OCEAN DRILLING PROGRAM

LEG 116 PRELIMINARY REPORT

INTRAPLATE DEFORMATION AND DISTAL BENGAL FAN

James R. Cochran
Co-Chief Scientist, Leg 116
Lamont-Doherty Geological Observatory
Columbia University
Palisades, NY 10964

Dorrik A. V. Stow
Co-Chief Scientist, Leg 116
Department of Geology
Nottingham University
University Park
Nottingham, NG7 2RD
United Kingdom

Christian A. Auroux
Staff Scientist, Leg 116
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

September 1987

This informal report was prepared from the shipboard files by the scientists who participated in the cruise. The report was assembled under time constraints and is not considered to be a formal publication which incorporates final works or conclusions of the participating scientists. The material contained herein is privileged proprietary information and cannot be used for publication or quotation.

Preliminary Report No. 16

First Printing 1987

Copies of this publication may be obtained from the Director, Ocean Drilling Program, Texas A&M University, College Station, Texas 77843-3469. In some cases, orders for copies may require a payment for postage and handling.

D I S C L A I M E R

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

Department of Energy, Mines and Resources (Canada)

Deutsche Forschungsgemeinschaft (Federal Republic of Germany)

Institut Francais de Recherche pour l'Exploitation de la Mer (France)

Ocean Research Institute of the University of Tokyo (Japan)

National Science Foundation (United States)

Natural Environment Research Council (United Kingdom)

European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Iceland, Italy, Greece, the Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey)

Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, the participating agencies, Joint Oceanographic Institutions, Inc., Texas A&M University, or Texas A&M Research Foundation.

SCIENTIFIC REPORT

The scientific party aboard JOIDES Resolution for Leg 116 of the Ocean Drilling Program consisted of:

James Cochran, Co-Chief Scientist (Lamont-Doherty Geological Observatory, Palisades, New York)
Dorrik A.V. Stow, Co-Chief Scientist (Department of Geology, Nottingham University, Nottingham, United Kingdom)
Christian Auroux, ODP Staff Scientist (Ocean Drilling Program, Texas A&M University, College Station, Texas)
Kazuo Amano (Department of Earth Sciences, Ibaraki University, Ibaraki, Japan)
Peter S. Balson (British Geological Survey, Keyworth, Notts, United Kingdom)
Jacques Boulegue (Laboratoire de Geochimie, Universite Pierre et Marie Curie, Paris, France)
Garrett Brass (University of Miami, Miami, Florida)
Jeffrey Corrigan (Department of Geological Sciences, University of Texas at Austin, Austin, Texas)
Stefan Gartner (Department of Oceanography, Texas A&M University, College Station, Texas)
Stuart Hall (Department of Geosciences, University of Houston, Houston, Texas)
Silvia Iaccarino (Istituto di Geologia, Universita di Parma, Parma, Italy)
Toshio Ishizuka (Ocean Research Institute, University of Tokyo, Tokyo, Japan)
Irena Kaczmarska (Mount Allison University, Sackville, New Brunswick, Canada)
Heidemarie Kassens (Geologisch-Palaeontologisches Institut, Universitaet Kiel, Kiel, Federal Republic of Germany)
Gregory Leger (Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada)
Franca Proto Decima (Istituto di Geologia, Universita di Padova, Padova, Italy)
Venkata Challagundla Raman (Department of Geology, Andhra University, Visakhapatnam, India)
Will Sager (Department of Oceanography, Texas A&M University, College Station, Texas)
Kozo Takahashi (Woods Hole Oceanographic Institution, Woods Hole, Massachusetts)
Thomas Thompson (580 Euclid Avenue, Boulder, Colorado)
Jean-Jacques Tiercelin (Oceanologie et Geodynamique, Universite de Bretagne, Brest Cedex, France)
Mark Townsend (Department of Geology, University of Nottingham, Nottingham, United Kingdom)
N. P. Wijayananda (Oceanography Unit, National Aquatic Resources Agency, Colombo, Sri Lanka)
Andreas Wetzel (Geologisches Institut, Tubingen, Federal Republic of Germany)
Colin Williams (Lamont-Doherty Geological Observatory, Palisades, New York)

INTRODUCTION

Leg 116 was designed to investigate tectonic and sedimentary processes as recorded in the sedimentary sequence of the distal Bengal Fan in a region that is undergoing significant intraplate deformation (Eittreim and Ewing, 1972; Stein and Okal, 1978). The Bengal Fan is the largest single sedimentary feature in the world, extending 3000 km from the slope south of the Ganges-Brahmaputra Delta to merge with the Sri Lanka Abyssal Plain near the Afanazy Nikitin seamount group (Figure 1). The maximum sediment thickness beneath the upper fan may exceed 16 km (Curray et al., 1982); the thickness in the distal fan investigated on Leg 116 is about 1.5-2.0 km. These sediments are of interest not only for the investigation of sediment transport and deposition mechanisms in a distal fan environment, but also because they record the history of the tectonic uplift and erosion of the Himalayas.

The fan sediments also preserve a record of the compressional deformation experienced by the oceanic lithosphere of the Central Indian Ocean Basin south of India. The increased resistance to subduction and shortening across the Himalayas, combined with continued seafloor spreading on the Southeast Indian Ridge, implies that the Central Indian Ocean is under a strong north-south compressive stress regime. Within the affected area, which extends roughly from the Chagos-Laccadive Ridge to the Sunda Trench and from 5^{o}N to 10^{o}S, the oceanic crust and the overlying sediments have been deformed into long-wavelength (100-300 km) undulations (or folds) with peak-to-trough amplitudes of 1-3 km (Weissel et al., 1980; Geller et al., 1983). Faulted blocks 5-20 km wide bounded by high-angle faults that offset the top of the crust by up to 0.5 s (approx. 500 m) on seismic reflection records are superimposed on the long-wavelength undulations. The continuing sedimentation during the rotation of the fault blocks has preserved a record of motion on the faults.

The main objectives of drilling on Leg 116 were:

1. To determine the age of the beginning of the intraplate deformation and the subsequent history of the displacement of the fault blocks.
2. To characterize the lithofacies present on the distal Bengal Fan and to determine the depositional processes responsible for them.
3. To investigate the nature of early diagenesis (to a depth of 1 km) in the submarine fan sediments.
4. To establish the provenance of the terrigenous sediments and to use facies variations to document the uplift history of the Himalayas.
5. To understand the relationship between the fault zones, bedding planes, fractures and the flow of water deduced from surface heat flow measurements.
6. To investigate the effects of the regional compressive stress regime and high heat flow on the physical, hydrological and magnetic properties of the sediment and on the diagenetic process.
7. To investigate depositional processes and rates through time and the growth of the Bengal Fan by obtaining a section extending well before the onset of deformation.

JOIDES Resolution departed Colombo, Sri Lanka, on 7 July 1987. During the 43 days of operations, ten holes were drilled at three sites to meet the scientific objectives outlined above. A total of 3326.2 m of sediment was drilled, of which 2299.4 m were cored and 991.4 m were recovered (Table 1). The ship returned to Colombo on 19 August.

DRILLING RESULTS

Leg 116 drilled a total of three sites (Sites 717-719). Sites 717 and 719 are companion sites designed to investigate the timing and development of the intraplate deformation. These sites will be discussed first rather than going through the sites chronologically.

Seismic reflection records allow the sedimentary section in the vicinity of the Leg 116 sites to be clearly divided into a lower pre-deformation sequence 1.2-1.3 s thick and an upper syn-depositional sequence of greatly varying thickness (Figure 2). Site 717 is located on the northern (lower) end of one of the fault blocks that make up the tectonic fabric of the region. It is situated in the thickest portion of the upper sedimentary sequence at the axis of a syncline that developed in the sediments between the faults bounding the block. The objective at Site 717 was to obtain a complete section of the syn-deformation sediments in a location where the unconformity marking the onset of deformation (reflector "A," Figure 2) appears to have become conformable on seismic records. Site 717 also serves to provide a record of distal fan sedimentation through the period of intraplate deformation for studies of lithofacies, provenance, diagenesis and depositional mechanisms. Site 719 was located part-way up the block in an area where the syn-deformation sediments are thinner (0.52 s on seismic reflection records as opposed to 0.70 s at Site 717) in order to determine what portion of the section is missing and how and when the attenuation occurred. The main objective at Site 719 was to obtain a section through the syn-deformation sequence in order to determine the history of motion and uplift on the block by comparison of the sedimentary record with that at the reference Site 717.

Site 718 is located on the next fault block south from Sites 717 and 719, where the syn-deformation section is quite thin (Figure 2), and provides an opportunity to probe further back into the sedimentary record of the distal Bengal Fan. It was therefore planned to continue this site as deep as time allowed. The exact location of Site 718 was chosen to place it on a local heat-flow high (Figure 3) in order to investigate possible hydrothermal circulation and to investigate the effects of the high heat flow on sediment diagenesis.

SITE 717

Three holes were drilled at Site 717 (target site ID-1) in a water depth of 4735 m. Hole 717A missed the mud line, so a second hole was spudded-in at a depth a few meters shallower. Holes 717B and 717C together cored a continuous section from the seafloor to 828.2 meters below seafloor (mbsf). Core recovery averaged 59%, being good in the finer grained mud lithologies and poor in unconsolidated silts. Only two APC cores were obtained, but a new record for XCB penetration was set at Hole 717C. Loss of the bottom hole assembly (BHA) near the mud line prevented the scheduled logging runs from being carried out at Hole 717C.

Site 717 successfully established a reference section for comparison with other sites higher up the fault blocks. There may be some evidence, from the physical properties measurements, of horizontal stress but the heat flow is normal for 78-Ma crust and a complete sedimentary sequence was recovered with no marked unconformities. The recovered stratigraphic section ranges from upper Quaternary to the base of the upper Miocene and has been divided into five main lithologic units (Figures 2 and 4). The dominant lithologies and ages of the stratigraphic sequence are as follows:

Unit I: (0-5.5 mbsf) Muds, mud turbidites and pelagites of (?)Holocene to latest Pleistocene age;
Unit II: (5.5-152.0 mbsf) Micaceous silty turbidites with thin intervening muds and calcareous clays of late Pleistocene age;
Unit III: (152.0-302.0 mbsf) Biogenic mud turbidites and mud turbidites with thin interbedded pelagic clays of Pleistocene and late Pliocene age;
Unit IVA: (302.0-335.0 mbsf) Silt turbidites with thin muds and mud turbidites of early Pliocene age;
Unit IVB: (335.0-456.0 mbsf) Mud turbidites with interbedded pelagic clays of early Pliocene to late Miocene age;
Unit IVC: (456.0-465.2 mbsf) Silt and silt to mud turbidites with minor amounts of mud of late Miocene age;
Unit IVD: (465.2-533.2 mbsf) Mud turbidites with interbedded pelagic clays of late Miocene age;
Unit V: (533.2-828.2 mbsf) Silt and silt to mud turbidites with rare intervals of pelagic clay and organic-rich mud turbidites of late Miocene age.

Sedimentation at Site 717 has been dominated by fan sedimentation processes and consists mainly of a sequence of turbidites. Unit I represents the topmost muds, mud turbidites and pelagites of (?)Holocene and latest Pleistocene age. Although the surface layer was washed away during penetration, a minimum sediment accumulation rate of about 25 m/m.y. can be calculated. Unit II is dominated by micaceous silt turbidites, with thin intervening muds and pelagites, deposited rapidly during the late Pleistocene at a rate probably in excess of 350 m/m.y. This unit constitutes a distinctive seismic-stratigraphic unit that in places truncates lower reflectors (reflector "B," Figure 2). Units III and IV together represent a thick section of mainly mud turbidites and thin interbedded pelagic clays that accumulated at a slower average rate of nearly 70 m/m.y. from the late Miocene to early Pleistocene. Distinctive biogenic mud turbidites are characteristic of Unit III, and at least two distinct pulses of silty turbidites occur within Unit IV. The top of Unit V corresponds to seismic reflector "Z" (Figure 2). The unit comprises repeated micaceous silt and silty mud turbidites separated by intervals (5-20 m thick) of muds and pelagic clays. The average accumulation rate for the whole of this late Miocene interval is about 75 m/m.y., although we assume that the silt turbidites were deposited much more rapidly than the intervening muds. Seismic reflector "A," representing the top of the pre-deformation sequence, occurs approximately 75 m below the top of the unit (Figure 2) and does not correspond to a change of lithology. Interpolation between paleontologic markers suggests an age of about 7 Ma for the onset of deformation.

The biostratigraphic control at Site 717 is based largely on calcareous nannofossils, as most of the other microfossil groups are either poorly preserved or absent in all but the uppermost unit. Clearly, the site has been below or very close to the carbonate compensation depth (CCD) from at least 10 Ma to the present. Slightly better preservation of carbonate microfossils from about 1.0 Ma onward, compared with the barren pelagic intervals before that time, indicates a general increase in the depth of the CCD to the present. Most of the biota studied have been resedimented as turbidites derived from shallower water, but the absence of mixing between nannofossil zones indicates that resedimentation took place shortly after deposition. The almost complete absence of siliceous microfossils beneath the supposed equatorial high-productivity zone remains a problem to be resolved.

The sequence of lithostratigraphic units at Site 717 gives a very good record of sedimentation on the distal fan for the past 10 m.y., showing the nature, thickness and vertical succession of turbidites that have been transported over a distance of 2500 km. At least three different sources of turbidites can be tentatively identified: gray silts and muds from the Ganges-Brahmaputra delta, dark gray to black organic-rich muds and thin greenish biogenic turbidites from the upper slope of the western Bay of Bengal margin, and almost white biogenic turbidites from a local seamount source, probably one or more of the Afanazy Nikitin seamount group.

SITE 719

Two holes were drilled at Site 719 (target site ID-2) in a water depth of 4737 m. Hole 719A was cored continuously from the seafloor to a depth of 460.2 mbsf, acquiring one APC core and then utilizing the XCB system. Core recovery averaged 40% and, as at the two other sites, was good in the mud sections and poor in the presumed loose silts and sandy silts. The second hole (719B) was located immediately adjacent to the first and was washed down to 460.2 mbsf for wireline logging. Three successful logging runs were completed in good hole conditions and without technical problems.

Sedimentation at Site 719, as at Site 717, has been almost exclusively through fan deposition processes, and the section consists primarily of a sequence of turbidites. The stratigraphic section recovered ranges from upper Quaternary to upper Miocene and has been divided into five main lithologic units (Figure 5). The dominant lithologies and ages of the stratigraphic sequence are as follows:

Unit I: (0.0-4.0 mbsf) Clay and calcareous clay and mud of Holocene to latest Pleistocene age;
Unit II: (4.0-135.0 mbsf) micaceous silt and silty turbidites with thin intervening muds of late Pleistocene age;
Unit III: (135.0-207.0 mbsf) mud turbidites and biogenic mud turbidites with thin interbedded pelagic clays of Pleistocene to early Pliocene age;
Unit IVA: (207.0-240.0 mbsf) silt turbidites with thin muds and mud turbidites of early Pliocene age;
Unit IVB: (240.0-357.0 mbsf) mud turbidites with thin interbedded pelagic clays of early Pliocene and late Miocene age;

Unit V: (357.0-460.2 mbsf) silt and silty mud turbidites with rare intervals of pelagic clay and organic-rich mud turbidites of late Miocene age.

Unit I represents the topmost calcareous clays and mud turbidites of late Quaternary age that are present at all of the Leg 116 sites, although the Holocene section is mostly missing and is assumed to have been washed away during initial core penetration. Unit II is dominated by micaceous silt turbidites in the 10% of section recovered. We assume that the non-recovered intervals are of a similar lithology and, by extrapolation between widely spaced age control, that sediment accumulation rates were extremely high. The base of this unit corresponds to seismic reflector "B" in Figure 2, which at the location of Site 719 appears on the seismic records to be an erosional surface. Units III and IV are a 222-m-thick section of mainly light and dark gray mud turbidites and thin interbedded pelagic clays, which are calcareous only in the upper 20-30 m. It is within these units that most of the attenuation of the sedimentary section between Sites 717 and 719 occurs. Unit III is characterized by distinctive greenish-colored biogenic turbidites, and Unit IV by an increased proportion of silty turbidites. The average accumulation rate was between 40 and 50 m/m.y. Slightly over 100 m of gray micaceous silts were penetrated in Unit V before drilling was stopped just below a 10-m-thick greenish clay zone that correlates with a similar interval near the top of Unit V at Site 717. A synthetic seismogram based on the logs indicates that seismic reflector "Z" marks the top of the silty section and reflector "A," marking the onset of motion on the fault block, is about 70-100 m deeper (Figure 2).

The sedimentary section at Site 719 corresponds closely to the section obtained at Site 717 (Figure 6). The main lithologic units can be readily correlated, and a number of marker horizons can also be recognized within the units. These correlations are supported by the biostratigraphic data and, for the most part, by the other shipboard analyses. However, certain discrepancies remain to be resolved by further shorebased work: for example, the degree of erosion at the top of Unit III.

There is an approximate 30% reduction in the upper syn-deformation section between Sites 717 and 719. Most of the reduction (160 m) takes place within Units III and IV, much less within Unit II (15 m), and no observable difference in the topmost part of Unit V. Detailed correlation indicates that this reduction has taken place in part by the thinning of individual turbidite beds, in part by the pinching out of beds, and in part by erosion at the top of Unit III. It appears that this process has been relatively constant through most of the period since the onset of fault-block rotation at about 7 Ma, suggesting that movement on the fault has also been gradual and fairly constant. The preliminary analysis suggests that the rate of motion may have increased slightly with time.

The limiting factor in determining the deformation history will probably prove to be the age resolution that can be obtained from the biostratigraphy. The biostratigraphic control at Site 719 is based largely on nannofossils as most of the other microfossil groups are either poorly preserved or absent in all but the uppermost unit. The seafloor at the site apparently lay beneath the CCD for much of its early history and then beneath the lysocline for the past 2-3 m.y. Siliceous fossils also probably have been removed by dissolution. Most of the fossils used for dating appear to have been resedimented by turbidity currents. However, the general absence of mixing of various zonal indicator species indicates that resedimentation took place shortly after deposition.

The apparent blanketing of the uplifting fault block by the silts of Unit II suggests that during the last 0.7 m.y. the rate of sediment accumulation outstripped motion on the fault. Prior to that time, the uplift rate of the tip of the fault block and the sedimentation accumulation rate were comparable, and the top of the block probably usually represented a positive bathymetric feature. The existence of a fault block with a significant elevation above the surrounding seafloor had a profound effect on the deposition of turbidites on this part of the fan. Many turbidity currents clearly passed over the obstacle but deposited thinner beds higher up the flank. Some currents passed into a non-depositional or erosional mode, while other more minor ones may have been deflected completely.

SITE 718

Five holes were drilled at Site 718 (target site ID-6) in a water depth of 4731 m. Hole 718A was a single APC core 9.42 m long that was taken specifically for detailed pore-water geochemical measurements of the uppermost sediments. Hole 718B was a repeat APC and together with Hole 718C drilled a continuous section from the seafloor to 935 mbsf, setting yet another depth record for XCB penetration. Core recovery, however, was relatively poor, at only 30% of the interval cored, mainly because of the abundance of unconsolidated silts and sandy silts that were apparently washed away ahead of the bit. Hole 718C was logged as far as possible although hole problems prevented a complete suite of logs being obtained below a bridge at about 560 mbsf. Hole 718D was washed down to 71 mbsf in order to take further water samples and temperature measurements. Two cores were attempted in this zone where recovery in Hole 718C had been zero, and 0.17 m of loose sandy silt was recovered. After completing all of the objectives at Site 719, JOIDES Resolution returned to Site 718 to attempt to extend the record of fan sedimentation further back in time. Hole 718E was washed to 933.0 mbsf, just shy of the depth reached in Hole 718C, and was cored from there using a rotary bit. However, rapidly deteriorating hole conditions made it necessary to stop coring after obtaining only three additional cores and deepening the hole to 961.6 mbsf. One logging run was achieved to the bottom of the hole before the site was abandoned.

Site 718 was located on the fault block immediately to the south of the block drilled at Sites 717 and 719, in an area of locally high heat flow (Figure 3). Two main acoustic-stratigraphy units can be identified on seismic reflection lines: a lower pre-deformation sequence (1.2-1.3 s thick), that shows a constant character throughout the area, and an upper syn-deformation sequence (0.25 s thick) (Figure 2). This upper sequence overlies reflector "A" (Figure 2) and is markedly thinner than at either Site 717 or Site 719. There were two principal objectives for drilling at Site 718. One was to investigate the nature and effects of possible hydrothermal activity suggested by the high and variable heat flow measurements taken during the site survey. The second objective was to take advantage of the thin syn-deformation section to obtain a record of the earlier history of deposition on the distal fan.

The recovered stratigraphic section ranges from Holocene to early Miocene (about 17 Ma) and has been divided into four main lithologic units (Figure 7). The dominant lithologies and ages of the stratigraphic sequence are as follows:

Unit I:	(0.0-2.0 mbsf) Clay and calcareous clay of Holocene to latest Pleistocene age;
Unit II:	(2.0-100.0 mbsf) micaceous silt and silty mud turbidites of late Pleistocene age;
Unit III-IV:	(100.0-185.0 mbsf) mud turbidites with thin interbedded pelagic clays and scattered silty mud turbidites of Pleistocene to late Miocene age;
Unit VA:	(185.0-605.0 mbsf) silt and silty mud turbidites with thin, sporadic interbeds of mud turbidites and pelagic clays of late to middle Miocene age;
Unit VB:	(605.0-961.6 mbsf) silt and silty mud turbidites with up to 20-m-thick intervals of interbedded mud turbidites, biogenic mud turbidites and pelagic clays of middle to early Miocene age.

As at the other Leg 116 sites, sediment accumulated at Site 718 almost exclusively through fan deposition processes, and the section consists mainly of a sequence of turbidites. The lithologic units correspond approximately to the units identified at Sites 717 and 719. Unit I is a thin upper layer of muds and pelagic oozes of Holocene and latest Pleistocene age, overlying the thick, poorly recovered section of silt and silt-mud turbidites that makes up Unit II.

Unit III-IV is the equivalent of Units III and IV at Sites 717 and 719. Identification of the Plio-Pleistocene hiatus, which occurs within Unit III at the other sites, indicates that at least 5.5 m of Unit III is present. However, no clear lithologic distinction is found between Units III and IV at Site 718. The greenish biogenic turbidites that characterize Unit III at the other sites are absent at Site 718. Therefore, these two units have been combined at this site. Unit III-IV is made up of thin- to medium-bedded mud turbidites, some thin silt-mud turbidites and interbedded pelagic clays of Pleistocene to late Miocene age. A significant hiatus toward the top of this unit eliminates most of the lower Pleistocene and upper Pliocene, and a possible further hiatus or highly condensed sequence exists between the Pliocene and Miocene. The average accumulation rate for Unit III-IV is about 20 m/m.y., while that for the overlying silts is at least an order of magnitude greater. The thinner post-Miocene section reflects the fact that the fault block under Site 718 sits higher than the block under Sites 717 and 719.

The remaining section (Unit V) is characterized by silt and silty mud turbidites with zones of pelagic red and green clays, very thin-bedded green silty mud turbidites and thin carbonate silt turbidites that are more common in the lower Miocene section below 605 mbsf (Unit VB). The thin silty mud turbidites may be derived from a source other than the Ganges

Delta source that dominates most of the section. The calcareous biogenic turbidites were probably derived from a local seamount source. Accumulation rates for Unit V range from 50 to over 200 m/m.y. and average about 75 m/m.y.

The biostratigraphic control at Site 718 is based largely on sparse nannofossils and some foraminifers that have been preserved below the CCD by resedimentation in turbidites. Abundant calcareous and siliceous microfossils occur only in the uppermost unit. The reason for the complete absence of diatoms and radiolarians in the pelagic clays is not clear.

The discovery that the Bengal Fan was well established at Site 718, 2500 km from the Ganges Delta, by the early Miocene, and has been depositing sediment, including wood fragments and coarse-sand-sized grains, since that time, was a surprise, as major uplift of the Himalayan Mountains is generally dated as beginning in the middle Miocene (Gansser, 1964, 1966; Powell and Conaghan, 1973). About 750 m of the pre-deformation section was penetrated without sign of nearing the bottom of the fan deposits, with an age of about 17 Ma determined at the base of the hole. Seismic reflection records across the site (Figure 2) show no change in character below the base of Hole 718E, which can be easily interpreted as the base of the fan; it is conceivable that most of the remaining sedimentary section at the Leg 116 sites also consists of Bengal Fan sediments. The early development of the fan this far from the Ganges Delta and the deposition of relatively coarse silty turbidites during the early Miocene implies that the major uplift of the Himalayas must have occurred earlier than is generally assumed.

Downhole temperature measurements found dramatic evidence in the form of a temperature inversion, indicating vigorous hydrothermal circulation. Three temperature measurements taken between depths of 70 and 80 mbsf in the silty turbidites of Unit II were scattered (4.18°-11.78°C) and were actually higher than temperatures measured in the upper part of the underlying clay turbidites of Unit III-IV. The temperature inversion can be maintained only by lateral flow of warm water through the upper silts accompanied by a reverse flow of cold water through permeable layers within Unit III-IV. The downhole variation in pore water geochemistry also can be interpreted in terms of an active hydrothermal convection cell or cells. Both Mg and SO_4 show a marked decrease down to about 220 mbsf and then co-vary through a series of highs and lows through the remaining section. The water chemistry shows the effects of mixing between two end members, one of which is seawater and the other a water that has been chemically altered through interaction with basement rocks or by diagenetic processes. Warm water appears to be rising up the fault to the north of Site 718 and spreading laterally through permeable layers in the upper silty turbidites. At the same time, cooler seawater must be flowing downward through silt layers within the predominantly clay turbidites below, which appear on seismic reflection records to crop out a few kilometers to the south (Figure 2). There are two spikes in alkalinity and silica concentrations at depths of about 750 and 820 mbsf that are also best interpreted as reflecting flow of water along permeable zones. The water has originated from a deeper zone of sediment/fluid interaction at elevated temperatures. A diagram of possible fluid circulation within the sedimentary section in the area of Site 718 is shown in Figure 8.

Interpretation of other downhole geochemical data, together with the preliminary observation of sediments and shipboard carbonate, XRD, and XRF data, indicates that considerable early diagenesis has already taken place. In the lower 200 m of the hole, the red and green pelagic clays are well compacted and semilithified, and the carbonate turbidites are weakly cemented, while the gray turbidite silts and clays are loose and less compacted. The silts contain up to 24% $CaCO_3$ that is probably diagenetic in origin. Further shore-based work will help establish to what extent these diagenetic changes have been affected by the particular heat flow characteristics at Site 718.

Two logging runs were completed successfully in open hole from about 560 mbsf up to 100 mbsf in Hole 718C. One suite of logs included gamma ray, resistivity and sonic traces (the DIT-E/SDT-A/NGT-C tool string) and the other, gamma ray, spectral gamma, lithodensity and geochemical logs (the ACT/NGT/GST/LDT tool string). A run with the DIT-E/SDT-A/NGT-C tool was also carried out to the bottom of Hole 718E. Preliminary results confirm the lithological distinction between Units II, III-IV and VA and indicate that zones of poor recovery in Unit V consist of the same alternation of silt and silt-mud turbidites as observed in the recovered sections. There are marked coarsening-upward and fining-upward trends within Unit V on a scale of 3 to 15 m that might be related to turbidite compensation cycles. In addition, there appears to be a slight overall coarsening-upward trend through the whole of Subunit VA.

SUMMARY AND CONCLUSIONS

Fan history and Himalayan uplift

Field studies on land have shown that the first main phase of Himalayan uplift began with the "hard" continent to continent collision in the middle Miocene (Gansser, 1964, 1981; Powell and Conaghan, 1973). Only one well had been drilled previously on the Bengal Fan some 1000 km farther north (DSDP Site 218, Leg 22; Von der Borch, Sclater, et al., 1974) that had bottomed in turbidite silts of late Miocene age. It had therefore been concluded that the onset of rapid fan growth coincided with this mountain-building episode (Curray and Moore, 1971; Curray et al., 1982).

The first Leg 116 site (Site 717) was designed to obtain a complete section of the syn-deformation sediments at a location where the unconformity marking the onset of deformation appears to have become conformable (Figure 2). The site was drilled to a depth of 828.2 m into the thickest syn-deformation sedimentary section on the low side of a faulted block and recovered a nearly continuous section back to 10 Ma (Figure 3). Site 718, on the next fault block south, where the post-Miocene section is greatly attenuated, provided an opportunity to probe further back into the sedimentary history of the distal fan. At this site, a sedimentary section was obtained to a depth of 961.6 m, penetrating 775 of the approximately 1200 m of pre-deformation sediment (Figure 2), so that a complete history of the past 17 m.y. of fan deposition was obtained.

Sedimentation at both sites has been primarily through fan deposition processes and the section consists almost entirely of turbidites. At the bottom of Hole 718E, fan sediments of early Miocene age were still being penetrated, with no evidence of having reached the base of the fan. The average sedimentation rate was about 70 m/m.y. through the Miocene.

This observation demonstrates that the Bengal Fan was well established and delivering sediment up to coarse-sand size to the Leg 116 sites, 2500 km from the Ganges Delta, by the early Miocene. The presence of such a large volume of terrigenous sediment in the early Miocene implies the existence of a voluminous sediment source at that time. This suggests that considerable relief existed in the India-Asia collision zone and that major uplift of the Himalayas may have occurred earlier than had been assumed generally.

This evidence also implies that nearly the entire sedimentary section of the Central Indian Ocean consists of Bengal Fan turbidites. Since the oceanic crust in this area was formed about 78 Ma, the whole of the Upper Cretaceous and Lower Tertiary sequence must be represented by very slow mid-ocean pelagic accumulation.

Intraplate deformation

Drilling at all three sites penetrated the entire syn-deformation sequence and the available biostratigraphic data allow an age of about 7 Ma for the onset of faulting and block rotation. These movements appear to have continued to the present day.

On the more northerly fault block, correlation between the two sites shows an almost 30% reduction in the top 600 m of section from Site 717 to Site 719 (Figure 6). Most (160 m) of this thinning takes place within the more slowly deposited muddy intervals (lithologic Units III and IV), while the the upper silty turbidites (lithologic Unit II) are reduced by only 15 m at Site 719, and no thinning is noted in the upper part of Unit V.

This dramatic reduction in section thickness between sites that are only 3 km apart on the distal fan could have been accomplished by three means. The first is by marked thinning of individual turbidites, which can be clearly demonstrated for some beds but which does not appear adequate to account for the full section loss. The second is by non-deposition of certain beds, which also seems evident from preliminary correlation between the sites. The third is by erosion, which appears likely from the seismic reflection record to have occurred at the top of Unit III.

It appears that motion on the block has been gradual and has been occurring at a fairly constant rate for the past 7 m.y. This rate can be calculated from the amount of displacement on oceanic crust across the fault at about 50 m/m.y. There is some indication that the rate of motion may have increased slightly with time. However, the detailed correlation now in progress, when combined with biostratigraphic data, will allow a detailed history of the motion to be developed.

The limiting factor in determining the deformation history will probably prove to be the resolution on ages that can be obtained. Biostratigraphic control at all of the Leg 116 sites is provided primarily through nannofossils, since the other microfossil groups are either absent or poorly preserved. However, subject to the resolution provided by the nannofossil zones, the data obtained at Sites 717 and 719 should allow a detailed history of motion on the fault block to be determined.

Controls on Sedimentation

The gross character of sedimentation changed several times through the 17-m.y. record recovered at the Leg 116 drill sites. The most obvious first-order change was from the more silty turbidite sections that characterize the Miocene to the sections of mainly finer mud turbidites separated by pelagic clays that characterize Pliocene deposition and back to coarser silty turbidites in the Pleistocene. The change in the nature of the sedimentation near the end of the Miocene is not related to the onset of deformation, since that event clearly occurred within the lower silty unit (Figure 6).

There appear to have been a number of factors influencing sedimentation on the distal Bengal Fan. A primary control is the uplift history of the Himalayas, which are the main source of sediments. This is seen, for example, in the pulse of coarser grained silty turbidites in the Pleistocene following a major phase of mountain building (Gansser, 1964, 1981). A second influence is variations in sea level. A sharp rise in sea level near the Miocene/Pliocene boundary (Haq et al., 1987) may have contributed greatly to the change from silty to more muddy turbidite deposition at that time. A third influence is tectonic activity related to the intraplate deformation. The block containing Site 718 has been elevated relative to the block containing Sites 717 and 719 (Figure 2), and as a result the post-Miocene sedimentary history of the two blocks differs considerably. A final influence on the sedimentation is normal fan processes such as channel migration and lobe switching.

A consistent feature of the biostratigraphic record at all three Leg 116 sites is a marked hiatus between the Pliocene and the late Pleistocene. Just less than 1 m.y. of the early Pleistocene is absent at Sites 717 and 719. The hiatus may also include some of the late Pliocene at Site 718, although the record simply may be more condensed at this site. At present the origin and regional extent of this hiatus is uncertain. The lack of turbidity current deposits might be due to a diversion of the main turbidity current pathways to a distant part of the fan. The lack of pelagic sediment during this time appears to require an intensified bottom circulation, perhaps related to climatic or oceanographic changes.

Turbidites and turbidites

Enormous volumes of sediment are supplied to the distal portion of the fan, in some periods at sediment accumulation rates in excess of 350 m/m.y. The thickness of individual turbidites recovered ranges from less than 0.01 to over 2.5 m, the mean grain size (at the turbidite base) ranges up to coarse silt/fine sand, and the maximum size of quartz grains deposited was coarse sand. A high percentage of terrigenous plant debris is present in many of the turbidites, dispersed through the dark gray muds, concentrated in silty laminae or as isolated wood fragments up to several centimeters in length.

Several different turbidite facies can be identified, and these reflect different sources. The most common gray micaceous silts and silt to mud turbidites are believed to derive directly from the sediment load deposited on and beyond the Ganges Delta. On average, they reach the distal fan with a frequency on the order of one every 1000 years. Dark gray mud turbidites, commonly with up to 5% plant debris, may have derived from the slumping of unstable sediments on the upper slope in the northern and/or western Bay of Bengal. These apparently reach the distal fan with a frequency of about one every 10,000 years. Distinctive greenish-colored biogenic turbidites and white silty calcareous turbidites are interbedded with the terrigenous material in specific zones. The white turbidites were most likely derived from more local seamounts of the Afanazy Nitikin group, at much less frequent intervals. The greenish turbidites have a benthic shelf or upper slope fossil assemblage and may be derived from the continental margin of Sri Lanka or India.

Much shore-based work is needed to refine and confirm our preliminary interpretations of sediment source. For example, it is possible that the thin-bedded green silt-mud turbidites and interbedded reddish brown clays that become more common toward the base of the recovered section reflect the increased importance of a more local Indian margin source earlier in the fan history. Work is also in progress on the nature of the magnetic susceptibility signature found in the dark gray mud turbidites, and on the distinctive nature of sediments that appear to have been deposited beneath turbid clouds beyond the reach of the turbidity current itself.

Hydrothermal circulation

Heat flow in the intraplate deformation area is mostly higher than expected for oceanic crust of its age and shows considerable scatter. A detailed heat-flow survey conducted as part of the pre-cruise site survey showed great variability on the scale of a few kilometers. Site 718 was located on a local heat-flow high, both to study the effects of high heat flow on sediment diagenesis and to investigate the possibility of hydrothermal circulation. Dramatic evidence for vigorous hydrothermal circulation was encountered in the form of a temperature inversion at a depth of about 100 m below seafloor.

Temperatures measured in the Pleistocene silty turbidites of Unit II (Figure 3) were highly scattered (4.2°-11.8°C) and were actually higher than in the upper part of the underlying muddy turbidites. It appears that warm water is rising up the fault plane to the north of Site 718 and spreading laterally through permeable layers in the upper silty turbidites. At the same time, cooler sea water must be flowing down through permeable silt layers within the predominantly mud turbidites below (Unit III; Figure 8), which appear to crop out several kilometers to the south at the tip of the fault block (Figure 2).

These conclusions are supported by geochemical studies of interstitial water that show the effects of mixing between two end members, one of which is seawater and the other a water which has been chemically altered by interaction with basement rocks or by diagenetic processes within the sediments.

Conclusions

The preliminary scientific conclusions of Leg 116 can be summarized as follows:

1. The history of the Bengal Fan goes back to at least the early Miocene, and the fan is at least 1.3 km thick some 2500 km from the Ganges Delta. The fact that large quantities of relatively coarse sediment were being delivered to the distal fan by the early Miocene implies that major uplift of the Himalayan Mountains occurred earlier than the middle Miocene age often assigned to it.
2. Intraplate deformation began to affect this part of the Central Indian Ocean about 7 Ma. Block rotation along high angle faults has been relatively constant since that time.
3. The primary source of sediments for the fan has been the Ganges-Brahmaputra drainage basin. However, there has also been a significant input from the continental margins of the western Bay of Bengal, and a lesser but distinctive contribution from local seamounts.
4. The uplift history of the Himalayas and variations in sea level have been the major factors controlling the nature and rate of sedimentation on the distal fan. Local tectonic activity and normal fan processes such as channel mig[illegible]

Powell, C.M.A., and Conaghan, P. J., 1973. Plate tectonics and the Himalayas. Earth Planet. Sci. Lett., **20**:1-12.
Stein, S., and Okal, E. A., 1978. Seismicity and tectonics of the Ninety East Ridge area: Evidence for internal deformation of the Indian plate. J. Geophys. Res., **83**:2233-2245.
Von der Borch, C. C., Sclater, J. G., et al., 1974. Init. Repts. DSDP, **22**: Washington (U.S. Govt. Printing Office).
Weissel, J. K., Anderson, R. N., and Geller, C. A., 1980. Deformation of the Indo-Australian plate. Nature, **287**:284-291.

TABLE 1. LEG 116 SITE SUMMARY

HOLE	LATITUDE	LONGITUDE	WATER DEPTH (m)*	NUMBER OF CORES	METERS CORED	METERS RECOV'D	PERCENT RECOV'D	METERS TOTAL PENET.
717A	00°55.785'S	81°23.408'E	4735	1	9.5	9.64	101.5	9.5
717B	00°55.785'S	81°23.408'E	4735	3	13.5	13.43	99.5	23.0
717C	00°55.785'S	81°23.408'E	4735	91	814.7	480.20	58.9	828.2
718A	01°01.252'S	81°24.065'E	4731	1	9.5	9.42	99.2	9.5
718B	01°01.252'S	81°24.065'E	4731	2	18.8	9.26	49.3	18.8
718C	01°01.252'S	81°24.065'E	4731	98	925.7	274.05	29.6	935.0
718D	01°01.252'S	81°24.065'E	4731	2	19.0	0.17	0.9	90.0
718E	01°01.252'S	81°24.065'E	4731	3	28.5	9.92	34.8	961.6
719A	00°57.646'S	81°23.967'E	4737	49	460.2	185.3	40.3	460.2
719B	00°57.646'S	81°23.967'E	4737	0	0	0	0	460.2

*Corrected to sea level from dual-elevator stool (DES) on the rig floor.

FIGURE CAPTIONS

Figure 1: Morphometric map of the Bengal fan area showing the location of the Leg 116 drilling sites (modified from Emmel and Curray, 1984).

Figure 2: *Conrad* C2706 single-channel seismic reflection line across the Leg 116 sites. Lithologic units are shown at location of sites with depth of unit boundaries converted to two-way traveltime. Reflectors "A," "B," and "Z" discussed in text are noted to left of the profile. Total length of the seismic line is 18.5 km.

Figure 3: Contour map of heat flow measurements obtained during the pre-cruise site survey on R/V *Robert D. Conrad* cruise C2706 (after Weissel, unpublished data). Squares and circles are locations of heat flow stations; heat-flow values in mW/m^2. Location of Site 718 shown with large black dot.

Figure 4: Age, core number and recovery, lithology, and lithologic units at Site 717. Age zonations based on nannofossils.

Figure 5: Age, core number and recovery, lithology, and lithologic units at Site 719. Age zonations based on nannofossils.

Figure 6: Lithologic columns from the three Leg 116 sites showing correlations between sites based on detailed sedimentologic and biostratigraphic comparisons.

Figure 7: Age, core number and recovery, lithology, and lithologic units at Site 718. Ages based on sparse nannofossils.

Figure 8: Diagram of geologic section in the area of Leg 116 sites (based on *Conrad* C2706 seismic line) showing possible water circulation pattern suggested by heat flow and interstitial water data.

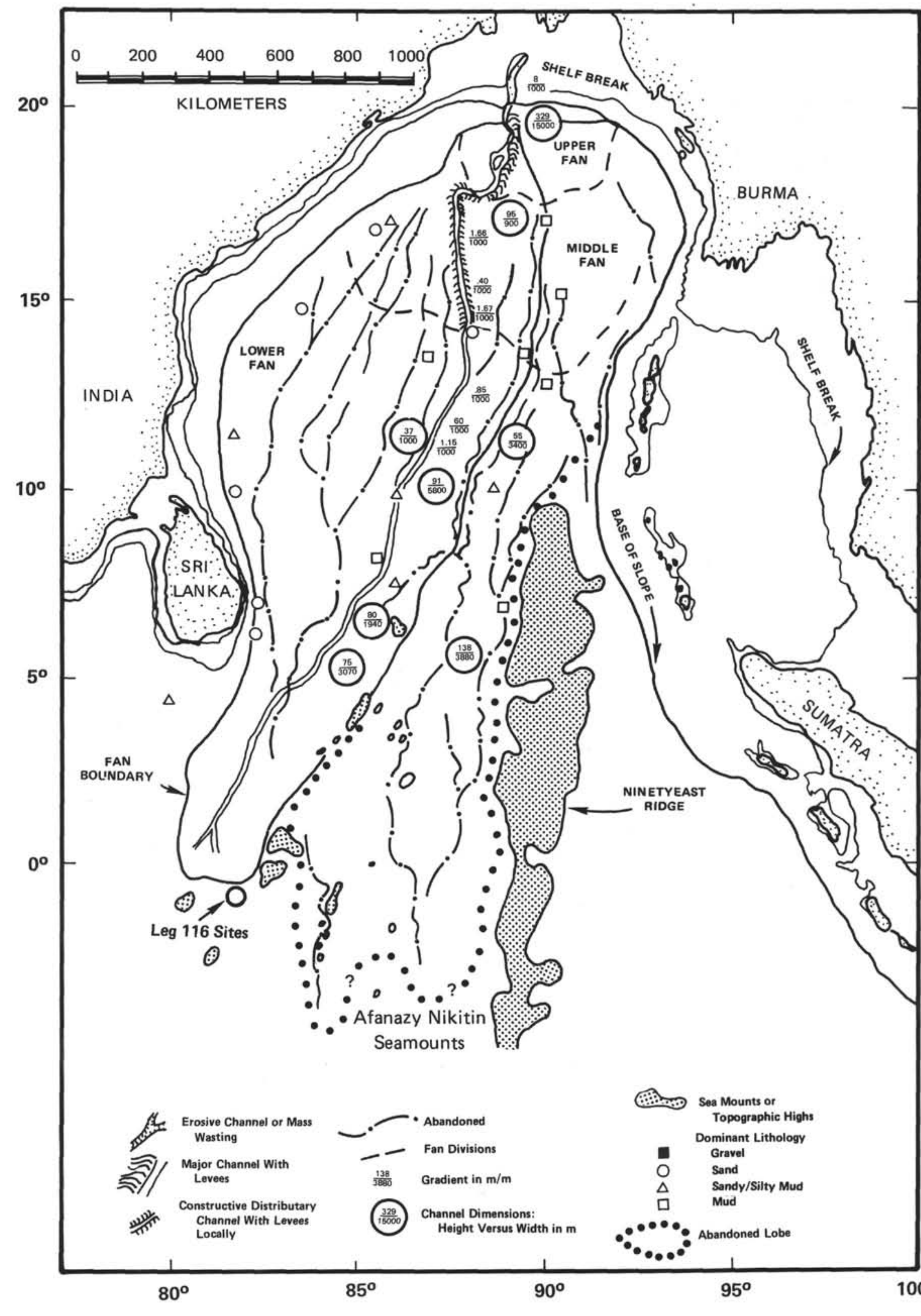
0 200 400 600 800 1000
KILOMETERS
20°
15°
10°
5°
0°
80°
85°
90°
95°
100°
SHELF BREAK
UPPER FAN
BURMA
MIDDLE FAN
LOWER FAN
INDIA
SRI LANKA
SHELF BREAK
BASE OF SLOPE
SUMATRA
FAN BOUNDARY
NINETYEAST RIDGE
Leg 116 Sites
Afanazy Nikitin Seamounts
Erosive Channel or Mass Wasting
Major Channel With Levees
Constructive Distributary Channel With Levees Locally
Abandoned
Fan Divisions
Gradient in m/m
Channel Dimensions: Height Versus Width in m
Sea Mounts or Topographic Highs
Dominant Lithology
Gravel
Sand
Sandy/Silty Mud
Mud
Abandoned Lobe

Figure 1.

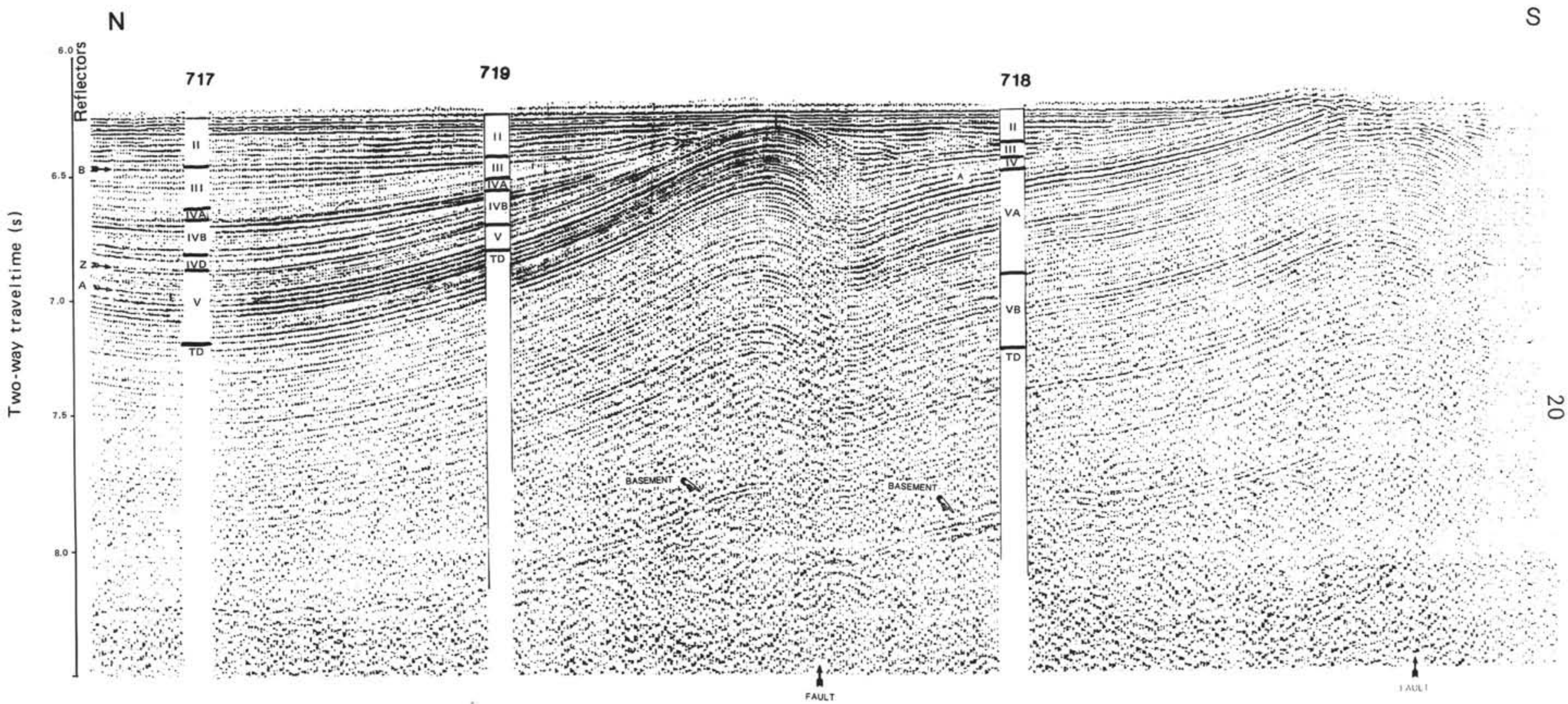
N
S
Reflectors
Two-way traveltime (s)
6.0
6.5
7.0
7.5
8.0
B
Z
A
717
719
718
II
III
IVA
IVB
IVD
V
TD
II
III
IVA
IVB
V
TD
II
III
IV
VA
VB
TD
BASEMENT
BASEMENT
FAULT
FAULT

Figure 2.

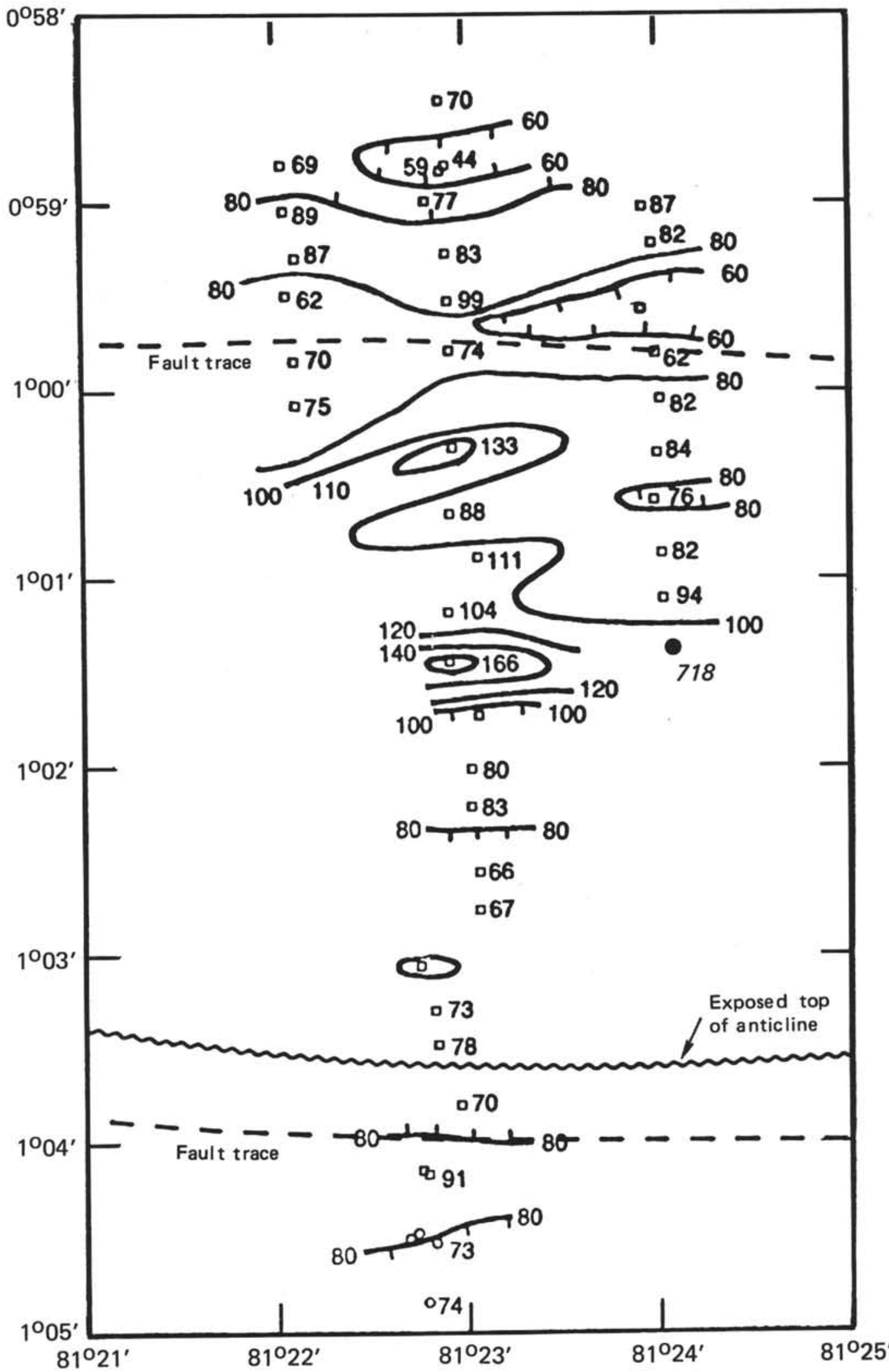
0°58′
0°59′
1°00′
1°01′
1°02′
1°03′
1°04′
1°05′
81°21′
81°22′
81°23′
81°24′
81°25′
Fault trace
Fault trace
Exposed top of anticline
718
70
60
69
59
44
60
80
80
87
77
89
82
80
87
83
60
80
62
99
60
74
62
70
80
82
75
133
84
80
100
110
76
80
88
82
111
94
104
100
120
140
166
120
100
100
80
83
80
80
66
67
73
78
70
80
80
91
80
80
73
74

Figure 3.

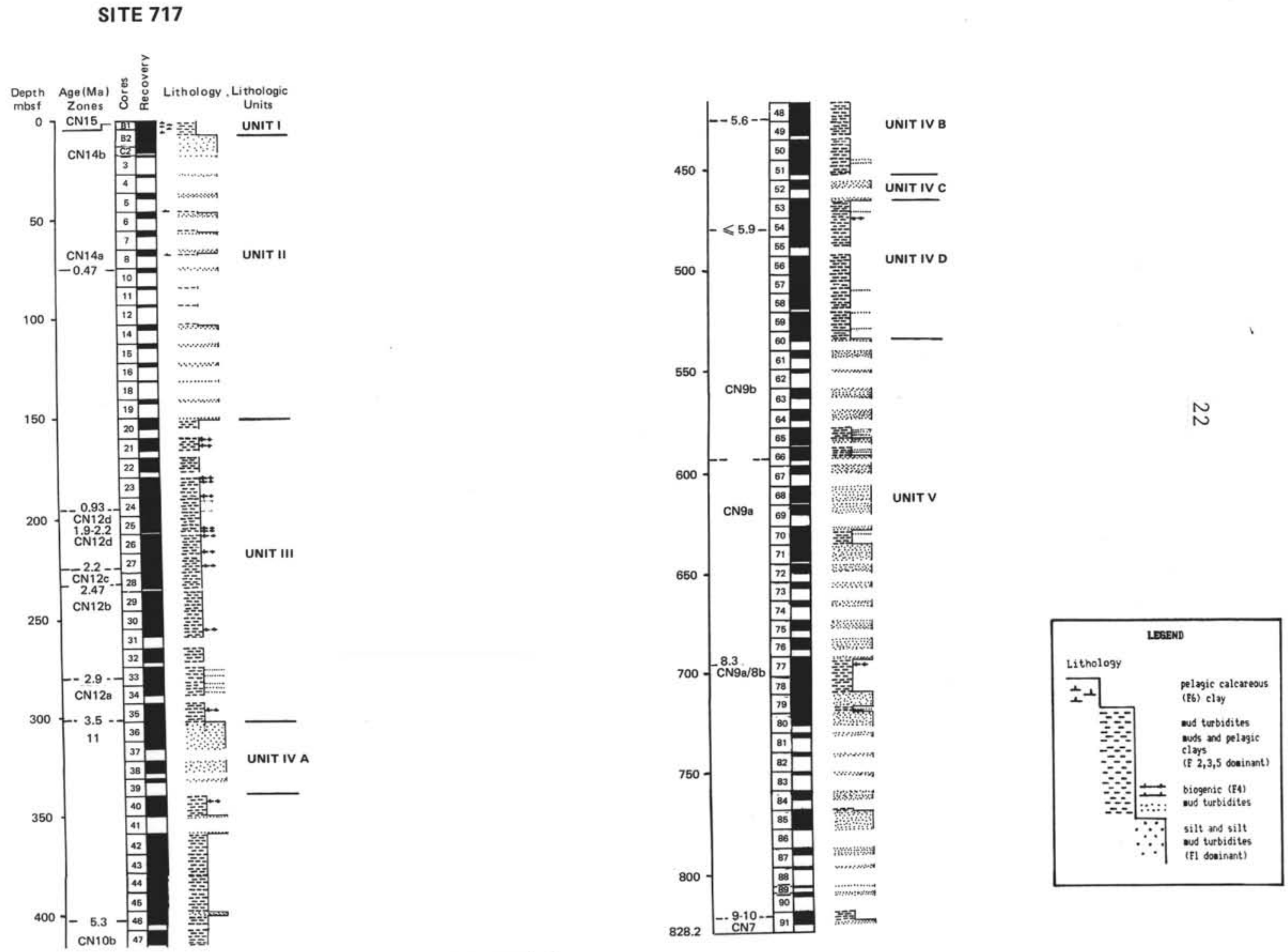
SITE 717
Depth mbsf
Age (Ma) Zones
Cores
Recovery
Lithology
Lithologic Units
CN15
CN14b
CN14a
0.47
0.93
CN12d
1.9-2.2
CN12d
2.2
CN12c
2.47
CN12b
2.9
CN12a
3.5
11
5.3
CN10b
UNIT I
UNIT II
UNIT III
UNIT IV A
5.6
≤ 5.9
CN9b
CN9a
8.3
CN9a/8b
9-10
CN7
828.2
UNIT IV B
UNIT IV C
UNIT IV D
UNIT V
LEGEND
Lithology
pelagic calcareous (F6) clay
mud turbidites
muds and pelagic clays (F 2,3,5 dominant)
biogenic (F4) mud turbidites
silt and silt mud turbidites (F1 dominant)

Figure 4.

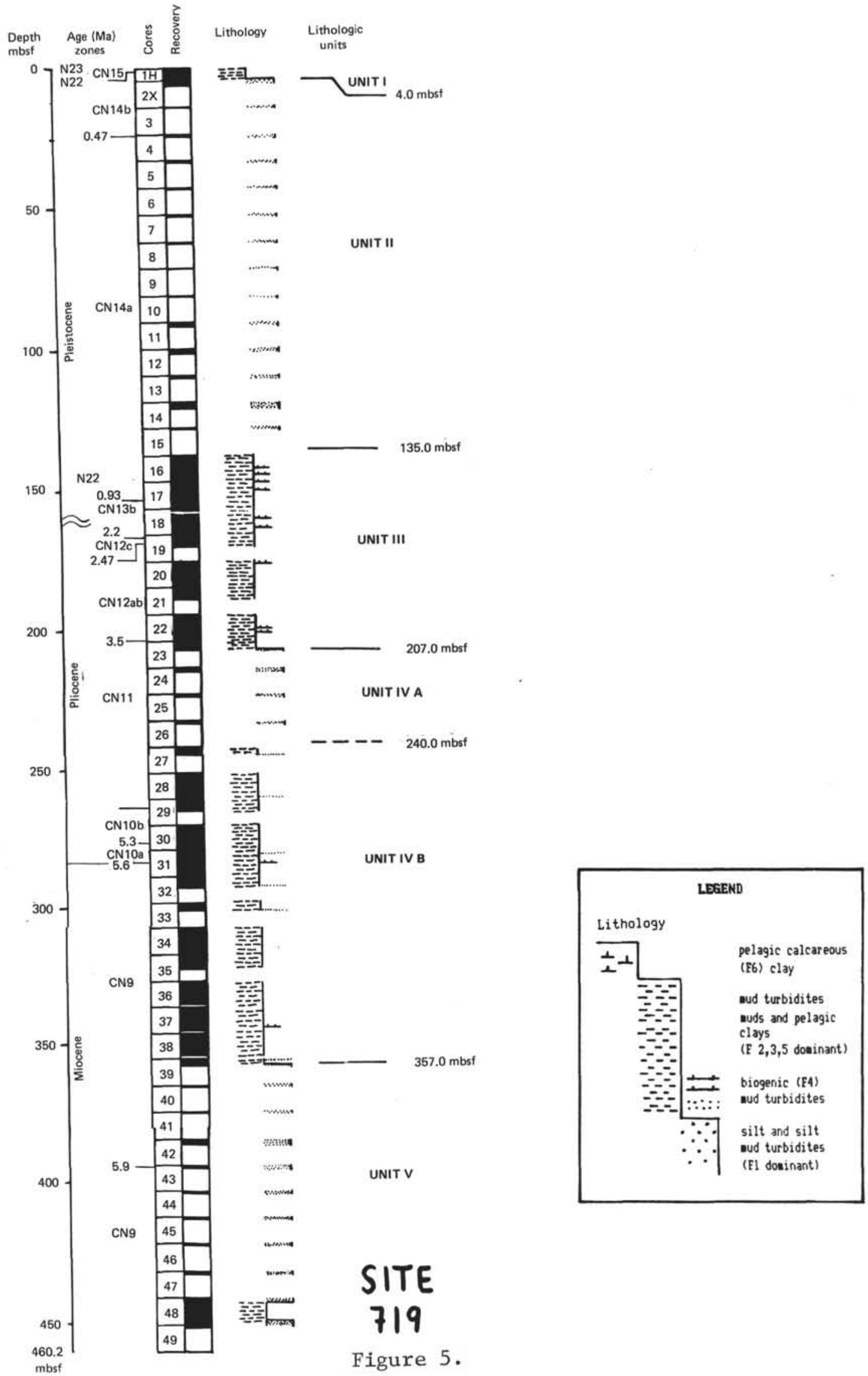
Depth mbsf
Age (Ma) zones
Cores
Recovery
Lithology
Lithologic units
UNIT I
4.0 mbsf
UNIT II
135.0 mbsf
UNIT III
207.0 mbsf
UNIT IV A
240.0 mbsf
UNIT IV B
357.0 mbsf
UNIT V
Pleistocene
Pliocene
Miocene
460.2 mbsf
SITE 719
LEGEND
Lithology
pelagic calcareous (F6) clay
mud turbidites muds and pelagic clays (F 2,3,5 dominant)
biogenic (F4) mud turbidites
silt and silt mud turbidites (F1 dominant)

Figure 5.

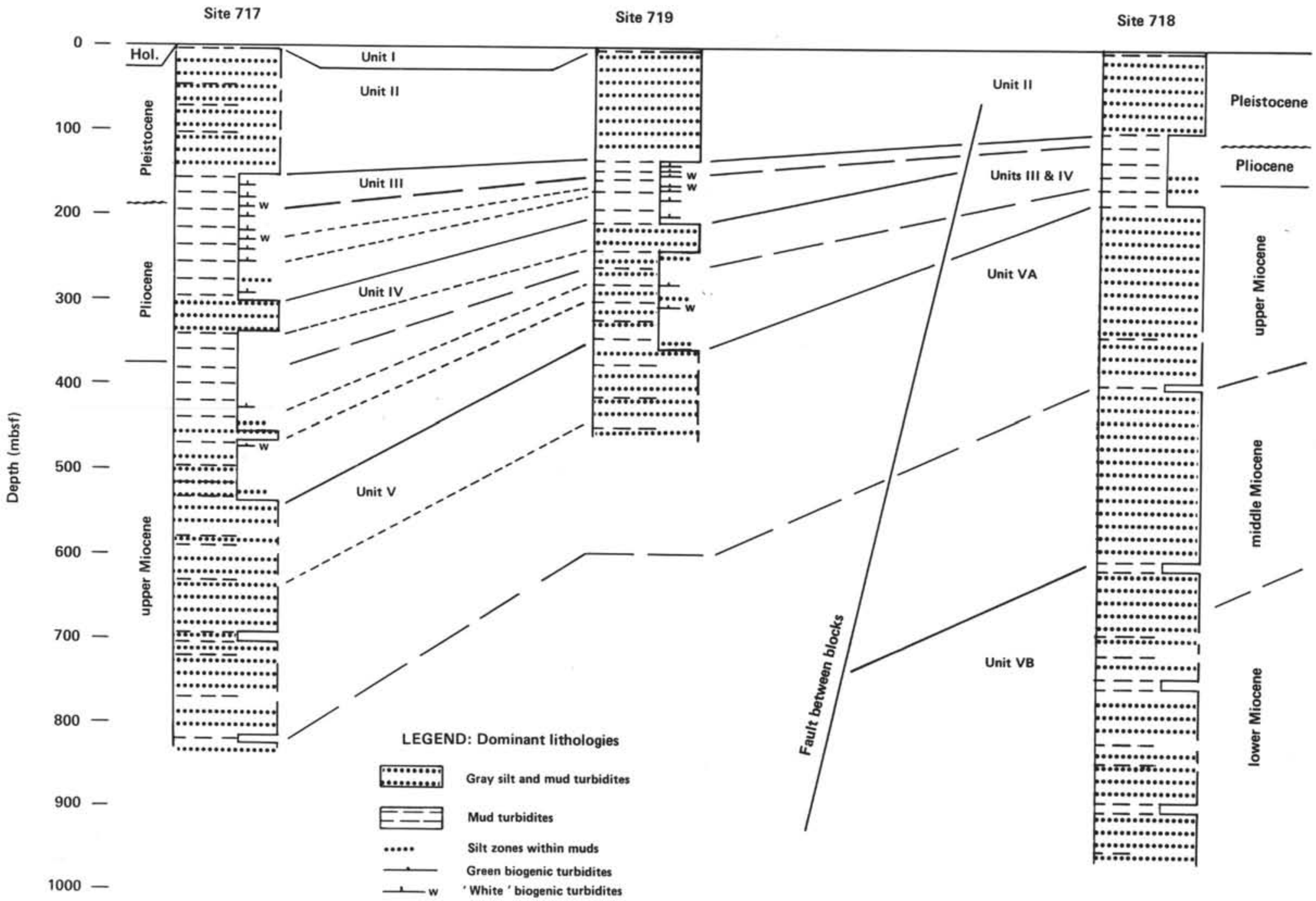
Site 717
Site 719
Site 718
Depth (mbsf)
0
100
200
300
400
500
600
700
800
900
1000
Hol.
Pleistocene
Pliocene
upper Miocene
Unit I
Unit II
Unit III
Unit IV
Unit V
Units III & IV
Unit VA
Unit VB
Fault between blocks
middle Miocene
lower Miocene
w
LEGEND: Dominant lithologies
Gray silt and mud turbidites
Mud turbidites
Silt zones within muds
Green biogenic turbidites
' White ' biogenic turbidites

Figure 6.

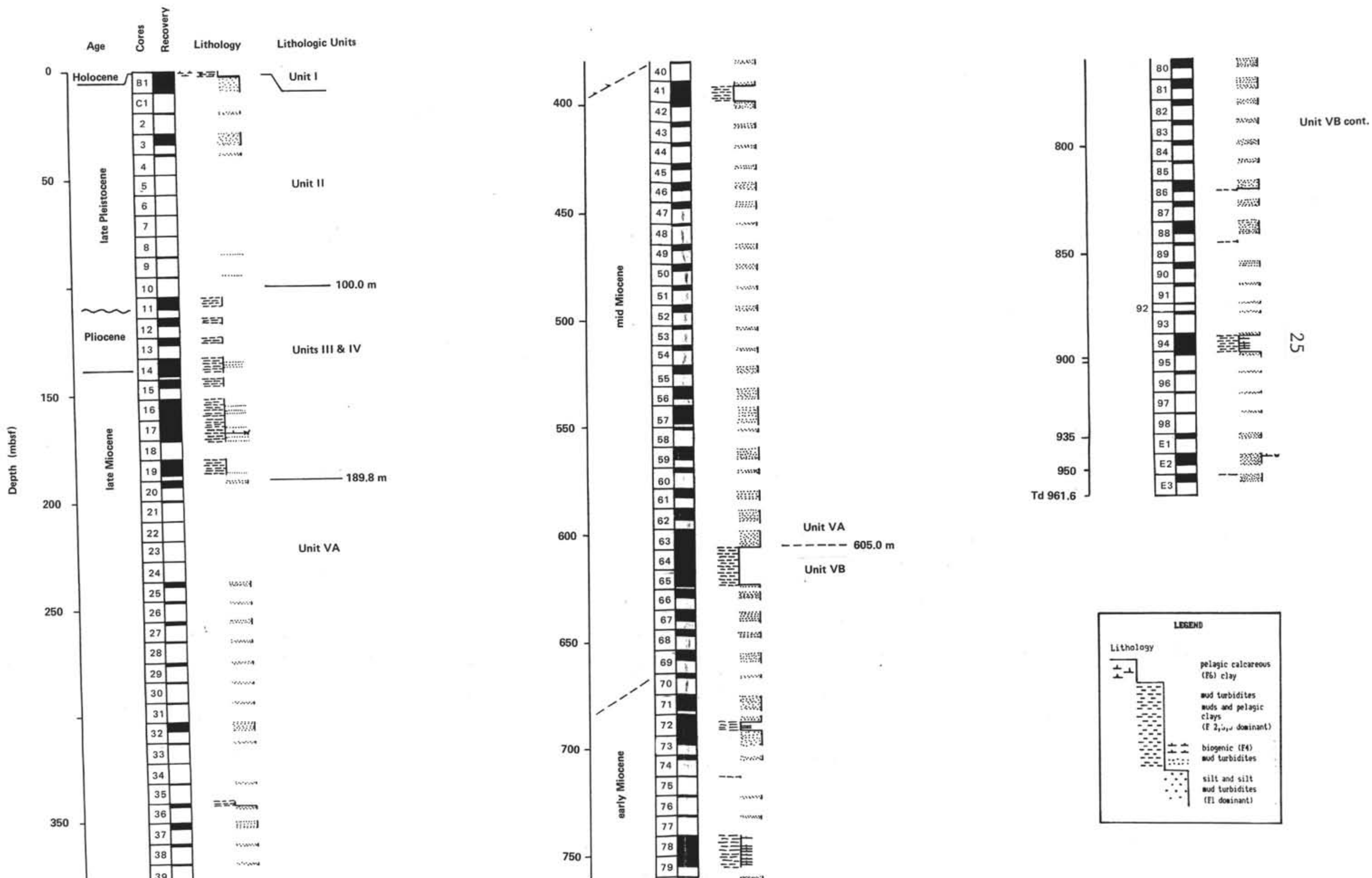
Age
Cores
Recovery
Lithology
Lithologic Units
Depth (mbsf)
Holocene
late Pleistocene
Pliocene
late Miocene
mid Miocene
early Miocene
Unit I
Unit II
100.0 m
Units III & IV
189.8 m
Unit VA
605.0 m
Unit VB
Unit VB cont.
Td 961.6
LEGEND
Lithology
pelagic calcareous (F6) clay
mud turbidites
muds and pelagic clays
biogenic (F4) mud turbidites
silt and silt mud turbidites (F1 dominant)

Figure 7.

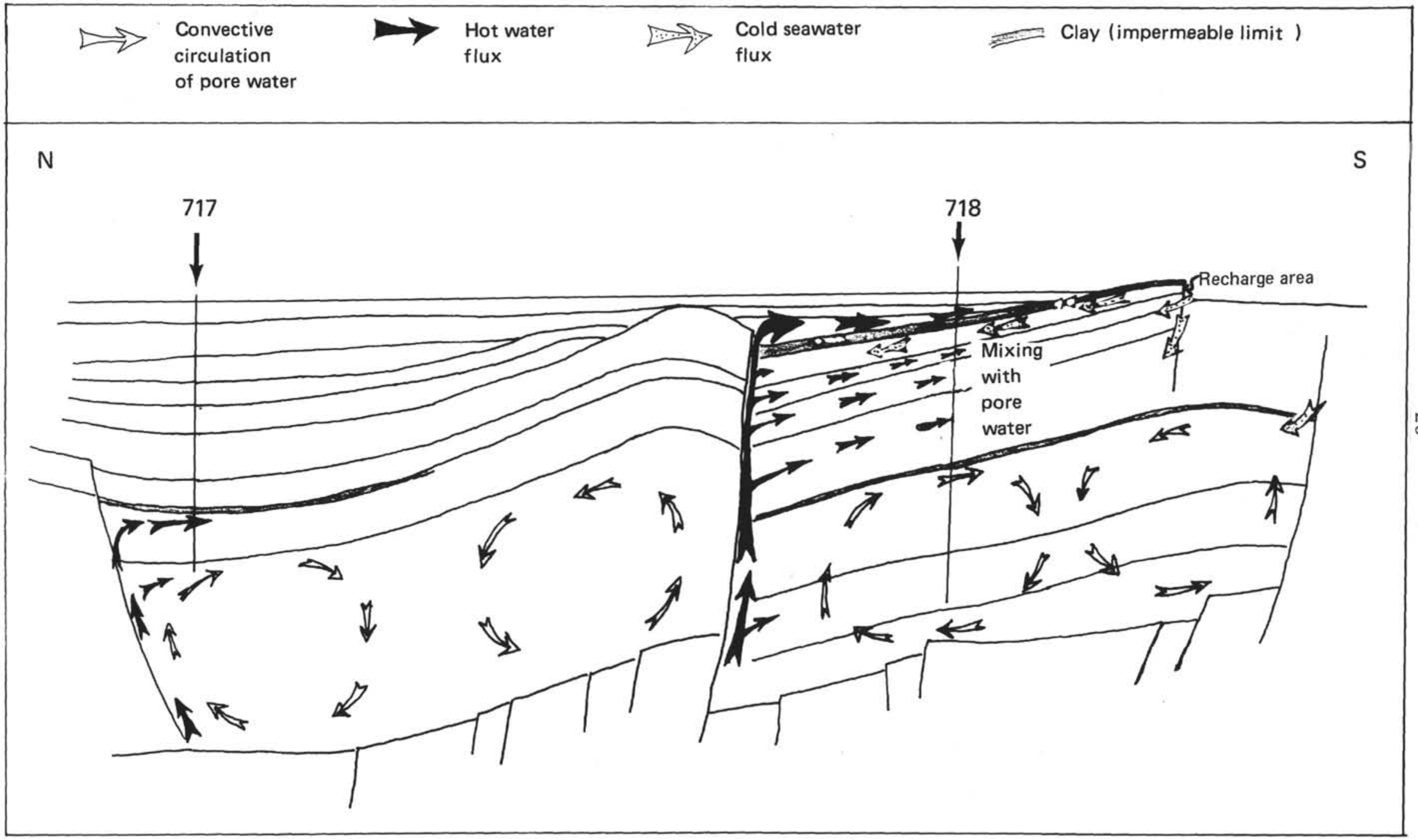
Convective circulation of pore water
Hot water flux
Cold seawater flux
Clay (impermeable limit)
N
S
717
718
Recharge area
Mixing with pore water

Figure 8.

OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard JOIDES Resolution for Leg 116 were:

Operations Superintendent	Charles Hanson
Special Tools Engineer	Patrick Thompson

Other operations personnel aboard for Leg 116 were:

Logging Engineer	David Hsieh Schlumberger Houston 8460 Gulf Freeway Houston, TX 77023

OPERATIONS SYNOPSIS
LEG 116

Leg 116 officially commenced at 0645 hr on 2 July 1987 in the port of Colombo, Sri Lanka. JOIDES Resolution docked first at the container terminal to take aboard a new drill line and then moved to Dock BQ2. By early evening of 5 July all personnel and cargo were aboard. JOIDES Resolution sailed for the first site at 1725 hr 7 July.

SITE 717 (ID-1)

Hole 717A

After an uneventful voyage the ship arrived at the first site at 0545 hr 9 July. The drill pipe was lowered and the bit was positioned at 4747.3 m for the first APC core. (Depths will be given in meters from the rig floor dual elevator stool [DES] and in meters below seafloor [mbsf]). A full 9.64 m core was recovered indicating that the bit had been below the mud line.

Hole 717B

The second shot was taken with the bit at 4740.3 m, and the mud line was determined to be at 4745.8 m. Core 116-717B-2H produced a bent core barrel and Core 116-717B-3H a broken barrel, half of which was left in the hole.

Hole 717C

The ship was moved 10 m to avoid the lost barrel. The second APC core produced another bent barrel. It was concluded that the formation near the seabed consisted of about 8 m of soft clay lying on top of hard sand that could not be penetrated by the APC. At 17.5 mbsf APC coring was terminated and the XCB deployed.

The formation was interpreted to be mostly sand, and initial recovery was very poor. At 112.5 mbsf the formation became clay interbedded with fine sand, and the recovery increased. Recovery in the clay-like material was often near 100%, and hole conditions were good. Three heat-flow measurements were run and yielded good results. Core 116-717C-87X at 797 mbsf severely over-torqued the outer barrel, and a piece of cemented sandstone about a foot long was recovered. A diamond core shoe was run in anticipation of additional hard material but only clay was recovered in subsequent cores. This sample later proved to be the only "rock" recovered during the entire leg.

At 828.2 mbsf the co-chiefs concluded that the scientific objectives had been reached and coring was terminated. A new below-the-seafloor penetration record was reached by the XCB. Recovery for the hole was 59%.

In preparation for running electric logs the hole was swept with mud, and a short trip was made to 182 mbsf. After sweeping the hole with additional mud, the mechanical bit released was activated, and the bit and flapper valve dropped to the bottom of the hole.

The Schlumberger logging tools were picked up and the side entry sub (SES) was installed. The tools did not pass deck tests and about 14 hr was lost making repairs. After repairs, the tools and SES were run to 4735 m, but they would not go deeper. The sonic indicated the tool was not inside steel. It was then determined that about 40,000 lbs of drill string weight was missing. Collective evidence suggested the BHA had parted at or near the seabed.

The logging tools, SES, and drill pipe were recovered. The BHA was missing below the top drill collar. The reason for the failure is not known. No additional logging operations were possible in Hole 717C, and the ship got under way for the next site at 2116 hr, 19 July 1987.

SITE 718 (ID-6)

Hole 718A

Target site ID-6 is 4 nmi from Hole 717C, and after a short site survey the positioning beacon was dropped at 0145 hr, 20 July. The first APC core was a full barrel, and the entire core was dedicated for testing by the chemists.

Hole 718B

The bit was positioned at 4741.5 m and a mud line core of 9.26 m was recovered. The second core was fired at 2800 psi, and when the barrel reached the surface it was found that it had failed in compression. It was concluded that it had been fired into a hard sand, and that additional APC coring would result in the damage of more equipment.

Hole 718C

The ship was moved 10 m to avoid possibly drilling into the lost barrel, and the bit was washed to 9.3 mbsf. The first ten cores down to 104.3 mbsf were in the same sand formation that was present at the other locations, and the recovery was next to nothing. Below 104.3 mbsf, the recovery was only fair in spite of using many combinations of weight, rotary speed, pump rate, and extension sub length. The recovered formation was mostly clay or silty sand. Near 600 mbsf the recovery increased as the clay became firmer. Core 116-718C-98X at 935.0 mbsf was declared total depth. The overall recovery was 29.6%, and an XCB penetration record was set for the second time during the leg.

Although the record is a credit to the XCB equipment, the primary reason for being able to set the record was the soft clay at the site. The reason for the relatively low recovery rate is not fully understood but is likely due to the sand content of the formation and the soft clay packing off in the XCB cutter barrel.

A major effort to log the hole was begun by circulating 50 barrels of mud and short-tripping the drill pipe up to the soft sands at 157 mbsf. Tight hole and stuck pipe at 291 and 205 mbsf were dealt with by circulating water and mud. The drill pipe was run back to bottom and the hole swept with additional mud. The mud was circulated out leaving the hole filled with seawater, and the bit was released on bottom. The pipe was pulled to 130 mbsf and the Schlumberger logging equipment was rigged up; the SES was not used.

The first log run was the DIT-E/SDT-A/NGT-C. The tool failed at 2500 m. After repair, the tool was lowered out the end of the drill pipe at 157 mbsf, but a bridge was encountered at 220 mbsf. The logging tools were recovered and the bit-less drill pipe was run to near bottom where the pipe became stuck. Using 200,000 lb overpull and mud slugs, the pipe was worked loose in 2 hr. The hole was circulated clean and loaded with prehydrated gel mud treated with KCl and Drispac. Since it was suspected that the sticking problem originated in the shallow sands, additional mud was spotted with the drill pipe at 262 mbsf. With the drill pipe at 129 mbsf, the first log reached 565 mbsf where a solid bridge was encountered. A good log was obtained back to the drill pipe.

The second log was the LDT/GST/ACT/NGT. After a tool failure at 3700 m, a log was obtained from the bridge at 553 mbsf to the drill pipe.

Although it cannot be known for certain, it is believed that the stuck pipe and bridges in Hole 718C were caused by unconsolidated sand falling into the well bore. Generous use of high-viscosity mud to suspend the sand probably reduced the bridging, but the cause and treatment of hole problems is always speculative. The logging equipment was rigged down on 1 August and the BHA cleared the seafloor at 1115 hr.

Hole 718D

For additional heat-flow tests, the ship was moved 10 m where Hole 718D was drilled to 71 mbsf, and three heat-flow measurements were taken to 90 mbsf. The TV camera was run on the outside of the drill pipe in an operational test of the new 100-horsepower hydraulic TV winch motor.

SITE 719 (ID-2)

Hole 719A

The next site was less than 4 nmi from Hole 718D. JOIDES Resolution made the move in 3.7 hr in dynamic-positioning mode while the drill pipe was being pulled. The beacon was dropped at 2045 hr, 2 August.

Drilling this hole was of special interest to operations because a new core bit design was to be tested. The bit, a 9 7/8" APC/XCB, has no moving parts. The cutters are fixed blades that are composed of a composite of carbon-tungsten steel and synthetic diamonds.

The first 15 cores of Hole 719A penetrated the same sands that had been present at the previous sites, and core recovery was less than 10%. Cores 116-719A-16X to 116-719A-22X and 116-719A-28X to 116-719A-38X had good recovery. Cores 116-719A-29X to 116-719A-49X exhibited low recovery. The hole reached a total depth of 460.2 mbsf on 5 August; total core recovery was 40%. Because a bit release was not in the BHA, the bit could not be released, and it was necessary to round-trip the drill pipe to remove the flapper valve from the BHA for logging. The drag bit reached the rig floor at 1445 hr, 6 August. The bit was in near-perfect condition after having made 460.2 m of hole in 8.32 on-bottom rotating hours or 34,944 revolutions: a very respectable run.

Hole 719B

The ship was moved 10 m south. Hole 719B was drilled, not cored, as a logging hole. The diamond drag bit was re-run without the flapper valve. It drilled the same 460.2 m as in Hole 719A in 3.8 on-bottom hours, with only a small amount of wear.

In preparation for logging, the hole was treated with a massive amount of mud and circulated vigorously to prevent sand filtering down the hole and forming bridges. After circulating water and mud to clean out the sand, a short trip was made. As a final prophylactic against sand settling, the hole was filled with mud composed of gel prehydrated in freshwater, Drispac, and seawater.

Three successful logging runs were made. The drill pipe was positioned at 96 mbsf, and log # 1 was the DIT-E/SDT-A/NGT-C. There was 10 m of fill (based on the logging line measurement) and the log was run from 450-87 mbsf on the first attempt. Log # 2 was the GST/ACT/NGT which was run from 450-87 mbsf. Log # 3 was the LDT/CNT/NGT from 450-87 mbsf. The logging equipment was rigged down, and the hole was departed at 1600 hr, 9 August.

RETURN TO SITE 718

Hole 718E

After drilling Site 719, JOIDES Resolution returned to Site 718. Hole 718E was planned as a deep offset to Hole 718C. The hole was drilled without coring to 933.1 mbsf. Three cores were then cut to a total depth of 961.6 mbsf, and the drill pipe was stuck during each of the connections. We surmised that the plastic clay formations were flowing into the well bore and that the probability of getting permanently stuck was very high.

The decision was made to abandon coring attempts and instead to log the hole. The initial attempt to log had to be aborted when the hydraulic bit release failed to function. It was decided to drop a mini-cone, pull the drill pipe, remove the bit, and then attempt a reentry with the drill pipe. Following an on-bottom flooding of the TV camera and 13.5 hr trying to stab the drill pipe into the 8-ft-wide mini-cone, reentry was accomplished.

Log run #1 was the DIT/SDT/NGT. Hole conditions were excellent and the log was run from 961.5 to 166.5 mbsf. The second logging tool (LDT/CNT/NGT) would not pass below 4585 m, which was 156 m above the seabed. Efforts to pump the tool down were unsuccessful. The logging tool was recovered, but there was not sufficient time left to try again. The lack of time for another attempt was regretted, especially because indications were that the hole was a good one in which to work.

The drill pipe was recovered, and a bent joint of pipe was found where the logging tool had been stopped. It is not known how or when the pipe was bent, but the unsuccessful stab attempts while trying to enter the mini-cone are certainly possibilities.

JOIDES Resolution departed for Colombo, Sri Lanka, at 1500 hr, 17 August 1987. At 0026 hr, 18 August near 1°09.5'N, 80°58.00'E, the ship logged her 100,000th nautical mile since leaving the builder's yard. The first line was ashore at 0915 hr 19 August, 1987, ending Leg 116.

OCEAN DRILLING PROGRAM
OPERATIONS RESUME
LEG 116

TOTAL DAYS (2 JULY 1987 - 19 AUGUST 1987)		48.1
TOTAL DAYS IN PORT		5.44
TOTAL DAYS UNDER WAY (INCLUDING SURVEY)		3.61
TOTAL DAYS ON SITE		39.05
DRILL ACTUAL	2.25	
CORING INCLUDING WIRELINE TIME	20.03	
CONDITION MUD AND CIRCULATE	1.19	
TRIP	6.09	
DOWNHOLE SCIENCE	5.54	
RE-ENTRY OPERATION	1.52	
OTHER	2.43	
	39.05	

TOTAL DISTANCE TRAVELED (NAUTICAL MILES)	1052.4
AVERAGE SPEED (KNOTS)	11.3
NUMBER OF SITES	3
NUMBER OF HOLES	10
TOTAL INTERVAL CORED (M)	2299.4
TOTAL CORE RECOVERY (M)	991.4
% CORE RECOVERY	43.1
TOTAL INTERVAL DRILLED	1026.8
TOTAL PENETRATION (M)	3326.2
MAXIMUM WATER DEPTH (M FROM DRILLING DATUM)	4747.3
MINIMUM WATER DEPTH (M FROM DRILLING DATUM)	4741.3

OCEAN DRILLING PROGRAM
SITE SUMMARY
LEG 116

HOLE	LATITUDE	LONGITUDE	DEPTH METERS	NUMBER OF CORES	METERS CORED	METERS RECOVERED	% RECOVERED	METERS DRILLED	TOTAL PENETR.	TIME ON HOLE	TIME ON SITE
717A	0°55.785'S	81°23.408'E	4756.8	1	9.50	9.64	101.5	0	9.50	16.50	------
717B	0°55.785'S	81°23.408'E	4768.8	3	13.50	13.43	99.5	0	23.00	2.75	------
717C	0°55.785'S	81°23.408'E	5574.0	91	814.70	480.20	58.94	13.5	828.20	254.5	273.75
718A	1°1.252'S	81°24.065'E	4750.8	1	9.50	9.42	99.16	0	9.50	15.75	------
718B	1°1.252'S	81°24.065'E	4760.3	2	18.80	9.26	49.26	0	18.80	3.00	------
718C	1°1.252'S	81°24.065'E	5676.5	98	925.70	274.05	29.60	9.3	935.00	257.00	------
718D	1°1.252'S	81°24.065'E	4831.5	2	19.00	0.17	0.89	71	90.00	29.25	------
719A	0°57.646'S	81°23.967'E	5207.5	49	460.2	185.33	41.93	0	460.20	94.25	------
719B	0°57.646'S	81°23.967'E	------	------	------	------	-------	460.2	460.2	73.25	167.50
718E	1°1.252'S	81°24.065'E	5703.2	3	28.50	9.92	34.81	933	961.60	191	496.00
TOTAL					2299.4	991.42	43.1				937.25

TECHNICAL REPORT

The ODP Technical and Logistics personnel aboard JOIDES Resolution for Leg 116 of the Ocean Drilling Program were:

Laboratory Officer:	Bill Mills
Computer System Manager:	John Eastlund
Curatorial Representative:	Gail Clement
Yeoperson:	Michiko Hitchcox
Electronics Technician:	Mike Reitmeyer
Electronics Technician:	Barry Weber
Photographer:	Christine Galida
Chemistry Technician:	Matt Mefferd
Chemistry Technician:	Joe Powers
X-ray Technician:	Christian Segade
Marine Technician:	Wendy Autio
Marine Technician:	Jenny Glasser
Marine Technician:	Ted Gustafson
Marine Technician:	Kazushi Kuroki
Marine Technician:	John Leonard
Marine Technician:	Kevin Rogers
Marine Technician:	Don Sims
Weather Observer:	Vernon Rockwell

LEG 116 TECHNICAL REPORT

Port Call: Colombo, Sri Lanka

Port call activities began at 0730 hr, 2 July when JOIDES Resolution docked temporarily at the container facility to load drilling line. Final berthing was delayed to 1730 hr because of problems with local port authorities in clearing customs. This gave us little time for crossover, as offgoing technicians were required to clear customs that night.

Shipments to and from the ship were moved with few problems. The greatest difficulties resulted from shipments arriving at odd hours of the night. We departed Colombo for our first site at 1725 hr, 7 July.

Underway Activities

Underway geophysical gear saw light duty this trip. From port to the location of our sites, we ran at full speed (approx. 11 kt). High-quality magnetometer and acceptable PDR data were collected.

Several hours out from our first site, the ship's speed was slowed to 6 kt and both 80-cubic-inch water guns were deployed. A survey was made over all three sites and the adjacent area. Good analog records were collected, but timing difficulties with the particular combination of deep water delay and recording window, as requested by the co-chiefs, precluded digital recording. Upon leaving our first site, the survey route was repeated with the intention of collecting a digital record. This goal was partially achieved. An intermittent problem with the deep water delay resulted in a random offset of shot lines. This problem was later traced to a faulty black box power supply which has since been repaired.

On-site Activities

Three sites comprising ten holes were cored on Leg 116. Deep water and poor recovery in silty sediments made for a slow pace in the lab, with only a few equipment problems early in the cruise.

Curation: Although sampling density was high, low recovery constrained the total number of samples collected to 7868.

Physical properties: All equipment was operational throughout the leg. The new P-wave program (PRO-350 version) was installed.

Paleomagnetics: This lab functioned smoothly throughout the leg. Only two piston cores were taken during the leg, so most measurements were done on discrete samples. All susceptibility measurements were made by the shipboard scientists. The shipboard scientists noticed anomalously high Z-component NRM values that appeared to be induced by the core barrels. The core barrels were successfully demagnetized, but when it took only one round trip for them to become fully re-magnetized, the procedure was dropped as impracticable.

Downhole measurements: On our first run of the Von Herzen temperature recorder, the core barrel was sheared off, and one of our two available recorders was lost. Because of the sandy formation, the XCB coring method was used almost exclusively, and no other attempts to use the Von Herzen recorders were made. Because heat-flow measurements were a major science objective of this leg, the Uyeda temperature recorder was used extensively. Out of 15 deployments, 12 usable temperature records were collected. Unfortunately, our attempts to collect water samples were not as successful. Out of seven attempts only three runs returned water, and that water was heavily contaminated by drilling fluids. Our poor record was attributed to the clayey formation and to failure of the new wireline deployment tool to latch in properly.

The new ODP wireline tool delivery system was tested this leg. This tool is designed to allow our heat-flow/pore-water tools to be decoupled from ship's motion and to allow the tools to retract up into the drill string if 11,000-15,000 lb of resistance to penetration is encountered. The tool generally worked well; it is easier to handle on deck because of its shorter length and the retraction feature provides more safety for our tools. But several failures of our tools to get a usable record were attributed to improper function of the collet. This tool certainly has the potential of being the preferred way of deployment, but the advantages of this system over the "Hayes" system have yet to be conclusively demonstrated.

XRD-XRF lab: Although core recovery was low, both the XRD and XRF equipment were kept busy this leg. A total of 436 XRD analyses was completed this leg on both bulk and clay fractions. A new microprocessor board was installed at the beginning of the leg, which solved the communications problems experienced on previous legs. No other major problems were noted.

This leg conducted an extensive XRF analysis of sediments. One hundred eight samples were processed in the XRF lab. Most of these samples were analyzed for ten major and thirteen trace elements for an approximate total of 2800 measurements. Also, nine new standards were processed and major software modifications were made.

Chemistry: The chemists conducted routine organic and inorganic analyses.

Computer facilities: Because of low core recovery, the computer facilities were not bogged down as on past legs. The VAX experienced errors on two memory boards and a disk controller. These errors were self correcting and damaged no files.

Storekeeping: New MATMAN software version was installed.

Casing hold and shop: Advantage was taken of the unusually low level of supplies in the casing hold by covering the rough oak planks with plywood. Several layers of plywood were used to smooth out the surface. Additional dividers and a plywood bottom were added to the materials rack, for ease of handling sheet stock. Scrap wood and steel supplies were high-graded.

Weather equipment: We were unable to test the new down converter, and the crystal we received for the Russian satellite was the wrong one and has been reordered. Other than these problems, everything worked fine.

Fantail: While on site a thorough inventory and organization of air- and water-gun parts and equipment were done.

Reentry equipment: Because of cutbacks in SEDCO personnel, reentry equipment was returned to ODP for storage, routine maintenance, and repair. Space was finally made in the ET shop, downhole logging lab and lower sack storage. The video reentry system was run twice this leg, once to test out the new hydraulic pump on the winch, and second to reenter a mini-cone at the last site.

Safety

The Marine Emergency Technical Squad (METS) participated in the weekly SEDCO fire drills. We also had several meetings with the second mate and went over lifeboat operations with emphasis on engine start-up and operation.

Dr. Nickerson held CPR classes, and several of our technicians had their certificates updated. First-aid classes were held for small groups of people. The emphasis of these classes was to train assistants to help the ship's doctor with emergencies.

Boxes were made to hold our Scott gas masks and burn first-aid kits. Four masks and one burn kit are stationed across from the core log station, and the other burn kit is in the chemistry lab.

Personnel

A hot tropical cruise was welcome relief for the technical staff after their antarctic adventure on Leg 114. The more relaxed lab pace allowed for completing many projects and for training five technicians in new areas.