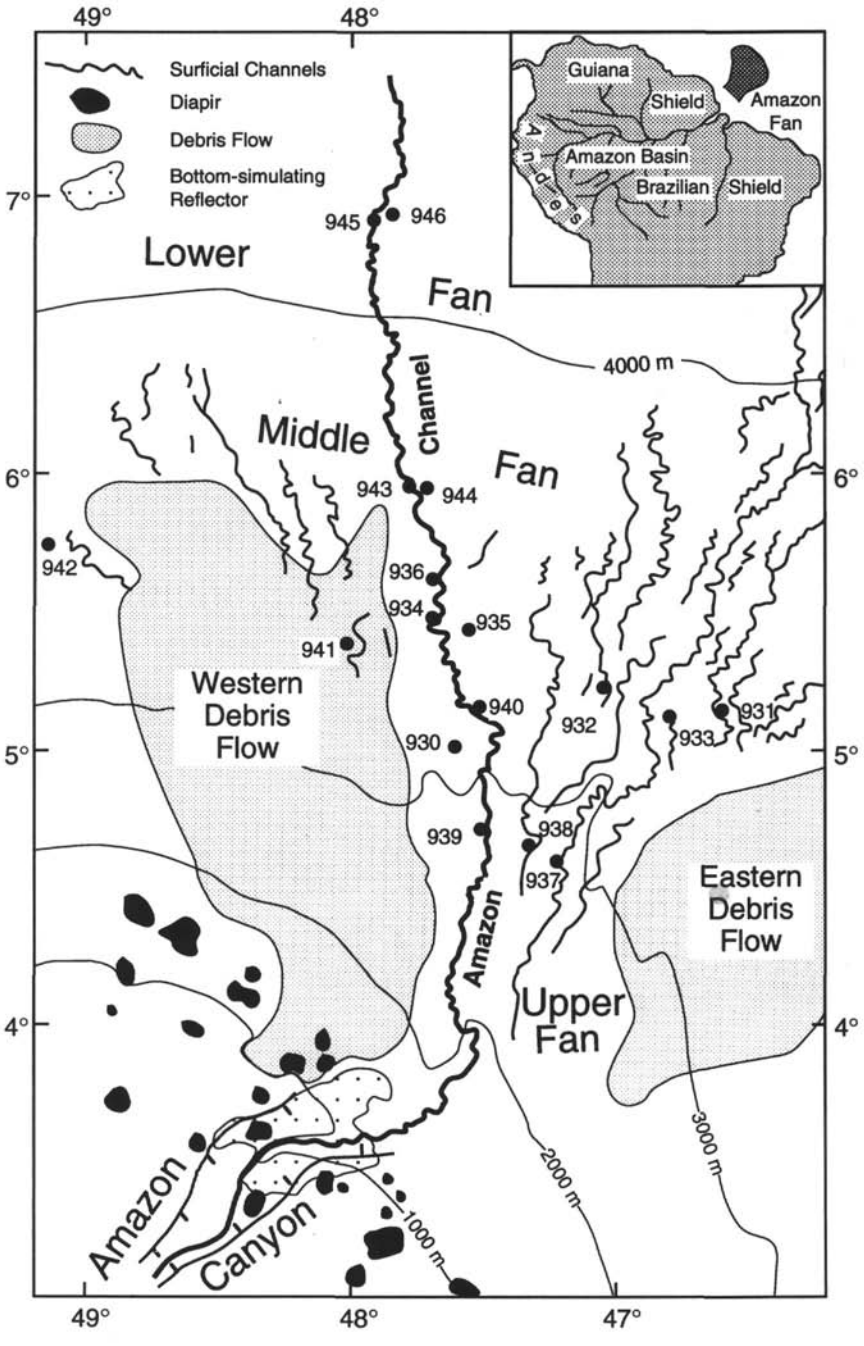
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Western Debris Flow
Eastern Debris Flow
Amazon
Upper Fan
Amazon Canyon
2000 m
3000 m
1000 m

1940DP, GEC

# OCEAN DRILLING PROGRAM

# LEG 155 PRELIMINARY REPORT

# AMAZON FAN


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## ABSTRACT

Drilling of 17 sites (Sites 930-946) on the Amazon deep-sea fan has shown that major glacial to interglacial changes in sea level and climate are reflected in the architecture and lithology of turbidite deposits. Hemipelagic muds that accumulated at 1-3 m/k.y. on the levee crests of abandoned channels contain a detailed biostratigraphic record. The combination of foraminiferal, isotopic, and paleomagnetic data will allow an unprecedented level of time resolution for paleoclimate studies and for correlation between different fan environments. The high sedimentation rates, abundance of terrestrial organic detritus, and iron-rich character of Amazon sediment result in vigorous production of biogenic methane and the common occurrence of diagenetic iron phosphates.

## INTRODUCTION

Continental margins are important repositories of information about the Earth's history. Sediments deposited in this environment, although sometimes difficult to decipher, contain records of material flux to the oceans (related in part to sea-level changes), of ocean circulation, and of land and ocean climate. Margin environments have steep environmental gradients and high sedimentation rates, thus providing high-resolution marine and terrestrial records in sensitive areas. Interpreting these records requires a detailed understanding of sediment processes and distribution patterns.

Submarine fans are particularly sensitive to the effects of land climate, sea-level change, and tectonic activity in the source area. Nevertheless, they provide nearly continuous records in several sedimentary facies, each of which can provide a different record of marine and terrestrial detritus. For example, submarine channels transport materials from rivers to be deposited on levees while oceanic biota accumulate at lower rates on local topographic highs including abandoned levee crests. Rapid burial of river-derived organic matter makes the fan an excellent area in which to investigate early diagenesis. During fan progradation, the locus of most active sedimentation and the nature of the sedimentary facies deposited at any given place change through time. Study of these facies patterns in their modern setting helps us understand the processes that form them, and thus allows predictive interpretation of ancient turbidite systems.

The Amazon Fan (Fig. 1) extends 700 km seaward of the continental shelf and is a typical passive-margin deep-sea fan (Stow et al., 1985). The Amazon River, which transports 10% of the world-total of fluvial sediment, has supplied sediment to the Amazon Fan since Andean uplift in the Miocene. The present high sea-level stand prevents the Amazon River sediment from crossing the shelf (Nittrouer et al., 1991), but during lowered glacial sea levels the river crossed the emerged shelf and discharged directly into a submarine canyon. The canyon crosses the continental slope and leads to large, sinuous channels with high levees that cross the upper and middle fan (Fig. 2). The channels are perched on top of lens-shaped, aggradational turbidite overbank deposits, forming lenticular channel-levee systems (Fig. 3). Only one channel (Amazon Channel) is now connected to the submarine canyon. Older channel segments were progressively abandoned as breaching of a channel wall (avulsion) repeatedly allowed the aggrading channel to follow a new, steeper path. As the sandy lower fan is reached, levee deposits thin and channels die out. The abandoned channel-levee systems seen in seismic sections can be grouped into larger complexes (Fig. 4) that are separated by zones of acoustically incoherent and transparent sediment interpreted as debris-flow deposits and by hemipelagic sediments (Flood et al., 1991).

Seventeen sites were occupied on the Amazon Fan during Leg 155 to meet four main objectives:

1. To determine the relationship between the development of fan deposits, sea-level change, and climatic and possibly tectonic changes in the Amazon Basin.
2. To determine the sediment lithologies characteristic of distinctive acoustic facies and sedimentary processes.
3. To use the stratigraphic record of the Amazon Fan to better understand climatic change within the Amazon drainage basin and the overlying western equatorial Atlantic.
4. To characterize and understand the nature, origin, and early diagenesis of organic carbon present in different fan units.

## LITHOSTRATIGRAPHY AND ACOUSTIC STRATIGRAPHY

The stacked lenticular channel-levee systems seen in seismic-reflection profiles provide a basic stratigraphic context for the sites that were drilled. Relative ages have been assigned to these channel-levee systems based on the way they lap on to one another on seismic profiles (Damuth et al., 1983; Manley and Flood, 1988). The uppermost seven systems on the western fan are, in

order of increasing age, Amazon Channel, Brown, Aqua, Purple, Blue, Yellow, and Orange (Figs. 4 and 5). Abandoned channels on the eastern fan are Channel 5 (? between Yellow and Orange) and Channels 6A, 6B, and 6C. All these channel-levee systems make up the Upper Levee Complex, which is separated by an apparent debris flow, Unit R, from the Middle Levee Complex. In the central part of the fan, the Middle Levee Complex consists of only the Red channel-levee system. The more deeply buried channel-levee systems, Green, Gold, Lime, Grey, and Pink, form the Lower Levee Complex and are underlain by the Bottom Levee Complex.

Because avulsion tends to occur in the middle and lower reaches of channels, several channel-levee complexes tend to become coincident toward the upper part of the fan. Thus, for example, at Site 939, which is upstream from the point at which avulsions separated the Amazon, Brown, and Aqua channels, the three channels and levees are the same.

Sites 931, 933, 935, 936, 944, and 946 sampled the section below the Upper Levee Complex, providing a basic stratigraphic framework for the fan (Figs. 4 and 6). Sites 932, 937, 938, and 942 were primarily intended as biostratigraphic reference sites in the slower sedimentation-rate sections above abandoned levees (Figs. 5 and 6). Sites 939, 930, 940, 935, 936, 944, and 946 provided sections through the levee of the Amazon Channel from the upper to the lower fan (Figs. 2 and 6). Sites 934, 943, and 945 sampled sediments within channels; Site 941 investigated a near-surface debris flow.

The levee crests of abandoned channel systems had bioturbated mud. Levees built by active channels consist of mud with abundant thin beds of silt and sand. They have prograded over thick medium sand beds deposited at the end of an active channel. Mass-transport deposits of slides and debris flows, up to 120 m thick, consist of contorted blocks of mud, with dimensions from centimeters to many meters, generally with little matrix material. The surface meter of sediment on the fan is a calcareous mud; a similar lithology was found on top of some of the deeply buried levees.

## CHRONOLOGY AND CORRELATION

### Biostratigraphy

Several stratigraphic tools provided shipboard age control. Additional age evidence will come from shore-based studies, including stable isotopes and $^{14}C$ dating. Planktonic foraminifers and calcareous nannofossils provide useful age markers at about 6, 9, 11, 40, 85, 130, and 260 ka. The channel-levee systems of the Upper Levee Complex other than Channel 6 and Orange are younger than
40 ka.

Calcareous clays containing interglacial foraminifers are interpreted as analogues of the Holocene calcareous clay that covers the entire fan and has a sedimentation rate of <0.1 m/k.y. Such calcareous clays form only during marine highstands, when Amazon River sediment is advected northwestward along the inner continental shelf. Three such calcareous clay beds at Site 942 are interpreted as dating from isotopic stage 5: the middle clay contains a paleomagnetic excursion (the Blake event, 105 ka). Calcareous clays that immediately overlie the top of the Lower Levee Complex (Sites 935, 939, and 944) and the ?Bottom Levee Complex (Sites 931 and 933) (Fig. 4) have different nannofossil assemblages from those at Site 942. Our shipboard interpretation is that isotopic stage 7 rests on the Lower Levee Complex, and isotopic stage 9 on the ?Bottom Levee Complex. Isotopic stage 5 appears to overlie the Middle Levee Complex, but in many areas it has been removed by the overlying Unit R debris flow.

### Magnetostratigraphy

Paleomagnetic studies provided two unexpected techniques for dating and correlating sites: a widespread and distinctive paleomagnetic excursion that appears to be the Lake Mungo event (ca. 30 ka) (Fig. 7) and oscillations in magnetic declination, inclination, and intensity interpreted as geomagnetic secular variation (Fig. 7). These show two wavelengths of variation, with periods of a few hundred and a few thousand years, based on sedimentation rates determined from biostratigraphic markers. These high-resolution paleomagnetic records will help to understand short-term variability of the Earth's magnetic field.

Sedimentation Rates

Glacial-age sedimentation rates on the fan are measured in meters per thousand years and are quite variable between sedimentary environments (Fig. 8). The levee crests of abandoned channels, which stand above all but the thickest turbidity currents, had "low" sedimentation rates of 1-3 m/k.y., and despite dilution by terrigenous sediment contain continuous foraminiferal records suitable for isotope stratigraphy. The levees built by active channels accumulated at rates of 10-25 m/k.y., and sandy lobes deposited downstream from channels at rates averaging 2 m/k.y. Calcareous clays deposited across the fan during marine highstands, with sedimentation rates of about 0.1 m/k.y., provided a basic stratigraphic framework.

## FAN SEDIMENTATION PROCESSES

The scientific understanding of turbidites and deep-sea fans has resulted from work with three types of data: ancient flysch sequences on land, modern deep-sea fans, and principally seismic-reflection data from hydrocarbon basins. Because of the differences in tools used to investigate each type of data and the differences in scale, it is commonly difficult to relate the three types of data (Normark et al., 1993). Studies of ancient fans often focus on regions with good outcrop exposure but little information about the morphological setting in which the sediments accumulated. Studies of modern marine fans have good morphological data but little information on the sediments deposited below the reach of standard piston cores (ca. 10 m). We are beginning to bridge this gap by characterizing the sediments in a range of settings on a large, muddy fan. Similar studies will be needed to characterize smaller, sand-rich fans.

The drilling results from Leg 155 (Fig. 9), integrated with previous seismic-reflection studies, show that the Amazon deep-sea fan has aggraded as a result of rapid deposition in channel-levee complexes that have prograded across medium- to coarse-grained sands deposited at the downstream ends of channels. Rare pebbles are found in sands at 3500-m water depth. Channel termination sands are thick bedded, and some occur in upward-coarsening sequences. We achieved high core recoveries when APC-coring coarse channel sands, which formed beds up to 18 m thick (Fig. 10). The medium and coarse sand overall is concentrated within shoestring bodies (channels and channel termination zones) within the predominantly muddy fan. Some levees form upward-fining sequences of mud with beds of silt and fine sand.

Our preliminary chronology shows that the major shifts in channel position by avulsion on the upper fan took place every 5 to 10 k.y. in the late Pleistocene. Many individual channel-levee systems show fluctuations in the abundance of overbank silt on a scale of 0.5 to 1.5 k.y. which suggests that controls in addition to sea-level change affect sediment supply to the deep sea. Shore-based isotopic chronology should allow us to relate such changes to sea-level and climate history. On a longer time scale, initial results suggest that each major levee complex of the Amazon Fan corresponds to a glacial stage (Fig. 4).

Debris-flow deposits over 100 m thick occur near the present seafloor over more than half the mid-fan (Fig. 1), and others are intercalated with older levee deposits (Fig. 4). The lower parts of these debris-flow deposits appear to be large slide blocks, whereas the upper parts resemble muddy debris flows. No clear relation between debris-flow activity and sea level has yet emerged.

## CLIMATE CHANGE AND OCEANIC CIRCULATION

Shipboard studies have shown that cores can be used to infer the climatic history of the Amazon Basin; however, care is being used, because deep-sea fans are mostly built of reworked sediment. Pollen is much more abundant at low sea-level stands than in Holocene and interglacial sediments. Cerrado (grassland) species are well represented in samples from the last glacial maximum. Although proportions of clay minerals are influenced by grain-size effects, kaolinite appears more abundant during assumed isotopic stages 2 and 6 than at other times, possibly reflecting changes in weathering in the Amazon Basin. Shore-based studies of organic geochemistry, pollen, and mineralogy and geochemistry of terrigenous detritus should provide important information on the climatic history of the Amazon Basin and surrounding highlands.

The western equatorial Atlantic Ocean, above the Amazon Fan, is important in the Earth's heat budget, because the Northeast Brazil Current is the only major current to cross the equator. Shore-based isotopic and paleontological work will be necessary to interpret our high-resolution records of oceanic circulation, temperature, and productivity.

## EARLY DIAGENESIS

The diagenetic environment on the Amazon Fan is unusual for its combination of high sedimentation rates (typically 3-8 m/k.y.), abundant supply of carbon of terrestrial origin, and iron-rich terrigenous detritus (≈ 8 wt% $Fe_2O_3$). Sulfate reduction is complete by 10 mbsf (Fig. 11), and almost uniform concentrations of methane are found below this level, with organic carbon decreasing from 1% in near-surface levee muds to 0.8% at subbottom depths of several hundred meters. Excessive gas expansion, honeycomb-like structures in muds, and wireline-log data all suggest that gas hydrates may occur locally. Pore-water phosphate peaks at about 6 mbsf, and iron at 14 mbsf. Iron appears to be precipitated first as sulfide and then at greater depth as vivianite (an iron phosphate), which forms small diagenetic nodules throughout the cores. Detailed understanding of the diagenesis of organic matter awaits shore-based study.

## MARGIN DRILLING - CHALLENGES AND OPPORTUNITIES

Leg 155 has shown that continental-margin sediments with a considerable proportion of sand can be successfully cored if holes are carefully chosen. Continental margins contain a high-resolution record of paleoclimatic events on both the adjacent continent and the overlying ocean. A well-designed drilling program can answer important questions about the processes by which continental-margin sediment bodies accumulate, and the nature of early diagenesis in a high-sedimentation-rate environment.

The tools needed for continental-margin drilling are different from those used successfully for the study of ocean history at blue-water sites. High sedimentation rates and 1% organic carbon leads to an abundance of biogenic methane that extends to sub-bottom depths of hundreds of meters. Expanding methane disturbs the physical properties of cores, so that detailed sedimentological descriptions, magnetic characteristics, and high-resolution seismic-reflection profiles are the best tools for correlating between holes. Detailed sedimentological features are largely revealed by ephemeral colors that disappear within a few hours as a result of oxidation. Sampling of sediment, pore fluids, and gases at *in situ* pressures is essential for understanding the record preserved in the depressured cores. Improved technology is also needed to ensure sand recovery, particularly in sediments in which the APC cannot be used. The scientific problems addressed on this leg were not accessible by techniques other than by ocean drilling.

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## FIGURES

**Figure 1.** Map of Amazon Fan showing the location of drill sites in relation to surface channels and debris flows. The most recently active channel is Amazon Channel.

**Figure 2.** Gridded and contoured multibeam bathymetric map of a portion of the Amazon Channel. The locations of the eight Leg 155 drill sites near the Amazon Channel are shown. Two additional sites, Sites 945 and 946, sampled the Amazon Channel and levee 115 km to the north.

**Figure 3.** Seismic section and line drawing showing acoustic facies and stacked channel-levee systems (after Manley and Flood, 1988; Flood et al., 1991). HAR = high-amplitude, nearly vertical reflections beneath channels. HARP = high-amplitude reflection packet beneath levees. The projected location of Site 935 is shown by the arrow. ULC = Upper Levee Complex. MLC = Middle Levee Complex. LLC = Lower Levee Complex. BLC = Bottom Levee Complex. DF = Debris flow.

**Figure 4.** Schematic cross section of the upper Quaternary sediments of the Amazon Fan. Stacked channel-levee systems result from aggradation by turbidity currents flowing down channels, followed by abrupt switching of the channel to a new path. Each system has prograded across sands deposited at the downstream end of the channel. Groups of stacked channel-levee systems make up levee complexes (MLC = Middle Levee Complex). Am, Aq, Pu, Bl, Ye, 5, Or, and 6 signify successively older channel-levee systems of the Upper Levee Complex.

**Figure 5.** Series of schematic cross sections showing the surficial expression of channel-levee complexes of the Upper Levee Complex and the Western Debris Flow (after Damuth et al., 1983) and the general location of Leg 155 sites.

**Figure 6.** Summary of the relationship between facies drilled at each site and their acoustic stratigraphy.

**Figure 7.** Changes in declination, inclination, and remanence intensity associated with the Lake Mungo geomagnetic excursion. **A** indicates the beginning of the excursion, and **B** marks the sharp rise in field intensity and inclination (which corresponds to motion of the pole toward the equator)

characteristic of this excursion. The excursion was recorded over a 4-meter interval in Hole 930B and in eight other holes drilled on Leg 155.

**Figure 8.** Secular variation in geomagnetic inclination as recorded in the top 45 m of Hole 937B. Thirty-four cycles are indicated. The Holocene is represented in the top meter of the core; the age of the base of the illustrated sequence is estimated to be 20-25 ka.

**Figure 9.** Preliminary correlation diagram of the Leg 155 sites, showing sediment facies from cores and logs, magnetostratigraphic and biostratigraphic datums, and seismic reflection correlation.

**Figure 10.** A cut-off meander of the Amazon Channel was sampled at Site 934. (A) Shaded-relief multibeam bathymetric map (upper) and contour map (lower) showing the sinuous Amazon Channel and the cutoff meander. (B) Lithologic representation of the sediments recovered from the cutoff channel meander at Site 934 along with natural gamma and resistivity log profiles. Sediments recovered at this site include coarse sand and gravel and form an upward-fining sequence.

**Figure 11.** Pore-water concentrations of iron and sulfate (open squares) and phosphate and alkalinity (closed squares) from Leg 155, Hole 931C. The profiles are typical of Amazon Fan sediments, and illustrate the rapid changes in pore-water chemistry occurring in the upper few meters. Note that the peak in phosphate concentration occurs at the same depth as complete sulfate reduction. Above this point, iron is primarily precipitated as iron sulfides and below it as vivianite, $Fe_3(PO_4)_2$.

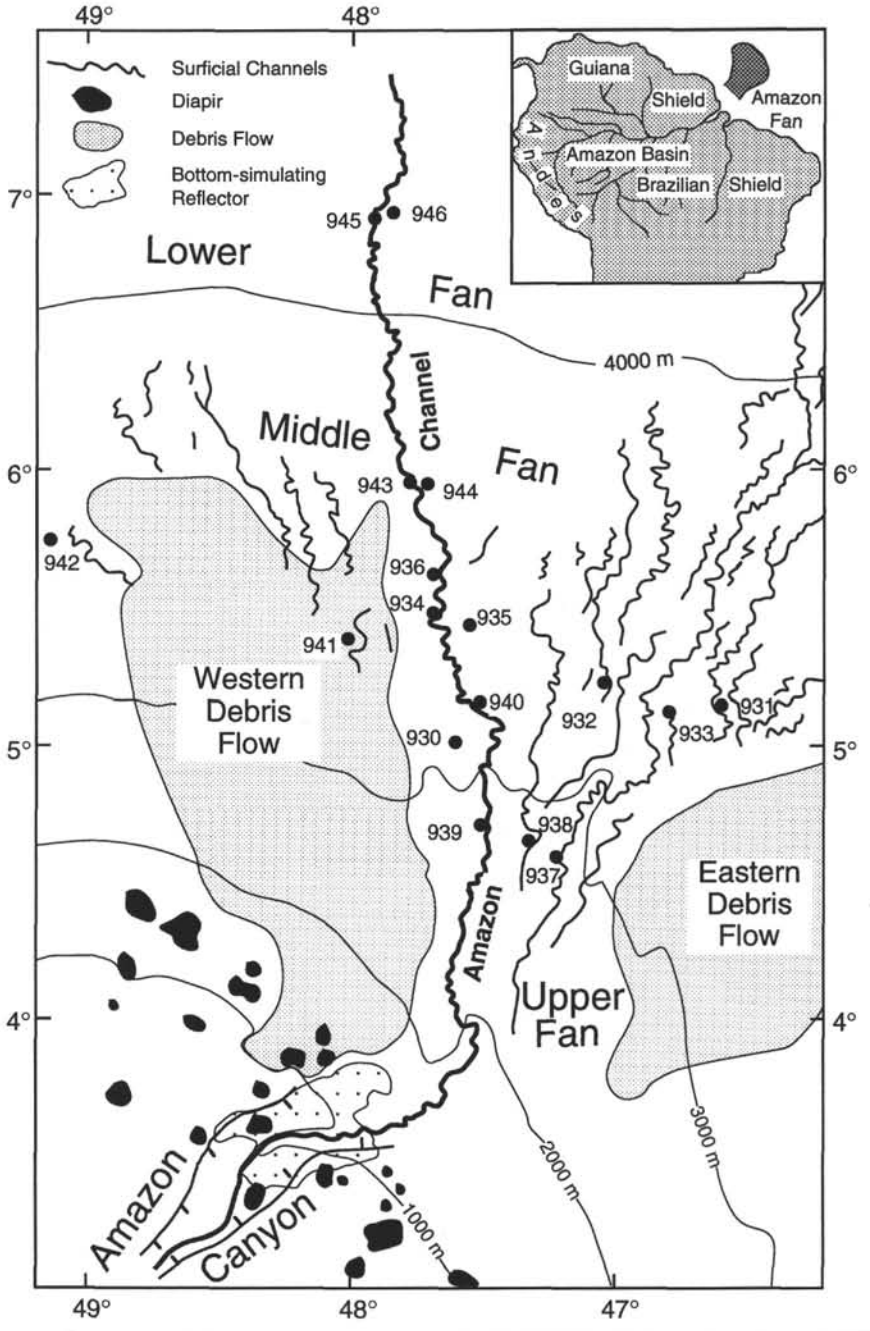
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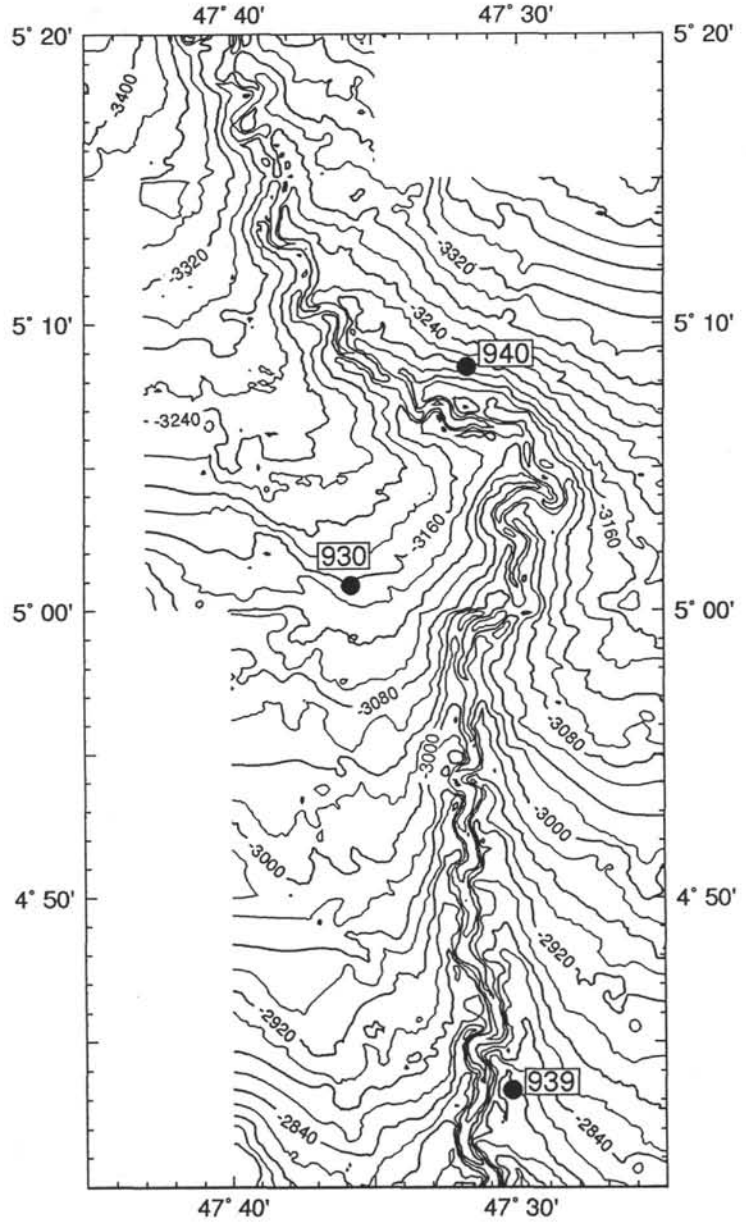
**Figure 1**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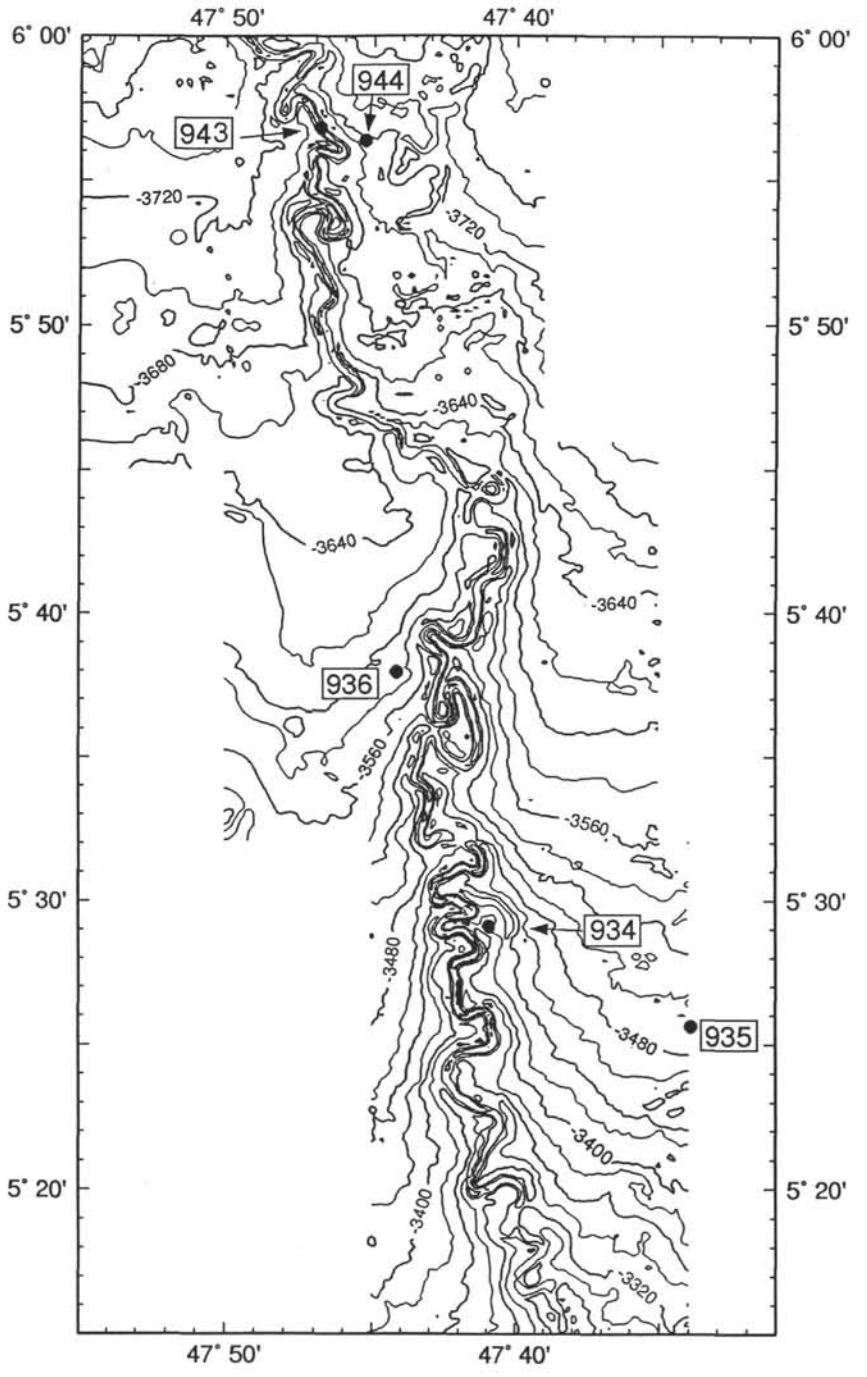
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47° 40'
6° 00'
5° 50'
5° 40'
5° 30'
5° 20'
-3720
-3680
-3640
-3560
-3550
-3480
-3400
-3320
944
943
936
934
935

**Figure 2**

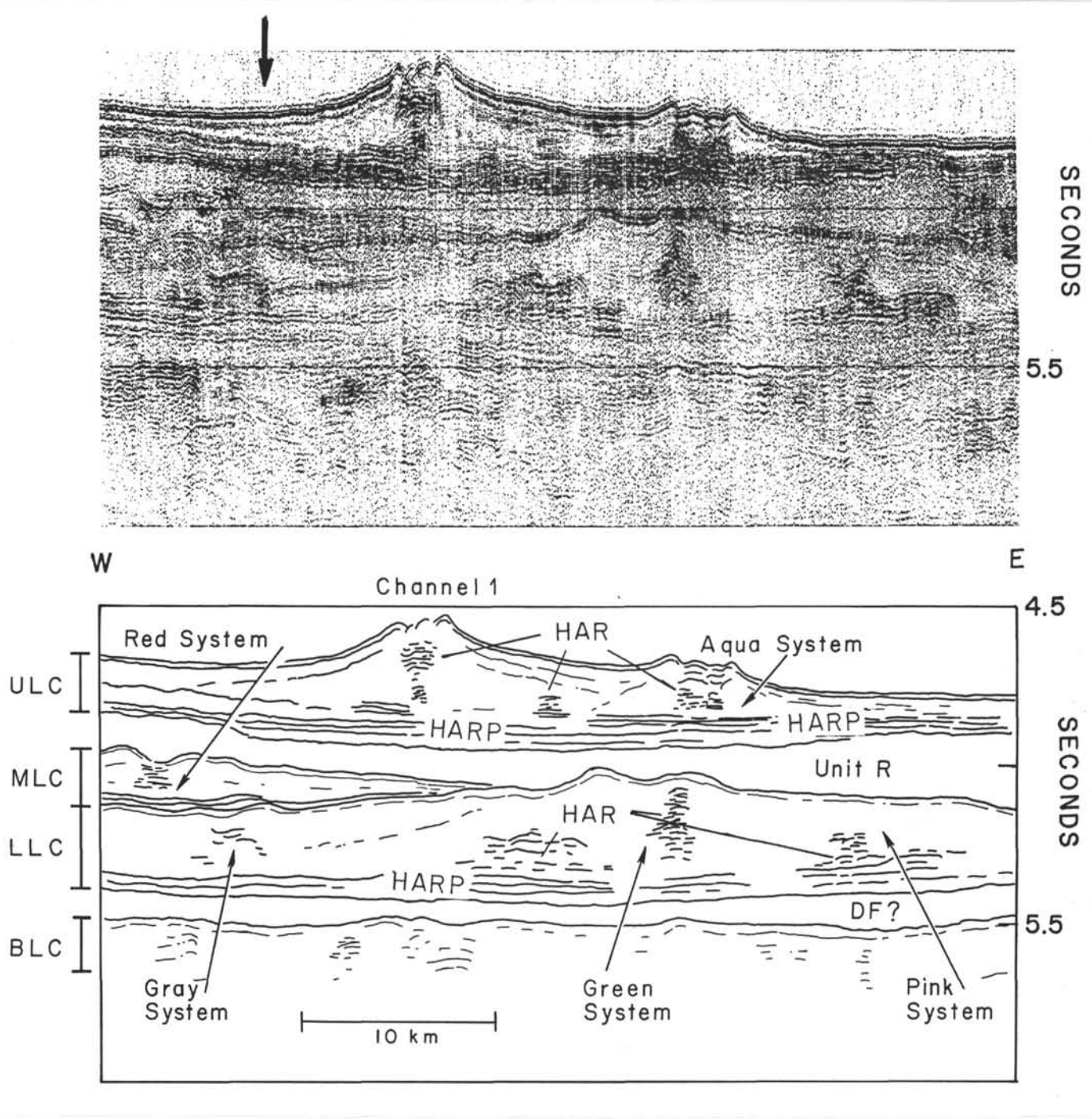

SECONDS
5.5
W
E
Channel 1
4.5
Red System
HAR
Aqua System
ULC
HARP
HARP
MLC
Unit R
HAR
LLC
HARP
DF?
5.5
BLC
Gray System
Green System
Pink System
10 km
SECONDS

**Figure 3**

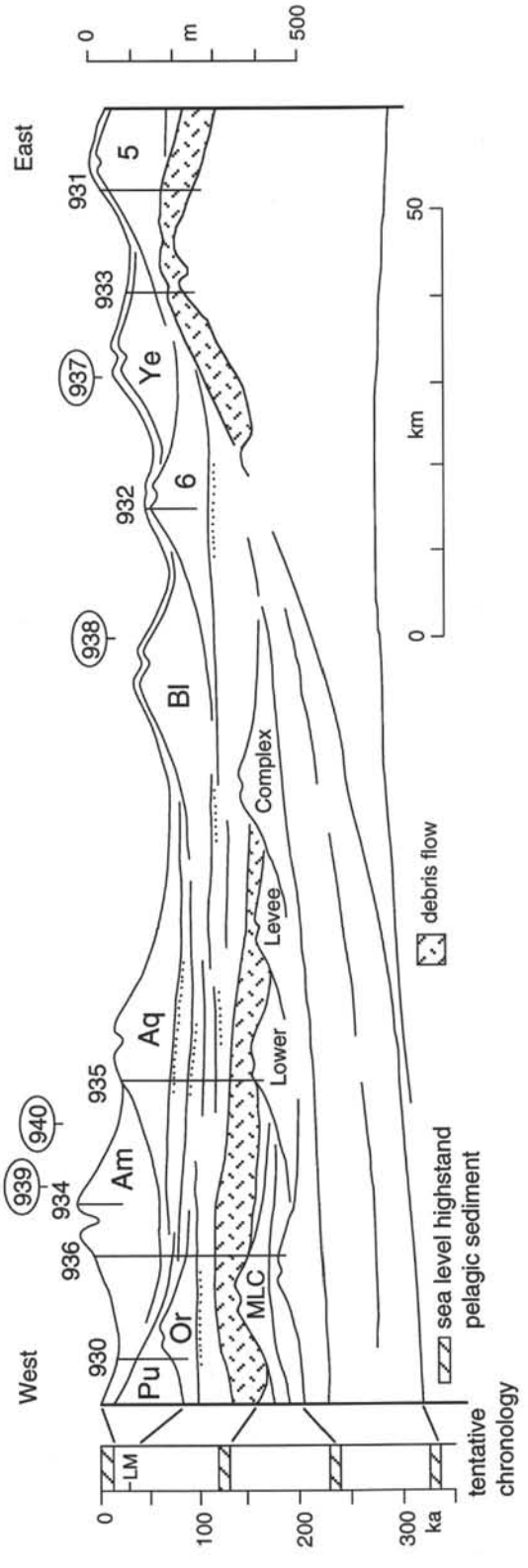

West
East
0
m
500
km
50
0
930
931
932
933
934
935
936
937
938
939
940
Pu
Or
Am
Aq
Bl
Ye
5
6
MLC
Lower
Levee
Complex
debris flow
sea level highstand
pelagic sediment
tentative
chronology
LM
0
100
200
300
ka

**Figure 4**

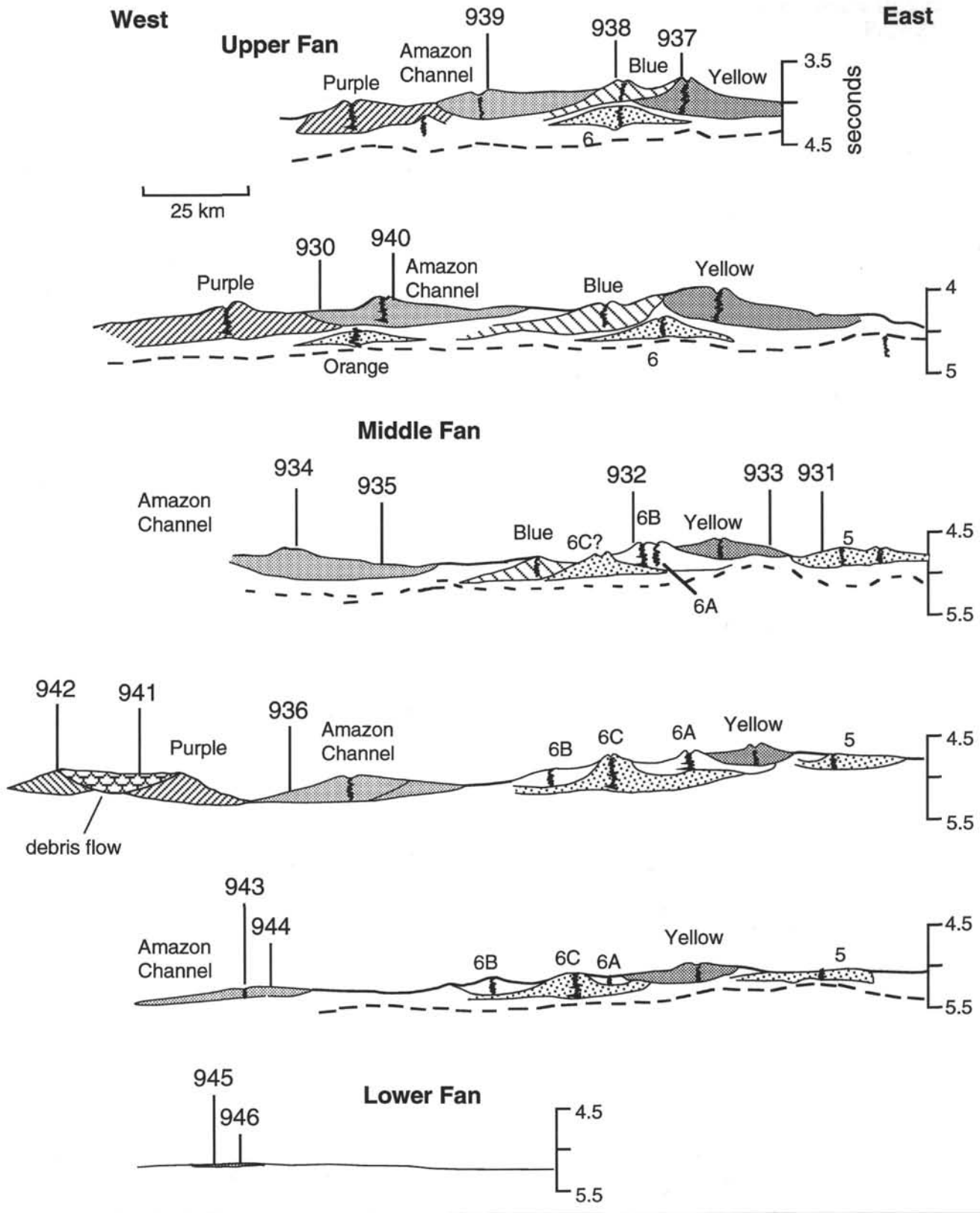

West
East
Upper Fan
939
938
937
Amazon
Channel
Purple
Blue
Yellow
3.5
4.5
seconds
6
25 km
930
940
Amazon
Channel
Purple
Blue
Yellow
4
5
Orange
6
Middle Fan
934
935
932
933
931
Amazon
Channel
Blue
6C?
6B
Yellow
5
4.5
5.5
6A
942
941
936
Purple
Amazon
Channel
6B
6C
6A
Yellow
5
4.5
5.5
debris flow
943
944
Amazon
Channel
Yellow
6B
6C
6A
5
4.5
5.5
945
946
Lower Fan
4.5
5.5

**Figure 5**

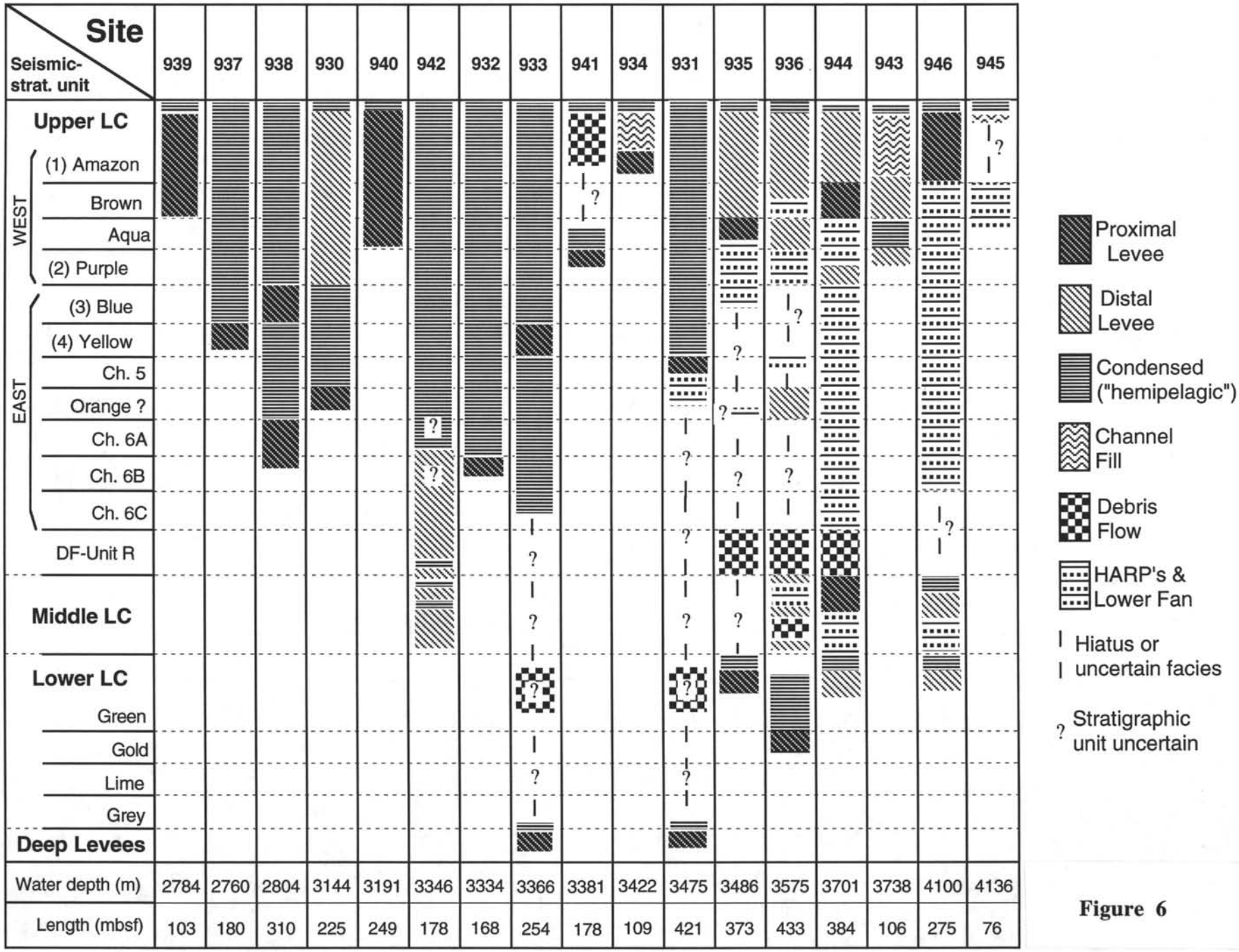

Site
Seismic-strat. unit
939
937
938
930
940
942
932
933
941
934
931
935
936
944
943
946
945
Upper LC
(1) Amazon
Brown
Aqua
(2) Purple
WEST
(3) Blue
(4) Yellow
Ch. 5
Orange ?
Ch. 6A
Ch. 6B
Ch. 6C
EAST
DF-Unit R
Middle LC
Lower LC
Green
Gold
Lime
Grey
Deep Levees
Water depth (m)
2784
2760
2804
3144
3191
3346
3334
3366
3381
3422
3475
3486
3575
3701
3738
4100
4136
Length (mbsf)
103
180
310
225
249
178
168
254
178
109
421
373
433
384
106
275
76
Proximal Levee
Distal Levee
Condensed ("hemipelagic")
Channel Fill
Debris Flow
HARP's & Lower Fan
Hiatus or uncertain facies
Stratigraphic unit uncertain

**Figure 6**

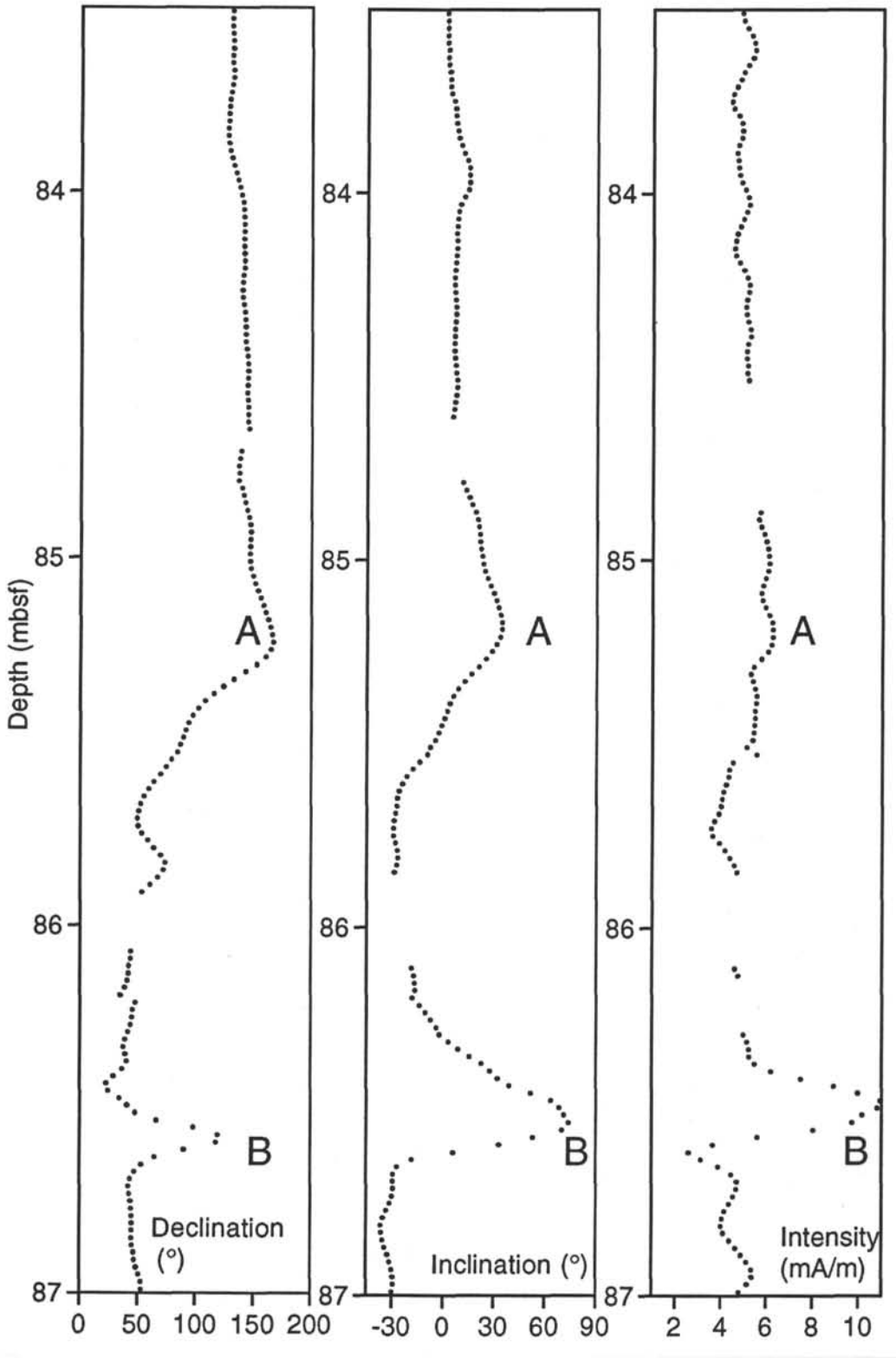

Depth (mbsf)
84
85
86
87
A
B
Declination (°)
0 50 100 150 200
Inclination (°)
-30 0 30 60 90
Intensity (mA/m)
2 4 6 8 10

**Figure 7**

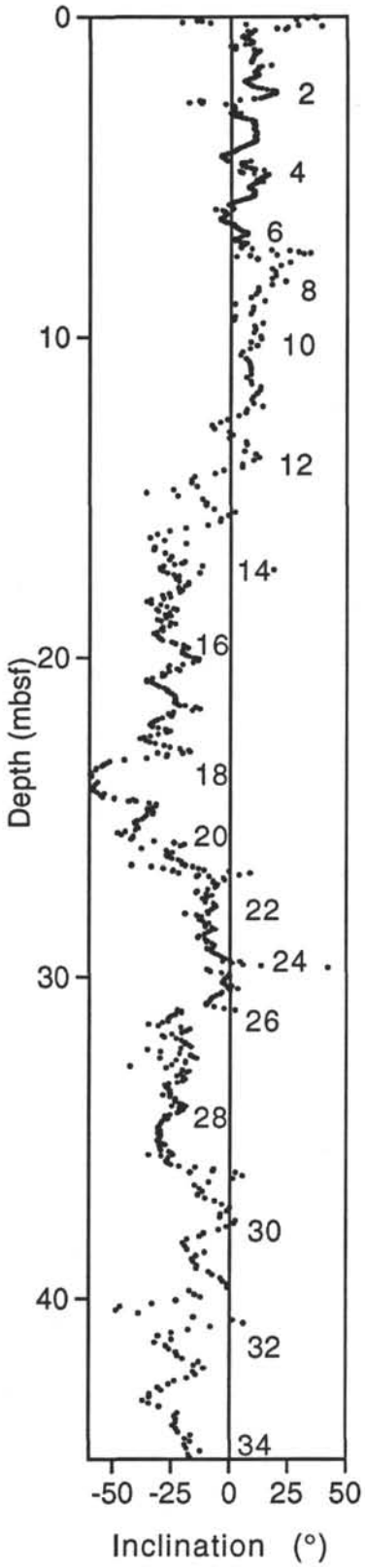

0
2
4
6
8
10
10
12
14
16
20
18
20
22
24
30
26
28
30
40
32
34
Depth (mbsf)
-50 -25 0 25 50
Inclination (°)

**Figure 8**

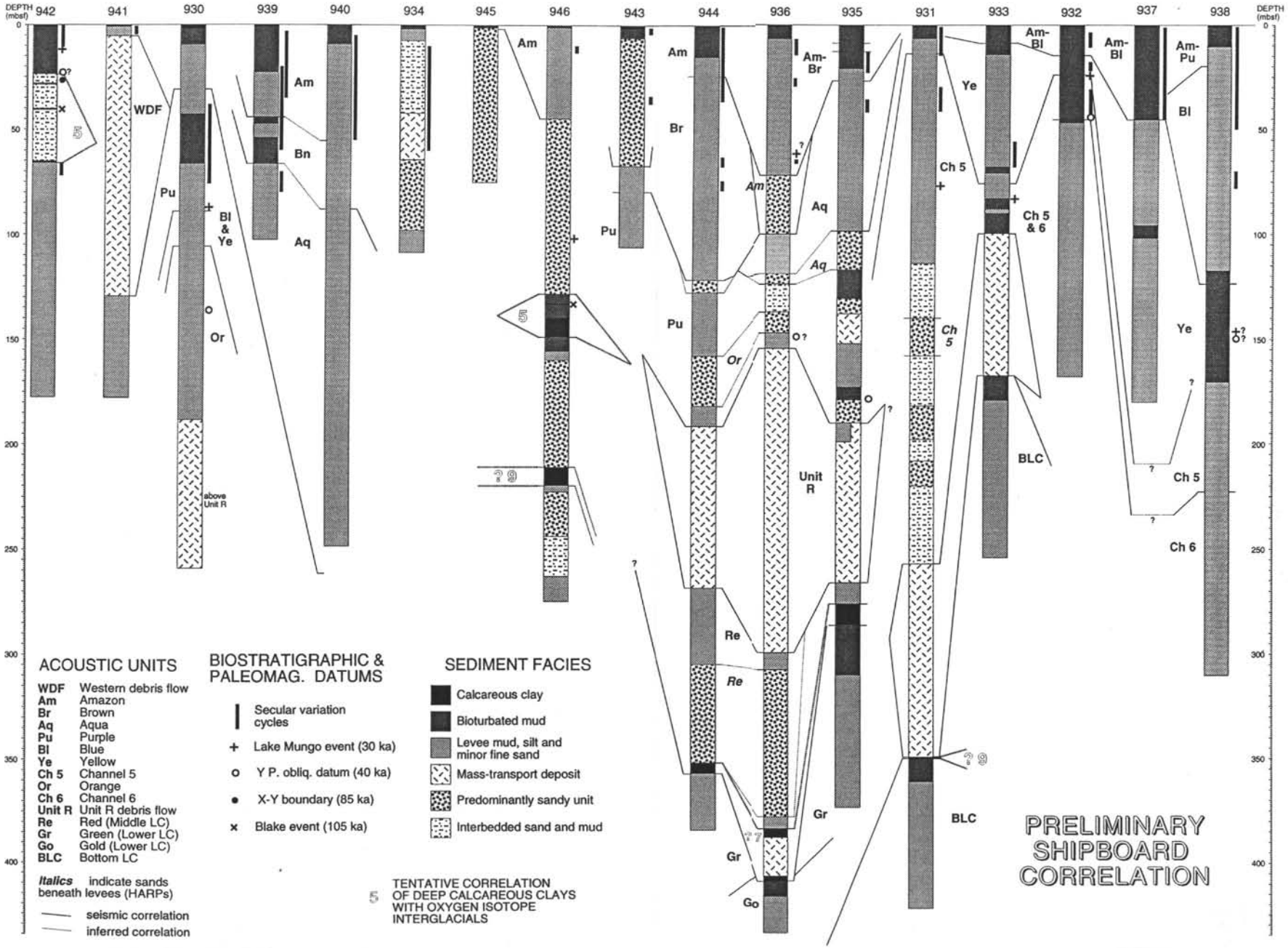
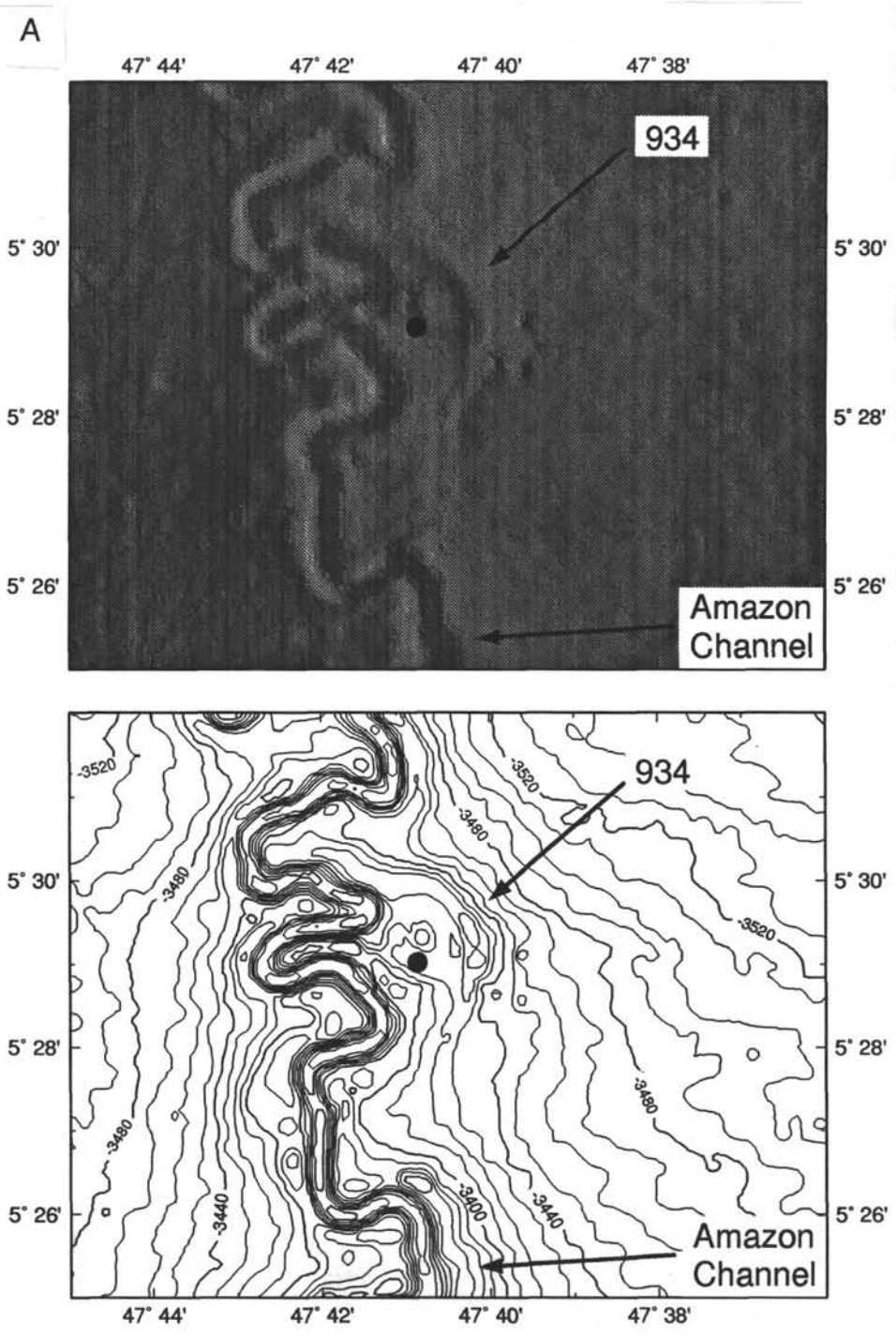

DEPTH (mbsf)
942
941
930
939
940
934
945
946
943
944
936
935
931
933
932
937
938
WDF
Pu
Bl & Ye
Or
above Unit R
Am
Bn
Aq
Br
Re
Gr
Go
Am-Br
Ch 5
Ch 5 & 6
BLC
Am-Bl
Am-Pu
Bl
Ye
Ch 6
Unit R
PRELIMINARY SHIPBOARD CORRELATION
ACOUSTIC UNITS
WDF Western debris flow
Am Amazon
Br Brown
Aq Aqua
Pu Purple
Bl Blue
Ye Yellow
Ch 5 Channel 5
Or Orange
Ch 6 Channel 6
Unit R Unit R debris flow
Re Red (Middle LC)
Gr Green (Lower LC)
Go Gold (Lower LC)
BLC Bottom LC
Italics indicate sands beneath levees (HARPs)
seismic correlation
inferred correlation
BIOSTRATIGRAPHIC & PALEOMAG. DATUMS
Secular variation cycles
Lake Mungo event (30 ka)
Y P. obliq. datum (40 ka)
X-Y boundary (85 ka)
Blake event (105 ka)
SEDIMENT FACIES
Calcareous clay
Bioturbated mud
Levee mud, silt and minor fine sand
Mass-transport deposit
Predominantly sandy unit
Interbedded sand and mud
TENTATIVE CORRELATION OF DEEP CALCAREOUS CLAYS WITH OXYGEN ISOTOPE INTERGLACIALS

**Figure 9**


A
47° 44'
47° 42'
47° 40'
47° 38'
5° 30'
5° 28'
5° 26'
934
Amazon
Channel
-3520
-3480
-3440
-3400

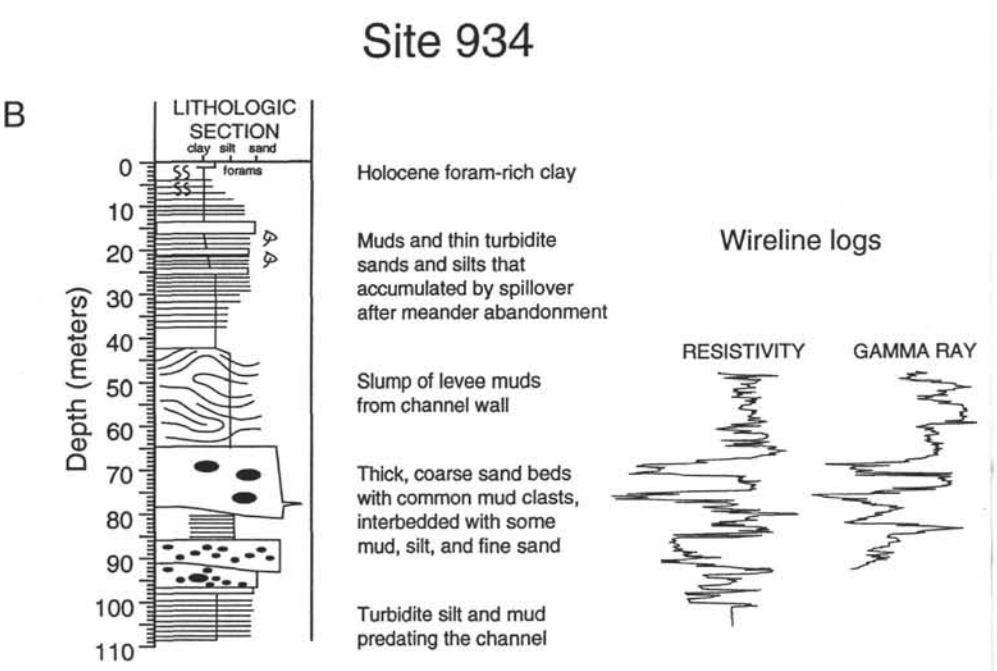
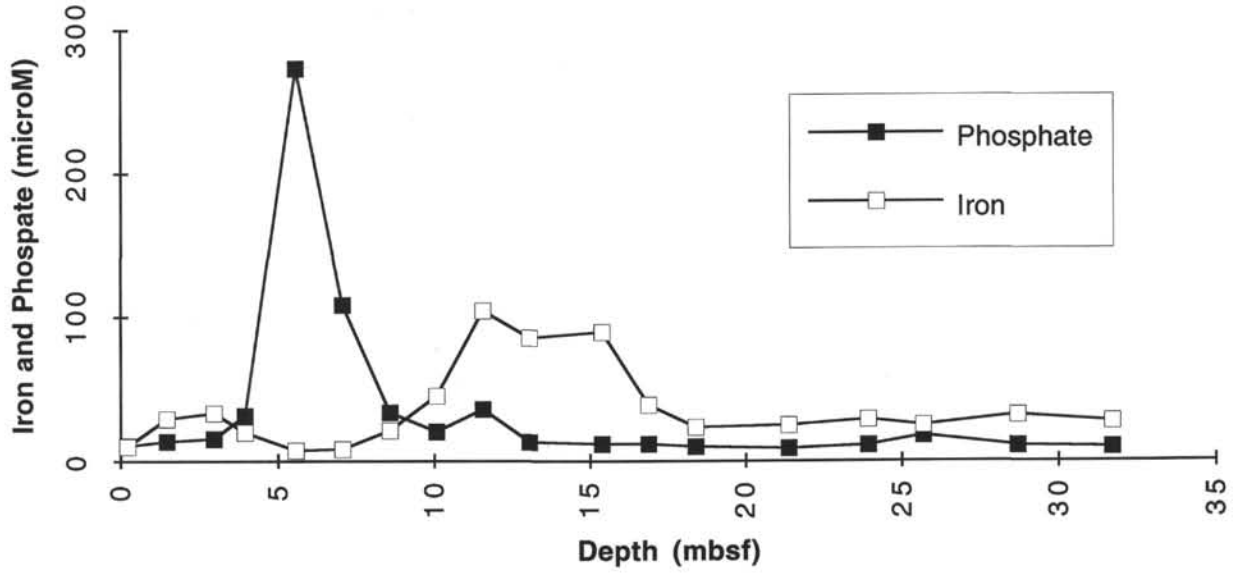

Site 934
B
LITHOLOGIC
SECTION
clay silt sand
forams
Depth (meters)
0
10
20
30
40
50
60
70
80
90
100
110
Holocene foram-rich clay
Muds and thin turbidite sands and silts that accumulated by spillover after meander abandonment
Slump of levee muds from channel wall
Thick, coarse sand beds with common mud clasts, interbedded with some mud, silt, and fine sand
Turbidite silt and mud predating the channel
Wireline logs
RESISTIVITY
GAMMA RAY

**Figure 10**


Iron and Phospate (microM)
0
100
200
300
Phosphate
Iron
0
5
10
15
20
25
30
35
Depth (mbsf)

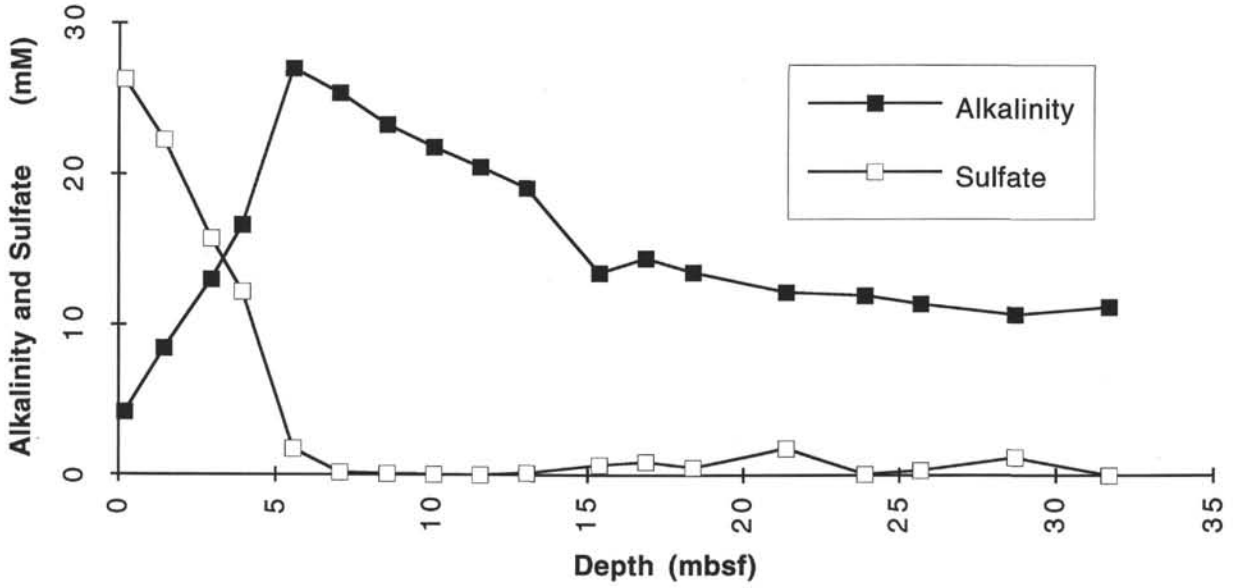

Alkalinity and Sulfate (mM)
0
10
20
30
Alkalinity
Sulfate
0
5
10
15
20
25
30
35
Depth (mbsf)

**Figure 11**

## SITE RESULTS

Site 930

Site 930 (proposed site AF-21) is located on the upper part of Amazon Fan, in a slight topographic low formed between the levees of the buried Purple channel and the recently active Amazon Channel. The primary objectives of this site were to determine the chronology of the middle part of the Upper Levee Complex and the sedimentological and geochemical characterization of levee flank, levee crest, and hemipelagic acoustic facies.

The hole penetrates several acoustic units on the fan. The uppermost unit is the feather edge of the western levee of Amazon/Brown/Aqua channel (coincident at this location). It also penetrates the underlying flank of the Purple levee about 20 km east of its corresponding channel and the crest of the Orange east levee about 500 m from its channel axis. Hemipelagic sediments were predicted to overlie the Orange levee and underlie the Purple at this location. The water depth of 3144 m is well above the regional lysocline.

The site was selected from seismic profile C2514 at 0300 hr on 2 December. A 6-hr seismic survey was run from the *JOIDES Resolution* to locate the site precisely. The 3.5-kHz echo-sounder profiles show that sediment waves are present in the uppermost 30-35 m of the sediment column. They have an east-west orientation, heights of 1-4 m, and spacings of 200-1000 m (average 600 m).

Hole 930A overshot the mud line by 1.75 m, penetrated 9.5 m, and recovered 10.05 m. Hole 930B was cored by APC to 100.7 mbsf, then by XCB to 225.3 mbsf, with total core recovery of 203.20 m (90.2%).

Temperature measurements were made at 52 and 72 mbsf (ADARA) and 101 and 149 mbsf (WSTP) in Hole 930B, indicating a mean geothermal gradient of 32°/km. There was gas expansion in all cores, but this was most severe in Cores 155-930B-2H to 155-930B-4H. Methane abundance was greatest in Cores 155-930B-2H and 155-930B-4H, with concentrations of 8000 ppm in headspace samples, decreasing downhole. Only trace amounts of ethane were detected.

Hole 930C was offset 20 m to the north. It was designed to resample intervals in which important paleontological markers had been identified. We washed to 29.0 mbsf, APC cored to 95.5 mbsf, XCB cored to 143.7 mbsf, washed to 201.1 mbsf, and then XCB cored to total depth (TD) at 259.0 m. Total core recovery was 135.47 m (78.5%).

Holes 930A, B, and C were all located on the downslope flank of a sediment wave. Hole 930D was offset 185 m to the north of Hole 903C, to sample the adjacent sediment wave crest. We APC cored to a TD of 51.5 m. Total recovery was 53.27 m (103.4%).

Three lithologic units are recognized.

Unit I (0-1.65 mbsf) is a Holocene nannofossil- and foraminifer-rich clay with about 30% carbonate content. It represents deposition since the early Holocene rise in sea level, which caused the retreat of the Amazon River mouth landward across the continental shelf.

Unit II (1.65-188.42 mbsf) consists of mud with interbedded laminae and thin beds of silt and very fine sand. The mud has about 2% carbonate content. Subunit IIA (1.65-9.64 mbsf) comprises color banded and mottled mud of latest Pleistocene to early Holocene age. Subunit IIB (9.64-43.00 mbsf) consists of mud with thin beds and laminae of silt and silty sand. It was deposited on the levee flank of the latest Pleistocene Amazon Channel system and shows sedimentary structures suggesting that the subunit consists largely of overbank turbidites. Rare thin disrupted zones with slightly elevated bulk density and strength suggest local slump deposits. Individual beds can be correlated from Hole 930B on the flank of a sediment wave to Hole 930D on the adjacent crest, where the overall section is thicker and the proportion of sand is higher. Subunit IIC (43.00-66.65 mbsf) is lithologically similar to Subunit IIA and corresponds to times when the Purple channel (an earlier channel now buried) was active. Subunit IID (66.65-188.42 mbsf) is lithologically similar to Subunit IIB and largely corresponds to the levee crest of the former Orange channel of the Amazon Fan (that was active prior to the Purple channel). Between 110 mbsf and 180 mbsf there is a steady increase in grain density from 2.71 to 2.78 g/cm$^3$ that does not correlate with grain-size changes and thus may indicate a change in clay mineralogy.

Unit III (188.42-242.90 mbsf) comprises muddy sands with "floating" pebble clasts, abundant plant debris, and mud clasts interbedded with thick overconsolidated clay sequences. The clays contain mixed foraminiferal faunas including cool interstadial planktonic assemblages and upper slope benthic foraminifers. The presence of echinoid spines and abundant plant debris further suggests an upper slope-outer shelf source. High total S (1.0%) and N (0.2%) occur in the clay, and one pore-water sample showed unusual characteristics including low chlorinity. It is unclear whether Unit III is a single debris-flow deposit or represents several flows with interbedded discrete slides (olistoliths).

Foraminifer abundances are low below unit IIC and biostratigraphic age picks are tentative. *P. obliquiloculata* is present below 137 mbsf, suggesting an age >40 ka. No evidence was found for faunas of prior interglacials except in reworked blocks in the Unit III debris-flow deposit. A distinctive magnetic excursion was recognized at about 90 mbsf in both Holes 930B and 930C and is interpreted as the Lake Mungo event (≈30 ka). Unit IIC may show secular variation in natural remanent magnetization with about 15 small cycles grouped in three larger cycles over 35 m. Overall sedimentation rate in Unit II was probably 4-5 m/k.y.

Pore-water profiles show rapid concentration changes in the upper 20 mbsf, including complete sulfate reduction by 13 mbsf, and suggest precipitation of carbonate and phosphate. Such precipitation may be represented by vivianite (iron phosphate) spherules found in the sediment that are white when the core is first split and then turn blue. Total organic carbon in Unit II is about 0.8% with a slight decrease downcore.

The preliminary data from Site 930 suggest that the Amazon Fan aggraded at an extremely rapid rate. Much of the exposed Upper Levee Complex of the Amazon Fan appears to date from the last glacial period (oxygen isotopic stages 2-4). The fan contains an expanded record of foraminifers, which with shore-based studies will provide an isotope stratigraphy and paleoecological interpretation. There is sufficient detrital pollen for shore-based studies of climatic change in the Amazon Basin. There is considerable lithologic variability within acoustically defined stratigraphic units that suggests that changes in sea level, Amazon River discharge, and levee growth patterns all may influence sediment facies development within individual channel-levee complexes.

Site 931

Site 931 (proposed site AF-10) is the most easterly site to be drilled on the Amazon Fan. It is located on a flat terrace on the western levee of the buried Channel 5 system. The hole penetrates a thin acoustic unit interpreted as muds with minor turbidite silts overlying the Channel 5 system, then the thick Channel 5 levee sequence, passing down into high-amplitude reflection packets (HARPs) interpreted as sandy lobes associated with channel avulsion. Three HARP units overlie a thick acoustically incoherent unit (interpreted as a debris flow) that laps out to the west against the crest of a 500-m-thick levee that may be part of the Lower Levee Complex or may be older.

The site was selected from an *R/V Ewing* seismic profile (E9209; 1637 hr on 20 September). Following Site 930, we ran a 12-hr seismic survey across Sites 940, 932, 933, and 931 to provide high-resolution seismic data for the proposed coring intervals.

Hole 931A was cored to 53.6 mbsf and recovered 56.99 m. Hole 931B was cored by APC to 76.8 mbsf, then by XCB to 344.4 mbsf. Recovery was poor from 142.2 to 219.1 mbsf (15.6%) in alternating sands and muds. Total coree recovery was 296.1 m (70.3%). Temperature measurements were made at 48 and 68 mbsf (ADARA) and 104 and 142 mbsf (ADARA) in Hole 931A, indicating a mean geothermal gradient of 34°/km. There was gas expansion in many cores. Methane was found throughout the hole, with a sharp increase at 10 mbsf, and peaks at about 50 mbsf and 400 mbsf. Only trace amounts of ethane and propane were detected in a few deep cores.

Because some pipe had to be raised to retrieve a stuck core barrel, Hole 931B was conditioned for logging prior to taking the final two cores. On the first logging run, the sonic and natural gamma tools of the Quad combination flooded. They were replaced and the tool run to 251 mbsf, where a bridge prevented further passage downhole. The hole was logged from 251 to 90 mbsf, the pipe was raised to 72 mbsf, and the interval 150-72 mbsf was logged. A similar procedure was used on subsequent log runs with the FMS, Geochemical and GHMT combinations. Hole conditions were good, except in a few parts of the interval from 140 to 240 mbsf, where sand beds had washed out. Hole 931C was then cored to 32.6 mbsf and recovered 34.43 m (105.6% recovery).

Five lithologic units are recognized.

Unit I (0-0.57 mbsf) is a Holocene nannofossil- and foraminifer-rich clay that is bioturbated and contains about 50% calcium carbonate.

Unit II (0.57-190.20 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud contains about 3% carbonate. Subunit IIA (0.57-6.70 mbsf) comprises bioturbated and color-banded mud. Subunit IIB (6.70-27.50 mbsf) consists of mud with <20% silt laminae. These two subunits represent sediments that accumulated since the abandonment of Channel 5. Subunit IIC (27.50-190.20 mbsf), corresponding to the crest of the Channel 5 levee, contains mud with thin to thick beds of silt and fine sand, which increase in frequency and thickness toward the base of the subunit. The thickest sand beds contain mud clasts. Recovery was low in the lower 70 m of Subunit IIC and included abundant sand beds, equivalent to the seismically identified HARPs. Logging indicated that there were two major sequences of upward-diminishing sand abundance ("upward-fining cycles"), with their bases at 198 mbsf and 158 mbsf. Individual sand packets up to several meters thick appear to be separated by muddier units at the bases of these cycles. Sand in the lower cycle includes abundant wood fragments.

Unit III (199.8-349.25 mbsf): The upper part of Unit III (199.8-257.8 mbsf) appears to correlate with the lowest HARP in the seismic data. Recovery in this interval was low, consisting of muddy sand containing some mud clasts, alternating with mud containing silt laminae. Most of this interval was logged, and it apparently consists of alternating sands and muds. Sands from 200 to 229 mbsf contain distinctive subrounded quartz grains and common wood fragments. Core-catcher samples contain probable continental-slope benthic foraminifers (*Bolivina striata*). The lower part of Unit III (257.8-349.25 mbsf) consists of various types of overconsolidated mud, in places clearly occurring as clasts, some of which consist of foraminifer- and nannofossil-rich clay. Benthic foraminifers in this part of the unit are deep-water taxa such as *Uvigerina*. The lower part of the unit is interpreted as a mud-clast conglomerate deposited by one or more debris flows.

Unit IV (349.25-349.46 mbsf) consists of a highly bioturbated dark gray (10Y 4/1) foraminifer-nannofossil clay with <35% calcium carbonate.

Unit V (349.46-421.3 mbsf) consists of a sequence similar to Subunits IIA and IIB, with bioturbated and color-banded mud (Subunit VA, to 360.87 mbsf) overlying mud with silt laminae (Subunit VB). This unit is correlated with the deep levee system.

Foraminifers are rare except in Units I (Holocene) and IV. In Unit IV and the upper 5 m of Unit V, the foraminiferal assemblage is interglacial, with common *G. menardii* and *G. tumida*. *G. tumida flexuosa* was not detected. The nannofossils consist predominantly of medium-sized *Gephyrocapsa*, and *P. lacunosa* is absent. The lowermost clasts in the debris flow (Unit III) have microfossil assemblages similar to those in underlying Units IV and V. One clast at 335 mbsf contains common *G. tumida flexuosa*. In the middle part of Unit III are clasts with a foraminiferal fauna characteristic of 40-85 ka. The Lake Mungo magnetic event was not detected in the APC cores (i.e., down to 77 mbsf), but correlation of susceptibility with Site 930 suggests that it may occur at 78 mbsf. The first *P. obliquiloculata* below the Holocene occurred at 238.4 mbsf, in the upper part of Unit III, where it is probably reworked. However, foraminifer abundances are very low from 90 to 238 mbsf, so the *P. obliquiloculata* zonal marker (40 ka) may not have been detected.

A detailed pore-water profile was made in Hole 931C from 0 to 32 mbsf, taking one sample per 1.5 m. It showed a pronounced peak in alkalinity and phosphate at 6 mbsf, with phosphate decreasing to background values by 10 mbsf just below the limit of sulfate reduction. Pore-water iron peaks at 12-16 mbsf. These distributions suggest that once iron is no longer removed as sulfide, it is precipitated as vivianite (iron phosphate), which forms small blue microcrystalline nodules. High total sulfur values are found in sediment at 12-15 mbsf. Total organic carbon averages 1.0% in the upper part of the hole, decreasing to about 0.8% near the base of the hole.

Downhole variations in mud mineralogy (determined by XRD) show much scatter and are difficult to interpret because of grain-size effects. A higher kaolinite/illite ratio occurs in places in Unit II between 30 and 100 mbsf, in a carbonate clay clast in Unit III, and in unit V. If these variations are real, they may be indicative of periods of increased rainfall in the Amazon Basin.

Magnetic susceptibility data show a small-scale correlation with silt-mud alternations, but also show a longer period variation over tens of meters. These correlate both with long-period

variations in the GRAPE data and with variations in illite to quartz ratio from XRD data. Susceptibility measured with the GHMT logging tool shows a strong correlation with log indicators of sand/mud ratio such as natural gamma and aluminum.

Units I and II show variations in porosity and bulk density that suggest normal consolidation. Many of the blocks in Unit III appear overconsolidated. Unit V shows profiles that suggest normal consolidation, but their water content is rather high for the depth of burial, which may indicate that the debris flow inhibited dewatering. Within Subunit IIC, at least three cycles of variation in resistivity, probably related to sediment fabric, can be distinguished.

The preliminary data from Site 931 indicate that the thick deep levee sequence (Unit V) is of middle Pleistocene age. It is capped by an interglacial calcareous clay that is lithologically similar to Holocene Unit I. Observations later in the leg at Sites 942 and 946 suggest that this interglacial is older than isotopic stage 5 and possibly corresponds to isotopic stage 9. We do not have insights into why the deep channel-levee system is so thick, but it may be caused by purely autocyclic processes. Seismic-reflection data suggest that later Amazon Fan sedimentation shifted westward, onlapping the thick deep levee. The lower part of the debris flow (Unit III) contains no material diagnostic of an upper slope or shelf source. The presence of deep-water benthic foraminifers suggests that it may have originated by local failure of the deep levee or levees of an adjacent channel. The upper part of Unit III and the lower part of Subunit IIC are correlated with three HARPs in the seismic-reflection profile. The logging data suggest that the HARPs consist of the sandy parts of upward-fining sequences and comprise packets of sand up to several meters thick separated by thinner muds.

Site 932

Site 932 (proposed site AF-11) is located on the eastern part of Amazon Fan, 200 m east of the crest of the western levee of abandoned Channel-levee system 6B. The site was intended to provide a hemipelagic biostratigraphic and magnetostratigraphic reference section above Channel-levee system 6B and to sample the upper part of the levee crest. This channel-levee system is the stratigraphically oldest part of the Upper Levee Complex, and, based on the results at Site 930, we thought it possible that we would reach sediments from late in the last interglacial.

The site was selected from an *R/V Ewing* seismic-reflection profile (E9209; 0635 hr on 21 September). High-resolution seismic-reflection data through the planned drilling interval were obtained from the pre-site survey from *JOIDES Resolution*.

Hole 932A was cored by APC to 91.5 mbsf, then by XCB to 168.3 mbsf, with total core recovery of 154.71 m (91.9%). Hole 932B was cored to 52.5 mbsf and recovered 54.09 m (103.0%).

Temperature measurements at 63 and 82 mbsf (ADARA) and at 120 mbsf (WSTP) show a mean geothermal gradient of 31°/km, with a higher gradient in the upper part of the hole. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Two lithologic units are recognized.

Unit I (0-0.70 mbsf) is a Holocene bioturbated nannofossil-foraminifer clay, with about 50% calcium carbonate, similar to Unit I at previous Leg 155 sites.

Unit II (0.70-168.30 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud has about 3% carbonate content. The unit is subdivided into two subunits, analogous to those at Sites 930 and 931. Subunit IIA (0.70-47.0 mbsf) comprises bioturbated mud. Disturbed sediment (probably a debris-flow deposit) is found at 41-42 mbsf. This subunit represents sediment that accumulated since the abandonment of Channel 6B. Subunit IIB (47.0-168.3 mbsf) contains the youngest sediment from the crest of the Channel 6B levee. This subunit is composed of mud with thin to thick beds of silt and fine sand, which increase in frequency and thickness toward the base of the subunit, particularly below 130 mbsf.

Foraminifer abundances are generally common in Subunit IIA and low in Subunit IIB. At 44 mbsf, abundant *P. obliquiloculata* reappears, suggesting an age >40 ka. A magnetic excursion, correlated with a similar feature at Site 930 and interpreted as the Lake Mungo event (30 ka), was found at 24 mbsf. Variation in magnetic declination, interpreted as secular variation, was detected with 9 cycles between 31 and 43 mbsf.

A palynological study was made of three stratigraphic levels: Holocene, last glacial (20 ka) and the *P. obliquiloculata* datum (40 ka). The Holocene section is nearly barren. Last glacial assemblages are well preserved and diverse. The major pollen types include *Euphorbiaceae*, *Rhizophoraceae*, *Gramineae*, *Cyperaceae*, and Tricolporate, Tricolpate, and Stephanoporate types. Fern spores include *Cyatheaceae*, *Lycopodidae*, and Monolete spores. The pollen and spore assemblage from the 40-ka level contains lower abundances and diversities than the last glacial assemblage. Major pollen types include Tricolporate and Tricolpate types and *Cyperaceae*. Fern spores include *Cyatheaceae*, Trilete, and Monolete spores.

Pore-water data, the abundance of methane, and total organic carbon contents were similar to those observed at Sites 930 and 931. In general, physical properties data also show trends similar to those established at Sites 930 and 931. Unusually low bulk density and high water content between 14 and 21 mbsf may relate to increased sedimentation rate or the presence of trapped gas beneath a clathrate horizon. No clathrates were observed in the cores, although gas expansion occurs throughout this interval.

As at Site 931, downhole variations in mud mineralogy (determined by XRD) show much variability. Kaolinite/illite and quartz/clay mineral ratios are higher below 70 mbsf than in the upper part of the hole.

The preliminary data from Site 932 confirm the bio- and magnetostratigraphic markers established at Site 930. The sequence of bioturbated muds with rare silt laminae above the Channel 6B levee system is about 46 m thick, and the upper 45 m of the levee is also considerably bioturbated, suggesting relatively low sedimentation rates. The levee section that was cored is an upward-fining sequence of turbidites. Extrapolating sedimentation rates from the upper 45 mbsf suggests that Channel-levee system 6B dates from about 60-80 ka, immediately prior to the last interglacial.

Site 933

Site 933 (near proposed site AF-9) is located on the eastern part of the Amazon Fan, on the eastern levee flank of the Yellow channel-levee system, about 4 km from the channel. The site was intended to resample microfossil-rich sediment on the crest of the thick mid-Pleistocene levee first sampled at Site 931. Site 933 also provided an opportunity to log the debris-flow interval that was

not logged at Site 931 because of hole conditions. The site was selected from crossing seismic-reflection profiles (1943 hr on 10 April and 0242 hr on 11 April) from *JOIDES Resolution* pre-site survey.

Hole 933A was cored by APC to 91.2 mbsf, then by XCB to 254.2 mbsf, with total core recovery of 177.59 m (69.9%). Temperature measurements at 53 and 82 mbsf (ADARA) show a geothermal gradient of 46°/km. There was gas expansion in many cores. Methane was found throughout the hole; no higher molecular-weight hydrocarbons were detected.

Four lithologic units are recognized.

Unit I (0-0.52 mbsf) is an intensely bioturbated Holocene nannofossil-foraminifer clay, with about 50% calcium carbonate.

Unit II (0.52 to 97.62 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. Subunit IIA (0.52 to 14.35 mbsf) comprises moderately bioturbated and color-banded mud. Carbonate content ranges from 0.3% to 10.6%. This subunit is correlated with the Amazon to Blue seismic stratigraphic intervals. Subunit IIB (14.35-97.62 mbsf) consists of mud with thin beds of silt and fine sand. Several intervals with abundant silt and sand laminae and thin beds alternate with intervals, 3-8 m thick, of moderately bioturbated mud with only a few silt laminae. At 60-64 mbsf, a massive black clay contains abundant plant detritus, shell fragments, bathyal benthic foraminifers, and rounded quartz sand grains. The section to 70 mbsf is correlated with the levee flank of the Yellow channel-levee system, whereas the lower part of Subunit IIB corresponds to the levees of Channel-levee systems 5 and 6.

Unit III (99.80-167.31 mbsf) consists of various types of overconsolidated mud, commonly showing deformational structures. The unit is interpreted as a mass-flow deposit comprising large deformed blocks of mud. Benthic foraminifers indicate a source for the blocks on the continental slope.

Unit IV (167.31-249.72 mbsf) consists of a sequence similar to Subunits IIA and IIB, forming the upper part of the levee cored at the bottom of Site 931. Bioturbated mud (Subunit IVA, 167.31- 179.03 mbsf) overlies mud with silt laminae and fine sand beds (Subunit VB), which

form an upward-fining and -thinning sequence of turbidites. The resistivity log showed a zone of anomalously low resistivity from the top of the unit to 190 mbsf, corresponding to a 1.2° temperature anomaly and minor pore-water anomalies.

Foraminifers are few in Unit IIA and rare in Unit IIB. An apparent paleomagnetic excursion was observed at 81.6 mbsf and is correlated with a similar feature at Sites 930 and 932, interpreted as the Lake Mungo event (30 ka). The upper part of the mass-flow deposit (Unit III) lacks *P. obliquiloculata* and *G. tumida*, suggesting an age <40 ka, but these species and rare *G. menardii* appear in clasts in the lower part of Unit III. Unit IVA has a warm-water planktonic assemblage, including *G. tumida* and *G. menardii*, but *G. tumida flexuosa* is very rare. The nannofossil assemblage includes abundant *Gephyrocapsa* and lacks *P. lacunosa*; shore-based SEM studies will be required to check the presence or absence of *E. huxleyi*. Unit IV at Site 933 is correlated with Unit V at Site 931 on the basis of seismic-reflection continuity and lithologic and biostratigraphic similarity, and is assigned a pre-last interglacial age, possibly correlating with isotopic stage 9.

Pore-water data, the abundance of methane, and total organic carbon contents were similar to Sites 930, 931, and 932. Sulfate is removed by 13 mbsf, but pore-water sulfate is also found in the lower part of the debris flow (Unit III) in concentrations of 1-2 mM. Total nitrogen, which averages 1.0 to 1.2% in Unit II, drops to 0.06%-0.08% in the debris flow, with a high [C/N]a. Chlorinity levels in the lower part of Unit III and in Subunit IVA are low (around 550 mM) compared with most of the section (around 560 mM) and are similar to the interglacial interval of Unit I.

In general, physical-properties data also show trends similar to those established at Sites 930, 931, and 932. Unit IV sediments have a higher water content than would be expected under normal consolidation, suggesting that dewatering has been inhibited. A pronounced elliptical reduction in the size of the borehole at 215 mbsf corresponds to an abrupt decrease in wet-bulk density from 2.0 to 1.9 g/cm$^3$ and corresponding changes in water content and porosity, indicating an overpressured formation.

The preliminary data from Site 933 confirm the stratigraphic observations at Site 931, namely that the deep levee on the eastern Amazon Fan is of middle Pleistocene age. Further shore-based work

will be needed to confirm its age. The overlying mass-flow deposit contains blocks of continental-slope sediments. The levee-flank sediments in Subunit IIB have abundant cross-lamination, in contrast to the lack of cross-laminated sands in the levee-crest sediments of Subunit IVB. With refined shore-based bio- and isotope stratigraphy, it should be possible to interpret the alternations of silty and bioturbated intervals through Subunit IIB.

Site 934

Site 934 (proposed site AF-15) is located in a cutoff meander bend of the main (Amazon) channel of Amazon Fan. The site was selected from SeaBeam data and 3.5-kHz profiles. A short pre-site 3.5-kHz survey was made to verify site location. The present seafloor in the abandoned bend is 55 m shallower than the main channel floor. This elevation difference results from mud sedimentation in the abandoned meander bend (and possibly from incision of the main channel) after the cutoff. The 100-m-deep holes allowed sampling of old channel sediments unaffected by any latest Pleistocene channel incision. A short string consisting of the resistivity and gamma tools was used to log the hole.

Hole 934A was cored by APC to 108.8 mbsf and recovered 111.66 m (102.6%). Hole 934B was offset 50 m to the south, closer to the old channel axis, and cored to 108.8 mbsf, recovering 106.92 m (98.3%). This is excellent recovery for a site with 30% sand beds. Temperature measurements at 63 and 82 mbsf (ADARA) show a geothermal gradient of 35°/km. Gas expansion in many cores destroyed bedding structures in most sands. Methane was found throughout the hole, but higher molecular-weight hydrocarbons were not detected. Logging was hindered by initial hole collapse, but successful resistivity and gamma data were obtained from 50 to 103 mbsf after hole was cleaned.

Five lithologic units are recognized.

Unit I (0-0.87 mbsf) is an intensely bioturbated Holocene nannofossil- and foraminifer-rich clay, with up to 45% calcium carbonate. A dark brown crust occurs at 0.48 mbsf.

Unit II (0.87-42.30 mbsf) consists of mud with thin beds and laminae of silt and sand. The unit is interpreted as sediment that filled the abandoned meander bend by spillover from

turbidity currents flowing down the main Amazon Channel after the meander was cut off. Subunit IIA (0.87-7.70 mbsf) consists of prominently color-banded clays, some of which are mud turbidites with hemipelagic tops containing nannofossils. Subunit IIB (7.70-37.89 mbsf) consists of silty clays with silt laminae and some graded beds of silty sand, a few of which are more than 1 m thick. Subunit IIC (37.89-42.30 mbsf) consists of mud that is slightly color banded and mottled. Samples from the unit contain 5%-20% $CaCO_3$, although generally foraminifer and nannofossil abundances are very low.

Unit III (42.30-64.56 mbsf) consists of mud with thin beds and laminae of silt and sand, which have all been affected by wet-sediment deformation, including plastic folding, injection of sand and mud, and partial mixing of different sediment types. The unit is interpreted as a slump deposit formed by sediment failure of the adjacent channel wall. This unit has an abruptly higher wet-bulk density and shear strength compared with Unit II; shear strength within the unit decreases downhole.

Unit IV (64.56-98.09 mbsf) consists of medium- to very thick beds of fine- to medium-grained sand and coarse silt, with thin interbedded mud beds. Many of the sand beds contain mud clasts. At the top of the unit is an 18-m-thick sand bed that contains folded mud clasts up to 70 cm thick. No evidence was seen that this bed is amalgamated, but internal structures are obscured by gas expansion. Near the base of the bed are patches of 1-2-mm quartzose sand, some granules, and shell debris. This unit is interpreted as the original channel-fill sediment deposited before meander abandonment. Beds thicken from Hole 934A to 934B, which is 50 m to the south and closer to the original channel axis. Mud clasts show shear strengths of 50-120 kPa, compared with 25-50 KPa in Unit III.

Unit V (98.09-108.8 mbsf) consists of mud with thin beds and laminae of silt and sand. The mud contains a few planktonic and upper bathyal benthic foraminifers. Shear strength is similar to that of the mud clasts in Unit IV, whereas wet-bulk density is a little higher (2.0 g/cm$^3$, cf. 1.9 g/cm$^3$ in the mud clasts). The unit is interpreted as sediment predating the channel in the meander loop.

Foraminifer abundances are generally very low except in Unit I. A detailed abundance profile in Unit I showed that *G. fibriata* disappeared at 0.3 mbsf, *G. menardii* at 0.4 mbsf, and *G. tumida* at 0.9 mbsf. The *G. tumida* datum is taken as approximately the base of the Holocene.

Total organic-carbon concentrations in mud range from 0.8% to 1.1%. Total sulfur is as much as 0.16% in the upper part of the sediment column, but below 29 mbsf no sulfur was detected.

The fine sands in Units II and IV consist of quartz (30%-50%), feldspar (5%-20%, mostly plagioclase), and mica (4%-40%). Accessory minerals include zircon, hornblende, clinopyroxene, orthopyroxene, and opaque oxide minerals. Medium to coarse sand grains are texturally distinct, comprising 90% well-rounded quartz grains with iron-rich surface coatings.

We interpret the sediments at this site to represent pre-channel silt and mud (Unit V), channel-fill sand (Unit IV), and muddy slump (Unit III), overlain by overbank sedimentation into the abandoned meander loop (Unit II), and capped by the ubiquitous Holocene hemipelagic calcareous clay (Unit I). The 18-m-thick sand bed at the top of Unit IV was deposited by an unusually large flow or set of flows, probably a cohesionless debris flow, capable of transporting granules of quartz and meter-size boulders of mud. This flow deposit and the overlying contorted slump deposit may have plugged the channel, causing diversion of turbidity currents across the narrow meander neck to the west, consequently cutting off this meander loop.

By coring and logging Unit IV, we have for the first time documented the character of the sandy fill of an active aggrading channel in a modern deep-sea fan, where transport distance and morphology of channel and levee are known. This will provide an important reference for the interpretation of channel processes and of ancient channel-fill deposits. The log data are strongly influenced by the presence of clay clasts in the channel-fill sediment. Without the core, we would have interpreted the gamma-ray and resistivity logs to indicate thinner sand beds, separated by interbedded muds. The logs thus provide a possibly misleading impression of the size of sand depositional units and the potential vertical connectivity of sand bodies.

Site 935

Site 935 (proposed site AF-15) is located on the flank of the Aqua channel, one of the paleo-channel pathways from which the most recently active (Amazon) channel branched. The site was one of a series designed to characterize the development of the levees of the Amazon Channel. It was also intended to sample the underlying flat-lying high-amplitude reflection packets (HARPs). The site had a stratigraphic objective to determine the age of the Unit R debris flow and the underlying Green levee crest of the Lower Levee Complex. A limited logging program was undertaken to characterize the HARP units, the debris-flow deposit, and the buried levee crest.

The site was selected from an *R/V Conrad* seismic profile (C2514; 0222Z on 3 December 1984), which our pre-site survey showed was mis-navigated by about 0.9 mi to the east. The site was further shifted 0.5 km west of the proposed location, off the crest of the Green levee, to increase the chances of recovering sediment at the top of the Green stratigraphic interval.

Hole 935A was cored by APC to 104.6 mbsf and recovered 111.33 m (106.4%). The hole was then cored by XCB to 372.6 mbsf, with 59.4% recovery in this lower part of the hole. Temperature measurements at 51 and 80 mbsf (ADARA) and 132 mbsf (WSTP) show a geothermal gradient ranging from 35°/km near the surface to 25°/km at depth, with a linear mean of 32°/km. There was gas expansion in many cores, destroying sedimentary structures in most sands. Honeycomb structure, suggestive of gas hydrate, was found at 3.5-5.5 mbsf. Methane was found throughout the hole, but higher hydrocarbons were not detected. Logging was hindered by poor hole conditions near 200 mbsf. The Quad-combination and FMS tools were run from 64 to 180 mbsf and 230 to 290 mbsf.

Six lithologic units are recognized.

Unit I (0-0.65 mbsf) is a Holocene, bioturbated, nannofossil- and foraminifer-rich clay with up to 38% carbonate. The unit includes five indurated brown crusts between 0.36 and 0.65 mbsf.

Unit II (0.65-98.50 mbsf) consists of thin-bedded mud with beds and laminae of silt and sand. Subunit IIA (0.65 5.94 mbsf) is a slightly to moderately bioturbated clay. Subunit IIB (5.94-

21.20 mbsf) consists of silty clay with silt laminae. Subunit IIC (21.20-43.40 mbsf) consists of silty clay with scattered laminae and thin beds of silt and fine sand. Subunit IID (43.40-98.50 mbsf) is similar to Subunit IIC, but has more common and thicker laminae and beds (<3 cm) of silt and fine sand, with cross-lamination in about 5% of the sand beds. Magnetic remanence intensity in this subunit is more than double that in under- and overlying sediments. Subunits IIA and IIB correspond to the Amazon-Brown levee flank 15 km from the channel; Subunits IIC and IID correspond to the Aqua levee flank less than 1 km from the channel.

Unit III (98.50-199.30 mbsf) corresponds to high-amplitude reflection packets (HARPs) in seismic-reflection profiles. The unit consists of fine to coarse sands, commonly with mud clasts, alternating with silty clay with laminae and thin beds of silt and fine sand. Recovery was only 52.3% in this unit. Subunit IIIA (98.50-151.67 mbsf) consists of thick beds of medium sand intercalated with thick silty clay intervals that generally have contorted bedding, suggesting that mass transport has occurred. Log data provide additional information on sand-bed distribution and characteristics. Subunit IIIB (151.67-199.30 mbsf) is principally clay with laminae and thin beds of silt and sand, with a thick bed of coarse to medium sand at the base of the subunit. At 173-179 mbsf, the clay is moderately bioturbated and contains a few foraminifers, suggesting relatively slow hemipelagic sedimentation.

Unit IV (199.30-276.30 mbsf) consists of very dark gray silty clay, with <5% contorted beds of silty clay with organic detritus. Clasts of carbonate-rich clay occur at 219-226 mbsf. Pore-water sulfate concentrations of 1.0-3.3 mM are found at 223 and 250 mbsf. The unit is interpreted as a mass-transport deposit (slides and/or debris-flow deposits) and corresponds to a unit of incoherent reflections in seismic-reflection profiles (the "Unit R debris flow").

Unit V (276.30-286.04 mbsf) is a foraminifer-nannofossil-rich and -bearing clay, with ephemeral black color mottling and banding. This unit has a high total sulfur content (0.9-1.8%). It has low electrical resistivity.

Unit VI (286.04-369.03 mbsf) corresponds to the flank of the Green levee. The unit consists of silty clay with laminae and thin beds of silt and fine sand. Subunit VIA (286.04-310.32 mbsf) is silty clay with rare silt laminae. Subunit VIB (310.32-363.00 mbsf) is silty clay with silt laminae and thin beds of silt and fine sand, some of which are cross laminated.

The frequency of silt and sand beds decreases downhole. Subunit VIC (363.00-369.03 mbsf) consists of silty clay with discontinuous laminae and thin beds of silt..

Clasts of nannofossil- and foraminifer-bearing clay are found in sands in Unit III and as blocks in Unit IV. Most clasts in Unit III are of calcareous nannofossil zone CN15b. A coarse sand near the base of Unit III contains reworked foraminifers including *G. menardii*. Most blocks in Unit IV have a low abundance of nannofossils, but one clast contains a rich nannofossil assemblage similar to that in Unit V, indicating that substantial reworking has occurred.

The bioturbated clay interval at 173-179 mbsf near the base of Unit III contains a few nannofossils. The presence of clasts within the underlying unit containing nannofossils representing zone CN15b indicates that the base of Unit III must be younger than 85 ka. The sparse foraminifer assemblage includes *P. obliquiloculata*, indicating an age >40 ka. The absence of *G. menardii* and *G. tumida* is consistent with an age of <85 ka.

Unit V contains a nannofossil assemblage dominated by 4-5.5-micrometer-sized *Gephyrocapsa. P. lacunosa* is absent, and *E. huxleyi* appears to be present, but this identification must be confirmed by shore-based SEM study. The foraminifer assemblage is an interglacial assemblage including *G. tumida flexuosa* and *G. hexagonus*. Comparison with Sites 942 and 946, cored later in the leg, suggests that this interglacial predates the last interglacial (isotopic stage 5) sampled at those sites and probably corresponds to the interglacial of isotopic stage 7.

Five oscillations in magnetic declination and inclination from 35 to 42 mbsf are interpreted as secular variation cycles. No geomagnetic excursion was detected at this site.

The clay mineral fraction of mud was systematically examined by XRD at this site. The data show that smectite/kaolinite is highest in the Holocene calcareous clay (Unit I), in the HARP unit (Unit III) and at the top of the Green levee (Units V and VI). Illite/kaolinite tends to be higher in the same intervals. Kaolinite is most abundant in the Amazon-Aqua interval (Unit II) and the mass-transport deposit (Unit IV).

In general, organic-carbon content ranges from 0.8% to 1.0% with $[C/N]_a$ ratios of 6 to 10. Two organic-rich sands have organic-carbon contents of 2.0% and 4.9% and $[C/N]_a$ ratios of 20 and

34, characteristic of vascular-plant debris. Four bitumen analyses show predominance of odd-carbon-numbered n-alkanes with maximum concentrations of n-$C_{29}H_{60}$ and n-$C_{31}H_{64}$, suggesting derivation from higher terrestrial plants.

Site 935 is an important chronologic reference for the Middle and Lower levee complexes. Hemipelagic sediment dated between 40 and 85 ka is found 25 m above the "Unit R debris flow" (Unit IV). More important, the Green levee is capped by interglacial sediments (Units V and VIA) that show many characteristics similar to the extreme latest Pleistocene-Holocene section. Our shipboard interpretation is that this interval represents isotopic stage 7, but this remains to be confirmed by shore-based taxonomic and isotopic studies. It does appear to be an interglacial younger than 0.45 Ma. Such shore-based work will provide a chronology for the top of the Lower Levee Complex and thereby help us meet the objectives of relating fan growth to sea-level change and inferring terrestrial climate from detritus reaching the fan.

Site 936

Site 936 (near proposed site AF-1) is located on the western levee of Amazon Channel. It was one of a series of sites designed to characterize the development of the most recently active channel-levee system. It was also planned to sample and date Unit R, the Middle Levee Complex, and the Gold levee of the Lower Levee Complex. The site was moved about 3 km east of proposed site AF-1 and positioned over the flank of the Gold levee in order to avoid the levee crest, which may have been eroded. The revised site was selected from an *R/V Conrad* seismic profile (C2514; 1132Z on 3 December 1984).

Hole 936A was cored by APC to 92.0 mbsf, then by XCB to 433.8 mbsf, with total hole recovery of 274.42 m (63.3%). Temperature measurements were made at 51 and 73 mbsf (ADARA) and at 135 mbsf (WSTP), yielding a geothermal gradient of 29°/km. There was gas expansion in many cores. Methane was found throughout the hole, with highest concentrations at the base of the hole; no higher molecular-weight hydrocarbons were detected. The Quad-combination, FMS, and geochemical logging tools were run at this site, but hole conditions prevented logging below 310 mbsf.

Six lithologic units are recognized.

Unit I (0-0.96 mbsf) is an intensely bioturbated Holocene nannofossil-foraminifer clay, with about 42% calcium carbonate at the top of the unit, decreasing to 6% near the base. One rust-colored diagenetic crust is present at 0.46 mbsf.

Unit II (0.96-72.10 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. Calcium carbonate content is uniformly low (1.2%-2.3%). The unit is correlated with the levee flanks of the Amazon-Brown channel-levee system. Subunit IIA (0.96-6.97 mbsf) comprises intensely bioturbated mud. Subunit IIB (6.97-72.10 mbsf) consists of mud with thin beds of silt and fine sand. Although the unit shows an overall upward-fining trend, several intervals with abundant laminae and thin beds of silt and sand alternate with 1-3-m-thick intervals of moderately bioturbated mud with few silt laminae. A small slump occurs at 56 mbsf. Silt beds in Unit II have a higher mica content than those deeper in the hole.

Unit III (72.10-154.50 mbsf) corresponds to an interval of poor core recovery (33.6%) that is correlated with a high-amplitude reflection packet (HARP) in the seismic-reflection profile. Subunit IIIA (72.1-106.30 mbsf) recovered medium to coarse sands, some in graded beds and others in massive beds with mud clasts. Some interbedded mud is also present. One pebble of siltstone was recovered. Log data suggest that the subunit corresponds to a sequence of sand beds, with the base at 100 mbsf. This subunit correlates to the Brown HARP interval. Subunit IIIB (106.30-117.00 mbsf), corresponding to the flank of the Aqua levee, consists of color-banded mud with laminae and thin beds of silt and sand. The top of the subunit is bioturbated. Subunit IIIC (117.00-154.50 mbsf) recovered mud with silt laminae and a few 15-25-cm-thick fine sand beds. Log data suggest a sequence of sand beds, typically 1-2 m thick and possibly thickening and coarsening upward, from the base of the subunit to about 122 mbsf. The sand sequence is capped by muddier sediment that forms the base of an upward- fining sequence continuing into Subunit IIIB. The sandy interval of Subunit IIIC correlates with the HARP intervals associated with the Aqua and earlier systems.

Unit IV (154.50-294.16 mbsf) consists of dark gray mud, much of which appears deformed. The unit is correlated with the seismically defined "unit R" and is similar to Unit IV at

Site 935. The top 15 m of the unit contains various mud clasts, wood, shell fragments, and fine pebbles (0.5 cm). One clast contains Miocene nannofossils. Between 190 and 260 mbsf, natural gamma logs show six cycles with a gradual downward decrease in counts, followed by an abrupt increase at the top of the next cycle. In the upper part of the unit, there are at least three 10-15-m-thick intervals that show a gradual upward decrease in water content (ranging from 22% to 30%) and resistivity (lab and log data), interpreted as resulting either from surface drainage of successive debris flows or from cyclic variation in grain size (as suggested by the natural gamma log). Below 225 mbsf, sediment strength is much higher, water content is more uniform at 19%-23%, and resistivity anisotropy shows a large scatter. This part of the unit consists principally of uniform dark mud, but also contains rare deformed sand beds, mud clasts of various shades of gray, and rare rock granules. An anomalously low concentration of pore-water chloride (547 mM) was found at 267 mbsf, and sulfate was present in two pore-water samples in this unit. Similar anomalous chloride and sulfate are found in mass-transport deposits at some previous Leg 155 sites.

Unit V (294.16-405.69 mbsf) is correlated seismically with the Red channel-levee system (Middle Levee Complex). Subunit VA (294.16-307.35 mbsf) consists of mud with laminae and thin beds of silt and fine sand. Some sand beds are <25 cm thick. Log data suggest that the subunit forms an upward-fining sequence. Logging also shows that this subunit has low resistivity, which may be related to undercompaction immediately beneath the mass-transport unit, as was observed at Sites 931, 933, and 935. Subunit VB (307.35-377.40 mbsf) corresponds to an interval of poor core recovery (4.5%) of fine- and medium-grained sand. This part of the hole was severely washed out, and only the top could be logged: these data suggest a predominance of sand. Seismic profiles of the Red system here also suggest that the flank of the levee is more reflective (?coarser) than other levee units. Subunit VC (377.40-387.52 mbsf) consists of mud with laminae and thin beds of silt and fine sand, interpreted as distal levee deposits. The base of the subunit is color banded, with 11% calcium carbonate, and contains a microfossil assemblage of calcareous nannofossils, interglacial planktonic foraminifers, and abyssal benthic foraminifers. It is possible that this lithology is a clast in the underlying debris-flow deposit. Subunit VD (387.52-405.69 mbsf) is a mud-clast conglomerate interpreted as a debris-flow deposit. It contains some carbonate-rich clasts (22%-32% calcium carbonate) with microfossils similar to those in the base of Subunit VC.

Unit VI (405.69-433.80 mbsf) corresponds to the top of the Gold levee of the Lower Levee Complex. Subunit VIA (405.69-415.35 mbsf) comprises moderately bioturbated carbonate-bearing clay (at least 7% carbonate), with a high total sulfur content, similar to that seen in Holocene Unit I and a rich microfossil assemblage similar to Subunit VC. The subunit passes gradually downcore into Subunit VIB (415.35-433.8 mbsf), comprising mud with laminae and thin beds of silt and rare fine sand.

An apparent paleomagnetic excursion was observed at 60.5-61.5 mbsf. The excursion has the same general form as those in the previous holes and is therefore interpreted as the Lake Mungo event. Its presence at this depth, however, is inconsistent with the seismostratigraphic interpretation of this site. Resolution of this inconsistency will require shore-based oxygen isotope stratigraphy and radiocarbon dating. Immediately below the excursion, a 2-m-thick interval of silty clays records eight oscillations in declination, inclination, and intensity, interpreted as secular-variation cycles. If this cyclicity corresponds to the 500-year secular-variation period, a sedimentation rate of only 0.5 m/ka is implied.

Microfossil assemblages are similar to those at Site 935 and increase our confidence that a simple stratigraphic sequence is present at both sites. The base of the Holocene is at about 1 mbsf. The 40-ka *P. obliquiloculata* datum cannot be identified because of barren intervals in the core. The first downcore reappearance of *P. obliquiloculata* at 150 mbsf is associated with a nannofossil assemblage representing zone CN15b, placing its age between 40 and 85 ka. As at Site 935, bioturbated sediment (Unit VIA), a short distance beneath the main mass-transport deposit (Unit IV), has a warm-interglacial microfossil assemblage. Nannofossils appear to represent zone CN15a and include a high proportion of *Gephyrocapsa*. Foraminifers include high proportions of *G. tumida flexuosa* and *G. hexagonus*. As in the Holocene section, pollen is rare. Comparison with Sites 942 and 946, cored later in the leg, suggests that this interglacial predates the last interglacial (isotopic stage 5) sampled at those sites and probably corresponds to the interglacial of isotopic stage 7.

In general, organic-carbon content decreases from 1.2% near the top of the hole to 0.8% near the base. As at Site 935, bitumen analyses from glacial-age sediments show n-alkanes with mainly odd numbers of carbon atoms and n-$C_{29}H_{60}$ as the major n-alkane. One analysis of Holocene sediment shows a noticeably lower predominance of odd-numbered alkanes.

This site is important in that it supports the stratigraphic identification of probable isotopic stage 7 at the top of the Lower Levee Complex, first proposed at Site 935. Confirmation of this chronology will require shore-based study. The tentative chronology from the two sites implies that there is an overall sea-level control of the growth of major channel-levee complexes. The log data from this site confirm that HARP sands characteristically form upward-coarsening sequences and interbed with distal-levee upward-fining sequences of turbidites.

Site 937

Site 937 (proposed site AF-17) is located on the eastern part of Amazon Fan, on the crest of the western levee of the abandoned Yellow channel-levee system. The site was intended to provide a hemipelagic biostratigraphic and magnetostratigraphic reference section above the Yellow channel-levee system and to sample the upper part of the levee crest for comparison with Site 933.

The site was originally selected on the eastern levee crest (*R/V Farnella* seismic-reflection profile, FR815; 0758 hr on 12 January). Because the 3.5-kHz profile obtained during the pre-site survey from *JOIDES Resolution* showed that sediments on the eastern levee were more slumped than expected, we relocated the site 2 km to the west, on the western levee crest.

Hole 937A was cored by APC to 0.2 mbsf. A longer mud-line core was obtained at Hole 937B, which was cored by APC to 83.5 mbsf, then by XCB to 180.3 mbsf, with total core recovery of 159.71 m (88.6%). Hole 937C was cored to 76.5 mbsf and recovered 80.52 m (105.2%). The pressure core sampler (PCS) was used from 75.5 to 76.5 mbsf but recovered no sample. Hole 937D was cored to 16.7 mbsf and recovered 17.26 m (103.3%).

Temperature measurements were made at 54 and 84 mbsf (ADARA) in Hole 937B, showing a mean geothermal gradient of 31°/km. There was gas expansion in many cores, most severely at about 60 mbsf. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Two lithologic units are recognized.

Unit I (0-0.85 mbsf) is a Holocene bioturbated, nannofossil-foraminifer clay, containing 48% calcium carbonate at the mud line decreasing to 8% at 0.5 mbsf. It is similar to Unit I at previous Leg 155 sites. The unit includes four indurated iron-rich clay crusts between 0.15 and 0.38 mbsf.

Unit II (0.85-180.30 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The unit is subdivided into four subunits. Subunit IIA (0.85-10.50 mbsf) comprises mud that it is intensely bioturbated. At the base of the subunit is a 2.3-m-thick mud with particularly intense black coloration from hydrotroilite (>1% total sulfur) with steeply dipping boundaries, possibly corresponding to diagenetic activity along a fault. Subunit IIB (10.50-37.43 mbsf) comprises mud, with only indistinct mottling. Rare pale-blue vivianite patches are present. This subunit is probably the lateral equivalent of the Blue channel-levee system, 10 km distant at Site 938. Subunit IIC (37.43-93.51 mbsf), corresponding to the top of the Yellow levee crest, consists of faintly mottled mud with a few laminae and thin beds of silt. The frequency and thickness of silt laminae and beds vary on a scale of a few meters. Large burrows, 1-2 cm in diameter, concentrated along the tops of silt beds, were probably formed by echinoids, whose spines are a common component of the sediment. Subunit IID (93.51-180.3 mbsf) consists of faintly mottled mud with laminae and thin beds of silt and fine sand. Sand beds are up to 10 cm thick, and some are cross-laminated. Below 153 mbsf, sediment appears disturbed and includes several carbonate-rich intervals. This subunit also appears to be part of the Yellow levee.

Calcareous nannofossils are rare or absent in Unit II. Foraminifer abundances are generally moderate in Subunits IIA and IIB and are low in Subunit IIC and IID. Aragonitic pteropods are found throughout Unit II. Wood fragments are abundant in the lower part of Unit IID. Unit II can be constrained in age to less than 40 ka by the absence of *P. obliquiloculata*.

No magnetic excursion was detected at this site. Variation in magnetic declination, interpreted as secular variation, is well-developed between 1 and 45 mbsf, corresponding to the interval of the

Amazon, Aqua, Purple, and Blue channel-levee systems. Thirty-four cycles were detected, with wavelength increasing downhole. At Sites 931 and 933, the Lake Mungo magnetic excursion (30 ka) was detected just below the Blue seismostratigraphic interval, so the age of the 1-45-mbsf interval is inferred to be 10 to 25-28 ka. This implies that the cycles are of average 500-yr duration, similar to those inferred from archeological and observatory data.

Total organic-carbon content is almost constant at 1% from 20 mbsf to the base of the hole. Total sulfur exceeds 0.5% between 3.5 and 11 mbsf.

This site will provide a long reference isotopic and magnetostratigraphic section in bioturbated muds corresponding to the Amazon, Aqua, Purple, and Blue channel-levee systems. Shore-based study should permit the calibration of the secular-variation record to carbon-14 and stable-isotopic chronologies. The site also sampled part of the Yellow levee. The total thickness of the levee is unclear from seismic-reflection data, but could be as great as 450 m. As noted at other sites, there is considerable variation in the abundance of silt and sand beds in the levee sections. Asymmetric cycles in the frequency of these beds are not apparent: rather, the beds tend to occur in clusters or packets. This may indicate a source influence on turbidite sedimentation that is perhaps related to climatic or sea-level fluctuations or autocyclic changes in river-mouth sedimentation. The correlative section of the Yellow levee in Site 933 on the middle fan also shows fluctuations in the abundance of silt laminae. Any detailed correlation will require data on the chronology of the two sites.

Site 938

Site 938 (proposed site AF-16) is located on the eastern part of Amazon Fan, on the flank of the western levee of the abandoned Blue channel-levee system. The site was intended to provide a hemipelagic biostratigraphic and magnetostratigraphic reference section above the Blue channel-levee system and to sample the Blue levee. Below the Blue levee, we hoped to sample hemipelagic sediment above the levee sediments of Channel 6, which could be compared with Site 932.

The site was selected from an *R/V Farnella* seismic-reflection profile (FR815; 0904 hr on 21 January). A short seismic section and a 3.5-kHz profile across the site were obtained from the pre-site survey from *JOIDES Resolution*.

Hole 938A was cored by APC to 83.6 mbsf, then by XCB to 309.2 mbsf and PCS to 310.2, with total hole recovery of 242.68 m (78.2%). The PCS recovered no sample. Hole 932B was cored to 81.3 mbsf and recovered 79.53 m (97.9%).

Temperature measurements were made at 46 and 84 mbsf (ADARA) and show a mean geothermal gradient of 34°/km. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Two lithologic units are recognized.

Unit I (0-0.44 mbsf) is a bioturbated, Holocene nannofossil-foraminifer clay, with 33% calcium carbonate at 0.08 mbsf, similar to Unit I at previous Leg 155 sites.

Unit II (0.44-306.35 mbsf) consists of mud with intervals of interbedded laminae and beds of silt and very fine sand. The carbonate content of the mud is generally 1%-5%. The unit is subdivided into six subunits on the basis of frequency of silt and sand layers. Subunit IIA (0.44-10.55 mbsf) comprises bioturbated mud. Subunit IIB (10.55-71.84 mbsf) is composed of mud with silt laminae and rare thin beds of silt and very fine sand. Subunit IIC (71.84-117.45) consists of mud with numerous silt laminae and beds of silt and very fine sand. Burrow mottles are common, and many silt laminae are disrupted. Sand beds are as thick as 9 cm. The lower parts of Subunit IIB and Subunit IIC correspond to the flank of the Blue levee. Subunit IID (117.45-170.53) is mud with rare silt laminae and common bioturbational mottling. Carbonate content averages 3.6% and reaches 18.9% in a 2-cm-thick light-colored interval that may be a clast. A few loosely cemented diagenetic nodules of siderite were observed. This subunit corresponds to the seismostratigraphic interval from Channel 5 to the Yellow channel-levee system. Subunit IIE (170.53-233.73 mbsf) consists of mud with abundant laminae and thin beds of silt and very fine sand. Recovery was only 50% in this interval, suggesting that more sand may have been present than was recovered. Subunit IIE is correlated acoustically with part of the Channel 5 channel-levee system that appears to have filled abandoned Channel 6. Subunit IIF (233.73-306.35 mbsf) is mud with laminae and thin beds of silt and very fine sand, but in less abundance than in Subunit IIE. The average calcium carbonate content exceeds 3%, compared with <2.5% in the overlying subunit. Subunit IIF

corresponds to the upper part of the 200-m-thick Channel 6 levee crest. Changes in the trend of the water-content downhole profile correspond approximately to the upper boundaries of Subunits IID and IIF, suggesting changes in sedimentation rate.

Foraminifer abundances are generally high in Unit I, moderate in Subunits IIA, parts of IIC and IID, and low elsewhere. At 149 mbsf, abundant *P. obliquiloculata* reappears, suggesting an age >40 ka. The absence of *G. menardii* and *G. tumida* at the base of the hole indicates an age <85 ka. Abyssal benthic foraminifers are found in finer grained intervals of subunits IIB and IIC, suggesting periods of a lower sedimentation rate. Bathyal benthic foraminifers in Subunits IID and IIE are associated with iron-stained foraminifers, wood, and mica, and indicate a reworked component.

An apparent paleomagnetic excursion was tentatively identified at 147 mbsf within an XCB core. This event has a similar character to the Lake Mungo event (30 ka) that was identified at a similar seismostratigraphic level at Sites 930 and 933. A clear secular variation pattern was detected in the declination records at two intervals in Hole 938A. Between 15 and 45 mbsf, 5 cycles are present that can be correlated with cycles of similar character in Holes 937B and 930C. Another 16 cycles of declination were found between 70 and 78 mbsf in Hole 938A.

The proportion of illite (and mica) to other clay minerals is highest in the interval from 20 to 40 mbsf, corresponding to hemipelagic sediment equivalent to the Amazon, Aqua and Purple seismostratigraphic intervals. A similar pattern is seen at Site 936 over the same seismo-stratigraphic units, but at that site the sediments are of levee facies. This suggests that the trend reflects changes in the mineralogy of sediment supplied to the fan, rather than being a consequence of analyzing samples of different grain sizes.

This site has yielded a long biostratigraphic record, as it contains common foraminifers that can be related directly to magnetostratigraphy. As at other sites, we have learned that levees are built of irregular alternations of mud-rich and silt-rich intervals, on a scale of a few meters to tens of meters. The good stratigraphic control at this site will help permit an interpretation of such changes.

Site 939

Site 939 (proposed site AF-12) is located about 1.0-1.5 km east of the crest of the eastern levee of Amazon Channel on the upper Amazon Fan. It is one of a series of sites located on the flank of the Amazon Channel intended to study the late-glacial/early-interglacial evolution of the fan channel and changes in organic-matter diagenesis and pore-water chemistry. The 480-m offset of Holes 939A and 939B provides an opportunity to study lateral variability in upper-fan overbank turbidites.

The site was selected from an *R/V Conrad* 3.5-kHz profile (C2514; 0837 hr on 8 December 1984). Hole 939A was located about 480 m to the west of Holes 939B and 939C to assess the lateral variability in sedimentation. Hole 939C was used for detailed geochemical and paleontological sampling.

Hole 939A was cored by APC to 83.7 mbsf, then by XCB to 102.7 mbsf, with a total sediment recovery of 97.57 m (95.0%). Hole 939B was cored by APC to 80.0 mbsf, then by XCB to 99.4 mbsf, with total recovery of 99.51 m (100.1%). Hole 932C was cored to 36.1 mbsf and recovered 36.98 m (102.4%).

Temperature measurements were made at 51 and 80 mbsf (ADARA) in Hole 939B, indicating a mean geothermal gradient of 29°/km. There was gas expansion in all cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Two lithologic units are recognized, using Hole 939B as a type section.

Unit I (0-0.68 mbsf) is a Holocene bioturbated foraminifer-nannofossil clay, underlain by an iron-rich crust and a gray nannofossil-rich clay. A similar lithologic sequence occurs in Unit I at previous Leg 155 sites.

Unit II (0.68-99.40 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud has a calcium carbonate content of <3%. Most of the unit is stained by diagenetic hydrotroilite in irregular patches or color bands. Small soft nodules of hydrotroilite, 1-2 mm in diameter, are common, and larger concretions and continuous bands are present

from 8 to 16 mbsf. The unit is subdivided into five subunits, based mainly on the frequency of silt laminae and beds. Subunit IIA (0.68-23.00 mbsf) comprises bioturbated mud. A prominent change in reflection character seen at 15 mbsf on 3.5-kHz profiles appears to form a seismic discontinuity but has no corresponding lithologic change other than common 1-2-cm hydrotroilite nodules. Subunit IIB (23.00-44.23 mbsf) consists of moderately bioturbated mud with laminae and thin beds of silt. Burrows cut and obliterate parts of silt layers. Subunit IIC (44.23-66.17 mbsf) consists mainly of moderately bioturbated mud, with one short interval with many silt laminae. Subunit IID (66.17-81.50 mbsf) resembles Subunit IIB, except for a greater frequency of silt laminae and beds. Subunit IIE (81.50-99.4 mbsf) consists of mud with some color banding, rare silt laminae, and structureless mud turbidites.

Hole 939A was located 480 m west of Hole 939B, closer to the levee crest. The sediment sequence thickens toward the levee crest, and lithostratigraphic boundaries near the bottom of Hole 939A are about 13 m deeper than in Hole 939B. Both the number and thickness of silt beds decrease away from the channel. These decreases might indicate that, after spilling out of the channel, turbidity currents accelerated down the levee and deposited progressively less sediment.

Foraminifer abundances are generally low below Subunit IIA. *P. obliquiloculata* is not present below the Holocene, indicating an age <40 ka for Unit II. Unit I and Subunit IIA contain pteropods. Echinoid spines occur from 24 to 80 mbsf. Rare abyssal benthic foraminifers are present in Subunits IIA and IID.

No paleomagnetic excursion was found at this site. In Hole 939A, variation in magnetic inclination, interpreted as secular variation, was detected between 3 and 35 mbsf, with a short 1-2-m wavelength variation superimposed on a longer 8-20-m wavelength variation. There are three well-defined oscillations in declination over a range of 90° from 20 to 60 mbsf and two oscillations of <35° between 70 and 80 mbsf.

Physical-properties data suggest that the site experienced normal compaction, except for an interval from 17 to 27 mbsf, where compaction was inhibited and shear strength is low.

At Hole 939C, interstitial waters were collected at 1.5-m intervals to 18.5 mbsf and thereafter at 3-m intervals to 37 mbsf. Samples were also taken every 20 m in Hole 939B. Magnesium and calcium decrease from 55 mM (Mg) and 12 mM (Ca) at 0.2 mbsf to about 43 mM (Mg) and 4 mM (Ca) near 30 mbsf, thereafter remaining almost constant. Mg and Ca concentrations correlate well, suggesting that their loss from the pore water is related. Pore-water sulfate diminishes from 27 mM at 0.2 mbsf to 21 mM at 1.4 mbsf and to zero by 9 mbsf. Alkalinity increases rapidly to 31 mM at 9 mbsf and then decreases to 10 mM at 40 mbsf, remaining constant below that. Balancing possible sources and sinks of alkalinity suggests that almost all alkalinity removed from pore fluids can be accounted for as Ca or Mg carbonate. Pore-water phosphate peaks at 98 mM, at the depth of complete sulfate reduction (9 mbsf). Dissolved iron is between 56 and 94 mM in the upper 33 mbsf, reaches a peak of 326 mM at 42 mbsf, and then decreases to 143 mM at 73 mbsf. Organic carbon ranges from 1.0%-0.8% in Unit II. No discrete carbonate phases have been identified in the cores, although calcium carbonate determinations show 1%-3% carbonate in mud. Vivianite (iron phosphate) nodules are common and displace surrounding sediment, cross-cutting earlier-formed iron monosulfides that fill pore space. Organic-carbon concentration is almost constant through the interval of detailed pore-water study. Slight changes in elemental compositions may be related to diagenetic changes, such as low nitrogen values (<0.07%) at 0.5-8.0 mbsf, which could indicate preferential oxidation of reactive nitrogenous organic compounds. Shore-based analyses of more reactive organic fractions will be necessary in order to assess the effect of organic-matter diagenesis on pore-water chemistry and vivianite formation.

This site represents probably the highest near-surface sedimentation rate on Leg 155. The upper part of the pore-water profile (0-5 mbsf) is similar to that at Site 931, where the sedimentation rate is several times lower, but the peaks in phosphate and iron are several meters deeper than at Site 931. Fluctuations in the deposition of silt beds on the upper fan occur with a period estimated to be on the order of hundreds to a few thousands of years.

Site 940

Site 940 (proposed site AF-6) is located on the flank of the eastern levee of Amazon Channel about 3 km from the levee crest. Changes in reflection character in seismic profiles mark growth phases in the levee that may correlate with the avulsion of the Amazon-Brown channel from the earlier Aqua channel 5 km north of the site. The site was chosen to understand the processes associated

with levee growth and to provide a biostratigraphic section of the Amazon-Aqua levee. The site was selected from an *R/V Conrad* seismic profile (C2514; 1716 hr on 15 December 1984) and was confirmed by a *JOIDES Resolution* pre-site survey.

Hole 940A was cored by APC to 69.3 mbsf, then by XCB to 248.6 mbsf, with total recovery of 209.12 m (84.1%). A temperature measurement was made at the mud line and at 50 mbsf (ADARA) and shows a geothermal gradient of 29°/km. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected. The Quad-combination and FMS logs were run from 233 to 75 mbsf. A borehole deviation of 5°-7° south was detected with the FMS log.

Two lithologic units are recognized.

Unit I (0-0.24 mbsf) is a Holocene bioturbated nannofossil-foraminifer clay, similar to Unit I at previous Leg 155 sites. Calcium carbonate content decreases downhole from 29% at 0.11 mbsf.

Unit II (0.24-248.60 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud has about a 3% carbonate content. The unit is subdivided into nine subunits. Core-seismic correlation suggests that the upper two subunits were deposited after the avulsion of the Amazon from the Brown channel farther downstream. Subunit IIA (0.24-9.50 mbsf) comprises color-banded and bioturbated mud. Subunit IIB (9.50-31.81 mbsf) is composed of mud with thin to thick beds of silt and fine sand, which increase in frequency and thickness toward the base of the subunit. Three thin intervals of contorted sediment are interpreted as slumps.

The section of the levee that was deposited when the Brown channel was active downstream is correlated with Subunits IIC-IIE and the upper part of Subunit IIF. Subunit IIC (31.81-34.39 mbsf) consists of slightly bioturbated, color-banded mud. Subunit IID (34.39-55.71 mbsf) consists of mud with common laminae and beds of silt and fine sand, with the greatest abundance of sand at about 50 mbsf. Subunit IIE (55.71-60.01 mbsf) consists of moderately bioturbated mud with silt laminae that have been tilted and deformed and is interpreted as a slump. Subunit IIF (60.01-142.6 mbsf) consists of mud with laminae and thin

beds of silt. The frequency of these beds fluctuates, but silt is more abundant near the base of the unit. Intervals of upward-decreasing gamma-ray response from 72 to 76 and 77 to 85 mbsf and of upward-increasing gamma-ray response from 85 to 91 mbsf do not correlate with any visible changes in sediment type.

Seismic profiles suggest that Unit II below 90 mbsf was deposited when the Aqua channel was active. An upward increase in gamma-ray response from 92 to 115 mbsf corresponds to an upward-fining sequence in the lower part of Subunit IIF. Log data suggest abundant silt or sand in unrecovered intervals at 112-114 and 130-132 mbsf, the latter overlain by a 5-m-thick upward-thinning sequence. Subunit IIG (142.6-210.57 mbsf) consists of mud with common laminae and beds of silt and sand. The top of the subunit is marked by a slump similar to that in Subunit IIE and is characterized by an abrupt increase in gamma-ray and resistivity response in log data. The slump overlies an upward- fining sequence from 140 to 160 mbsf. Recovery was poor through several intervals in this subunit. Subunit IIH (210.57-236.14 mbsf) comprises mud with laminae and beds of silt and common beds of sand up to 10 cm thick. Logs show substantial borehole washout at 218-230 mbsf. Subunit IIJ (236.14-248.60 mbsf) consists of mud with laminae of silt. Core-seismic correlation suggests that the hole was terminated just above the base of the Aqua levee.

Foraminifers are relatively abundant throughout the hole. The base of the Holocene was determined to occur between 2.1 and 2.5 mbsf. *P. obliquiloculata* is absent below the Holocene section, indicating that the entire hole is younger than 40 ka. Cerrado-type vegetation is well represented in the palynomorph assemblage from Unit II, with Byrsonima, Compositae, and Graminae.

No magnetic excursion was detected at this site. Variation in magnetic inclination, interpreted as secular variation, can be tentatively correlated with Site 939 and suggests that 52 mbsf at Hole 940A correlates with 32 mbsf at Hole 939A.

In Unit II, carbonate content ranges from 1% to 3%, and organic carbon from 0.8% to 1.2%. Pore-water samples show that sulfate reduction is not complete until 20-29 mbsf, the deepest encountered on Leg 155, and the peaks in phosphate (29 mbsf) and iron (91 mbsf) concentration

are also deep. These observations suggest slower relative rates of organic-carbon remineralization than at other sites on Leg 155, probably as a result of the high depositional rate.

Sites 940 and 939, and proposed sites AF-3 and AF-24, provide a detailed stratigraphy near the crests of the youngest levees (Amazon, Brown and Aqua) on the upper, middle, and lower fan. Site 940 has confirmed that the proportion of silt and sand to mud that are deposited fluctuates considerably within a single levee, but that each levee growth phase is represented by an overall upward-fining sequence. The relatively common foraminifers and the detailed paleomagnetic record at both Sites 939 and 940 indicate that shore-based study should provide a detailed correlation and chronology of the two sites. This will allow a detailed interpretation of the processes leading to variations in levee deposition, both down-fan and in a single hole.

Site 941

Site 941 (proposed site AF-5) is located on the western side of the Amazon Fan in a surficial debris-flow deposit that fills a depression between two levees. The site was intended to determine the lithologic nature and geotechnical properties of the debris-flow deposit for an understanding of debris-flow dynamics and for comparison to deeply buried debris-flow deposits recovered at Sites 931, 933, 935, and 936. It was also intended to date the underlying levee flank deposits that may be related to the Purple system.

The site was selected from an *R/V Ewing* seismic profile (E9209; 2325 hr on 21 September 1993). The site was confirmed by a short seismic survey from *JOIDES Resolution*.

Hole 941A was cored by APC to 62.3 mbsf, then by XCB to 177.9 mbsf, with total hole recovery of 122.85 m (69.1%). An attempt was then made to log the hole using the Quad-combo and FMS tools from 175-90 mbsf, but the hole kept closing, and logging was abandoned. Hole 941B was offset 500 m south-southeast of Hole 941A to assess the lateral extent of large blocks in the debris-flow deposit. Hole 941B was cored by recovery using the APC tool until the sediment became too consolidated at 85.1 mbsf, and overall core recovered was 96.15 m (113%, the extra sediment largely as a result of flow-in). Whole-round samples for geotechnical analysis were taken in Hole 941B.

One temperature measurement was made at 53 mbsf (ADARA) and, together with the mud-line temperature, shows a mean geothermal gradient of 32°/km. There was gas expansion in many cores, but less than was experienced at most other sites on Leg 155. Methane was found throughout the hole, but higher hydrocarbons were not detected. Extreme gas expansion and a honeycomb structure to the mud were observed at 45 mbsf in Hole 941B.

Four lithologic units are recognized, using Hole 941A as a type section.

Unit I (0-0.98 mbsf) is a Holocene bioturbated nannofossil-foraminifer clay, with about 50% calcium carbonate, similar to Unit I at previous Leg 155 sites. Hole 941A is exceptional in that the calcareous clay is underlain by a foraminifer sand with common pteropods, interpreted as a turbidite. This sand is absent in Hole 941B.

Unit II (0.98-5.30 mbsf) consists of dark gray mud, with carbonate content between 0.6% and 5.7%. Euhedral crystals of ikaite, several centimeters in size, were found at 3-4 mbsf. They began to disintegrate a few hours after the core was split.

Unit III (5.30-129.70 mbsf) consists of mud and sandy mud of varying consistency and color that shows soft-sediment deformation. The presence of clasts is indicated by abrupt changes in lithology and color. Folds occur on scales from centimeters to meters. Some boundaries between clasts show shear deformation. Fault contacts are common, and layering in many clasts is offset by a series of microfaults. Rare pebbles of siltstone and unidentified rock are found, but sand is very sparse. In general, the body appears to be a clast-supported breccia, and little matrix mud was identified. The unit is interpreted as a debris-flow or slump deposit, but the number of depositional events is uncertain. Recovery was very poor in the lower half of this unit (24% from 72 to 130 mbsf).

Unit IV (129.70-177.90 mbsf) consists of mud with many laminae and thin beds of silt and fine sand, similar to levee sequences cored at other sites on Leg 155.

Total organic carbon is lower than at other Leg 155 sites, and is typically 0.6%-0.85%. Nevertheless, measured headspace methane concentrations are similar to those at other sites.

As at other sites on Leg 155, Unit I is Holocene in age. Unit II also contains a Holocene foraminiferal fauna including *G. tumida*. Unit IV contains a Y-zone[1] fauna lacking *P. obliquiloculata* and is therefore interpreted as younger than 40 ka. The age of Unit IV supports the suggestion that the levee correlates with the Purple channel-levee system.

Clasts in the debris-flow deposit are of two main biozones. One type comprises Y zone assemblages, including *P. obliquiloculata* (i.e., probably 40-85 ka). The other consists of X zone assemblages, including a relatively high abundance of *G. menardii, G. tumida,* and *G. tumida flexuosa*, indicating an interglacial assemblage, probably from isotopic stage 5. Preliminary data suggest that biozones alternate down through the debris-flow deposit, with each zone being 10-20 m thick. In addition, clasts of olive-gray mud with 7% total carbonate at 30-35 mbsf contain rich Miocene nannoflora. Echinoid plates are locally abundant. Bathyal benthic foraminifers, pteropods, ostracode shells, and fish scales are also found in Unit III.

Unlike previous Sites 931, 933, 935, and 936, where deeply buried debris-flow deposits were cored, there is no decrease in wet-bulk density and increase in porosity in the levee sediments immediately underlying the debris flow, nor is there evidence for overpressuring.

A pore-water sample at 112 mbsf has a salinity of 29.5 and unusually low chloride (496 mM) and magnesium (29.5 mM). These low concentrations suggest pore-water dilution, probably through melting of gas hydrates. The extreme gas expansion and honeycomb structure at 45 mbsf also may be evidence of gas hydrates.

This site provided a detailed section through a young debris-flow deposit, which appears to be of earliest Holocene age. It shows many of the sedimentological features of more deeply buried debris-flow deposits. The general lack of muddy matrix material is noteworthy. Blocks are inferred to range in size from centimeters to many meters and are both folded and faulted. The

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[1] Glacial-interglacial fluctuations of *Globorotalia menardii* and *Globorotalia tumida* occur throughout the Pleistocene and are referred to as Ericson zones. These ecostratigraphic zones are climatically driven and compare well with oxygen isotope stratigraphy (Pflaumann, U., 1986. Sea-surface temperatures during the last 750,000 years in the eastern equatorial Atlantic: Planktonic foraminiferal record of *Meteor* cores 13519, 13521, and 16415. *Meteor Forsch-Ergebnisse C.*, 40:137-161).

repetitive biozones suggest that the debris-flow deposit may have formed by repeated retrogressive failure of last glacial sediments overlying last interglacial sediments. Previous seismic-reflection profiles and confirmation of acoustic facies by Leg 155 holes has shown that about 20% of the sediment in the upper few hundred meters of the Amazon Fan is made up of a few vast debris-flow deposits of the type cored at this site.

Site 942

Site 942 (proposed site AF-20) is located on the crest of an abandoned levee to the west of the main part of the Amazon Fan. It was intended to provide a hemipelagic reference section on the western side of the fan to study equatorial Atlantic paleoclimate and paleocirculation patterns. A secondary objective of the site was to date and characterize the sediment source of the underlying levee.

The site was selected from an *R/V Conrad* seismic-reflection profile (C1612; 1905 hr on 26 July). The precise position was determined from a pre-site echosounder profile from *JOIDES Resolution.*

Hole 942A was cored by APC to 104.0 mbsf, then by XCB to 177.6 mbsf, with total hole recovery of 152.6 m (85.9%). Hole 942B was cored to 74.0 mbsf and recovered 56.91 m (76.9%). Hole 942C was cored to 71.5 mbsf, with the exception of 13.8-36.0 and 55.0-62.0 mbsf, which were drilled without coring. Total recovery was 44.03 m (104.1%). Correlation of lithology and magnetic susceptibility shows that measured depths below seafloor in Hole 942C below Core 155-942C-1H are about 4 m shallower than the corresponding depths in Holes 942A and 942B. This offset is attributed to a coring problem: the sediment zones are flat-lying.

Temperature measurements made at 51 and 80 mbsf (ADARA) show a mean geothermal gradient of 38°/km. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Six lithologic units are recognized, using Hole 942A as a type section.

Unit I (0-0.66 mbsf) is a bioturbated Holocene foraminifer-nannofossil clay, with a diagenetic iron-rich crust at its base, and is similar to Unit I at other Leg 155 sites.

Unit II (0.66-28.10 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud has 1.4%-4.5% carbonate content. The unit is subdivided into two subunits. Subunit IIA (0.66-23.85 mbsf) comprises bioturbated mud with hydrotroilite-stained mottles. It includes one sand bed at 14 mbsf. Rare laminae and thin beds of silt occur below 17 mbsf. Subunit IIB (23.85-28.10 mbsf) is composed of mud with thin to thick beds of silt and fine sand, which increase in frequency and thickness toward the base of the subunit.

Unit III (28.10-40.18 mbsf) comprises a thin calcareous mud resting on a sequence of mud with interbedded silt and sand. Subunit IIIA (28.10-28.80 mbsf) is a foraminifer-nannofossil-rich silty clay, with 14% carbonate. Is has a gradational contact with the underlying subunit. Subunit IIIB (28.80-40.18 mbsf) consists of bioturbated mud, mottled with hydrotroilite, with interbedded laminae and beds of silt and sand. Silt and sand beds are particularly abundant from 36 to 40 mbsf. Spreiten burrows (probably *Echinocardium*) commonly disrupt the tops of sand beds.

Unit IV (40.18-65.20 mbsf) resembles Unit III, comprising a thin calcareous mud resting on a sequence of mud with interbedded silt and sand. Sand is more abundant than in Unit III. Subunit IVA (40.18-40.80 mbsf) is a foraminifer-nannofossil-rich clay similar to that in Subunit IIIA and with a gradational lower boundary. Subunit IVB (40.80-65.20 mbsf) consists of moderately burrowed dark greenish gray mud, alternating with beds and laminae of very fine sand and coarse silt, many of which are cross-laminated. Ripple-migration directions, determined on oriented cores, are to the north. The abundance of ripple lamination at this site probably reflects the abundance of very fine sand, compared with the dominance of silt at previous Amazon Fan sites.

Unit V (65.20-66.07 mbsf) consists of greenish-gray foraminifer-nannofossil clay with as much as 31% carbonate and gradational boundaries.

Unit VI (66.07-171.28 mbsf) consists of gray mud with laminae and rare beds of silt. Color banding and mottling are common. Carbonate content is generally 0.7-4%. Two light-colored muds at the tops of turbidite beds with 14%-17% carbonate contain diagenetic siderite.

Foraminifers and nannofossils are common to abundant in Units I-V and the upper part of Unit VI, but are rare in the lower part of Unit VI. The *P. obliquiloculata* 40-ka datum is found at 23.03 mbsf, and the top of the X zone (85 ka) is between 33 and 42 mbsf. *G. tumida* is absent below 70.38 mbsf: this lower interval is interpreted as the W zone (isotopic stage 6, >130 ka).

Two short intervals of anomalous remanence direction and intensity, which could represent geomagnetic excursions, were observed. The first occurs at 11.5 mbsf in Hole 942A, but was not detected in Hole 942B, and has characteristics similar to the Lake Mungo event (30 ka). The second, at 41.5 mbsf in Hole 942B (also found in Hole 942C), may correlate to the Blake event (105 ka). Short-wavelength (about 0.5 m) oscillations in magnetic inclination, interpreted as secular variation, were detected between 1 and 12 mbsf. Remanence intensity variation can be correlated between holes.

Index properties in Units II-V show more scatter than samples at similar depths at previous Leg 155 sites. Some samples at the base of Unit IV and the top of Unit VI have anomalously high grain density (2.8-2.9 g/cm$^3$).

Total organic-carbon content is generally 0.4%-0.8% in Units I-V, but then gradually increases to >1.0% in the lower part of Unit VI. Elevated sulfur content occurs immediately below Units I and V. In pore-water samples, calcium, magnesium, alkalinity, and salinity are low in the interval from 30 to 100 mbsf.

This site provides a reference section for biostratigraphy and stable isotopes on the western side of Amazon Fan. The three carbonate-rich intervals (Subunits IIIA and IVA and Unit V) are interpreted to correspond to isotopic stages 5a, 5c, and 5e, with the Blake paleomagnetic event in stage 5c and the greatest abundance of microfossils when sea level was highest in stage 5e. They will serve as a standard against which to interpret the carbonate-rich intervals of Sites 931, 933, 935, and 936. The overall sedimentation rate in stage 5 is estimated to be 0.8 m/k.y. Turbidites in Subunits IIB to IVB (isotopic stages 3-5) contain a high proportion of fine sand to silt and may be

compositionally distinct from Amazon Fan levee turbidites: these sandy turbidites may be derived from a source north of the mouth of the Amazon River. The silty turbidites of Unit VI (isotopic stage 6) appear to be of of the same provenance as Amazon Fan sediments.

Site 943

Site 943 (proposed site AF-23) is located in the main (Amazon) channel on the central part of the Amazon Fan. It was intended to sample the coarsest sediments transported by recent turbidity current flows within the constraints of a known channel geometry and to determine the nature of the high-amplitude reflections (HARs) that underlie the channel in seismic profiles. Nearby Site 944 (proposed site AF-3) sampled the levee of this channel.

The site was selected from an *R/V Conrad* seismic-reflection profile (C2514; 0605 hr on 4 December) and multibeam bathymetry. The precise position was determined by pre-site survey from the *JOIDES Resolution*. The site is in a straight reach of the channel 2 km down-channel from the *R/V Conrad* seismic profile. The site was positioned using a *JOIDES Resolution* profile.

Hole 943A was cored by APC to 40.2 mbsf, then by XCB to 106.3 mbsf, with total hole recovery of 66.46 m (62.5%). No temperature measurements were made. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Four lithologic units are recognized.

Unit I (0-1.58 mbsf) is a bioturbated, Holocene, brown nannofossil-foraminifer clay. It differs from Unit I at other Leg 155 sites in that it is interbedded with a 73-cm-thick interval of mass-flow deposit and silt-clay turbidite(s), which may be slumped. An iron-rich diagenetic crust is developed at 1.28 mbsf. A gray foraminifer-nannofossil clay occurs at the base of the unit.

Unit II (1.58-6.26 mbsf) comprises bioturbated mud with increasing amounts of black hydrotroilite staining below 3 mbsf, associated with a high total sulfur content (0.77%).

Unit III (6.26-62.88) consists of mud with interbedded sand. Recovery was only 48%, and some recovered sand appeared to be flow-in. At the top of the unit, a fine sand with millimeter-

size plant fragments was recovered in two cores, but its original thickness is unknown, and it may be mostly flow-in. A large clast of nannofossil-bearing clay occurs at the top of the sand. An interval from 32.8 to 40.2 mbsf recovered mud with abundant beds of silt and sand, commonly with erosive bases. There is a general trend toward thicker beds in the lower part of the interval. The thickest bed recovered is an 81-cm-thick silt bed with mud clasts. In the lower part of the unit, a thick bed of silt with minor mud clasts overlies a 19-cm-thick graded bed from very coarse sand to silt, which is underlain by a 2-m-thick bed of clasts of mud with silt laminae in a coarse sand matrix.

Unit IV (67.80-106.25) consists of mud with laminae and thin beds of silt. It is divided into subunits on the basis of the frequency of silt laminae and beds. Subunit IVA (67.8-89.19 mbsf) has abundant silt beds and laminae. Subunit IVB (89.19-93.29 mbsf) comprises mottled mud, locally with color banding. Subunit IVC (93.29-106.25 mbsf) consists of color-banded mud with common beds and laminae of silt. Siderite bands are present in this subunit. Subunits IVB and IVC appear to correlate with the Purple channel-levee system.

Foraminifer and nannofossil abundances are generally high in Unit I, except in the resedimented deposits, and low throughout the remaining units. *P. obliquiloculata* was not found below the Holocene section, suggesting an age <40 ka for the base of the hole.

This site has provided a channel-fill section through the Amazon Channel on the lower mid-fan that can be compared with Site 934, 60 km up-fan. The channel-fill sequence is about 60 m thick, with coarse sand near its base. Otherwise, no sediment coarser than fine sand was recovered. The channel overlies levee sediments, suggesting that it has migrated laterally as the levee has accreted. Correlation with levee sediments of adjacent Site 944 will also provide information on the nature of flows and may permit more precise interpretation of the pre-channel units at the base of the hole.

Site 944

Site 944 (near proposed site AF-3) is located on the middle Amazon Fan, on the eastern levee of Amazon Channel, down-fan from the Amazon-Brown avulsion. The site is about 2 km from the channel axis and on the outside of a meander bend. It is one of a series of sites designed to

understand the evolution of the Amazon channel-levee system. It was also designed to sample the Unit R debris flow, the Middle and Lower Levee complexes, and the equivalent of interglacial calcareous clays previously recovered up-fan at Sites 935 and 936. The site was expected to be more sandy than these previous sites, and Quad-combination and FMS logs were planned to better understand the geometry of sand beds and debris-flow deposits.

The site was selected from an *R/V Conrad* seismic-reflection profile (C2514; 0557Z on 4 December 1984). We located Site 944 at a corresponding position on a *JOIDES Resolution* seismic-reflection profile (2020Z on 11 May 1994).

Hole 944A was cored by APC to 97.1 mbsf, then by XCB to 384.2 mbsf, with a total hole recovery of 208.1 m (54.1%). Hole 944B was offset 300 m to the southwest and cored to 47.8 mbsf and recovered 46.81 m (97.9%). Hole 944C was offset 300 m to the northeast of Hole 944A and failed to obtain a mud-line core (recovered 9.6 m). Hole 944D, 20 m from Hole 944C, was cored to 44.6 mbsf, with a total recovery of 43.37 m (97.2%). This hole was sampled in detail for pore-water and diagenetic-mineral studies. Hole 944A was logged from 74 to 384 mbsf.

Temperature measurements made in Hole 944A at 51 and 80 mbsf (ADARA) show a mean gradient of 39°/km, with a steeper geothermal gradient at depth. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected.

Six lithologic units are recognized. Depths are based on a type section in Hole 944A.

Unit I (0-0.54 mbsf) is a Holocene, bioturbated, nannofossil-foraminifer clay, with up to 38% carbonate, similar to Unit I at previous Leg 155 sites.

Unit II (0.54-191.60 mbsf) consists of mud with interbedded laminae and beds of silt and very fine sand. The mud has 2%-3% carbonate content. The unit is subdivided into four subunits. Subunit IIA (0.54-15.38 mbsf) comprises intensely bioturbated mud, stained to varying degrees by black hydrotroilite. Subunit IIB (15.38-37.42 mbsf) consists of mud with silt laminae. An interval of sediment deformation interpreted as a slump occurs from 32.4 to 36.9 mbsf. Subunit IIC (37.42-163.23) comprises mud with laminae of silt and thin beds of silt and very fine, fine, and medium sand. The frequency of silt and sand beds fluctuates

through the unit, but no very fine sand beds occur above 111 mbsf, and no medium sand above 143 mbsf. Moderate bioturbation is common. Two thin intervals of contorted or dipping beds occur at 44 and 57 mbsf. Wireline-log data suggest that sand is common in the interval of poor recovery in the lower half of the subunit, notably at 122-128 mbsf and 158-180 mbsf. Subunit IID (182.00-191.60 mbsf) consists of mud with thin beds and laminae of silt and thin beds of fine sand. Log data suggest that this subunit forms an upward-coarsening sequence. Seismic correlation shows that Unit II corresponds to levees of the Amazon and Brown channel-levee systems, and high-amplitude reflection packets (HARPs) associated with the Brown, Purple, and Orange systems, with some interbedded distal levee deposits of the Purple system.

Unit III (191.60-268.70 mbsf) consists of various types of mud that appear to occur as blocks and have been affected by soft-sediment deformation. Many carbonate-rich clasts are found in the upper and middle parts of the unit. This unit is interpreted as a mass-transport deposit that correlates seismically with the Unit R debris flow. Log data show generally rather uniform gamma-ray response, except for a washed-out interval at 226-233 mbsf. High resistivity from 218-226 mbsf corresponds to an interval with large numbers of carbonate-rich clasts in cores. Color-reflectance data suggest that the interval from 192 to 220 mbsf is compositionally different than the one from 230 to 260 mbsf.

Unit IV (268.70-335.40 mbsf) consists of mud with laminae and thin beds of silt and sand. This unit correlates seismically with the Red channel-levee system. Two subunits are distinguished on the basis of the occurrence of sand beds. Subunit IVA (268.70-293.07 mbsf) consists of bioturbated and color-banded mud with abundant laminae of silt. Subunit IVB (293.07-355.40 mbsf) consists of mud with numerous silt laminae and thin beds of silt and very fine sand. Only 1 m of core was recovered in the lower 47 m of this subunit, and wireline logs suggest that the base of the subunit is at 352 mbsf. The borehole diameter is particularly large through this subunit, which affected the quality of log data. Log characteristics in general are similar to those in the lower part of Subunit IIC and suggest that there are several upward-coarsening sequences within Subunit IVB, whereas Subunit IVA is more uniformly fine grained.

Unit V (355.40-357.53 mbsf) contains two short intervals of nannofossil-foraminifer clay, with up to 17% carbonate content, passing both uphole and downhole into nannofossil-bearing clay. The entire unit suffered severe coring disturbance. Wireline-log data suggest that this lithology extends uphole to about 352 mbsf.

Unit VI (357.53-384.20 mbsf) consists of mud with laminae and thin beds of silt. It correlates seismically with the levee of the Green channel-levee system. Log data suggest a downhole increase in the abundance of silt.

Foraminifer and nannofossil abundances are generally high in Units I and V, and in some calcareous clasts in Unit III. Otherwise, nannofossils are almost absent and foraminifers are in low abundance in Subunits IIA and IIB and Unit VI, and rare to absent in Subunits IIC and IID and Unit IV. *P. obliquiloculata* was not detected above the Unit III debris-flow deposit, but this could result from the low foraminifer abundance. Some clasts in Unit III contain well-preserved nannofossils of Zone CN15b, which indicate that the debris-flow deposit is younger than 85 ka. In Unit V, the well-preserved and abundant nannofossils, dominated by *Gephyrocapsa*, and foraminifers, including *G. tumida* and *G. tumida flexuosa*, indicate interglacial conditions. These microfossil assemblages are similar to those sampled at depth at Sites 935 and 936. Shore-based study will be required to determine which interglacial stage is represented, but comparison with Site 942 suggests that stage 7 is most probable.

Short-wavelength oscillations in magnetic inclination, declination, and remanence intensity were detected throughout the APC cores, with generally 2-4 cycles per meter. These oscillations are interpreted as geomagnetic secular variation. No magnetic excursion was found in APC cores.

A detailed pore-water profile in Hole 944D showed that alkalinity peaks at 4.4 mbsf (22 mM), decreasing to 10 mM by 10 mbsf and then remaining approximately constant. Pore-water sulfate decreases to zero by 4.4 mbsf; at the same depth, phosphate peaks at 0.4 mM. Dissolved iron concentrations are variable. Pore-water geochemical profiles at this site change more rapidly with depth than at Sites 931 and 939.

Elevated total sulfur (0.5%-1.5%) was measured in the lower part of Unit III (debris flow) and the lower part of Unit V. Total organic carbon decreases from about 0.9% in Unit II to 0.7% in Unit VI. Log data show anomalously low values of velocity from 305 to 315 mbsf, which may indicate higher concentrations of gas in the formation. Cores from this interval had an unusual number of gas-filled voids.

An interval from 17 to 22 mbsf shows almost constant water content and does not appear to have undergone normal compaction. Similar intervals were identified near the top at Sites 939 and 940. The detailed samples of reactive iron minerals taken at this site may help determine if these zones of constant water content are related to diagenesis.

Site 944 sampled a similar stratigraphic section to that of Site 936, but farther down-fan. Units II and IV, corresponding to levee and HARP sediments in the Upper and Middle Levee complexes, respectively, were sandier than at Site 936. The Unit III mass-transport deposit is thinner and has a higher proportion of decimeter- to meter-sized blocks compared with Site 936. As at Site 936, the carbonate-rich layer above the Lower Levee Complex is of interglacial origin, possibly isotopic stage 7. At this site, the series of holes away from the levee crest shows substantial changes in silt-bed thickness and abundance over distances of a few hundred meters, which, together with data from Site 943 in the adjacent channel, will permit analysis of turbidity-current flow dynamics and deposition.

Site 945

Site 945 (proposed site AF-25) is located in the main (Amazon) channel of the Amazon Fan, near the transition from the middle to the lower fan. By sampling in the channel we expected to sample the coarsest sediments transported to the site by latest Pleistocene turbidity currents. The channel is incised about 48 m below the levee crest. Site 946 (proposed site AF-24), 1.2 km to the east, sampled the adjacent levee of this channel to characterize overflow events, as well as deeper layers that underlie both the channel and levee.

The site was selected from an *R/V Conrad* seismic-reflection profile (C2514; 0217 hr on 18 December 1984). The precise position was determined by a pre-site seismic and a 3.5-kHz survey from *JOIDES Resolution.*

Hole 945A was cored by APC to 75.5 mbsf and recovered 74.75 m (99.0%). Only partial strokes were achieved on the three deepest cores, and some sand appears to have been sucked-in. There was gas expansion in many cores. Methane was found throughout the hole but higher hydrocarbons were not detected. A 50-cm-thick zone of honeycomb structure in a sand bed at 61 mbsf may indicate the presence of gas hydrates.

Three lithologic units are recognized.

Unit I (0-0.45 mbsf) is a bioturbated Holocene nannofossil-foraminifer clay, similar to Unit I at previous Leg 155 sites. An iron-rich crust occurs at the base of the unit.

Unit II (0.45-1.46 mbsf) consists of mottled, slightly bioturbated olive-gray mud.

Unit III (1.46-75.26 mbsf) consists of medium- to thick-bedded sands interbedded with mud and thin-bedded sand and silt. Most of the sand is very fine to fine grained, but some beds contain abundant medium sand with rare to common coarse grains and rare granules. Most sand beds are graded. Many of the thicker beds contain angular to well-rounded clasts of mud. At the top of the unit is an 8-m-thick sand bed with abundant folded mud clasts. The water content of these clasts is about 10% lower than for normally consolidated mud at this sub-bottom depth and is more typical of sediments at 30 mbsf. The clasts are set in a matrix of medium sand, whereas the upper part of the graded bed is fine sand. An interval of bioturbated mud occurs at 19-20 mbsf. Lower in the unit, layers of organic detritus occur in some sands. In the lower part of the unit, sand beds appear organized in two upward-thinning sequences, from 75.25 to 53 mbsf and from 53 to 40 mbsf.

Foraminifers and nannofossils range from abundant to few in Units I and II. The boundary between Ericson zones Z and Y is near the base of Unit II (1.4 mbsf). Rare nannofossils and foraminifers are found in a few samples from Unit III. *P. obliquiloculata* is absent, suggesting an age <40 ka for the upper part of Unit III that contains foraminifers. Because of the sandy character of the cores, paleomagnetic results are inconclusive.

The major changes in organic-carbon, nitrogen, and sulfur content are associated with changes in grain size. Well-sorted fine sand has low contents of all three elements.

Comparison of seismic-reflection profiles and lithology shows that Unit III can be correlated in detail with similar sand, silt, and mud beds at Site 946. The only possible channel-fill deposit at Site 945 is the 8-m-thick sand bed with abundant mud clasts at the top of Unit III. This bed is lithologically similar to that at 58-63 mbsf at Site 943, which also contains large numbers of mud clasts and was interpreted to represent the first deposit following an avulsion. The 8-m-thick bed at Site 945 is, however, at the same stratigraphic level as a thick sand at Site 946: it is therefore possible that no sand has accumulated in this reach of the Amazon Channel, as a result of downcutting following avulsion.

Site 946

Site 946 (proposed site AF-24) is located near the transition from the middle to the lower Amazon Fan. It is one of a series of sites designed to characterize the development of the most recently active channel of the Amazon Fan (the Amazon Channel). The hole penetrated the Amazon levee and the underlying highly reflective seismic units characteristic of the lower fan. Site 945 was located 1.2 km to the west on the adjacent channel floor.

The site was selected from an *R/V Conrad* seismic-reflection profile (C2514; 0210Z on 18 December 1984). The precise position was confirmed by pre-site survey from *JOIDES Resolution*.

Hole 946A was cored by APC to 140.0 mbsf, then by XCB to 275.0 mbsf. APC recovery was 127.91 m (91.4%), and XCB recovery was 44.3 m (32.8%). Temperature measurements made at the mud line and at 64 mbsf (ADARA) show a mean geothermal gradient of 43°/km. There was gas expansion in many cores. Methane was found throughout the hole, but higher hydrocarbons were not detected. The site was logged with the Quad-combination and FMS tool strings from 78 to 274 mbsf.

Seven lithologic units are recognized.

Unit I (0-0.45 mbsf) is a Holocene bioturbated, nannofossil-foraminifer clay, similar to Unit I at previous Leg 155 sites.

Unit II (0.45-1.18 mbsf) consists of clay with burrow mottles and faint color banding.

Unit III (1.18-128.72 mbsf) consists of mud, silt, and sand beds, with a general trend to thicker sand beds and sand beds with abundant mud clasts downhole. The thickness of some sand beds may have been inflated by sand flow during coring. The unit is subdivided based on the relative abundance of sand beds. Subunit IIIA (1.18-4.42 mbsf) comprises mud with numerous graded beds of fine sand to silt, on average 6 cm thick, making up 30% of the subunit. Subunit IIIB (4.42-24.72 mbsf) contains bioturbated mud with numerous laminae and thin beds of silt. Subunit IIIC (24.72-128.72 mbsf) consists of mud with numerous laminae and beds of silt and sand. Silt beds are as thick as 75 cm and are graded. Sand beds have abundant 1-10-cm mud clasts and generally grade upward from poorly sorted fine sand to silt, although rare medium sand is present. Some of the sand beds appear to be more than 1 m thick. The alternation of sandier and siltier intervals below 45 mbsf can be correlated with similar alternations at Site 945, with a distinctive bioturbated interval at 55 mbsf in Hole 946A corresponding to 19 mbsf in Hole 945A. The upper part of Unit III (to 18 mbsf) is correlated seismically with the Amazon Channel levee, and the middle part (to 45 mbsf) with an underlying levee. The lower part of the unit corresponds to lower fan sands over which the levees have prograded. When deposited, these sands were located beyond the contemporary channel termination.

Unit IV (128.72-155.82 mbsf) consists of a series of intervals of mud with silt laminae and minor beds of silt interspersed with beds of calcareous clay that have carbonate contents of 7%-36%. The contents of organic carbon (0.4%) and nitrogen (0.1%) are low in the calcareous intervals. Burrow mottles are common to abundant throughout this unit. The top of the unit is an apparently erosional boundary overlain by a 50-cm-thick graded bed of medium to fine sand. A thin calcareous clay occurs at 133.25-133.75 mbsf. From 140 to 149 mbsf, several 20-30-cm-thick intervals of greenish-gray nannofossil-foraminifer-rich clay alternate with dark-gray foraminifer-bearing clay.

Unit V (155.82-211.37 mbsf) had only 21% recovery, and most of its sand was highly disturbed by coring. The upper 5 m of the unit comprises mud with thin to thick silt beds. Below this, recovery was sparse and consists of two cores of abundant mud clasts in a poorly sorted matrix of fine to medium sand. Wireline-log data suggest that much of this unit consists of "clean" sand, which below 180 mbsf forms three upward-coarsening sequences. FMS images show packets of 0.5-1-m-thick sand beds. The data suggest that individual sand packets are thicker than in the lower part of Unit III, which was also logged, but muddy intervals are thicker and less silty in Unit V. Seismically, this unit and the overlying Unit IV are correlated with the feather edge of either the Middle or the Lower Levee Complex.

Unit VI (211.37-220.0 mbsf) consists of greenish gray calcareous clay interbedded with dark gray mud with laminae and thin beds of silt. Burrow mottling is common. The top of the unit is an irregular erosional surface, and the overlying sand contains rip-up clasts from this unit.

Unit VII (220.0-273.67 mbsf) had less than 19% recovery, almost all of which was in two cores from the top and base of the unit that consist of mud with silt laminae, similar to levee sequences recovered elsewhere on Leg 155. Wireline logs, however, show that from 218 to 250 mbsf, the unit consists predominantly of sand. From 250 to 262 mbsf, log response suggests alternating sand and mud in an upward- thinning sequence, which is underlain by a predominantly muddy sequence below 262 mbsf corresponding to the mud with silt laminae recovered in Core 155-946A-29X. FMS images suggest sand-bed thicknesses of 3-5 m at the top of the unit, decreasing downhole.

Foraminifers and nannofossils are well preserved and abundant in the calcareous clays of Units I, IV, and VI. Otherwise, microfossils are sparse, and nannofossils are commonly etched. The bioturbated interval at 55 mbsf in Subunit IIIC contains a few etched specimens of *Gephyrocapsa.* Our preliminary shipboard study suggests that Unit IV nannofossil assemblages are similar to those in Units III, IV, and V at Site 942. Unit VI nannofossil assemblages are dominated by *Gephyrocapsa* and thus resemble those near the base of Sites 931 and 933. *P. obliquiloculata* is found in a sandy interval at 53.5 mbsf in Unit III and is probably reworked. Units IV and VI contain interglacial foraminifers including *G. menardii*, *G. tumida*, and *G. tumida flexuosa*. *G. hexagonus* is present in Unit IV.

Two anomalous intervals of remanence direction and intensity, interpreted as geomagnetic excursions, occur at 101.5 mbsf and 133.5 mbsf, the latter in an interval of calcareous clay. On the basis of the pattern of their remanence behavior, these are interpreted as the Lake Mungo (30 ka) and Blake (105 ka) events. Oscillations in paleomagnetic declination and inclination, interpreted as secular variation, are best developed from 10 to 13 mbsf, with a wavelength of 0.25 m.

Individual sand beds and packets of mud with silt beds can be tentatively correlated between Site 945 and the upper 110 m of Site 946, using continuity of seismic reflections as a guide. The depth below seafloor of any particular feature is about 40 m greater at Site 946. This lateral continuity of sandy units implies that these sediments were deposited on the lower fan beyond the limit of strongly channelized flow.

This site was a fitting end to a highly successful leg. It is the only site to have recovered two major units containing interglacial calcareous clay beds, with a thick sandy interval (Unit V) between them. The presence of the Blake geomagnetic excursion and the tentative biostratigraphic correlation with Site 942 allow us to correlate Unit IV with the interglacial of isotopic stage 5. Units IV and VI have different nannofossil and foraminifer assemblages and are separated by a thick sand unit. Unit VI therefore appears to date from an earlier interglacial and correlates biostratigraphically with the interglacial sediments near the base of Sites 931 and 933. The excellent recovery to 160 mbsf and the remarkably good correlation between sands at Sites 945 and 946 provide unparalleled sedimentological detail of the sandy depositional lobe beyond the termination of the fan channel.

# OPERATIONS REPORT

The ODP Operations and Engineering personnel aboard *JOIDES Resolution* for Leg 155 were:

| | |
|---|---|
| Operations Superintendent: | Gene Pollard |
| Schlumberger Engineer: | Steven Kittredge |

## TRANSIT - BARBADOS TO SITE 930

*JOIDES Resolution* departed Barbados at 1205, 28 March. All times reported in this Operations Synopsis are reported in local time. During Leg 155, the local time is UTC minus 4 hr. The 848-nmi sea voyage to Site 930 required approximately 91.0 hr at an average speed of 9.3 kt. During the transit we collected navigation, 3.5- and 12-kHz reflection, and magnetic data.

## SITE 930
## (Proposed site AF-21)

Seismic Survey

The single-channel seismic survey started at 0730 hr on 1 April and lasted about 6 hr. The seismic gear was retrieved, and the ship returned to GPS coordinates 5°00.85'N, 47°35.78'W. The ship was on location in dynamic positioning mode (DP) at 1430 hr, and a Datasonics commandable retrievable beacon was dropped at 1515 hr, 1 April.

In this report "m" will be used to designate "meters below rig floor" (mbrf) unless otherwise indicated. Depending on the ship's draft, the distance from sea level to mbrf was approximately 10.74 m for Holes 930A, 930B, and 930C and 10.71 m for Hole 930D. The 3.5-kHz depth recorded indicated a discontinuous reflector at 3159.4 m and a continuous, strong reflector at 3164.5 m.

Hole 930A

A Polycrystalline Diamond Compact (PDC) APC/XCB bit was attached to monel drill collars and run to the seafloor. The monel drill collars are intended to minimize remagnetization caused by the drill collars, allowing magnetic orientation of the APC cores. Core 155-930A-1H was taken with the bit at 3155.5 m (3.9 m above the highest reflector), and 10.05 m of sediment was recovered. It was interpreted that the core was taken below the mud line by about 1.3 m. Hole 930A was terminated, and the bit pulled above the seafloor.

Hole 930B

The ship was not offset, and the bit was positioned at 3145.5 m. The first attempt to core recovered mostly water and only a trace of clay. The bit was repositioned at 3150.5 m, and Hole 930B was spudded at 0130 hr, 2 April. Core 155-930B-1H recovered 5.7 m; therefore, the seafloor was defined to be 3154.3 m. Mud line water samples were obtained for paleontology from the muddy water above the top of the sediment from all mud line cores during this leg. In most of the cores recovered at Site 930, sediment began to extrude from the core liner due to gas expansion, once the liner was taken out of the core barrel. During APC coring, several core liners collapsed or were extremely difficult to extract from the core barrel. In some cases this significantly disturbed the recovered sediment.

ADARA heat measurements were performed during Cores 155-930B-6H and -8H at 53.2 and 72.2 mbsf, respectively. Core orientation using the Tensor tool was performed for Cores 155-930B-4H to -11H. A suspected bad rechargeable battery pack rendered the data useless for Cores 155-930B-4H to -10H. Non-rechargeable batteries were used for Core 155-930B-11H, and the tool produced good results. Using the APC, we cored 100.7 m, recovering 104.56 m (104% recovery).

Core 155-930B-11H was a partial stroke (later confirmed to have approximately 2 m of flow-in at the bottom of the core) and required 35,000 lb overpull to extract the core barrel from the formation. We then decided to switch to the XCB coring method. Prior to the first XCB core, the first WSTP temperature was obtained at 100.7 m.

XCB Cores 155-930B-12X to -24X were taken from 3255.0-3379.6 m (100.7 to 225.3 mbsf), with 124.6 m cored and 97.18 m recovered (78.0% recovery). The first XCB core, Core 155-930B-12X, apparently was washed away due to circulating seawater at 200 gpm (a low pump rate, considering the sticky nature of the formation and its tendency to plug the nozzles in the bit). Subsequent cores were cut using a circulation rate of 100 gpm or less until it took more than 25 min to cut at about 190 m. No hole problems were encountered. Coring was terminated at 225.3 mbsf when the geological objectives were met. Hole 930B officially ended when the bit cleared the seafloor at 0832 hr, 3 April.

Hole 930C

The ship was moved 20 m north, and Hole 930C was spudded at 0925 hr, 3 April. The mud line was assumed to be 3154.3 m, and the hole was drilled ahead, without coring, to 3183.3 m (29.0 mbsf). APC Cores 155-930C-1H to -7H were taken from 3183.3 to 3249.8 m (29.0-95.5 mbsf), with 66.5 m cored and 71.96 m recovered (108.2% recovery). In an effort to reduce APC core disturbance due to flow-in, XCB Cores 155-930C-8X to -12X were taken from 3249.8 to 3298.0 m (95.5-143.7 mbsf), with 48.2 m cored and 38.73 m recovered (80.3% recovery).

Based on interesting paleontological results at the base of Hole 930B, Hole 930C was drilled (without coring) from 3249.8 to 3355.4 m (143.7-201.1 mbsf), and XCB coring resumed at 201.1 mbsf. XCB Cores 155-930C-13X to -18X were taken from 3355.4 to 3413.3 m (201.1-259.0 mbsf), with 57.9 m cored and 24.96 m recovered (43.1% recovery). The XCB recovery for Hole 930C was 66.3%. The combined APC/XCB recovery for Hole 930C was 78.6%. Hole 930C was terminated, and the bit was pulled above the seafloor at 0600 hr, 4 April.

Hole 930D

The ship was moved 186 m north of Hole 930C. The PDR indicated a water depth of 3161.4 m. The bit was positioned at 3150.5 m, and Hole 930D was spudded at 0600 hr, 4 April. The recovery from Core 155-930D-1H was 4.03 m. The water depth is therefore defined as 3156.0 m. APC Cores 155-930D-1H to -6H were taken from 3156.0 to 3207.5 m (0-51.5 mbsf), with 51.5 m cored and 53.27 m recovered (103.4% recovery). Hole 930D was terminated, and the bit was pulled above the seafloor at 1315 hr, 4 April.

## SITE 931
## (Proposed site AF-10)

Seismic Survey

At 2136 hr, 4 April, we began a seismic reflection survey from Site 930, over proposed sites AF-6, -8, -19, -11, and -9 and -10. The survey lasted about 12 hr.

Hole 931A

After the seismic gear was retrieved, the ship returned to GPS coordinates 5°08.529'N, 46°37.981'W, and dropped a beacon at 1203 hr, 5 April. We assembled a bottom-hole assembly similar to that used at Site 930 and ran the bit to the seafloor. The distance from sea level to mbrf was approximately 10.71 m for Hole 931A, 10.74 m for Hole 931B, and 10.87 m for Hole 931C. The 3.5-kHz depth recorded indicated a depth of 3489.4 m.

We positioned the bit at 3480.0 m, and Hole 931A was spudded at 1820 hr, 5 April. Core 155-931A-1H recovered 6.15 m of sediment. The mud line was then defined to be 3483.4 m. Cores 155-931A-1H to -6H were taken from 3483.4 to 3537.0 m (0-53.6 mbsf), with 53.6 m cored and 56.99 m recovered (106%). In most of the cores recovered at Site 931, sediment began to extrude from the core liner due to gas expansion, once the liner was taken out of the core barrel. During APC coring, several core liners collapsed, in some cases significantly disturbing the recovered sediment.

Hole 931B

We moved the ship 20 m to the north and spudded Hole 931B at 2345 hr, 5 April. The bit was positioned at 3478.0 m, and Core 155-931B-1H recovered 0.84 m of sediment. The mud line was defined to be at 3486.7 m. We then took Cores 155-931B-1H to -9H from 3486.7 to 3563.5 m (0-76.8 mbsf), with 76.8 m cored and 82.97 m recovered (108.0%). We used the Tensor tool for core orientation on Cores 155-931B-3H through -9H, and the ADARA temperature shoe while taking Cores 155-931B-6H and -8H.

We then switched to XCB coring. XCB Cores 155-931B-10X to -45X were taken from 3563.5 to 3908.0 m (76.8-421.3 mbsf), with 344.5 m cored and 213.72 m recovered (62.0%). Although there is no reported recovery for Core 155-931B-24X, a few small pieces of rock and a small amount of sediment in the core catcher were taken for paleontological analysis. The combined APC/XCB recovery for Hole 931B was 70.4%. We used the WSTP temperature tool prior to Cores 155-931B-11X, -13X, and -17X. While retrieving the core barrel containing Core 155-931B-43X, the barrel became stuck at 203 m. The drill pipe with the stuck core barrel was pulled above the rig floor, removed from the drill string, and the core was retrieved.

Expansion of the cores due to gas sometimes resulted in core material being ejected from the core liner on the rig floor, resulting in severe core disturbance (especially Core 155-931B-31X) and some loss of core material. Cores 155-931B-17X, -18X, and -20X (142.2-180.7 m) had no recovery, despite drilling the interval with only minimal circulation. The bit was pulled out of the hole, clearing the seafloor at 0230 hr, 10 April.

Hole 931C

We moved the ship approximately 20 m to the north and spudded Hole 931C at 0359 hr, 10 April. The bit was positioned at 3469.1 m, and Core 155-931B-1H recovered 4.1 m of sediment. The mud line was defined to be at 3474.5 m. We then took Cores 155-931C-1H through -4H (0-32.6 mbsf), recovering 57.0 m of sediment (106%). The beacon was recovered, and the bit cleared the drill floor at 1430 hr, 10 April.

## SITE 932
## (Proposed site AF-11)

Seismic Survey

Based on results at Site 931, additional seismic information was needed to adjust proposed site AF-9 that would be drilled after Site 932. We therefore conducted a seismic survey (about 43 nmi) along the crest of the deep, buried levee in the vicinity of proposed site AF-9. We then moved to Site 932.

Hole 932A

After retrieving the seismic gear, we returned to GPS coordinates 5°12.683 'N, 47°01.770'W, and deployed a beacon at 0131 hr, 11 April. We assembled a bottom-hole assembly similar to that used at Sites 930 and 931 and ran the bit to the seafloor. The distance from sea level to mbrf was approximately 10.90 m for Holes 932A and 932B. The 3.5-kHz depth recorded indicated a depth of 3382.4 m.

We positioned the bit at 3341.0 m and spudded Hole 932A at 0742 hr, 11 April. Core 155-932A-1H recovered 6.00 m of sediment. The mud line was defined to be 3344.5 m. Cores 155-932A-1H to -10H were taken from 3344.5 to 3436.0 m (0-91.5 mbsf), recovering 93.21 m of sediment (102% recovery). In most of the cores recovered at Site 932, sediment began to extrude from the core liner due to gas expansion, once the liner was taken out of the core barrel. Core disturbance was minimized by drilling small holes in nearly all of the core liners to allow gas to escape.

We oriented Cores 155-932A-3H through -10H using the Tensor tool and made ADARA heat-flow measurements during Cores 155-932B-7H and -9H. During APC coring, some core liners ruptured, in some cases significantly disturbing the recovered sediment.

XCB Cores 155-932A-11X to -18X were taken from 3436.0 to 3512.8 m (91.5-168.3 mbsf), coring 76.8 m and recovering 61.06 m (80%). The WSTP tool was run prior to Core 155- 932A-14X. The combined APC/XCB recovery was 91.6%. Hole angle was 1.6° at 25.0 m, 2.7° at 34.5 m, 2.5° at 63.0 m, and 3.0° at 82.0 m. We pulled the bit above the seafloor at 0430 hr, 12 April.

Hole 932B

We moved the ship 20 m north and spudded Hole 932B at 0513 hr, 12 April. The bit was positioned at 3342.5 m, and Core 155-932B-1H recovered 5.05 m. The seafloor was defined to be at 3347.0 m. We attempted to offset Core 155-932B-1H from Hole 932A in an effort to recover a possible magnetic event and should have recovered 7.5 m. We took Cores 155-932B-1H to -6H from 3347.0 to 3399.5 m (0-52.5 mbsf) and recovered 54.04 m of sediment (103% recovery). The hole angle was 1.9° at 24.0 m, 3.7° at 33.5 m, 3.1° at 43.0 m, and 3.0° at 52.5 m. We pulled the bit above the seafloor at 1024 hr, 12 April, and it cleared the rig floor at 1645 hr, 12 April. We then recalled and recovered the beacon.

## SITE 933
## (Proposed site AF-9)

Transit

The transit from Site 932 to Site 933 covered approximately 14 nmi in just over 1.5 hr. We proceeded directly to GPS coordinates 5°05.917'N, 46°48.778'W, and deployed a retrievable

beacon at 1905 hr, 12 April. This position was moved from that originally proposed as a result of the seismic reflection data collected prior to drilling Site 932.

Hole 933A

We assembled a bottom-hole assembly similar to that used at the previous sites (Sites 930 to 932) and ran the bit to the seafloor. The distance from sea level to mbrf was approximately 10.90 m for Hole 933A.

We positioned the bit at 3373.0 m and spudded Hole 933A at 0742 hr, 11 April. Core 155-933A-1H recovered 5.70 m of sediment. The mud line was defined to be 3376.8 m. We took Cores 155-933A-1H to -10H from 0 to 91.2 mbsf (3376.8-3468.0 m) and recovered 100.61 m of sediment (110% recovery). In many of the cores recovered at Site 933, sediment began to extrude from the core liner due to gas expansion, once the liner was taken out of the core barrel. Core disturbance was minimized by drilling small holes in nearly all of the core liners to allow gas to escape.

Cores were oriented using the Tensor tool from Core 155-933A-3H through -10H. ADARA heat-flow measurements were taken at Cores 155-933A-6H and -9H. The liner of Core 155-933A-8H was split and was difficult to pull out of the core barrel. Overpull (when retrieving the core barrel from in the sediment) was 20,000 lb at Core 155-933A-6H (53.2 mbsf) and increased to 50,000 lb at Core 155-933A-9H. A slim-nose APC shoe was used on Core 155-933A-10H to determine if this would reduce the overpull; however, it was not reduced, and there was no change in recovery. The core barrel only partially completed its stroke during Core 155-933A-10H. While retrieving Core 155-933A-10H (at about 1051 hr, 13 April), the beacon self-released and ceased working. We deployed a backup beacon at 1055 hr, 13 April.

XCB Cores 155-933A-11X to -27X were taken from 91.2 to 254.2 mbsf (3468.0-3631.0 m), coring 163.0 m and recovering 78.62 m (48.2% recovery). The last core, Core 155-933A-27X, appeared to drill faster than the previous cores. The combined APC/XCB recovery at Site 933 was 69.9%. Hole angle, measured by the tensor tool was 2.8° at 24.7 m, 3.0° at 53.2 m, 3.2° at 72.2 m, and 3.4° at 91.2 m.

In preparation for logging, we pulled the drill pipe to 68.0 mbsf (3444.8 m) and then moved back to the bottom of the hole. Only about only 1 m of sediment had filled the bottom of the hole. We pumped the go-devil (to open the lockable float valve, LFV), and the pipe was pulled to 86.6 mbsf (3463.4 m). We then arranged the drill pipe to make it possible to pick up the drill pipe an additional 30 m to log the upper part of the hole. The Quad-combo, FMS, and GHMT logs were run. The GHMT tool activated (closed) the LFV as it exited the drill pipe. The LFV had to be pumped open to allow the tool to reenter the pipe after logging. We pulled the bit above the seafloor at 0753 hr, 15 April, and it cleared the rig floor at 1315 hr, 15 April. We then recalled and recovered the beacon.

## SITE 934
## (Proposed site AF-15)

Transit

During the transit from Site 933 to Site 934, we performed a short (~9-nmi) seismic survey over Site 935 (proposed site AF-14). We did this so that, after finishing Site 934, we could move in DP mode to Site 935 without retrieving the drill string. Once we arrived near Site 934, we performed a 20-nmi, 3.5-kHz PDR survey over proposed site AF-15 to verify its position. The transit and surveys covered about 70 nmi in about 9.0 hr. We deployed a commandable retrievable beacon at 2321 hr, 15 April.

Hole 934A

We assembled a bottom-hole assembly similar to that used at the previous sites (Site 930 to 932), except we left out the 7" drill collar to improve the bending strength in this shallow hole, and ran the bit to the seafloor. The distance from sea level to mbrf was approximately 10.96 m for Hole 933A. We positioned the bit at 3427.5 m and spudded Hole 934A at 0625 hr, 16 April.
Core 155-934A-1H recovered 4.29 m, and the mud line was defined to be at 3432.7 m. Cores 155-934A-1H to -12H were taken from 0 to 108.8 mbsf (3432.7- 3541.5 m) and recovered 111.65 m of sediment (102.6%). Many of the cores recovered at Site 934 began to extrude sediment from the core liner due to gas expansion, once the liner was taken out of the core barrel. Core disturbance was minimized by drilling small holes in nearly all of the core liners to allow gas

to escape. The core liner of Core 155-934A-7H was split while coring. The top part sof the first sections of Cores 155-934A-5H, -6H, and -8H extruded onto the rig floor. Cores 155-934A-3H to -12H were oriented with the Tensor tool, and ADARA heat-flow measurements were taken during Cores 155-934A-4H and -8H. The deviation of the borehole from vertical (using the Tensor tool) was 3.3° at 23.3 mbsf, 3.3° at 32.8 mbsf, 3.8° at 42.3 mbsf, and 3.8° at 51.8 mbsf. We then pulled the bit above the seafloor.

Hole 934B

We offset the ship 50 m to the south and positioned the bit at 3430.0 m. Hole 934B was spudded at 1845 hr, 16 April. Core 155-934B-1H recovered 7.49 m, and the mud line was defined to be at 3432.0 m. Cores 155-934B-1H to -12H were taken from 0 to 108.8 mbsf (3432.0-3540.8 m) and recovered 106.92 m of sediment (98.3%). Cores 155-934B-3H through -12H were oriented using the Tensor tool. Poorly consolidated, coarse-grained sediment was recovered from parts of the hole. The core liner of Core 155-934B-6H was split while coring. The top parts of the first sections of Cores 155-934B-8H and -9H extruded onto the rig floor. Cores 155-934B-9H to -12H were partial strokes.

In preparation for logging, we circulated a 30 bbl (?) mixture of sepiolite and seawater in the hole. The bit was positioned at 78 mbsf and configured so that it could be picked up 30 mbsf to log the upper part of the hole. The Dual Induction/Gamma Ray tool was able only to pass 5 m below the bit, to 83 mbsf. We picked the pipe up to 68 mbsf, but the tool still could not get past 83 mbsf. We then picked the pipe up to 58 mbsf, and this time the tool could not pass 73 mbsf. This suggested that the hole was filling in rapidly. The logging tool was pulled out, the sand bridge drilled out, and the hole cleaned out again to 108.8 mbsf. Another 30 bbl of sepiolite/seawater mixture was circulated, and the pipe was positioned at 78 mbsf. The DIL/GR was run in and found bottom at 3538 m (3 m fill), and the hole was logged up to the bit at 48 mbsf.

The bit cleared the seafloor at 1750 hr, 17 April, and was pulled up another 100 m to prepare for the DP transit to proposed site AF-14 (Site 935). The beacon was retrieved at 1915 hr, 17 April.

# SITE 935
## (Proposed site AF-14)

Transit

The 9-nmi transit in DP mode from Site 934 to Site 935 took 8.1 hr at 1.1 kt. When the ship arrived at 5°25.612'N, 47°33.893'W, we deployed a beacon at 0345 hr, 18 April. The same BHA was used at Sites 934 and 935.

Hole 935A

We positioned the bit at 3490.5 m and spudded Hole 935A at 0630 hr, 18 April. The distance from sea level to mbrf was approximately 10.96 m for Hole 933A. Core 155-935A-1H recovered 3.52 m of sediment, and the mud line was defined to be at 3496.5 m. Cores 155-935A-1H to -12H were taken from 0 to 104.6 mbsf (3496.5-3601.1 m), recovering 111.33 m (106.4%). Many of the cores recovered at Site 934 began to extrude sediment from the core liner due to gas expansion, once the liner was taken out of the core barrel. Core disturbance was minimized by drilling small holes in nearly all of the core liners to allow gas to escape. Parts of Cores 155-935A-10H, -31X, -33X, and -36X extruded from the liner onto the rig floor. Core 155-935A-1H was difficult to remove from the barrel and may have been slightly disturbed. The core barrel only partially stroked while taking Core 155-935A-12H. Cores 155-935A-3H to -12H were oriented using the Tensor tool. ADARA heat-flow measurements were attempted during Cores 155-935A-4H, -6H, and -9H.

XCB Cores 155-935A-13X to -40X were taken from 104.6 to 372.6 mbsf (3601.1-3869.1 m), coring 268.0 m and recovering 157.24 m (58.7%). The combined APC/XCB recovery was 72.1%. A WSTP temperature measurement was take prior to Core 155-935A-16X.

The hole was circulated clean with a sepiolite/seawater mixture. We pulled the pipe up to 61.5 mbsf (3558.0 m), and while lowering it back down the hole was blocked at 188.5 mbsf (3683.0 m). We reamed out the bridge (about 2 m thick), but the bit encountered fill at 3841.0 m. The 28 m of soft fill was reamed out, and the go-devil was pumped to open the LFV. We then pulled the pipe up to 80.2 mbsf (3576.7 m) and set-up to pick up 20 m to log the upper hole. The hole was logged in two sections. During the first Quad-combo run, the tool tagged a bridge at

184.5 mbsf (3681.0 m), and we decided to log the hole above and below the bridge. The Quad-combo run above the bridge required 4.3 hr. The FMS tool tagged the bridge at 171.5 mbsf (3668.0 m) and required 3.6 hr to log.

We washed and reamed with the bit down to 3690.0 m and then lowered the bit to 212.0 mbsf (3708.5 m). The CSES was not used because the bridge had to be drilled out, which requires bit rotation. We decided that the logging tools would be at risk if not protected by pipe when going through this unstable "hard bridge." The second run of the Quad-combo tagged bottom at 298.5 mbsf (3795.0 m; 74.1 m above the total depth of the hole) and required 5.75 hr. The second FMS run tagged bottom at 270.5 mbsf (3767 m; 102.1 m above TD) and required 3.8 hr.

The bit cleared the seafloor at 0245 hr and cleared the rig floor at 0845 hr, 22 April.

## SITE 936
## (Relocated proposed site AF-1)

Transit

The transit from Site 935 to Site 936 covered 12 nmi in about 1.1 hr. We conducted a 16-nmi seismic survey over Site 936 in 2.8 hr at about 5.8 kt. We returned to 5°39.941'N, 47°44.131'W, and deployed a beacon at 1401 hr, 22 April. A BHA, similar to that used at Site 935, was assembled and run to the seafloor.

Hole 936A

We positioned the bit at 3583.0 m and spudded Hole 936A at 2050 hr, 22 April. The distance from sea level to mbrf was approximately 11.05 m for Hole 936A. Core 155-936A-1H recovered 6.54 m, and the mud line was defined to be at 3586.0 m. Cores 155-936A-1H to -10H were taken from 3586.0 to 3678.0 m (0-92.0 mbsf), recovering 88.52 m (96.2%). Cores 155-936A-3H to -10H were oriented using the Tensor tool. ADARA heat-flow measurements were taken during Cores 155-936A-6H and -8H. The core barrel only partially stroked while taking Cores 155-936A-9H and -10H (Core 155-936A-10H was in sand with 90,000 lb overpull).

XCB Cores 155-936A-11X to -46X were taken from 3678.0 to 4019.8 m (92.0-433.8 mbsf), coring 341.8 m and recovering 185.51 m (54.3% recovery). A WSTP temperature measurement was taken at 3711.5 m (135.2 mbsf).

The formation from 308 to 376 m was unstable, and the hole fill increased to 12 m with very heavy flow-back while adding new stands of drill pipe. Numerous mud sweeps were required to keep the hole moderately clean, although hole conditions remained good. The combined APC/XCB recovery was 63.1%. The hole angle was 1.75° at 70.0 mbsf and 1.4° at 89.0 mbsf. Core disturbance due to gas expansion was minimized by drilling small holes in nearly all of the core liners. Parts of Cores 155-936A-6H, -7H, -8H, -16X, -24X, -27X, -43X, -45X, and -46X were disturbed due to gas-induced extrusion of core out of the liner or collapsed liners.

The hole was circulated clean with two sweeps of sepiolite mud (20 and 30 bbl), and we pulled the pipe up to 65 mbsf with 10,000 lb overpull. While running the pipe back to the bottom of the hole (TD), a 7-m bridge had to be reamed out 382 mbsf (52 m above the bottom of the hole) and encountered 25 m of soft fill. We circulated 35 bbl of sepiolite mud, pumped the go-devil to open the LFV (to enable logging), and pulled back the pipe to 3669.5 m (83.5 mbsf) for logging. At the end of each logging run, we pulled the bit up to 65 mbsf to log the upper part of the hole. However, each time we did this the soft sediment formed a bridge at the end of the pipe that prevented passage of the logging tools. Logs were run as follows: (1) the Quad-combo tool was run to 3915 m (329 mbsf) in 4.6 hr, (2) the FMS tool was run to 3894 m (308 mbsf) in 4.3 hr, and (3) the Geochemical log was run to 3680 m (94 mbsf) in 7.4 hr. We pulled the bit above the seafloor at 1925 hr, 26 April. The bit cleared the rig floor at 0135 hr, 27 April, and the beacon was recovered.

## SITE 937
## (Proposed site AF-17)

The 59-nmi transit from Site 936 to Site 937 took 6.1 hr. We conducted a single-channel seismic reflection survey over Site 938 (proposed site AF-16) and then pulled in the seismic gear and conducted a 3.5-kHz PDR survey over Site 937. The ship returned to 4°35.75'N, 47°12.45'W, and deployed a beacon at 1115 hr, 27 April. A BHA, similar to that used at Site 936, was assembled and run to the seafloor.

Hole 937A

We positioned the bit at 2762.0 m and spudded Hole 937A at 1620 hr, 27 April. Core 155-937A-1H recovered 0.21 m, and the mud line was defined to be at 2771.3 m. The distance from sea level to mbrf was approximately 11.14 m for Holes 937A and 937B, and 11.17 for Holes 937C and 937D. A good mud line was obtained, but a more complete mud line core was desired, so this short core was archived as Hole 937A.

Hole 937B

We positioned the bit at 2769.0 m, without moving the ship, and spudded Hole 937B at 1700 hr, 17 April. Core 155-937B-1H recovered 7.53 m (which was later corrected to 7.57 m, accounting for expansion), and the mud line was defined to be at 2771.0 m. Cores 155-937B-1H to -9H were taken from 2771.0 to 2854.5 m (0-83.5 mbsf) and recovered 87.51 m (104.8%). Cores 155-937B-3H through -9H were oriented using the Tensor tool. ADARA heat-flow measurements were taken during Cores 155-937B-6H and -9H.

XCB Cores 155-937B-10X to -19X were taken from 2854.5 to 2951.3 m (83.5-180.3 mbsf), coring 96.8 m and recovering 71.69 m (74.1%). Parts of Cores 155-937B-1H, -4H, -6H, -7H, and -11X were disturbed due to gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. The pipe was pulled above the seafloor at 1135 hr, 28 April.

Hole 937C

We moved the ship 20 m north, positioned the bit at 2767.0 m, and spudded Hole 937C at 220 hr, 28 April. Core 155-937C-1H recovered 9.05 m, and the mud line was defined to be at 2767.5 m. Cores 155-937C-1H to -8H were taken from 2767.5 to 2843.0 m (0-75.5 mbsf) and recovered 80.52 m (106.6%). Cores 155-937C-3H through -8H were oriented, and no heat-flow measurements were taken.

Increasing gas voids in Hole 937B led us to try using the Pressure Core Sampler (PCS). Although the clay was not yet stiff enough to recover with the XCB, a decision was made to run the PCS to

obtain a pressurized sample at in-situ pressures. Core 155-937C-9P was taken at 2843.0-2844.0 m (75.5-76.5 mbsf), but no sediment was recovered. The 1.0-m-long core was cut in 2 min with 8,000 lb WOB (weight-on-bit) at 80 rpm with 125-250 amps torque circulating a minimal 50 gpm at 125 psi. Torque was variable, suggesting that the bit was cutting. The ball valve was operated (closed) twice. Some pressure was trapped (~3700 psi; below hydrostatic for this depth), the ball valve had closed, and no core was recovered. There was no indication that core had ever entered into the bit throat or diaphragm catcher. When the ball-valve assembly was removed, muddy water was released.

The bit was pulled above the seafloor at 1915 hr, 28 April.

Hole 937D

We moved the ship 20 m north, positioned the bit at 2766.0 m, and spudded Hole 937D at 1940 hr, 28 April. Core 155-937D-1H recovered 7.20 m, and the mud line was defined to be at 2768.3 m. Cores 155-937D-1H and -2H were taken from 2768.3 to 275.5 m (0-16.7 mbsf) and recovered 17.26 m (103.4%). No core-orientation or heat-flow measurements were taken. The pipe was pulled above the seafloor at 2045 hr, 28 April, and we recovered the beacon. We then pulled the pipe up to 2674.1 m in preparation for the DP transit to Site 938.

## SITE 938
## (Proposed site AF-16)

We transited the 7 nmi from Site 937 to Site 938 in DP mode. At 0330 hr, 29 April, we deployed a beacon at 4°39.503'N, 47°18.731'W, a position determined during the seismic reflection survey conducted prior to drilling Site 937.

Hole 938A

We used the same BHA as at Site 937, since we transited in DP mode and did not retrieve the drill string. We positioned the bit at 2813.5 m and spudded Hole 938A at 0535 hr, 29 April. The distance from sea level to mbrf was approximately 11.26 m for Holes 938A and 938B. Core 155-938A-1H recovered 7.60 m of sediment, and the mud line was defined to be at 2815.4 m.

Cores 155-938A-1H to -9H were taken from 2815.4 to 2899.0 m (0-83.6 mbsf), recovering 90.73 m of sediment (108.5%). Overpull was 40,000 lb on Core 155-938A-9H. Cores 155-938A-3H through -9H were oriented using the Tensor tool. ADARA heat-flow measurements were made during Cores 155-938A-6H and -9H.

XCB Cores 155-938A-10X to -33X were taken from 2899.0 to 3125.6 m (83.6-309.2 mbsf), coring 225.6 m and recovering 150.87 m (66.9%). The overall APC/XCB recovery was 77.8%. Parts of Cores 155-938A-4H, -5H, -6H, -7H, -9H, -23X, and -25X were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapse of core liners.

The Pressure Core Sampler (PCS) was run in an effort to obtain a sample at in-situ pressure. Core 155-938A-34P was taken at 3124.4-3125.4 m (309.0-310.0 mbsf) with no recovery. The 1.0-m core was cut in 6 min with 10.000 lb WOB at 80 rpm with 125-250 amps torque. We circulated a minimal 50 gpm at 125 psi for the first 0.5 m and then drilled the final 0.5 m with only minimal circulation (to wash cuttings away, allowing the bit to advance). The ball valve had not actuated; therefore in-situ pressure was not maintained. No core was recovered. Only a trace of mud was noted above the catcher diaphragm.

Hole 938B

We moved the ship 20 m to the west, positioned the bit at 2811.0 m, and spudded Hole 938B at 1920 hr, 30 April. Core 155-938B-1H recovered 5.28 m, and the mud line was defined to be at 2815.3 m. Cores 155-938B-1H to -9H were taken from 2815.3 to 2896.6 m (0-81.3 mbsf) and recovered 79.53 m (97.8%). No heat-flow measurements were made, and the cores were not oriented. The core barrel did not appear to make a full stroke while taking Cores 155-938B-7H, -8H, and -9H. Parts of Cores 155-938B-4H, -6H, and -8H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapse of the core liners. The bit cleared the seafloor at 0120 hr, cleared the rig floor at 0650 hr, 1 May, and the beacon was recovered.

A drill-string magnetic overprint had been inferred in the XCB cores (similar results had been observed during Leg 154; Shackelton, Curry, et al., in press). The magnetic-field strength of the

PDC bit, float valve, both XCB shoes, spacer subs, and core catchers was measured. A small 2-10 Oersted (Oe) reading was obtained everywhere except against the facing on the XCB shoe teeth, which measured 50 Oe. The XCB shoes were demagnetized to see if any change was noted.

## SITE 939
## (Proposed site AF-12)

Transit

We transited 10 nmi from Site 938 to Site 939 in 0.9 hr and conducted a seismic reflection survey over the site. At 0921 hr, 1 May, we deployed a beacon at 4°43.307'N, 47°30.110'W.

Hole 939A

We offset the ship about 250 m east of the beacon and assembled a BHA similar to that used at Site 938. We positioned the bit at 2793.0 m and spudded Hole 939A at 1450 hr, 1 May. The distance from sea level to mbrf was 11.23 m for Holes 939A and 939B, and 11.26 m for Hole 939C. Core 155-939A-1H recovered 7.68 m of sediment, and the mud line was defined to be at 2794.8 m. Cores 155-939A-1H to -9H were taken from 2794.8 to 2878.5 m (0-83.7 mbsf), recovering 86.70 m (103%). Cores 155-939A-4H through -9H were oriented using the Tensor tool. No heat-flow measurements were made. Overpull was 40,000 lb while retrieving Core 155-939A-9H from the formation.

XCB Cores 155-939A-10X to -11X were taken from 2878.5 to 2897.5 m (83.7-102.7 mbsf), coring 19.0 m and recovering 10.87 m of sediment (57%). The overall APC/XCB recovery was 95%. Parts of Cores 155-939A-2H, -3H, -6H, and -7H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners.

Hole 939B

We offset the ship about 500 m east of Hole 939A, positioned the bit at 2798.0 m, and spudded Hole 939B at 0137 hr, 2 May. Core 155-939B-1H recovered 4.00 m, and the mud line was defined to be at 2803.5 m. Cores 155-939B-1H to -9H were taken from 2803.5 to 2883.5 m (0-

80.0 mbsf) and recovered 83.84 m (105%). Cores 155-939B-3H to -9H were oriented using the Tensor tool. ADARA heat-flow measurements were taken during Cores 155-939B-6H and -9H. The core barrel only partially stroked while taking Core 155-939B-9H and equired an overpull of 70,000 lb to retrieve from the formation.

XCB Cores 155-939B-10X to -11X were taken from 2883.5 to 2902.9 m (80.0-99.4 mbsf), coring 19.4 m and recovering 15.67 m (80.8% recovery). The overall APC/XCB recovery was 100.1%. Parts of Cores 155-939B-3H, -8H, and -9H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners.

Hole 939C

We offset the ship about 20 m west of Hole 939B, positioned the bit at 2800.5 m, and spudded Hole 939C at 1250 hr, 2 May. Core 155-939C-1H recovered 7.60 m, and the mud line was defined to be at 2802.4 m. Cores 155-939C-1H to -4H were taken from 2802.4 to 2838.5 m (0-36.1 mbsf) and recovered 36.98 m (102.4%). No cores were oriented, and no heat-flow measurements were made. Part of Core 155-939C-3H was disturbed as a result of a collapsed core liner. The bit cleared the rig floor at 2100 hr, 2 May, and we retrieved the beacon.

## SITE 940
## (Proposed site AF-6)

Transit

The 24-nmi transit from Site 939 to Site 940 took 2.7 hr. A seismic survey had been conducted earlier in the leg. At 0114 hr, 3 May, we deployed a beacon at 5°86'N, 47°31.73'W.

Hole 940A

We assembled a BHA similar to that used at the Site 939 except we used an 11-7/16", 4-cone roller bit (Security H86F) with upward discharge jets. This bit was used in an attempt to reduce XCB core disturbance (biscuiting). We positioned the bit at 3196.0 m and spudded Hole 940A at 0913 hr, 3 May. The distance from sea level to mbrf was 11.26 m for Hole 940A. Core 155-940A-1H

recovered 2.85 m, and the mud line was defined to be at 3202.7 m. Cores 155-940A-1H to -8H were taken from 3202.7 to 3272.0 m (0-69.3 mbsf) and recovered 69.95 m (100.9%). We oriented Cores 155-940A-3H to -8H with the Tensor tool. An ADARA heat-flow measurement was taken during Core 155-940A-6H.

XCB Cores 155-940A-9X to -27X were taken from 3272.0 to 3451.3 m (69.3-248.6 mbsf), coring 179.3 m and recovering 138.61 m (77.3%). A WSTP temperature measurement was attempted prior to Core 155-940A-14X at 113.6 mbsf. The overall APC/XCB recovery was 83.9%. Parts of Cores 155-940A-5H, -7H, -8H, -14X, and -23X were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners.

The 4-cone roller bit with upward discharge jets appeared to reduce core biscuiting. The size of biscuits appeared to be larger, and recovery appeared to be better. However, the rate of penetration was slower, and the hole diameter was considerable larger (about 15 in. or 38 cm), reducing the quality of some of the logs, particularly the FMS. We decided to use the PDC (polycrystalline diamond compact) bit for the rest of the leg.

In preparation for logging, we circulated 20 bbl and then 30 bbl of sepiolite mud, and pulled the pipe up to 63 mbsf with negligible overpull. We then lowered the pipe down to the bottom of the hole; no sediment fill was encountered. The go-devil was pumped through the LVF to allow logging tools to pass through the bit, and the pipe was pulled back up to 90.5 mbsf to log. At the end of each logging run, the bit was pulled up to 63 mbsf to log the upper part of the hole. The Quad-combo tool run took 4.1 hr, and then the FMS run took 3.4 hr. The hole diameter ranged from 14 to 15.75 in.The bit cleared the seafloor at 1420 hr, cleared the rotary table at 2000 hr, 5 May, and the beacon was recovered.

## SITE 941
## (Proposed site AF-5)

Transit

The 29.4-nmi transit from Site 940 to Site 941 took 2.7 hr. We conducted a 16.7-nmi seismic survey to confirm the proposed position based on pre-cruise data. At 0220 hr, 6 May, we deployed

a beacon at 5°22.51'N, 48°1.60'W. Surface currents were estimated to range from 0.5 to 1.65 kt from the northeast, but the beacon was carried 600 m to the southeast by deeper currents before landing on the seafloor.

Hole 941A

We positioned the ship 300 m to the northwest of the beacon, positioned the bit at 3388.0 m, and spudded Hole 941A at 0942 hr, 6 May. We assembled a BHA similar to that used at Site 939. The distance from sea level to mbrf, which depends on the ship's draft, was 11.35 m for Holes 941A and 941B. Core 155-941A-1H recovered 5.30 m, and the mud line was defined to be at 3392.2 m. Cores 155-941A-1H to -7H were taken from 3392.2 to 3454.5 m (0-62.3 mbsf) and recovered 62.12 m (99.7%). Cores 155-941A-3H through -7H were oriented using the Tensor tool, and an ADARA heat-flow measurement was made during Core 155-941A-6H. Parts of Cores 155-941A-3H, -5H, -6H, -7H, and -16X were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. Three core liners split (Cores 155-941A-3H, -5H, and -7H), and two of them had to be pumped out of the core barrel. While pulling the core barrel out of the sediment during Cores 155-941A-5H, -6H, and -7H, the overpull was 20,000 to 35,000 lb.

XCB Cores 155-941A-8X to -19X were taken from 3454.5 to 3570.1 m (62.3-177.9 mbsf), coring 115.6 m and recovering 60.63 m (52.4%). The overall APC/XCB recovery was 69.0%.

In preparation for logging, we circulated 20 bbl and then 30 bbl of sepiolite mud, and pulled the pipe up to 63 mbsf with negligible overpull. While lowering the pipe to the bottom of the hole, there was 30,000 lb of drag to 85 mbsf. We therefore decided to place the bottom of the pipe at about 90 mbsf for logging. We encountered 15 m of hard fill in the bottom of the hole, dropped the go-devil to open the LVF, and circulated 30 bbl of sepiolite mud to clean the fill out of the hole. The pipe was then pulled back up to 3482.0 m (89.8 mbsf) for logging below the unstable section. The Quad-combo tool was run in the hole but could not pass 3492.0 m (99.8 mbsf), or about 10.0 m below the bit, so we retrieved the logging tool. We then reamed out the hole from 3482.0 to 3521.3 m (89.8-129.1 mbsf) through the unstable debris-flow section, using up to 15,000 lb WOB, but the hole had collapsed and required drilling to clean out; the logging attempt was canceled. The bit cleared the seafloor at 2350 hr, 7 May.

Hole 941B

We moved the ship 300 m south of the beacon or about 490 m in a direction 154° from Hole 941A, positioned at bit at 3386.0 m, and Hole 941B was spudded at 0133 hr, 8 May. Core 155-941B-1H recovered 6.60 m, and the mud line was defined to be at 3388.9 m. Cores 155-941B-H to -12H were taken from 3388.9 to 3474.0 m (0-85.1 mbsf) and recovered 96.09 m (112.9%). While taking Cores 155-941B-6H to -12H, we used the advance-by-recovery method. Parts of Cores 155-941B-2H, -3H, -4H, -5H, -6H, -8H, -10H, -11H, and -12H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. Seven of the core liners had to be pumped out of the core barrel. Cores 155-941B-3H through -12H were oriented using the Tensor tool.

The primary objective of coring at Site 941 was to obtain undisturbed samples from the surficial debris flow. XCB cores from debris flows at other Leg 155 sites had been disrupted by the XCB coring process. The unusually stiff, dry clay in the debris flow had forced the change to XCB coring sooner than expected in Hole 941A, and XCB recovery was poor initially. We then decided to force the APC system deeper in Hole 941B. We coated the interior and exterior of the butyrate core liners (starting with Core 155-941B-3H) with a mixture of 1 qt of Minex drilling lubricant (polymer) and 5 gal of fresh water. We did this to try to facilitate entry of the core into the liner and help remove the liner from the core barrel when the stiff clay expanded. The lubricant could be felt on the liner after the core was retrieved, indicating that some of the polymer remained on the core liner after the wireline trip to bottom. However, 7 of 12 cores had to be pumped out, and this test was not considered successful. The bit cleared the seafloor at 1615 hr and cleared the rig floor at 2155 hr, 8 May.

## SITE 942
## (Proposed site AF-20)

Transit

The 68 nmi transit from Site 941 to Site 942 took 6.1 hr. We conducted a short 3.5-kHz PDR survey to locate the site. At 0725 hr, 9 May, we deployed a beacon at 5°44.552'N, 49°5.470'W.

Hole 942A

We positioned the bit at 3352.0 m and spudded Hole 942A at 1500 hr, 9 May. Core 155-942A-1H recovered 3.78 m, and the mud line was defined to be at 3357.7 m. The distance from sea level to mbrf, which depends on the ship's draft, was 11.38 m for Holes 942A, 942B, and 942C. Cores 155-942A-1H to -12H were taken from 3357.7 to 3461.7 m (0-104.0 mbsf) and recovered 104.96 m (100.9%). Cores 155-942A-3H through -12H were oriented with the Tensor tool, and ADARA heat-flow measurements were made during Cores 155-942A-6H and -9H. Parts of Cores 155-942A-5H, -9H, -11H, and -12H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. While retrieving the core barrel from the sediment during Cores 155-942A-9H, -10H, -11H, and -12H, the overpull was 20,000 to 40,000 lb; the core barrel only partially stroked on the last two.

XCB Cores 155-942A-13X to -20X were taken from 3461.7 to 3535.3 m (104.0-177.6 mbsf), coring 73.6 m and recovering 47.69 m (64.8%). The overall APC/XCB recovery was 86.0%.

We tested the XCB flow control valve (FCV) at this site. Four cores were obtained with the FCV and four without it. The four runs with flow control cored 34.9 m and recovered 25.56 m (73%), and the four runs without flow control cored 38.7 m and recovered 22.13 m (57%). Operating parameters were 10,000 lb WOB at 80 rpm with 100 amp torque, circulating 25 gpm at 125-150 psi. When we retrieved the bit after coring two additional holes (Holes 942B and 942C), we observed that all four PDC bit nozzles were plugged and half of the XCB shoe nozzles were plugged. It is possible that these were plugged during the test while coring Hole 942A and that the test results are anomalous. We assume that the low circulating rate would have prevented any effective valve operation.

Hole 942B

We offset the ship about 10 m to the east, positioned the bit at 3355.0 m, and spudded Hole 942B at 1325 hr, 10 May. Core 155-942B-1H recovered 7.45 m, and the mud line was defined to be at 3357.1 m. Cores 155-942B-1H to -8H were taken from 3357.1 to 3431.0 m (0-74.0 mbsf) and recovered 56.91 m (76.9% recovery). Only Cores 155-942B-7H and -8H were oriented with the

Tensor tool. Cores 155-942B-5H and -6H recovered no core, although this interval was recovered in both Holes 942A and 942C, suggesting a possible mechanical problem.

Hole 942C

We offset the ship about 20 m to the west, positioned the bit at 3355.0 m, and spudded Hole 942C at 2000 hr, 10 May. Hole 942C was designed to get additional mud line cores, recover sediment from an interval that was incompletely recovered in Holes 942A and 942B, and obtain additional material from a deep hemipelagic interval. Core 155-942C-1H was 4.30 m, and the mud line was defined to be at 3360.2 m. Based on lithologic and magnetic correlation, it is apparent that the following "reported" depths for Cores 155-942C-2H through -5H and for the seafloor depth below sea level are approximately 4 m too shallow. We infer that this may have been caused by cored sediment falling out of the mud-line core (Core 155-942C-1H) while being retrieved or an undetected partial stroke of the core barrel. Cores 155-942C-1H to -2H were taken from 3360.2 to 3374.0 m (0-13.8 mbsf). The hole was drilled (without coring) from 3374.0 to 3396.2 m (13.8-36.0 mbsf). Cores 155-942C-3H and -4H were taken from 3396.2 to 3415.2 m (36.0-55.0 mbsf). The hole was drilled from 3415.2 to 3422.2 m (55.0-62.0 mbsf), and Core 155-942C-5H was taken from 3422.2 to 3431.7 m (62.0-71.5 mbsf). In all, we drilled 29.2 m, cored 42.3 m, and recovered 44.03 m (104.1%). Cores 155-942C-3H through -5H were oriented using the Tensor tool. The bit cleared the rig floor at 0730 hr, 11 May.

## SITE 943
## (Proposed site AF-23)

Transit

The 76-nmi transit from Site 942 to Site 943 took 7.6 hr. We conducted a short seismic reflection survey to confirm the original survey position. At 1756 hr, 11 May, we deployed a beacon at 5°56.816'N, 47°46.827'W.

Hole 943A

We decided to use the XCB flow control valve, since the test results at Hole 942A indicated that the device would not reduce recovery. We suspected that the sticky clay might plug the bit

nozzles. A lockable flapper valve was run, because we planned to move to Site 944 in DP mode, where logging was planned.

We positioned the bit at 3744.5 m and spudded Hole 943A at 0108 hr, 12 May. Core 155-943A-1H recovered 4.27 m, and the mud line was defined to be at 3749.7 m. The distance from sea level to mbrf, which depends on the ship's draft, was 11.26 m for Hole 943A. Cores 155-943A-1H through -5H were taken from 3749.7 to 3789.9 m (0-40.2 mbsf) and recovered 29.94 m (75%). Cores 155-943A-3H through -5H were oriented with the Tensor tool. Part of Core 155-943A-2H was lost due to a crushed core liner. Cores 155-943A-3H through -5H were partial strokes with 20,000 to 30,000 lb overpull, and the APC was apparently unable to penetrate the sand.

XCB Cores 155-943A-6X through -12X were taken from 3789.9 to 3856.0 m (40.2-106.3 mbsf), coring 66.1 m and recovering 36.52 m (55%). The overall APC/XCB recovery was 63%. The flow control valve was run in defeated mode on alternate cores. It was not clear whether the flow control valve had any effect on core recovery. Coring parameters were 10,000 lb WOB at 80 rpm with 125-300 amps torque, while pumping little seawater ("dry coring" with 0-35 gpm) at 0-150 psi. The formation was predominantly unconsolidated sands. The bit cleared the seafloor, and we recovered the beacon at 1945 hr, 12 May.

## SITE 944
## (Proposed site AF-20)

Transit

We moved the 1.5 nmi from Site 943 to Site 944 in DP mode in about just over 2 hr. At 2200 hr, 12 May, we deployed a beacon at 5°56.354'N, 47°45.473'W.

Hole 944A

We positioned the bit at 3702.0 m and attempted to spud Hole 944A at 2330 hr, 12 May, but the core was empty. We lowered the bit 5 m to 3707.0 m and spudded Hole 944A at 0023 hr, 13 May. The distance from sea level to mbrf, which depends on the ship's draft, was 11.32 m for Hole 944A and 11.41 for Holes 944B, 944C, and 944D. Core 155-944A-1H recovered 3.87 m,

and the mud line was defined to be at 3712.6 m. Cores 155-944A-1H to -11H were taken from 3712.6 to 3809.7 m (0-97.1 mbsf) and recovered 86.92 m (89.5%).

While taking Cores 155-944A-10H and -11H the core barrel only partially stroked, and an overpull of 40,000 to 50,000 lb was observed when extracting Cores 155-944A-9H, -10H, and -11H from the sediment. Cores 155-944A-3H through -11H were oriented using the Tensor tool. ADARA heat-flow measurements were taken during Cores 155-944A-6H and -9H. Parts of Cores 155-944A-10H, -30X, -31X, and -32X were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. One liner had to be pumped out of the core barrel.

XCB Cores 155-944A-12X to -41X were taken from 3809.7 to 4096.8 m (97.1-384.2 mbsf), coring 287.1 m and recovering 121.17 m (42.2%). The overall APC/XCB recovery was 54.4%.

The flow control valve (FCV) was run in defeated (inactive) mode on alternate cores through Core 155-944A-30X. The FVC was run in the defeated mode from Cores 155-944A-31X through -41X. The pump rate and pressure were increased while taking Cores 155-944A-23X through -29X to increase the rate of penetration through the debris flow. Cores 155-944A-34X to -38X were taken in soft material, which took less than 10 min to cut each core (sand) with 8-finger core catchers instead of the 8-finger/4-petal combination that had been used throughout most of the leg. Cores 155-944A-39X and -40X were severely disturbed, because the 4-petal's were installed backwards. They would not fully retract; therefore, the core was trimmed and deformed by them.

In preparation for logging, we circulated a 20-and then a 30-bbl sepiolite and seawater mixture. While pulling the pipe up to 73.4 mbsf, we experienced negligible overpull. We encountered 15 m of soft fill on the trip back to the bottom of the hole. The go-devil was dropped to open the lockable flapper valve, the bottom 310 m of hole was filled with sepiolite mud (8.8 parts per gal), and the pipe was pulled back up to 92.0 mbsf for logging. At the end of each logging run, we pulled the bit up to 74 mbsf to obtain logs of the upper parts of the hole. We first ran the Quad-combo in to 3437.0 m (384.2 mbsf), and no fill was encountered. This logging run lasted about 5 hr. We then ran the FMS tool in to 3437.0 m (384.2 mbsf), and once again we encountered no fill. This run lasted about 4.75 hr. The hole diameter ranged from 11 to 13 in. (28-33 cm) diameter

down to 305 mbsf, where it increased to 15 in. (38 cm). The bit cleared the seafloor at 0824 hr, 16 May.

Hole 944B

We moved 300 m to the west-southwest (bearing 240°) of Hole 944A in DP mode. We positioned the bit at 3699.0 m and spudded Hole 944B at 1010 hr, 16 May. Core 155-944B-1H recovered 0.32 m, and the mud line was defined to be at 3708.2 m. Although we only recovered a short core, it appears to have been a good mud line core. In addition, the core liner was cracked while taking Core 155-944B-1H. Cores 155-944B-1H to -6H were taken from 3708.2 to 3756.0 m (0-47.8 mbsf), coring 47.8 m and recovering 46.81 m (97.9%). Parts of Cores 155-944B-5H and -6H were disturbed as a result of split core liners. Cores 155-944B-3H through -6H were oriented with the Tensor tool. No heat-flow measurements were taken. The bit cleared the seafloor at 1545 hr, 16 May.

Hole 944C

We moved the ship 600 m east-northeast (060°) in DP mode. We positioned the bit at 3720.0 m and attempted to spud-in. A small amount of gray clay (probably from just below the mud line) was in the core catcher, and apparently whatever mud line core had been in the liner had fallen out. We then positioned the bit at 3722.0 m and spudded Hole 944C at 1835 hr, 16 May. Core 155-944C-1H recovered 9.60 m, and the mud line was defined to be at 3721.9 m. However, it appeared that the mud line was not recovered, and we suspected that Core 155-944C-1H was taken about 2.0 m below the mud line (about 2.0-11.6 mbsf). We decided to terminate Hole 944C, and the bit cleared the seafloor at 1900 hr, 16 May.

Hole 944D

We did not move the ship, positioned the bit at 3717.0 m, and spudded Hole 944D at 1915 hr, 16 May. Core 155-944D-1H recovered 6.60 m, and the mud line was defined to be at 3719.9 m. APC Cores 155-944D-1H to -5H were taken from 3717.0 to 3764.5 m (0-44.6 mbsf) and recovered 43.37 m (97.2%). Parts of Cores 155-944D-4H and -5H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners. The

bit cleared the seafloor at 2305 hr and cleared the rig floor at 0823 hr, 17 May. In preparation for the end of the leg, we inspected the bottom-hole assembly on the trip out.

## SITE 945
## (Proposed site AF-25)

Transit

The 60-nmi transit from Site 944 to Site 945 took about 5.6 hr. We conducted a short (~8-nmi) seismic reflection line to confirm the original proposed position. At 1605 hr, 17 May, we deployed a beacon at 6°57.012'N, 47°55.724'W.

Hole 945A

We positioned the bit at 4147.0 m and spudded Hole 945A at 2325 hr, 17 May. Core 155-945A-1H recovered 9.03 m, and the mud line was defined to be at 4147.5 m. The distance from sea level to mbrf, which depends on the ship's draft, was 11.35 m for Hole 945A. Cores 155-945A-1H to -8H were taken from 4147.5 to 4223.0 m (0-75.5 mbsf) and recovered 74.75 m (99.0%). One liner collapsed, and the core barrel only partially stroked while taking Cores 155-945A-6H, -7H, and -8H. Cores 155-945A-3H through -8H were oriented using the Tensor tool. No heat-flow measurements were taken. The bit cleared the seafloor at 0823 hr, 18 May, and the beacon was recovered at 0927 hr.

## SITE 946
## (Proposed site AF-24)

Transit

The ~1.0-nmi transit from Site 945 to Site 946 was made in DP mode and took about 1.1 hr. At 1034 hr, 18 May, we deployed a beacon at 6°56.978'N, 47°55.156'W. The precise position was selected from a seismic-reflection survey conducted prior to Site 945.

Hole 946A

We positioned the bit at 4107.0 m and attempted to spud Hole 946A. It appeared that about 4 m of sediment had fallen out of the liner. We repositioned the bit at 4109.0 m and spudded Hole 946A at 1300 hr, 18 May. Core 155-946A-1H recovered 7.05 m, and the mud line was defined to be at 4111.5 m. The distance from sea level to mbrf, which depends on the ship's draft, was 11.35 m for Hole 946A. Cores 155-946A-1H to -15H were taken from 4111.5 to 4251.5 m (0-140.0 mbsf) and recovered 127.51 m (91.1%). Three core liners failed, including an imploded bottom, a split bottom, and a burst top. Cores 155-946A-3H through -15H were oriented using the Tensor tool. ADARA heat-flow measurements were taken during Cores 155-946A-5H (bad data) and -7H. Core 155-946A-7H misfired when the shear pins failed to shear with 3000 psi. The formation was predominantly loose sand. Parts of Cores 155-946A-2H, -14H, and -15H were disturbed as a result of either gas-induced extrusion of core out of the liner onto the rig floor or collapsed core liners.

XCB Cores 155-946A-16X to -29X were taken from 4251.5 to 4386.5 m (140.0-275.0 mbsf), coring 135.0 m and recovering 44.11 m (32.7%). The overall APC/XCB recovery was 62.4%. Recovery was poor in what we infer to be loose sands.

In preparation for logging, we circulated a 20-bbl and then a 30-bbl sepiolite/seawater mud sweep, and the pipe was pulled up to 79.0 mbsf with negligible overpull. When running the pipe back to the bottom of the hole, we encountered 7 m of soft fill on the bottom. We dropped the go-devil to open the LFV and filled the hole with 8.8 ppg sepiolite mud. The pipe was pulled back up to 97.0 mbsf for logging. The bit was pulled up to 78 mbsf to log the upper hole at the end of each logging run.

Logs were run as follows:

The Quad-combo was run in to 4385.0 m (273.5 mbsf; there was 1.5 m of fill) in 5.5 hr. Initially, the FMS string would not pass through the bit, and the drill string was stuck. The drill string was freed with 100,000 lb overpull by pumping 150 gpm at 3000 psi. Then, the drill string was pulled up to 79 mbsf, and the FMS tool passed through the bit into the hole. The FMS log was run in to 4385.0 m (273.5 mbsf; there was 1.5 m of fill) in 5.2 hr.

The drill string was coated internally with corrosion inhibitor on the trip out. The bit cleared the seafloor at 1820 hr, 20 May. The beacon was retrieved at 1952 hr, 20 May. The bit cleared the rotary table at 0242 hr, 21 May. The drill floor, thrusters, and hydrophones were secured at 0352 hr. The BHA was laid down, so Leg 156 could start with a new BHA for a "logging-while-drilling" (LWD) experiment. The sea voyage began at 0400 hr, 21 May.

## TRANSIT TO BARBADOS

The sea voyage from Site 946 to Barbados covered 786 nmi in 74.25 hr. Leg 155 ended with the first line ashore in Barbados at 0615 hr, 24 May.

## OBSERVATIONS

### APC Core Liner Failures

The silty and sandy clays on levees and debris flows were unusually stiff, dry, and gassy. Debris flows were over-compacted. The APC system was pushed as far as possible to maximize scientific returns, because XCB coring caused disking (biscuiting), which obscured stratigraphy; however, there were an abnormally large number of core-liner failures and pump-out jobs required as a result. Problems were encountered duirng the entire leg with the butyrate plastic core liners being imploded (sucked inward), exploded (belled outward-mostly at the top end), crushed, cracked longitudinally (sometimes over the entire length), and shattered (mostly at the top). At Hole 944B, a mud line core that recovered <1 m of sediment cracked longitudinally.

### XCB Core Disturbance

XCB coring caused disking (biscuiting), which obscured stratigraphy. The shallower formations had low torsional strength due to the numerous silt layers and broke into 1-2-cm-thick disks. Debris flows consisting of large blocks of over-compacted clay were cored with the XCB at most sites; however, the shallower cores were too badly disked for good structural analysis. A debris flow was near the surface at Site 941 (Holes 941A and B); however, the unusually stiff, dry clay

in the debris flow forced the change to XCB coring sooner than expected in Hole 941A, and XCB recovery was poor initially.

Circulation Rates

The silty, sandy, dry clay formations proved to be very easily washed away by any circulation; therefore, many XCB cores in soft formations were "dry cored" by breaking circulation only as required to maintain penetration rate.

Few hole problems were noted except for occasional sand bridging, fill on bottom, and soft clay squeezing into the well bore (mainly from debris-flow units, which proved to be the most unstable sections).

PDC vs. 4-Cone Roller Bit

An 11-7/16" Security S86F 4-cone core bit was used to take XCB Cores 155-940A-9X to -27X from 3272.0 to 3451.3 m (69.3-248.6 mbsf), with 179.3 m cored and 138.61 m recovered (77.3% recovery). The 4-cone roller bit has 4 upward-discharge jets in addition to the 4 bottom jets. Core disking was reduced during XCB coring, and core sections increased from about 1 to 10 cm between rotational surfaces. Recovery was slightly better than at offset sites to the same depth (proposed site AF-21 was 78%, and proposed site AF-14 was 69.7%). Logging was completed with good hole conditions; however, the rate of penetration was slower, and the resulting hole was larger for logging. Therefore, a decision was made to return to the PDC bit for further coring.

Core Catchers

A combination of 8-finger and 4-petal core catchers was used during most of the leg for XCB cores taken in soft sands and silts (less than 10 min rotation/core - probably sand).

Logging

In general, logs showed hole angles to be 3° to 5°. The holes were slightly elliptical, with a diameter of 11 to 15 in. (12.5 in. average). Some holes had swollen down to 5 in. diameter in

unstable debris flows. The closures were asymmetric (elliptical), suggesting that tectonic or gravitational forces were extruding the clay into the well bore to relieve stress (as opposed to uniform extrusion by lithostatic overburden or hydrophilic clay expansion). Holes 944A and 946A were displaced with sepiolite mud and logged to TD, despite several large sand sections.

Heat Flow

ADARA heat-flow measurements were not stable above 50 mbsf, and compacted debris flows generally precluded using them below 85 mbsf (switched to XCB); therefore, heat-flow measurements were normally taken at 50 and 85 mbsf. WSTP temperatures were taken at about 120 m to provide a third set of heat-flow measurements. The average geothermal gradient was 33.5°C/km (i.e., relatively cool).

# OPERATIONS SUMMARY
## Leg 155

| | |
|---|---|
| Total Days ( 28 March 1994 - 24 May 1994) | 60 |
| Total Days in Port | 3.2 |
| Total Days Underway | 12.1 |
| Total Days on Site | 44.78 |

| | |
|---|---|
| Trip Time | 8.3 |
| Coring Time | 28.0 |
| Drilling Time | 0.1 |
| Reentry Time | 0 |
| Downhole Trouble Time | 0.1 |
| Other | 9.7 |

| | |
|---|---|
| Total Distance Traveled (nmi) | 2265.0 |
| Average Speed (kt) | 8.9 |
| Number of Sites | 17 |
| Number of Holes | 36 |
| Number of Reentries | 0 |
| Total Interval Cored (m) | 5117.3 |
| Total Core Recovery (m) | 4049.31 |
| Percent Core Recovered | 79.1 |
| Total Interval Drilled (m) | 115.6 |
| Total Penetration (m) | 5236.3 |
| Maximum Penetration (m) | 433.8 |
| Maximum Water Depth (m from drilling datum) | 4147.5 |
| Minimum Water Depth (m from drilling datum) | 2767.5 |

# SITE SUMMARY
## LEG 155

| HOLE | LATITUDE | LONGITUDE | WATER DEPTH (meters) | NUMBER OF CORES | INTERVAL CORED (meters) | CORE RECOVERED (meters) | PERCENT RECOVERED (percent) | DRILLED (meters) | TOTAL PENETRATION (meters) | TIME ON HOLE (hours) | TIME ON SITE (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 930A | 05°00.894'N | 47°35.743'W | 3155.5 | 1 | 9.5 | 10.05 | 105.8% | 0.0 | 9.5 | 8.75 | 0.365 |
| 930B | 05°00.894'N | 47°35.743'W | 3154.3 | 24 | 225.3 | 201.74 | 89.5% | 0.0 | 225.3 | 32.50 | 1.354 |
| 930C | 05°00.905'N | 47°35.746'W | 3154.3 | 18 | 172.6 | 135.65 | 78.6% | 86.4 | 259.0 | 21.50 | 0.896 |
| 930D | 05°01.005'N | 47°35.747'W | 3156.0 | 6 | 51.5 | 53.27 | 103.4% | 0.0 | 51.5 | 13.50 | 0.563 |
| | | **Site 930 TOTALS:** | | **49** | **458.9** | **400.71** | **87.3%** | **86.4** | **545.3** | **76.25** | **3.177** |
| 931A | 05°08.511'N | 46°37.983'W | 3483.4 | 6 | 53.6 | 56.99 | 106.3% | 0.0 | 57.0 | 11.25 | 0.469 |
| 931B | 05°08.521'N | 46°37.984'W | 3486.7 | 45 | 421.3 | 296.69 | 70.4% | 0.0 | 421.3 | 99.25 | 4.135 |
| 931C | 05°08.531'N | 46°37.986'W | 3485.4 | 4 | 32.6 | 32.11 | 98.5% | 0.0 | 32.6 | 12.00 | 0.500 |
| | | **Site 931 TOTALS:** | | **55** | **507.5** | **385.79** | **76.0%** | **0.0** | **510.9** | **122.50** | **5.104** |
| 932A | 05°12.682'N | 47°01.770'W | 3344.5 | 18 | 168.3 | 154.27 | 91.7% | 0.0 | 168.3 | 27.00 | 1.125 |
| 932B | 05°12.690'N | 47°01.770'W | 3347.0 | 6 | 52.5 | 54.04 | 102.9% | 0.0 | 52.5 | 12.25 | 0.510 |
| | | **Site 932 TOTALS:** | | **24** | **220.8** | **208.31** | **94.3%** | **0.0** | **220.8** | **39.25** | **1.635** |
| 933A | 05°05.801'N | 46°48.738'W | 3376.8 | 27 | 254.2 | 179.23 | 70.5% | 0.0 | 254.2 | 66.25 | 2.760 |
| | | **Site 933 TOTALS:** | | **27** | **254.2** | **179.23** | **70.5%** | **0.0** | **254.2** | **66.25** | **2.760** |
| 934A | 05°29.047'N | 47°40.857'W | 3432.7 | 12 | 108.8 | 111.66 | 102.6% | 0.0 | 108.8 | 19.00 | 0.792 |
| 934B | 05°29.020'N | 47°40.860'W | 3432.0 | 12 | 108.8 | 106.92 | 98.3% | 0.0 | 108.8 | 25.00 | 1.042 |
| | | **Site 934 TOTALS:** | | **24** | **217.6** | **218.58** | **100.5%** | **0.0** | **217.6** | **44.00** | **1.833** |
| 935A | 05°25.612'N | 47°33.893'W | 3496.5 | 40 | 372.6 | 268.57 | 72.1% | 0.0 | 372.6 | 101.00 | 4.208 |
| | | **Site 935 TOTALS:** | | **40** | **372.6** | **268.57** | **72.1%** | **0.0** | **372.6** | **101.00** | **4.208** |
| 936A | 05°37.936'N | 47°44.134'W | 3586.0 | 46 | 433.8 | 274.03 | 63.2% | 0.0 | 433.8 | 107.50 | 4.479 |
| | | **Site 936 TOTALS:** | | **46** | **433.8** | **274.03** | **63.2%** | **0.0** | **433.8** | **107.50** | **4.479** |

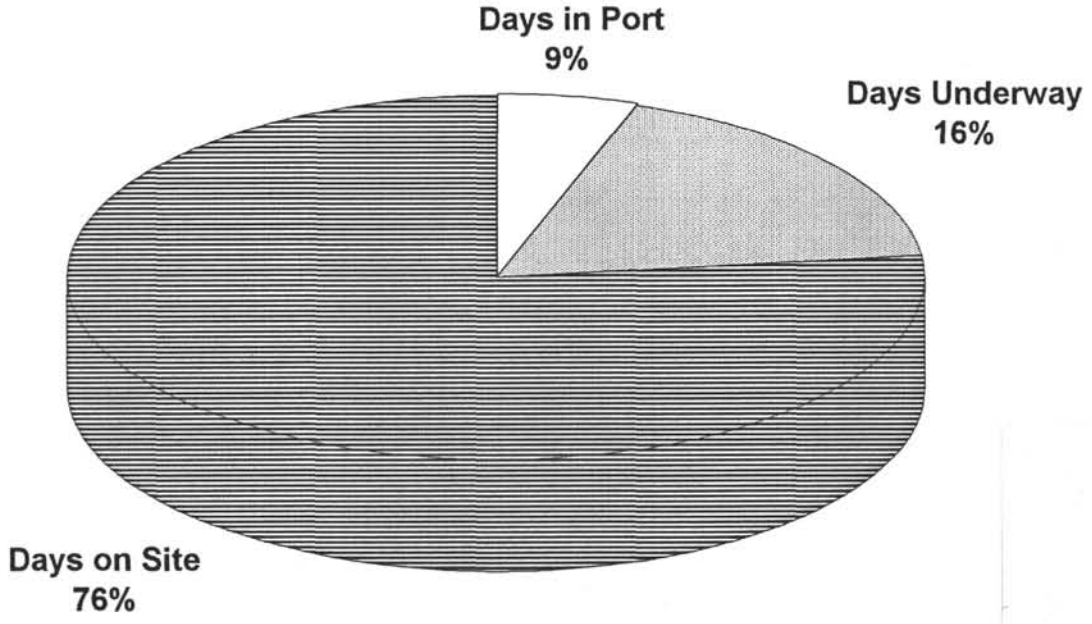
# SITE SUMMARY
## LEG 155

| HOLE | LATITUDE | LONGITUDE | WATER DEPTH (meters) | NUMBER OF CORES | INTERVAL CORED (meters) | CORE RECOVERED (meters) | PERCENT RECOVERED (percent) | DRILLED (meters) | TOTAL PENETRATION (meters) | TIME ON HOLE (hours) | TIME ON SITE (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 937A | 04°35.749'N | 47°12.449'W | 2771.3 | 1 | 0.2 | 0.21 | 105.0% | 0.0 | 0.2 | 5.50 | 0.229 |
| 937B | 04°35.749'N | 47°12.449'W | 2771.0 | 19 | 180.3 | 159.20 | 88.3% | 0.0 | 180.3 | 18.75 | 0.781 |
| 937C | 04°35.760'N | 47°12.444'W | 2767.5 | 9 | 76.5 | 80.52 | 105.3% | 0.0 | 76.5 | 7.75 | 0.323 |
| 937D | 04°35.773'N | 47°12.444'W | 2768.3 | 2 | 16.7 | 17.26 | 103.4% | 0.0 | 16.7 | 2.50 | 0.104 |
| | | **Site 937 TOTALS:** | | **31** | **273.7** | **257.19** | **94.0%** | **0.0** | **273.7** | **34.50** | **1.438** |
| 938A | 04°39.504'N | 47°18.740'W | 2815.4 | 34 | 310.2 | 241.61 | 77.9% | 0.0 | 310.2 | 38.75 | 1.615 |
| 938B | 04°39.505'N | 47°18.746'W | 2815.3 | 9 | 81.3 | 79.53 | 97.8% | 0.0 | 81.3 | 12.50 | 0.521 |
| | | **Site 938 TOTALS:** | | **43** | **391.5** | **321.14** | **82.0%** | **0.0** | **391.5** | **51.25** | **2.135** |
| 939A | 04°43.308'N | 47°30.201'W | 2794.8 | 11 | 102.7 | 97.57 | 95.0% | 0.0 | 102.7 | 14.75 | 0.615 |
| 939B | 04°43.305'N | 47°29.940'W | 2803.5 | 11 | 99.4 | 99.52 | 100.1% | 0.0 | 99.4 | 12.50 | 0.521 |
| 939C | 04°43.307'N | 47°29.944'W | 2802.4 | 4 | 36.1 | 36.98 | 102.4% | 0.0 | 36.1 | 8.50 | 0.354 |
| | | **Site 939 TOTALS:** | | **26** | **238.2** | **234.07** | **98.3%** | **0.0** | **238.2** | **35.75** | **1.490** |
| 940A | 05°08.596'N | 47°31.732'W | 3202.7 | 27 | 248.6 | 208.56 | 83.9% | 0.0 | 248.6 | 66.75 | 2.781 |
| | | **Site 940 TOTALS:** | | **27** | **248.6** | **208.56** | **83.9%** | **0.0** | **248.6** | **66.75** | **2.781** |
| 941A | 05°22.384'N | 48°01.732'W | 3392.2 | 19 | 177.9 | 122.75 | 69.0% | 0.0 | 177.9 | 45.50 | 1.896 |
| 941B | 05°22.384'N | 48°01.732'W | 3388.8 | 12 | 85.1 | 96.09 | 112.9% | 0.0 | 85.1 | 22.25 | 0.927 |
| | | **Site 941 TOTALS:** | | **31** | **263.0** | **218.84** | **83.2%** | **0.0** | **263.0** | **67.75** | **2.823** |

# SITE SUMMARY
## LEG 155

| HOLE | LATITUDE | LONGITUDE | WATER DEPTH (meters) | NUMBER OF CORES | INTERVAL CORED (meters) | CORE RECOVERED (meters) | PERCENT RECOVERED (percent) | DRILLED (meters) | TOTAL PENETRATION (meters) | TIME ON HOLE (hours) | TIME ON SITE (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 942A | 05°44.552'N | 49°05.452'W | 3357.7 | 20 | 177.6 | 152.65 | 86.0% | 0.0 | 177.6 | 29.25 | 1.219 |
| 942B | 05°44.557'N | 49°05.460'W | 3357.1 | 8 | 74.0 | 56.91 | 76.9% | 0.0 | 74.0 | 6.75 | 0.281 |
| 942C | 05°44.546'N | 49°05.464'W | 3360.2 | 5 | 42.3 | 44.03 | 104.1% | 29.2 | 71.5 | 12.00 | 0.500 |
| | | **Site 942 TOTALS:** | | **33** | **293.9** | **253.59** | **86.3%** | **29.2** | **323.1** | **48.00** | **2.000** |
| 943A | 05°56.808'N | 47°46.831'W | 3749.7 | 12 | 106.3 | 66.46 | 62.5% | 0.0 | 106.3 | 25.75 | 1.073 |
| | | **Site 943 TOTALS:** | | **12** | **106.3** | **66.46** | **62.5%** | **0.0** | **106.3** | **25.75** | **1.073** |
| 944A | 05°56.335'N | 47°45.469'W | 3712.6 | 41 | 384.2 | 208.09 | 54.2% | 0.0 | 384.2 | 82.50 | 3.438 |
| 944B | 05°56.259'N | 47°45.606'W | 3708.2 | 6 | 47.8 | 46.81 | 97.9% | 0.0 | 47.8 | 7.25 | 0.302 |
| 944C | 05°56.415'N | 47°45.339'W | 3721.9 | 1 | 9.6 | 9.60 | 100.0% | 0.0 | 9.6 | 3.25 | 0.135 |
| 944D | 05°56.424'N | 47°45.332'W | 3719.9 | 5 | 44.6 | 43.37 | 97.2% | 0.0 | 44.6 | 13.50 | 0.563 |
| | | **Site 944 TOTALS:** | | **53** | **486.2** | **307.87** | **63.3%** | **0.0** | **486.2** | **106.50** | **4.438** |
| 945A | 06°57.019'N | 47°55.732'W | 4147.5 | 8 | 75.5 | 74.75 | 99.0% | 0.0 | 75.5 | 17.50 | 0.729 |
| | | **Site 945 TOTALS:** | | **8** | **75.5** | **74.75** | **99.0%** | **0.0** | **75.5** | **17.50** | **0.729** |
| 946A | 06°56.977'N | 47°55.161'W | 4111.5 | 29 | 275.0 | 171.62 | 62.4% | 0.0 | 275.0 | 64.25 | 2.677 |
| | | **Site 946 TOTALS:** | | **29** | **275.0** | **171.62** | **62.4%** | **0.0** | **275.0** | **64.25** | **2.677** |
| | | **LEG TOTALS:** | | **558** | **5117.3** | **4049.31** | **79.1%** | **115.6** | **5236.3** | **1074.75** | **44.781** |

# *LEG 155*
# *TOTAL TIME DISTRIBUTION*




**Total days of leg = 60.1 days**

**TECHNICAL REPORT**

The following ODP Technical and Logistics personnel were aboard *JOIDES Resolution* for Leg 155 of the Ocean Drilling Program:

| | |
|---|---|
| Laboratory Officer: | Brad Julson |
| Assistant Laboratory Officer, X-Ray: | "Kuro" Kuroki |
| Marine Laboratory Specialist/Curatorial Representative: | Erinn McCarty |
| Marine Laboratory Specialist/Curatorial Representative: | Steve Prinz |
| Marine Computer Specialist/System Manager: | John Eastlund |
| Marine Computer Specialist/System Manager: | Barry Weber |
| Marine Laboratory Specialist/Yeoperson: | Jo Ribbens |
| Marine Laboratory Specialist/Chemistry: | Anne Pimmel |
| Marine Laboratory Specialist/Chemistry: | Robert Kemp |
| Marine Laboratory Specialist/Core Laboratory: | Andy Deady |
| Marine Laboratory Specialist/Core Laboratory: | Jeff Walsh |
| Marine Laboratory Specialist/Paleomagnetics: | Margaret Hastedt |
| Marine Laboratory Specialist/Photography: | Randy Ball |
| Marine Laboratory Specialist/Physical Properties: | Jon Lloyd |
| Marine Laboratory Specialist/Storekeeper, Thin Sections: | Tim Bronk |
| Marine Laboratory Specialist/Downhole Measurements: | Jaque Ledbetter |
| Marine Laboratory Specialist/X-Ray: | Wendy Autio |
| Marine Electronics Specialist: | Bill Stevens |
| Marine Electronics Specialist: | Mark Watson |

## PORT CALL

On 25 March 1994, *JOIDES Resolution* docked in Bridgetown, Barbados, ending Leg 154. Later that same morning, the Leg 155 technicians arrived and began the crossover.

Close to 900 boxes of core were unloaded into three 40-ft refrigerated containers. The Philips XRD representative, Joe Ombres, performed maintenance on the XRD, which included re-alignment of the goniometer. Bill Goodman from 2G assisted in the liquid helium refill of the cryomagnetometer. Two shooters from England met with ODP personnel to plan the VSP experiment, which is scheduled for Leg 156. Emile Meylan of Serco Technical Services performed maintenance on the microscopes.

Cesar Flores and several people from ODP administration inventoried the computer equipment aboard ship. The Pollution Prevention and Safety Panel toured the ship and investigated the ship's capabilities.

Dave Anderson, an architect with Earl & Wright, surveyed the ship and talked with ODP personnel about the ODP proposal to add a level to the lab stack.

The Brazilian observer did not arrive and the ship left port on 28 March 1994 and headed toward Brazil.

## UNDERWAY LABORATORY

Underway watches began as soon as we left port. The 3.5- and 12-kHz precision depth recorders (PDRs) were used, as was the magnetometer. Since the Doppler sonar was not initially registering the correct speed, it was raised until the bottom of the transducer was parallel with the hull, producing excellent results for about half the leg. Later, it was noticed that the Doppler readings were inaccurate, and the transducer was lowered a few inches; the readings again became consistent with the pittlog and the GPS.

The Underway Laboratory was heavily used during this leg. We ran 14 lines, 9 of which were seismic surveys using the 80-in.$^3$ water gun. One of the Co-Chiefs collected the 3.5-kHz data on his own personal portable DAT (digital audio tape) player. The Electronics Technicians made an interface to connect to the PDR.

The depth at which the streamer was towed was adjusted to that of the guns by watching the depth indicator and pulling the streamer in closer to the ship. The shape of the signal was also closely watched.

Both the Sun and the MASSCOMP computers were used to record the digital seismic information. A manual to describe data collection on the Sun was begun. Procedures for the collection of data were further fine-tuned. The AGCNAV navigation program was used on all the transits.

A new magnetometer cable was installed, and the fish was re-headed.

## PHYSICAL PROPERTIES LABORATORY

Four scientists used the Physical Properties Laboratory. Since the holes were fairly shallow in penetration, the MST was used extensively. At the beginning of the leg, we experienced track positioning problems which, at first, were attributed to the Natural Gamma detector, because the problems could be eliminated by turning off this detector. Further investigation isolated the problem to track slippage. The mechanic built a new shaft, ground flats on the shaft and the stepper motor, and added a locking screw on the motor shaft. There were no further problems.

A new GRAPE power supply was installed, and the power was increased to 900 volts. Cleaning the PC card connection helped reduce drift on the standard calibration. We did not experience interference between the P-wave logger and the scriber.

## PALEOMAGNETICS LABORATORY

The Paleomagnetics Laboratory functioned very well during this leg, running more than 2500 sections and a few dozen discrete samples at a variety of demagnetizing levels. The auxiliary equipment was little used, but the Tensor core-orientation tools saw very heavy use, as the majority of cores were of the APC type. The NiCad rechargeable battery packs worked extremely well. Unfortunately, the tools did not function as well, and two will be returned for repair.

The cryogenic magnetometer was refilled with liquid helium during the port call. A virus was discovered in one of the computers in the laboratory, and the computer was removed.

## CORE LABORATORY

The drill-floor camera broke down during the port call. After extensive troubleshooting, SEDCO installed a new camera to replace the broken one. Responsibility for repair of the camera has yet to be determined.

The two top racks in the core-splitting room were moved to the bottom when a paleomagnetic scientist found a magnetic field in the wall and suspected that it might alter the core's natural magnetic field. There was also a possibility that, when the ADARA heat-flow tool was in use, its batteries may have altered the magnetic field of the cores. This was not substantiated in later tests.

There were a large number of crushed liners during this leg, making it difficult to curate the cores.

## CHEMISTRY LABORATORY

The Chemistry Laboratory was heavily used during Leg 155, as we sailed two organic and two inorganic geochemists.

The high gas content in the sediment cores produced gas disturbances and crushed liners, and resulted in core being blown out of the liners. Real-time gas-safety monitoring was conducted on every core, and, although we found high concentrations of methane, there was almost no ethane or heavier hydrocarbon gases, primarily because all the holes were shallow penetrations.

Interstitial-water samples were analyzed for a suite of elements. High-resolution interstitial-water sampling and studies were conducted at a few sites. Solid core samples were analyzed for inorganic and total carbon analysis (using the coulometer and the CNS instrument). Based on their organic-carbon content, some samples were selected and analyzed with the Rock-Eval instrument. A few samples were also run on the Geofina Hydrocarbon Meter (GHM). The capillary gas chromatograph was used to conduct analyses of high-molecular-weight hydrocarbons and long-chain alkenones, which were derived from extracts of the sediment.

## X-RAY LABORATORY

Both the XRD (X-ray diffraction) and the XRF (X-ray fluorescence) devices were used during Leg 155 to analyze the sediments. The XRD was realigned by a Philips service representative during the port call, but a bad high-voltage connector was discovered; this connector will be replaced at the next port call. This problem limited the XRD to running at only 20 mA during the entire cruise instead of at our normal 35 mA. In spite of this problem, more than 300 samples were run on the XRD, most for bulk mineralogy and some as clay separations. During Leg 155, the XRF was calibrated to analyze major and trace elements for sediments. Seventy sediment XRF samples were analyzed.

At one site, the clays were separated, using the sonic dismembrator technique developed on Leg 149. Samples from the other sites were very clay rich, so bulk samples were analyzed, and the clays could still be identified.

During Leg 155, the XRF was calibrated for sediment analysis within a value range suggested by the inorganic geochemist who was studying the XRF data. She brought out some new standards, and two of our soil standards were also used. Trace elements were calibrated, using an ARL software function; no offline corrections or pseudo-element corrections were used.

XRF sediment samples were washed, because the inorganic geochemist wanted to obtain precise sodium values. The abundant clays were very difficult to remove from suspension after they had been washed with fresh water. The addition of a little methanol prior to centrifuging helped settle the clays.

## COMPUTERS

The computers were heavily used this leg, and a number of new software products were installed. A "Draw" and a "Paint" program were installed on the Sun computers. GeoRef, a geology reference utility on CD, was installed on two CD players in the Computer User Room. This reference should always be on-line for reference searches.

Three of the laser printers broke down, and all our spares were in use. Another laser writer will be sent from the “beach.”

The E-mail system worked well and was widely used.

Retrospect Remote, a Macintosh daily backup routine that backs up hard drives across the network, proved very helpful in recovering lost files.

## CURATION

Two curators sailed during Leg 155 to assist with the heavy sampling. Many samples were taken for isotope work after the leg. There also was a large organic geochemistry sampling program. Leaves, twigs, and wood fragments were saved for later $^{14}C$ analysis. Authigenic phosphate nodules, or vivianite, discovered during the cruise, will be analyzed later. Many whole-round physical property samples were taken, as well as a U-channel of the interval spanning the Lake Mungo event for later analysis. The FAXITRON was set up, and slabs were X-rayed during the leg. The negatives were developed on board.

A large number of the sampling requests were deferred until oxygen isotope values, age, and stratigraphy have been defined. It is the shipboard party's intent to identify all units and ages before formulating a sampling plan.

Gas expansion was a serious problem at all sites, and there were more than 85 damaged liners, a much higher number than was experienced during other organic-rich sampling legs. Recovery was poor in the HARP (high-amplitude reflection packet) layers, debris-flow units, and layers with high concentrations of sand.

## DOWNHOLE TOOLS

The ADARA heat-flow tool was used 29 times, and the WSTP heat-flow tool was used 9 times, all for temperature only. Calculated geothermal gradients were low at all sites. These low-equilibrium sediment temperatures and calculated geothermal gradients are entirely consistent with the passive margin/deltaic tectonic setting of the Amazon Fan. Geothermal gradients are characteristically depressed on submarine fans with very high sedimentation rates, particularly when these sediments are deposited on relatively old (cold) oceanic crust.

A new data recorder known as the "Tattletale" was brought on board and tested during Leg 155. Simultaneous tests were run at a variety of temperatures to compare the results with our current data recorder.

Three new parts cabinet were installed during the leg. These cabinets should provide bench space for laying out tools.

## PALEONTOLOGY LABORATORY/MICROSCOPES

Four paleontologists worked in the Paleontology Laboratory during Leg 155. Some of the equipment was shared with the XRF sample-preparation laboratory. Hydrofluoric acid (HF) was used by the palynologist, and no problems were encountered.

The microscopes were serviced by Emile Meylan of Serco Technical Services at port call, and there were no major problems with any of the microscopes. The microscopes and parts were inventoried.

## PHOTOGRAPHY LABORATORY

The Photography Laboratory was extremely busy. Over 6000 prints were made, consisting of core photos, close-ups, photomicrographs, and FAXITRON negatives.

## MISCELLANEOUS

On a number of occasions, the Birdwell air-conditioning unit tripped off in the Underway Laboratory. The corroded cooling line was reamed to increase flow. New piping has been ordered to prevent a similar occurrence in the future.

There were a number of welding modifications made during Leg 155. The Lower T'ween platform was renovated to improve safety during loading and unloading in port call, and an air tugger was installed to facilitate raising and lowering of the platform.

# LABORATORY STATISTICS

**General Statistics:**

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|---|---|
| Number of Sites: | 17 |
| Number of Holes: | 36 |
| Cored Interval (m): | 5,117.3 |
| Core Recovered (m): | 4,049.31 |
| Percent Recovered: | 79.1 |
| Total Penetration (m): | 5,236.3 |
| Time on Site (days): | 42.10 |
| Number of Cores: | 558 |
| Number of Samples: | 18,477 |

**Samples Analyzed:**

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|---|---|
| Inorganic Carbon($CaCO_3$): | 785 |
| Total Carbon (NCHS): | 785 |
| Water Chemistry (the suite includes pH, Alkalinity, Sulfate, Calcium, Magnesium, Chlorinity, Potassium, Silica, Salinity): | 243 |
| Pyrolysis Evaluation (Rock Eval and GHM): | 38 |
| Gas Samples: | 525 |
| Extractions: | 12 |
| Thin Sections: | 17 |
| XRF: | 70 |
| XRD: | 349 |
| MST Runs: | 3,101 |
| Cryomagnetometer Runs: | 2,558 |
| Cubes: | 28 |
| Oriented Cores: | 169 |
| Physical Properties Velocity: | 165 |
| Thermal Conductivity: | 323 |
| Index Properties: | 2,103 |

**Underway Geophysics:**

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|---|---|
| Bathymetry (nmi): | 1,996 |
| Magnetics (nmi): | 1,576 |
| Seismic Survey (nmi): | 249 |
| XBT's Launched: | 24 |

**DownHole Tools:**

| | |
|---|---|
| WSTP: | 9 |
| ADARA: | 29 |

**Additional:**

| | |
|---|---|
| Close-up Photographs: | 2,986 |
| Whole-Core Photographs: | 3,156 |
| Total Core Photographs: | 6,082 |