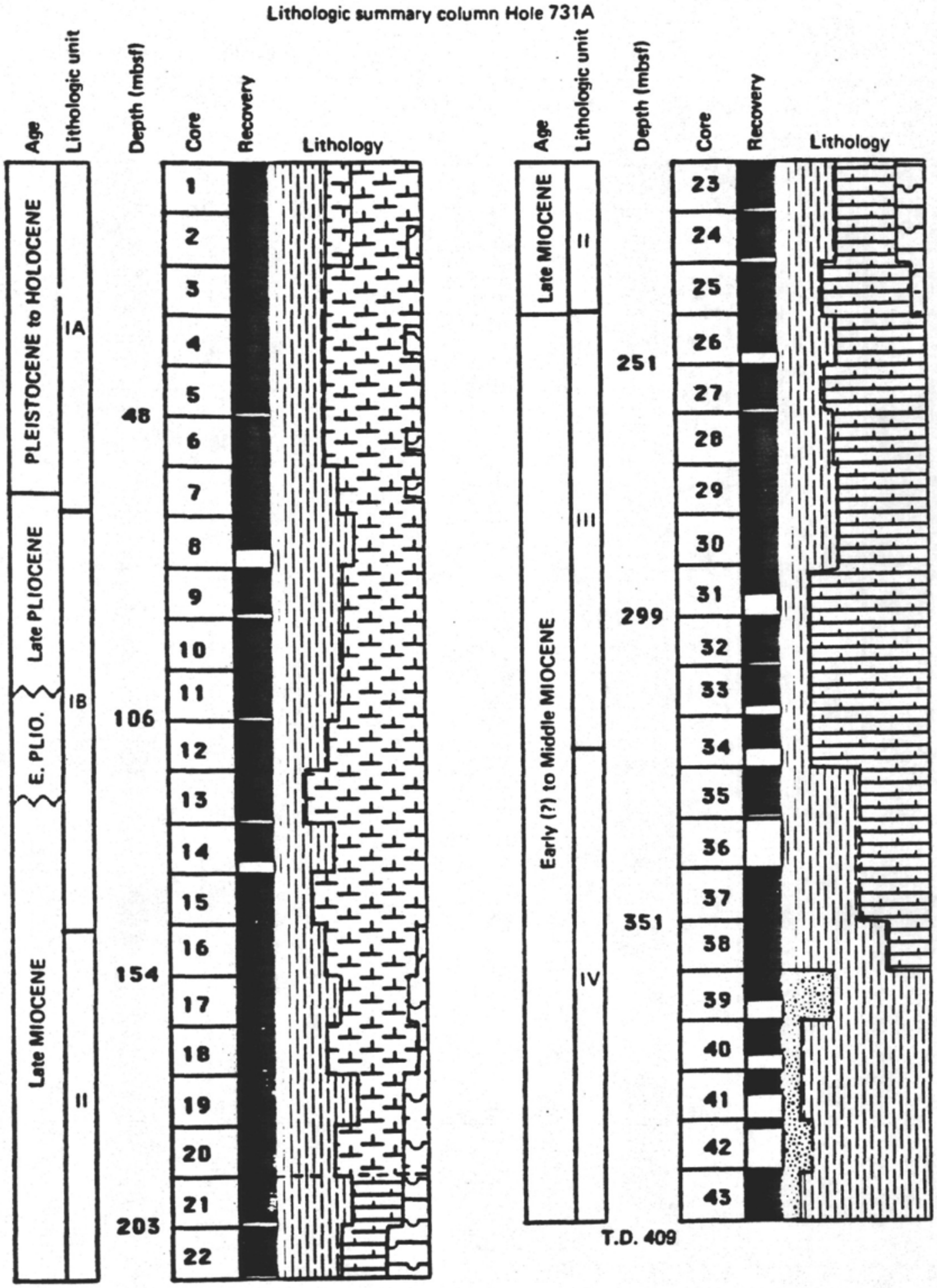

Lithologic summary column Hole 731A
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
PLEISTOCENE to HOLOCENE
Late PLIOCENE
E. PLIO.
Late MIOCENE
IA
IB
II
48
106
154
203
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Late MIOCENE
Early (?) to Middle MIOCENE
II
III
IV
251
299
351
T.D. 409
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43

Figure 14A.

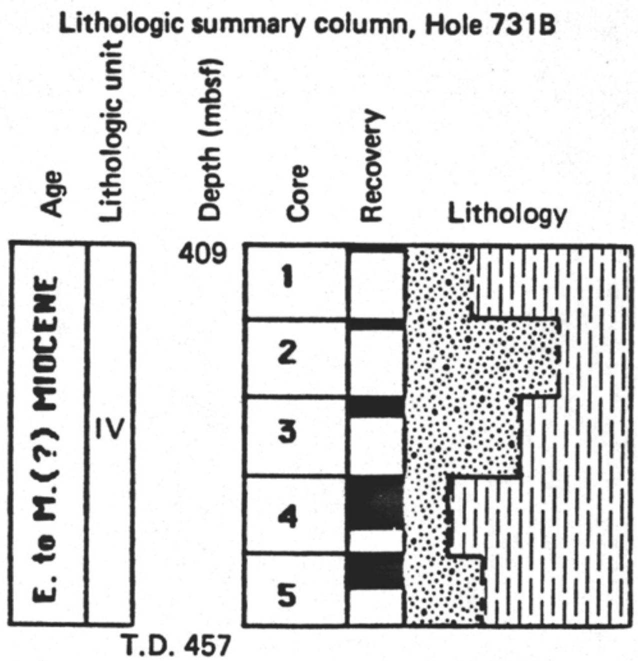

Lithologic summary column, Hole 731B
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
E. to M.(?) MIOCENE
IV
409
1
2
3
4
5
T.D. 457

Figure 14B.

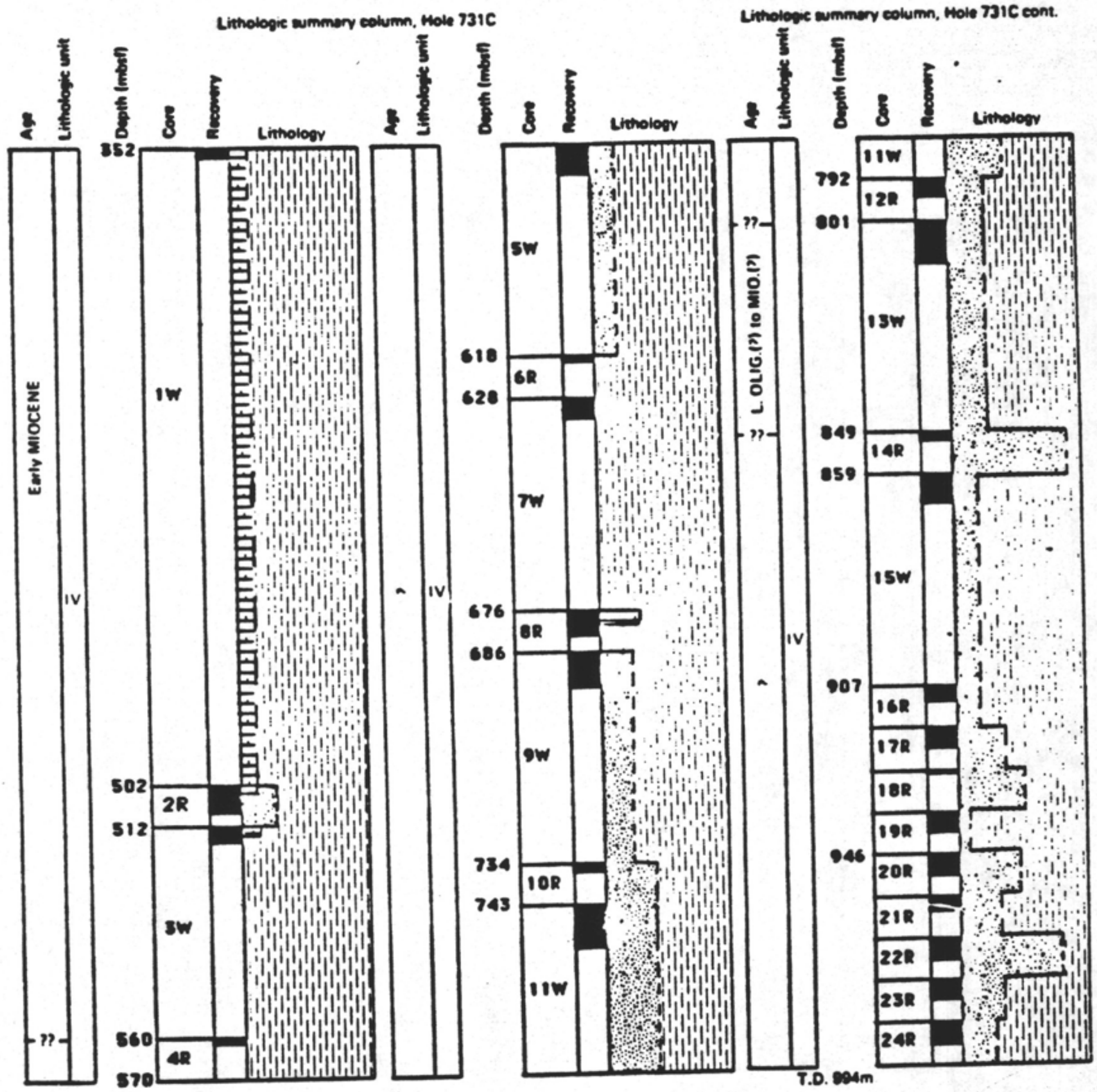
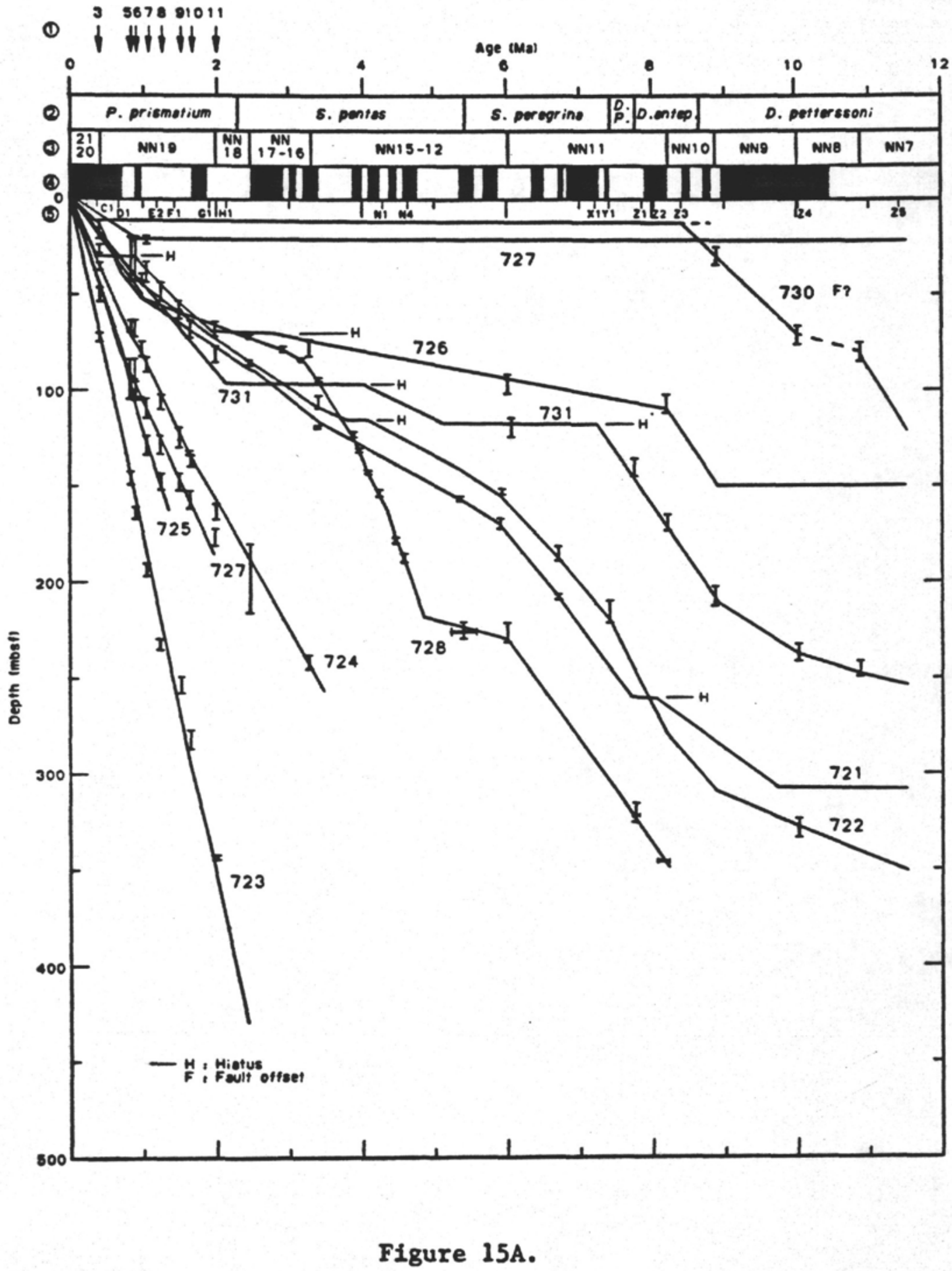
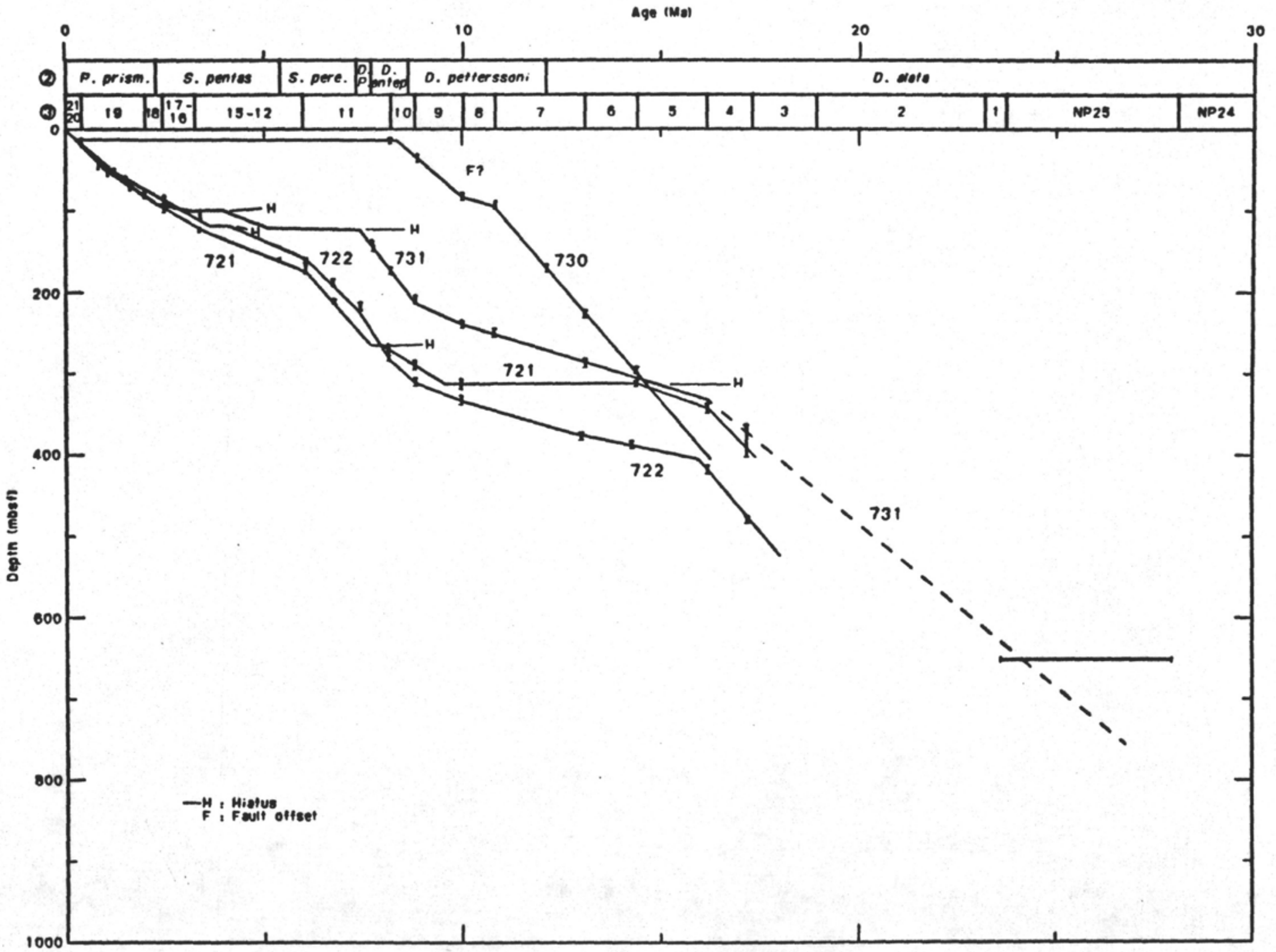

Lithologic summary column, Hole 731C
Lithologic summary column, Hole 731C cont.
Age
Lithologic unit
Depth (mbsf)
Core
Recovery
Lithology
Early MIOCENE
IV
L. OLIG.(?) to MIO.(?)
T.D. 994m
1W
2R
3W
4R
5W
6R
7W
8R
9W
10R
11W
12R
13W
14R
15W
16R
17R
18R
19R
20R
21R
22R
23R
24R
502
512
560
570
618
628
676
686
734
743
792
801
849
859
907
946

Figure 14C.



①
3 5 6 7 8 9 10 11
Age (Ma)
0
2
4
6
8
10
12
②
P. prismatium
S. pentas
S. peregrina
D. P.
D. antep.
D. petterssoni
③
21 20
NN19
NN 18
NN 17-16
NN15-12
NN11
NN10
NN9
NN8
NN7
④
⑤
727
730
F?
726
731
731
725
727
724
728
721
722
723
Depth (mbsf)
100
200
300
400
500
H : Hiatus
F : Fault offset

Figure 15A.



Age (Ma)
0
10
20
30
②
③
P. prism.
S. pentas
S. pere.
D. P
D. antep
D. petterssoni
D. alata
21 20
19
18
17-16
15-12
11
10
9
8
7
6
5
4
3
2
1
NP25
NP24
Depth (mbsf)
0
200
400
600
800
1000
F?
H
721
722
731
730
—H : Hiatus
F : Fault offset

Figure 15B.

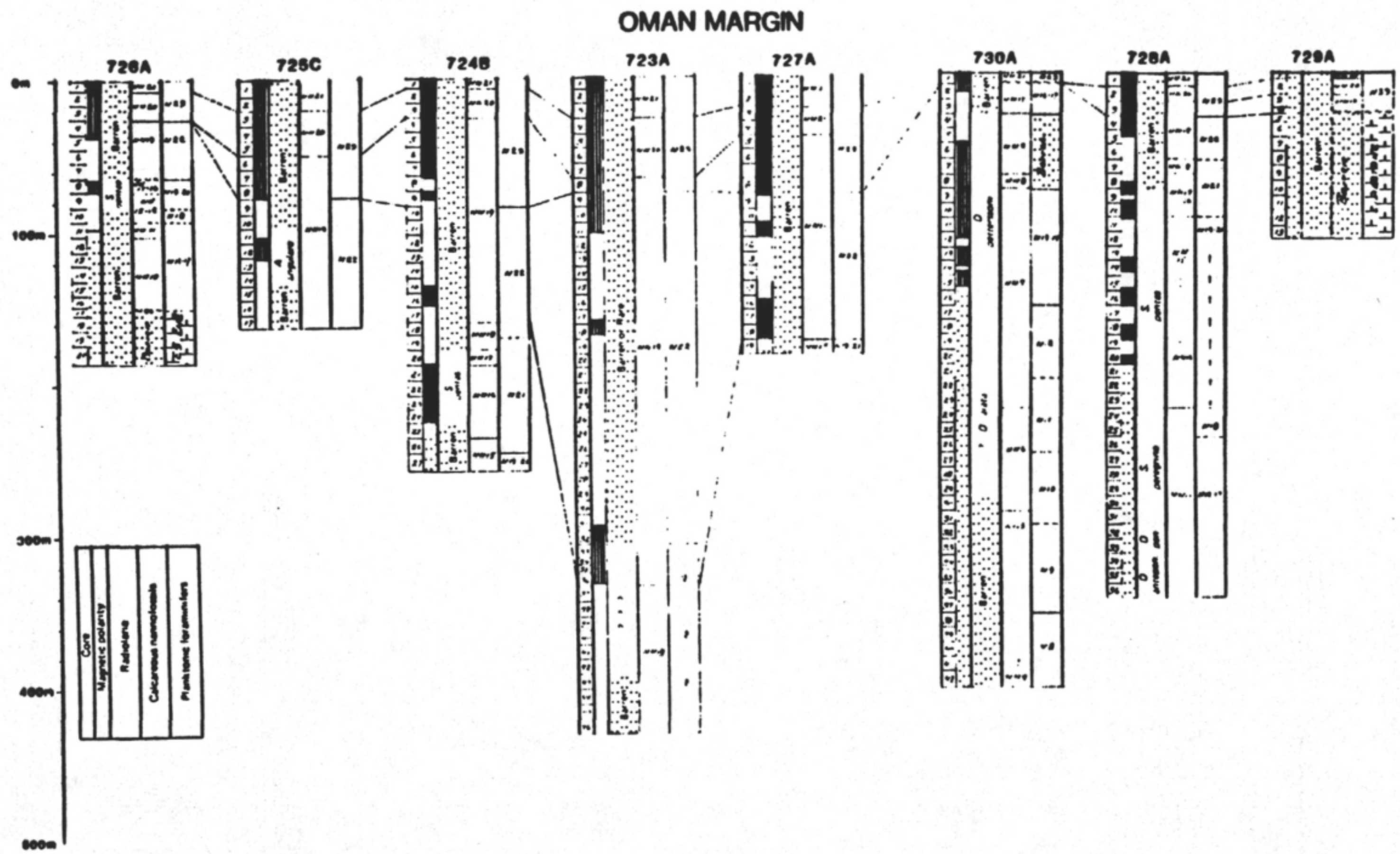

OMAN MARGIN
726A
725C
724B
723A
727A
730A
728A
729A
Core
Magnetic polarity
Radiolaria
Calcareous nannofossils
Planktonic foraminifers

Figure 16A.

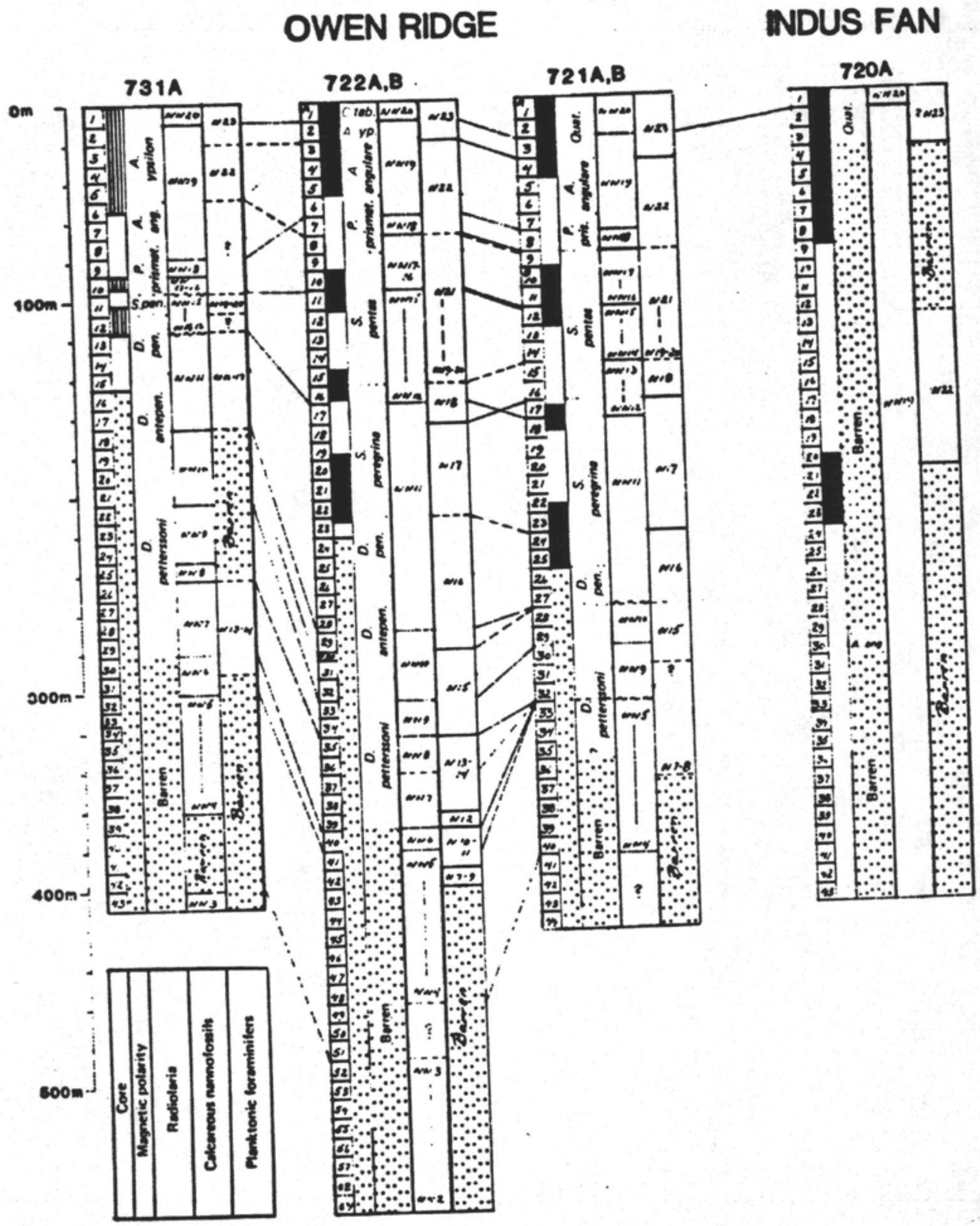

OWEN RIDGE
INDUS FAN
731A
722A,B
721A,B
720A
0m
100m
300m
400m
500m
Core
Magnetic polarity
Radiolaria
Calcareous nannofossils
Planktonic foraminifers
Barren

Figure 16B.

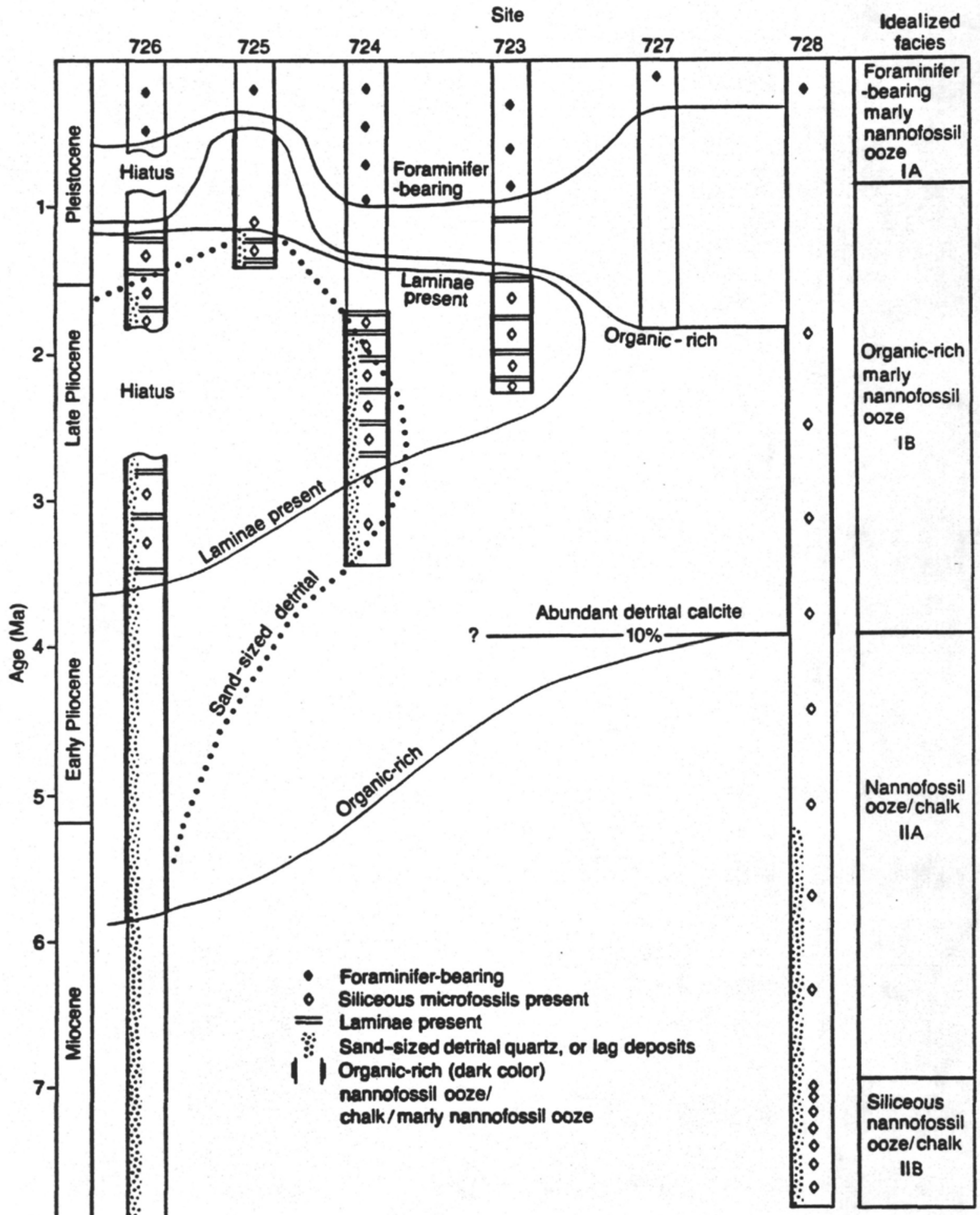
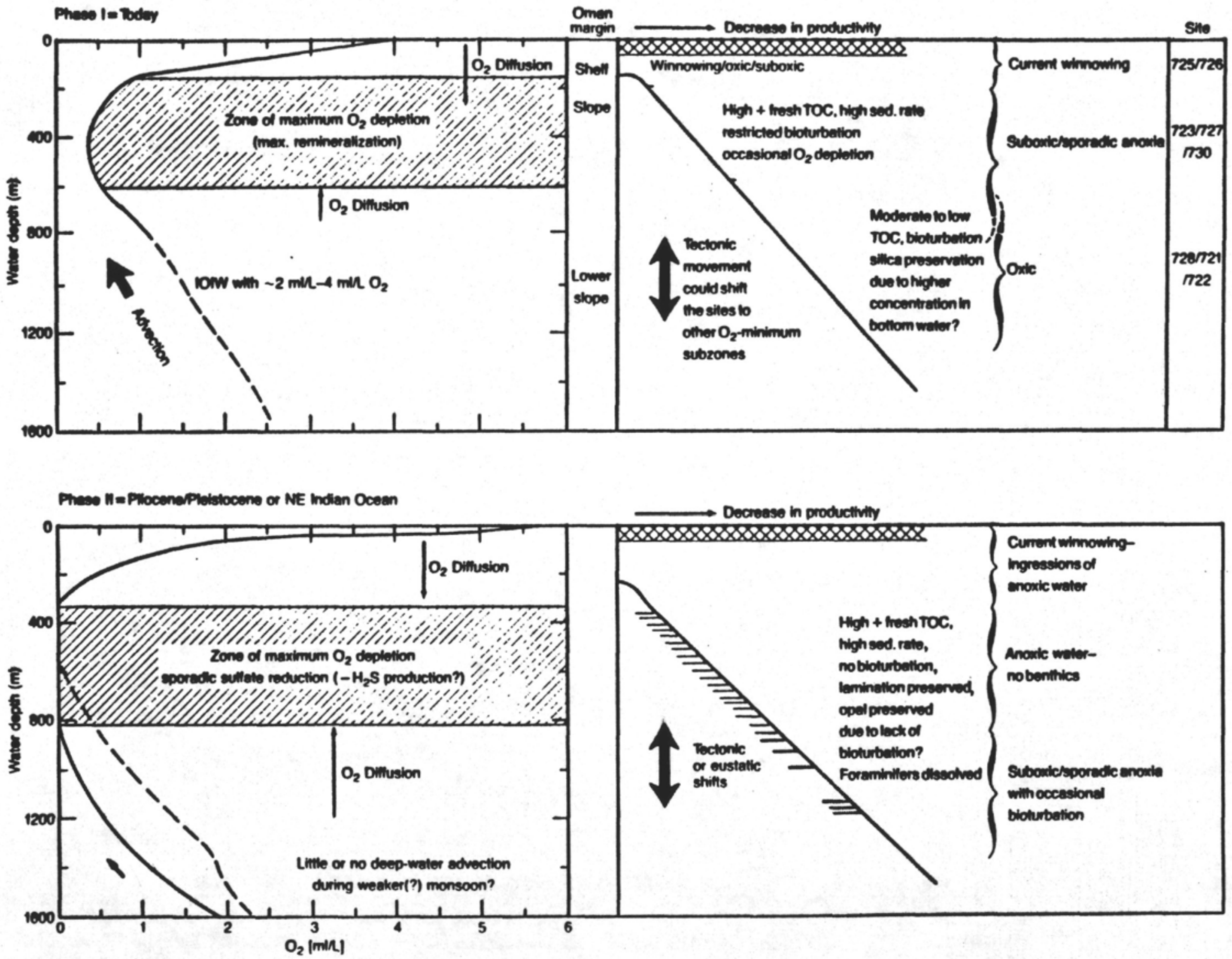

Site
726
725
724
723
727
728
Idealized facies
Foraminifer -bearing marly nannofossil ooze
IA
Organic-rich marly nannofossil ooze
IB
Nannofossil ooze/chalk
IIA
Siliceous nannofossil ooze/chalk
IIB
Pleistocene
Late Pliocene
Early Pliocene
Miocene
Age (Ma)
1
2
3
4
5
6
7
8
Hiatus
Hiatus
Foraminifer -bearing
Laminae present
Organic - rich
Laminae present
Sand-sized detrital
Abundant detrital calcite
?
10%
Organic-rich
Foraminifer-bearing
Siliceous microfossils present
Laminae present
Sand-sized detrital quartz, or lag deposits
Organic-rich (dark color) nannofossil ooze/ chalk/marly nannofossil ooze

Figure 17.



Phase I = Today
Oman margin
Decrease in productivity
Site
O_2 Diffusion
Shelf
Winnowing/oxic/suboxic
Current winnowing
725/726
Slope
Zone of maximum O_2 depletion
(max. remineralization)
High + fresh TOC, high sed. rate
restricted bioturbation
occasional O_2 depletion
Suboxic/sporadic anoxia
723/727
/730
O_2 Diffusion
Water depth (m)
Moderate to low
TOC, bioturbation
silica preservation
due to higher
concentration in
bottom water?
Tectonic
movement
could shift
the sites to
other O_2-minimum
subzones
Lower
slope
IOIW with ~2 ml/L–4 ml/L O_2
Advection
Oxic
728/721
/722
0
400
800
1200
1600
Phase II = Pliocene/Pleistocene or NE Indian Ocean
Decrease in productivity
O_2 Diffusion
Current winnowing–
ingressions of
anoxic water
Zone of maximum O_2 depletion
sporadic sulfate reduction (– H_2S production?)
High + fresh TOC,
high sed. rate,
no bioturbation,
lamination preserved,
opal preserved
due to lack of
bioturbation?
Foraminifers dissolved
Anoxic water–
no benthics
O_2 Diffusion
Tectonic
or eustatic
shifts
Suboxic/sporadic anoxia
with occasional
bioturbation
Little or no deep-water advection
during weaker(?) monsoon?
0
1
2
3
4
5
6
O_2 (ml/L)

Figure 18.

OPERATIONS REPORT

The Operations and Engineering personnel aboard JOIDES Resolution for Leg 117 were:

Operations Superintendent	Lamar Hayes
Special Tools Engineer	Alan Milton
Weather Observer	Ferrell Johnson

INTRODUCTION

Leg 117 began on 19 August 1987, when the first line was received at Colombo harbor, Sri Lanka. The leg ended at Port Louis, Mauritius, 57 days later on 18 October 1987. During this leg, JOIDES Resolution traveled 4409 nmi and cored 25 holes at 12 sites. Some of the highlights of this leg are the following:

- A new recovery record was established with 4367 m of core recovered, in which over 3000 m was recovered with the XCB system.
- A new XCB bit seal (pollypack) system was tested and used successfully on all XCB holes after the first site.
- Five holes were logged successfully, two of which were logged through the lockable flapper valve (LFV).
- The leg was completed with no equipment down-time.

PORT CALL, COLOMBO, SRI LANKA

Leg 117 officially commenced when the first line was received at Colombo fuel dock at 0914 hr, 19 August 1987. A total of 1062.6 MT of fuel was taken on board. After receiving fuel, the ship was turned with the port side nearest the dock to allow use of the port cranes. The cores from Legs 115 and 116 were offloaded. Air freight and surface freight shipments were taken aboard. The pipe handling and traveling equipment was magnafluxed. Sixty "big bags" of cement were blown into the cement "P" tanks. Fifteen hundred MT of potable water was taken aboard.

COLOMBO TO THE FIRST SITE

The last line was received on board at 2200 hr, 23 August. During pilotage, while leaving the quayside, JOIDES Resolution came into brief contact with the harbor wall. This resulted in a sewage line being damaged, which in turn slowed the underway progress of the vessel to 5.5 kt because of water intake into the ODP heavy tools storage area. The damage was repaired and full speed was resumed at 0300 hr, 24 August 1987. A course heading of 295° was set for the first site. The magnetometer gear was deployed during the passage. Work was conducted on the modified lockable flapper valves and one was assembled and readied for use. A hydraulic bit release and a mechanical bit release were also worked on and assembled for use.

During the passage to the first site, the ship encountered strong monsoon winds of 35-40 kt and heavy seas and swells, which slowed the speed to 9.5-10 kt.

SITE 720 (TARGET SITE IN-1)

Hole 720A

The pipe was being tripped through the rotary table by 1115 hr and the mud line was established at 4045.3 m at 2400 hr on 23 August. Three APC cores were recovered at a recovery rate of 99.4%, until 40,000 lb of overpull in sands below Core 117-720A-3H made XCB coring necessary. Recovery declined dramatically in silty sands and sands retrieved in Cores

117-720A-4X to 117-720A-43X, and average recovery dropped to 15.7%. Overall rate of recovery of Hole 720A, drilled to a total depth of 414.3 mbsf with Core 117-720A-43X, was 21.6%.

In light of the poor recovery, coring was terminated at 1130 hr on 1 September. The hole was conditioned for logging by sweeping with 30 bbl of gel and by a wiper trip to 70 mbsf. Maximum overpull at this stage was 20,000 lb. On 1 September at 2230 hr, the pipe was set at 70 mbsf and the three-string Schlumberger tool was rigged and lowered. After a successful run with the DIT/LSS/GR combination in the interval 4458-4152 mbsf, the tool became stuck on the way out at a bridge 20 m below the bottom-hole assembly (BHA). An attempt to crimp the tool and cut the logging wire to retrieve the tool with the pipe failed and the tool was lost with about 2000 m of logging wire. Hole 720A was cleared by 1430 hr on 2 September, and the ship was under way to Site 721 by 2100 hr.

SITE 721 (TARGET SITE OR-1)

Holes 721A-C

The vessel departed Site 720 at 2100 on 2 September for the area of the Owen Ridge target sites OR-1 and OR-2. Because of the proximity of target sites OR-1 and OR-2, it was decided to survey both locations on approach to OR-1, and the seismic gear was deployed upon departure from Site 720. Good GPS coverage ensured accurate positioning throughout the survey and site approach, and a high-resolution positioning chart was obtained for the ship's track. When the target location of Site 722 (OR-2) was reached at 0900 hr on 3 September, a beacon was dropped and the ship continued her approach to Site 721 (OR-1), where the beacon was dropped at 1100 hr, in a wter depth of 1949-1952 m.

Nine APC cores were drilled with a maximum overpull of 10,000 lb with excellent recovery (100%) to a total depth for Hole 721A of 86.4 mbsf. Core 117-721A-10H stuck in a clay-rich interval, and the core barrel failed at 140,000 lb overpull, so that Hole 721A had to be abandoned.

Hole 721B was spudded 20 m west of Hole 721A at 0017 hr on 4 September. Nine APC cores recovered 100% of the cored section to 86.0 mbsf. Because of an increase of overpull to 25,000 lb, the drilling mode was switched to XCB coring from Core 117-721B-10X. Forty-four cores were drilled to the target depth of 424.2 mbsf with an average recovery of 81%. After clearing the mud line, the ship positioned 20 m west of Hole 721B and spudded Hole 721C at 0335 hr on 6 September. Ten APC cores yielded 100% recovery to a depth of 89.9 mbsf, where a maximum overpull of 35,000 lb necessitated a switch to XCB coring. Overall recovery was 97% in the 138.6 m total depth of Hole 721C. The in-situ wireline pore-water sampler was deployed twice in Hole 721. At 2230 hr on 6 September the mud line was cleared and the ship relocated to Site 722.

SITE 722 (TARGET SITE OR-2)

Holes 722A and 722B

Moving the ship 6 nmi in dynamic positioning mode while tripping pipe, the rig relocated from Site 721 at 0230 hr on 7 September to the beacon dropped at Site 722 during the joint survey for Sites 721 and 722. The first core was shot at 0455 in 2034.0 m water depth.

Hole 722A was cored by APC to Core 117-722-9H (86.5 mbsf), when overpull rose to 50,000 lb from the previous 5,000 lb and made deployment of the XCB necessary. Cores 117-722A-5H to 117-722A-9H were oriented. Recovery of the nine APC cores averaged 102%. Core 722A-29X was the last core to be cut in Hole 722A, which reached a total depth of 280.0 mbsf. Recovery in the XCB mode averaged 71%, so that the overall recovery rate in Hole 722A averaged 80.7%. The hole was terminated at this depth because the in-situ pore water sampler (PWS) became stuck in the flapper valve. The drill string had to be pulled to retrieve the PWS; upon inspection of the BHA the tool was found to be stuck at the flapper and was recovered on the rig floor. The ship offset 20 m to the northwest, where Hole 722B was spudded at 1615 hr on 8 September.

In order to obtain the mud line and to overlap the cores of Holes 722A and 722B, the bit was positioned 5 m above the mud line, where Core 117-722B-1H was shot. Ten APC cores with an average recovery of 103% were drilled to 91.9 mbsf, below which 25,000 lb of overpull in Core 117-722B-10H made continuation by XCB necessary. Oriented cores were taken from Core 117-722B-7H to 117-722B-10H. A total depth of 565.1 mbsf was reached with Core 117-722B-59X on 10 September. The average recovery for the XCB system was 61% and varied widely in response to variable lithology and sediment lithification. Overall recovery for Hole 722B was 68.3%.

Wiper trips to total depth and sweeping with polymer conditioned the hole for logging with the Side Entry Sub to facilitate removal of potential bridges. After two runs with the shifting tool to release the bit, the BHA was positioned 90 mbsf at the bottom of the section excellently recovered by APC. A string consisting of Sonic/Gamma Ray/Resistivity/Caliper tools was deployed first and obtained a good log from approximately 558 mbsf to the BHA at 90 mbsf in the first run. A second string with LDT/CNL/NGT tools was disabled by a short in the cable head, repaired, and deployed a second time. The run failed because of a defect in the swivel head of the tool, and it was decided to log without the SES after good hole conditions were established by running the pipe to the bottom of the hole. The third deployment of logging string #2 was successful, and good logs were obtained from 90 mbsf to 558 mbsf (7 m above total depth).

Upon retrieval of logging string #2, the bow spring of the tool became stuck at the end of the BHA. Eight thousand lb of pull on the logging line failed to free the tool and a crimping tool was pumped down to crimp the logging line and subsequently cut it with a Kinley cutter. In order to be able to reenter the hole if the crimper had failed to hold the tool, a minicone was deployed before the drill string was pulled. The tool was found stuck in the BHA upon retrieval.

TRANSIT TO MASIRAH AND SITE 723

JOIDES Resolution departed Site 722 on 13 September en route to the island of Masirah (Oman) in order to pick up two Omani geologists who participated in the remainder of the leg. The rendezvous point was reached on 14 September at 0815 hr. By 0930 hr the helicopter had departed, and the ship set course for Site 723 (target site OM-1). On the approach to Site 723, the gear was streamed at 0700 hr on 15 September and by 1145 hr the location of Site 723 had been chosen. The first beacon was lowered on a taut wire in 816 m water depth. Erratic beacon signals necessitated the deployment of two more beacons.

SITE 723 (TARGET SITE OM-1)

Holes 723A-C

The mud line of Hole 723A was shot at 1645 hr and Hole 723A was cored to 85.1 mbsf using the APC (Cores 117-723A-1H to 117-723A-9H) with an average recovery rate of 104%. Gas expansion and strong H_2S odors were noted throughout. An overpull of 80,000 lb during retrieval of Core 117-723A-9H made the switch to XCB drilling necessary at this level, and coring was continued to Core 117-723A-46X (432.3 mbsf total depth). Recovery in the 347.2 m interval cored by XCB was 60%, so that the gross recovery of Hole 723A was 69%.

The ship offset 10 m to the south on 16 September, where the mud line of Hole 723B was cored at 0530 hr. Nine APC cores were taken to a depth of 81.6 mbsf with an average recovery rate of 104%, until a maximum overpull of 70,000 lb was reached. Drilling to 429.0 mbsf total depth in XCB mode recovered 66% of the cored section. It was decided to drill ahead with a center bit in that part of the hole, where dolomite stringers and nodules prevented recovery of any sediment (Core 117-723B-30X). Average recovery for the entire hole amounted to 73.7%. Some core was lost through core expansion. Even though most of the gas pressure appeared to be due to high CO_2 pressure, the C_1/C_2 ratio in vacutainer gas samples had decreased to 800 in Core 117-723B-40X. The last sample taken from Core 117-723B-44X had a ratio of 1400. Coring terminated after cutting Core 117-723B-44X and seeing no improvement in recovery.

Prior to logging, the Lockable Flapper Valve (LFV) was tested successfully with a dummy core barrel run on the sand line. After a wiper trip to total depth and sweeping with polymer, a go-devil was pumped down to lock open the LFV for logging and the hole was displaced with polymer mud. The BHA was positioned at 90 mbsf for the first logging run with the DIT/BHC/GR/CAL combination tool. The second string used the LDT/CNL/NGT combination tool, and the third string employed GST and ACT tools. Except for slight hardware problems upon retrieval of the second run, all logs were of good quality and successful. After completion, the BHA was pulled clear of Hole 723B by 1415 hr on 19 September.

Hole 723C was spudded by 1430 hr without offsetting the ship, and eight APC cores were shot to a total depth of 76.8 mbsf. Upon retrieval of Core 723C-8H, constant overpull of 100,000 lb was needed, so that shooting a ninth core, which was planned as the deepest core for the hole, was not attempted. The pore water sampler was deployed after cores 723C-5H, 723C-7H and 723C-8H. The recovery rate of Hole 723C was 107%. The mud line was cleared, the taut-wire beacon was retrieved, and the ship was under way to Site 724 by 0030 hr on 20 September.

SITE 724 (TARGET SITE OM-3)

Holes 724A-C

After locating the site on the survey line, the beacon was lowered on a taut wire in 602.5 m water at 1045 hr, and the mud line was shot at 1200 hr on 20 September. After successfully coring to Core 117-724A-5H in APC mode (0.0-44.5 mbsf; 100.7% recovery), the core barrel parted at retrieving Core 117-724A-6H at 120,000 lb overpull and Hole 724A had to be abandoned.

Hole 724B was spudded at 1600 hr on 20 September without offsetting the ship and 5 APC cores averaging 102% recovery were obtained from the interval 0.0-45.0 mbsf before switching to XCB coring mode. Coring of Hole 724B ended at a total depth of 257.7 mbsf, the target depth, after cutting Core 117-724B-27X. Average recovery in 22 XCB cores was 79%. As was the case at Site 723, core expansion caused by gas was severe throughout the cored section. Overall recovery in Hole 724B was 82.9%.

Clearing the mud line of Hole 724B at 0800 on 21 September, Hole 724C was spudded after offsetting 10 m to the southwest at 0830 hr on 21 September. Recovery of 5 APC cores (0.0-40.8 mbsf) averaged 105%, and coring in XCB mode for the remaining cores to 252.4 mbsf total depth averaged 94%, including some voids from core expansion. The average recovery for the 27 cores was 96.2%. The hole was displaced with weighted mud, the pipe pulled, and the ship was under way in dynamic positioning mode to Site 725 by 2400 hr on 21 September.

SITE 725 (TARGET SITE OM-4)

Holes 725A-C

The drillship arrived at Site 725 in dynamic positioning mode at 0230 hr, 22 September. The site, which had been surveyed jointly with Site 724, is located in 323 m of water. A shallow-water beacon was lowered on the taut wire, and by 0430 hr Core 117-725A0-1H was shot. The core barrel parted at shooting Core 117-725A-2H and Hole 725A had to be abandoned. Recovery of Core 117-725A-1H (0.0-4.5 mbsf) was 100%.

Without offset, Hole 725B was spudded at 0600 on 22 September in XCB coring mode. Coring recovered only 11.9% of the cored interval 0.0-93.8 mbsf, dominated by sand and silt, and after Core 117-725B-10X had been retrieved, coring in Hole 725B was suspended and the string pulled. Hole 725C was spudded at 1415 hr on 22 September, 20 m northeast of Hole 725B, after modification to the XCB cutting shoes.

Three APC cores recovered 100% of the interval 0.0-28.5 mbsf until overpull of 80,000 lb made XCB coring necessary. Cores 117-725C-4X to 117-725C-17X (28.5-162.8 mbsf) showed a much improved recovery of 52.3% in Hole 725C when compared to Hole 725B, so that overall recovery in Hole 725C was 60.6%. Having reached total depth, the hole was displaced with weighted mud, and after clearing the mud line and retrieving the beacon, the ship was under way to Site 726 by 2400 hr on 22 September.

SITE 726 (TARGET SITE OM-5)

Hole 726A

JOIDES Resolution departed Site 725 at 2400 on 22 September and relocated to Site 726 for seismic survey and drilling operations. Having established a seismic dip line during good GPS coverage on the first pass, the seismic gear was retrieved and the taut-wire beacon lowered in 340.1 m of water at 1000 hr on 23 September.

Core 117-726A-1H was shot at 1200 hr, followed by a rapid succession of five APC cores (0.0-54.1 mbsf) and a deployment of the PWS after Core 117-726A-4H. Overpull of 80,000 lb upon retrieval of Core 117-726A-6H made coring in XCB mode necessary starting with Core 117-726A-7X. Recovery in the section cored by APC was 103%. By 0120 hr, 24 September, Core 117-726A-22X had been cored to a total depth of 526.4 mbsf. Core 117-726A-22X was stuck in the bit and the BHA had to be pulled out to recover the core on the rig floor. In the cemented dolomite that comprised the section below Core 117-726A-16X, penetration and recovery had decreased (recovery in the interval cored by XCB was 40.7% and generally below 10% in the limestone/dolomite), and the hoped-for penetration to ophiolitic basement appeared unattainable in the allocated time. Hole 726A was therefore terminated and displaced with mud, and the drill string was pulled. The rig was under way to Site 727 by 0830 hr, 24 September.

SITE 727 (TARGET SITE OM-6)

Holes 727A and 727B

The ship departed Site 726 at 0830 hr, 24 September 1987, and surveyed Site 727 with the seismic gear streamed. The beacon was dropped at Site 727 in 921.5 m of water on the second pass, the seismic gear was retrieved, and the ship attained dynamic positioning mode by 1230 hr on 24 September.

The first of 10 APC cores was shot at 1430 hr, followed by 9 XCB cores to total depth of Hole 727A at 182.4 mbsf. A pull-out force of 110,000 lb upon retrieval of Core 117-727A-10H necessitated the switch to XCB mode after reaching 95.4 mbsf. Recovery in the section cored by APC was 104%. Recovery with XCB continued to be excellent down to total depth, and averaged 102% in calcareous oozes and clayey silts, even though gas expansion was less severe than at other sites.

At 0030 hr, 25 September, the hole was displaced with mud and the drill string was pulled after Hole 727 had reached target depth. Without offsetting the rig the bit was positioned to shoot the mud line of Hole 727B; recovered from this hole were three APC cores from the interval 0.0-27.1 mbsf. The hole was cored from 0215 to 0345 hr on 25 September 1987, with 103% recovery. Operations at Site 727 were finished after pulling the string, and the ship set out to survey Sites 728 and 729 by 0600 hr, 25 September.

SITE 728 (TARGET SITE OM-8)

Holes 728A and 728B

The ship left Site 727 at 0600 with the seismic gear deployed, crossed the target location of Site 728, and continued to Site 729, where a beacon was dropped at 0900 hr. JOIDES Resolution then returned to Site 728 and dropped a beacon at 1130 hr in 1433 m of water. The ship was positioned by 1230 hr, and the mud line of Hole 727A was shot at 1500 hr on 25 September.

Nine APC cores recovered 103% of the sediments from the interval 0.0-85.7 mbsf, after which an overpull of 80,000 lb necessitated a switch to XCB coring mode. Hole 728A was terminated at 0745 hr on 26 September at a total depth of 346.4 mbsf (Core 117-728A-36X) with an overall recovery of 99% owing to a cutting shoe modification and favorable sediments. The hole was conditioned, swept with mud, displaced with polymer, and prepared for logging with a wiper trip and bit positioning at 80 mbsf, after the lockable flapper valve had been opened.

Two logging strings were successfully run in Hole 728A. String #1 consisted of the DIT/BHC/GR/CAL combination, while #2 ran a GST/CNT/NGT combination. At 2315 hr, the logging tools were rigged down, the drill string was pulled out of Hole 728A, the ship offset 10 m to the northwest, and Hole 728B was spudded at 0100 hr, 26 September. Nine APC cores were followed by XCB coring to Core 117-728B-37X to a total depth of 347.7 mbsf. The in-situ pore water sampler was deployed after Cores 117-728B-6H, 117-728B-12X, 117-728B-17X, and 117-728B-25X. Overall recovery again averaged 100% for the entire hole, with 104% for the interval 0.0-77.3 mbsf cored in APC mode. The performance of the XCB system was extraordinary at this site.

Hole 728B was displaced with heavy mud, and the string cleared the mud line at 2400 hr, 26 September.

SITE 729 (TARGET SITE OM-10)

Hole 729A

JOIDES Resolution reached Site 729 in dynamic positioning mode after a transit of 1.5 hr from Site 728. Since Site 729 had been surveyed previously and marked with a beacon, no additional survey was performed. At 0600 hr, 28 September, the ship was positioned over the beacon in 1403.8 m water depth.

Because the objective at Site 729 was ophiolitic basement overlain by limestone, the rotary coring system was used and the first core was cut at 1030 hr on 28 September. After initially satisfying recovery expectations in nannofossil ooze to Core 117-729A-4R (26.3 mbsf), recovery dropped sharply in Miocene(?) limestone, of which only fragments in pebble size were recovered from Core 117-729A-5R to Core 117-729A-13R (109.1 mbsf total depth). Hole conditions deteriorated rapidly, and after Core 117-729A-13R came up the hole was abandoned. Overall recovery in Hole 729A was 29%. By 2230 hr on 28 September the ship was under way to Site 730.

SITE 730 (TARGET SITE OM-11)

Hole 730A

With permission from ODP to drill a new site (OM-11), JOIDES Resolution headed west to Site 730 with the seismic gear deployed. After a survey of 22 nmi, the site was located and the beacon was dropped at 0545 hr on 22 September. By 0630 hr, the mud line of Hole 730A was shot in 1071.4 m water depth.

APC cores 117-730A-1H to 117-730A-5H (0.0-46.3 mbsf) recovered 104% of the cored interval. During retrieval of Core 117-730A-5H a maximum overpull of 60,000 lb was registered and coring mode was switched to XCB. The total depth of Hole 730A was reached at 403.9 mbsf, where the core barrel parted upon retrieval of Core 117-730A-43X. XCB recovery in the interval 46.3-403.9 mbsf was 75%, which gives an average recovery of 80% at Site 730. The long-standing recovery record of 3841 m established during ODP Leg 108 was beaten with the recovery of 3920.2 m of core.

The hole was displaced with heavy mud, and the ship was under way to Site 731 by 1630 hr on 30 September.

SITE 731 (TARGET SITE OR-4)

Holes 731A-C

The seismic survey of Site 731 began at 0600 hr on 31 September after a 13-hr transit from Site 730. By 0730 hr, Site 731 had been located, the beacon was deployed, the seismic gear was retrieved, and the rig was positioned in 2370.9 m water depth.

Bending stress tests were carried out on an instrumented joint of drill pipe at three different tensile loads with the ship inclined at 5°. These were at 100,000 lb (34 stands of drill pipe suspended), 150,000 lb (62 stands), and 175,000 lb (76 stands). The test was finished successfully and the mud line of Hole 731A was shot by 2030 hr on 31 September. APC Cores 117-731A-1H to 117-731A-7H recovered 102.5% of the interval 0.0-67.0 mbsf, and XCB Cores 117-731A-8X through 117-731A-43X (67.0-409.0 mbsf) yielded 88% of the cored sediments. When cutting Core 117-731A-43X, the cutting shoe broke, and attempts to push the metal out with a center bit failed. The drill string was pulled to the rig floor, and Hole 731B was spudded after offsetting the rig 10 m north at 0600 on 4 October. The hole was drilled with a center bit to 408.7 mbsf and coring commenced in XCB mode to Core 117-731B-5X (408.7-457.1 mbsf total depth). The core barrel flared at this depth and after attempts to grind it down had failed, coring in Hole 731B was terminated. Recovery in Hole 731B averaged 31%.

Again the rig was offset 10 m to the north and Hole 731C was spudded with a rotary coring assembly at 1815 on 5 October. We drilled and spot-cored through the very thick turbidite sequence previously encountered on Owen Ridge, hoping to reach underlying sediments in the remaining time allocated for Leg 117. At a total depth of 994.2 mbsf, still in lower Miocene turbidites, coring was suspended and the hole was prepared for logging. Of 642.5 m combined washing and coring, 111.5 m core was recovered in Hole 731C. Total recovery during Leg 117 was established at 4367.2 m.

The hole was prepared for logging, and two logging runs were performed with the bit positioned at 90 mbsf; 14 m fill was encountered at the bottom of the hole. Two logging strings were run: #1 consisted of the combination DIT/BHC/GR/CAL, and #2 was the GST/CNT/NGT/GPIT combination. Logging conditions were good and log quality was excellent.

The ship was under way to Mauritius at 1700 hr on 9 October 1987.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 117

TOTAL DAYS: (19 AUG 87 - 18 OCT 87)	59.9
TOTAL DAYS IN PORT:	4.53
TOTAL DAYS UNDERWAY: (Including site survey time)	19.00
TOTAL DAYS ON-SITE:	35.55

TRIP TIME:	4.51
CORING TIME:	22.63
DRILLING TIME:	2.03
LOGGING/DOWNHOLE SCIENCE TIME:	5.53
REENTRY TIME:	0.0
MECHANICAL REPAIR TIME: (CONTRACTOR)	0.0
OTHER:	.84

TOTAL DISTANCE TRAVELED: (Nautical Miles)	4409.0
AVERAGE SPEED: (Knots)	9.0
NUMBER OF SITES:	12
NUMBER OF HOLES:	25
TOTAL INTERVAL CORED: (Meters)	5847.0
TOTAL CORE RECOVERY: (Meters)	4367.18
PERCENT CORE RECOVERED:	74.6
TOTAL INTERVAL DRILLED: (Meters)	1277.1
TOTAL PENETRATION: (Meters)	7126.1
MAXIMUM PENETRATION: (Meters)	994.2
MAXIMUM WATER DEPTH: (Meters from drilling datum)	4045.3
MINIMUM WATER DEPTH: (Meters from drilling datum)	323.0

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 117

HOLE	LATITUDE	LONGITUDE	WATER DEPTH METERS	NUMBER OF CORES	METERS CORED	METERS RECOVERED	PERCENT RECOVERED	METERS DRILLED	METERS TOTAL PENET.	TIME ON HOLE	TIME ON SITE
720	16° 07.796N	60° 44.621E	4045.3	43	414.3	89.38	21.5		414.3	107.50	107.5
721A	16° 40.636N	59° 51.879E	1952.2	9	86	89.28	100		86.4	13.00	13.00
721B	16° 40.636N	59° 51.779E	1949.0	44	424.2	342.75	81		424.2	50.25	63.25
721C	16° 40.636N	59° 51.779E	1949.1	15	138.6	133.19	97		138.6	20.25	83.50
722A	16° 37.312N	59° 47.755E	2034.0	29	280.0	225.96	81		280.0	37.00	37.00
722B	16° 37.312N	59° 47.755E	2034.0	59	565.6	385.91	68		565.6	99.50	136.50
723A	18° 03.079N	57° 86.561E	816.0	46	432.3	298.27	67		432.0	40.50	40.50
723B	18° 03.079N	57° 86.561E	816.0	44	400.1	295.40	74	28.9	429.0	58.00	99.25
723C	18° 03.079N	57° 86.561E	816.0	8	76.8	82.18	107		76.8	9.50	108.00
724A	18° 27.713N	57° 47.147E	602.5	5	44.5	44.76	100		5.25	5.25	16.00
724B	18° 27.713N	57° 47.147E	602.0	27	257.7	213.73	83		257.7	15.00	20.25
724C	18° 27.713N	57° 47.147E	602.0	27	252.4	242.70	96		242.4	17.00	37.25
725A	18° 29.200N	57° 42.030E	323.0	1	4.5	4.53	100		4.5	4.50	4.50
725B	18° 25.200N	57° 42.030	323.0	10	93.8	11.20	12		93.8	8.25	12.75
725C	18° 25.200N	57° 42.030E	323.0	17	162.8	98.76	61		162.8	9.75	22.50
726A	17° 48.945N	57° 22.200E	340.1	22	186.3	110.10	59		186.3	22.50	22.50
727A	17° 46.096N	57° 35.216E	921.5	19	182.4	188.40	103		188.4	13.50	13.50
727B	17° 46.096N	57° 35.216E	921.5	3	27.1	27.90			27.9	4.50	18.00
728A	17° 40.790N	57° 49.553E	1433.0	36	346.4	343.72	98		343.7	37.50	37.50
728B	17° 40.790N	57° 49.553E	1435.8	37	347.7	349.50	100		347.7	27.50	65.00
729A	17° 38.715N	57° 57.221E	1403.8	13	109.1	31.72	29		109.72	16.50	16.50
730A	17° 38.885N	59° 42.519E	1071.4	42	403.9	323.75	80			34.75	34.75
731A	16° 28.229N	59° 42.149E	2370.9	43	409.0	359.28	88		409.0	65.25	65.25
731B	16° 28.229N	59° 42.149E	2370.9	5	48.4	14.97	31	408.7	457.10	36.75	102.00
731C	16° 29.229N	59° 42.149E	2370.9	24	154.7	59.81	39	839.5	994.20	99.25	201.25
		TOTALS		618	5847	4367.18	74.6	1277.1	7126.1	853.25	853.25

OCEAN DRILLING PROGRAM
BIT SUMMARY
LEG 117

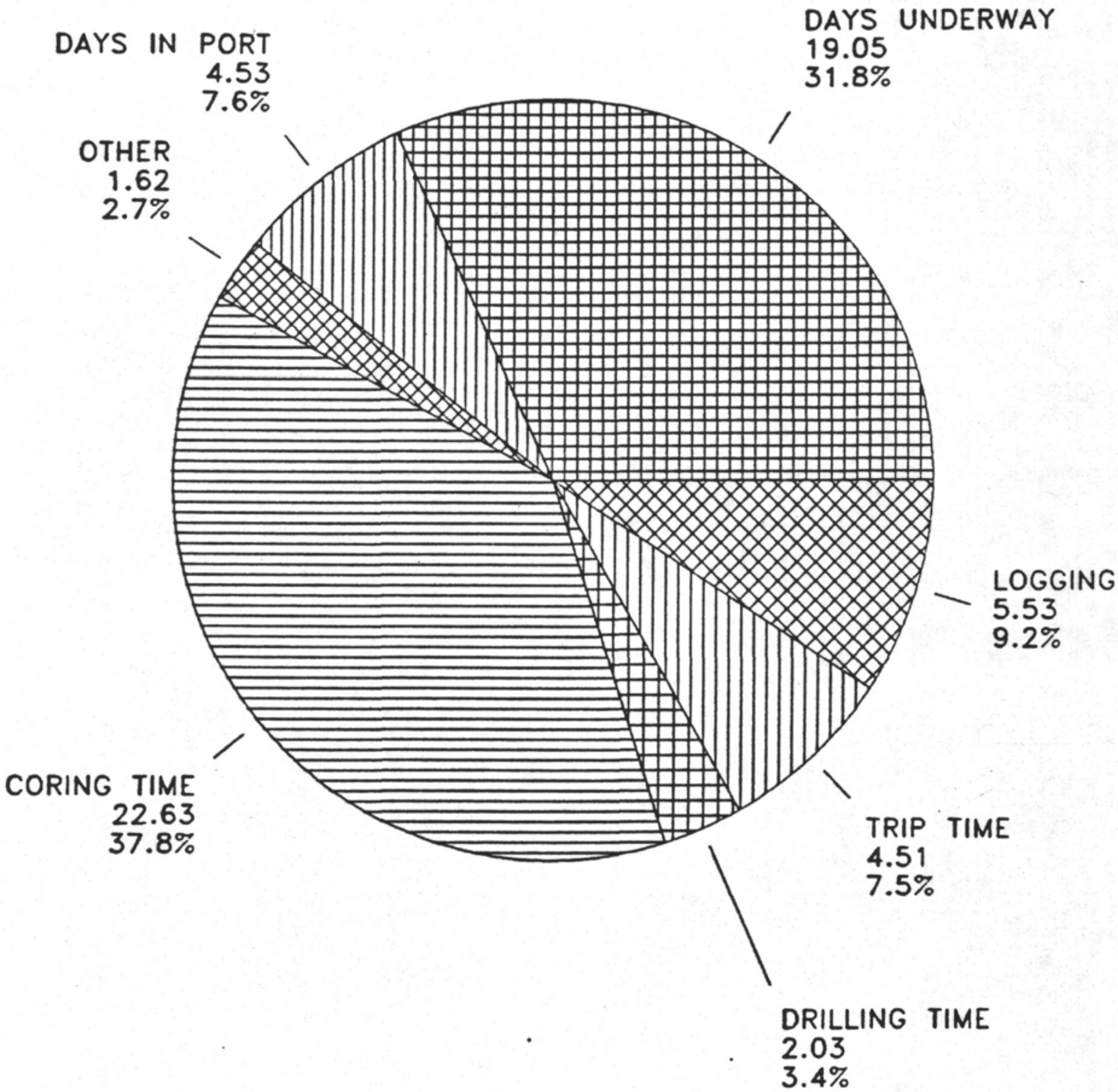
HOLE	MFG	SIZE	TYPE	SERIAL NUMBER	METERS CORED	METERS DRILLED	TOTAL PENET	CUMULATIVE METERS	HOURS THIS HOLE	TOTAL HOURS	CONDITION	REMARKS
720	SEC	11-7/16	C-3	469666	414.3		414.3	419.3	20.75	25.75	LEFT IN HOLE	W/ANGLE JETS 1/2
721A	SEC	11-7/16	C-3	469675	86.0		86	4121	0	40	N/A	POLLY PAK
721B	SEC	11-7/16	C-3	469675	424.2		424.2	4545.2	14	54	N/A	POLLY PAK
721C	SEC	11-7/16	C-3	469675	138.6		138.6	4683.8	1	55	B3,T1,I	RR FROM LEG 115
722A	SEC	11-7/16	C-3	469675	280.0		280	4963.8	10	65	N/A	POLLY PAK
722B	SEC	11-7/16	C-3	469675	565.6		565.0	5528.8	17	82	REL IN HOLE	POLLY PAK
723A	RBI	11-7/16	C-3	AE3376	432.3		432.3	432.3	10	10		POLLY PAK L.S
723B	RBI	11-7/16	C-3	AE3376	400.1	28.9	400	832.3	8	18		LIMESTONE, ETC.
723C	RBI	11-7/16	C-3	AE3376	76.8		76.8	909.1	0	18	B1,T1,I	POLLY PAK
724A	RBI	11-7/16	C-3	AE3376	4.5		4.5	913.6	0	18		POLLY PAK
724B	RBI	11-7/16	C-3	AE3376	257.7		257.7	1171.3	5	23		POLLY PAK
724C	RBI	11-7/16	C-3	AE3376	252.4		252.4	1423.7	4	27	B1,T1,I	POLLY PAK
725A	RBI	11-7/16	C-3	AE3376	4.5		4.5	1428.2	0	27		POLLY PAK
725B	RBI	11-7/16	C-3	AE3376	93.0		93.0	1521.2	3.5	30.5		POLLY PAK
725C	RBI	11-7/16	C-3	AE3376	162.8		162.8	1684	3.5	34	B1,T1,I	POLLY PAK
726A	RBI	11-7/16	C-3	AE3376	186.3		186.3	1870.3	6	40	B1,T1,I	POLLY PAK
727A	RBI	11-7/16	C-3	AE3376	182.4		182.4	2052.7	2	42		POLLY PAK
727B	RBI	11-7/16	C-3	AE3376	27.1		27.1	2079.8	0	42	B1,T1,I	POLLY PAK
728A	RBI	11-7/16	C-3	AE3376	346.4		346.4	2426.2	4	46		POLLY PAK
728B	RBI	11-7/16	C-3	AE3376	347.7		347.7	2773.9	3	49	B1-T1-I	POLLY PAK
729A	RBI	9-7/8	C-57	A5006	109.1		109.1	194	1	29.5	B1-T1,I	
730A	RBI	11-7/16	C-3	AE3376	403.9		403.9	3177.8	9	58	B2,T1,1/16	POLLY PAK
731A	RBI	11-7/16	C-3	AE3376	409.0		409.0	3586.8	12.5	70.5	B2,T1,1/16	POLLY PAK
731B	CHR	9-7/8	ECDP	0113355	48.4		457.1	1467.5	7.2	21.2	1 SET MISS	OK FOR RE-RUN
731C	RBI	9-7/8	C-57	A5006	154.7	839.5	994	1103	14	43.5	N/A	RELEASED IN HOLE

OCEAN DRILLING PROGRAM
BEACON SUMMARY
LEG 117

SITE	MAKE	FREQ KHZ	SERIAL NUMBER	HOURS SITE TIME	DEPTH METERS	REMARKS
720	DATSONICS	14.5	365	107.50	4045	GOOD SIGNAL
721	DATASONICS	14.5	373	83.75	1949	GOOD SIGNAL
722	DATASONICS	14.5	352	226.00	2033	GOOD SIGNAL
723	DATASONICS	16.5	402	2	816	ERRATIC SIGNAL (TAUT WIRE) RETRIEVE BEACON
723	DATASONICS	14.5	398	2	816	ERRATIC SIGNAL (BEACON WAS DROPPED)
723	DATASONICS	15.5	270	108.00	816	SIGNAL OK (TAUT WIRE)
724	DATASONICS	17	317	37.50	602	TAUT WIRE OK
725	DATASONICS	17	317	22.50	323	TAUT WIRE OK - WEAK SIGNAL
726	DATASONICS	16.5	393	22.50	340	OK
727	DATASONICS	15.5	370	18.00	921.5	OK
728	DATASONICS	16.5	399	62.00	1435	SIGNAL TOO WEAK. DROPPED BACK BEACON
728	DATASONICS	16.5	367	63.00	1435	BACK UP BEACON - OK
729	DATASONICS	16.5	359	16.50	1403.8	OK
730	DATASONICS	16.5	393	34.75	403.9	OK
731	DATASONICS	15.5	361	201.25	2370.9	OK

LEG 117 TIME DISTRIBUTION

TOTAL NUMBER OF DAYS 59.9



LOGGING REPORT

The logging personnel aboard JOIDES Resolution for Leg 117 were:

Richard Jarrard — LDGO Borehole Research Group

Steve Diana — Schlumberger Houston
8460 Gulf Freeway
Houston, TX 77023

LOGGING OPERATIONS

The logging program for Leg 117 consisted of logging at Sites 720, 722, 723, 728, and 731. During a total of 5.5 days of logging operations, 2566 meters of hole were logged, an ODP record. All logging runs were with Schlumberger tools.

The hole conditioning program was nearly the same at each site: (1) sweep the hole with 30 barrels of gel mud, (2) make a wiper trip, (3) sweep the hole again, (4) release the bit (at Sites 720, 722, and 731), (5) displace the hole with polymer mud, and (6) pull pipe to 70-94 mbsf for logging. This hole conditioning program was very successful. Fill at the bottom of the hole was usually less than 10 m during logging. Only one bridge was encountered (at Site 720) during Leg 117; the sidewall entry sub was deployed once (at Site 722) but was not needed for breaking bridges.

At Site 720, the seismic stratigraphic combination (long-spaced sonic, phasor resistivity, and spectral gamma ray) obtained downgoing logs for 78.8-390.8 mbsf and upcoming logs for 412.4-104.0 mbsf, before the tool was stuck in a bridge just below pipe. A new crimper and cutter combination was used to permit punching through the bridge with pipe, then retrieving the tool string along with the bottomhole assembly. However, the cable broke just below the crimper and the tool string was lost.

At Hole 722B, the seismic stratigraphic combination (borehole compensated sonic, dual induction resistivity, and gamma ray) obtained downgoing and upcoming logs for 94.3-555.5 mbsf. The lithoporosity combination (spectral gamma ray, neutron porosity, lithodensity, and magnetometer) obtained downgoing logs for 94.2-539.9 mbsf and upcoming logs for 550.9-71.4 mbsf. The bowspring on the lithodensity tool would not collapse sufficiently to enter pipe, so the crimper and cutter were used, and the tool string was recovered when the bottomhole assembly was pulled on deck.

At Hole 723B, the seismic stratigraphic combination obtained downgoing logs for 89.8-412.6 mbsf and upcoming logs for 427.3-98.5 mbsf. The lithoporosity combination obtained downgoing logs from the seafloor to 408.6 mbsf and upcoming logs from 424 mbsf to the sea floor. The geochemical combination (gamma spectroscopy, aluminum clay tool, and magnetometer) obtained upcoming logs for 419.9-68.3 mbsf.

At Hole 728A, the seismic stratigraphic combination collected downgoing logs for 76-326.2 mbsf and upcoming logs for 342.4-55.5 mbsf. A modified geochemical combination (spectral gamma ray, neutron porosity, and gamma spectroscopy) obtained downgoing logs from the sea floor to 323.6 mbsf, then upcoming logs for 340.7 mbsf to the seafloor.

At Hole 731C, the seismic stratigraphic combination collected downgoing logs for 85-973 mbsf and upcoming logs for 979-65 mbsf. The modified geochemical combination obtained downgoing logs from the seafloor to 966 mbsf and upcoming logs from 968 mbsf to the seafloor.

Operational improvements during Leg 117 included successful tests of the reliability of through-pipe logs, logging through the lockable flapper, and use of the crimper/cutter. In spite of early problems, virtually the entire openhole interval was always logged and the through-pipe interval was usually logged.

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 117 were:

Laboratory Officer:	Brad Julson
Curatorial Representative:	Robert Wilcox
Yeoperson:	Dawn Wright
Systems Manager:	Larry Bernstein
X-ray Technician:	Bettina Domeyer
Chemistry Technician:	Katie Sigler-Tauxe
Photographer:	Stacey Cervantes
Marine Technician:	Daniel Bontempo
Marine Technician:	Brant Bullard
Marine Technician:	Linda Chatham
Marine Technician:	Khalid Mahmood
Marine Technician:	Mark Neschleba
Marine Technician:	Greg Simmons
Marine Technician:	John Tauxe
Marine Technician:	John Weisbruch
Electronics Technician:	Jim Briggs
Electronics Technician:	Dwight Mossman

INTRODUCTION

Leg 117 officially began at 0915 hr, 19 August 1987 when the first line was received at Colombo harbor in Sri Lanka, and ended 61 days later in Port Louis, Mauritius on 18 October 1987.

PORT CALL, COLOMBO, SRI LANKA

Fuel transfer commenced quickly and 1062 MT of fuel was loaded. Later the ship was turned around so that the port side was next to the dock. The cores from Legs 115 and 116 were off loaded into two 40' refrigerated containers. A 40' frozen container was loaded with the frozen shipment and miscellaneous items. All three containers were surface shipped to TAMU. Oncoming freight included a surface shipment of two 40' containers and an air freight shipment. Sixty 1-ton bags of cement were blown into the ship's cement tanks. The high point of the port call was a visit by well-known science fiction author Arthur C. Clarke, who now lives in Sri Lanka.

UNDER WAY

The ship left Colombo and encountered strong monsoon winds of 30-35 kt and heavy swells and seas. Ship's speed sometimes exceeding 12 knots precluded streaming the seismic gear for this and other transits this leg. The magnetometer and the PDR's were used on all transits. The magnetic data and the navigational data from our GPS and TRANSIT positions were collected on tape.

Transits and surveys completely centered around the rather small GPS window in this region of the world. During surveys we pulled all gear at about 6 kt. The quality of our watergun records in this shallow water was very good and closely correlated with the profiles of the CONRAD surveys in this area. While logging at two of the sites we pulled one of the magnetometers to the middle of the ship, attached it to the current meter line and dropped it about 150' below the ship's keel. This was done to check for a diurnal shift in the basic magnetic background signal for the area, outside the field set up by the ship.

On the way to Mauritius at the end of the leg, a test was done with a small high-frequency section attached in front of our normal streamer. There was no improvement in our 3.5-kHz records.

LABORATORY REPORTS

Core Lab

At times during the cruise, we were at a different site every day, sometimes drilling two sites in less than a day. The activity in the core lab was often hectic because of the shallow APC/XCB sites. A new record was set for core recovery, with 4367 m recovered. Nearly 22,000 samples were taken. These cores were also gassy, with core expansion producing large voids. Owing to the nature of the gas, there was constant hydrocarbon surveillance. The smell of H_2S was ever-present. Because of the core expansion, the core log data base entry system had to be reprogrammed to accept core catchers up to 120 cm.

The cryogenic magnetometer was used little this leg since most of the sediments were too strongly overprinted for the limited power of the demagnetization coils. Consequently the minispin was used almost exclusively and gave consistently good results. Toward the end of the leg, the cryomag compressor shut off and a large amount of liquid helium was lost. A frozen air plug also developed in the vent line and was troublesome to remove. During Leg 118, the cryomag will be cooling down until the next helium transfer at the beginning of Leg 119. The susceptibility meter was used heavily this leg to correlate different holes to within centimeters. The sediments stiffened quickly as we drilled but all APC cores shot below about 50 mbsf were oriented.

The vertical GRAPE measurements were sped up through the use of both hardware and software revisions. The needle valve in the air cylinder's exhaust was adjusted and a check valve installed, and the stepper motor scan parameter was changed. The faster carriage speed eliminates this historic bottleneck in core processing. New transducers were brought out for the P-wave logger as well as a new electronics box. The receive and transmit cables were rewired, and the P-wave logger worked well in the sped-up configuration.

Nearly 22,000 samples were taken. There were a number of holes dedicated for specific sampling. One site was dedicated for organic chemistry and each section was further divided into three parts that had the ends taped and were put in the freezer. Gas voids are always hard to curate and on this leg it was made even more difficult for two reasons: (1) when the cores were GRAPEd vertically, the voids all migrated to the top; (2) when the cores were split in half, the splitting wire would tend to concentrate the core to one end.

Foc'sle Deck

Chemistry lab activities were for the most part hectic but with few problems. The coulometer was used for the many carbonate and organic carbon analyses; minor changes were made to the program. Hydrocarbon gases were monitored routinely, and one scientist used the capillary column in GC#2 for alkenone analysis from sediment extractions with excellent results. The Rock Eval suffered a myriad of small problems but was used heavily. Two scientists took many sediment samples for squeezing and performed a wide suite of analyses on the resultant pore waters. Especially interesting was a high uranium anomaly they found. The new hydrogen generator has been working well.

The thin section lab saw limited action but occasionally it was used for vacuum impregnations of sediment samples. The resin flow plug on this unit needs redesigning.

The scanning electron microscope was used very little but was tested for a problem experienced during Leg 116. The problem could not be duplicated.

The XRD was used to scan for bulk mineralogy on about 300 samples. The XRF was used by one of our staff scientists and by the logging personnel to calibrate one of their logging tools. The Scitech balance was also brought back on line for this lab.

Other Areas

The pore-water sampler (PWS) was used on 23 runs this leg. Three new stouter probes and probe tips were brought out. A larger filter block with increased surface area was also tried successfully. Although there were problems with bulkheads galling, pore-water and heat-flow data were obtained from most of the runs.

The dipoles of the weather satellite system were adjusted and a connection on the downconverter was fixed enabling us to receive satellite data. Later in the leg the dish crank system was modified with a brass bushing. The satellites allowed us to see weather maps extending to the east coast of the United States.

The computer area was used heavily. A number of new programs for individual labs were sent out for this leg. Many minor changes in programs were developed. A computer environment monitor was installed to monitor power conditions, operating temperatures and water flooding into the computer area. Three new DecNet nodes were configured in the core lab to speed up file transfer. The laser printer went down with a bad laser power supply and will be down until replacement parts arrive in port. We also had a scare when the backup central processing unit (CPU) would not properly boot at first, but in time it did finally boot up.

The photo lab work was routinely heavy. Photographer Roy Davis flew to Colombo before the start of the cruise to work on the kreonite processor. All the racks were taken out and cleaned. Leaks were traced and fixed. A new silver recovery unit was installed.

The air and surface shipments arrived in good condition in Colombo except for a hole in the ceiling of one container that produced minor water damage. The Lower Tween Reefer is almost completely filled with 638 core boxes. All items on MATMAN were inventoried. A new MATMAN system was also installed which now merges oncoming freight shipments with the current MATMAN data base. A new identification system was developed for the gas cylinders which makes it more readily apparent whether bottles are empty, full, in transit or in use. A partial physical inventory of capitol equipment was conducted.

The METS continued emergency training on a regular weekly basis. Training varied fom use of the Scott air packs to a fire-fighting drill on the heliport with hoses and complete fire-fighting clothing. We also had a thorough demonstration of the lifeboat which included launching the craft and training everyone to start and drive it. A large backup Halon cylinder was also delivered to the Koomey room.

The gym saw regular use from all the scientists. D-tubes were again moved back and forth onto the gym floor, rendering the gym unusable on the way into port because of the shortage of D-tube space aboard.

Special Projects

The UPS (backup battery power supply to the regulated power) was installed during the leg. This took about 17 hr to perform. There are about 60 new batteries and the other 230 are ten-year-old batteries from another UPS sytem. The first test was on the transit into Mauritius. All instruments on the regulated power were turned off as the initial circuit was spliced into the lines. This test was intended to see if, in the event of a failure of the regulated power, the unit would switch over to battery power. A surge suppressor on the "C" phase in the Liebert power conditioner in the computer lab blew out. This was attributed to component failure. A few days later, the UPS was tested again after the batteries had been charged. After putting a good load on the electrical system, the batteries could sustain the system for only 77 seconds.

One PRO-350 computer was wired to the VAX through the LO computer CPT box. Racks were made to accommodate the PWS barrels on the core roof. A system was designed to apply line dressing to the current-meter cable. The potable water was replumbed slightly to get into one of the tanks and clean it while keeping the water on line to the rest of the ship. Personal BLAST communication was officially made available to all shipboard personnel through ODP channels. Cables were run from the fantail into the U/W lab to monitor the pressure transducers on the guns. Parts were ordered to run the cables from the Colmek TV system to the ET shop. A new door with a window was installed in the stairwell near the copy machine to reduce the bottleneck at this junction. A return was hung between the co-chiefs' desks to give them more counter space. Both seismic winch drums were repainted and a rack was fabricated for the seismic guns. A counterweight was welded onto the upper hatch of the elevator shaft in order to make it easier to climb out.