OCEAN DRILLING PROGRAM

LEG 190 SCIENTIFIC PROSPECTUS

DEFORMATION AND FLUID FLOW PROCESSES IN THE NANKAI TROUGH ACCRETIONARY PRISM

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February 2000

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Scientific Prospectus No. 90

First Printing 2000

Distribution

Electronic copies of this publication may be obtained from the ODP Publications homepage on the World Wide Web at: http://www-odp.tamu.edu/publications

D I S C L A I M E R

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

Australia/Canada/Chinese Taipei/Korea Consortium for Ocean Drilling
Deutsche Forschungsgemeinschaft (Federal Republic of Germany)
Institut Français de Recherche pour l'Exploitation de la Mer (France)
Ocean Research Institute of the University of Tokyo (Japan)
National Science Foundation (United States)
Natural Environment Research Council (United Kingdom)
European Science Foundation Consortium for the Ocean Drilling Program (Belgium, Denmark, Finland, Iceland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, and Switzerland)
Marine High-Technology Bureau of the State Science and Technology Commission of the People's Republic of China

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

This Scientific Prospectus is based on precruise JOIDES panel discussions and scientific input from the designated Co-chief Scientists on behalf of the drilling proponents. 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 Manager 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 Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

Technical Editors: Karen K. Graber and Brenda Bridges

ABSTRACT

Leg 190 is the first of a two-leg program of drilling along two transects in the Nankai Trough, the type example of a convergent margin accreting a thick section of clastic sediments. The proposed sites will define the interrelationship of the dynamics of deformation and fluid flow processes in an accretionary prism characterized by thick terrigenous sediments. In situ measurements, including logging while drilling, will provide critical information on stress, pore pressures, and permeability. Sealing holes with advanced circulation obviation retrofit kits (ACORKs) will establish the framework for long-term observation of fluid flow parameters and fluid geochemistry. Our integrated structural, geochemical, and physical properties program will fully characterize the factors controlling development of this accretionary prism.

Leg 190 will focus on core recovery from sites in undeformed to highly deformed zones along the transects to investigate variability in deformational and hydrologic character. A second leg in 2001, Leg 196, will involve logging the sites drilled on Legs 131 and 190 to obtain a first-order picture of how physical properties change during accretion, as well as emplacing ACORKs for long-term monitoring of fluid flow processes.

INTRODUCTION

Earth scientists have long recognized the complex interplay of deformational, diagenetic, and hydrologic processes in developing mature mountain belts and have sought to understand the controls on and interactions among these fundamental processes. Accretionary prisms represent unique, accessible natural laboratories for exploring initial mountain building processes. The geometries and structures of accretionary prisms are relatively simple and have been well imaged seismically. Typically, the materials incorporated within prisms are only moderately altered from their original states, so competing active processes can often be isolated, quantified, and reproduced in the lab.

Studies of the processes occurring at convergent plate boundaries have established that fluids play a major role in how prisms and mountain belts evolve (e.g., Carson et al., 1990; Henry et al., 1989). Tectonic stresses lead to the expulsion of intergranular fluids through compaction of unlithified sediments (e.g., tectonic dewatering [Moore et al., 1986] or shear dewatering [Bray and

Karig, 1988], whereas thermal alteration of primary minerals produces excess fluids by dehydration (Moore and Vrolijk, 1992). These fluids move through the system under pressure gradients; the paths they take depend on the intergranular and fracture permeability of the rock. In turn, trapped fluids can induce high pore pressures, which may favor brittle deformation and the production of more fractures and discrete faults, thereby enhancing fluid flow. Thermal and chemical changes introduced by fluid flow may lead to mineralogical alteration or growth of authigenic phases. Chemical species transported by fluids may be deposited during flow, mineralizing and sealing fracture conduits, or cementing and strengthening grain contacts. In regions of substantial flow, advective transport may play an important role in chemical and thermal budgets. The magnitude of flow and dissolved mass transport and their effect on the global chemical balance are largely unknown and may rival that of mid-ocean ridges. Lithification of accreted materials through the interaction of physical and chemical processes leads the prism to become rigid enough to accumulate strain energy which is eventually released as mega-earthquakes.

The Nankai Trough accretionary prism represents an "end-member" prism accreting a thick terrigenous sediment section in a setting with structural simplicity and unparalleled resolution by seismic and other geophysical techniques. It, thus, represents a superb setting to address ODP's Long Range Plan objectives for accretionary prism coring, in situ monitoring, and refinement of mechanical and hydrological models. In this prospectus, we present a plan for drilling at the Nankai margin that carefully targets sites for coring, in situ observation, and long-term monitoring (1) to constrain and resolve aspects of prism hydrology and mechanics and (2) to test existing models for prism evolution. Two legs are planned: Leg 190, in mid-2000, will focus on coring and sampling the prism along two transects within a three dimensional (3-D) seismic survey (Fig. 1). Leg 196, in 2001, will use logging-while-drilling (LWD) technology to collect in situ physical properties data and install ACORKs (advanced circulation obviation retrofit kits; Davis et al., 1992) for long-term monitoring of prism processes.

BACKGROUND

Geological/Geophysical Database

The geological and geophysical database for the Nankai prism is exceptional. Existing data sets include high-quality industry and academic seismic reflection/refraction data (Aoki et al., 1982; Karig, 1986; Moore et al., 1990, 1991; Stoffa et al., 1992), complete swath bathymetry and side-scan coverage (Le Pichon et al., 1987; Taira and Ashi, 1993), heat-flow measurements (Kinoshita and Yamano, 1986) and three Deep Sea Drilling Project (DSDP)/Ocean Drilling Program (ODP) legs (DSDP Legs 31 and 87; ODP Leg 131). Newly acquired 3-D seismic data (*Ewing* 9907/8) were used to locate some of the proposed sites (Fig. 2). The seismic data provide excellent images of the décollement, proto-thrust zone (PTZ), and various structural domains landward of the frontal thrust to guide our choice of drilling targets, and the well-constrained seismic velocities provide the basis for models of dewatering. The swath bathymetry and side-scan data reveal surficial features to further guide siting of drill holes. The heat-flow data and submersible observation of the seafloor are valuable for hydrologic modeling and indicate that subsurface fluid flow must be significant in both the sediments of the Nankai accretionary prism and the oceanic crust of the Shikoku Basin.

Geologic Setting

The Nankai Trough is the topographic expression of the subduction boundary between the Shikoku Basin and the Southwest Japan Arc (Fig. 1). The Shikoku Basin is part of the Philippine Sea plate, which is subducting to the northwest under Japan at a rate of 2-4 cm/yr (Karig and Angevine, 1986; Seno, 1977), approximately normal to the plate margin. Active sediment accretion is presently taking place at the Nankai Trough. The record of accretion extends landward to Shikoku Island, where older accretionary prism rocks are exposed. The Cretaceous and Tertiary Shimanto Belt is characterized by imbricated thrust slices of trench turbidites and melanges composed of ocean-floor basalts, pelagic limestone and radiolarian chert and shale, and hemipelagic shale (Taira et al., 1988). The youngest part of the Shimanto Belt is early Miocene in age. The Shimanto Belt is interpreted as a direct ancient analog of the Nankai accretionary prism.

The well-resolved seismic profiles demonstrate several characteristic structural subdivisions across the accretionary prism. Based on the multichannel seismic (MCS) Profile 141 obtained by the *Ewing* 9907/8 cruise, the accretionary prism can be divided into several tectonic domains from the trench landward (Fig. 3): Nankai Trough axis zone, proto-thrust zone (PTZ), imbricate thrust zone (ITZ), first out-of-sequence thrust (OOST) zone, large thrust slice zone (LTSZ), and landward-dipping reflectors zone (LDRZ).

Nankai Trough Axis Zone

Legs 87 (Site 582) and 131 results indicate that the stratigraphy of the trench floor is composed of the following lithologic units in descending order: trench turbidites (Holocene-Pleistocene), turbidite-hemipelagite transition (Pleistocene), hemipelagite with tephra layers (early Pleistocene-late Pliocene), massive hemipelagite (mid-Pliocene to mid-Miocene), acidic volcaniclastics (15 Ma), and pillow basalts (16 Ma).

An additional unit is recognized within the surrounding Shikoku Basin sequence that is not present in the local trench stratigraphy on MCS Profile 141. This unit is characterized by a well-stratified sequence about 0.7 s thick. DSDP Leg 31 recovered Pliocene sands from a correlative seismic unit indicating that this unit may be composed of Pliocene-Miocene turbidites (hereafter called Pliocene-Miocene Turbidite Unit).

Proto-Thrust Zone (PTZ)

This area represents a zone of incipient deformation and initial development of the décollement within the massive hemipelagic unit. Above the décollement, the sediment thickness increases landward, probably due to tectonic deformation with the development of small faults and ductile strain as documented by Morgan and Karig (1995a, 1995b).

Imbricate Thrust Zone (ITZ)

Landward of the PTZ, a zone of well developed seaward-vergent imbricate thrusts can be recognized. The thrusts are sigmoidal in cross section with a mean angle of about 30° and typical thrust spacing of 0.5 km. The seaward edge of the ITZ marks the deformation front. One DSDP and one ODP leg were dedicated to coring at the frontal part of the imbricated thrust zone: Site 583 of DSDP Leg 87 and Site 808 of ODP Leg 131.

Site 583 is situated on the hanging wall of the frontal thrust. Although drilling failed to penetrate the décollement zone, good quality physical properties measurements were obtained from all of the holes, providing evidence that sediments dewater under tectonic stresses as they are accreted (Bray and Karig, 1988). The pore-water concentration depth profiles from these sites are far from being detailed enough to provide insight into the nature of fluid flow at this segment of the Nankai Trough (Kastner et al., 1993). The significant geochemical findings were that organic-fueled diagenesis is intense, and that at ~600 mbsf methane concentrations and the C_1/C_2 ratios abruptly decrease. Interestingly, similar abrupt decreases were observed at the décollement zone at Site 808. Fluid flow from a deep-seated source could explain these observations.

Site 808 (Fig. 4), which penetrated the whole prism and reached oceanic basement at 1290 mbsf during Leg 131, was particularly successful in terms of physical properties and structural geology measurements because of relatively high recovery rates and also because the sediments yielded consistently high-quality paleomagnetic data (Taira et al., 1991; 1992). These data allowed individual core sections and, in some cases, individual structural samples to be oriented relative to the present geographic coordinates. Physical properties generally varied smoothly downhole, except for sharp discontinuities across the frontal thrust and décollement zones. Discrete structures showed distinct concentrations in the vicinity of the fault zones as well as at several horizons above the décollement zone.

Pore waters were recovered throughout the sediment section at Site 808, including the frontal thrust, décollement zone, and underthrust package. Depth profiles for chemical concentrations and isotopic ratios (particularly D, O, Sr, and He) do not support active fluid flow along the décollement, despite its distinct reverse polarity seismic reflection, nor along the frontal thrust. They do, however, support lateral fluid flow (1) below the décollement at the approximate depth of the minimum in Cl concentration (~1100 mbsf) and (2) above the décollement along a horizon marking the lithological boundary between the volcanic-rich and -poor members of the Shikoku Basin sediments (~820 mbsf). The nature of the fluid flow, whether steady state or episodic, is as yet unresolved. Cores recovered from Site 808 also revealed that fractures within the décollement zone have not been mineralized; the overpressured décollement appears to form a leaky dynamic seal preventing significant lateral or vertical fluid flow. This contrasts with the situations at Barbados and Peru where the major tectonic structures have been mineralized, implying continuous confined fluid flow.

First Out-of-Sequence Thrust (OOST) Zone

About 20 km landward from the deformation front, the imbricate thrust packages are overthrust by a younger generation fault system. Because this fault system cuts the preexisting sequence of imbricate thrusts, it is called an OOST. Important and significant deformation also appears within the underthrust Shikoku Basin hemipelagite. The hemipelagic unit seems to be tectonically thickened, probably as a result of duplexing.

Large Thrust Slice Zone (LTSZ)

This zone is characterized by the development of at least four distinctive out-of-sequence thrusts that separate tectonic slices of either previously imbricated packages or relatively coherent sedimentary sequences. The coherent slices are composed of ~0.7-s-thick (maximum) stratified layers that closely resemble the Plio-Miocene Turbidite Unit recognized in depressions in the Shikoku Basin. Underneath these thrust slices, there are packages of strong reflectors that may be composed of thickly underplated Shikoku Basin hemipelagic units. Slope sediment in this zone shows landward tilting suggesting recent active uplift. Bottom-simulating reflectors (BSRs) are weakly developed in this zone and are patchy.

Landward Dipping Reflectors Zone (LDRZ)

This zone is characterized by landward dipping, semicontinuous strong reflectors. This zone seems to be divided into several discrete packages by thrust faults. Because the uppermost slope sediment layer is relatively undeformed, some of these faults may not have been active for some time. This zone might be composed of more rigid or consolidated sediments compared with the previous zones closer to the trench axis. A BSR is well developed throughout this zone and diminishes abruptly at the boundary between this zone and the LTSZ.

Along-Strike Variation

The structural domains described above show variation along the strike of the prism. Along two parallel transects, separated by about 100 km, sharp differences in prism architecture and structure are evident. The western transect, which includes Leg 87 sites (Fig. 5), displays a well developed PTZ, containing a series of subparallel dipping discontinuities of unknown origin. These features are not evident within the eastern PTZ (Leg 131 and Profile 141 region). Differences in prism taper and seismic character of the décollement along the two transects suggest that the mechanical behavior of the prism differs along strike and that this variability may result from significant differences in pore pressures and fluid-flow regimes at the two locations.

SCIENTIFIC OBJECTIVES

Structural and Hydrologic Evolution of the Décollement Zone

The nature of the décollement zone along the transect remains a big puzzle. Seismic profiles across the transect represent the décollement as a reverse polarity reflection that extends well in front of the deformation front; this has been interpreted to indicate (1) the presence of fluids along a high-porosity fault zone and (2) probably the presence of high pore pressures (Moore and Shipley, 1993). The décollement zone was penetrated at Site 808 and revealed itself to be a 20-m-thick zone of intensely fractured sediment, with evidence for shear-induced brecciation, pore collapse, and local phyllosilicate reorientation (Byrne et al., 1993). Sediments from within the décollement have much lower porosities than samples from above and below. A subtle mottled texture in some samples led Maltman et al. (1993) to infer localized zones of elevated fluid pressure within the zone. The normal polarity seismic reflection marking the décollement beneath the western prism toe has not been sampled. We need to sample the décollement zone at critical points beneath the Nankai prism and PTZ to document the spatial variations in structure and fluid pressure to test these hypotheses of décollement formation and evolution.

Fluid Flow Paths and Chemical Gradients

The origin of the Cl concentration depth profile is of great importance to the understanding of the hydrogeochemistry of the Nankai Trough eastern region. Site 808 is characterized by a broad region of lower than seawater Cl concentration (~20% seawater dilution) within the Shikoku Basin hemipelagic section (~560-1240 mbsf), with a minimum concentration in the underthrust section at ~1100 mbsf (Kastner et al., 1993). Preliminary one-dimensional modeling of this profile excludes the possibility of in situ production of water, hence requiring its introduction from elsewhere. The chemical and isotopic signatures of the pore fluids indicate a deep-seated elevated temperature (>150°C) source. It seems that a combination of active or episodic lateral fluid flow along one or more sediment horizons and fluid advection may be responsible for this strikingly broad Cl profile. The sites along the eastern transect will be aimed at understanding lateral variability of fluid flow.

Spatial Distribution and Temporal Progression of Deformation

Although core recovery at Site 808 was exceptional and physical properties and structural observations complete, the results yield only a one-dimensional view of the interior of the Nankai prism. We have almost no constraint on how various fabrics, structures, physical properties, or geochemistry vary along and across strike or how these variations translate over time. This lack of spatial and temporal control makes it nearly impossible to determine the relationships between deformation, diagenesis, and fluid flow. However, first-order predictions for the distribution of physical properties and structures in two dimensions and the role of fluid pressures in their evolution have been made based on high-quality seismic images, velocities, and dispersed core data. The results provide models to test and guide the selection of future drill sites at the Nankai Trough, as well as the associated sampling and analysis. To test this distribution of structures and the role of diagenesis and fluid pressure in its development and to obtain better constraints on physical properties from which these models are derived, across-strike drill holes are desperately needed. Site ENT-03A should represent a less deformed analog to Site 808, penetrating the incipient thrust fault in the PTZ as well as the vertically thickened sediments in the footwall. Sites ENT-06A and 07A will penetrate a highly deformed and evolved portion of the prism. Site ENT-04A will characterize the intermediate zone in terms of deformation and chemical gradient.

Contrasting Deformational and Fluid Flow Behavior Along Strike

Seismic profiles of the western and eastern transects across the prism indicate significant differences in prism architecture, structure, and physical properties in the two locations. These are assumed to reflect variances in fluid-flow regimes, but, to date, the mechanisms responsible for such variability are unknown. Structural differences between the western and eastern regions suggest that there may be significant variation in how deformation is accommodated along the two transects; this contrast in behavior may also shed some light on the hydrologic differences. The taper of the prism toe along the western transect (8°-10°; Fig. 5) is greater than that of the eastern toe (4°-5°; Fig. 3), a situation that may arise from relatively stronger décollement to the west or lower internal sediment strength. A strong décollement might arise from a lack of pressurized fluids within the fault zone, consistent with the normal polarity reflection. Alternatively, this difference in strength might be due to a variation in clay mineralogy in the décollement zone. Site WNT-01A will drill through the upper 300 m of the section previously cored at Site 582 and will core the subducting sediment section to document its clay mineralogy.

The western PTZ also contains an enigmatic series of closely spaced dipping seismic discontinuities, which are absent to the east (Fig. 5). Their origin is unclear, but they may mark zones of concentrated fractures that may serve as dewatering conduits. The presence of such fractures in the PTZ would also point to a more brittle mode of deformation, which can be induced by localized high pore pressures. Drilling through the western PTZ is a secondary objective aimed at understanding these features and their roles in defining the hydrology of the prism toe. A comparison of these structures with observations from the eastern PTZ will elucidate the dissimilarities in internal sediment strength and behavior between the two regions, which is critical to distinguishing the different effects of material properties and fluid pressures in how these sediments deform.

DRILLING STRATEGY

To provide structural, physical properties, and geochemical gradients across the accretionary prism, Leg 190 will core a series of sites along the eastern Nankai transect, including a reference site (Site ENT-01A), one into the PTZ (Site ENT-03A), two sites into the out-of-sequence thrusts (OOSTs) higher on the slope (Sites 06A and 07A), and a reference site along the western transect (WNT-01A). Alternate sites are in the OOST (Sites ENT-04A and ENT-05A), the LDRZ (Sites ENT-08A and 09A), and the western PTZ (Site WNT-03B). Experience on Legs 87 and 131 has shown that the shallow sedimentary section usually contains thick beds of poorly consolidated sand. Casing the upper part of Hole 808C on Leg 131 provided enough stability to allow drilling to proceed to more than 1300 m. Since Site ENT-03A is close to Hole 808, we have included a deployment of drill-in casing (DIC) in the operations time estimate to ~100 mbsf at this site. We will have additional drill-in-casing capabilites for other sites, if required. Core recovery on Leg 131 was good after stabilizing the shallow sands, so we anticipate similar success on Leg 190. Sites ENT-01A, 03A, and 06A will use advanced hydraulic piston corer (APC)/extended core barrel (XCB) to ~350 mbsf and rotary core barrel (RCB) to total depth (TD). Site ENT-07A will use only APC/XCB and, and Site WNT-01A will use only RCB.

LOGGING PLAN

Because Leg 196 will conduct LWD operations at the Leg 190 sites, we will have a minimal logging program on Leg 190. Following coring operations at the reference site (Site ENT-01A), we will run the triple combo and Formation MicroScanner (FMS)/sonic tool strings and then carry out a vertical seismic profile (VSP) with the well seismic tool (WST). The triple-combo string includes natural gamma ray, neutron porosity, density, and resistivity tools and will be deployed with Lamont-Doherty Earth Observatory temperature/acceleration/pressure (LDEO-TAP) tool. The FMS/sonic string includes the FMS, the dipole shear sonic imager (DSI) or long-space sonic sonde, and the LDEO-TAP tool. A VSP will be conducted with the three component WST with shots conducted at three levels. No logging is planned at any other site during Leg 190.

SAMPLING STRATEGY

Sampling guidelines and policy are available at the following Web site URL: http://www-odp.tamu.edu/publications/policy.html. The Sample Allocation Committee (co-chiefs, staff scientist, and ODP curator onshore and curatorial representative on board ship) will work with the entire scientific party to formulate a formal leg-specific sampling plan for shipboard and postcruise sampling. Modification of the strategy during the leg must be approved by the co-chiefs, staff scientist, and curatorial representative on board ship.

The minimum permanent archive will be the standard archive half of each core. All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

At each Leg 190 site, the APC/XCB hole will only overlap the RCB hole by ~10 m. Therefore, there will only be one copy of the section available for core description and sampling. In some critical intervals (e.g., faults, décollement, veins, etc.) there may be considerable demand for samples from a limited amount of recovered core material. These intervals may require special handling, a higher sampling density, or reduced sample size. A coordinated sampling plan may be required before critical intervals are sampled.

PROPOSED SITES

Primary Sites

Site ENT-01A

Proposed Site ENT-01A is a reference site to be drilled to basement seaward of the décollement tip to provide baseline physical properties and fluid flow measurements.

Site ENT-03A

Proposed Site ENT-03A will drill through the PTZ to sample a zone of incipient deformation and fluid flow. This site would penetrate into the subducting sediment section all the way to basement. A high priority is to sample pore fluids in great detail across the extensions of the 560 mbsf, 820 mbsf, décollement, and 1100 mbsf boundaries.

Site ENT-06A

Proposed Site ENT-06A will drill through the LTSZ and OOST to sample and investigate the nature of lithology, defomation, physical properties gradient, and fluid flow path within the older part of the accretionary prism. The penetration would be 800 mbsf. Fluid sampling across the OOST is a high priority at this site.

Site ENT-07A

Proposed Site ENT-07A will penetrate the slope sediments which cover the LTSZ. Investigation of the age and lithological characteristics would provide information on the history of accretion and deformation of the prism. The drilling plan is to conduct APC/XCB to refusal.

Site WNT-01A

Proposed Site WNT-01A is a seaward reference site in the western transect.

Alternate Sites

Site ENT-02A

Proposed Site ENT-02A is an alternate to ENT-01A, the reference site.

Site ENT-04A

Proposed Site ENT-04 would drill through the first OOST zone to sample deformed accreted sediments and across the seaward edge of the OOST. This site would provide information on the gradient of deformation and chemistry of fluid intermediate between the less deformed section (Sites ENT-01A and ENT-03A) and highly deformed and lithified section (Site ENT-06A).

Site ENT-05A

Proposed Site ENT-05A is located to penetrate slope basin sediments and the seaward-most OOST.

Site ENT-08A

Proposed Site ENT-08A is an upper-slope site that would sample slope sediments, an older portion of the accretionary prism in the LDRZ, and gas hydrates.

Site ENT-09A

Proposed Site ENT-09A is an upper-slope site that would sample slope sediments, an older portion of the accretionary prism in the LDRZ, and gas hydrates.

Site WNT-02A

Proposed Site WNT-02A is a site that would penetrate the frontal thrust in the western transect.

Site WNT-03B

Proposed Site WNT-03B is located in the proto-thrust zone to explore conditions of initial deformation (ductile strain and seismic discontinuities) and the nature of the décollement in comparison with the eastern transect.

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FIGURE CAPTIONS

Figure 1. ODP Leg 190 Nankai Trough drilling area, 3-D (dark gray shaded rectangle) and regional (light gray shaded lines) seismic data, and previous DSDP/ODP drill sites (black squares). Large rectangle outlines area shown in Figure 2. The straight arrow shows the convergence direction of the Shikoku Basin beneath Japan. Inset is a tectonic map of the Philippine Sea region that includes the Nankai Trough.

Figure 2. Bathymetric map of the Nankai margin south of Shikoku showing the location of the 1999 3-D seismic survey (gray rectangle), proposed Leg 190 Eastern Nankai Trough drill sites (stars), Site 808 (black square), and Line 141-2D. Primary sites are indicated by larger site numbers.

Figure 3. **A**. Line drawing interpretation of seismic Line 141-2D. **B.** Interpreted cross section showing location of proposed Leg 190 sites. Primary sites are in bold.

Figure 4. Correlation between seismic data and porosity at Site 808, ODP Leg 131 (after Taira, Hill, Firth, et al., 1991; Taira et al., 1992).

Figure 5. Regional seismic reflection line across the toe of the western Nankai Trough (WNT) accretionary prism showing locations of previous Deep Sea Drilling Project (DSDP) drill sites and proposed alternate Leg 190 sites in the WNT. PTZ = proto-thrust zone.

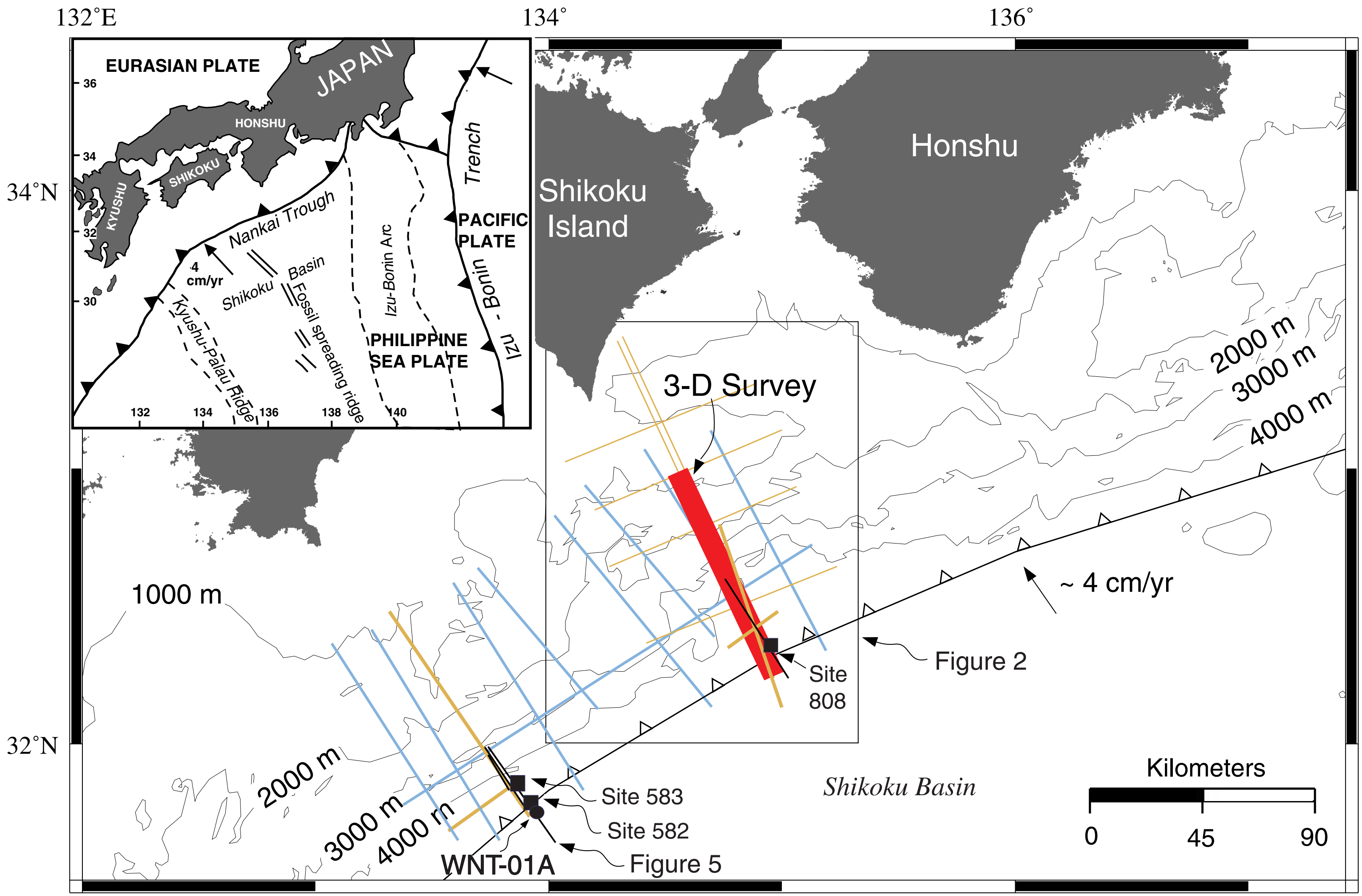

132˚E
134˚
136˚
34˚N
32˚N
EURASIAN PLATE
JAPAN
HONSHU
SHIKOKU
KYUSHU
Nankai Trough
Trench
PACIFIC PLATE
4 cm/yr
Shikoku
Basin
Fossil spreading ridge
Izu-Bonin Arc
Izu - Bonin
Kyushu-Palau Ridge
PHILIPPINE SEA PLATE
36
34
32
30
132
134
136
138
140
Shikoku Island
Honshu
3-D Survey
2000 m
3000 m
4000 m
1000 m
~ 4 cm/yr
Figure 2
Site 808
Site 583
Site 582
Figure 5
WNT-01A
Shikoku Basin
Kilometers
0
45
90

Figure 1

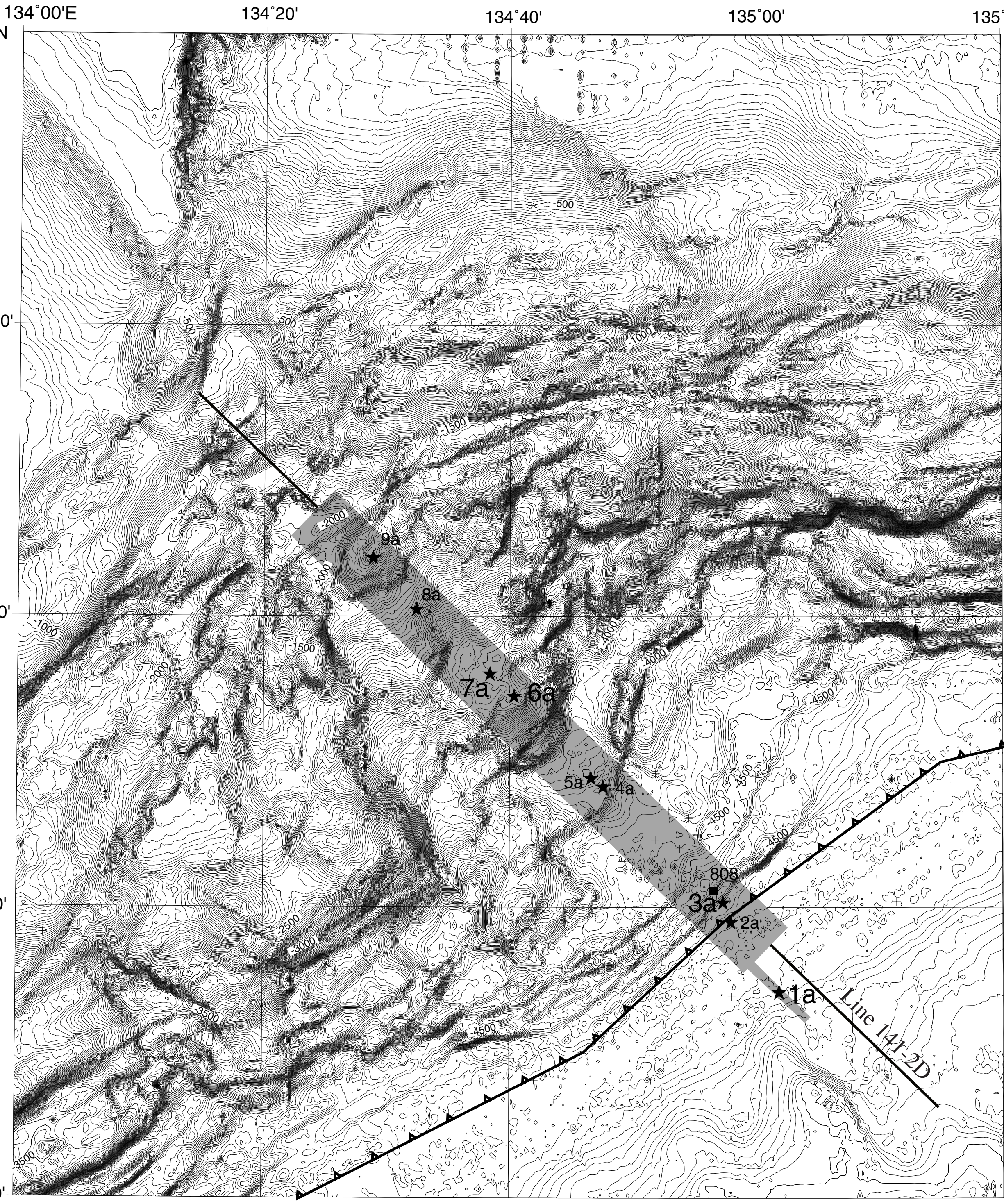
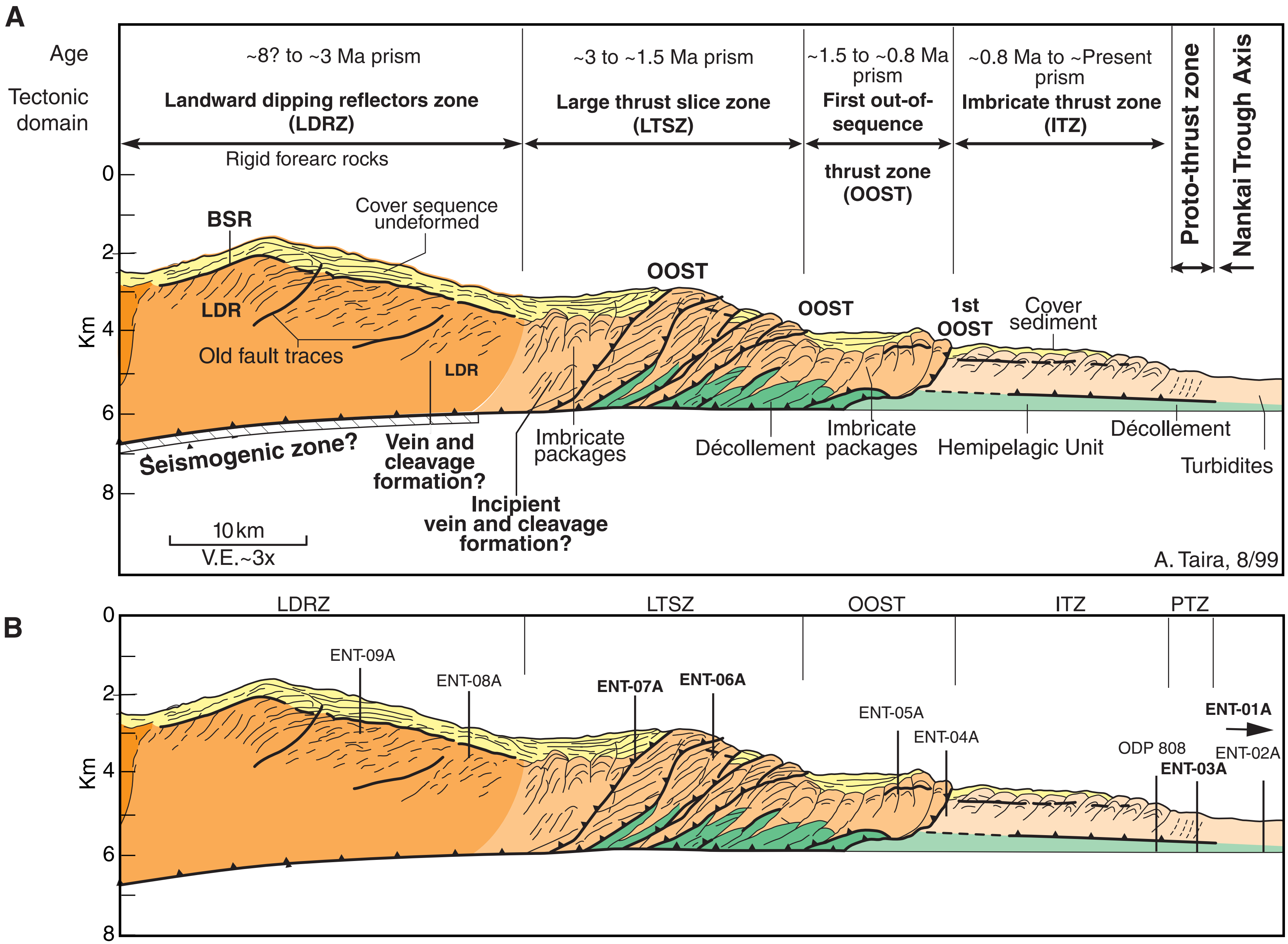

134˚00'E
134˚20'
134˚40'
135˚00'
135˚20'
33˚20'N
33˚00'
32˚40'
32˚20'
32˚00'
9a
8a
7a
6a
5a
4a
808
3a
2a
1a
Line 141-2D
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500

Figure 2



A
Age
Tectonic domain
~8? to ~3 Ma prism
Landward dipping reflectors zone (LDRZ)
Rigid forearc rocks
~3 to ~1.5 Ma prism
Large thrust slice zone (LTSZ)
~1.5 to ~0.8 Ma prism
First out-of-sequence
thrust zone (OOST)
~0.8 Ma to ~Present prism
Imbricate thrust zone (ITZ)
Proto-thrust zone
Nankai Trough Axis
BSR
Cover sequence undeformed
LDR
Old fault traces
LDR
OOST
OOST
1st OOST
Cover sediment
Km
0
2
4
6
8
Seismogenic zone?
Vein and cleavage formation?
Incipient vein and cleavage formation?
Imbricate packages
Décollement
Imbricate packages
Hemipelagic Unit
Décollement
Turbidites
10 km
V.E.~3x
A. Taira, 8/99
B
LDRZ
LTSZ
OOST
ITZ
PTZ
ENT-09A
ENT-08A
ENT-07A
ENT-06A
ENT-05A
ENT-04A
ODP 808
ENT-03A
ENT-02A
ENT-01A

Figure 3

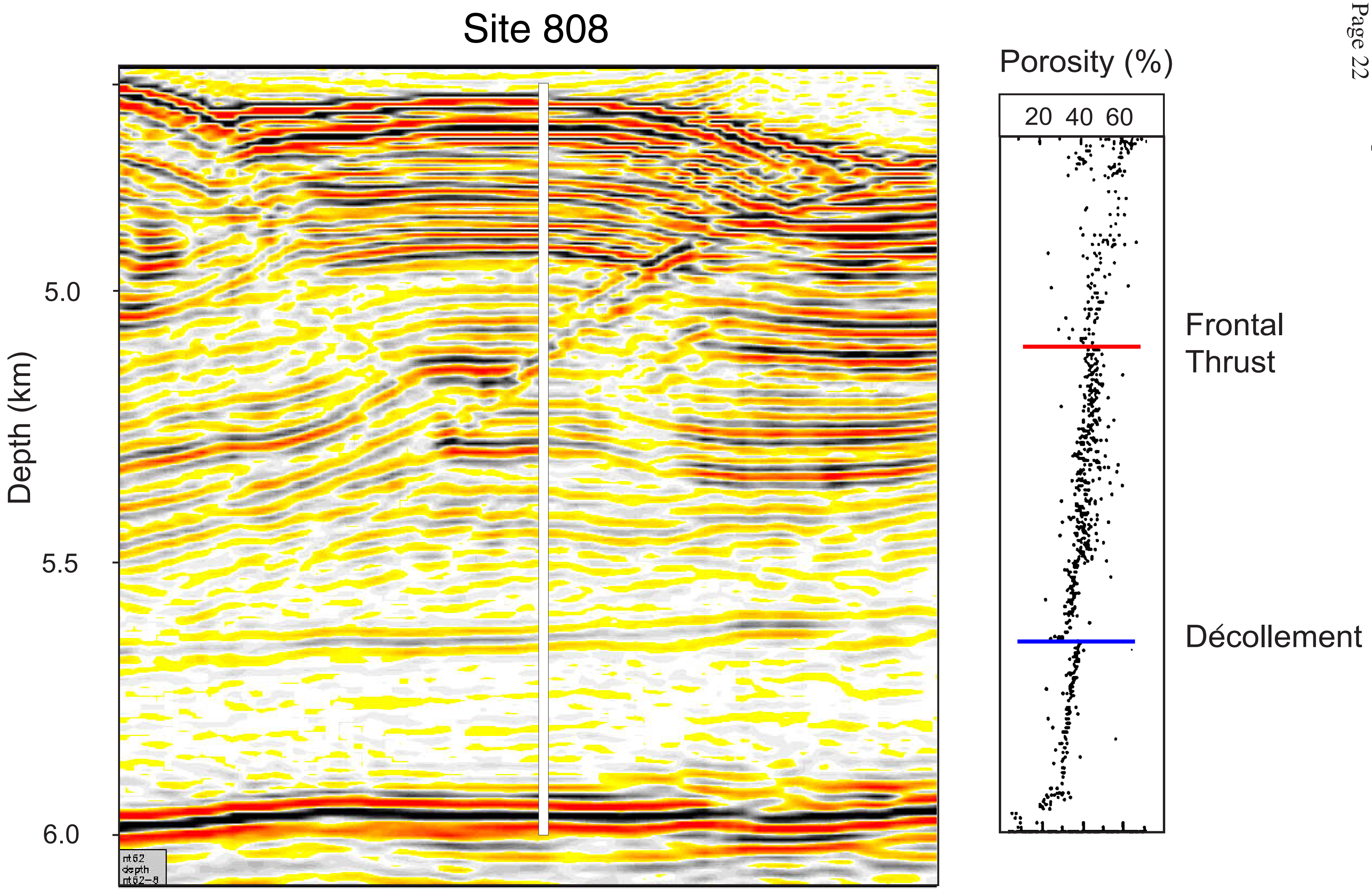

Site 808
Depth (km)
5.0
5.5
6.0
Porosity (%)
20 40 60
Frontal
Thrust
Décollement

Figure 4

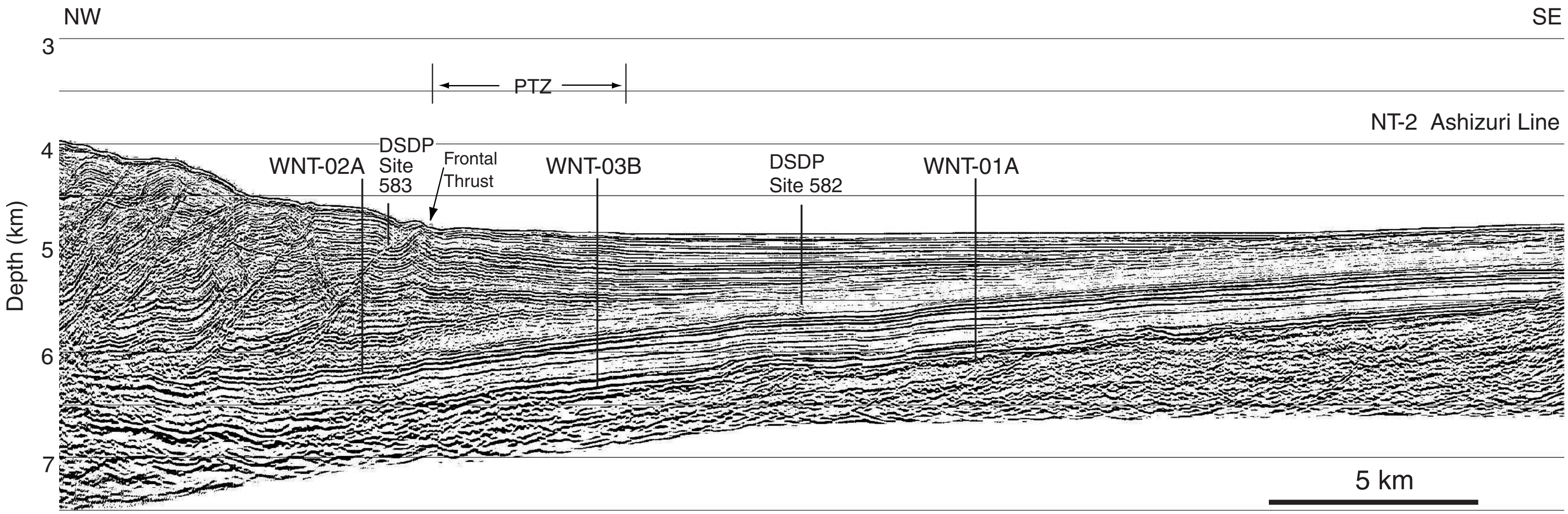

NW
SE
3
4
5
6
7
Depth (km)
PTZ
NT-2 Ashizuri Line
WNT-02A
DSDP
Site
583
Frontal
Thrust
WNT-03B
DSDP
Site 582
WNT-01A
5 km

Figure 5

Leg 190 - Nankai Trough Accretionary Prism (Proposal No. 445-6)
Operations Plan and Time Estimate for Primary Sites

Revision: 7 Date: 27 Jan 00

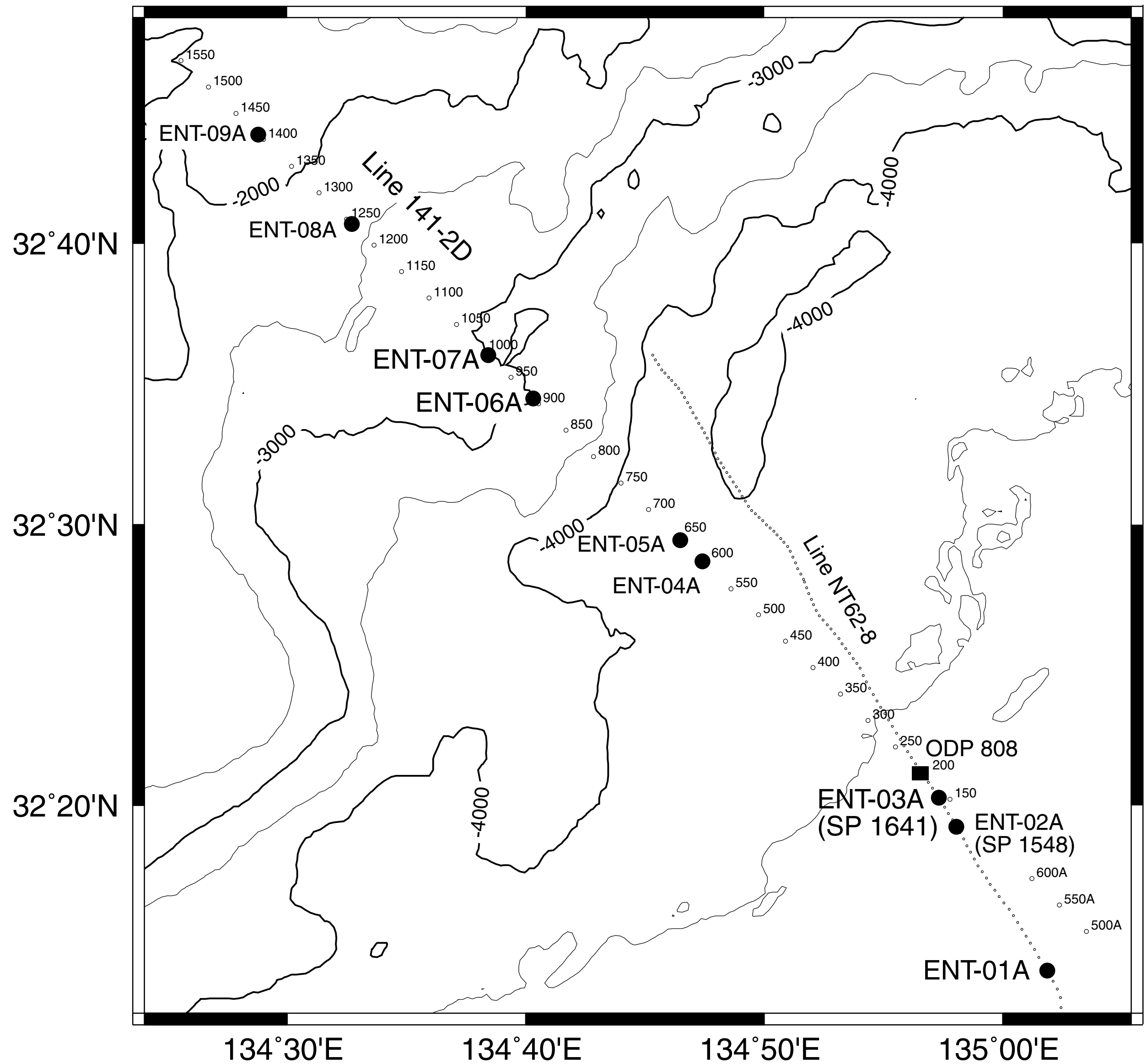
Site No.	Location Lat/Long	Water Depth	Operations Description	Days per hole	Transit (days)	Drilling (days)	Logging (days)	Total On-site
Guam	13°27'N		**Transit 1244.2 nmi from Guam to ENT-01A**		4.9			
	144°38'E		Seismic survey on approach to site		0.30			
ENT-01A	32°14.14'N	4760 m	**Hole A: APC core to 125 mbsf, XCB to 350 mbsf**	4.6		10.2	1.8	12.0
	135°01.87'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 340 mbsf, RCB to 700 mbsf	7.3				
			~3 ea DVTP, ~ 4 ea WSTP					
			Log - triple-combo, FMS-sonic, VSP check shot					
			NOTE: PPSP approved depth is 700 mbsf					
			Transit 7.3 nmi from ENT-01A to ENT-03A		0.0			
ENT-03A	32°20.30'N	4730 m	**Hole A: APC to 125 mbsf, XCB to 350 mbsf**	4.4		15.1	0.0	15.1
	134°57.25'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 340 mbsf, RCB core to 1150 mbsf	10.7				
			1 ea DIC, ~3 ea DVTP, ~4 ea WSTP					
			NOTE: PPSP approved depth is 1160 mbsf					
			Transit 22.6 nmi from ENT-03A to ENT-07A		0.1			
ENT-07A	32°36.03'N	3022 m	**Hole A: APC to 200 mbsf, XCB to 400 mbsf**	3.3		3.3	0.0	3.3
	134°38.42'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
			Transit 2.6 nmi from ENT-07A to ENT-06A		0.1			
ENT-06A	32°34.49'N	3045 m	**Hole A: APC core to 200 mbsf, XCB to 500 mbsf**	4.1		8.6	0.0	8.6
	134°40.31'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 490 mbsf, RCB to 800 mbsf	4.4				
			~3 ea DVTP, ~4 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
			Transit 61.8 nmi from ENT-06A to WNT-01A		0.2			
WNT-01A	31°43.87'N	4850 m	**Hole A: Drill 0 to 300 mbsf, RCB 300 mbsf to 700 mbsf**	6.7		6.7	0.0	6.7
	133°56.85'E		~3 ea DVTP, ~4 ea WSTP					
			NOTE: PPSP approved depth is 1200 mbsf					
Yokohama	35°28'N		**Transit 374.8 nmi from WNT-01A to Yokohama**		1.6			
	139°38'E							
				Subtotals	**7.3**	**43.9**	**1.8**	**45.7**

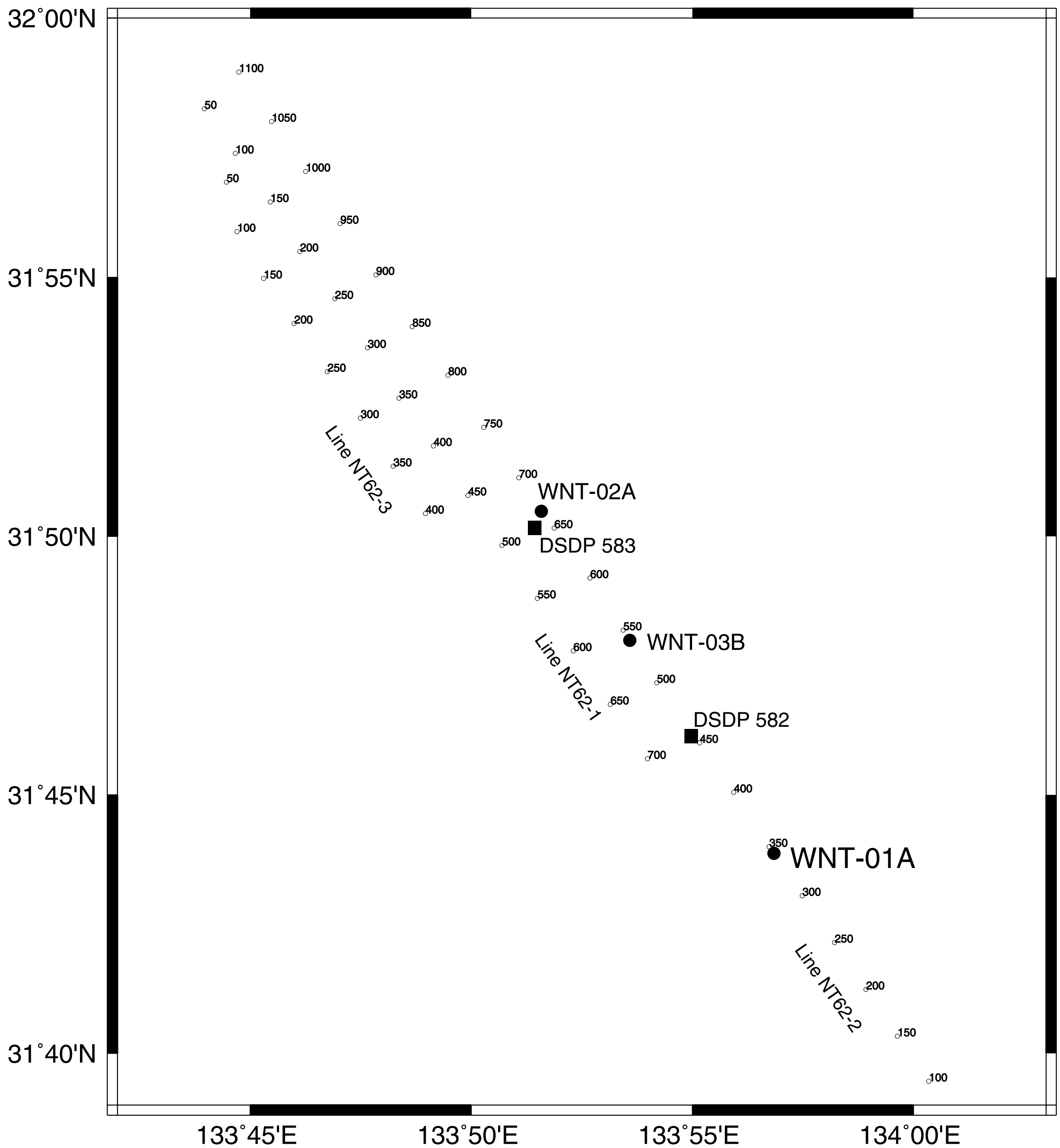
TOTAL DAYS:	**53.0**

Leg 190 - Nankai Trough Accretionary Prism (Proposal 445-6)
Operations Plan and Time Estimate for Alternate Sites

Revision: 7 Date: 27 Jan 00

Site No.	Location Lat/Long	Water Depth	Operations Description	Days per hole	Transit (days)	Drilling (days)	Logging (days)	Total On-site
ENT-02A	32°19.26'N	4790 m	**Hole A: APC core to 125 mbsf, XCB to 350 mbsf**	4.7		12.0	0.0	12.0
	134°58.06'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~3 ea WSTP					
			Hole B: Drill to 340 mbsf, RCB core to 1150 mbsf	7.3				
			~3 ea DVTP, ~4 ea WSTP					
			NOTE: PPSP approved depth is 1050 mbsf					
ENT-04A	32°28.71'N	4050 m	**Hole A: APC core to 200 mbsf, XCB to 650 mbsf**	4.9		9.9	0.0	9.9
	134°47.40'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~3 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
ENT-05A	32°29.46'N	4125 m	**Hole A: APC core to 200 mbsf, XCB to 500 mbsf**	4.9		9.9	0.0	9.9
	134°46.48'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 490 mbsf, RCB core to 800 mbsf	5.0				
			~3 ea DVTP, ~ 4 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
ENT-08A	32°40.68'N	2437 m	**Hole A: APC core to 200 mbsf, XCB to 500 mbsf**	4.4		8.3	0.0	8.3
	134°32.70'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP,					
			~8 ea PCS					
			Hole B: Drill to 490 mbsf, RCB core to 800 mbsf	3.9				
			~3 ea DVTP, ~ 4 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
ENT-09A	32°43.86'N	1778 m	**Hole A: APC core to 200 mbsf, XCB to 500 mbsf**	3.6		7.0	0.0	7.0
	134°28.77'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP,					
			~8 ea PCS					
			Hole B: Drill to 490 mbsf, RCB core to 800 mbsf	3.4				
			~3 ea DVTP, ~ 4 ea WSTP					
			NOTE: PPSP approved depth is 800 mbsf					
WNT-02A	31°50.48'N	4600 m	**Hole A: APC core to 150 mbsf, XCB to 350 mbsf**	4.3		21.9	0.0	21.9
	133°51.59'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 340 mbsf, RCB core to 1700 mbsf	17.6				
			~3 ea DVTP					
			NOTE: PPSP approved depth is 1700 mbsf					
WNT-03B	31°47.99'N	4850 m	**Hole A: APC core to 150 mbsf, XCB to 350 mbsf**	4.4		19.2	0.0	19.2
	133°53.59'E		Oriented APC, ~2 ea Adara, ~3 ea DVTP, ~4 ea WSTP					
			Hole B: Drill to 340 mbsf, RCB core to 1520 mbsf	14.9				
			~3 ea DVTP					
			NOTE: PPSP approved depth is 1520 mbsf					


32°40'N
32°30'N
32°20'N
134°30'E
134°40'E
134°50'E
135°00'E
Line 141-2D
Line NT62-8
ENT-09A
ENT-08A
ENT-07A
ENT-06A
ENT-05A
ENT-04A
ODP 808
ENT-03A
(SP 1641)
ENT-02A
(SP 1548)
ENT-01A
-2000
-3000
-4000
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
600A
550A
500A


32˚00'N
31˚55'N
31˚50'N
31˚45'N
31˚40'N
133˚45'E
133˚50'E
133˚55'E
134˚00'E
Line NT62-3
Line NT62-1
Line NT62-2
WNT-02A
DSDP 583
WNT-03B
DSDP 582
WNT-01A
1100
50
1050
100
1000
50
150
950
100
200
900
150
250
200
850
300
250
800
350
300
750
400
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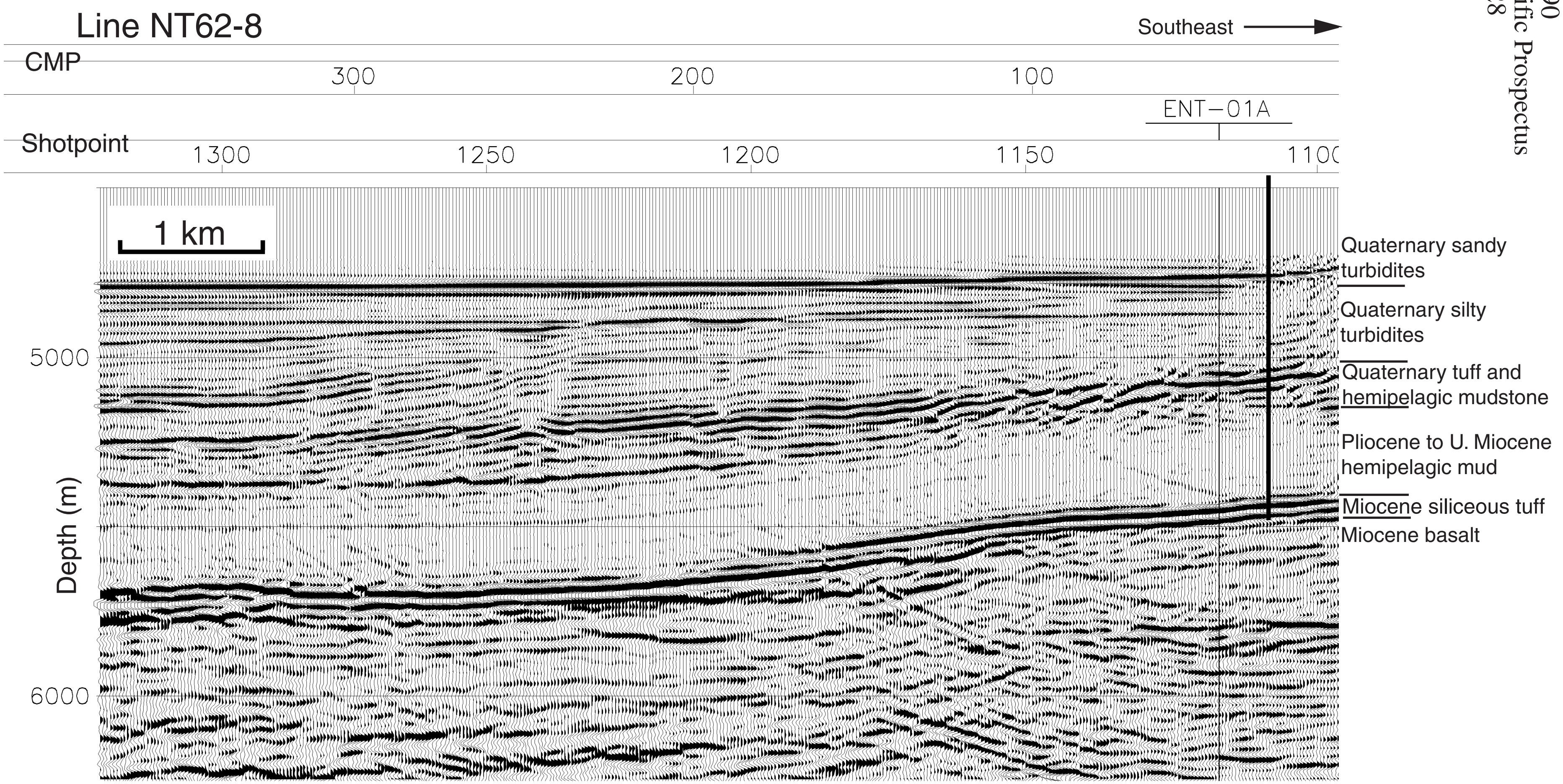
300
250
200
150
100


Line NT62-8
Southeast
CMP
300
200
100
ENT-01A
Shotpoint
1300
1250
1200
1150
1100
1 km
5000
6000
Depth (m)
Quaternary sandy turbidites
Quaternary silty turbidites
Quaternary tuff and hemipelagic mudstone
Pliocene to U. Miocene hemipelagic mud
Miocene siliceous tuff
Miocene basalt

SITE SUMMARIES

Site: ENT-01A

Priority: 1
Position: 32°14.14'N, 135°01.87'E
Water Depth: 4760 m
Sediment Thickness: 700 m
Target Drilling Depth: 700 m
Approved Maximum Penetration: 700 mbsf
Seismic Coverage: *Fred Moore* Line NT62-8, shotpoint (SP) 1116 (common depth point [CDP] 45); 1999 3-D sesimic survey, Line 105, SP 106

Objectives: The objectives of ENT-01A are to:

1. Drill to basement at a position seaward of the proto-décollement tip to provide baseline physical properties, fluid flow measurements, and stratigraphy

2. Determine the structural and hydrologic evolution of the décollement zone

3. Determine the fluid flow paths and chemical gradients

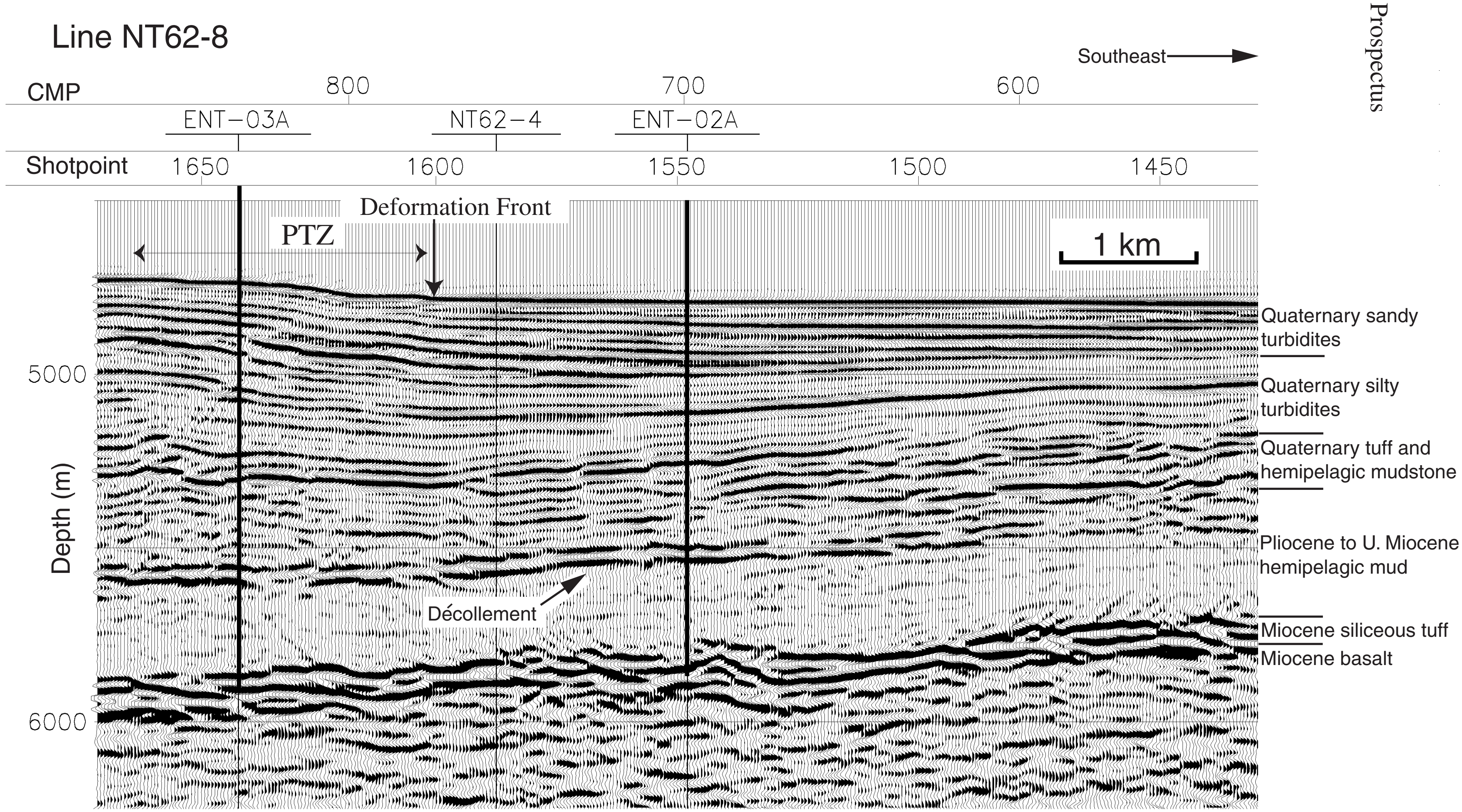
4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC, XCB, and RCB

Logging: Triple-combo, FMS-sonic, WST for velocity check-shot survey

Downhole Tools: APC core orientation, Adara and DVTP temperature, water sampling temperature probe (WSTP) water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites, tuff


Line NT62-8
Southeast
CMP
800
700
600
ENT−03A
NT62−4
ENT−02A
Shotpoint
1650
1600
1550
1500
1450
PTZ
Deformation Front
1 km
Quaternary sandy turbidites
Quaternary silty turbidites
Quaternary tuff and hemipelagic mudstone
Pliocene to U. Miocene hemipelagic mud
Miocene siliceous tuff
Miocene basalt
Décollement
5000
6000
Depth (m)

Site: ENT-02A

Priority: 3
Position: 32°19.26’N, 134°58.06’E
Water Depth: 4790 m
Sediment Thickness: 1040 m
Target Drilling Depth: 1040 m
Approved Maximum Penetration: 1050 m
Seismic Coverage: *Fred Moore* Line NT62-8, SP 1548 (CDP 699)

Objectives: The objectives of Site ENT-02A are to:

1. Contrast deformational and fluid flow behavior along strike

2. Determine the structural and hydrologic evolution of the décollement zone

3. Determine the fluid flow paths and chemical gradients

4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites, tuff

Site: ENT-03A

Priority: 1
Position: 32°20.30'N, 134°57.25'E
Water Depth: 4730 m
Sediment Thickness: 1150 m
Target Drilling Depth: 1150 m
Approved Maximum Penetration: 1160 m
Seismic Coverage: *Fred Moore* Line NT62-8, SP 1641 (CDP 833); 1999 3-D seismic survey, Line 141, SP 165

Objectives: The objectives of ENT-03A are to drill through the protothrust zone to:

1. Determine the spatial distribution and temporal progression of deformation
2. Determine the structural and hydrologic evolution of the décollement zone
3. Determine the fluid flow paths and chemical gradients

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites, tuff

See seismic line for Site ENT-02A

Site: ENT-04A

Priority: 2
Position: 32°28.71'N, 134°47.40'E
Water Depth: 4050 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 602, crossing line 802

Objectives: The objectives of Site ENT-04A are to drill through the seaward-most OOST to:

1. Sample fluids along the OOST

2. Sample the older part of the accretionary prism

3. Determine the fluid flow paths and chemical gradients

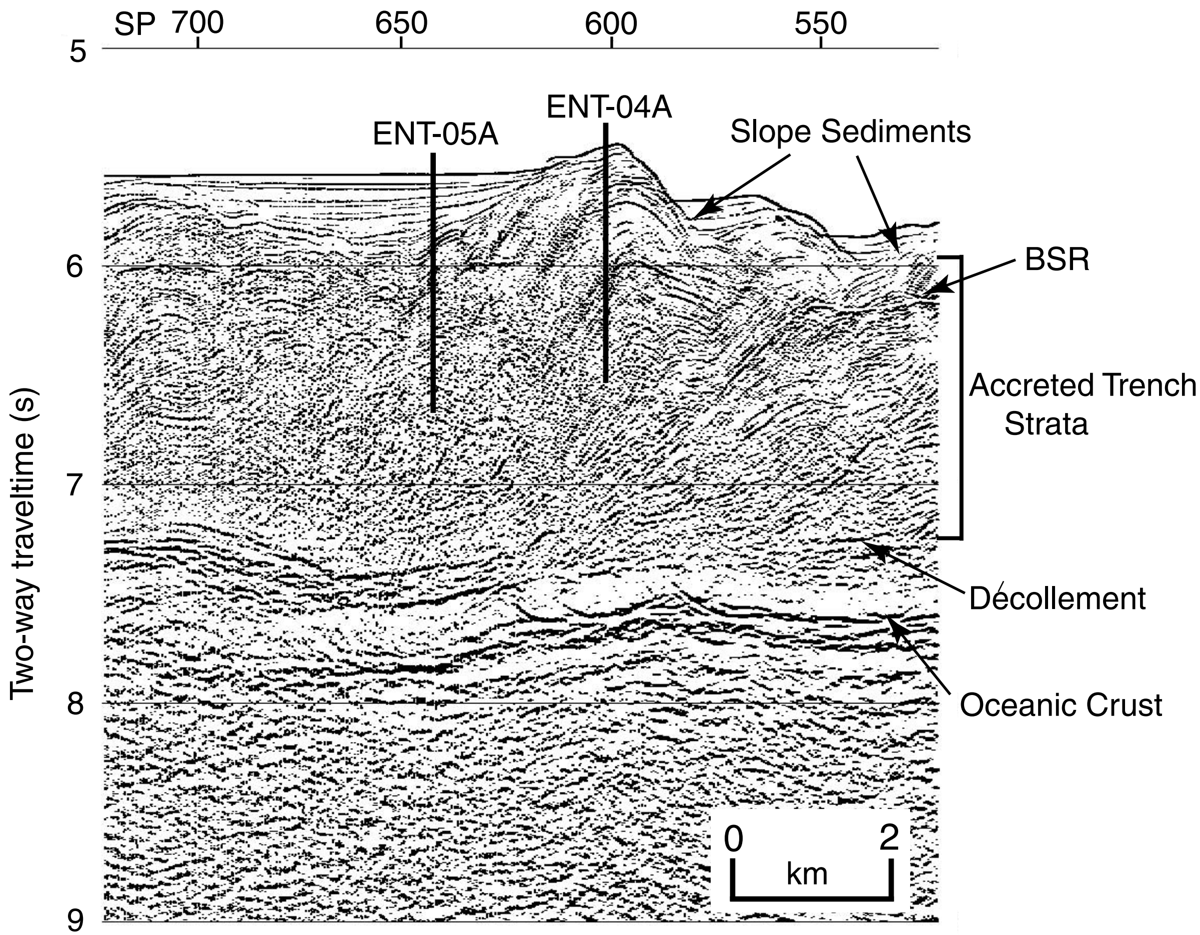
4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC and XCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites, tuff


SP
700
650
600
550
5
6
7
8
9
Two-way traveltime (s)
ENT-05A
ENT-04A
Slope Sediments
BSR
Accreted Trench
Strata
Décollement
Oceanic Crust
0
2
km

Site: ENT-05A

Priority: 2
Position: 32°29.46’N, 134°46.48’E
Water Depth: 4125 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 642, crossing line 842

Objectives: The objectives of Site ENT-05A are to:

1. Sample slope basin strata to date prism deformation
2. Penetrate seaward-most OOST for fluid sample
3. Date an older part of the prism
4. Determine the fluid flow paths and chemical gradients
5. Determine the spatial distribution and temporal progression of deformation

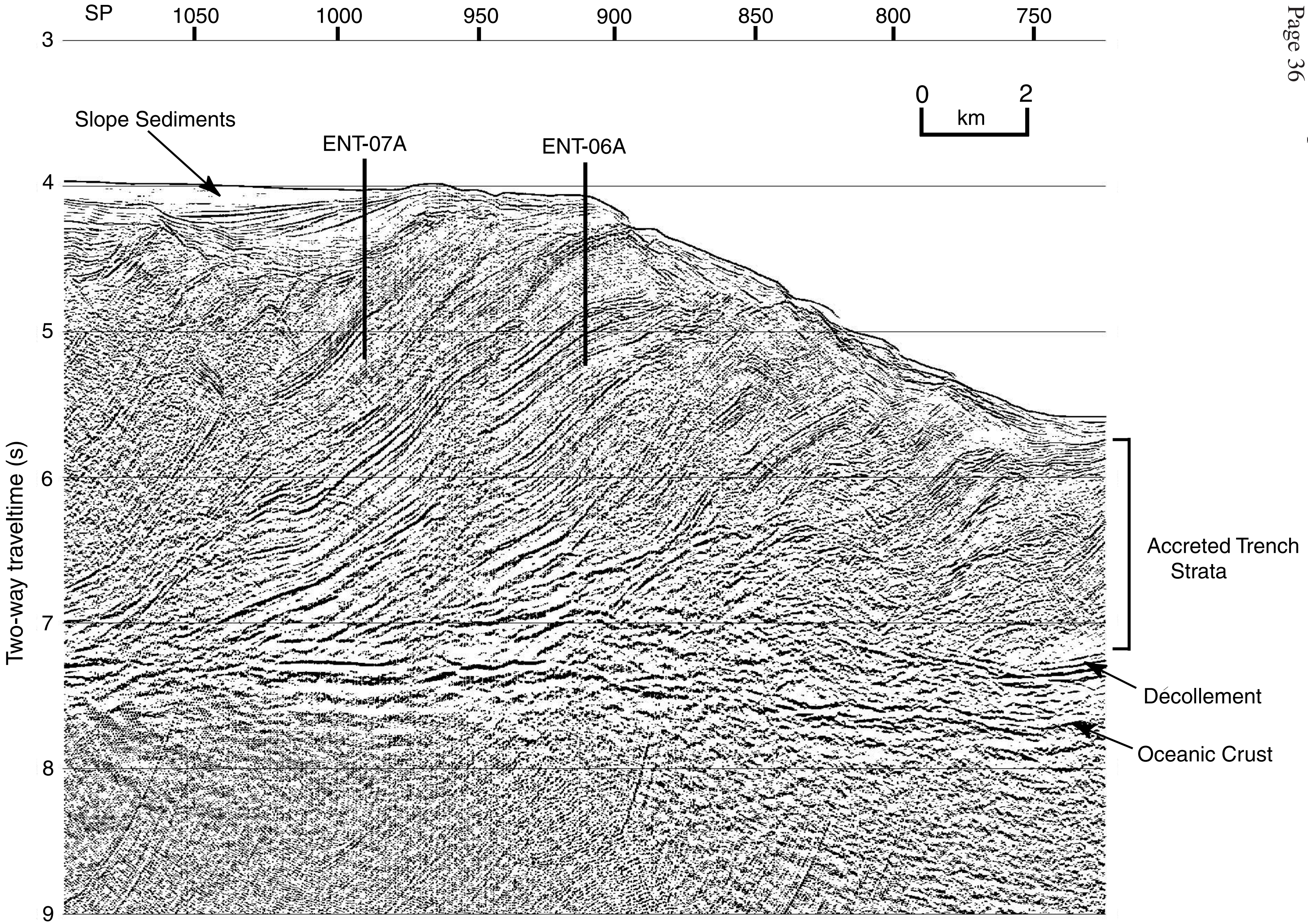
Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites

See seimsic line for ENT-04A


SP
1050
1000
950
900
850
800
750
3
4
5
6
7
8
9
Two-way traveltime (s)
0
2
km
Slope Sediments
ENT-07A
ENT-06A
Accreted Trench
Strata
Décollement
Oceanic Crust

Site: ENT-06A

Priority: 1
Position: 32°34.49'N, 134°40.31'E
Water Depth: 3045 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 910, crossing line 1110

Objectives: The objectives of Site ENT-06A are to penetrate a major OOST in the mid-slope region to:

1. Sample the OOST for fluids
2. Date an older part of the prism
3. Determine the fluid flow paths and chemical gradients
4. Determine the spatial distribution and temporal progression of accretionary prism deformation

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites

Site: ENT-07A

Priority: 1
Position: 32°36.03'N, 134°38.42'E
Water Depth: 3022 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 992, crossing line 1192

Objectives: The objectives of Site ENT-07A are to:

1. Sample slope basin sediments to date prism deformation

2. Date underlying accretionary prism

3. Determine the fluid flow paths and chemical gradients

4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC, XCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites

See seismic line for Site ENT-06A

Site: ENT-08A

Priority: 3
Position: 32°40.68’N, 134°32.70’E
Water Depth: 2437 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 1257, crossing line 1460

Objectives: The objectives of Site ENT-08A are to:

1. Sample slope sediments and older accreted strata

2.Determine the spatial distribution and temporal progression of deformation

3. Determine the fluid flow paths and chemical gradients

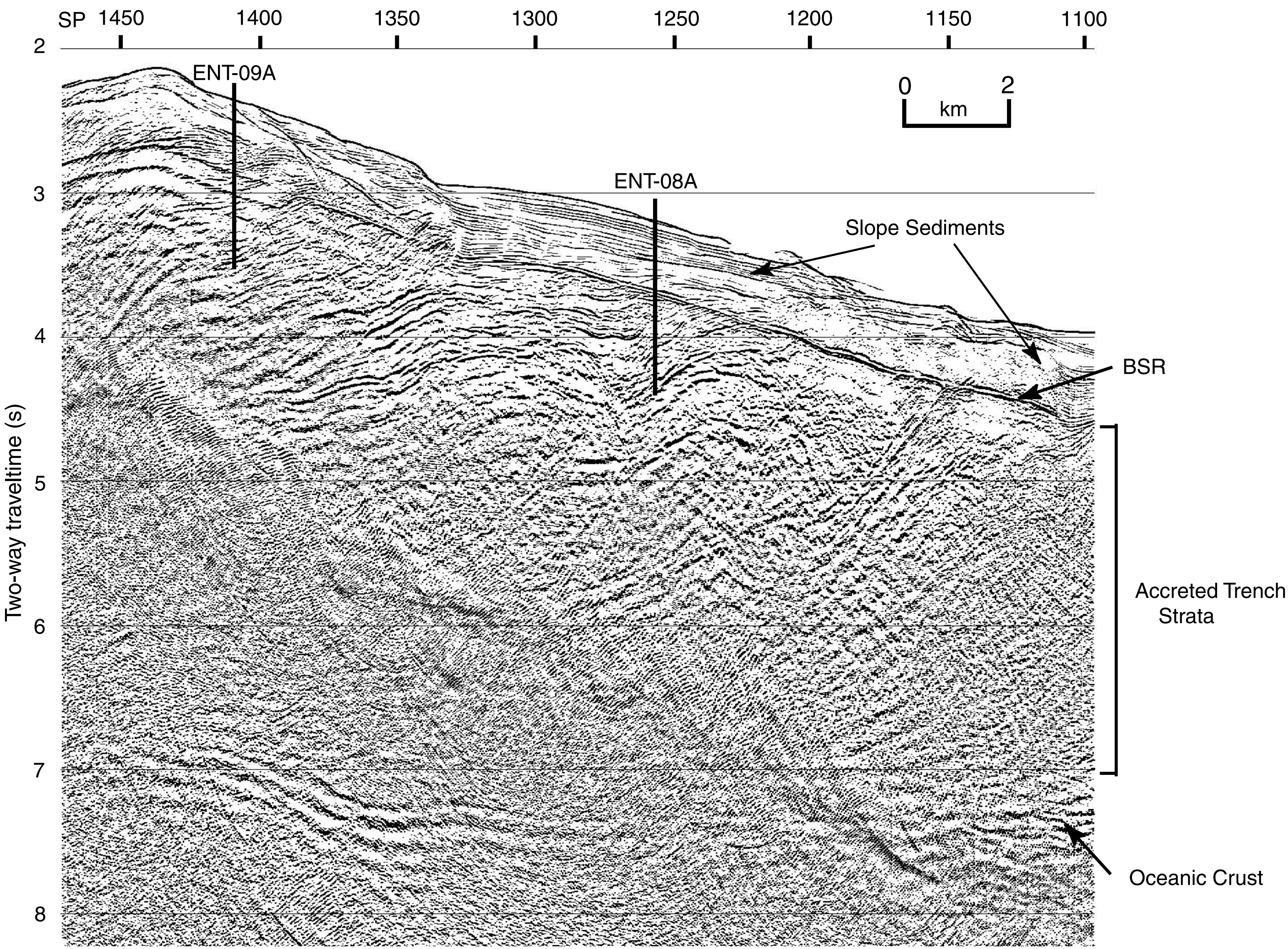
4. Obtain samples of gas hydrate

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites


SP
1450
1400
1350
1300
1250
1200
1150
1100
2
3
4
5
6
7
8
Two-way traveltime (s)
ENT-09A
ENT-08A
0
2
km
Slope Sediments
BSR
Accreted Trench
Strata
Oceanic Crust

Site: ENT-09A

Priority: 3
Position: 32°43.86'N, 134°28.77'E
Water Depth: 1778 m
Sediment Thickness: 3000 m
Target Drilling Depth: 800 m
Approved Maximum Penetration: 800 m
Seismic Coverage: 3-D seismic survey in 1999, Line 141-2D SP 1410, crossing line 1610

Objectives: The objectives of Site ENT-09A are to:

1. Sample slope sediments and older accreted strata
2. Determine the spatial distribution and temporal progression of deformation
3. Determine the fluid flow paths and chemical gradients
4. Obtain samples of gas hydrate

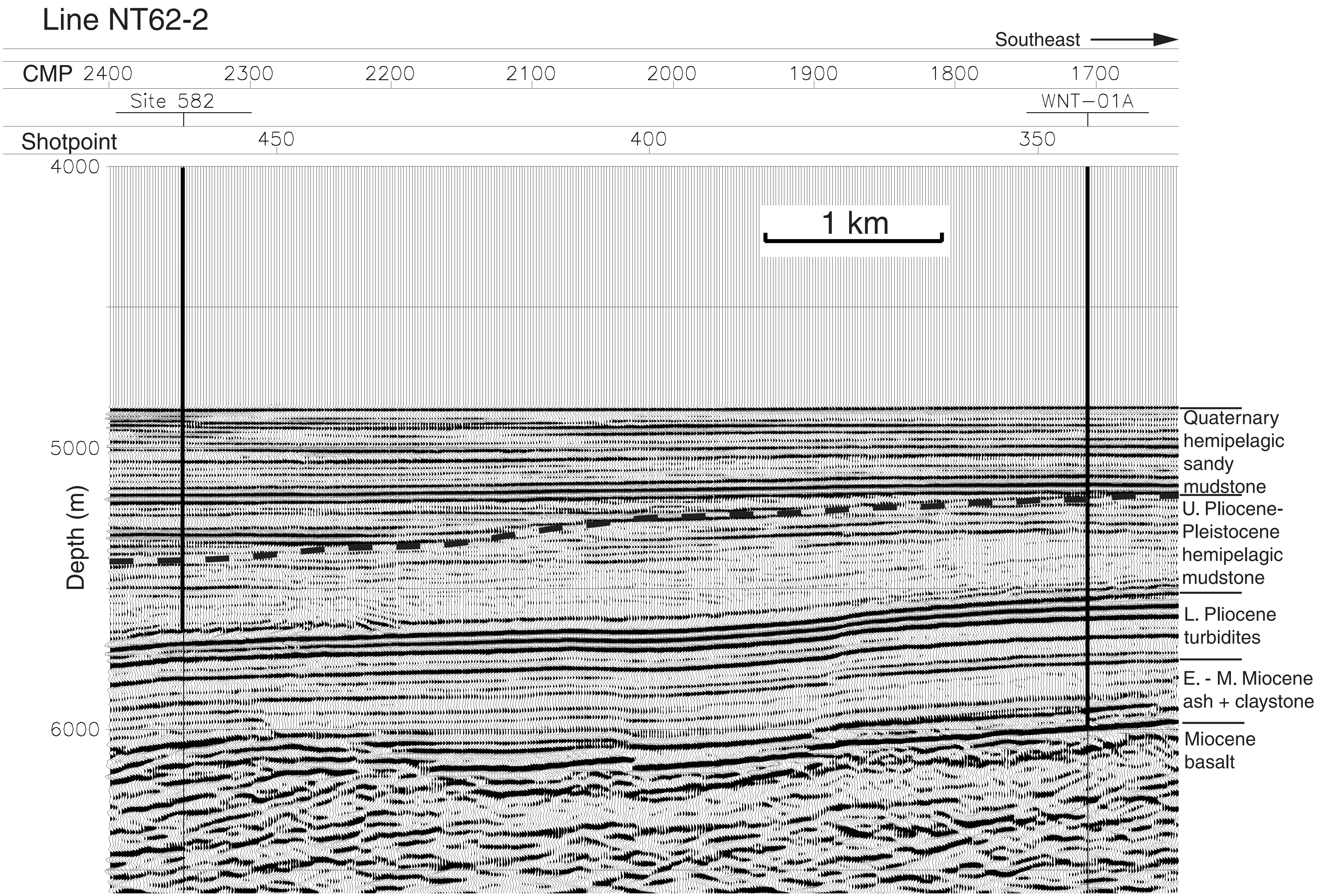
Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites

See seismic line for Site ENT-08A


Line NT62-2
Southeast
CMP 2400 2300 2200 2100 2000 1900 1800 1700
Site 582
WNT−01A
Shotpoint 450 400 350
4000
5000
6000
Depth (m)
1 km
Quaternary hemipelagic sandy mudstone
U. Pliocene-Pleistocene hemipelagic mudstone
L. Pliocene turbidites
E. - M. Miocene ash + claystone
Miocene basalt

Site: WNT-01A

Priority: 1
Position: 31°43.87’N, 133°56.85’E
Water Depth: 4850 m
Sediment Thickness: 1150 m
Target Drilling Depth: 700 m
Approved Maximum Penetration: 1200 m
Seismic Coverage: *Fred Moore* Line NT62-2, SP 343 (CDP 1706)

Objectives: The objectives of Site WNT-01A are to:

1. Contrast deformational and fluid flow behavior along strike

2. Determine the structural and hydrologic evolution of the décollement zone

3. Determine the fluid flow paths and chemical gradients

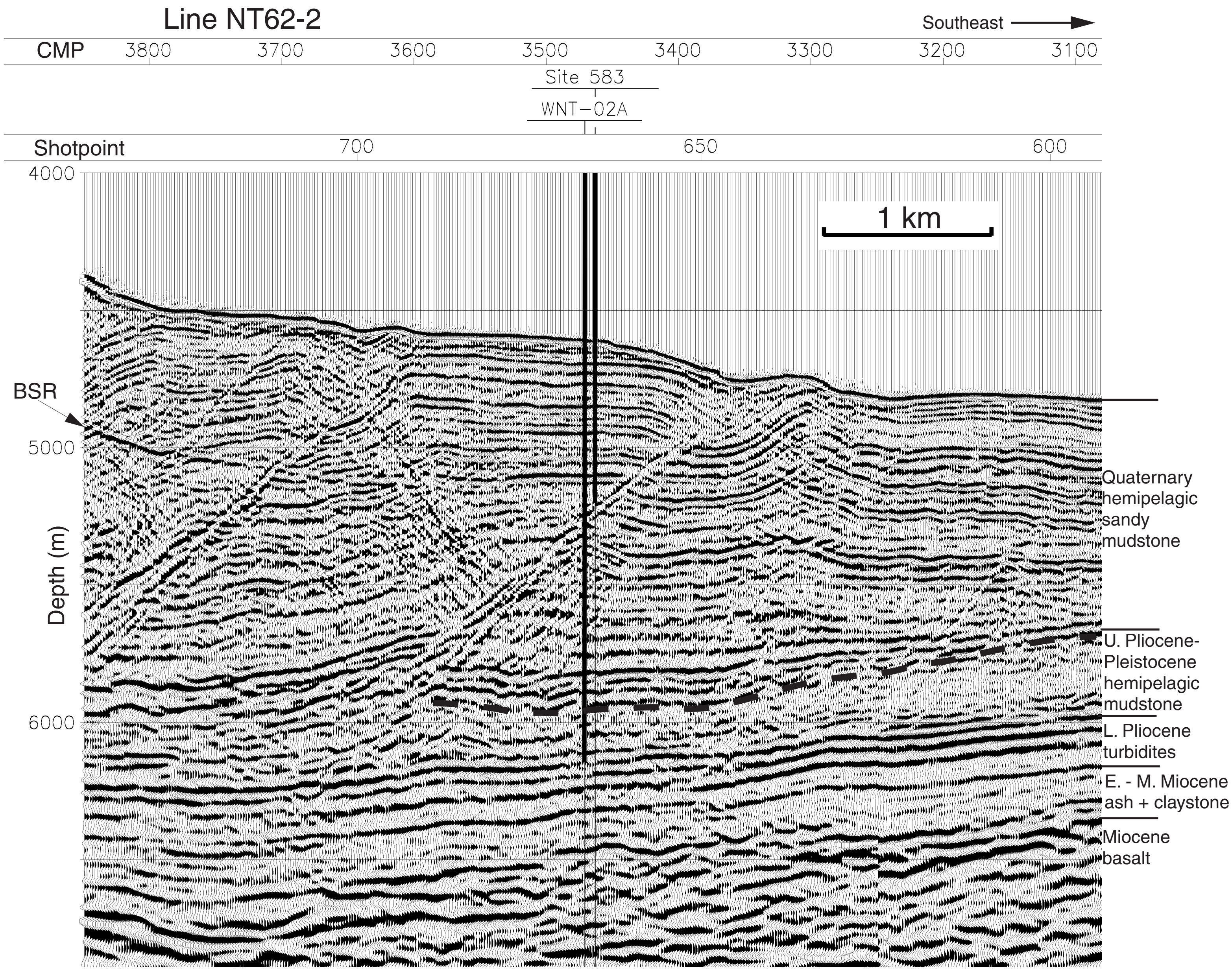
4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: RCB

Logging: None

Downhole Tools: DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites


Line NT62-2
Southeast
CMP
3800
3700
3600
3500
3400
3300
3200
3100
Site 583
WNT-02A
Shotpoint
700
650
600
4000
5000
6000
Depth (m)
1 km
BSR
Quaternary hemipelagic sandy mudstone
U. Pliocene-Pleistocene hemipelagic mudstone
L. Pliocene turbidites
E. - M. Miocene ash + claystone
Miocene basalt

Site: WNT-02A

Priority: 3
Position: 31°50.48'N, 133°51.59'E
Water Depth: 4600 m
Sediment Thickness: 2000 m
Target Drilling Depth: 1700 m
Approved Maximum Penetration: 1700 m
Seismic Coverage: *Fred Moore* Line NT62-2, SP 667 (CDP 3471)

Objectives: The objectives of WNT-02A are to:

1. Contrast deformational and fluid flow behavior along strike

2. Determine the structural and hydrologic evolution of the décollement zone

3. Determine the fluid flow paths and chemical gradients

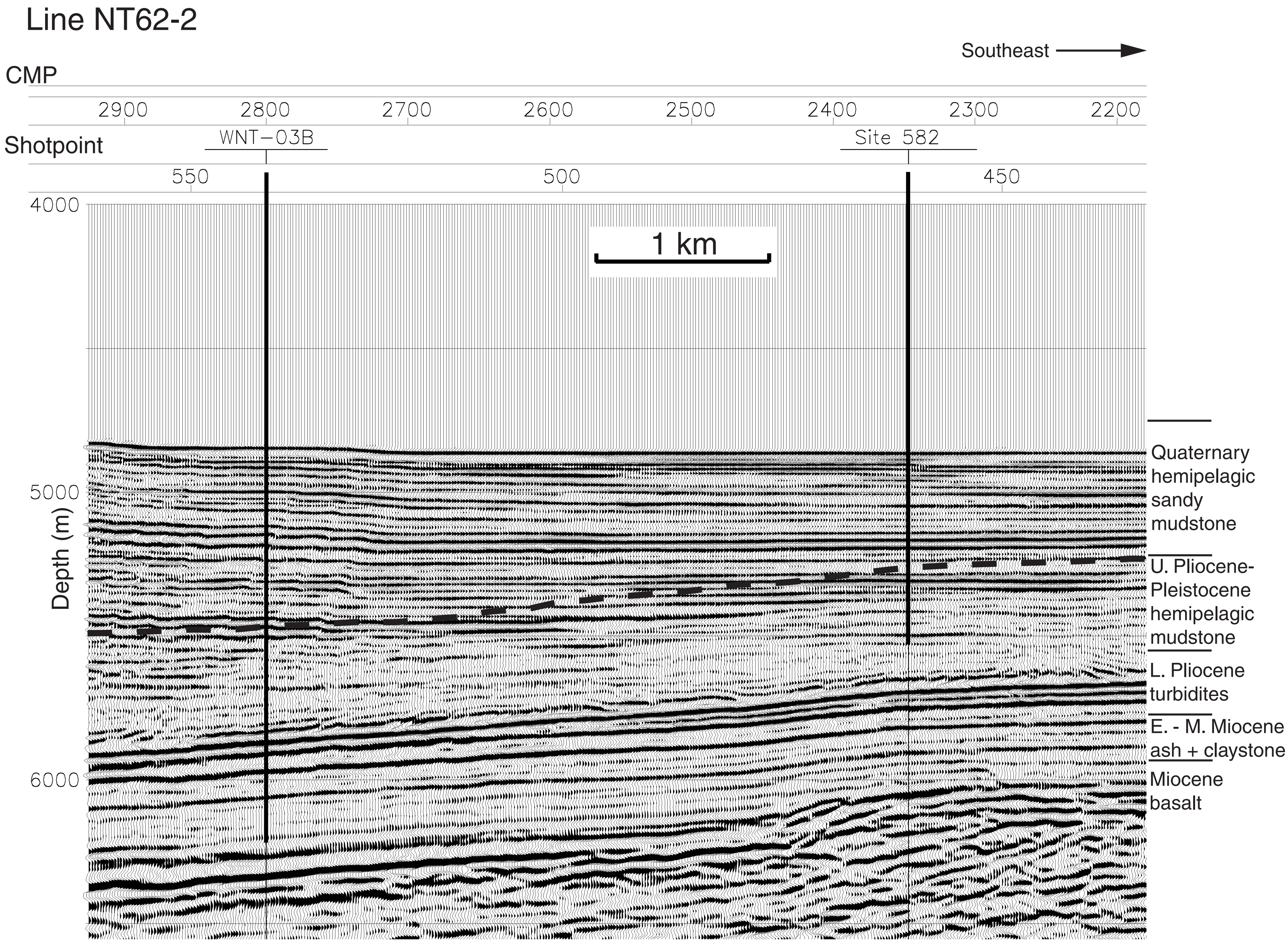
4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites


Line NT62-2
Southeast
CMP
2900
2800
2700
2600
2500
2400
2300
2200
Shotpoint
WNT−03B
Site 582
550
500
450
4000
5000
6000
Depth (m)
1 km
Quaternary hemipelagic sandy mudstone
U. Pliocene-Pleistocene hemipelagic mudstone
L. Pliocene turbidites
E. - M. Miocene ash + claystone
Miocene basalt

Site: WNT-03B

Priority: 2
Position: 31°47.99'N, 133°53.59'E
Water Depth: 4850 m
Sediment Thickness: 1510 m
Target Drilling Depth: 1510 m
Approved Maximum Penetration: 1510 m
Seismic Coverage: *Fred Moore* Line NT62-2, SP 540 (CDP 2800)

Objectives: The objectives of WNT-03B are to:

1. Contrast deformational and fluid flow behavior along strike
2. Determine the structural and hydrologic evolution of the décollement zone
3. Determine the fluid flow paths and chemical gradients
4. Determine the spatial distribution and temporal progression of deformation

Drilling Program: APC, XCB, and RCB

Logging: None

Downhole Tools: APC core orientation, Adara and DVTP temperature, WSTP water samples

Nature of Rock Anticipated: Interbedded hemipelagic mud/silty-sandy turbidites, basalt

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