OCEAN DRILLING PROGRAM

LEG 171A SCIENTIFIC PROSPECTUS

BARBADOS ACCRETIONARY PRISM LOGGING WHILE DRILLING (LWD)

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

ABSTRACT

Deformation and fluid flow in sedimentary sequences cause changes in physical properties. In situ measurement of physical properties evaluates processes (consolidation, cementation, dilation) operating during deformation, fluid flow, and faulting. Because seismic images are affected by changes in physical properties, their measurement allows for calibration of seismic data as a tool for remotely sensing processes of deformation and fluid flow. Logging-while-drilling (LWD) provides an industry-standard tool for in situ evaluation of physical processes, including transient borehole conditions. Leg 171B will drill a series of LWD holes to measure the physical properties of sediments through a deforming accretionary prism and across plate-boundary faults off Barbados. Extensive drilling and three-dimensional seismic surveys provide a rich framework for log interpretation, seismic calibration, and process evaluation. The results will assist with the interpretation of similar, but less active, systems in sedimentary basins elsewhere, thereby contributing to the analysis of groundwater, hydrocarbon migration, and earthquake processes.

INTRODUCTION

Deformation of accretionary prisms changes the physical properties of sediments, thereby producing fluid, controlling fluid flow, altering rheologic properties, and affecting seismic arrival times and reflection characteristics. Consolidation and chemical diagenesis change the specific physical properties of porosity, density, and sonic velocity. These changes are both distributed (because of the loss of fluids in response to accumulating stresses; Bray and Karig, 1985; Bangs et al., 1990) and localized along discrete structures (such as faults) in response to overpressuring, fluid migration, or fault collapse (Shipley et al., 1994; Tobin et al., 1994). Because consolidation and fluid overpressuring affect seismic arrival times and seismic reflections, seismic data provide direct clues to physical properties evolution and to physical properties changes coupled with deformation.

Physical properties evolution in sedimentary sequences cannot be comprehensively evaluated from recovered cores. Elastic rebound and microcracking of coherent sedimentary samples degrade shipboard physical properties measurements. Fault gouge and other incoherent lithologies are either not recovered or cannot be measured after recovery; therefore, transient properties (e.g., overpressuring) must be measured in situ (Fisher, Zwart, et al., 1996).

Sediments in tectonically active areas undergo rapid changes in physical properties. Because of this rapid deformation and the shallow burial depth of the deformed features, accretionary prisms are exceptional, natural laboratories to study these changes that can therefore be drilled and imaged seismically. The information discerned at convergent margins about fault geology and overall sedimentary consolidation, in addition to seismic imaging of these processes, will be applicable to other, less active, sedimentary environments, and therefore will impact our understanding of hydrocarbons, groundwater, and aspects of earthquake systems. To better understand the interrelationships of deformation, fluid flow, seismic imaging, and changes in physical properties, we propose a logging-while-drilling (LWD) transect of a setting dramatically influenced by pore fluids: the Barbados accretionary prism.

BACKGROUND

Logging-while-drilling is the most effective tool for measurement of physical properties in poorly consolidated sediments. LWD acquires data from sensors integrated into the drill string immediately above the drill bit, and records data minutes after cutting the hole when it most closely approximates in situ conditions. It is an "off the shelf" industry technology already used by the Ocean Drilling Program (ODP) during Leg 156. This technology provides high-quality logging information in environments where standard wireline systems previously acquired either no data or poor-quality data because of the typically difficult hole conditions. Specifically, LWD provides excellent-quality results in the shallowest sediment sections and in holes with marginally stable conditions that preclude wireline log runs. Wireline tools are more sophisticated than LWD tools, and, in principle, should yield more accurate measurement of physical properties. However, the difficult hole conditions encountered by drilling, especially at active margins, destroy the inherent advantage of wireline tools. The LWD tools to be used during Leg 171A provide neutron porosity, resistivity, density, and gamma-ray data, but not sonic velocity data. If time permits, sonic log velocity data will be obtained by focused wireline measurements.

The absence or failure of wireline logging operations in convergent margins means that numerous, previously drilled, Deep Sea Drilling Project (DSDP) and ODP holes provide scientifically exciting locales for LWD. Barbados is especially attractive for focused LWD investigation because:

- Drilling at Barbados has occurred with high-quality structural, pore-water chemistry, heat flow, and shipboard physical properties studies (DSDP Leg 78A, ODP Legs 110 and 156). Such information provides independent determinations of locations of faults, of fluid flow activity, and of correlative physical properties such as grain density. The scientific results from this information provide a rich framework for log interpretation.
- Previous studies of Barbados show that physical properties are dramatically influenced by fluids. We anticipate observation of significant fluid-related effects from physical properties in the LWD logs.

- The décollement zone occurs at easily drillable depths at Barbados, and many previously drilled holes penetrate the décollement there. In contrast, thick turbidite-dominated sequences at many other convergent margins include unstable sand layers that hinder drilling and logging operations.
- Barbados is one of only two convergent margins with a state-of-the-art, three-dimensional seismic reflection survey. This extraordinary data set vastly expands the opportunity for core-log-seismic integration and three-dimensional extrapolation to problems of deformation and fluid flow in accretionary prisms.

SCIENTIFIC OBJECTIVES

1. Overall Prism Consolidation.

Porosity is the foundation for a variety of studies about the large-scale, long-term fluid budget of accretionary prisms. Logs can be used to determine a continuous record of density and porosity as a function of depth, as was done during Leg 156. Between-site variation in the porosity-depth relationship provides an estimate of the amount of fluid expulsion (and therefore volumetric strain). Unfortunately, measurements of volume change are usually impossible with standard logs, as they frequently fail because of bad hole conditions in this setting. Even under ideal conditions wireline logs do not obtain data from the top 60 to 120 m because the drill pipe must extend below the seafloor during logging, nor do they often sense the bottom 60–120 m of the hole because of fill. The shallowest 100 m, where porosity reduction is the greatest, is of particular interest in this study. Only LWD can obtain reliable porosity logs from the entire depth range, including the critical top 100 m.

Profiles of porosity vs. depth provide a tantalizing but incomplete view of the fluid expulsion pattern of an accretionary prism. Velocity data, either from multichannel seismic data (Bray and Karig, 1985; Bangs et al., 1990; Cochrane et al., 1994) or ocean-bottom seismograph (OBS) studies, are powerful tools for studying prism porosity structure. The fundamental limitation in determining porosity from velocity is the conversion between these two parameters. This relationship is well known for normally consolidated, low-porosity sediments (e.g., Gardner et al., 1974), but it is much less certain for high-porosity sediments, where changes in terms of fluid production and volumetric strain are more important. Furthermore, our analysis of logs from the Cascadia accretionary prism indicates that prism deformation dramatically changes the porosity-velocity relationship (Jarrard et al., 1995). In contrast to pelagic sediments, accretionary prism sediments of the same porosity can exhibit a wide range of elastic moduli and, therefore, velocities; this complexity results from variability in cementation, compression-induced modification of intergrain contacts, and fracturing. Theoretical relationships of porosity to velocity (e.g., Gassman, 1951) are of little utility in this environment; we must determine the velocity-porosity relationship for each prism empirically, and we must investigate the possibility that this relationship changes laterally within a prism. In situ velocity and porosity logs that sample the section completely are the only means of reaching this objective.

The overall fluid budget of the Barbados prism requires analysis to evaluate the fluid loss and geochemical budgets (e.g., Bekins et al., 1995). The series of LWD holes planned here, plus existing penetrations, will help constrain this problem. We anticipate obtaining excellent in situ porosities at all sites. The velocity-porosity relationship will be constrained by wireline sonic logs at proposed Site NBR-5A, and from the previously logged Site 948.

2. Correlation of Physical Properties of Faults with Displacement and Fluid Flow.

An LWD transect across the Barbadian décollement can address the following questions:

(1) do faults collapse and strain harden with displacement (e.g., Karig, 1986), and (2) does active fluid flow retard this process, and are collapsed faults inactive with respect to fluid flow (e.g., Brown et al., 1994)? Structural, biostratigraphic, and seismic reflection criteria identify faults. Anomalies in pore-water geochemistry (e.g., Kastner et al., 1991) and thermal anomalies (Fisher and Hounslow, 1990) indicate fluid flow. With the positive identification of faults, LWD can measure their physical properties. These properties then can be correlated to variations in displacement and fluid activity.

3. Consolidation State of Sediments in and Around Faults.

At Site 948 in the Barbados prism, high-quality density measurements demonstrated underconsolidation around faults, indicating that the faults had recently loaded subjacent sediments. The consolidation state can also be interpreted in terms of effective stress and fluid pressure. Clearly, consolidation varies around faults and should be defined to develop any tectonic-hydrologic model of the fluid expulsion system.

4. Polarity and Shape of the Seismic Waveform from Fault Zones.

Seismic reflections are created by changes in physical properties that can in turn be measured in boreholes. In principle, the seismic data provide a proxy for these larger-scale changes in physical properties. The polarity and shape of the seismic waveform were mapped and various models formulated for the waveform across décollement zones beneath accretionary prisms (Bangs and Westbrook, 1991; Moore and Shipley, 1993). Negative polarity reflections have been interpreted as resulting from either (1) overthrusting of higher-impedance sediment over lower-impedance sediment in Costa Rica (Shipley et al., 1990), or (2) the reduction of fault-zone impedance through dilation at Barbados (Bangs and Westbrook, 1991; Shipley et al., 1994; Bangs et al., 1996). The modeling, however, is incomplete without ground truthing by the in situ measurement of physical properties across fault zones in areas with high-quality, three-dimensional seismic data.

Logging data have only been acquired at one décollement locality (Shipboard Scientific Party, 1995). These LWD data from Barbados are in an area of positive reflection polarity, and show impedance increases that reproduce the positive polarity in synthetic seismograms (Shipboard Scientific Party, 1995). The LWD results also suggest thin (0.5–1.5 m) hydrofractures within the interval of positive polarity in the décollement zone. The hydrofractures apparently are too thin to be resolved seismically. A major question is whether negative polarities elsewhere in the Barbados décollement consist of thicker zones of hydrofractures.

LOGGING AND DRILLING STRATEGY

LWD investigations of the Barbados prism will build on existing LWD measurements. Proposed LWD sites will focus on determining the characteristics of the negative polarity reflections at Barbados, measuring the physical properties of faults, and determining the physical properties of the incoming sedimentary sequence. The sum of all penetrations will provide an overview of prism consolidation and velocity-porosity relationships. In prior drilling through the North Barbados Ridge accretionary prism during Leg 156, 1152 m of logs in Hole 947A and 948A was obtained using LWD technology. Leg 171A is specifically designed to acquire more LWD data in additional holes in the Barbados accretionary prism. There will be no coring on this leg.

Based on previous experience in accretionary prism environments, we anticipate that operational problems will be encountered during LWD such that we will only complete the four primary sites. In the unlikely event that no problems are encountered (as was assumed when producing the time estimates in Table 1), additional LWD has the highest priority. However, current cost constraints may limit any LWD penetrations in addition to the four primary sites. Accordingly, a second-priority activity is acquisition of wireline sonic velocity data.

The proposed tools will be the same as those used during Leg 156, directly measuring in situ resistivity, porosity, density, and natural gamma ray. An LWD sonic tool is not available for this leg. Sonic velocity information is available from Site 948, logged during Leg 156. If possible, new sonic velocity data will be obtained using wireline logging. Leg 171 will start with a complete set of LWD tools and a backup. In the event of a tool loss during the first site, a backup tool will be resupplied to the ship from Trinidad. If a tool is lost at or after the second site, no time will be available for replacement. Estimated operational times are shown in Table 1, and assume no significant hole problems.

PROPOSED SITES

Operations will commence by dropping beacons for all sites, and the sites will then be drilled in the following order: NBR-11A, 5A, 9A, 10A (Figs. 1, 2).

Primary Sites

Proposed Site NBR-11A

Proposed Site NBR-11A is located at the oceanic “reference” Site 672, 6 km east of the deformation front. This site showed incipient deformation and a geochemical anomaly at the stratigraphic level of the projected décollement zone. LWD here will provide information on the inception of deformation and fluid flow in the incoming sedimentary section, as well as a general overview of physical properties of the oceanic sedimentary section.

Proposed Site NBR-5A

Proposed Site NBR-5A will establish the physical properties of the negative polarity reflections in the Barbados prism. It is located in an area of negative polarity about 2500 m west of the deformation front. Shipley et al. (1994) predict that the negative polarities are dilatant zones. Accordingly, they may be characterized by “hydrofractures” or zones of fluidized sediment more numerous than those encountered at Site 948. Because the depth of the décollement is 400 m as opposed to the more than 600 m at Site 947, and the negative amplitude is less than at Site 947, proposed Site NBR-5A can be successfully completed. The site has never been cored; however, safety problems are not anticipated because nearby penetrations show negligible hydrocarbons. Correlations from nearby holes and the three-dimensional seismic data should provide basic lithologic information.

Proposed Site NBR-9A

Proposed Site NBR-9A, located at CORK Site 949, 1800 m west of the deformation front, will establish the physical properties of a décollement zone with intermediate reflection polarity characteristics, and determine the physical properties profile at this borehole seal site. This site is also cut by an imbricate thrust fault that is actively deforming the accretionary prism, and will provide information on the physical properties of thrusts.

Proposed Site NBR-10A

Proposed Site NBR-10A, located at Site 676, will determine the character of the initial deformation of the accretionary prism. This site is located about 800 m inboard of the deformation front, and penetrates the incipiently developed décollement zone and several thrusts in the offscraped section.

Alternate Sites

Proposed Site NBR-1A

Proposed Site NBR-1A is an alternate for proposed Site NBR-11A. This site, approved for Leg 156, is located about 4 km closer to the deformation front than NBR-11A and provides similar reference information.

Proposed Site NBR-8A

Proposed Site NBR-8A is an alternate to NBR-5A. All primary features and objectives are the same.

Proposed Site NBR-12

Proposed Site NBR-12 is a reoccupation of Site 541. Permission is currently being sought for this site. The site is located where the décollement is of positive polarity. Site 541 was continuously cored and contains several thrust faults from which we would like to obtain LWD signatures.

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SITE TIME ESTIMATE TABLE

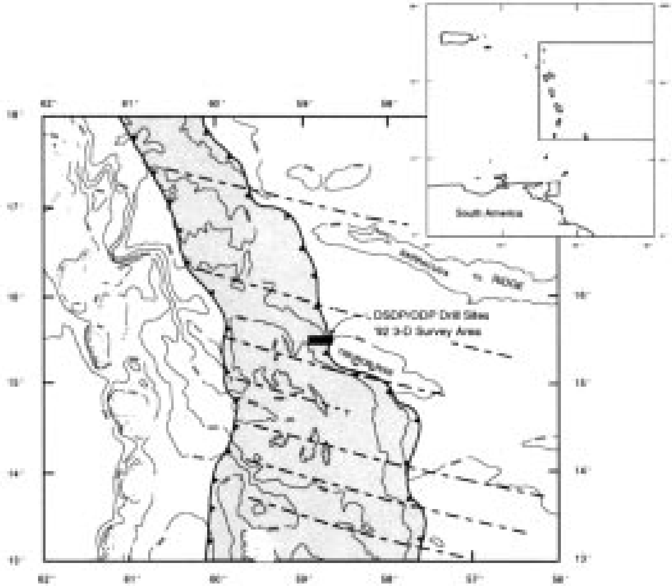
Primary Sites

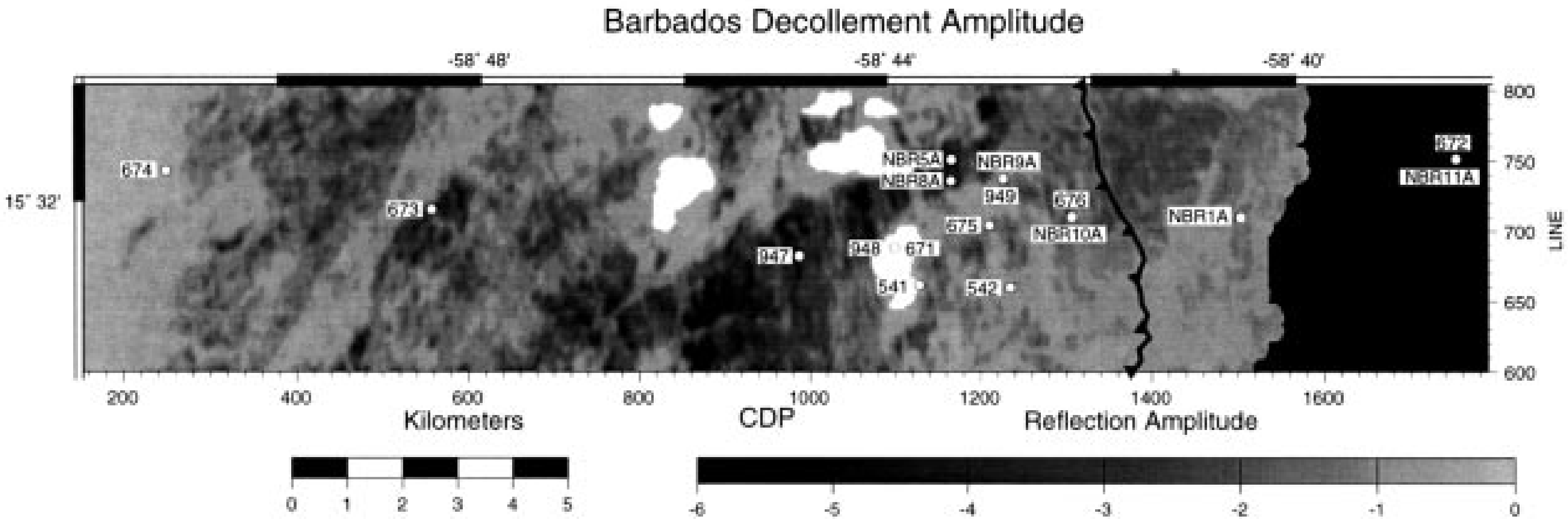
Site	Latitude	Longitude	Water depth (mbsl)	Penet-ration (mbsf)	Transit (days)	Logging -while - drilling (LWD) (days)	Sonic logging (days)	Total (days)
Transit Panama to Site NBR-5A					5.5			5.5
NBR-11A (Site 672)	15°32.40′N	58°38.46′W	4938	700		2.6		2.6
NBR-5A	15°32.40′N	58°43.395′W	4970	800		2.7	2.0	4.7
NBR-9A (Site 949)	15°32.161′N	58°42.849′W	4894	600		2.3		2.3
NBR-10A (Site 676)	15°32.85′N	58°42.20′W	5052	500		2.1		2.1
Transit from Site NBR-10A to Bridgetown, Barbados					0.8			0.8
Total					6.3	9.7	2.0	18.0

Alternate Sites

NBR-1A	15°32.026′N	58°40.574′W	5026	750				
NBR-8A	15°32.21′N	58°43.39′W	4756	800				
NBR-12A (Site 541)	15°31.2′N	58°43.7′W	4950	650				

Note: The following assumptions were used to produce the above time estimates: no hole problems, penetration rate = 20 m/hr, transit speed = 10 nmi/hr.


South America
DSDP/ODP Drill Sites
'92 3-D Survey Area


Barbados Decollement Amplitude
-58° 48'
-58° 44'
-58° 40'
15° 32'
674
673
947
948
671
541
575
542
NBR5A
NBR8A
NBR9A
949
676
NBR10A
NBR1A
672
NBR11A
LINE
CDP
Kilometers
Reflection Amplitude

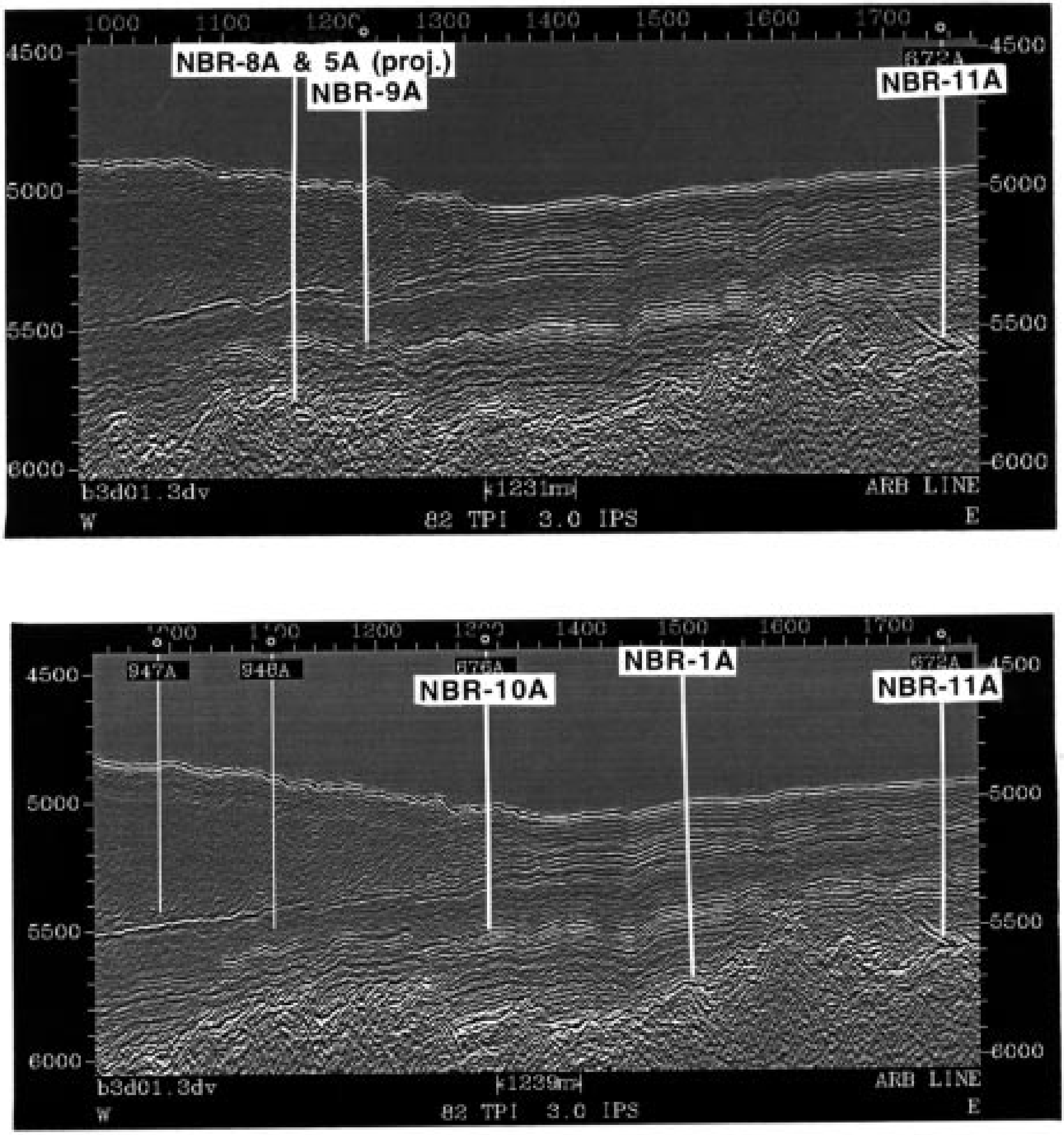


Figure 2. Seismic cross sections through proposed sites. Depths in meters. V.E. about 4:1. Black reflections are positive polarity and white reflections negative polarity.
Top: Cross section through NBR-8A & 5A (projected), NBR-9A, and NBR-11A.
Bottom: Cross section from Site 947 through Site 948, NBR-10A, NBR-1A, and NBR-11A.

Site: NBR-5A

Priority: 1

Position: 15˚32.40′N, 58˚43.395′W

Water Depth: 4970 m

Sediment Thickness: 776 m

Total Penetration: 800 mbsf

Seismic Coverage: 3D-grid Line 751-SP 1154

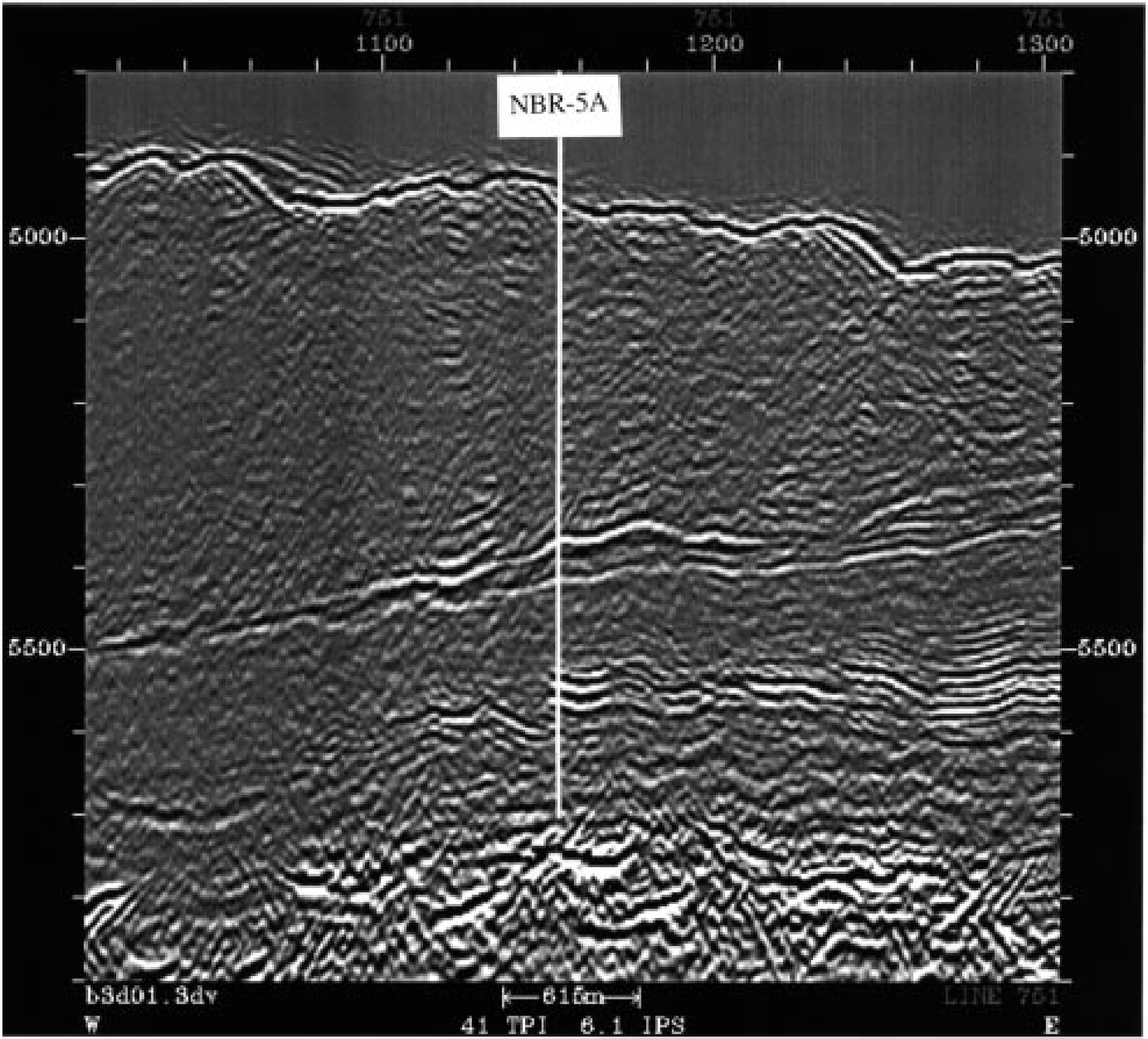
Objectives: The objectives of NBR-5A are

1. To determine physical properties through a negative polarity reflection at the décollement zone.
2. To provide a reference profile of physical properties through the accretionary prism, décollement zone, and underthrust sedimentary section.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in underthrust section.



East-West seismic profile through Site NBR-5A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-8A (alternate to proposed Site NBR-5A)

Priority: 2

Position: 15˚32.21′N, 58˚43.39′W

Water Depth: 4756 m

Sediment Thickness: 800 m

Total Penetration: 800 mbsf

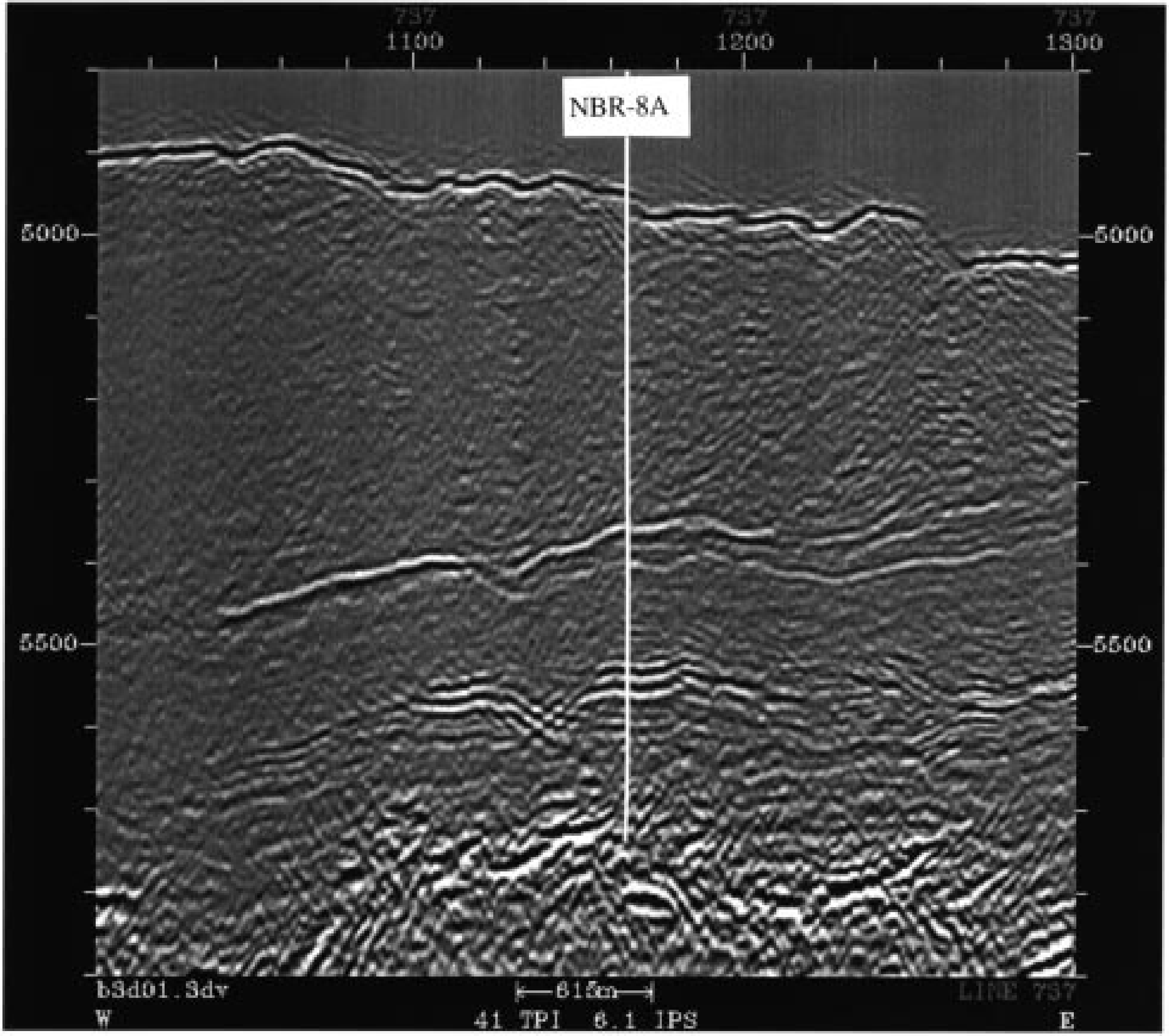
Seismic Coverage: 3-D survey, Line 736 SP-1165

Objectives: The objectives of proposed Site NBR-8A are identical to those of Site NBR-5A.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



East-West seismic profile through Site NBR-8A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-9A

Priority: 1

Position: 15°32.161′N, 58°42.849′W

Water Depth: 4984 m

Sediment Thickness: 810 m

Total Penetration: 600 mbsf

Seismic Coverage: 3-D survey, Line 736 SP 1230

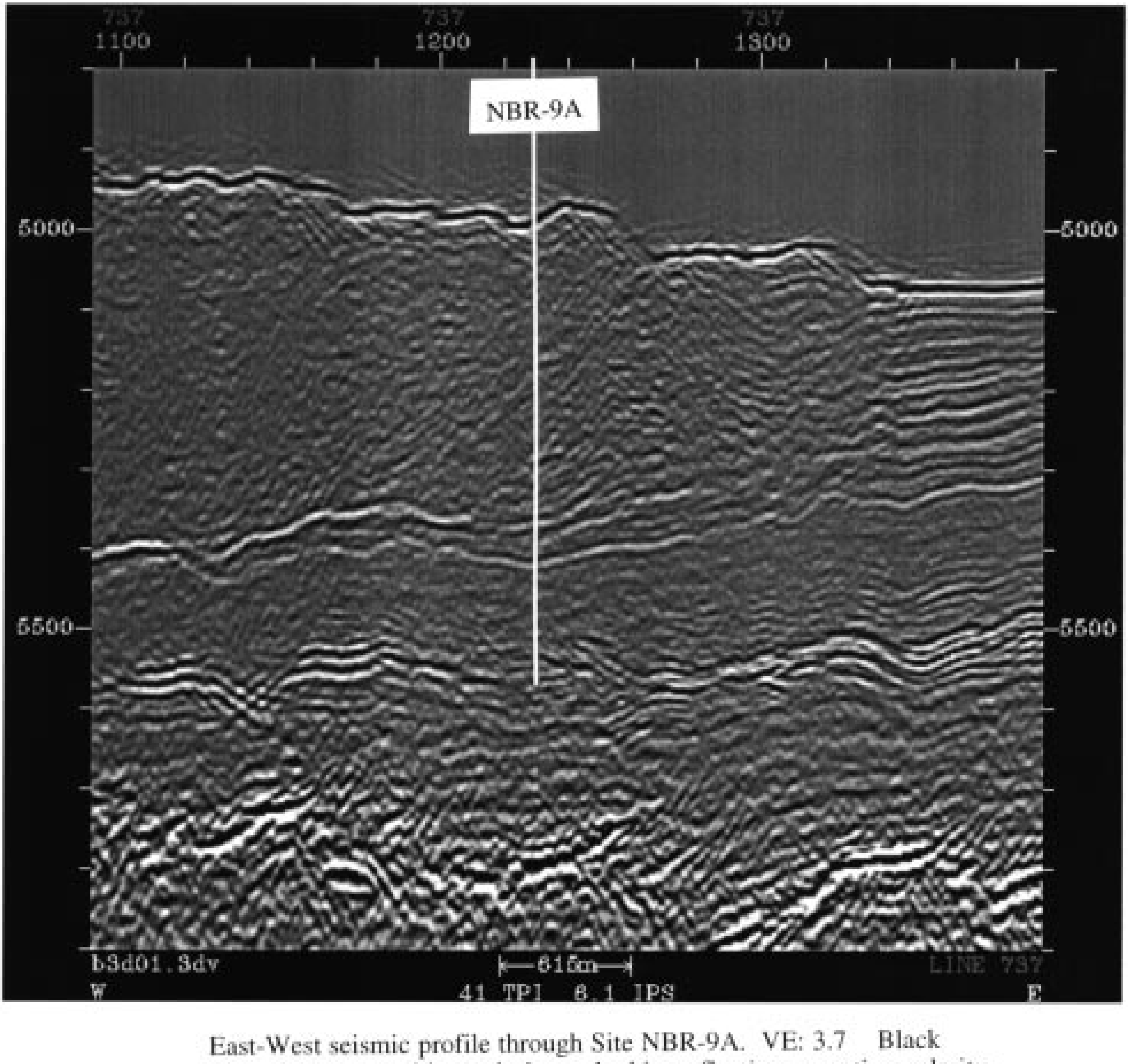
Objectives: The objectives of proposed Site NBR-9A are

1. To determine physical properties through a weakly developed negative polarity reflection at the décollement zone.
2. To determine the physical properties through the accretionary prism, décollement zone, and into the upper portion of the underthrust sediment section at Site 949 where borehole monitoring is successfully underway.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



East-West seismic profile through Site NBR-9A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-10A

Priority: 1

Position: 15°32.85′N, 58°42.20′W

Water Depth: 5052 m

Sediment Thickness: 797 m

Total Penetration: 500 mbsf

Seismic Coverage: 3-D survey, Line 710 SP-1308

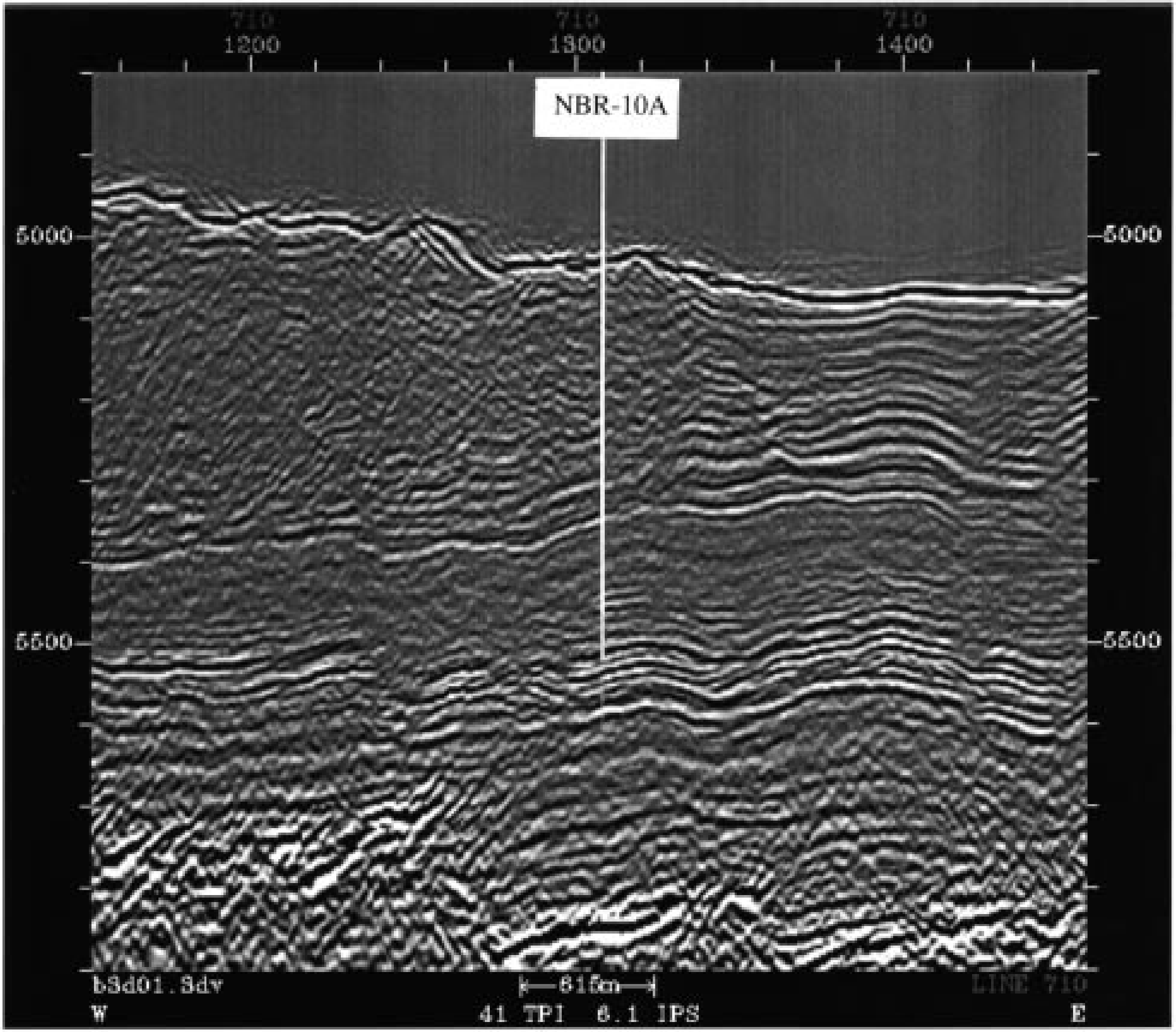
Objectives: The objectives of proposed Site NBR-10A are

1. To determine the physical properties of the accretionary prism, décollement zone, and the underthrust section at the deformation front.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



East-West seismic profile through Site NBR-10A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-11A

Priority: 1

Position: 15°32.40′N, 58°38.46′W

Water Depth: 4938 m

Sediment Thickness: 641 m

Total Penetration: 700 mbsf

Seismic Coverage: 3-D survey, Line 751, SP-1753

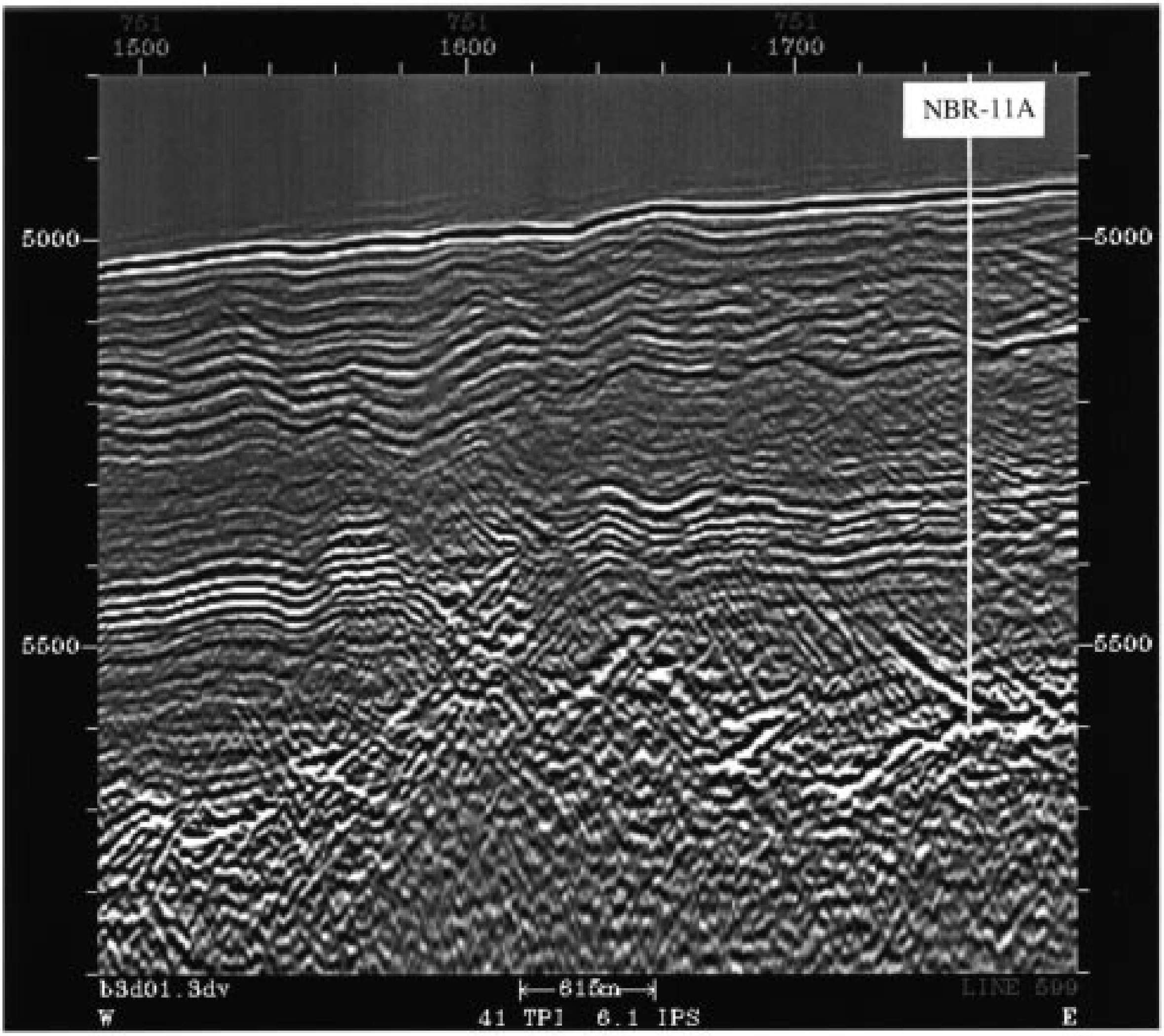
Objectives: The objectives of proposed Site NBR-11A are

1. To establish a reference physical properties profile through incoming sedimentary section.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



East-West seismic profile through Site NBR-11A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-1A (alternate to proposed Site NBR-11A)

Priority: 2

Position: 15˚32.026′N, 58˚40.574′W

Water Depth: 5026 m

Sediment Thickness: 709 m

Total Penetration: 750 mbsf

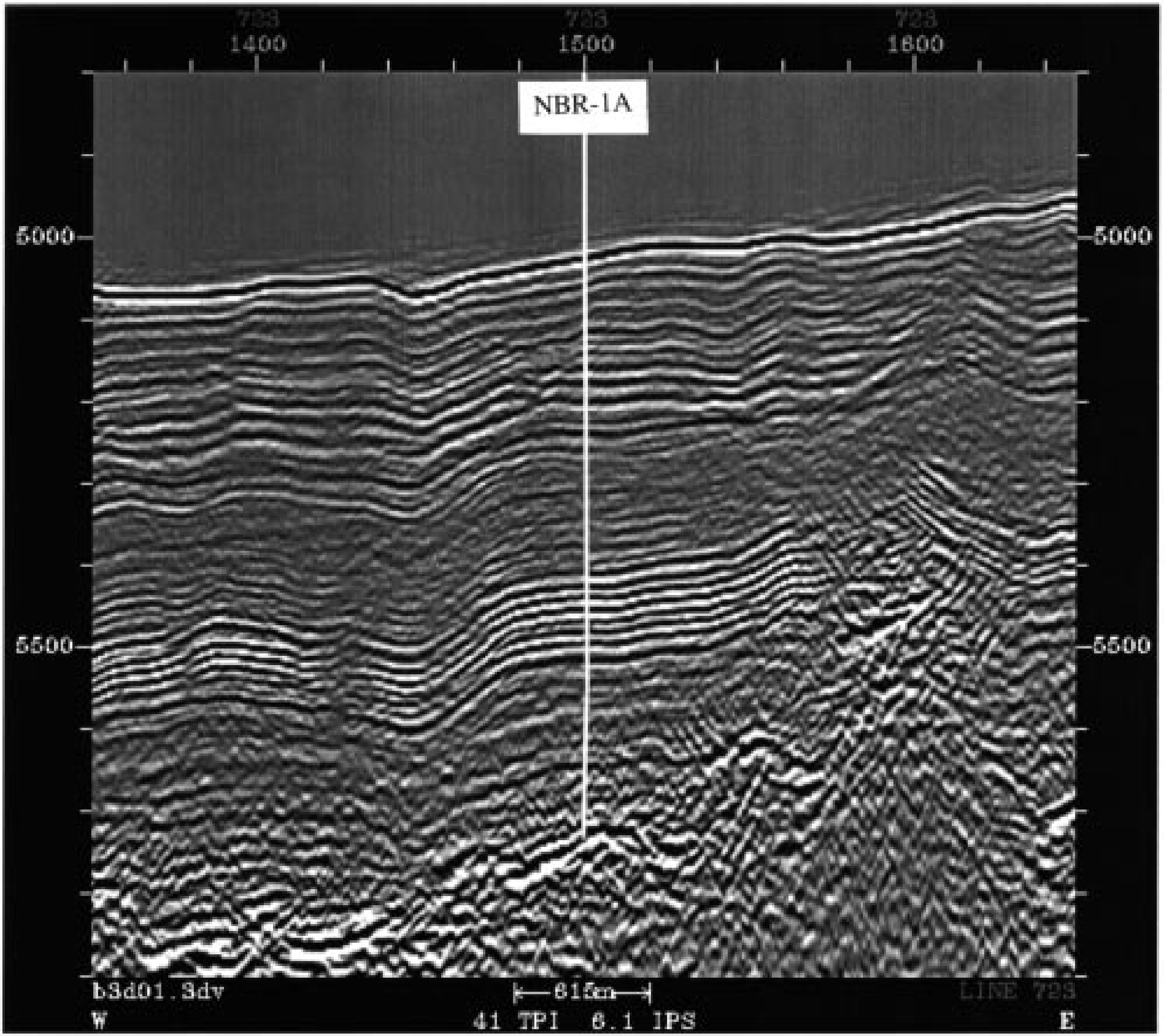
Seismic Coverage: 3-D survey, 3D-Grid line 723-SP 1500

Objectives: The objectives of proposed Site NBR-1A are identical to those of proposed Site NBR-11A.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



East-West seismic profile through Site NBR-1A. VE: 3.7 Black reflections are positive polarity and white reflections negative polarity

Site: NBR-12 (reoccupation of Site 541)

Priority: 2

Position: 15˚31.21′N, 58˚40.07′W

Water Depth: 4940 m

Sediment Thickness: 900 m

Total Penetration: 700 mbsf

Seismic Coverage: EW9207 3D-grid Line 661-SP 1129

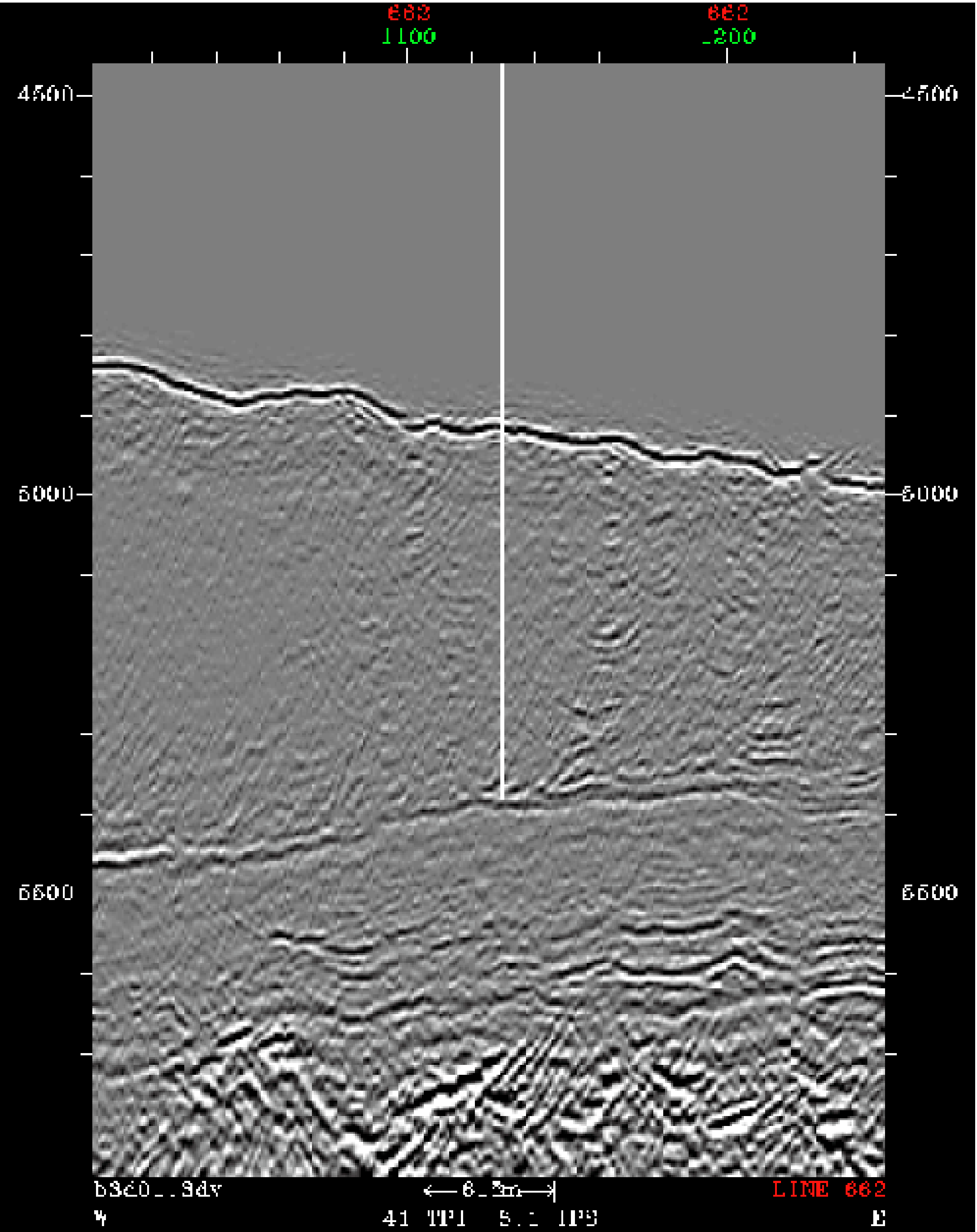
Objectives: The objectives of proposed Site NBR-12 are

1. To determine the physical properties of the accretionary prism, décollement zone, and the underthrust section at the deformation front.

Drilling Program: No cores.

Logging and Downhole: LWD.

Nature of Rock Anticipated: Pelagic and hemipelagic sediments, local distal turbidites in the underthrust section.



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