OCEAN DRILLING PROGRAM

LEG 156 SCIENTIFIC PROSPECTUS

NORTHERN BARBADOS RIDGE

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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

The main objectives of the northern Barbados Ridge ODP Leg 156 are to examine the rates, effects, and episodicity of structural and fluid processes in an accretionary prism. As designed, the science program will investigate the interrelationship of fluids, tectonic features, and geochemical signatures, primarily focused on the décollement. Three sites will measure pore pressure and permeability at the décollement and then be instrumented to examine episodicity of fluid flow. The measurements require setting casing from the seafloor through the fault zone. Packer experiments within screened sections at the fault will provide both permeability and pressure data. The sites will then be closed-in using the CORK system for temperature and pressure monitoring for several years.

INTRODUCTION

The importance of fluids in accretionary prism tectonics was a special topic at a NATO-sponsored workshop in 1989 and spurred innovative experiments and new techniques (Langseth and Moore, 1990). Fluids critically affect the structural development and architecture of accretionary prisms and their potential evolution into mountain belts (e.g., Hubbert and Rubey, 1959). Structural and geochemical studies of recovered samples from Barbados and elsewhere attest to multiple fluid-flow events and evidence for the importance of both intergranular and fracture permeability (e.g., Moore and Vrolijk, 1992; Knipe et al. 1991; Moore et al., 1982). Yet we have not been able to tie these observations to even the most fundamental temporal and spatial scale to validate dynamic flow models (e.g., Screaton et al., 1990; Shi and Wang, 1988). On Leg 156, our objective is to combine both in situ measurements of permeability and fluid pressures, long-term monitoring of temperature and pressure, and fluid chemistry and structural fabric studies in an integrated program. This experiment is an important and necessary step in evaluating the role of faults in fluid transport, episodicity of fluid flow, and the relationship to seismicity. Understanding the fate of subducted and accreted fluids will also contribute to geochemical cycle definition (Kastner et al., 1991). This program is a logical step in advancing the technological and drilling techniques needed in this environment.

An east-west-trending seismic line that crosses through ODP Hole 671B illustrates the main structural features of the toe region (Shipley et al., 1992; Figs. 1 and 2). These data are consistent with earlier data and interpretations that show an extraordinary fault reflection extending at least 70 km westward of the trench (e.g., Biju-Duval et al., 1982; Westbrook and Smith, 1983). Based on drilling and seismic data, Brown et al. (1990) believe that the prism grows near the toe by imbrication of thin fault blocks. Also, they indicate that west of Hole 671B the prism deforms by large-scale folding, out-of-sequence thrusting (OOST), and probably underplating. Geochemical signatures, heat flow, and direct observations detected focused fluid flow in the toe region (e.g., Vrolijk et al., 1991; Langseth et al., 1988; Fisher and Hounslow, 1990). The Barbados prism has two distinct and active fluid regimes separated by the décollement that communicate only near the toe of the slope (Vrolijk et al., 1991). Both the décollement and several other faults show chemical and temperature anomalies that require active fluid advection. ODP Hole 671B (Leg 110) penetrated through the > 40-m-thick décollement and 151 m into the underlying underthrust section (Moore et al., 1988). Because of unsuccessful measurements of in-situ fault-zone fluid pressures on ODP Leg 110 the assertion of near lithostatic pressure at the décollement at DSDP Leg 78A, Site 542 ("the inadvertent packer experiment," Moore et al., 1982), remains unverified.

Within the Leg 156 area, a three-dimensional seismic reflection image of the low-angle detachment fault between the Caribbean and American plates characterizes spatial variations of fault properties (Fig. 3). Previous work links waveform characteristics of this fault to porosity and fluid pressure (Bangs and Westbrook, 1991). On the basis of the spatial pattern of décollement reflection amplitude, inferences about fluid content, migration paths, and fluid pressures are possible. The fault-zone reflection is usually a compound reversed-polarity reflection modeled as a low-velocity, high-porosity zone 10-14 m thick. This thickness is significantly less than the drilling-defined >40-m zone of deformation at ODP Hole 671B, located within the surveyed area. We infer that the seismically defined fault is mostly a thin high-porosity zone and is thus an undercompacted, high-fluid-pressure, dilatant section. If these inferences are correct, then map view variations in seismic reflection phase and amplitude illustrate complex patterns of fault-zone fluid content and fluid migration. The amplitude map suggests kilometer-wide channels of locally high porosity and focused fluid flow. These paths are only subparallel to the expected minimum head as inferred from overburden variations in the overlying sediment wedge; other factors must modify fluid migration. Several normal-polarity portions of the fault may be locally drained areas producing strong asperities in an otherwise weak fault. One is coincident with ODP Hole 671B and may explain the success of drilling through the fault zone here. In part the drilling will calibrate the spatial seismic signature of the décollement.

SCIENTIFIC OBJECTIVES AND METHODOLOGY

Leg 156 constitutes a drilling and experimental program to evaluate the effects, rates, and episodicity of fluid flow in the accretionary prism environment. The program will focus on a study of deeply sourced fluids in the décollement zone of the Barbados Ridge Complex and include efforts to measure fluid flow through the accretionary prism and sediments underthrust beneath the décollement zone. Proposed efforts efficiently utilize the geologic and hydrogeologic framework developed by previous drilling of the Northern Barbados Ridge and take advantage of a three-dimensional seismic reflection survey and submersible investigations completed in 1992.

Fluid Pressure in and around The Décollement Zone

No reliable fluid-pressure measurements exist for the frontal area of accretionary prisms, though several attempts at measurement (inadvertent or otherwise) have been made (Biju-Duval, Moore, et al., 1984; von Huene, 1985). Fluid pressure is the driving force for fluid flow, and must be known to create any reasonable model of fluid expulsion. Fluid pressure must be known in order to evaluate structural models of prism tectonics.

Permeabilities of Prism Sediments and Associated Fault Zones

Although measurements on recovered core samples provide estimates of matrix permeability (e.g., Taylor and Leonard, 1990), in-situ measurements are essential to determine permeability at the scale of the flow system. Some models suggest that fault zones may be 3-5 orders of magnitude more permeable than the matrix (Screaton et al., 1990). Obviously, information on permeability will dramatically influence the understanding of the dynamics of fluid flow.

Amplitude Anomalies or "Bright Spots" Along Faults

High-amplitude, reversed-polarity reflections in seismic reflection data from the Northern Barbados Ridge (Bangs and Westbrook, 1991) have been modeled as dilatant zones. Similar reversals in the Oregon accretionary prism which correlate with surface vents (Moore et al., 1991) have also been interpreted as dilatant zones. Seismic data from the new 3-D survey in the Leg 110 area show a large negative polarity amplitude anomaly along the décollement zone. Proposed sites are located to penetrate this amplitude anomaly, monitor its fluid pressure, and ultimately measure its migration.

Continuous or Episodic Flow?

Although groundwater systems driven by semi-constant water tables tend to flow continuously, structural and seismologic intuition suggests that tectonohydrologic systems are episodic. The nature of the earthquake cycle (Kanamori, 1986) and related fluid flow (Sibson, 1981), and the ubiquitous crack-seal textures of deformed rocks (e.g., Ramsay, 1980), support this view. Accordingly, the temporal and spatial variability of fluid flow along a convergent plate boundary, the décollement zone, must be determined.

The Space/Time Variation in Fluid Composition and its Comparison with Veins and Authigenic Mineral Phases

The variability of fluid composition in space and time will provide information on potential fluid sources and allow modeling of solute fluxes.

DRILLING PLAN/STRATEGY

The planned two-month ODP program can accommodate at the most three CORK holes (Fig. 4; Davis et al., 1992). Figure 4 is a schematic cross section of the margin and seismic line illustrating the relative positions of the sites. The high-amplitude compound negative-polarity reflection may be due to dilation of the fault zone, and proposed site NBR-3 is designed to test this hypothesis. Proposed site NBR-2 is where the fault-plane reflection has a positive polarity, and the fault may not have high fluid pressures. Proposed site NBR-1, about 1 km seaward of the thrust front, will examine incipient décollement deformation discovered at Site 672. At a minimum, plans call for these CORKed holes to be instrumented with a string of temperature sensors and a pair of pressure sensors in the well and at the seafloor. Two strings will be similar to those successfully used in the Juan de Fuca and Cascadia drilling programs. A French group led by Jean-Paul Foucher is supplying a third digital string. These strings are capable of monitoring changes in temperatures (a proxy for fluid flow) and pressures within the fault zone for at least 2 years. Chemical samplers under design may also provide time-series' samples retrievable during later ODP or submersible operations. Submersibles will allow for additional fluid sampling and transfer of long-term monitoring data. Planned packer experiments will make estimates of permeability with both pulse and flow tests. Vertical VSP's are planned at proposed sites NBR-1, NBR-2, and NBR-3, and a possible bottom-shot offset (shear-wave anisotropy) VSP experiment is scheduled for proposed site NBR-3. A complete fluids-geochemical sampling and analysis program is also planned. As time permits, additional conventional sites will refine the spatial view of the fault system. The elementary objectives of this drilling program, to make measurements of permeability, and to monitor both the temporal and spatial fluid pressures along an active detachment fault, are fundamental observations but have remained elusive because of the technical challenge. Our difficulty now is to implement CORK systems at record water depths and penetrations and to produce a compelling record of fluid activity along faults.

Special Tools, Experiments, and Sampling

Logging-while-drilling (LWD) is proposed at the three prime sites. LWD provides compensated dual resistivity, gamma-ray, and compensated density neutron data. An experimental sonic module could provide traveltime and waveform information. The primary advantage of the LWD is its likelihood to provide logs in these unstable conditions. Logging while continuing to rotate the bit with circulation should reduce the risk to downhole equipment. We propose the LWD at the three prime sites at the start of the leg to provide optimal planning for coring and casing operations, and to aid in planning wireline logging. Financial and logistical reasons are also accommodated with the early deployment of the LWD. LWD is a method new to ODP for logging which may be appropriate for this environment. If LWD funding is not available, the 5.5 days scheduled for LWD will be necessary to drill dedicated holes for logging. Holes dedicated to logging and without coring have had modest success in some active margin sites but at great expense of time and lost equipment.

Table 1
Special Experiments

	NBR-2	NBR-3	NBR-1
Logging-While-Drilling (LWD)	48 hrs	44 hrs	44 hrs
Logging	48	53	0
Wireline Sampler Temperature Probe (WSTP)	20	20	0
Vertical Seismic Profile (VSP)/Cement Bonding Tool (CBL)	18	20	8
VSP with bottom shots		18	
Packer	15	15	15
Total Experiments (hrs)	149	170	67
Total Experiments (days)	6.2	7.1	2.8

The standard logging program will include three runs in the open holes: Quad-combo tool (deep and intermediate velocity, shallow resistivity, and formation density), geochemical tool (measures relative concentrations of Si, Ca, Fe, S, H, and Cl; and wet weight percentages of K, U, Th, and Al plus others), and Formation Microscanner (two-dimensional, high-resolution images of the variations in microresistivity around the borehole wall). The Quad-combo will be split into two strings if safety concerns for the neutron source exist. This would increase the total number of runs to four, which in turn would decrease the likelihood for good hole conditions for subsequent logs (FMS, GLT). Hole conditions could prevent any logging run from being successful. Without LWD, conventional logging efforts will consist of dedicated holes, extensive mud programs, and side-entry-sub use. Should LWD be funded and successful, we still propose a fairly full logging program for comparison and expansion of the LWD data but would exclude dedicated logging holes. Also there would be little reason to take significant risks to downhole equipment. Given expected open-hole conditions, minimal basement penetration, and time constraints, we plan no Borehole Televiewer use.

The drill-string packer will measure fluid pressure and permeability in the cased hole. Open, screened sections placed within the fault zone will be isolated for pulse and flow experiments. Following the packer work, the strings of temperature and pressure monitors (along with fluid samplers in two of the holes) will be sealed-in with the CORK system.

Standard-geometry vertical seismic profiles (VSP) at the three prime sites will use the array seismic imager tool (ASI) in cased holes. The ASI is a 50-m-long tool with five 3-component magnetically coupling geophones. Use within the cased hole provides assurance that hole conditions do not preclude the experiment. However, the cased hole must have good coupling to the formation for the ASI tool. A cement bonding tool (CBT) will evaluate the cementing quality critical to both the ASI tool and hydrologic isolation of the décollement. The VSP will be run in two parts, once after the second (13-3/8-inch) casing string is set to just above the décollement; and then a second run in the bottom of the hole after setting of the third (10-3/4-inch) casing string. A second experiment will use 20 10-kg explosive bottom shots at proposed site NBR-3 with the ASI tool deployed at the décollement. The objective is to evaluate seismic anisotropy at the fault zone, which should be a proxy for interpretation of the local stress field.

Significant geochemical sampling will be carried out using the WSTP tool and interstitial water from whole-round core samples. Because of the importance of geochemical, permeability, structural, and deformation studies, an unusually large demand for whole-round samples is expected as an essential part of this program. Every effort will be made to coordinate sampling activities for multiple use. Even so, many whole rounds will be required in the main zones of interest as well as for general background characterization of fluid chemistry, physical and geotechnical properties, and deformation.

General Strategy

The primary sites, in order of scientific priority, are NBR-3, NBR-2, and NBR-1. Operation order will be NBR-2, NBR-3, and then NBR-1. Proposed site NBR-2 appears to pose fewer drilling problems than NBR-3. It will be drilled first to gain experience for the more difficult site NBR-3. Time constraints make all other sites alternates.

Proposed site NBR-2 (essentially Site 671) is about 150 m from Hole 671B, which penetrated well below the décollement zone. The site is at the center of one of the normal-polarity regions of the fault-plane reflection. A cased hole will extend to 590 m, 100 m below the décollement. Coring is limited to the fault zone from 420 to 590 m. Proposed site NBR-3 targets a relatively bright negative polarity fault-plane reflection. The cased hole will extend 723 m, 100 m below the décollement. The entire interval from 0 to 723 m will be cored. Proposed site NBR-1 is on the oceanic plate about 2 km east of the frontal thrust. It is located to evaluate the incipient deformation at the projected stratigraphic level of the main detachment fault. The cased hole will extend about 342 m. The present plan calls for coring from 190 to 290 m, encompassing the incipient fault zone.

Table 2
Site Time Estimates

	Water Depth [m]	Total Penetration [mbsf]	Cored [m]	General Operations [days]	Special Experiments [days]	Total [days]
TRANSIT						0.4
NBR-2	4910	630	420 - 590	12.0	6.2	18.2
NBR-3	4852	723	0 - 723	16.3	7.1	23.4
NBR-1	5026	342	190 - 290	10.8	2.8	13.6
TRANSIT						0.4
Grand Total						56.0

Proposed site NBR-1 is the second-priority hole and will be drilled last. If LWD occurs, it may be necessary to forgo any or all of the special experiments and coring and just drill, set casing, run the packer experiment, and CORK the hole. The reduced time of special experiments at NBR-1 (Table 2) relfects this situation. If LWD is not available, we will do only enough coring or wireline logging to locate the décollement for the casing/packer/ CORK program. Time estimates will be refined after decisions about LWD and other special experiments have been made.

If LWD is available, it would be deployed first at the three prime sites. Then the general sequence of operations is the same for all three sites:

1) Site-specific coring program and Water Sampler Temperature Probe (WSTP)
2) Wireline logging, plug hole
3) Set reentry cone, 16" and 13-3/8" casing to just above fault
4) Conventional Vertical Seismic Profile (VSP) part I and Cement Bond Log (CBL)
5) Drill and set 10-3/4" casing with screened section at the fault
6) Conventional VSP part II

7) Shear-wave VSP (only NBR-3)
8) Packer experiment
9) CORK deployment

Effects of Time Contingencies on Planning

The program as currently constituted should achieve most objectives, with the exception of a complete coring program and a full suite of downhole experiments at NBR-1 (Table 2). Missing from the coring program is characterization of the lower part of the underthrust section, which will not be sampled.

Due to the time constraints, conventional wireline logging and the WSTP program may have to be cut . It is a major objective of the leg to deploy CORKs at three sites. However, this commitment might be jeopardized depending on the time available. Depending on the outcome of the "special experiments" and time remaining at NBR-2, some of the "special experiments" at NBR-3 might be abandoned to complete the minimum CORK/packer test at NBR-1. However, this decision depends on re-evaluation of the time estimates as the first site proceeds, and then time estimates and results of special experiments as they proceed at NBR-3.

The full coring program originally considered for NBR-1 (coring to 342 m) would take an additional 2 days, and the full suite of experiments (46 hr wireline logging, 20 hr WSTP, 14 hr VSP) would add another 3 days. The original program at NBR-2 included coring from 420 to 890 m (to basement) and would take an additional 3 days.

Should LWD not be funded for Leg 156, 5.5 days become available. Should funding of the bottom-shot VSP not be approved, 0.75 days become available. Available time would be used in one of several possible scenarios, which will be discussed in more detail when more information is available in February.

Other Time Considerations

Additional time for cementing efforts may be required to assure adequate bonding of the casing to the formation for hydrologic seals and VSP quality. Additional hole abandoning/sealing efforts may be necessary to guard against damaging the décollement fluid regime by the exploratory holes.

SAFETY AND POLLUTION PREVENTION

The main issue related to safety and pollution is the penetration of fault zones. Previous drilling in this area penetrated both out-of-sequence thrusts (OOST's) and the main detachment zone (décollement). The pre-existing DSDP and ODP drill sites give a good preview of our proposed drilling. Previous drilling sampled all stratigraphic sections and discovered no hydrocarbon occurrences above background. There was no detection of free gas. There was no measurement of abnormal fluid pressures. Anecdotal data associated with hole instability suggest the possibility of overpressures at some of the décollement sites.

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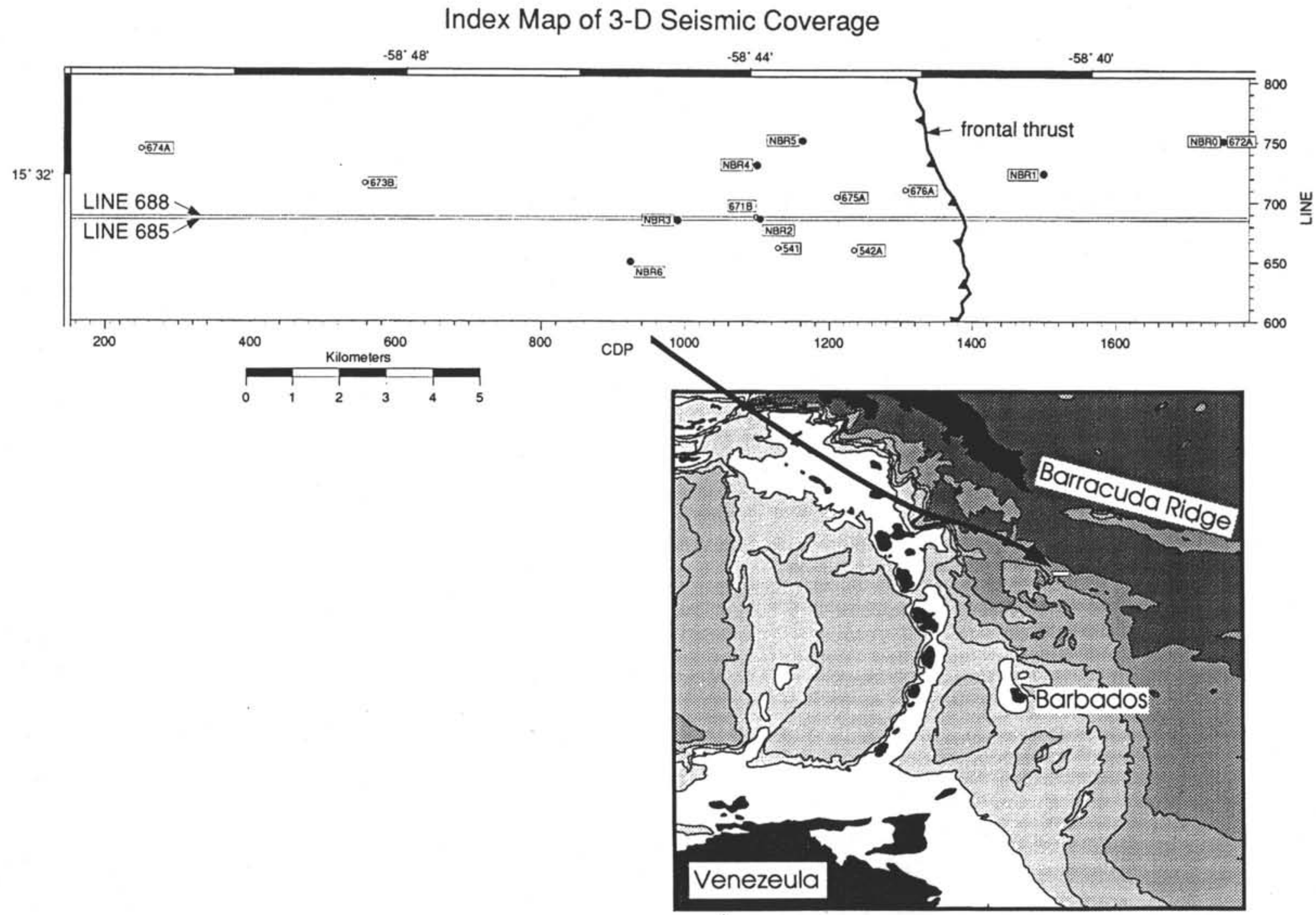


Figure 1. The 5 x 25 km 3-D seismic survey at top is shown at true scale at bottom-right. Proposed sites are solid circles, pre-existing sites are open circles. CDP and LINE numbers are along the bottom and right hand sides. Post-processing line separation is 25 m, CDP separation 15 m.

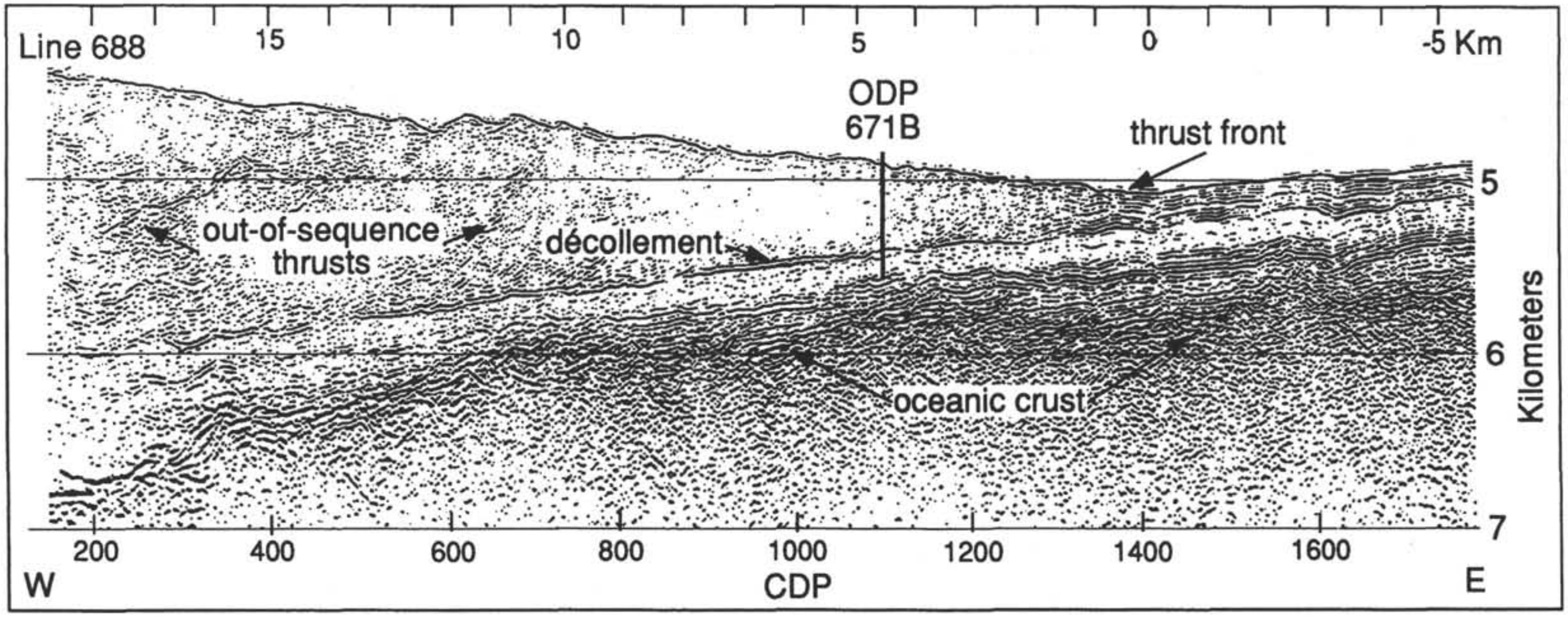


Figure 2. Relative true-amplitude depth section of east-west seismic Line 688 (passing through ODP Hole 671B) is example of seismic data. Even at this scale the décollement reflection clearly stands alone, separated by reflection-free intervals above and below, simplifying its study. Out-of-sequence thrusts become seismically identified westward of km 10. The velocity function used in migration and depth conversion started with DSDP/ODP data and then was modified by trail migration velocity studies.

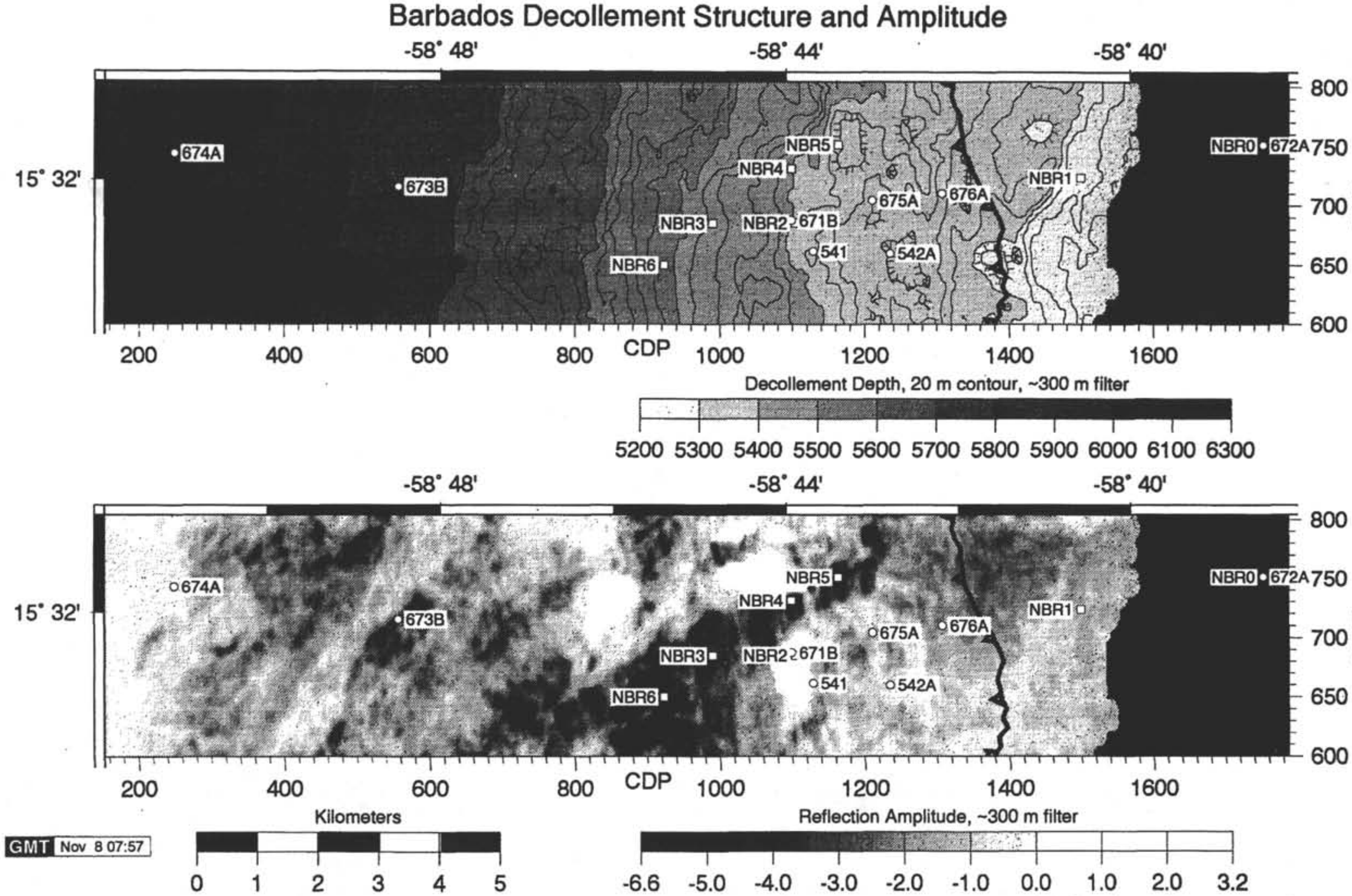


Figure 3. This map shows the structure (top) and amplitude of the generally negative-polarity fault- plane reflection. From previous work, the more negative parts of the fault zone indicate higher fluid content and higher porosity (Bangs and Westbrook, 1991). Modeling indicates the zone is 10-14 m thick. The big NE-trending "bright" area in the central part of the map may be a "pulse" of migrating fluids at abnormally high fluid pressures. In contrast, the isolated positive polarity sections of the fault zone may represent locally drained portions of the fault, producing a locally strong asperity. Note that Hole 671B, which drilled 150 m below the décollement, is located on one of these positive polarity features. The amplitude patterns are little influenced by overlying fault and fold geometry.

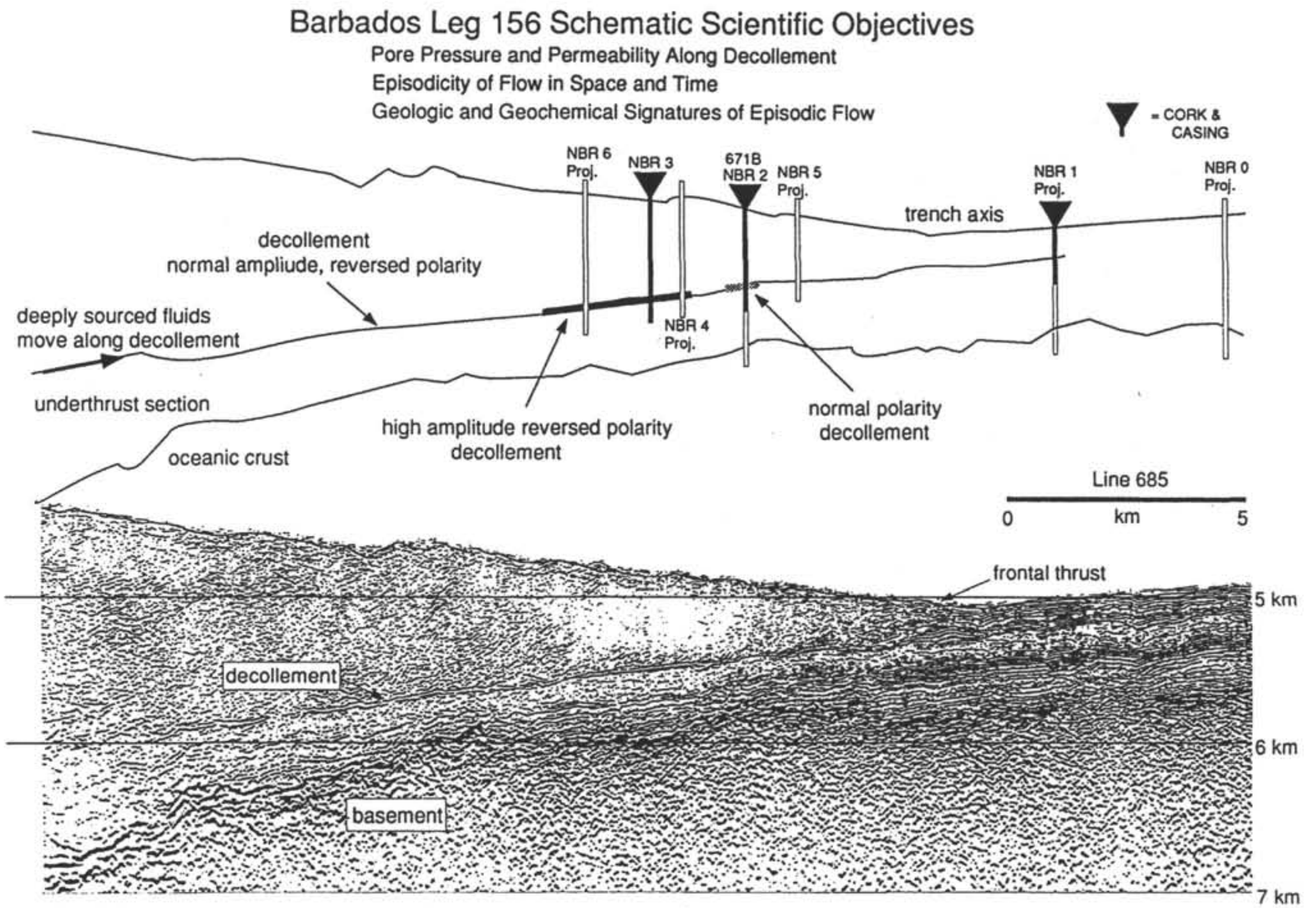
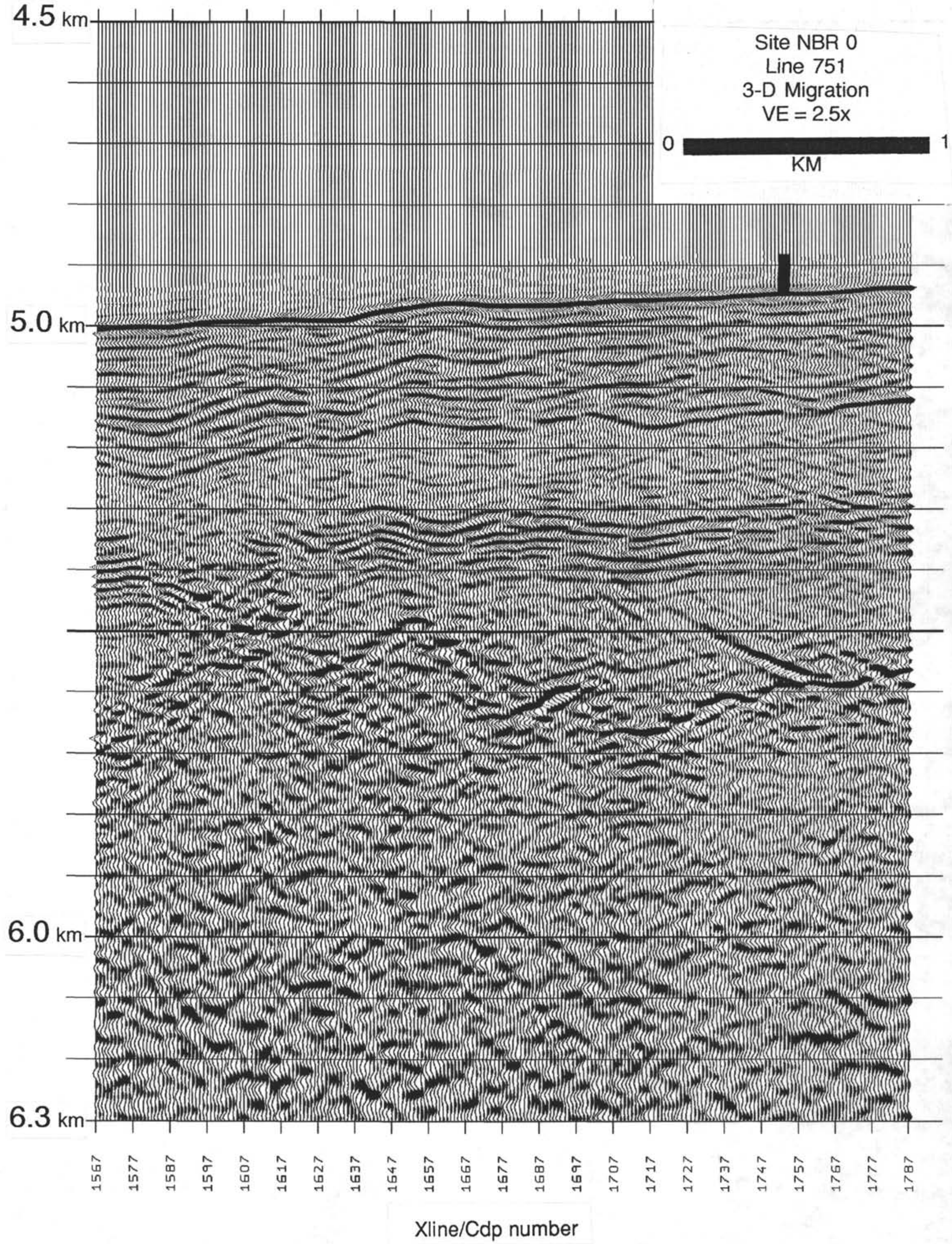


Figure 4. Basic cross section showing position of proposed drill sites (NBR-1, NBR-2, and NBR-3 are the primary sites; the others are alternates depending on circumstances, including time). Note that NBR-2 and NBR-3 are placed to sample the normal and reversed-phased seismic décollement. NBR-1 will sample the incipient disruptions at the stratigraphic equivalent of the décollement seaward of the frontal thrust.

Leg 156 Proposed Sites

Site	Latitude [1]	Longitude [1]	Line [2]	CDP [2]	Water Depth (m)	Décollement (mbsf)	Basement (mbsf)	Total Drill Depth (mbsf)	CORK
NBR-0	15.54004	-58.64083	751	1753	4947	216	641	691	ALT
NBR-1	15.53377	-58.67623	723	1500	5026	242	709	342	Yes
NBR-2	15.52526	-58.73164	685	1104	4910	490	890	590	Yes
NBR-3	15.52525	-58.74759	685	990	4852	623	1105	723	Yes
NBR-4	15.53553	-58.73234	731	1099	4932	486	768	568	ALT
NBR-5	15.54000	-58.72325	751	1164	4970	397	776	497	ALT
NBR-6	15.51743	-58.75696	650	923	4813	701	1232	801	

1. WGS-84 reference system using differential GPS
2. UTIG-processed April-93, 3-D



Site NBR 0
Line 751
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
1567
1577
1587
1597
1607
1617
1627
1637
1647
1657
1667
1677
1687
1697
1707
1717
1727
1737
1747
1757
1767
1777
1787
Xline/Cdp number

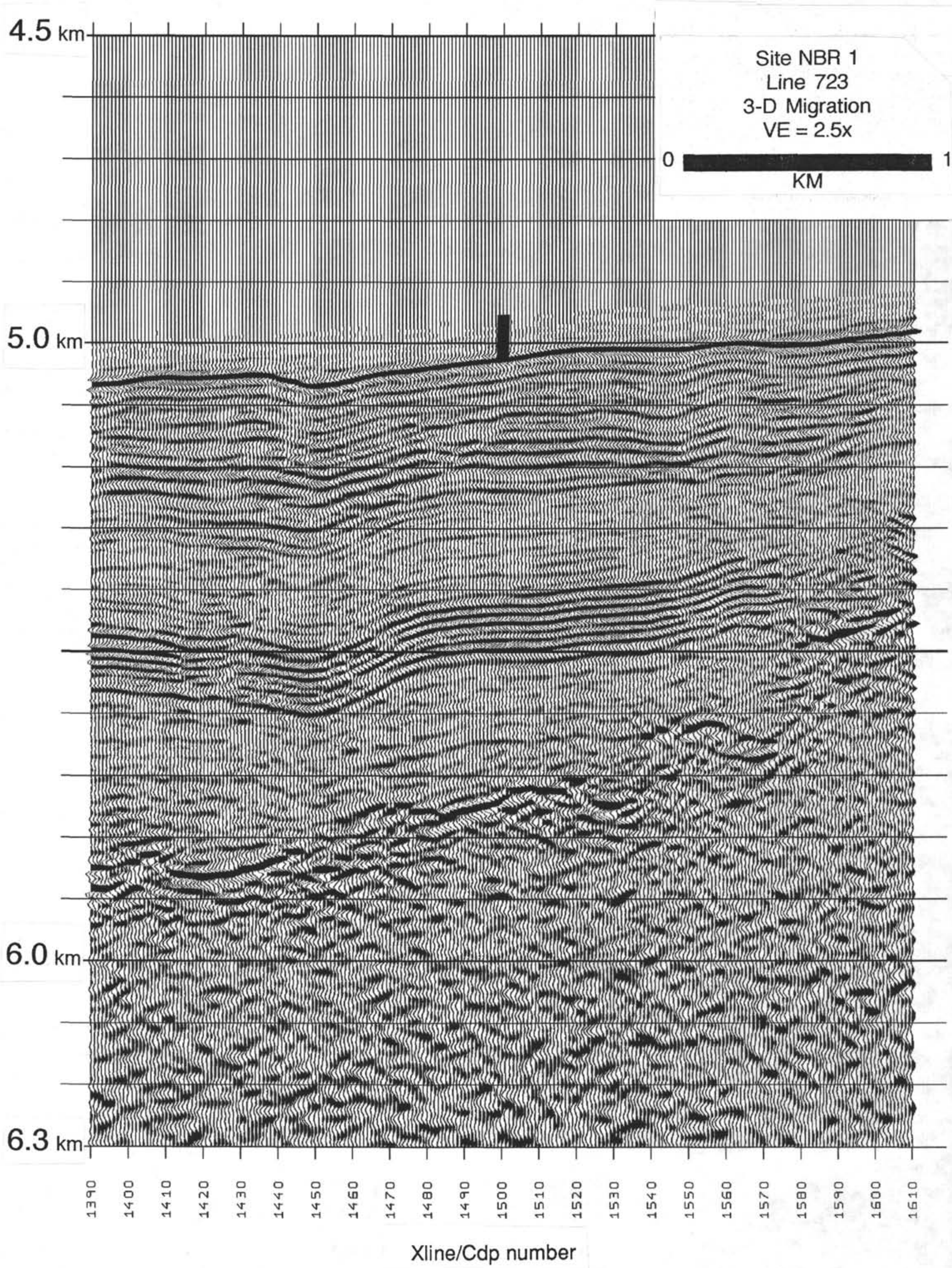
Site: NBR-0
Priority: 3
Position: 15.54004; -58.64083 - in WGS-84 reference system using differential GPS
Water Depth: 4947 m
Thickness: décollement - 216 mbsf; basement - 641 mbsf
Seismic Coverage: CDP 1753 Line 751 (UTIG-processed April-93, 3-D)

Objectives: Alternate reference site.

Drilling Program: XCB/RCB to 691 mbsf (T.D.).

Logging and Downhole Operations: -

Nature of Rock Anticipated: Nannofossil mud, radiolarian clay, and pelagic clays. Basement: MOR.



Site NBR 1
Line 723
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
1390
1400
1410
1420
1430
1440
1450
1460
1470
1480
1490
1500
1510
1520
1530
1540
1550
1560
1570
1580
1590
1600
1610
Xline/Cdp number

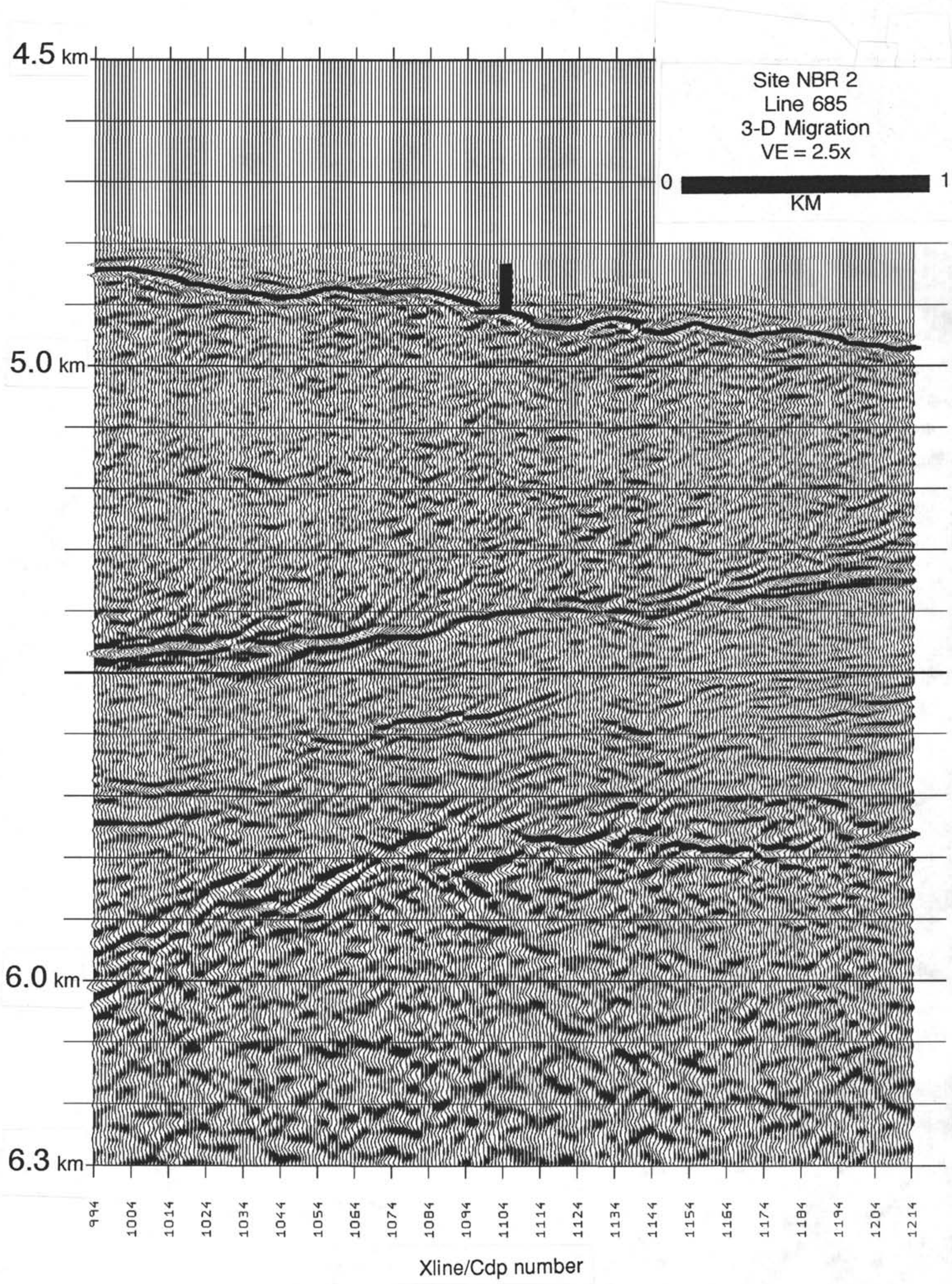
Site: NBR-1
Priority: 2
Position: 15.53377; -58.67623 - in WGS-84 reference system using differential GPS
Water Depth: 5026 m
Thickness: décollement - 242 mbsf; basement - 709 mbsf
Seismic Coverage: CDP 1500 Line 723 (UTIG-processed April-93, 3-D)

Objectives: To characterize the incipient fault zone.

Drilling Program: XCB/RCB to 342 mbsf (T.D.), CORK, and casing LWD.

Logging and Downhole Operations: WSTP, Packer, VSP, and Becker/Davis CORK string.

Nature of Rock Anticipated: Nannofossil mud, radiolarian clay, and pelagic clays. Basement: MOR.



Site NBR 2
Line 685
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
994
1004
1014
1024
1034
1044
1054
1064
1074
1084
1094
1104
1114
1124
1134
1144
1154
1164
1174
1184
1194
1204
1214
Xline/Cdp number

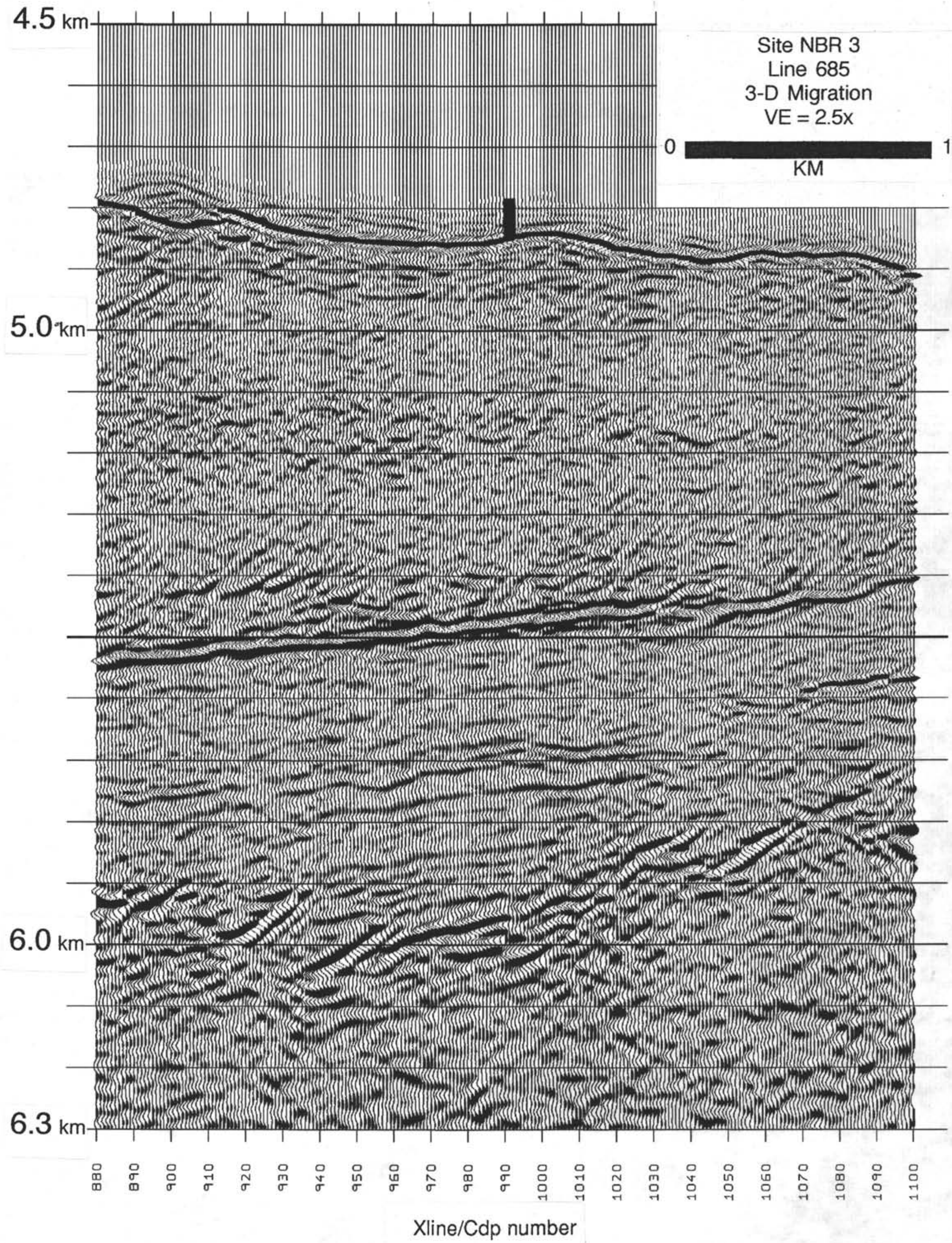
Site: NBR-2
Priority: 1
Position: 15.52526; -58.73164 - in WGS-84 reference system using differential GPS
Water Depth: 4910 m
Thickness: décollement - 490 mbsf; basement - 890 mbsf
Seismic Coverage: CDP 1104 Line 685 (UTIG-processed April-93, 3-D)

Objectives: To characterize the chemistry, fluid pressure, and permeability of the décollement. To place long-term temperature and pressure monitors in sealed hole, open at the décollement.

Drilling Program: XCB/RCB to 590 mbsf (T.D.), CORK, and casing LWD.

Logging and Downhole Operations: WSTP, Packer, VSP, and French CORK string with chemical samplers.

Nature of Rock Anticipated: Marls, chalk, clay, mud and siltstone, and pelagic clays at bottom. Basement: MOR.


4.5 km
5.0 km
6.0 km
6.3 km
Site NBR 3
Line 685
3-D Migration
VE = 2.5x
0
1
KM
880
890
900
910
920
930
940
950
960
970
980
990
1000
1010
1020
1030
1040
1050
1060
1070
1080
1090
1100
Xline/Cdp number

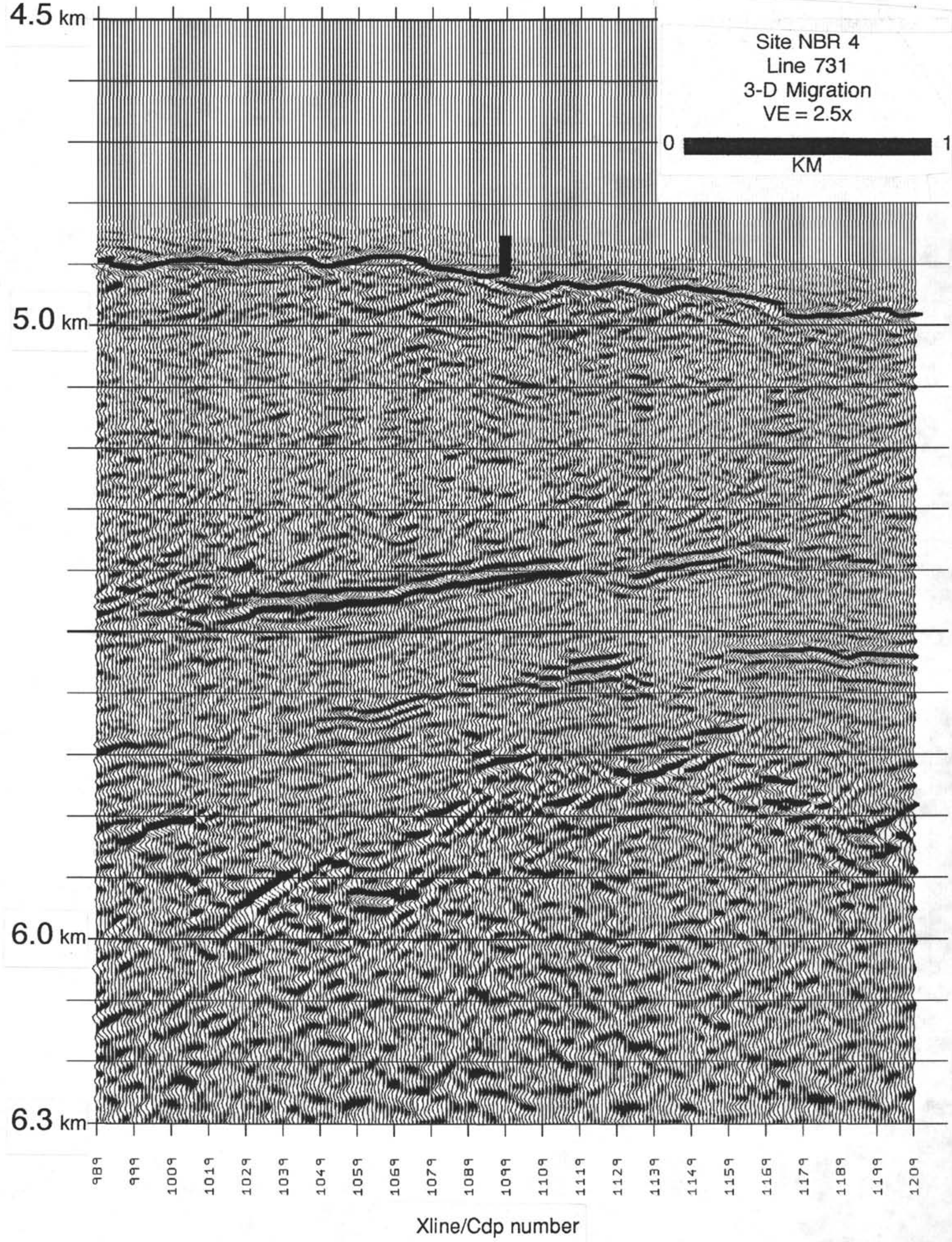
Site: NBR-3
Priority: 1
Position: 15.52525; -58.74759 - in WGS-84 reference system using differential GPS
Water Depth: 4852 m
Thickness: décollement - 623 mbsf; basement - 1105 mbsf
Seismic Coverage: CDP 990 Line 685 (UTIG-processed April-93, 3-D)

Objectives: To characterize the chemistry, fluid pressure, and permeability of the décollement. To place long-term temperature and pressure monitors in sealed hole, open at the décollement.

Drilling Program: XCB/RCB to 723 mbsf (T.D.), CORK, and casing LWD.

Logging and Downhole Operations: WSTP, Packer, VSP, and Becker/Davis CORK string with chemical sampler.

Nature of Rock Anticipated: Marls, chalk, clay, mud and siltstone, and pelagic clays at bottom. Basement: MOR.



Site NBR 4
Line 731
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
989
999
1009
1019
1029
1039
1049
1059
1069
1079
1089
1099
1109
1119
1129
1139
1149
1159
1169
1179
1189
1199
1209
Xline/Cdp number

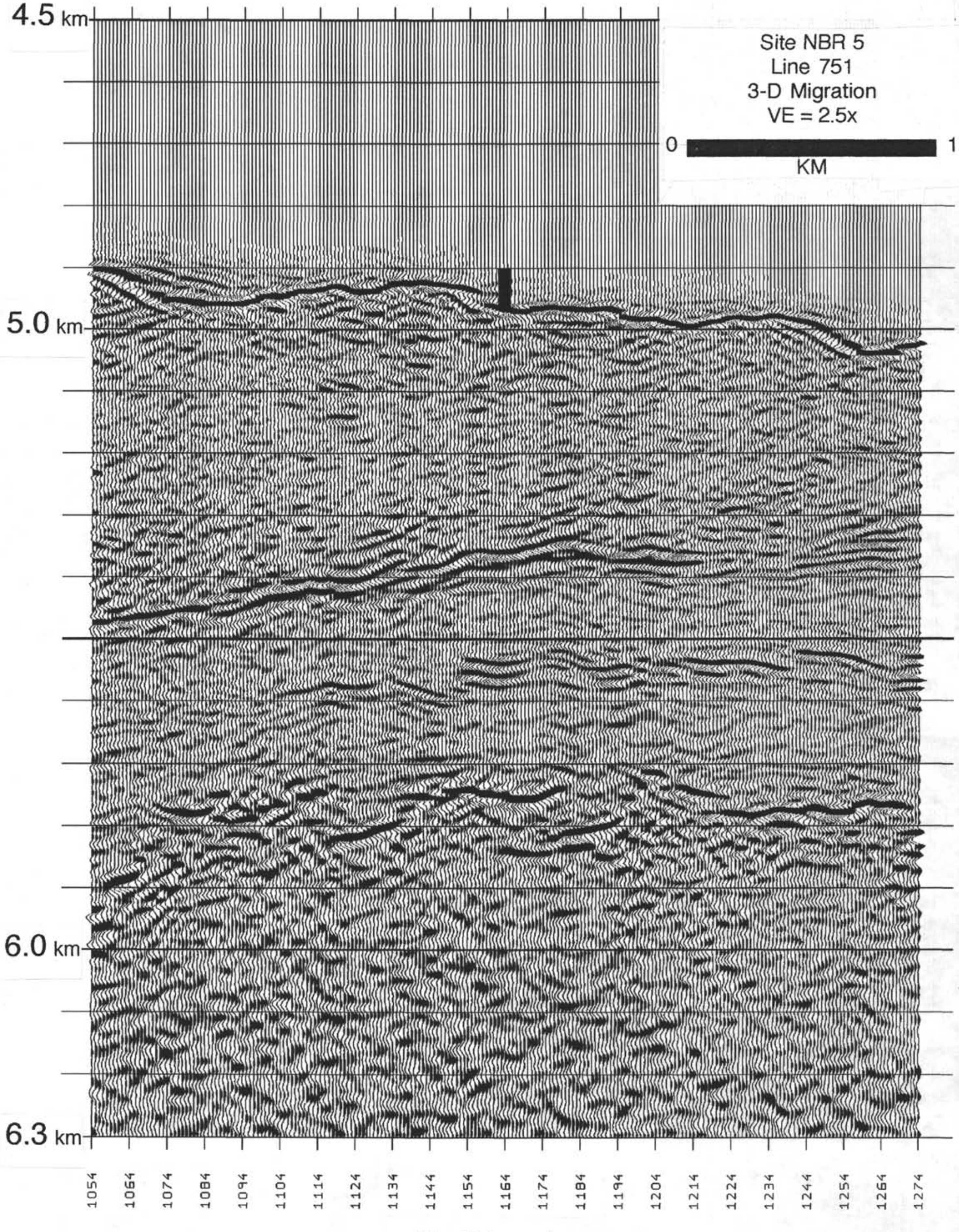
Site: NBR-4
Priority: 3
Position: 15.53553; -58.73234 - in WGS-84 reference system using differential GPS
Water Depth: 4932 m
Thickness: décollement - 486 mbsf; basement - 768 mbsf
Seismic Coverage: CDP 1099 Line 731 (UTIG-processed April-93, 3-D)

Objectives: To characterize the chemistry, fluid pressure, and permeability of the décollement. To place long-term temperature and pressure monitors in sealed hole, open at the décollement.

Drilling Program: XCB/RCB to 568 mbsf (T.D.), CORK, and casing. Alternate to proposed site NBR-3.

Logging and Downhole Operations: WSTP, Packer, VSP, and Becker/Davis CORK string with chemical sampler.

Nature of Rock Anticipated: Marls, chalk, clay, mud and siltstone, and pelagic clays at bottom. Basement: MOR.



Site NBR 5
Line 751
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
1054
1064
1074
1084
1094
1104
1114
1124
1134
1144
1154
1164
1174
1184
1194
1204
1214
1224
1234
1244
1254
1264
1274
Xline/Cdp number

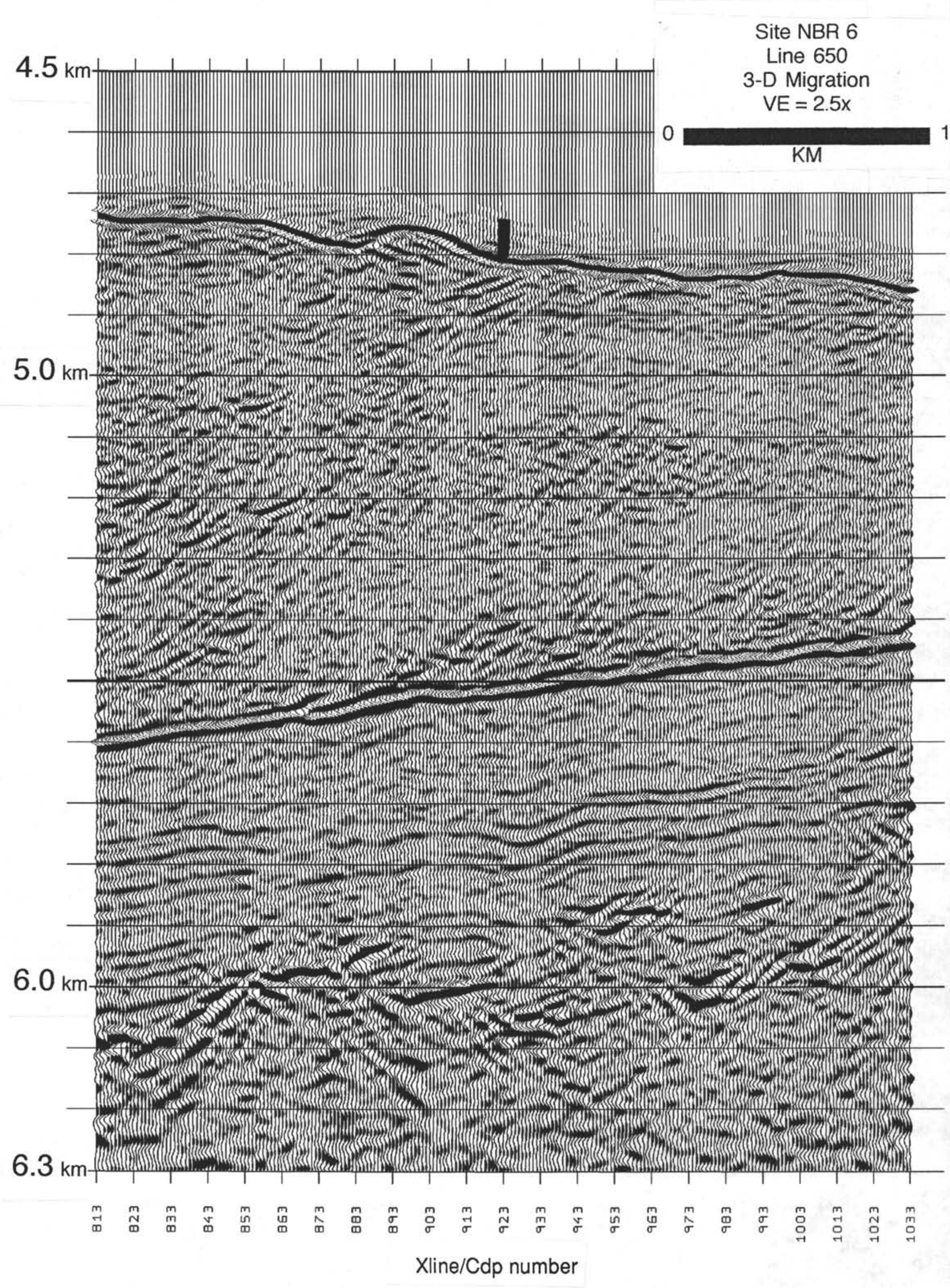
Site: NBR-5
Priority: 3
Position: 15.54000; -58.72325 - in WGS-84 reference system using differential GPS
Water Depth: 4970 m
Thickness: décollement - 397 mbsf; basement - 776 mbsf
Seismic Coverage: CDP 1164 Line 751 (UTIG-processed April-93, 3-D)

Objectives: To characterize the chemistry, fluid pressure, and permeability of the décollement. To place long-term temperature and pressure monitors in sealed hole, open at the décollement.

Drilling Program: XCB/RCB to 497 mbsf (T.D.), CORK, and casing. Alternate to proposed site NBR-3.

Logging and Downhole Operations: WSTP, Packer, VSP, and Becker/Davis CORK string with chemical sampler.

Nature of Rock Anticipated: Marls, chalk, clay, mud and siltstone, and pelagic clays at bottom. Basement: MOR.



Site NBR 6
Line 650
3-D Migration
VE = 2.5x
0
1
KM
4.5 km
5.0 km
6.0 km
6.3 km
813
823
833
843
853
863
873
883
893
903
913
923
933
943
953
963
973
983
993
1003
1013
1023
1033
Xline/Cdp number

Site: NBR-6
Priority: 3
Position: 15.51743; -58.75696 - in WGS-84 reference system using differential GPS
Water Depth: 4813 m
Thickness: décollement - 701 mbsf; basement - 1232 mbsf
Seismic Coverage: CDP 923 Line 650 (UTIG-processed April-93, 3-D)

Objectives: Addition of spatial sampling of fluid and physical properties of the prism and décollement.

Drilling Program: XCB/RCB to 801 mbsf (T.D.).

Logging and Downhole Operations: WSTP.

Nature of Rock Anticipated: Marls, chalk, clay, mud and siltstone, and pelagic clays at bottom. Basement: MOR.

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*Staffing schedule is subject to change.