# Integrated Ocean Drilling Program Expedition 322 Scientific Prospectus

# NanTroSEIZE Stage 2: subduction inputs


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## Disclaimer



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## Abstract

Integrated Ocean Drilling Program (IODP) Expedition 322 is part of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE). This multiexpedition drilling project was designed to investigate fault mechanics and seismogenesis along subduction megathrusts through direct sampling, in situ measurements, and long-term monitoring in conjunction with laboratory studies and numerical modeling. The primary goal for Expedition 322 is to characterize the composition, architecture, and state of sediments and upper igneous crust entering the subduction system offshore the Kii Peninsula, Japan. Proposed drilling Site NT1-07A will penetrate ~1200 meters below seafloor through an important interval of turbidite-rich strata overlying the flanks of an oceanic basement high. If time and borehole conditions permit, we will also core and log up to 40 m of basement. The data will provide much-needed constraints on the initial conditions for the "subduction conveyor," which transports the incoming sediments and igneous crust to higher pressure-temperature (P-T) conditions. Ultimately, according to the overarching hypotheses of NanTroSEIZE, the changes imparted on rocks and fluids by those higher P-T conditions drive the onset of seismogenic fault behavior. The architecture of the incoming sediment is also important as a potential control on spatial heterogeneities in permeability, pore pressure, fluid chemistry, and mechanical strength. We will test how and to what extent sandy turbidites in the lower Shikoku Basin facies serve as permeable conduits for draining deeper sections of the underthrust sequence as they pass beneath the accretionary wedge. Focused fluid flow may lead to the development of overpressured compartments, thereby modulating shear strength. In this *Scientific Prospectus* we present the scientific background and objectives, the drilling operations designed to achieve them, a contingency plan strategy, the currently understood risks and steps taken to mitigate them, and the coordinated stages of the NanTroSEIZE research plan.

## Schedule for Expedition 322

Expedition 322 evolved from the original Integrated Ocean Drilling Program (IODP) drilling Proposals 603-CDP3, 603A-Full2, and related proposals (603B-Full2, 603C-Full, and 603D-Full2) (available at **www.iodp.org/600/**). Following ranking by the IODP Scientific Advisory Structure , the IODP Operations Task Force created the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Project Management Team (NT-PMT) to formulate a strategy for achieving the overall scientific objectives in these proposals. The resulting overall goals and multistage implementation strategy are described in Tobin and Kinoshita (2006a, 2006b). For operations in 2009, the IODP Operations Task Force scheduled two expeditions by D/V *Chikyu*: one with riser and riserless drilling for future borehole observatories (Expedition 319) and the other with riserless coring and wireline logging (Expedition 322). The highest priority components of IODP Expedition 322 were originally scheduled for drilling in 2007 by R/V *JOIDES Resolution* as part of NanTroSEIZE Stage 1, but operations were deferred several times for a variety of reasons. The supporting site survey data for Expedition 322, and the whole of NanTroSEIZE expeditions, are archived at the **IODP Site Survey Databank.**

Expedition 322 is currently scheduled to begin from Shingu, Japan, on 1 September 2009 and to return to Shingu on 10 October 2009. After a 4 day port call, a total of 36 days will be available for the drilling, coring, wireline logging, and downhole measurement operations described in this prospectus. At the time of publication, the ship schedule has not been finalized and may change. Refer to **www.iodp.org/expeditions** for more information and a current detailed schedule. Details on the *Chikyu* can be found at **www.jamstec.go.jp/chikyu/eng/**.

# Introduction

## Overview of NanTroSEIZE complex drilling project

Subduction zones account for 90% of global seismic moment release, generating damaging earthquakes and tsunamis with potentially disastrous effects on heavily populated coastal areas (e.g., Lay et al., 2005). Understanding the processes that govern the nature and distribution of slip along these plate boundary fault systems is a crucial part of evaluating earthquake and tsunami hazards. More generally, characterizing fault behavior through direct sampling, near-field geophysical observations, and measurement of in situ conditions at the depths of coseismic slip is a fundamental goal of modern earth science. To this end, several recent and ongoing drilling programs have targeted portions of active plate boundary faults that either slipped coseismically during large earthquakes or nucleate clusters of smaller events. These efforts include the San Andreas Fault Observatory at Depth (Hickman et al., 2004), the Taiwan-Chelungpu Drilling Project (Ma et al., 2006; Hirono et al., 2006), and IODP NanTroSEIZE drilling (Tobin and Kinoshita, 2006a, 2006b).

NanTroSEIZE is a multiexpedition, multistage project focused on understanding the mechanics of seismogenesis and rupture propagation along plate boundary faults.

The IODP science plan outlines a coordinated effort to sample and instrument the plate boundary system at several locations offshore the Kii Peninsula (Figs. **F1, F2**). The main objectives are to improve understanding of

- The aseismic–seismic transition of the megathrust fault system,
- The mechanics of earthquake and tsunami generation, and
- The hydrologic behavior of the plate boundary and subduction margin (Tobin and Kinoshita, 2006a, 2006b).

As NanTroSEIZE progresses, scientists will evaluate a set of core hypotheses through a combination of riser and riserless drilling, long-term observatories, and associated geophysical, laboratory, and numerical modeling efforts. The following hypotheses are paraphrased from the original IODP proposals and outlined in Tobin and Kinoshita (2006a, 2006b):

1. Systematic, progressive material and state changes control the onset of seismogenic behavior on subduction thrusts.
2. Subduction megathrusts are weak faults (i.e., they slip under relatively low stress).
3. Plate motion is accommodated primarily by coseismic frictional slip in a concentrated zone (i.e., the fault is locked during the interseismic period).
4. Physical properties of the plate boundary system change with time during the earthquake cycle.
5. A laterally extensive "megasplay" fault system slips in discrete events that may include tsunamigenic slip during great earthquakes. The fault remains locked during the interseismic period and accumulates strain.
6. To test these hypotheses, we need to document initial conditions within subducting sediment and basalt, beginning at "reference sites" seaward of the deformation front.

Sediment-dominated subduction zones such as Nankai margin are characterized by repeated occurrence of great earthquakes of ~M 8.0 (Ruff and Kanamori, 1983). Although the causative mechanisms are not well understood (e.g., Byrne et al., 1988; Moore and Saffer, 2001; Saffer and Marone, 2003), the updip limit of the seismogenic zone is thought to correlate with a topographic break along the outer rise of the forearc (e.g., Byrne et al., 1988; Wang and Hu, 2006). At Nankai, high-resolution seismic reflection profiles clearly document an out-of-sequence thrust or megasplay fault system that branches from the plate boundary (décollement) within the coseismic rupture zone of the 1944 Tonankai M 8.2 earthquake (Park et al., 2002) (Fig. **F2**). As stated above, two of the first-order goals of this project are to document the role of the megasplay fault in accommodating plate motion and to characterize its mechanical and hydrologic behavior. Ultimately, we plan to intersect the plate interface itself at seismogenic depths.

The Japanese Center for Deep Earth Exploration (CDEX) conducted three coordinated riserless expeditions during 2007–2008 as Stage 1 of NanTroSEIZE, drilling a series of sites across the continental margin offshore the Kii Peninsula. The transect is located within the inferred coseismic slip region of the 1944 Tonankai M 8.2 earthquake (Figs. **F1, F2**) (Tobin and Kinoshita, 2006a, 2006b). The first expedition (IODP Expedition 314) successfully obtained a comprehensive suite of geophysical logs and other downhole measurements at sites along the transect using state-of-the-art logging-while-drilling (LWD) technology (Kinoshita et al., 2008). Unfortunately, the expedition ended before LWD data could be obtained from any of the "subduction input" sites. This was followed by a coring expedition (IODP Expedition 315) to collect materials from and to characterize in situ conditions within the accretionary wedge and Kumano forearc basin at IODP Sites C0001 and C0002 (Ashi et al., 2008). The third expedition (IODP Expedition 316) collected core samples from shallow fault zones, including the frontal thrust near the trench (IODP Sites C0006 and C0007) and the older accretionary prism and megasplay fault at 400 meters below seafloor (mbsf) (IODP Sites C0004 and C0008) (Kimura et al., 2008).

NanTroSEIZE proceeds to Stage 2 in 2009. IODP Expedition 319 will drill two holes for future long-term observatories, which in conjunction with a planned dense ocean floor network system will monitor earthquakes and tsunamis (Kinoshita et al., in press). The first-ever riser hole in scientific ocean drilling history will be drilled and cased to 1600 mbsf at a site just above the locked zone of the plate interface. A riserless cased hole for another long-term observatory is also included in the expedition plan.

Some of the tasks remaining from NanTroSEIZE Stage 1 will be implemented following the riser expedition. Expedition 322 will characterize the sedimentology, physical properties, physical and chemical hydrogeology, and in situ conditions of the incoming sediment and uppermost igneous crust at proposed Site NT1-07A. A companion site (proposed Site NT1-01A) is included in the contingency plan.

# Background

## Geologic setting

The Nankai Trough formed by subduction of the Philippine Sea plate to the northwest beneath the Eurasian plate at a rate of ~4 cm/y (Seno et al., 1993). The convergence direction is approximately normal to the trench axis and sediments of the Shikoku Basin and trench-wedge are actively accreting at the deformation front. Great earthquakes during the past 3000 y are well documented in historical and archeological records (e.g., Ando, 1975). The Nankai Trough has been selected as a focus site for studies of seismogenesis by both IODP and the U.S. National Science Foundation (NSF) MARGINS initiative.

The region offshore the Kii Peninsula on Honshu Island was identified through a series of international workshops as the best location for seismogenic zone drilling for several reasons. First, the rupture area of the most recent great earthquake, the 1944 Tonankai M 8.2 event, is well constrained by recent seismic and tsunami waveform inversions (Tanioka and Satake, 2001; Ichinose et al. 2003; Kikuchi et al., 2003). Second, a horizon of significant coseismic slip is reachable by drilling with the Japanese riser drilling vessel *Chikyu* (Fig. **F2**). Third, the Kii-Kumano region is typical of the Nankai margin in terms of heat flow and sediment on the incoming plate, whereas the previously drilled area offshore Cape Muroto is anomalous due to stratigraphy associated with basement topography and high heat flow (Moore, Taira, Klaus, et al., 2001). Fourth, data from ocean bottom seismometers and onshore high-resolution geodetic studies indicate significant interseismic strain accumulation (Miyazaki and Heki, 2001; Obana et al., 2001).

Data from existing boreholes (Deep Sea Drilling Project and Ocean Drilling Program [ODP] Legs 31, 87, 131, 190, and 196) show that the décollement in the Nankai Trough propagates through Miocene strata of the lower Shikoku Basin facies near the prism toe (Fig. **F2**). Seismic reflection data clearly document that the décollement is hosted within this section to at least 25–35 km landward of the trench, where it downsteps to near the sediment/ocean crust interface (Fig. **F2**) (Park et al., 2002). Thus, this stratigraphic interval, rather than the overlying trench wedge, is the essential one for tracking physical-chemical changes toward seismogenic depths as sediments are exposed to increasing pressure and temperature. Regional-scale analysis of seismic data shows large amounts of complexity and variability in terms of acoustic character and stratigraphic thickness (Ike et al., 2008). Previous drilling also demonstrated that seafloor relief (created during construction of the underlying igneous basement) strongly influenced the basin's early depositional history (Moore, Taira, Klaus, et al., 2001; Ike et al., 2008). For example, the axis of a fossil (middle Miocene) backarc spreading center coincides with a prominent basement high; younger seamounts of the Kinan chain are superimposed on the fabric of the ridge. Evidently, elevation of the seafloor inhibited transport and deposition of sand by gravity flows, so Miocene–Pliocene sediments above the ridge consist almost entirely of hemipelagic mudstone. The seismic reflection response within this facies is nearly transparent. On the flanks of the basement high, coeval strata consist largely of sand-rich turbidites. Semicontinuous high-amplitude reflectors are characteristic of this acoustic facies. The control that basement exerts on stratigraphic architecture provides the strategic backdrop for drilling two reference sites within the NanTroSEIZE transect, at proposed Sites NT1-01A (above a basement high) and NT1-07A (above an adjacent basement plain) (Fig. F3). In the following section, we elaborate on the significance of these drilling targets.

## Thematic context for drilling subduction inputs

### *Frictional sliding*

Multiple interrelated controls need to be considered when evaluating downdip changes in frictional properties and their potential for affecting a transition from stable sliding (aseismic) to unstable or conditionally stable fault behavior:

1. A shift to negative frictional velocity dependence (velocity weakening)—potentially caused by alteration of rock composition (e.g., clay-mineral or silica reactions, cementation, or pressure solution), changes in effective normal stress (e.g., Saffer and Marone, 2003), and/or shear localization and fabric development (Marone, 1998), all of which may be driven by incipient metamorphic reactions, cumulative shear strain, cementation, and/or phyllosilicate growth (i.e., phyllitic cleavage);
2. Increasing effective stress that increases the tendency for unstable slip—driven by declining fluid overpressure and coupled (perhaps) with exhaustion of mineral dehydration reactions (Moore and Saffer, 2001); and
3. Elastic stiffness of the fault plane and wall rock—necessary to allow sufficient strain accumulation to generate a recordable earthquake (Moore et al., 2007).

Overall, NanTroSEIZE plans to characterize fault rocks and document how the state variables and in situ parameters change as a function of lateral heterogeneity and downdip pressure-temperature (P-T) evolution. In other words, beginning with strata at the seafloor and seaward of the plate boundary, how do the physical (and chemical) properties of wall rocks and shear zones evolve down the "seismic conveyor belt?"

### *Weak faults*

A theoretical case was made decades ago for weak thrusts (Hubbert and Rubey, 1959). Suggested causes include

1. Intrinsic weakness of fault gouge (e.g., high content of clay minerals),
2. Excess pore fluid pressure resulting in low effective stress that may be either localized within the fault (i.e., a weak fault embedded within a "strong" crust) (Rice, 1992) or distributed regionally (i.e., a weak fault within a weak crust) (Davis et al., 1983), and
3. Dynamic weakening during rapid slip events (e.g., Segal and Rice, 2006).

In situ measurement of state variables will help quantify the respective contribution of each, but many questions remain unanswered:

- What is the ambient pore pressure in wall rocks and fault zones?
- Are pore pressures localized within faults?
- Are coseismic slip and fluid expulsion coupled?
- Are bound fluids in shear zones chemically distinct from those in adjacent wall rocks?
- Do such fluids provide chemical proxies to unveil their sources?
- Does resolved shear stress change gradually or abruptly downdip?

One of the key elements of this test will be to determine which stratigraphic intervals, if any, serve as conduits for focused fluid flow or seals for overpressured compartments. Fundamentally, we cannot determine how or why fault gouge, wall rock, or fluids change downdip without first completing the "baseline" characterization of the starting materials at the presubduction reference sites. Similarly, we cannot resolve whether elevated pore pressures (if present at all) are localized within faults or regionally pervasive without a series of downhole measurements distributed throughout the plate boundary system, including the Kumano Basin and uppermost accretionary wedge.

### *Basement structure*

Subduction zones respond differently to basement highs (e.g., seamounts as potential asperities) and smooth basement plains (Cloos, 1992; Cloos and Shreve, 1996), but several questions need to be answered within this context:

- Are the overlying sedimentary rocks fundamentally different because of autocyclic adjustments of sedimentary systems to basement/seafloor topography (i.e., in terms of texture, mineralogy, grain fabric, frictional properties, permeability, cohesion, etc.)?
- Do hydrologic properties within the upper igneous crust change from basement highs to plains, thereby influencing patterns of fluid flow, temperature, localization of excess pore pressure, strength variations on the décollement, and possibly earthquake behavior downdip?
- Does basement topography control patterns of heat and/or fluid flow?
- Do the presubduction histories of basalt alteration and/or diagenesis of the lowermost sedimentary strata make any difference?
    - If so, will superimposed products of sediment diagenesis, slaty fabric, and rock deformation change the fault strength?
    - If so, can those changes at depth be linked to inherited differences in texture, composition, or earlier mineral dehydration?

This expedition will attempt to address these questions by drilling through the basal sediments and into the upper basalt.

### *Position of décollement*

Seismic reflection profiles indicate that the Nankai plate boundary fault ramps downsection near the updip limit of the seismogenic zone (Fig. **F2**). Shifting a fault's position in the downdip direction from a sediment/sediment interface to the sediment/basalt or intrabasalt interface must be influenced by changes in the rock's mechanical properties or pore pressure, but the precise causative mechanisms remain unclear:

- Are some of the governing properties inherited from the primary depositional environments, or are they all imparted on the rock within a critical P-T or stress window regardless of primary composition?
- Is there any hydrologic control?

- Are evolutions of secondary porosity, fragmentation, cementation, and/or hydrothermal alteration key processes within the upper 100–200 m of basalt?

Our goal is to begin this assessment during Expedition 322.

## Seismic studies/site survey data

Site survey data have been collected in the drilling area over many years, including multiple generations of two-dimensional seismic reflection (e.g., Park et al., 2002), wide-angle refraction (Nakanishi et al., 2002), passive seismicity (e.g., Obana et al., 2004; Obara and Ito, 2005; Ito and Obara, 2006), heat flow (Yamano et al., 2003), side-scan sonar, swath bathymetry, and visual observations from submersible and remotely operated vehicle (ROV) dives (Ashi et al., 2002). In 2006, Japan and the United States conducted a joint three-dimensional (3-D) seismic reflection survey over a ~11 km × 55 km area, acquired by PGS Geophysical, an industry service company (Moore et al., 2007). This 3-D data volume was used to refine selection of drill sites and targets in the complicated megasplay fault region, define the regional structure and seismic stratigraphy, analyze physical properties of the subsurface through seismic attribute studies in order to extend information away from boreholes, and assess drilling safety. A smaller 3-D survey was conducted over proposed Sites NT1-01A and NT1-07A in 2006 by the Japan Agency for Marine-Earth Science and Technology–Institute for Frontier Research on Earth Evolution (JAMSTEC-IFREE) (Park et al., 2008). Prestack depth migration of those data led to refined velocity models and revised estimates of sediment thickness and total drilling depths.

### *Proposed Site NT1-07A*

#### Shikoku Basin, overlying flanks oceanic basement high

Water depth is ~4060 m at this site, which is located at the intersection between IFREE 3-D Line 95 (Fig. **F4**) and CDEX Line ODKM03-101 (Shotpoint 2520) (Fig. **F5**). Compared to the overlying sand-rich trench-wedge facies, strata in the Shikoku Basin are dominated by hemipelagic mud and mudstone. At ODP Sites 808 and 1173, the boundary between upper Shikoku Basin facies and lower Shikoku Basin facies was defined by a combination of lithology and diagenesis, with abundant layers of volcanic ash above the boundary and an abrupt reduction in porosity below the boundary because of opal cement dissolution (Spinelli et al., 2007). At proposed Site NT1-07A, we see prominent reflectors at ~270 and 400 mbsf, which may coincide with a comparable lithologic boundary. Interpretations of acoustic stratigraphy are not straightforward, however, and another interval of interest is related to potential cementation of mudstone by diagenetic opal. Based on the modeled thermal history of the sediment, opal cementation of the section is expected from ~270 to 515 mbsf (Fig. **F6**). Prominent reflectors at the top and bottom of the interval of inferred cementation indicate sharp contrasts in physical properties. Deeper in the section, the lower turbidite facies thickens and displays outstanding acoustic continuity. The interval of inferred turbidites begins at ~750 mbsf and clearly laps onto the basement high toward the southeast, thereby offering an optimal target for overpressured sands near the updip pinchouts. Recent analysis of 3-D seismic data indicates that the depth to basement at proposed Site NT1-07A is ~1200 mbsf.

# Scientific objectives

Drilling sites on the incoming plate (proposed Site NT1-07A) (**F1B, F2, F3**) will capture fundamental geologic properties that are likely to change downdip along the plate boundary (Underwood, 2007). Our goal during Expedition 322 is to document initial conditions at these presubduction reference sites. We acknowledge here that the time allocation for Expedition 322 may be insufficient to complete the entire subduction inputs component of NanTroSEIZE. As implementation of the entire NanTroSEIZE science plan progresses, our knowledge of these initial conditions will expand incrementally and improve the context for interpretation of results from progressively deeper coring depths. Coring will provide samples for critical shore-based studies aimed at evaluating processes hypothesized to govern the transition from stable sliding to seismogenic behavior.

## Key scientific questions

### How does the physical hydrology of Shikoku Basin respond to variations in primary lithologic architecture and basement structure?

As one moves parallel to strike across the NanTroSEIZE transect area (i.e., away from the northeast flank of the fossil backarc ridge), the bathymetry of Shikoku Basin becomes increasingly complicated because of off-axis volcanic seamounts and remnant fragments of Zenisu Ridge (Le Pichon et al., 1987; Mazzotti et al., 2002). Acoustic thickness generally decreases above larger basement highs (Ike et al., 2008), but the 3-D architecture of the lower Shikoku Basin, its composition, detrital source(s), and directions of gravity flow transport are largely unconstrained by seismic data. Basement relief probably blocked or deflected flow paths during early stages of basin infilling, but the effects remain uncertain in detail. Basement-influenced heterogeneity of the lower Shikoku Basin facies, moreover, carries with it implications for abrupt changes in permeability structure, zonation of fluid pressure, and inconsistent amounts of early diagenesis. Such variations are likely both outboard and inboard of the deformation front (Fig. F7).

To accurately characterize the distribution of porosity and permeability, we need to map the turbidite sand bodies using newly acquired IFREE 3-D seismic data (Park et al., 2008). We also need to characterize their contrasting hydrologic properties directly using cores and logs. The turbidite sand bodies of the Shikoku Basin almost certainly provide high-permeability conduits for fluid flow right up to the time when the pore space is occluded by chemical cement. Updip pinch-outs of sand bodies against basement highs probably create compartments of excess pore pressure even before those strata are buried beneath the trench wedge (Fig. F7). This situation would be expected if overpressures get translated laterally from sediments as they are buried rapidly beneath the trench wedge and/or accretionary prism (e.g., Bredehoeft et al., 1988). To evaluate this possibility quantitatively, our strategy is to measure the differences between hydrologic and geotechnical properties of coeval facies units above basement plain and basement high. The upper boundary of the turbidites is also a likely zone of weakness if fluids migrate out of the turbidite section, are unable to drain vertically through the overlying mudstone aquitard, and create an overpressured horizon at the boundary. As subduction progresses, the presence of sand intervals may simultaneously (1) sustain high pore pressures at the top of the sandy turbidites due to translation of pressure along permeable strata (Bredehoeft et al., 1988; Dugan and Flemings, 2000) and (2) allow improved drainage at their downdip edge, leading to significant changes in effective stress and fault strength in three dimensions (e.g., Saffer and Bekins, 2006).

#### How do fluids and fluid pressure in the igneous basement affect subduction processes?

Studies of ridge-flank environments show that seawater transport and chemical reactions in upper oceanic basement are complicated (e.g., Wheat et al., 2003). On the other hand, the physical, thermal, chemical characteristics of fluids in the igneous crust of Shikoku Basin remain completely unconstrained by direct sampling. During NanTroSEIZE, we must consider how basement fluids evolve chemically and physically in the downdip direction and determine if or how potentially "exotic" fluids migrate vertically or updip from the basement. Additionally, if heat transfer from the basement is affected by hydrothermal fluid circulation, we need to quantify its effects on temperatures and rock properties both in situ and downdip. Similarly, fluids derived from basement may be focused along fault zones. To adequately characterize the basalt's physical properties and fluid chemistry prior to subduction, reference holes must penetrate significantly into basement. As a longer term NanTroSEIZE goal, we plan to sample basement fluids in sealed boreholes as a component of observatory installations.

#### How have system-wide patterns of sediment dispersal affected composition within the trench wedge and Shikoku Basin, particularly on the northeast side of the fossil spreading ridge?

Sandstone diagenesis and porosity reduction depend heavily on the initial texture and mineral composition of the sand. Currently, we do not know whether the anticipated Miocene turbidites on the northeast side of Shikoku Basin shared a common provenance with coeval sand bodies on the southwest side (i.e., offshore Ashizuri and Muroto Peninsulas; Fig. **F1A**). If armed with core samples, pore water, and thermal data from the reference sites, scientists will be able to forecast the onset of cement precipitation (e.g., quartz, calcite, and zeolite), framework grain dissolution, and formation of pseudomatrix by compaction and/or tectonic deformation of ductile rock fragments and phyllosilicates. Currently, we know little about clay mineralogy, volcanic ash stratigraphy, or ash alteration on the northeast side of Shikoku Basin. Data from Expeditions 315 and 316 reveal temporal trends in clay content that are consistent with the Pliocene–Pleistocene sections of Muroto and Ashizuri (e.g., Underwood and Steurer, 2003; Underwood and Fergusson, 2005), but the older Miocene strata remain largely unsampled. The clay-mineral budget is integral to several important hydration and dehydration reactions (e.g., smectite to illite transition) (Saffer et al., 2008), and an abundance of clay-size particles lowers the coefficient of internal friction regardless of mineral type (Brown et al., 2003). One prediction to test is the enrichment of both detrital and authigenic smectite (an unusually weak expandable clay) in response to larger amounts of volcanogenic input from the Izu-Bonin arc and a weaker northeast-directed proto-Kuroshio Current during the Miocene (Underwood and Steurer, 2003; Underwood and Fergusson, 2005).

#### How do thermal structure and primary sediment/rock composition modulate diagenesis and fluid-rock interactions?

Thermal structure is a critical input variable to document because of its effect on sediment diagenesis and fluid chemistry. Subducting lithosphere within the Kii transect is ~20 Ma (Okino et al., 1994). Heat flow generally decreases with age and distance from the Kinan Seamounts (Fig. F8) (Wang et al., 1995; Yamano et al., 2003), but we must verify this first-order regional pattern with high-quality borehole temperature measurements. We expect fluids and physical properties to change downsection and downdip in response to both hydration reactions (e.g., volcanic glass to zeolite + smectite) and dehydration reactions (e.g., opal-to-quartz and smectite-to-illite), together with precipitation of crystalline cements (carbonates, zeolites, silica). Sharp diagenetic fronts (especially opal-to-quartz) may be responsible for anomalous offsets in profiles of porosity and other geotechnical properties (Spinelli et al., 2007). The contribution of dispersed volcanic glass is potentially important during diagenesis but, as yet, is poorly understood. Similarly, hydrous authigenic phases in the basalt (e.g., saponite from ridge-flank hydrothermal alteration) are susceptible to diagenetic reactions at higher temperatures. Migration of fluids from zones of deeper seated dehydration reactions is a distinct possibility (Fig. F9), and this can be tested through a comprehensive program of geochemical analyses.

#### Which factor(s) control(s) the décollement's position near the prism toe, as well as the location of ramps and flats and mechanical behavior throughout?

One generic possibility to consider is a reduction in shear strength along a specific stratigraphic interval with low intrinsic strength, caused perhaps by unusually high contents of clay-size particles and/or smectite-rich clay (e.g., Vrolijk, 1990; Deng and Underwood, 2001; Kopf and Brown, 2003). Another generic possibility is a reduction of effective stress because of excess pore pressure. Causes of excess pore pressure could be as diverse as rapid updip migration of pore fluids from deep-seated sources, in situ mineral dehydration within poorly drained mudstone, or compaction disequilibrium caused by rapid loading of an impermeable mudstone beneath the landward-thickening trench wedge. Pinch-outs of highly permeable sand against mudstone aquitards, if combined with compaction disequilibrium and pressure-driven fluid flow, could lead to a complicated 3-D geometry of stratigraphically controlled compartments of excess pore pressure. Strata near the basalt/sediment interface, moreover, may contain abundant volcaniclastic debris and smectite. If true, those rocks may form the deeper and more landward zones of preferential weakness where the décollement ramps down. The permeable sandy turbidites may also exert a primary control on décollement strength and downstepping via their effect on pore pressure and thus effective stress (Moore and Byrne, 1987; Saffer and Bekins, 2006). Other possibilities to consider include changes in the hydrologic properties of basal sedimentary rock and/or the upper igneous crust (i.e., heterogeneities in permeability might localize overpressures) and changes in rock fabric as a function of protolith (i.e., the uneven development of slaty or phyllitic fabric may respond to inherited variations in sediment texture, composition, and earlier diagenetic-metamorphic history).

**Does the plate boundary fault, near its updip limit of seismicity, shift its position from a sediment/sediment interface (stable sliding) to the sediment/basalt interface (stick-slip)?**

The plate boundary when traced in the downdip direction eventually ramps down from a sediment/sediment interface to the sediment/basalt or intrabasalt interface (Fig. F2). This shift in lithologic position must coincide with fundamental changes in the rock's mechanical and/or hydrologic properties, but how so? Shore-based studies indicate that systematic fragmentation of upper basement and incorporation of basalt slabs into shear-zone mélanges could be controlled by primary layering of the igneous rock (Kimura and Ludden, 1995). Our challenge will be to discriminate between the presubduction factors inherited from Shikoku Basin (documented during this expedition) and the changes imparted by increasing P-T conditions and stress changes at depth (documented in the future by deep riser drilling).

# Scientific strategies

Fundamentally, NanTroSEIZE is an ongoing interdisciplinary project that continues to require an unprecedented amount of collaboration and coordination, both within and among all of the individual expeditions. At the same time, scientists on each expedition will be expected to focus on a large number of topical objectives and employ the optimal methods for achieving those objectives. Furthermore, drilling is providing data and samples relevant to several secondary scientific objectives. Some of the ancillary topics include investigation of physical properties and pore water chemistry across a well-defined bottom-simulating reflector, reconstruction of the Kuroshio Current along the Japanese islands, regional tephrachronology, presubduction constraints on the geochemistry of "subduction factories," and sampling the biosphere along a continental margin at subbottom depths down to 1200 mbsf. The following list is just a starting point; we expect members of the invited science party to suggest and pursue additional strategies.

## Lithology

Scientific tasks in the field of lithology include integration of seismic stratigraphy with conventional core descriptions, wireline logs, and compositional analyses (grain size, bulk mineralogy, sand petrology, clay mineralogy, and dispersed and layered volcanic ash). This core-log-seismic integration will establish patterns of sediment dispersal, 3-D facies architecture, and their responses to autocyclic and allocyclic forcing. Much of this can be accomplished using standard shipboard protocols, including data from multisensor core loggers. Bulk-powder compositional analysis by X-ray diffraction (XRD) will be essential for core-log-seismic integration. Shore-based work should include detailed XRD analysis of clay minerals, inductively coupled plasma–mass spectrometry bulk chemistry, thin section petrography, environmental scanning electron microscope (SEM)-energy dispersive spectrometry (EDS) of mudstone fabric, chemical analyses for biogenic silica, volcanic glass geochemistry, stable isotope analyses, apatite fission-track geochronology, and radiometric dating of detrital phyllosilicates and K-feldspar. It is particularly important to document the fine details of sediment fabric with high-resolution microscopy and to characterize the "protolith" phyllosilicate composition (e.g., illite crystallinity index, mica polytype, mica $b_o$ value, and timing of crystallization) so we can compare these with incipient metamorphic phases sampled later in the downdip direction within the subduction zone. Such data will help test whether or not mineral changes and/or fabric changes affect the onset of stick-slip behavior during the transformation of mudstone to slate-phyllite.

## Physical and chemical hydrology

Aqueous fluids affect virtually all forms of subduction zone behavior (Moore and Vrolijk, 1992; Moore, Taira, Klaus, et al., 2001; Saffer and Bekins, 1998, 2002). Thus, we must consider (1) how spatial distribution of permeability, pore pressure, temperature, and fluid chemistry vary within different sedimentary rocks and igneous basement; (2) how fluid composition and pressure change in response to burial, tectonic consolidation, and diagenesis; (3) how changes in pore pressure affect fault strength; and (d) potential for hydrologic feedbacks to regional strain (e.g., flow of deep-seated fluids along sand layers within the lower Shikoku Basin facies; see Fig. **F9**). Therefore, horizontal and vertical permeability of the sediment will be measured using a combination of whole-round samples (from both sand-rich and mud-rich units, tested at in situ effective stresses). We will also attempt to measure formation pressure using the sediment temperature-pressure (SET-P) tool (formerly known as Davis-Villinger Temperature-Pressure Probe). Our long-term goal for NanTroSEIZE is to quantify hydrologic properties over a full range of well-characterized lithologies (including basalt), then scale upward from minicore and whole-round specimens to wireline logs and 3-D seismic reflection data. In addition to shipboard interstitial water chemistry, shore-based laboratories will need to concentrate on analyses of trace/minor elements in the pore fluids, together with isotopes (Sr, B, Li, O, H, Cl, and C) that are diagnostic of fluid sources and conditions of low- to medium-temperature fluid-rock reactions. Some of these goals will require installation of long-term borehole observatories, but the design and positioning of such observatories will depend on data from the cores.

## Thermal data

Mechanical properties, hydrologic properties, and rock fabrics evolve during compaction and diagenesis. Precise calculations of heat flow and documentation of presubduction diagenetic progress need to be carefully coordinated with parallel efforts in lithology, fluids, and physical properties. Most of the alteration products of early sediment and basalt diagenesis will be documented via shore-based chemical analyses of specific authigenic phases, XRD, transmission electron microscopy, and SEM-EDS. For example, temperature drives the opal-to-quartz reaction, which in turn may dictate where the diagenetic boundary between upper and lower Shikoku Basin facies is located (Spinelli et al., 2007). Thus, a high priority will be to pinpoint thermal structure where the alteration paths begin. These goals can be achieved through relatively high resolution borehole temperature measurements using both the advanced piston coring temperature (APCT-3) and SET-P tools.

## Basement coring and logging

Characterization of basement composition and structure is a high priority for NanTroSEIZE. Permeability and fluid flow within oceanic basalt are affected by many variables (Fisher, 1998). A long-term goal is to monitor and sample fluids using subseafloor observatories, but design of those experiments hinges on coring and logging results. As a prelude, we plan to concentrate first on documenting the basement's structural architecture, fluid composition at the sediment/basalt interface, hydrologic properties, and early alteration products. Products of early alteration within the uppermost basalt (e.g., saponite and calcite) change the rock's bulk chemistry and physical properties (porosity and permeability). The extent of this alteration is important for constraining the volatile content of subducting crust. In addition, coring at least 40 m into basement at proposed Site NT1-07A and wireline logging will capture heterogeneities in fracture patterns and porosity that might be involved in delamination of the basalt downdip in the seismogenic zone. Basement penetration at proposed Site NT1-01A is also included in the contingency plan (see **"Risks and contingency"**).

## Physical and geotechnical properties

We will document depth-dependent and facies-sensitive variations in bulk density, porosity, void ratio, electrical conductivity, and thermal conductivity using standard shipboard measurements. Wireline logs will measure the physical properties in situ, to be followed by a more time intensive program of shore-based geotechnical and rock mechanical experiments (e.g., one-dimensional consolidation and triaxial, direct shear, ring shear, and flow-through permeability) under a wide range of experimental conditions. Tests on whole-round core samples will define in situ burial conditions, establish whether states of over- or underconsolidation exist on a widespread basis, and pinpoint lithology-, grain size-, and temperature-dependent changes in deformation behaviors, permeability, and moduli (Giambalvo et al., 2000; Burland, 1990). Consolidation tests will also provide lithology-specific solutions to the relation between effective normal stress and void ratio, which will permit estimates of in situ pore pressure and effective stress (Moore and Tobin, 1997; Saffer, 2003; Ge and Screaton, 2005). Shearing experiments on intact and remolded material will document composition- and fabric-dependent variations in frictional strength and velocity dependence (Brown et al., 2003; Kopf and Brown, 2003; Saffer and Marone, 2003).

## Downhole logging

Downhole logging is an important method to achieve scientific objectives of the expedition. Resistivity, density, porosity, natural gamma ray, sonic velocity, and borehole image data are critical for core-log-seismic integration in terms of lithology, petrophysics, and sedimentary/basement structures.

Continuous logging data can be used to compensate for uncored intervals or cored intervals with poor recovery. Logging data will provide essential information to identify the critical intervals such as turbidite zones in lower Shikoku Basin and the sediment/basement interface where core quantity and quality are expected to be poor. Borehole images will provide excellent information to characterize possible fluid conduits such as individual sand layers, volcaniclastic successions, and internal structure of igneous rocks.

To fulfill the scientific objectives, natural gamma ray, resistivity, density, porosity, sonic velocity, and resistivity images are essential measurements as highest priority. Photoelectric effect (PEF) and spectroscopy gamma ray logs that provide concentrations of K, Th, and U are useful to identify lithologic determination. Interval velocity data determined by check shot are useful for log-seismic integration.

# Operations plan/drilling strategy

Our primary objectives are to take cores, obtain downhole in situ formation measurements, and to conduct wireline logging through the entire stratigraphic succession of Shikoku Basin. Our operations plan and time estimate for proposed Site NT1-07A are shown in Table **T1.**

Under normal circumstances, coring progresses from hydraulic piston coring system (HPCS) to extended shoe coring system (ESCS) coring (until refusal) to standard rotary core barrel (RCB) coring to obtain the highest quality, most complete core samples. Because of the need to obtain undeformed cores from the lowermost Shikoku Basin and the constraints of time, we plan to wash down to ~400 mbsf and begin coring using RCB. Following coring to basement, we will run downhole wireline logging measurements. If time permits after successful penetration of basement, we will core the upper 400 m using HPCS/ESCS. APCT-3 (formation temperature) and SET-P (formation temperature and pressure) measurements will be conducted during coring operations.

There are substantial risks to the successful outcome of the operational and scientific objectives of this expedition. Among these are

1. The lack of formation information at the proposed sites (particularly with respect to hole stability in the sandy intervals),
2. The unpredictable migration of the Kuroshio Current,
3. Typhoon and/or bad sea conditions,
4. Variability in rates of penetration, and above all,
5. Budgetary constraints.

In the following sections we will describe the operational sequence to be conducted on this expedition, document some of the known risks and steps we are taking to mitigate them, and present contingency strategies and priorities. Descriptions of coring, downhole, and logging tools are available at **www.jamstec.go.jp/chikyu/eng/Expedition/laboratories/index.html**.

## Operations plan

After departing Shingu (Japan), we will transit for ~1 day to proposed Site NT1-07A and prepare for drilling operations. The operations plan and time estimate are based on formations and depths inferred from seismic and regional geological interpretations without benefit of prior drilling in this area. We have, however, carefully considered information from ODP Legs 190 and 196 (especially Sites 1173, 1174, and 1177, which are located >200 km to the west-southwest). The primary plan for Expedition 322 is to conduct operations in one hole at proposed Site NT1-07A (Fig. **F10**). The overall operations plan is summarized in Table **T1.**

### *Proposed Site NT1-07A*

We will core one primary hole at proposed Site NT1-07A. The first hole at this site will be cored with the RCB. Coring will start at 400 mbsf and continue to the sediment/basalt interface at 1200 mbsf. If formation conditions permit, we will also attempt pressure measurements within and/or immediately above the unconsolidated sand intervals of the lower Shikoku Basin using the SET-P tool. The hole will be terminated at the sediment/basalt interface but may be continued ~40 m below the sediment/basalt interface. After the hole is conditioned, loaded with mud, and the bit is released in the hole, we will run two wireline logs and a check shot vertical seismic profile (VSP) in open hole. Poor borehole conditions may substantially impact the downhole in situ measurements.

A second hole at proposed Site NT1-07A may be cored as a contingency using HPCS/ESCS to refusal or overlap with the top of Hole A. We will conduct formation temperature measurements in the soft mud during HPCS coring (APCT-3) at a target spacing of every third or fourth core and pressure-temperature measurements (SET-P) as permitted by formation conditions. After operations are completed at proposed Site NT1-07A, the ship will be secured for ~1 day transit back to Shingu, Japan.

## Logging/Downhole measurements strategy

Downhole measurements focus on characterizing in situ formation conditions and properties, as well establishing the link between the cores, logs, and seismic data. Since LWD data were not collected during Expedition 314, downhole measurements are essential to the success not only of the expedition but also of the whole NanTroSEIZE project.

The primary downhole measurements conducted during coring operations will consist of formation temperature and pressure measurements with the SET-P tool. We will stabilize the hole with weighted mud when making the pressure measurements. IODP Expedition 308 used this technique successfully to extend formation measurement time without circulation (Long et al., 2008). The degree of induration will also increase with depth, however, and we have concerns about the reliability of pressure data if insertion of the tool tip causes the mudstone to fracture or within formations characterized by low hydraulic diffusivity that require unreasonably long times (>2 h) to obtain any meaningful pressure data. Thus, our deeper tests will be attempted within intervals of uncemented sand in the lower Shikoku Basin turbidite facies at proposed Site NT1-07A.

Once coring is completed in the first hole, we will conduct a series of downhole logging runs. Given the history of difficult formation conditions in convergent margins and its impact on the successes of downhole logging, weighted mud will be used to stabilize the hole to increase chance of obtaining downhole logs. Our logging plan consists of three primary tool strings (Fig. **F11**):

1. Highly Integrated Gamma Ray Neutron Sonde (HGNS) for natural gamma ray and neutron porosity, High-Resolution Laterolog Array Tool (HRLA) for latero-resistivity, and Hostile Environment Gamma Ray Sonde (HLDS) for density, PEF, and caliper;
2. Enhanced Digital Telemetry Cartridge (EDTC) for telemetry and natural gamma ray, Hostile Environment Gamma Ray Sonde (HNGS) for spectroscopy gamma ray, Dipole Sonic Imager (DSI) for sonic velocity (*P*-wave and *S*-wave velocity), and Formation MicroScanner (FMS) for resistivity image; and
3. Versatile Seismic Imager (VSI) for interval velocity by check shot.

These tool strings are described in detail at **www.jamstec.go.jp/chikyu/eng/Expedition/logging.html.**

The first run measures basic and important properties: natural gamma ray, resistivity, density, PEF, and porosity. These data help characterize finer scale stratigraphy that can be associated with cyclicity within turbidite intervals. The caliper log provided by the HLDS will also allow us to assess the hole conditions and chances of success of subsequent wireline runs. Since these measurements coincide with those in the LWD holes in Expedition 314 (Kinoshita et al., 2008), the data will be integrated.

The second run will include EDTC, HNGS, DSI, and FMS. The high-resolution FMS images will provide fine-scale stratigraphy and the best information about the extent of deformation and brecciation within the upper basement. The DSI will provide the first measurements of in situ formation sonic velocity that will allow generation of synthetic seismograms for detailed seismic log correlations and help characterize the petrophysical properties of the sediments.

The final run will be a VSP whose primary goal will be to tie precisely the well data to the 3-D seismic survey. This will be recorded with the VSI (containing a three-axis geophone). As the difficulty of getting proper mechanical coupling between the tool and the formation increases with the number of shuttles, the actual tool configuration will ultimately depend on the results of the caliper log and sea conditions.

# Risks and contingency

## Contingency

Figure **F12** shows the decision tree for contingencies if operations remain on schedule and days are not lost because of adverse weather, and so on. Our first priority will be to use the time for additional operation at proposed Site NT1-07A and/or to core and log proposed Site NT1-01A. On the other hand, substantial risks to full achievement of our scientific objectives include

1. Lack of data about hole conditions or formation properties,
2. Potential problems with the Kuroshio Current,
3. Unusually slow rates of penetration, and
4. Typhoon and bad sea state.

To mitigate these risks, we have devised a comprehensive contingency strategy. It is important to note that this contingency plan is based on our state of knowledge at the time of this writing and modification may be required as additional information becomes available, including recommendations from the NT-PMT. Within our primary operations plan, we have identified several potential contingency options in the case of hole problems and/or time constraints (Fig. **F12**). First, if coring operations at proposed Site NT1-07A require significantly more time than allocated, we will need to rebalance all of the remaining scientific objectives. Contingency options for typhoon evacuation are shown on Figure **F12.** If we must abandon a hole to escape bad weather, reentry will not be possible; a new hole will be drilled to the depth where coring stopped.

### *Optional operation at proposed Site NT1-07A*

Once the interface between sediment and basalt is encountered (at ~1200 mbsf), and if sufficient time remains to pursue additional objectives, we will consider several options. The first is to deepen the hole to at least 40 m below the sediment/basalt interface. This will permit logging tools to extend completely into basement and record the character of the lowermost sedimentary strata. After logging, the second option is to core the upper 400 m of sediment using HPCS and ESCS coring systems, thereby recovering the entire stratigraphic column at proposed Site NT1-07A. The third option is to occupy a new site (proposed Site NT1-01A), as described below. Criteria for making this decision will include the number of operational days remaining and an assessment of the scientific results from proposed Site NT1-07A.

## Alternate site

If hole conditions, strong currents, or mechanical problems preclude some of the operations at the proposed primary site, we will move to an alternate site. Alternate Site NT1-01A is described briefly below. For comprehensive site descriptions, refer to Proposals 603A-Full2, 603A-Add, and 603D-Full2. This site could also be drilled if a sufficient number of contingency days remain after operations at proposed Site NT1-07A have been completed.

### *Alternate proposed Site NT1-01A*

#### Shikoku Basin above basement high

This site will be drilled near the crest of a prominent bathymetric knoll (Kashinosaki Knoll) that is underlain by a basement high. The site is located on IFREE Line 95 at a water depth of ~3610 m (Fig. **F13**). The crossing line is CDEX Line ODKM03-22 (Shotpoint 1685) (Fig. **F14**). Visual observations and sampling from a JAMSTEC submersible indicate that strata at the seafloor are moderately lithified (Fig. **F15**), perhaps because of winnowing by strong bottom currents and/or precipitation of carbonate crusts. Acoustic character within the sediment column is largely transparent, which indicates that the strata are composed of hemipelagic mud and mudstone, with few sand packets. The boundary between upper and lower Shikoku Basin facies is ambiguous but could be near a relatively strong reflector at ~160 mbsf. Depth to an unusually strong basement reflector is ~600 m. We plan to core at least 40 m of the basement section; as a longer term goal, extending this penetration to 200 m below the sediment/basalt interface would be optimal.

## Risk and risk mitigation

In this section, we present some of the known risks to the successful expedition implementation and the steps being taken to minimize them. The risks include lack of formation information, the Kuroshio Current, and overall operations time available.

### *Lack of formation information*

One of the primary risks to the overall expedition success is the lack of information available regarding the formation at the proposed sites. Potential impacts range from not being able to achieve the total depth objectives (e.g., because of unstable hole conditions) to longer-than-anticipated drilling times (e.g., because of inaccurate seismic velocity models and erroneous estimates of depth to basement). The operations plan (Table **T1**) is based on formations and depths inferred from earlier seismic and regional geological interpretations and revised depths calculated from recently acquired 3-D seismic data. In particular, we have used lithologic information from the analogous reference sites that were cored and logged during ODP Legs 190 (Moore, Taira, Klaus, et al., 2001) and 196 (Mikada, Becker, Moore, Klaus, et al., 2002).

Encountering serious hole stability problems at the proposed primary sites (e.g., because of overpressured uncemented sands), however, would be problematic for our expedition because time and budget allocations will not permit any installation of casing. Given the potential for moderately unstable formation conditions and the priority of downhole measurements, we plan to use weighted mud liberally. This strategy will build upon the demonstrated successes of IODP Expedition 308 (Expedition 308 Scientists, 2005). We plan to fill the hole with weighted mud prior to conducting pressure measurements and wireline logging.

### *Kuroshio Current*

The Kuroshio Current is a swift western boundary current that presents substantial risk to all expedition operations. If we encounter the maximum Kuroshio Current strengths at any given drill site, drilling, coring, or logging operations may be impossible. The core of the current migrates and meanders significantly and unpredictably (Fig. **F16**), so efforts will be made to monitor its location and velocity using available online resources. Forecasting the current's general behavior a few months in advance is possible, but accurate and precise predictions are not. A strong Kuroshio Current will have adverse impacts on instrument deployments by inducing substantial amounts of drill string vibration. Previous work in the region demonstrated that such vibrations are potentially damaging to all hardware and tools deployed.

#### *Expedition operations time*

Unforeseen circumstances could result in insufficient time being available to complete the entire operations plan. Examples include collapse of a borehole because of difficult formation conditions (unstable sands), persistently adverse environmental conditions (e.g., Kuroshio Current), hazardous weather (typhoon), hardware failures, or unusually slow rates of penetration. In anticipation of challenging and fluctuating environmental conditions, we have included 11.5 days of contingency for the entire expedition in the operations plan and time estimate.

## Sampling and data sharing strategy

### NanTroSEIZE expeditions are part of a single coordinated science program

To maximize the science return, Expedition 322 will strive to achieve consistency in approach and cooperation with previous Stage 1 expeditions, as well as Expedition 319. This applies to all research activities including shipboard analysis, use of scientific terminology, measurement protocol, and sample requests for onshore research. There are three key points related to overall research planning (described below).

#### *Specialty coordinators*

Unlike traditional, stand-alone IODP expeditions, unusual amounts of coordination and collaboration must occur among science parties across NanTroSEIZE expeditions. Specialty Coordinators will be responsible for facilitating these essential collaborations and maintaining consistent protocols and terminologies. The NT-PMT has identified six specific research areas that require special effort over the project's duration:

1. Lithology and sedimentary petrology,
2. Structural geology,
3. Geotechnical properties and hydrogeology,
4. Geochemistry,
5. Core-log-seismic integration, and
6. Paleomagnetism and biostratigraphy.

Specialty Coordinators will provide technical and scientific guidance to each science party and facilitate cross-expedition collaborations among the science parties to achieve NanTroSEIZE objectives. Shipboard scientists should expect frequent communications with their relevant Specialty Coordinators before, during, and after the expedition.

### *Community samples*

As usual, individual scientists will collect samples for shipboard analyses and their postcruise research. In addition, however, we intend to collect substantial numbers of "community" archive samples, especially whole rounds. In some cases, these community samples will augment and/or provide redundancy for those requested by shipboard scientists. The goal is to preserve samples for a wide range of overall science objectives over the duration of the NanTroSEIZE project. This strategy, for example, will enable additional analyses of critical intervals once those zones are identified from initial shore-based laboratory tests.

### *Sample clusters*

To ensure achievement of overall NanTroSEIZE scientific objectives, it will be essential to colocate suites of essential data types. This must be done with appropriate and consistent sample spacing throughout each hole. During Expedition 322, sample clusters will be located immediately adjacent to all whole-round intervals extracted for pore water geochemistry and geotechnical/hydrogeology tests. The clusters may include subsamples for carbon-carbonate, bulk powder XRD, microfabric, clay-mineral XRD, moisture and density, grain size analysis, and bulk chemistry by X-ray fluorescence. Most of those analyses will be completed onboard the *Chikyu*.

## Research plan proposals (sample and data requests)

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy (**www.iodp.org/program-policies**). This document outlines the policy for distributing IODP samples and data and defines the obligations that sample and data recipients incur.

A research plan covering all samples and data, including those from potential contingency sites, is required well in advance of the expedition, which is scheduled to start in September 2009. Scientists must submit their research plans using the sample material curation system at **smcs.iodp.org**. We expect all of the individual expedition participants to honor expedition-specific as well as cross-expedition objectives and priorities. Such requests are also welcome from shore-based participants.

Access to data and core samples for specific research purposes, both during the expedition and during the subsequent 1 y moratorium, must be approved by the Sample Allocation Committee (SAC) for the expedition. The moratorium period will extend 1 y from the completion of the expedition, or if a significant postcruise sampling party is required, 1 y following the completion of the sampling party.

The SAC is composed of Co-Chief Scientists, Expedition Project Manager, the IODP curator on shore, and the curatorial representative in place of the shipboard curator. The six Specialty Coordinators will also contribute to this process as project-wide representatives of their respective disciplines. Because proposed Site NT1-01A could be drilled during Expedition 319 (as a contingency operation), the SACs from Expeditions 319 and 322 will be merged to evaluate requests for those samples.

Based on research (sample and data) requests submitted, the SAC will work with the scientific party as well as other Stage 2 SACs and Specialty Coordinators, if necessary, to formulate a formal expedition-specific sampling and data-sharing plan for shipboard and postcruise activities. Coordination of a whole-round sampling map will be particularly important and will include both personal samples and community samples. This map will be subject to frequent core-to-core adjustments depending on the actual material/data recovered and collaborations that may evolve between scientists before and during the expedition. Other modifications to the sampling plan during the expedition require the approval of the SAC.

All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, the expedition objectives, and project-wide NanTroSEIZE objectives. Success will require substantial amounts of cross-expedition collaboration, integration of complementary data sets, and consistent methods of analysis.

When critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals (e.g., highly deformed fault zone) may require special handling, a higher sampling density, reduced sample size, or continuous core sampling for a set of particular high-priority research objectives. The SAC may require an additional formal sampling plan before critical intervals are sampled.

All sampling to acquire ephemeral data types or to achieve essential sample preservation will be conducted during the expedition. Sampling for individual scientists' postcruise research may be conducted during the expedition or may be deferred to postcruise. Following Expedition 322, cores will be delivered to the IODP Core Repository at Kochi Core Center, Japan.

## Cruise-specific sampling

The unique nature of the NanTroSEIZE project requires some adaptation of existing IODP policies and procedures. As scientists develop their individual research plans for core samples and data, they should refer to this expedition's scientific objectives (see above), the three Stage 1 expeditions (Kinoshita et al., 2008; Ashi et al., 2008; Kimura et al., 2008), the Expedition 319 *Scientific Prospectus* (Araki et al., 2009), as well as the overarching Stage 1 *Scientific Prospectus* (Tobin and Kinoshita, 2006a).

We anticipate an extensive sampling program to achieve research objectives within most disciplines. When possible, our goal will be to make as many measurements as possible on common (or nearly co-located) samples, thus reducing the amount of material removed from the core and maximizing our ability to correlate different data types. These sample clusters (e.g., pore water, carbon-carbonate, moisture and density, bulk XRD, clay XRD, and bulk chemistry) will also improve our collective ability to complete and interpret complementary postcruise analyses. Substantial whole-round core sampling will be conducted to obtain appropriate samples for ephemeral shipboard analyses and to appropriately preserve samples for postcruise research. Such whole-round samples are especially important for geotechnical, hydrogeologic, and rock mechanics tests (e.g., permeability, consolidation, triaxial, ring-shear, etc.). Because different laboratories employ different protocols and have different capabilities and limitations (e.g., elevated temperature, stress ranges, and strain rates), there are no rigorous standardized approaches for many of the critical measurements. This, combined with a need for comprehensive characterization of core materials over the broadest possible range of experimental conditions, requires a coordinated sampling approach. Further, experience shows that it is impossible to identify all of the critical sampling intervals ahead of time (i.e., before the cores are split). Therefore, not only will whole-round samples be extracted for individual scientist's research, we will also build a community archive. The community whole-round specimens will be stored at the repository (Kochi) and released to scientists only after they file appropriate sample requests. These samples will be used primarily to ensure that there are no critical gaps in sample characterization both with respect to spatial sample distribution and scientific data types generated, for interlaboratory calibration, redundancy, and quality assurance (QA)/quality control (QC).

## Community labs for postexpedition analyses

Whereas many analyses can and will be conducted at sea, others require state-of-the-art instrumentation that is only available onshore. We are particularly concerned about stable isotopic measurements that depend on dedicated instruments not found at all universities and government laboratories. For example, we expect to collect pore waters to measure at least Sr, B, Li, O, H, Cl, and C stable isotopic compositions. It is doubtful that any individual scientist has the on-site capability to make all of the measurements listed above. Issues regarding QA/QC become significant. To get the most consistent and reliable data for all Stage 1 expeditions, the NT-PMT proposed that all samples for each category of geochemical analysis go to a single laboratory. Several laboratories (to be determined) will have to be involved. For example, one laboratory might measure O, H, and C isotopes while another might measure Cl isotopes or Li. The choice of a particular laboratory (and analytical technique) will be reached by consensus of the inorganic geochemists who sail on the Stage 2 expeditions, mediated by the Specialty Coordinator for Geochemistry and approved by expedition SACs. We anticipate that data generated from each laboratory will be shared by all members of the Expedition 322 scientific party for use as defined by the approved research plans. Similarly, shore-based collaborators who are part of the community team will be granted access to the results of shipboard geochemical analyses at the earliest convenience (i.e., as site reports are completed). This strategy was implemented successfully during the postexpedition phase of NanTroSEIZE Stage 1.

## Data sharing between expeditions

Data sharing across expeditions is normally accommodated through a formal data/sample request; that is, scientists from one expedition can apply as a shore-based scientist for shipboard data/samples from a completed or planned expedition. In this context, all Expedition 322 scientists are encouraged to submit a request for data/samples from other IODP expeditions, including Expedition 319, if they are interested in conducting postcruise research that furthers the science objectives of those expeditions. In the case of NanTroSEIZE, it is also possible that drilling or scientific objectives will overlap across two or more expeditions to such an extent that the expeditions will be considered one expedition in terms of shipboard data and samples. In these cases, data can be shared without a separate data/sample request. This may occur, for example, for scientific or logistical reasons during preexpedition planning or during the expedition if contingency sites are drilled that overlap with a planned expedition. The decision as to whether an expedition is a stand-alone expedition in terms of data/samples or is part of a suite of expeditions is made by the NT-PMT in consultation with the SAC and Co-Chiefs of the involved expeditions.

As a specific example, if proposed Site NT1-01A is drilled during Expedition 319 but partially or wholly analyzed during Expedition 322, the science parties of Expeditions 319 and 322 will be merged in order to best address the common theme of characterizing subduction inputs. In this scenario, scientists participating in either expedition will have full access to all samples and data from both expeditions, and sample requests will be reviewed and evaluated jointly by the two expedition SACs. This is somewhat different than most previous IODP expeditions but will follow the precedent and procedures defined during NanTroSEIZE Stage 1 drilling (e.g., Ashi et al., 2008; Kimura et al., 2008).

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**Table T1.** Operations plan and time estimate for Expedition 322.

**Expedition 322: NT1-07 Riserless Hole**
**(Core Hole)**

**Water Depth :** 4,062m
**Total Depth :** 1,200mbsf (5,262mMSL)

| Operation Description | Penetration | ROP | Days | Sub Total | Total |
|---|---|---|---|---|---|
| Port Call to Shingu | | | 4.0 | | 4.0 days |
| *4days Port Call will be changed according to the actual loading days required. | | | | | |

***<RCB Core Hole >***

| Operation Description | Penetration | ROP | Days | Sub Total | Total |
|---|---|---|---|---|---|
| 1) Move from Shingu to NT1-07 site | | | 0.5 | 0.5 | 0.5 |
| 2) Preparation for Spud | | | | | |
| Deploy Transponder, Move to up current, Rig up UWTV | | | 2.0 | 2.0 | 2.5 |
| 3) Cut 10-5/8"RCB Core | | | | | |
| M/up and & Run 10-5/8"RCB Coring Assembly w/drifting Run UWTV | | | 2.5 | | |
| Drill 10-5/8"hole to 400m w/RCB center bit | 0 - 400 mbsf | | 1.00 | | |
| Cut 10-5/8" RCB core from 400m to 1,000m | 400 - 1,000 mbsf | 60m/day | 10.5 | | |
| *SET-P(2run) survey at 700m～900mbsf | | | (0.5) | | |
| Cut 10-5/8" RCB core from 1,000m to 1,200m | 1,000 - 1,200 mbsf | 50m/day | 4.0 | 18.0 | 20.5 |
| 4) Wireline Logging | | | | | |
| Wiper Trip | | | 0.5 | | |
| Displace w/weighted mud, Drop bit, POOH to seafloor | | | 0.5 | | |
| W-Log | | | 1.0 | 2.0 | 22.5 |
| Run back Drill Pipe, Spot weighted mud for abandonment | | | | | |
| 5) POOH, Retrieve Transponder | | | 1.0 | 1.0 | 23.5 |
| 6) *Contingency* | | | 11.5 | 11.5 | 35.0 |
| 7) Move to Shingu | | | 1.0 | 1.0 | 36.0 |

**Total 40.0 days**

| | | | | | |
|---|---|---|---|---|---|
| ***Contingency breakdown*** | Typhoon Evacuation | 8.0 | 2 times | (4days/time) | |
| | Equipment Downtime Maintenance & Training | 2.5 | | 10% | |
| | Wait on Weather | 1.0 | | 5% | |
| **Total** | | **11.5days** | | **operation days** | 24.50 days |

**Figure F1. A.** Bathymetric map, Nankai Trough off southwestern Japan is the locus of subduction of the Philippine Sea plate (PSP) beneath Honshu and Shikoku islands. Arrow = convergence direction between PSP and Japan. Rupture zones of the last two large subduction earthquakes (1944 and 1946) are also shown. Stars = epicenter locations for earthquake nucleation. Red dashed line = Expedition 322 drilling area shown in B. Inset shows location of Nankai Trough. EP = Eurasian plate, PP = Pacific plate, NAP = North American plate. (**Continued on next page.**)

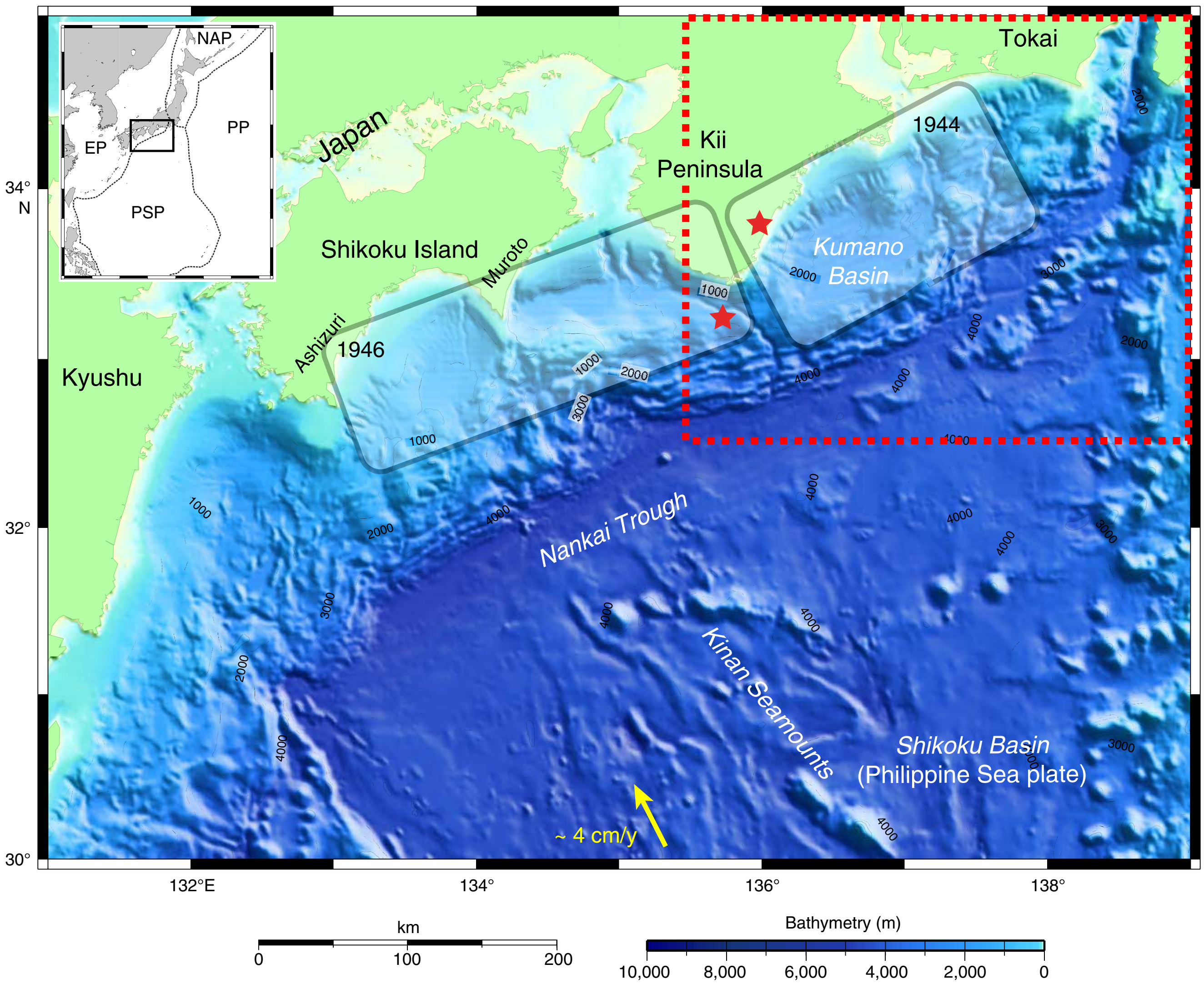


**Figure F1. (continued) B.** Bathymetric map, with all multichannel seismic profile locations and drill sites (Stage 1 and Stage 2). Expedition 322 will occupy proposed Site NT1-07A and contingency proposed Site NT1-01A. Portions of Line 5 are shown in Figure F2. White barbed line = position of deformation front of accretionary prism, arrow = convergence vector between Philippine Sea plate and Japanese Islands (Eurasian plate). Red dot = planned drilling Site NT1-07A, orange dots = Stage 1 sites, white dot = planned contingency Site NT1-01A.

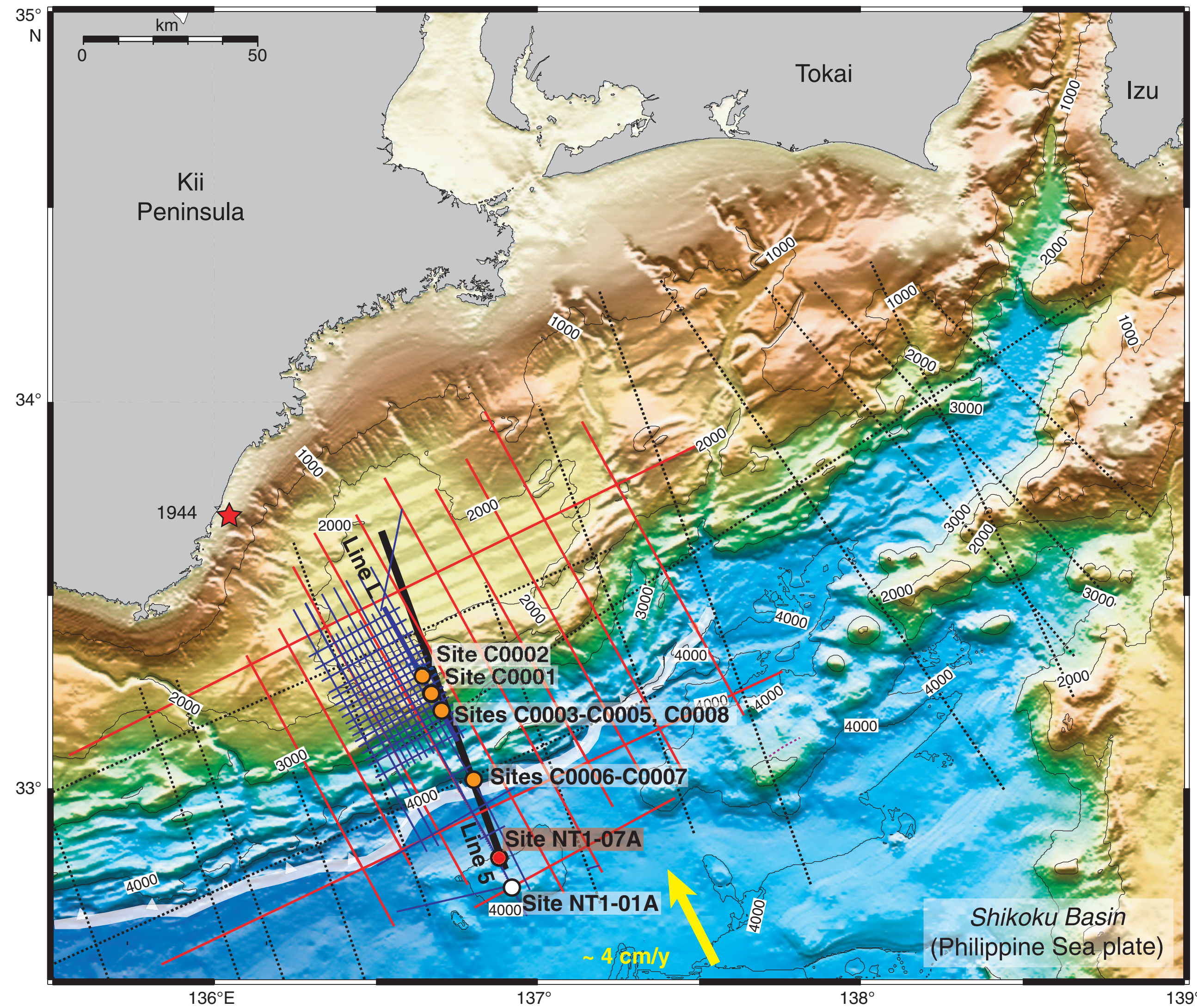


**Figure F2**. Seismic Line KR0108-5 (prestack, depth migration) from Park et al. (2002) showing projected locations of drilled and proposed NanTroSEIZE drill sites.

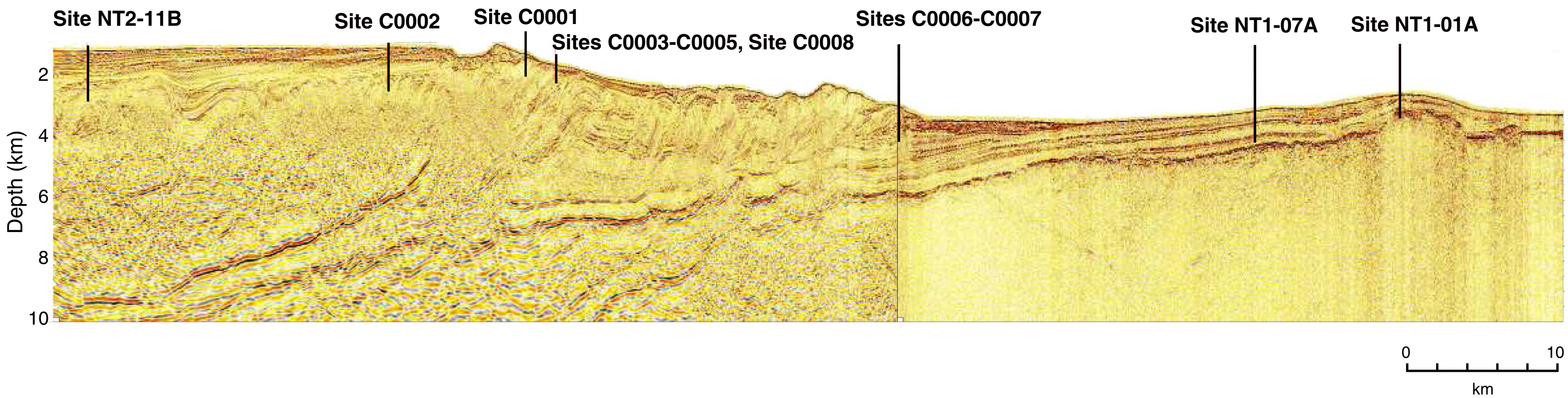


**Figure F3**. Primary drill Site NT1-07A and contingency Site NT1-01A distributed along a transect from the prism toe (Sites C0006 and C0007, IODP Expedition 316) to the subducting basement high (proposed Site NT1-01A). The sites are shown overlain on IFREE 3-D seismic reflection Line 95 (uninterpreted depth section). VE = vertical exaggeration.

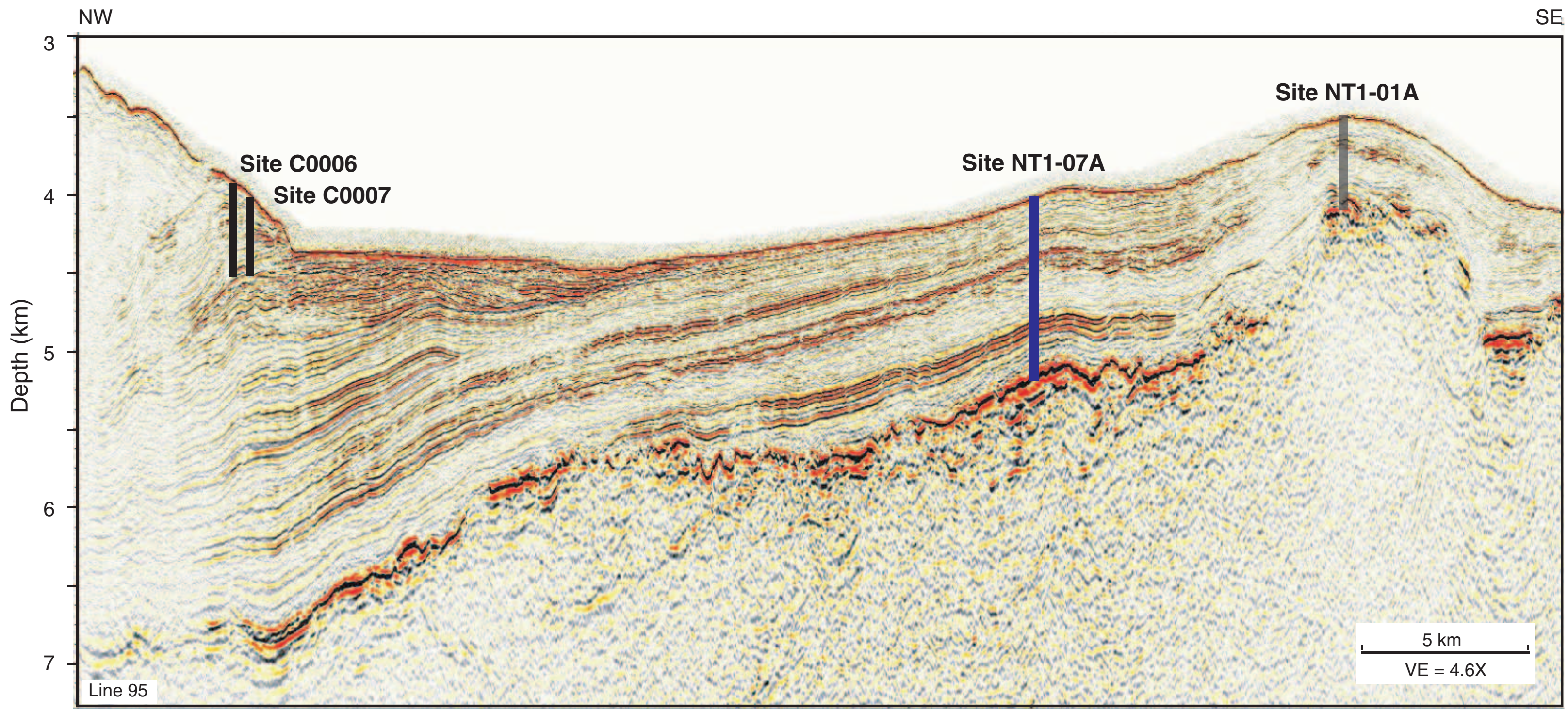


**Figure F4**. IFREE 3-D seismic reflection Line 95 showing location of proposed Site NT1-07A. VE = vertical exaggeration.

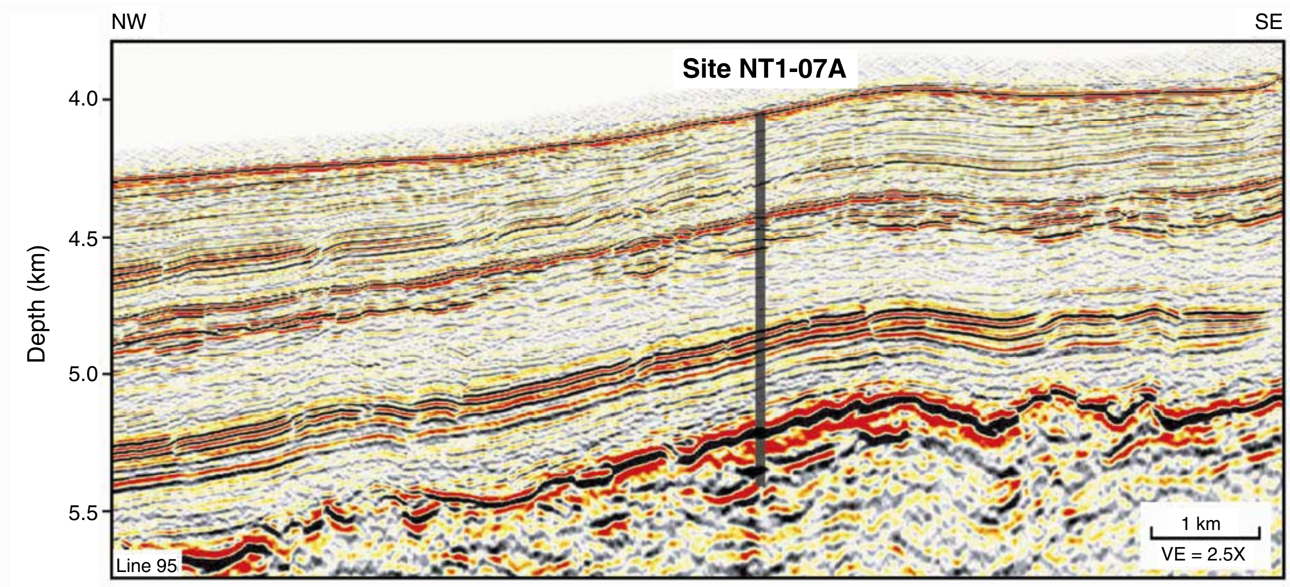


**Figure F5.** CDEX seismic reflection profile of Line ODKM03-101, oriented perpendicular to IFREE seismic reflection Line 95 (see Fig. F4).

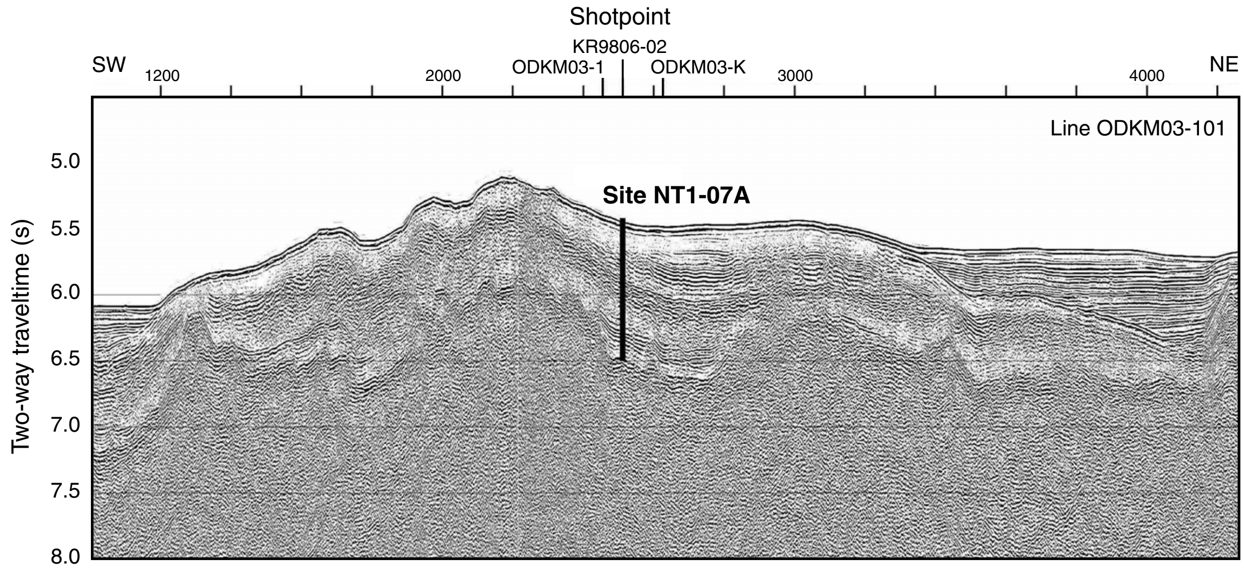


**Figure F6.** Estimated zone of opal cementation at proposed Site NT1-07A based on the modeled thermal history of the sediment. See Spinelli et al. (2007) for method and discussion of implications.

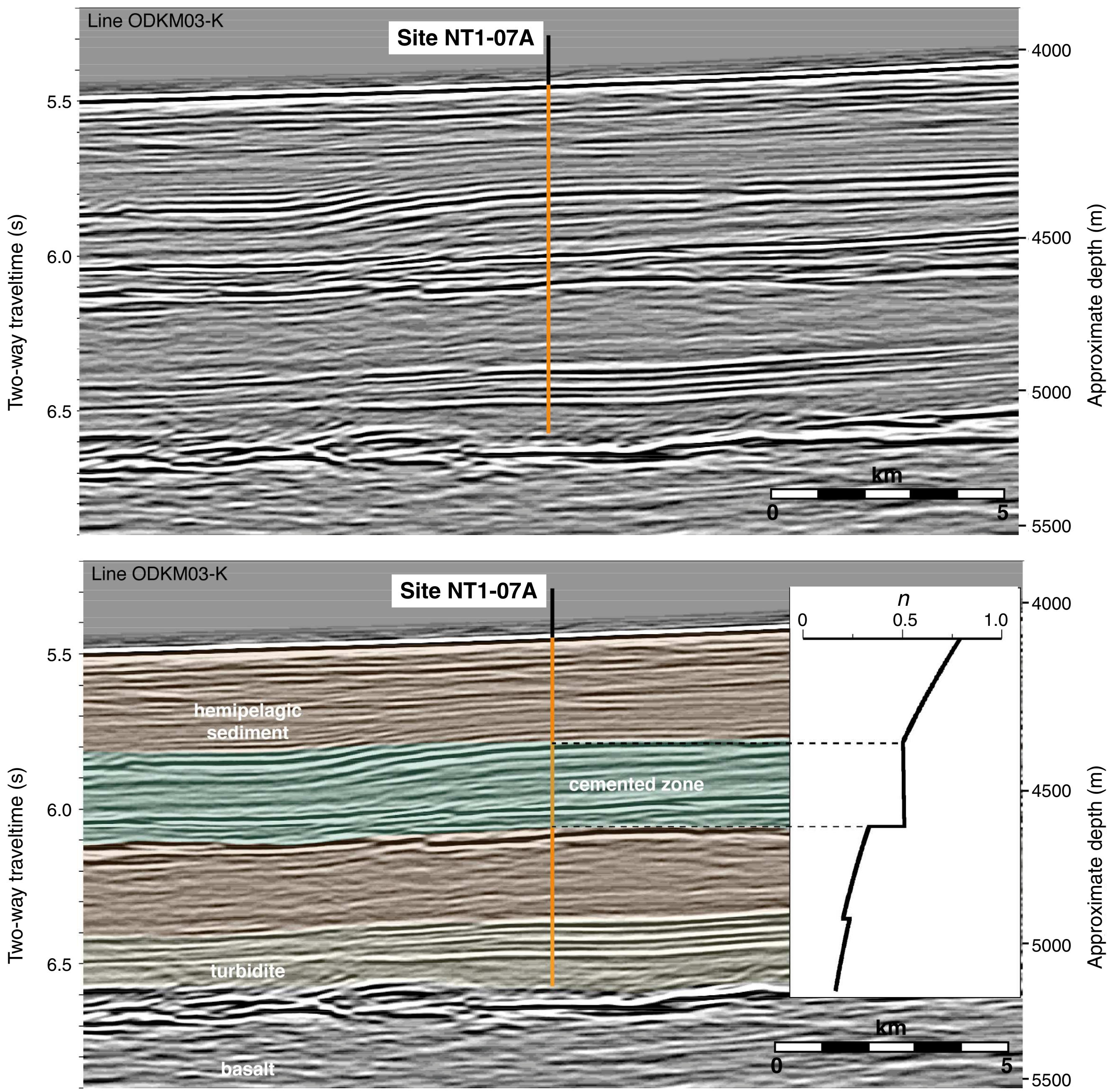


**Figure F7.** Conceptual diagram showing influence of basement topography on lithology within the Shikoku Basin.

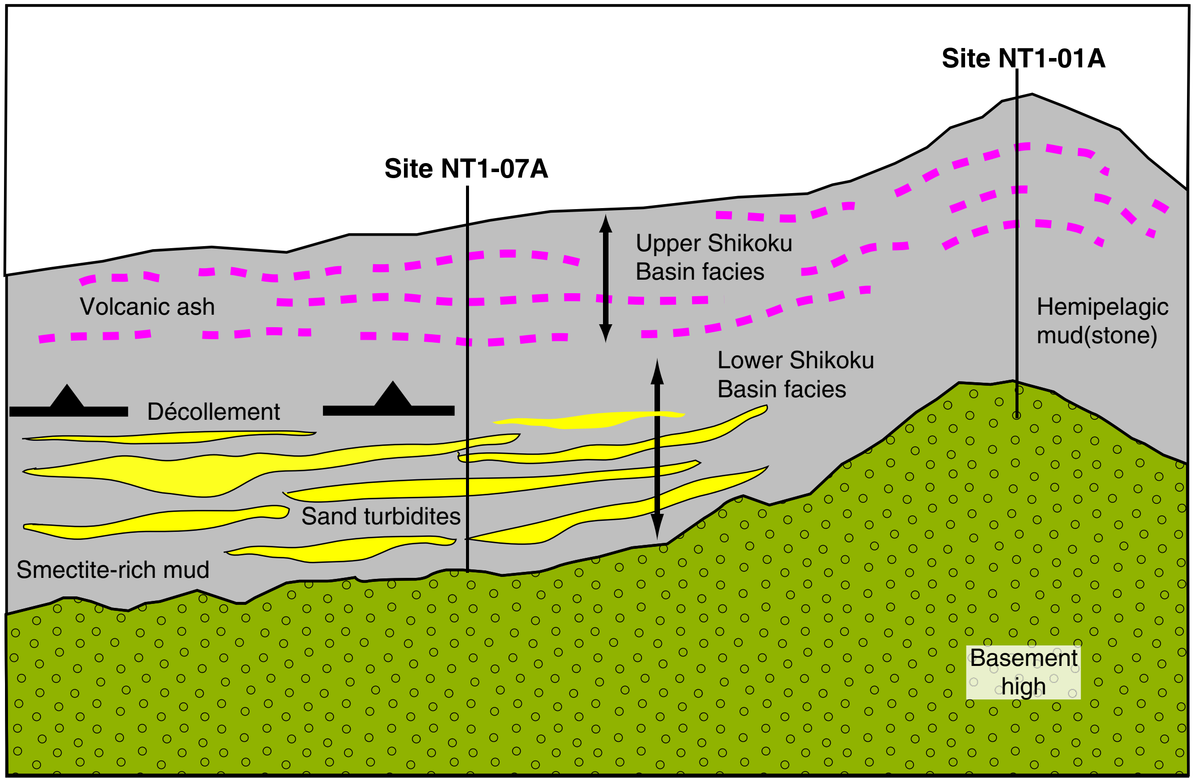


**Figure F8.** Heat flow data in the Nankai Trough area from Ashi et al. (1999). Includes data from analysis of bottom-simulating reflectors and shallow probe measurements.

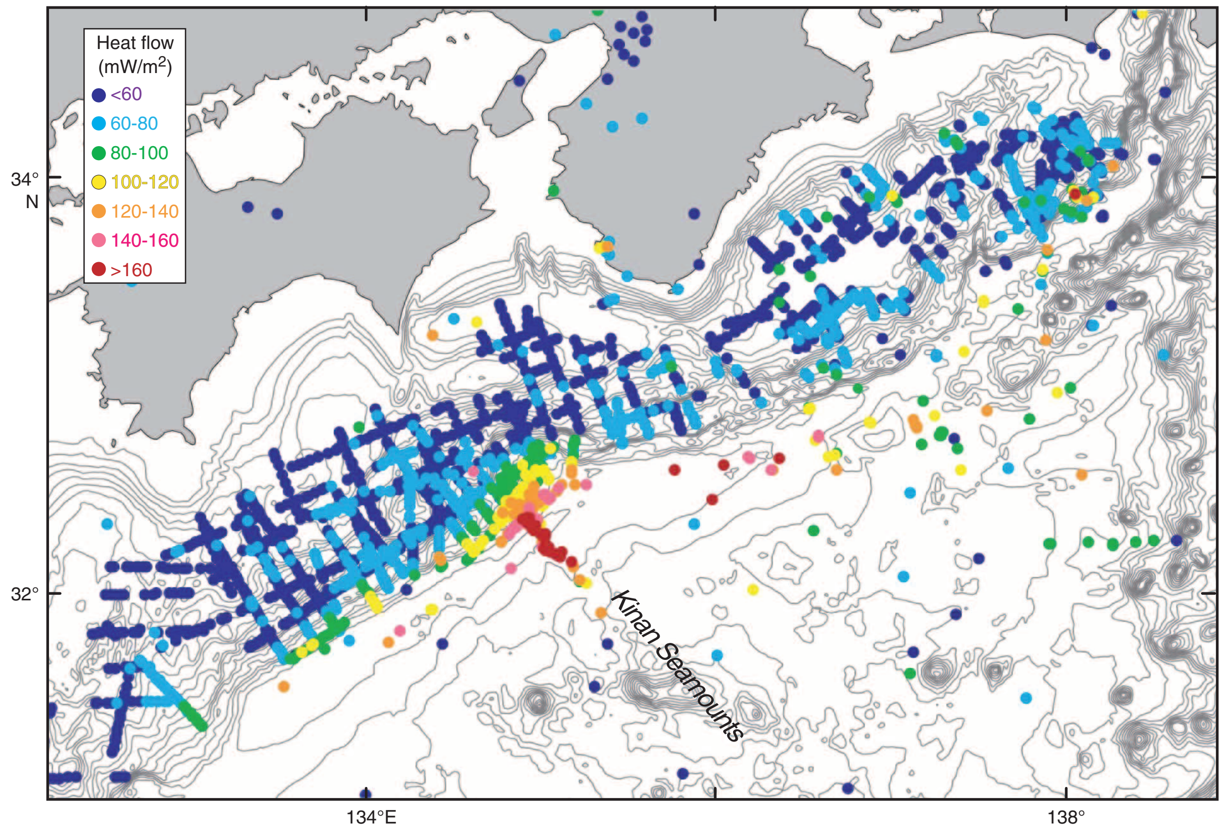


**Figure F9.** Conceptual diagram showing fluid migration from zones of deeper seated dehydration reactions (after Saffer et al., 2008).

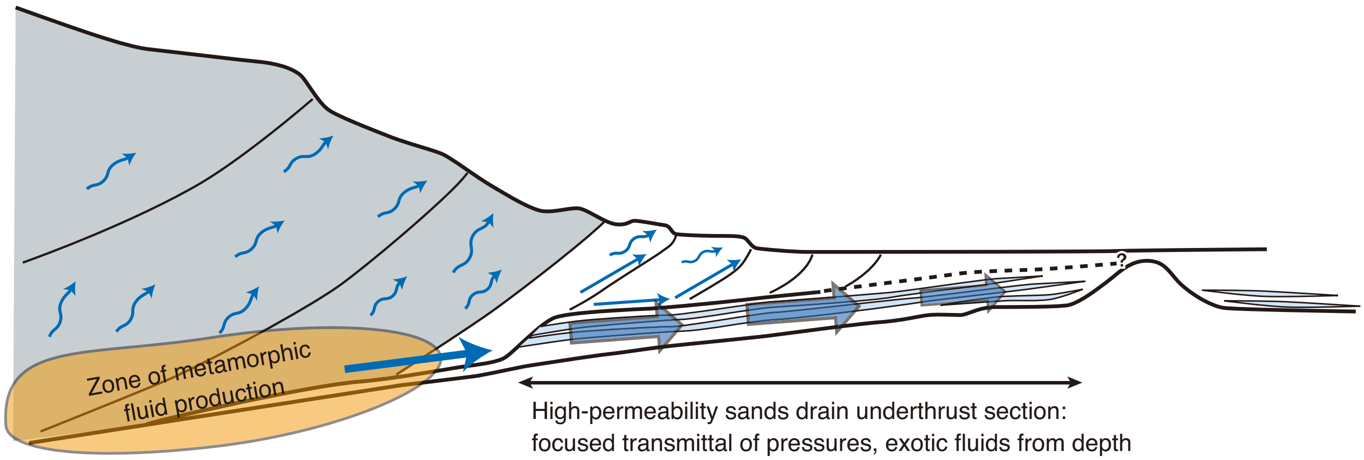


**Figure F10.** Operation plan (drilling sequence) at proposed Site NT1-07A in Shikoku Basin. See **"Operations plan/drilling strategy"** section for more detailed descriptions of drilling operations.

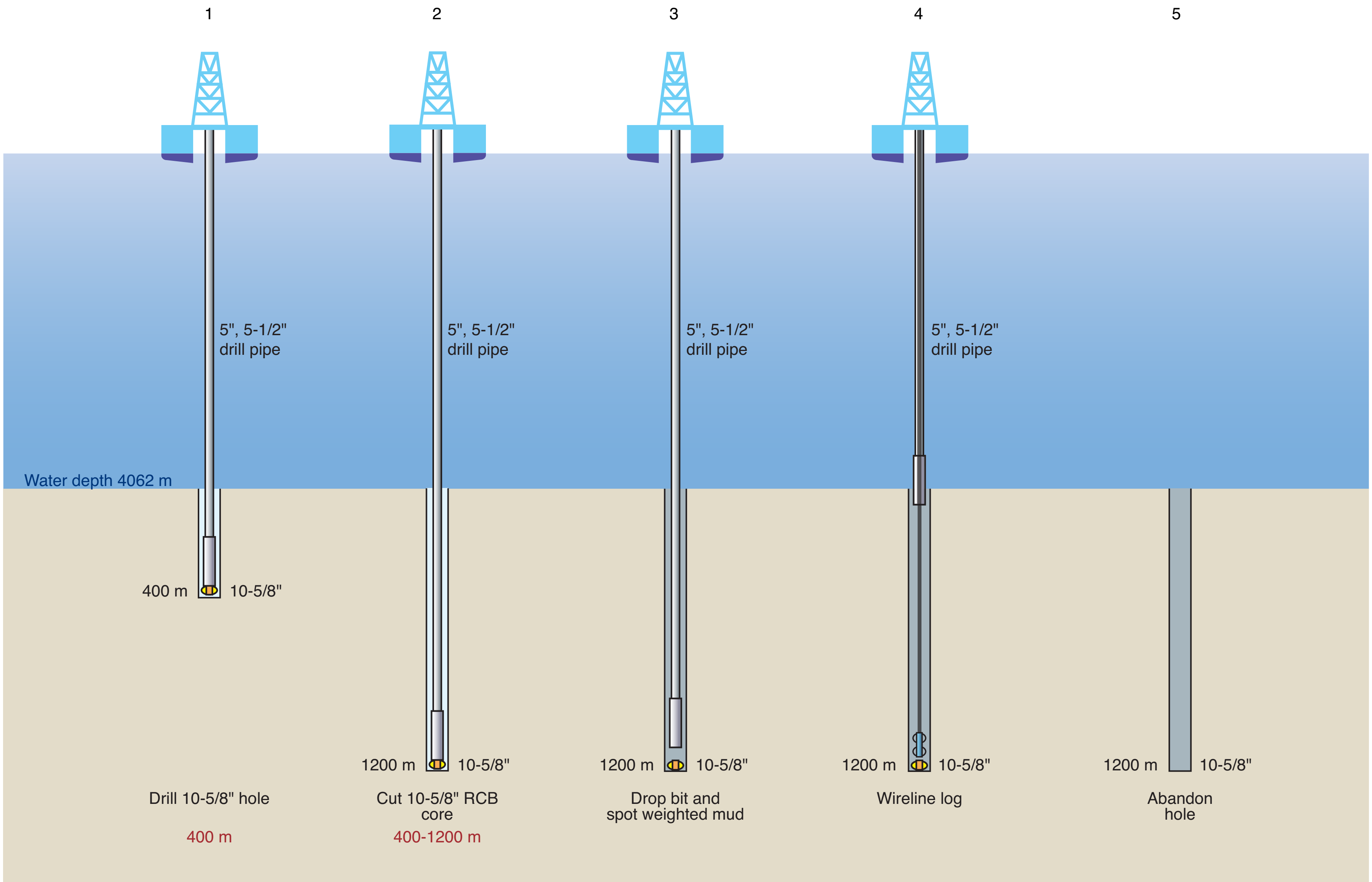


**Figure F11.** Logging tools, and respective tool lengths, as requested for use during Expedition 322. HGNS = Highly Integrated Gamma Ray Neutron Sonde, HRLA = High-Resolution Laterolog Array Tool, HLDS = Hostile Environment Gamma Ray Sonde, PEF = photoelectric effect, EDTC = Enhanced Digital Telemetry Cartridge, HNGS = Hostile Environment Gamma Ray Sonde, DSI = Dipole Sonic Imager, FMS = Formation MicroScanner.

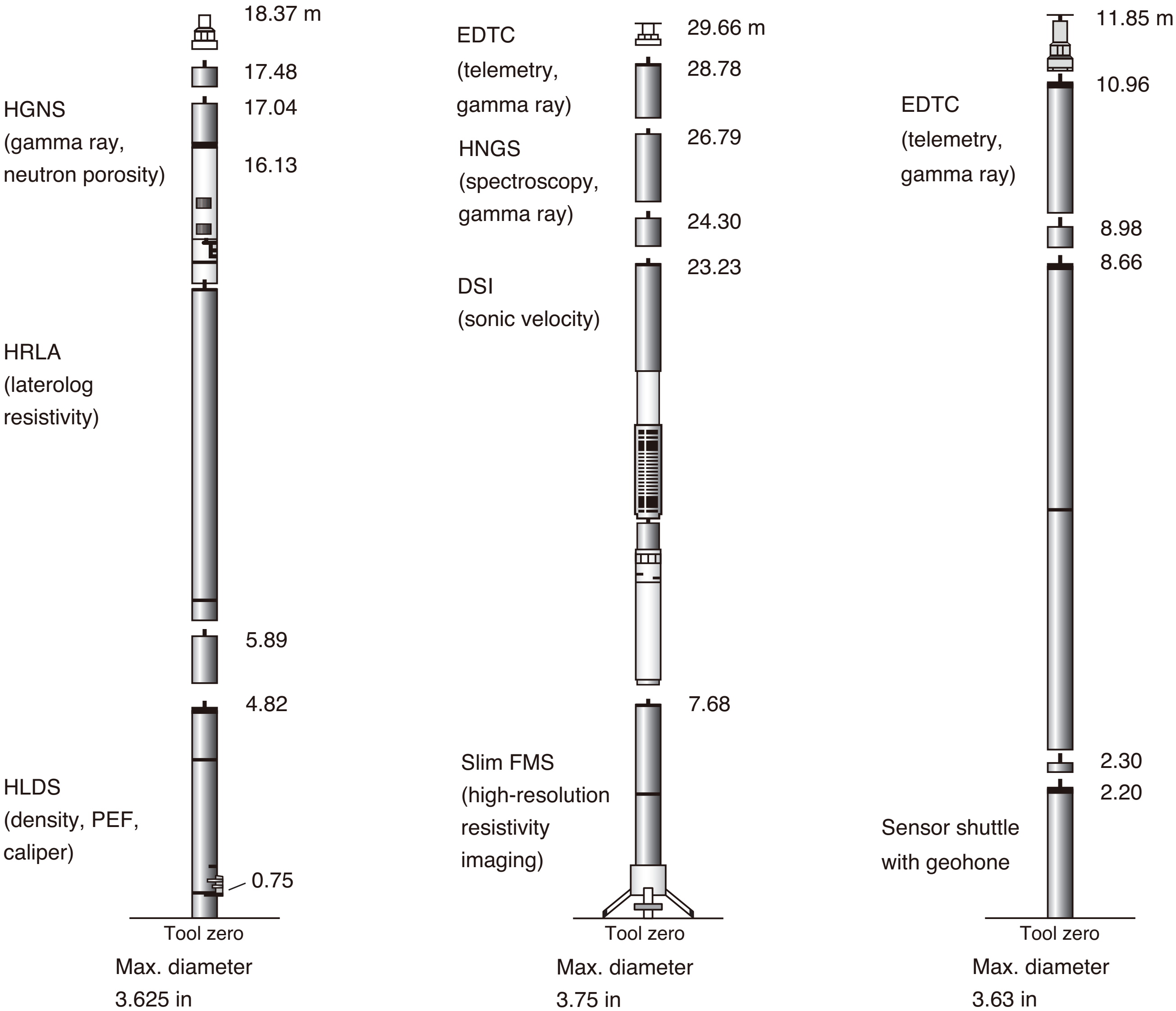


**Figure F12.** Likely decision trees, Expedition 322. POOH = pull out of hole. **A.** Main tree, proposed Site NT1-07A. SET-P = sediment temperature-pressure. (Continued on next two pages.)

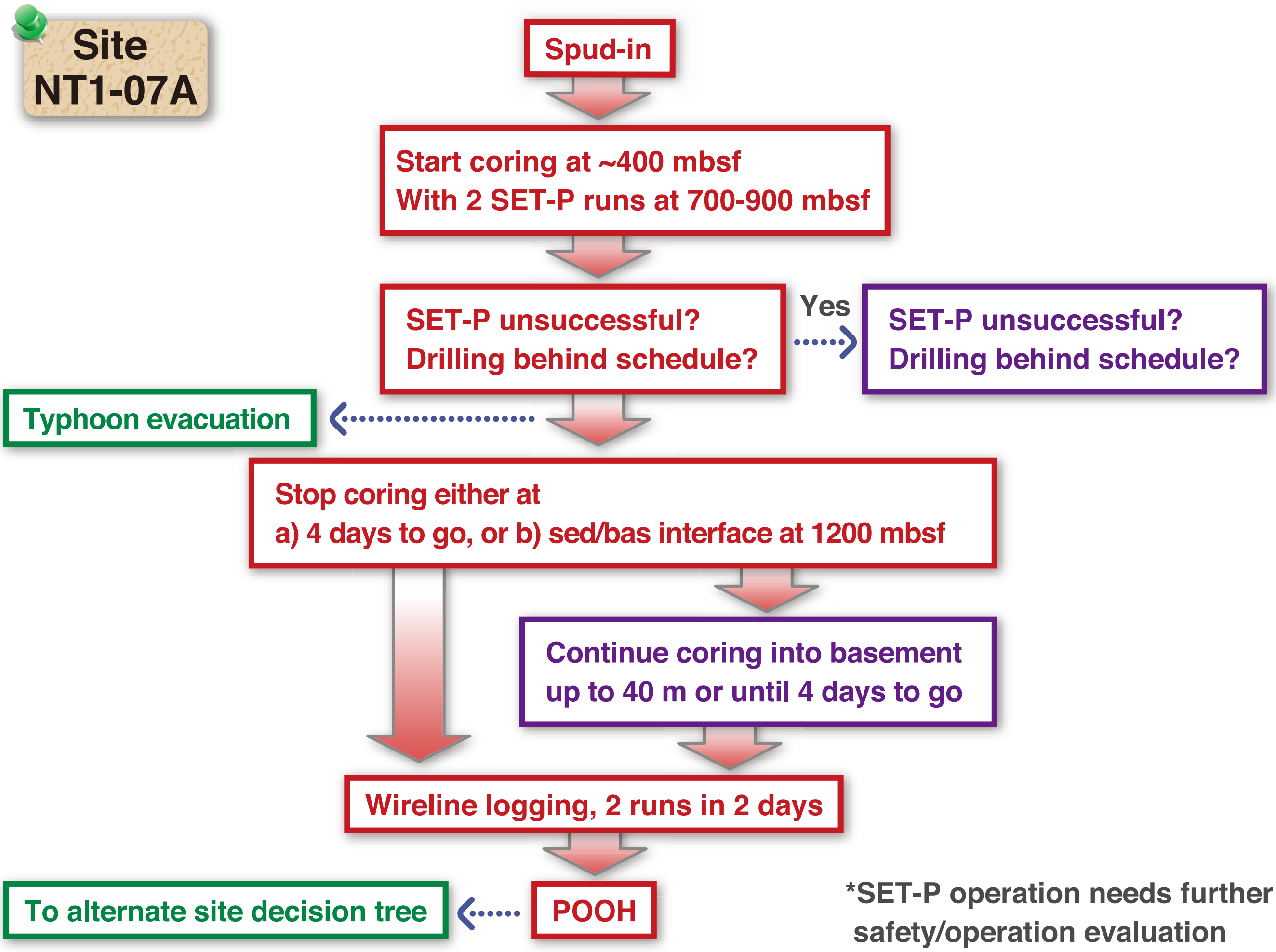


**Figure F12. (continued) B.** Typhoon evacuation, proposed Site NT1-07A. EXCOM = Executive Committee. (**Continued on next page.**)

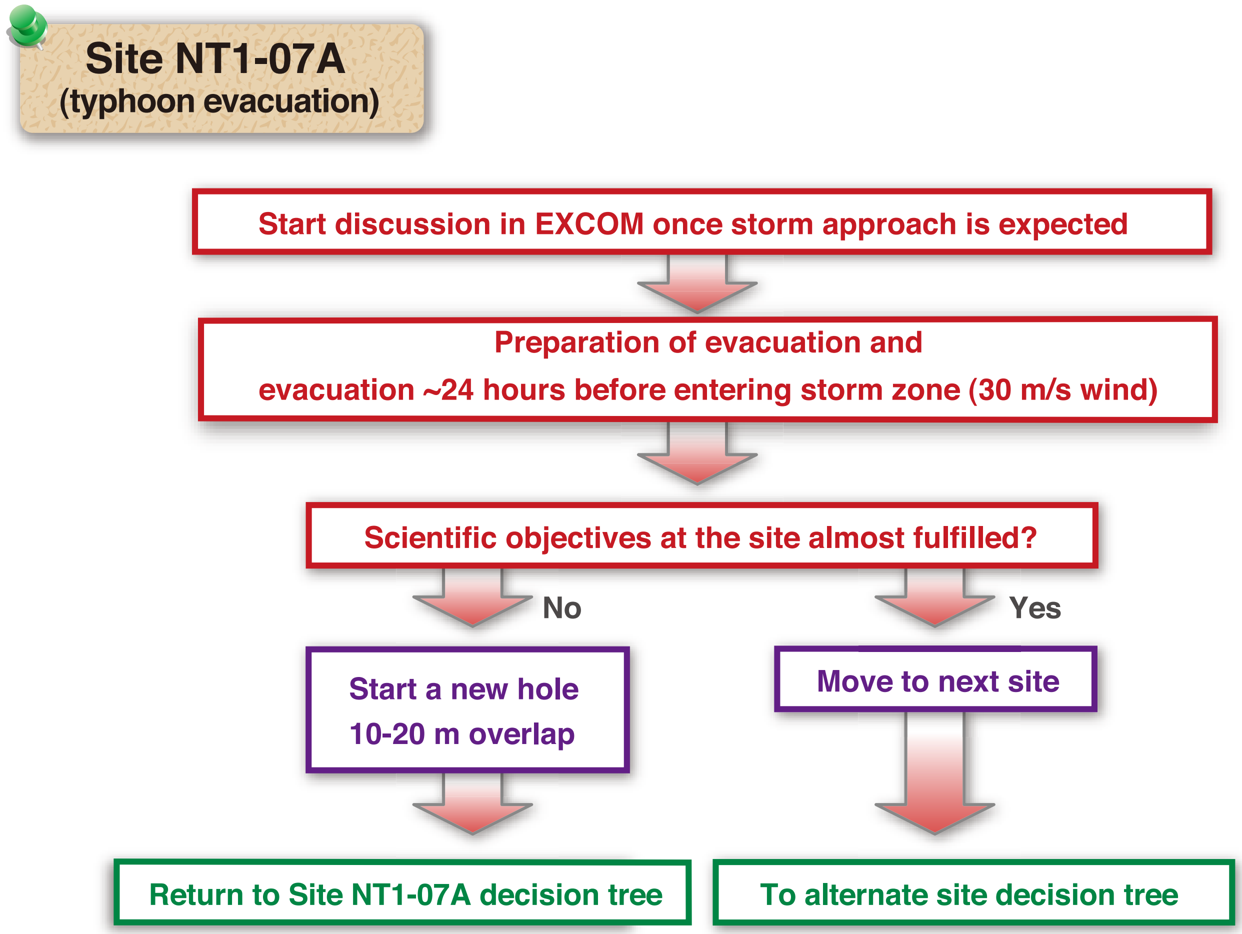


**Figure F12. (continued) C.** Alternate site selection. HPCS = hydraulic piston coring system, ESCS = extended shoe coring system. DHM = downhole measurements.

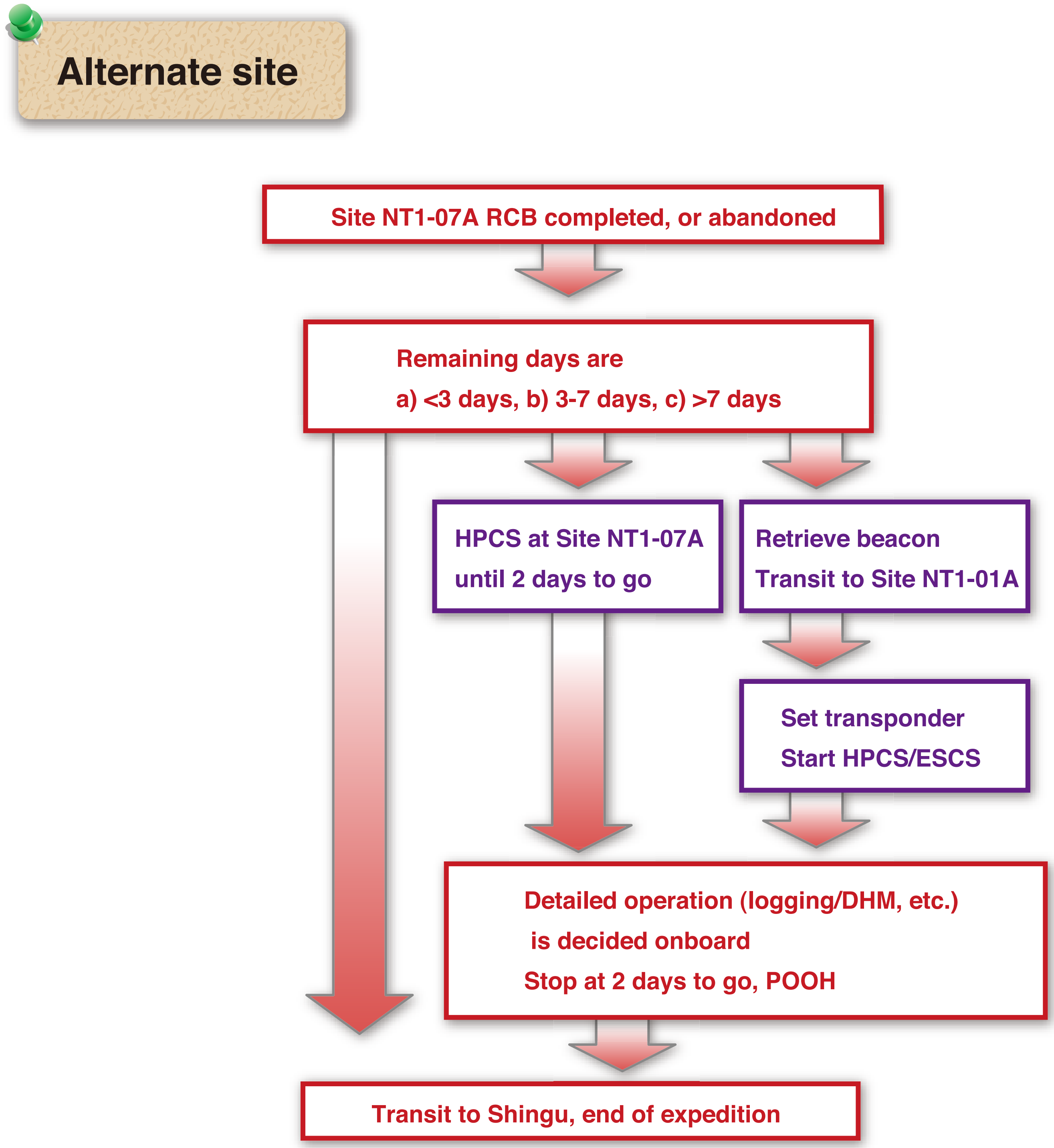


**Figure F13.** IFREE 3-D seismic reflection Line 95 showing location of proposed Site NT1-01A. VE = vertical exaggeration.

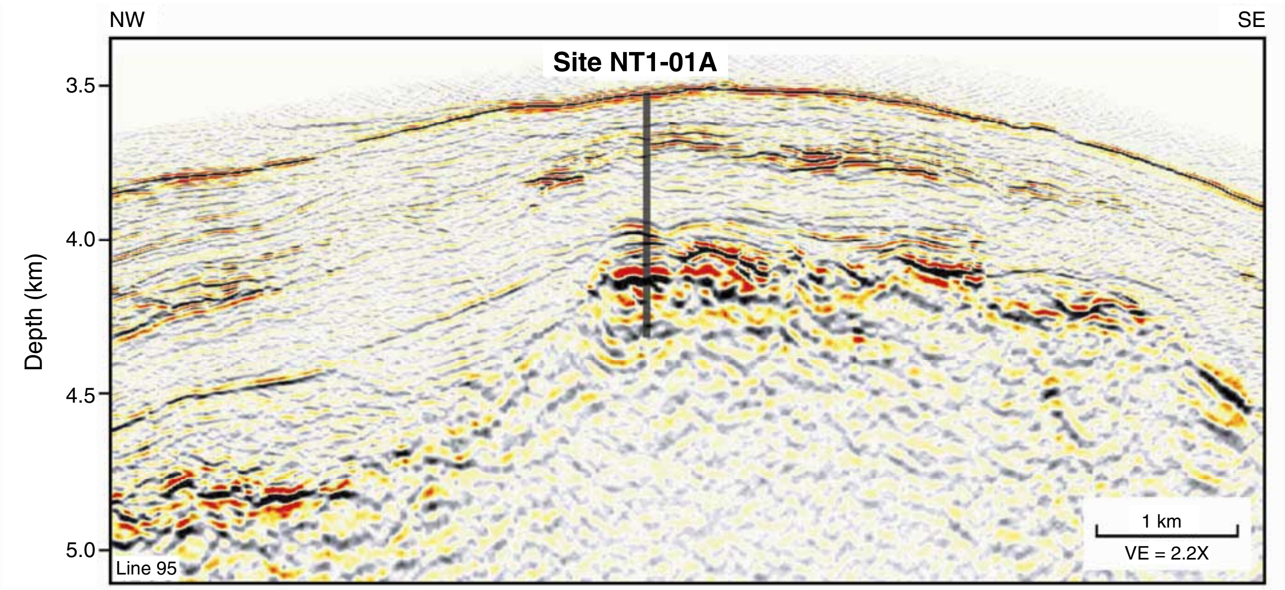


**Figure F14.** CDEX seismic reflection profile of Line ODKM03-22, located perpendicular to IFREE seismic reflection Line 95 (see Fig. F13). VE = vertical exaggeration.

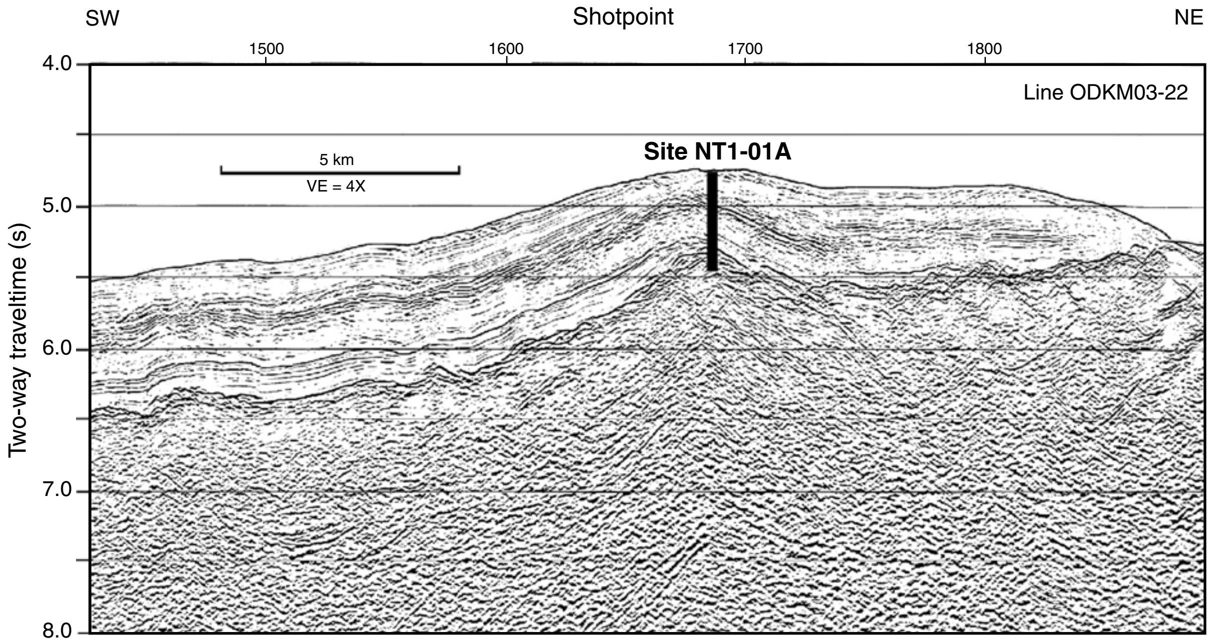


**Figure F15.** A seafloor photograph from an ROV video survey, proposed Site NT1-01A. Note significant induration of the surface sediments, which allows decimeter-sized pieces to be recovered using the manipulator arm of the vehicle.

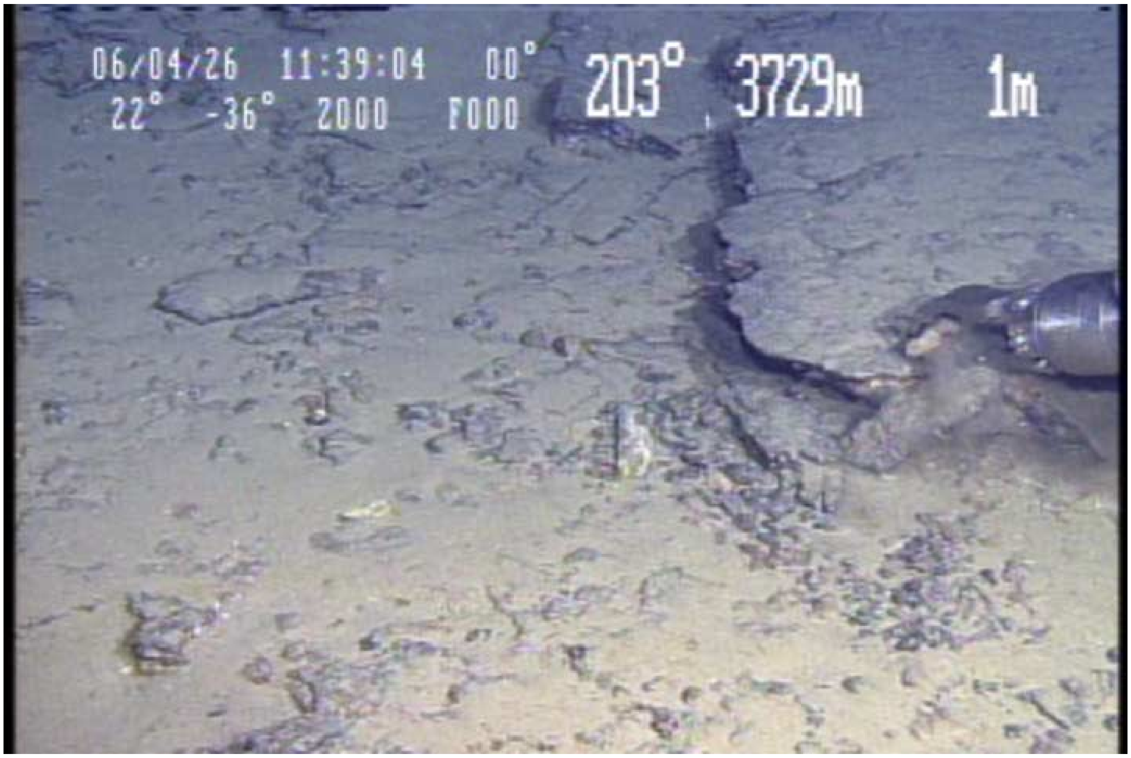
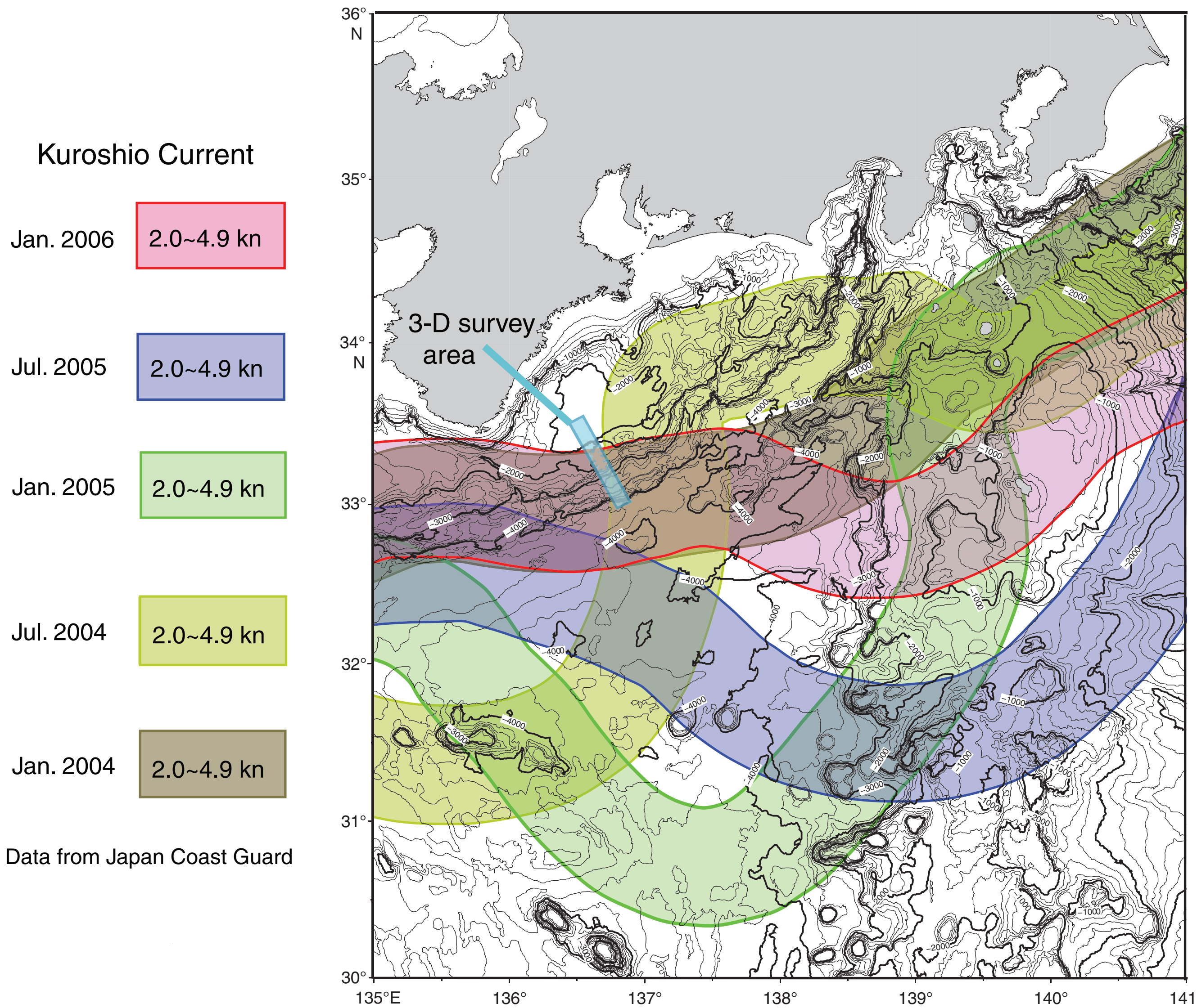


**Figure F16**. Map showing migration pattern for the core of Kuroshio Current.



# Site summaries

## Proposed Site NT1-07A

| | |
|---|---|
| **Priority:** | Primary: *Chikyu* Expedition 322 (subduction inputs) |
| **Position:** | 32°49.73′N, 136°52.89′E |
| **Water depth (m):** | 4062 |
| **Target drilling depth (mbsf):** | 1200 |
| **Approved maximum penetration (mbsf):** | 1400; waiting for final approval by EPSP |
| **Survey coverage:** | Extensive survey data outlined in Proposal 603A-Full2:<br>• Track map (Fig. **AF1**)<br>• Line ODKM03-101 Shotpoint 2524 (Fig. **F5**)<br>• IFREE 3-D Line 95 (Fig. **F4**) |
| **Objective (see text for full details):** | Reference site:<br>• Penetrate entire sedimentary section to oceanic crust<br>• Complete characterization of Shikoku Basin strata and upper igneous basement where basement topography is relatively flat and the lower Shikoku Basin sand facies is well developed<br>• Document lithologic, hydrologic, thermal, geotechnical, and geochemical properties of subduction inputs<br>• Core-log-seismic integration |
| **Drilling, coring, and downhole measurement program:** | *Chikyu* Expedition 322:<br>Hole A:<br>• Drill without coring to 400 mbsf<br>• Core to basement contact with RCB (up to 40 m into basement as contingency)<br>• Formation temperature and pressure measurements<br>• Wireline logging<br>Contingency:<br>Hole B: HPCS/ESCS to the start depth of Hole A |
| **Anticipated lithology:** | 0–250 mbsf: upper Shikoku Basin hemipelagics and volcanic ash<br>250–400 mbsf: lower Shikoku Basin hemipelagics and volcanic ash<br>400–1200 mbsf: lower Shikoku Basin hemipelagics and turbidite sands<br>>1200 mbsf: volcaniclastic sediments and basalt |

# Site summaries (continued)

## Contingency Site NT1-01A

| | |
|---|---|
| **Priority:** | Contingency:<br>• *Chikyu* Expedition 319 (riser and riserless observatory)<br>• *Chikyu* Expedition 322 (subduction inputs) |
| **Position:** | 32°44.8878′N, 136°55.0236′E |
| **Water depth (m):** | 3610 |
| **Target drilling depth (mbsf):** | 600 |
| **Approved maximum penetration (mbsf):** | 800; waiting for final approval by EPSP |
| **Survey coverage:** | Extensive survey data outlined in Proposal 603A-Full2:<br>• Track map (Fig. **AF2**)<br>• Line ODKM03-AB Shotpoint 2795 (Fig. **AF3**)<br>• Crossing Line ODKM03-22 Shotpoint 1685 (Fig. **F14**)<br>• IFREE 3-D Line 95 (Fig. **F13**) |
| **Objective (see text for full details):** | Reference site:<br>• Penetrate entire sedimentary section to oceanic crust<br>• Characterize Shikoku Basin strata and upper igneous crust where bathymetry is associated with a basement high<br>• Document lithologic, hydrologic, thermal, geotechnical, and geochemical properties of subduction inputs<br>• Core-log-seismic integration |
| **Drilling, coring, and downhole measurement program:** | *Chikyu* Expedition 319 and 322:<br>Hole A:<br>• HPCS to refusal and ESCS<br>• Formation temperature and pressure measurements<br>Hole B: RCB and wireline logging<br>• Drill without coring to the refusal depth of Hole A<br>• Core to basement contact with RCB<br>• Formation temperature and pressure measurements<br>• Wireline logging |
| **Anticipated lithology:** | 0–600 mbsf: Shikoku Basin hemipelagic sediments<br>>600 mbsf: volcaniclastic sediments and basalt |

**Figure AF1.** Proposed Site NT1-07A track map.

**Figure AF2.** Proposed Site NT1-01A track map.

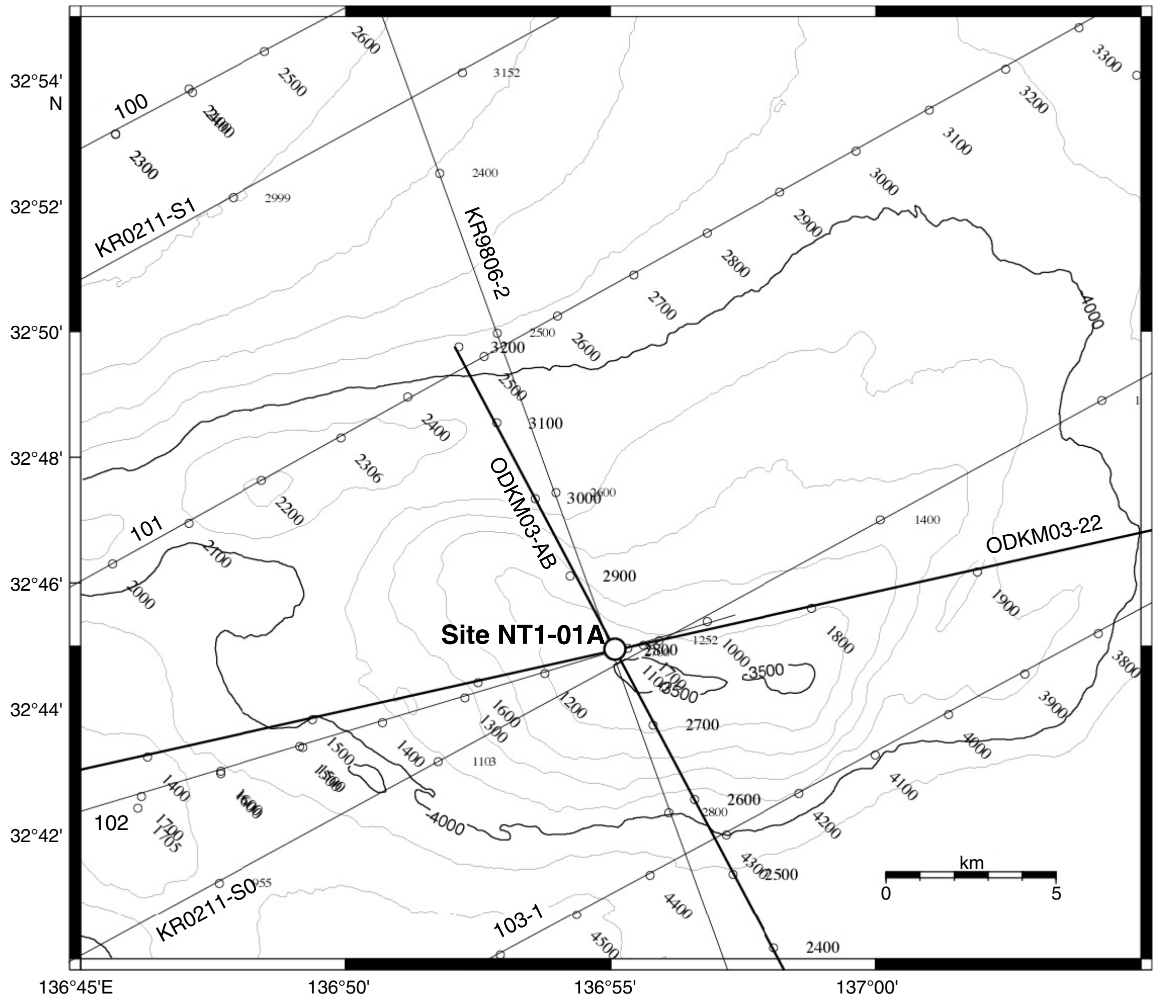
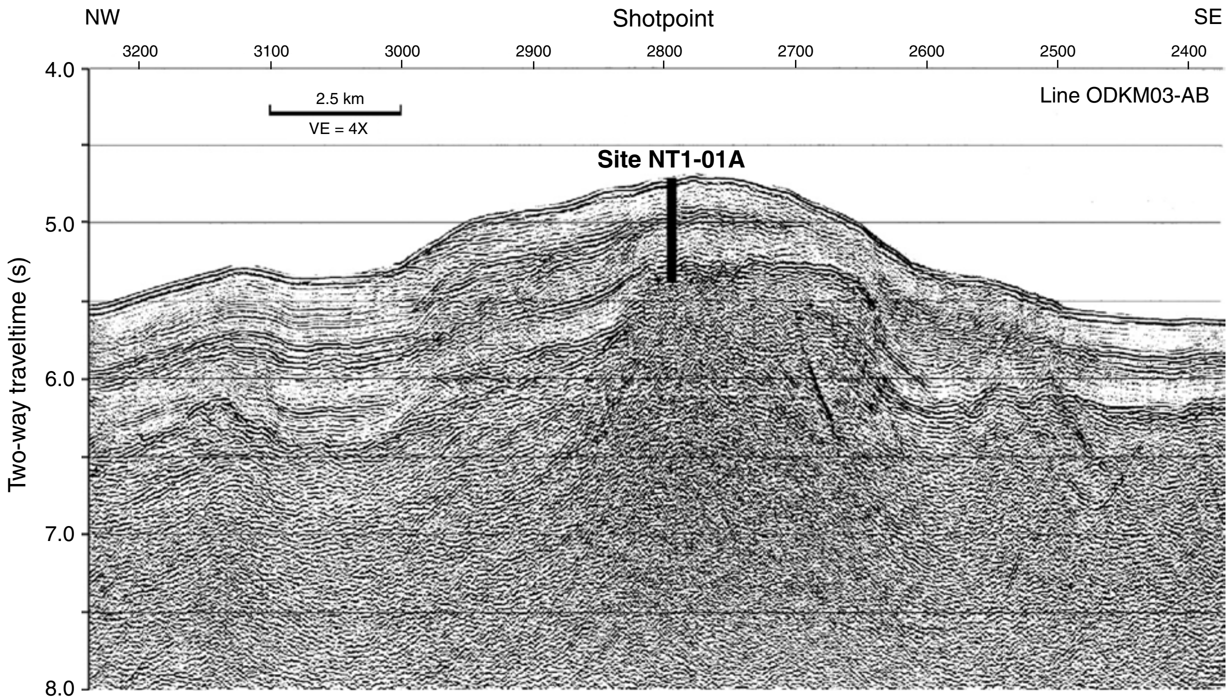


**Figure AF3.** Line ODKM03-AB seismic reflection profile. VE = vertical exaggeration.



# Scientific participants

The current list of participants for Expedition 322 can be found at **www.jamstec.go.jp/chikyu/eng/Expedition/NantroSEIZE/exp322.html.**