Integrated Ocean Drilling Program
NanTroSEIZE Project Stage 1 Scientific Prospectus

Investigations of seismogenesis at the Nankai Trough, Japan

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PUBLISHER'S NOTES

Citation:
Tobin, H.J., and Kinoshita, M., 2006. Investigations of seismogenesis at the Nankai Trough, Japan. *IODP Sci. Prosp.,* NanTroSEIZE Stage 1. **doi:10.2204/iodp.sp.nantroseize1.2006**

Distribution:
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Published by Integrated Ocean Drilling Program Management International (IODP-MI), Inc., for the Integrated Ocean Drilling Program and prepared by IODP U.S. Implementing Organization Science Services, Texas A&M University and Center for Deep Earth Exploration, Japan. Funding for the program is provided by the following agencies:

National Science Foundation (NSF), United States

Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan

European Consortium for Ocean Research Drilling (ECORD)

Ministry of Science and Technology (MOST), People's Republic of China

Korea Institute of Geoscience and Mineral Resources (KIGAM), Interim Asian Consortium

DISCLAIMER

This IODP Project Scientific Prospectus is based on Science Advisory Structure panel discussions and the scientific and operational implementation plan prepared by the Project Chief Scientists and the NanTroSEIZE Project Management Team on behalf of the drilling proponents and implementing organizations. During the course of the project, actual operations may indicate to the Project Chief Scientist and the Project Management Team that it would be scientifically or operationally advantageous to amend or modify the plan presented in this prospectus. A detailed Scientific Prospectus reflecting such possible changes will be prepared for each of the expeditions within this project.

August 2006

Introduction

This overview project prospectus for Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Stage 1 details the specific plans for drilling and related operations in the first stage of the project. It is intended primarily as a guide for interested scientists to assist in selecting among the expeditions. NanTroSEIZE is a multiyear, multistage, and multiplatform effort planned for IODP. The overall scientific goals and plans for this project are summarized here, in Tobin and Kinoshita (2006), and the original IODP NanTroSEIZE drilling proposals (603-CDP3, 603A-Full2, 603B-Full2, 603C-Full, and 603D-Full2) are available for download at **www.iodp.org/NanTroSEIZE.**

In late 2007, IODP will deploy two full-time scientific drilling platforms to initiate the NanTroSEIZE project: the new Japanese riser-capable drilling vessel (*Chikyu*) and the U.S. scientific ocean drilling vessel (SODV). The first stage of NanTroSEIZE drilling operations will comprise five individual expeditions, including three by *Chikyu* and two by the SODV (Table **T1**). As of this writing, *Chikyu* expeditions at the Nankai Trough are slated to begin in September 2007 and SODV expeditions in January 2008, but these dates are subject to change. The five Stage 1 expeditions are planned to extend from late 2007 through March 2008. The official expedition schedule will be posted at **www.iodp.org/expeditions** when available.

The following sections provide a brief introduction to the overall goals of NanTroSEIZE, followed by a description of the scientific goals and operational plans for each individual expedition in Stage 1. Each expedition has very different drilling targets and objectives and a Scientific Prospectus for each will be posted at **www.iopd.org/expeditions** when available.

Scientists interested in participating in NanTroSEIZE Stage 1 should carefully read ***"Stage 1 expeditions"*** *for descriptions of the expected scientific highlights of individual expeditions, in order to decide which is most appropriate given their interests and expertise*. Individual scientists from participating countries should apply through their national IODP Program Member Office (PMO; links to the PMOs are available at **iodp.org/apply to-sail**). Stage 1 operations in 2007–2008 alone will require the efforts of as many as 100 scientists. Because of the nature of the overall objectives of the NanTroSEIZE project, we anticipate that some scientists may be interested in applying for multiple expeditions within Stage 1 and that some scientists who participate in Stage 1 may be considered for participation in later stages of the project. Scientists will be given the opportunity to identify their first, second, and third priority options for their participation on the NanTroSEIZE Stage 1 expeditions.

Background

NanTroSEIZE overall goals

The IODP Nankai Trough Seismogenic Zone Experiment will, for the first time ever, attempt to drill into, sample, and instrument the seismogenic portion of a plate boundary fault or megathrust within a subduction zone where great earthquakes (M ~ 8.0) have repeatedly occurred in the past (Tobin and Kinoshita, 2006). Access to the interior of active faults where in situ processes can be monitored and fresh fault zone materials can be sampled is of fundamental importance to the understanding of great earthquake mechanics. As the December 2004 Sumatra earthquake and Indian Ocean tsunami so tragically demonstrated, great subduction earthquakes represent one of the greatest natural hazards on the planet. Accordingly, drilling into and instrumenting an active interplate seismogenic zone is a very high priority in the IODP Initial Science Plan (2001). Through a decade-long series of national and international workshops, a consensus emerged that the Nankai Trough is an ideal place to attempt drilling and monitoring of the seismogenic plate interface. The first stage of NanTroSEIZE drilling operations is now scheduled to start in September 2007. Stage 1 involves parallel deployment of both the new U.S. SODV and the riser-capable drilling vessel *Chikyu*.

The fundamental goal of the NanTroSEIZE Complex Drilling Project (CDP) (**www.iodp.org/NanTroSEIZE**) is the creation of a distributed observatory spanning the updip limit of seismogenic and tsunamigenic behavior at a location where great subduction earthquakes occur, allowing us to observe the hydrogeologic behavior of subduction megathrusts and the aseismic–seismic transition of the megathrust system. This will involve drilling of key elements of the active plate boundary system at several locations off the Kii Peninsula of Japan, from the shallow onset of the plate interface to depths where earthquakes occur (Figs. **F1, F2, F3**). At this location, the plate interface and active megasplay faults implicated in causing tsunami are accessible to drilling within the region of coseismic rupture in the 1944 Tonankai (magnitude 8.1) great earthquake. The most ambitious objective is to access and instrument the Nankai plate interface within the seismogenic zone at proposed Sites NT2-03 and

NT3-01, at depths of ~3.5 and ~6 km below the seafloor, respectively. The science plan entails sampling and long-term instrumentation of (a) the inputs to the subduction conveyor belt, (b) faults that splay from the plate interface to the surface and that may accommodate a major portion of coseismic and tsunamigenic slip, and (c) the main plate interface at a depth of up to 6 km.

There is a burgeoning interest in active fault drilling, represented by the San Andreas Fault Observatory at Depth (SAFOD), Taiwan Chelungpu Fault Drilling Project (TCDP), Corinth Rift Laboratory (CRL), Nojima Fault Drilling Project, and other active projects on land and at sea in addition to NanTroSEIZE. This is taking place in the context of rapidly growing research efforts on the mechanics and dynamics of faulting processes that integrate rock mechanics, seismology, geodesy, frictional physics, and fluid-fault interactions. Despite recent advances, there is at present no unified theory of fault slip to account for earthquake nucleation and propagation, nor to explain the mechanisms of strain across the spectrum of observed deformation rates ranging from seconds to years. Consequently, the question of whether precursor signals exist for major earthquakes, even in theory, remains under discussion. Progress on these topics is severely limited by a lack of information on ambient conditions and mechanical properties of active faults at depth. Extant rheological models for how faults behave depend on specific physical properties at the fault interface and in the surrounding rock volume. Coefficients of friction, permeability, pore-fluid pressure, state of stress, and elastic stiffness are examples of such parameters that can best (or only) be measured through drilling and through geophysical sensing of the surrounding volume.

Why Nankai Trough?

Subduction zones like the Nankai Trough (Fig. **F1A**), on which great earthquakes (M = 8.0) occur, are especially favorable for study because the entire width (dip extent) of the seismogenic zone ruptures in each great event, so the future rupture area is perhaps more predictable than for smaller earthquakes. The Nankai Trough region is among the best-studied subduction zones in the world. It has a 1300 year historical record of recurring and typically tsunamigenic great earthquakes, including the 1944 Tonankai (M = 8.1) and 1946 Nankaido (M = 8.3) earthquakes (Ando, 1975; Hori et al., 2004). The rupture area and zone of tsunami generation for the 1944 event are now reasonably well understood (Fig. **F1B, F1C**) (Ichinose et al., 2003; Baba and Cummins, 2005). Land-based geodetic studies suggest that the plate boundary thrust here is strongly locked (Miyazaki and Heki, 2001). Similarly, the relatively low level of microseismicity near the updip limits of the 1940s earthquakes (Obana et al., 2004) implies significant interseismic strain accumulation on the megathrust; however, recent observations of very low frequency (VLF) earthquake event swarms apparently taking place within the accretionary prism in the drilling area (Obara and Ito, 2005) demonstrate that interseismic strain is not confined to slow elastic strain accumulation.

The Kumano Basin region, off Kii Peninsula (Fig. **F1A**), was chosen based on three criteria: (1) the updip end of the seismogenic zone must be definable based on slip in past great earthquakes, (2) seismic imaging must present clear drilling targets, and (3) deep targets must be within the operational limits of riser drilling by *Chikyu* (i.e., maximum of 2500 m water depth and 7000 m subseafloor penetration). In the Kumano Basin, the seismogenic zone lies ~6000 m beneath the seafloor (Nakanishi et al., 2002). Slip inversion studies suggest that only here did past coseismic rupture clearly extend shallow enough for drilling (Ichinose et al., 2003; Baba and Cummins, 2005), and an updip zone of large slip (asperity) has been identified and targeted (Fig. **F1B**). Coseismic slip during events like the 1944 Tonankai earthquake likely occurred on the megasplay fault rather than on the décollement beneath it, though slip on either plane is permissible given the available data. The megasplay fault therefore is a primary drilling target equal in importance to the basal décollement zone.

Overall project scientific objectives

Conditions for stable versus unstable sliding—which define seismic versus aseismic behavior—have long been the subject of research and debate, as has the frictional strength of likely fault zone material. Fault zone composition, consolidation state, normal stress magnitude, pore-fluid pressure, and strain rate may affect the transition from aseismic to seismic slip (e.g., Saffer and Marone, 2003). NanTroSEIZE will sample fault rocks over a range of pressure and temperature (P-T) conditions across the aseismic–seismogenic transition; the composition of faults and fluids and associated pore pressure and state of stress and will address partitioning of strain spatially between the décollement and splay faults. NanTroSEIZE will also install borehole observatories to provide in situ monitoring of these critical parameters (seismicity, strain, tilt, pressure, and temperature) over time and test whether interseismic variations or detectable precursory phenomena exist prior to great subduction earthquakes. The overarching hypotheses to be addressed are as follows (please refer to the CDP document at **www.iodp.org/NanTroSEIZE** for detailed discussion of these hypotheses):

- Systematic, progressive material and state changes control the onset of seismogenic behavior on subduction thrusts.

- Subduction zone megathrusts are weak faults.
- Within the seismogenic zone, relative plate motion is primarily accommodated by coseismic frictional slip in a concentrated zone.
- Physical properties, chemistry, and state of the fault zone change systematically with time throughout the earthquake cycle.
- The megasplay (out-of-sequence thrust; OOST) thrust fault system slips in discrete events which may include tsunamigenic slip during great earthquakes.

Overall project drilling targets

We plan to drill at eight sites (Figs. **F2, F3**) to achieve the scientific objectives of the NanTroSEIZE project. Two sites target the incoming plate section, one will sample the frontal thrust of the accretionary wedge, three sites target the megasplay fault system at different depths, one site will sample the megasplay uplift history recorded in the forearc basin sediments, and one ultra-deep site targets the plate interface in the seismogenic zone.

Sampling of the sediments, fluids, and crustal rocks seaward of the deformation front will characterize the subducting materials before deformation. It has been hypothesized that sediment type (especially clay mineral content), fluid content, and basement relief on the incoming plate govern the mechanical state of the plate interface at depth and influence the formation of fault-zone asperities. Two sites (NT1-01 and NT1-07) are planned to sample the entire sedimentary section and as much as 100 m of the basement, respectively, on and off of a preexisting basement high that controlled deposition of thick turbidites in the lower part of the stratigraphic section. Long-term monitoring of pore pressure, seismicity, and other observations in these boreholes will define the hydrological and stress conditions and microseismicity at the point where sediments enter the subduction zone.

Three drill sites targeting the megasplay fault zone (NT2-01, NT2-02, and NT2-03) and one site targeting the frontal thrust (NT1-03) are designed to document the evolution of fault rock properties and the state of stress, fluid pressure, and strain at different P-T conditions. These sites will access faults from ~500 to 3500 m depth below the seafloor. Sealed borehole observatories at some of these sites will monitor pore-fluid pressure, crustal deformation, seismicity, and other properties to document the physical state of the fault zone and its wallrock environment. Proposed Site NT2-03 will cross the seismically reflective megasplay at a depth of 3000–3500 m, in a location where slip probably propagated in 1944.

After initial instrumentation at proposed Site NT2-03, our attention will turn to the 5500–6000 m deep Site NT3-01. Drilling there will pass through both the megasplay fault system and the basal detachment, bottoming in the oceanic crustal rocks of the subducting plate. Drilling of these deep objectives requires novel borehole engineering. Project scientists envision a multipath approach to allow collection of both logs and cores from deep target zones, as well as implementation of a comprehensive monitoring system (Fig. **F4**), and we are working with the borehole engineers to determine how best to implement this ambitious plan.

In addition to the primary fault zone targets, proposed Site NT3-01 will pass through ~1000 m of the Kumano forearc basin section, including an apparent gas hydrate reflector, several thousand meters of the active accretionary wedge, and a zone of potential underplated rocks below the splay fault. Proposed Sites NT3-01 and NT2-04 together will document the history and growth of the Kumano forearc basin, which has formed as a response to slip on the megasplay fault system, as well as processes of accretionary wedge growth. The basinal history will shed light on the evolution of this long-lived, mid-wedge fault that may be a primary feature of many subduction zone forearcs that produce great earthquakes (e.g., Wells et al., 2003).

Drilling will yield both geophysical logs and physical samples of the rocks and sediments (cores and cuttings), as well as formation fluids. Logging and borehole imaging will determine in situ physical properties and help define stress state (e.g., through borehole breakout and tensile fracture studies). Sampling the inputs and splay faults at several depths, and the plate interface at great depth, will provide key data on the evolution of fault zone composition, fabric development, and lithification state as a function of pressure, temperature, and cumulative slip. Finally, long-term monitoring through downhole instrumentation will yield in situ time-series data sets after the drilling disturbance signals have subsided, possibly including the preseismic near term for a future great earthquake. Ideally, thermal signals, fluid pressure, geochemical tracers, tilt and volumetric strain, microseismicity, and time-varying seismic structure will all be monitored at several locations.

Getting there: site surveys and plans for staged implementation

The IODP portion of the NanTroSEIZE project will span a number of years, many individual expeditions, multiple drilling platforms, and several significant stages to achieve all of the proposed scientific objectives, with onboard and shore-based scientific teams matched to the goals of each individual drilling expedition. In response to these challenges, the IODP Operations Task Force formed a project management team (PMT) consisting of two co-chief project scientists (the authors), several additional lead scientists, representatives of the implementing organizations (Center for Deep Earth Exploration [CDEX], and the U.S. Implementing Organization [USIO]), and IODP management (IODP-MI) to help craft strategies to ensure the overall science objectives of the NanTroSEIZE project are maximized. We anticipate that the composition of the PMT will continue to change over time to address the evolving planning and implementation requirements as the multistage NanTroSEIZE project progresses.

A significant volume of site survey data have been collected in the drilling area over many years, including multiple generations of two-dimensional (2-D) seismic reflection (e.g., Park et al., 2002), wide-angle refraction (Nakanishi et al., 2002), passive seismicity (e.g., Obana et al., 2004), heat flow (Kinoshita et al., 2003), side-scan sonar, and swath bathymetry, and submersible and remotely operated vehicle (ROV) dive studies (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. This 3-D data volume, the first deep-penetration, fully 3-D marine survey ever acquired for basic research purposes, will be used to refine selection of drill sites and targets in the complex megasplay fault region, to define the regional structure and seismic stratigraphy, to analyze physical properties of the subsurface through seismic attribute studies, to expand findings in the boreholes to wider areas, and to assess drilling safety.

Drilling activities are basically organized into four stages, each of which will include multiple individual expeditions.

Stage 1

NanTroSEIZE Stage 1 calls for drilling and sampling in riserless mode at six of the sites (see **“Stage 1 expeditions”** below):

- The incoming sediment of Shikoku Basin and underlying oceanic crust (two sites),
- The frontal thrust system at the toe of the accretionary wedge,
- The mid-wedge megasplay fault system, and
- Approximately 1000 m deep holes at the two sites planned for later deep penetrations of the seismogenic zone faults (two sites; one of which will have a subseafloor observatory).

"**Stage 1 expeditions**" contains further information about the specific breakdown of individual expeditions in Stage 1. In brief, comprehensive coring and logging of the boreholes is planned, including extensive use of logging-while-drilling (LWD) technology to obtain high-quality logs. One borehole observatory installation is planned for a pilot hole at proposed Site NT3-01 to monitor pore-fluid pressure, strain, temperature, and seismicity above the plate boundary. This observatory deployment (see Becker and Davis, 2005; Araki et al., 2004) will serve as a prototype and testbed for some of the technologies that might be used in future deeper borehole observatories. IODP currently plans to allocate approximately 8 months of ship time, divided between the new U.S. SODV and the *Chikyu,* for NanTroSEIZE Stage 1 drilling to take place from September 2007 through April 2008.

Stage 2

NanTroSEIZE Stage 2 will involve drilling the first of the two planned deep riser holes using the drillship *Chikyu,* targeting the megasplay fault zone at ~3000–3500 m below the seafloor at proposed Site NT2-03. Extensive coring, use of LWD, downhole experiments to measure pore pressure and seismic properties, and an initial, retrievable, long-term monitoring package are all planned for this site. Additional Stage 2 operations will include deepening and installing borehole observatory systems at several of the Stage 1 drill sites. Stage 2 is likely to begin in mid to late 2008 and extend into 2009.

Stage 3

NanTroSEIZE Stage 3 will focus on 5500–6000 m deep drilling into the seismogenic zone and across the plate interface into subducting crust at proposed Site NT3-01. This unprecedented deep ocean borehole will be accomplished through a program of riser-based drilling and a carefully planned casing program. The results of pilot-hole operations, 3-D seismic data, and real-time LWD and measurement-while-drilling (MWD) monitoring will guide the borehole design. Given the frontier nature of this drilling, it is uncertain how long it will take to complete the borehole, but it may exceed a full year of drilling. Once drilling is complete, an initial monitoring system will be deployed in the borehole, components of which remain to be designed. We intend for this monitoring system to remain in place for a period of 1–2 y, while the "final" long-term monitoring package is readied.

Stage 4

NanTroSEIZE Stage 4 will be concerned with installing the final long-term observatory systems into the two ultra-deep boreholes (Fig. **F4**). This monitoring installation will be planned as much as possible for robust, long-duration deployment, such that data pertinent to the behavior and evolution of the plate interface fault system during a significant portion of the seismic cycle can be recorded. In Japan, a system is proposed to deploy a seafloor fiber-optic network for seismic monitoring and other applications in the Kumano Basin region. One exciting possibility is that the NanTroSEIZE boreholes ultimately could be connected to this network in Stage 4, allowing real-time access to the data. We envision tentatively that Stage 4 installations will be completed sometime in 2012 or 2013; however, the schedule depends heavily on the previous stage success and readiness of sensors and infrastructure for borehole observatories.

Stage 1 expeditions

This section summarizes the science and operations plans for each Stage 1 expedition. The five expeditions that make up Stage 1 will take place on both the SODV and *Chikyu* (in riserless mode) between September 2007 and April 2008 (Fig. **F5**). Because both ships are new and these will be among their first expeditions, the exact dates of the individual expeditions are currently tentative and subject to change. In this Stage 1 prospectus, we provide only a brief overview of each expedition. Individual detailed prospectuses for each of the five Stage 1 Expeditions will be published in the coming months (**www.iodp.org/expeditions**) and each will present the expedition-specific scientific, operational, contingency, and sampling plans.

To maximize the science return, the five Stage 1 expeditions will be implemented as a single science program with samples and data freely shared across all five expeditions (and both drilling platforms). However, each Stage 1 expedition has very different drilling targets and science objectives that must be achieved. The invited co-chief scientists for these Expeditions are members of the NanTroSEIZE PMT to ensure coordination among Stage 1 expeditions toward achieving the overall NanTroSEIZE project science objectives. Furthermore, the PMT has assigned a few scientists ("Specialty Coordinators") to ensure quality and continuity of certain critical data types across the entire project.

Chikyu Expedition 1 (LWD Transect)

LWD logging at all Stage 1 sites (NT1-01, NT1-07, NT1-03, NT2-01, NT2-03, NT3-01)

On what is slated to be *Chikyu's* very first scientific ocean drilling expedition, NanTroSEIZE Stage 1 activities will begin with a dedicated drilling and logging program using LWD technology at all six Stage 1 sites. In the typically unstable formations associated with riserless drilling in the accretionary prism environment, LWD is the only option to obtain high-quality geophysical logs, as demonstrated at other convergent plate margins by Ocean Drilling Program (ODP) Legs 156 and 171A (North Barbados Ridge), 170 and 205 (Costa Rica), and 196 (Nankai Muroto transect). Note that the full set of LWD tools cannot be run simultaneously with coring, so no coring is planned for this expedition.

LWD operations consist of continuously drilling one or more holes at each site by drilling down at a controlled rate, with the logging tools incorporated into the bottom-hole assembly a few meters behind the bit. The log data are therefore acquired very soon after the hole is cut, providing the best-possible data quality. The majority of the data are recorded in memory downhole and downloaded after the drill string is brought back on board; however, some data will be transmitted to the surface in real time using MWD.

LWD log data will include gamma ray, resistivity, density and porosity, sonic velocity, and 360° borehole resistivity and density imaging. Use of LWD magnetic resonance imaging and "seismic-while-drilling" (a checkshot-like vertical seismic profile collected during drilling with the LWD string) are both currently under discussion and may be incorporated into the logging plan. Additional data to be recorded include quality assessment and drilling parameter logs such as acoustic caliper and annular pressure while drilling (PWD).

The first hole(s) drilled at each site (Fig. **F5**) in Stage 1 will be the LWD runs, which are intended to extend to the total depth planned for subsequent Stage 1 coring and observatory operations. The LWD operational and science data will be crucial for optimizing the subsequent four Stage 1 expeditions and for planning future stages. LWD plans are as follows:

- Site NT1-01: LWD drilling of entire sediment section to top of basement at an estimated depth of 470 meters below seafloor (mbsf). Anticipated lithologies are pelagic and hemipelagic muds, deepwater turbidites, and volcanic ash. No basement penetration is planned (Fig. **F6**).

- Site NT1-07: LWD drilling of entire sediment section to top of basement, at an estimated depth of 1020 mbsf. Anticipated lithologies are pelagic and hemipelagic muds, deepwater turbidites, and volcanic ash. No basement penetration is planned (Fig. **F6**).
- Site NT1-03: LWD drilling of the toe of accretionary wedge across frontal thrust and several hundred meters into footwall sediments. Approximately 600 m total penetration is planned in a faulted turbidite and hemipelagic sediment setting (Fig. **F6**).
- Site NT2-01: LWD drilling of ~1000 m of the mid-slope region, across at least one major strand of the megasplay fault system. The actual site selection will be refined by the end of 2006 based on the 3-D seismic survey and may change from what is shown here, but the objectives will remain the same. Anticipated lithology is deformed terrigenous sediment, faults, and potential gas hydrates, though there is no clear bottom-simulating reflector (BSR) at this site (Fig. **F7**).
- Site NT2-03: LWD drilling of ~1000 m of Kumano forearc basin section, including probable BSR and gas hydrate–bearing zones. This is intended primarily as a pilot hole for the first riser operations of Stage 2 to drill a deep hole to the megasplay fault later in 2008. LWD logs will provide critical physical property information for planning the riser drilling and casing to achieve those depth objectives (Fig. **F7**).
- Site NT3-01: LWD drilling of ~1340 m of the Kumano forearc basin section and the underlying older rocks of the accretionary wedge. This is intended in part as a pilot hole for (a) the first CORK observatory installation in NanTroSEIZE to be installed during USIO Expedition 2, and (b) the Stage 3 riser operations to drill a deep hole across the entire plate boundary. Scientific objectives include investigation of the outer forearc basin depositional systems, including possible earthquake-triggered turbidites; convergent margin deformation; likely gas hydrates and a BSR. LWD logs will also provide critical physical property information for planning the Stage 1 observatory pore pressure and strain sensor depths, and for Stage 3 riser drilling and casing plan to achieve the 5000+ m depth objectives (Fig. **F7**).

The shipboard scientific party for this LWD expedition will be focused on scientists with interest and expertise in physical properties, structural analysis, lithostratigraphy, logging interpretation, and log-seismic integration.

Chikyu Expedition 2 (Megasplay Riser Pilot)

Riserless coring at outer edge of Kumano Basin (Site NT2-03)

Chikyu Expedition 2 targets the uppermost 1000 m at one site (NT2-03) in the outer portion of the Kumano forearc basin. This site provides an opportunity for investigation of (a) the outer forearc basin depositional systems, including possible earthquake-triggered turbidites; convergent margin deformation; likely gas hydrates and a BSR; and (b) physical properties, fluid and gas chemistry, and hydrogeology in the region near the updip edge of the splay fault system.

Stage 1 drilling at this site is the first phase of a two-part strategy: the ultimate objective here is to perform riser drilling to ~3500 msbf during Stage 2, across the megasplay fault at depth, and establish a deep borehole observatory. To achieve the depth objective through riser-based drilling involves setting of multiple casing strings, the depth of each depending on the least principal stress, fracture strength of the formation, and pore fluid pressure gradient. The key part of this casing plan is the "tophole" portion, where tolerances on mud weight are tight. Planning the casing program requires excellent information on physical properties in the uppermost 1000 mbsf. Our strategy is therefore to drill this section riserless in Stage 1 in this pilot hole, then return for the deeper portion in Stage 2. We plan to core the entire 1000 m drilling range and collect wireline logs if possible to augment the LWD logs with higher quality sonic and resistivity imaging. The second half of this expedition may consist of only engineering and operations to set the riser seafloor structure and uppermost casing in preparation for Stage 2 riser operations.

The exact location of proposed Site NT2-03 as shown in Figure **F7** is likely to be modified later in 2006, based on the 3-D survey results, in part to locate it in a region of more gently sloping seafloor. The scientific objectives will remain the same, however. Forearc basin sediments overlie deformed accretionary wedge sedimentary rocks at this site. The forearc basin developed as a response to uplift by the megasplay and hence should preserve a record of that fault system's history. Age-depth relations for the basin sediments will be important. Establishing temperature gradients downhole is also critical. A key scientific question will be to investigate the degree to which forearc basin sediments are incorporated into the developing accretionary wedge and the structural mechanisms by which this happens. The gas hydrate system in this area of apparent weak BSR, adjacent to a strong BSR, will be addressed as well.

The shipboard scientific party for this expedition will be focused on scientists with interest and expertise in physical properties, lithostratigraphy and structure, geochemistry, and age-depth relations (micropaleontology and paleomagnetism).

Chikyu Expedition 3 (Thrust Faults)

Riserless coring of frontal thrust (Site NT1-03) and megasplay faults (Site NT2-01)

The third expedition on *Chikyu* will sample two major thrust fault systems at relatively shallow depths where they are accessible to riserless drilling. The first is the main frontal thrust at the seaward edge of the entire accretionary wedge (Figs. **F2, F6**). Based on seismic data and submersible diving studies, this thrust is thought to have placed moderately consolidated clastic rocks over the weak and unlithified late Quaternary trench section clastic sediments (Ashi et al., 2002). Propagation of an underlying décollement zone into the trench section is not clearly imaged, raising the alternative hypothesis that this frontal thrust fault is the main detachment, which propagates straight to the seafloor horizon. However, detailed analysis of the seismic data suggests that substantial footwall deformation exists in the first few hundred meters below the fault at this site location. Reflection amplitude of the fault plane is variable near this planned site, but generally it is a negative polarity reflector (Fig. **F6**). The objectives of drilling at proposed Site NT1-03 are comprehensive characterization of the deformation, evaluation of the inferred depth of detachment and structural partitioning at the décollement, physical properties of the fault zone and surrounding wallrocks, diagenesis, and chemical and other evidence for fluid flow in the frontal thrust fault. This will be accomplished by complete coring and a suite of downhole measurements (temperature, pressure, and packer tests) of the 600 m of planned drilling, with the fault zone targeted at 350–400 mbsf, along with the LWD logs from *Chikyu* Expedition 1. Later stages of drilling may target deeper intervals at this site, depending on what is discovered in Stage 1.

Operations at proposed Site NT2-01 will target the shallow portion of the megasplay fault system. On this expedition, we will conduct a coring and downhole measurement program, similar to that described above, to obtain samples of the fault rock and wallrock and characterize it as completely as possible in conjunction with the previously acquired logging data. We anticipate crossing the main fault at ~800 mbsf, in addition to possibly numerous subfaults and a generally deformed zone. Work on this expedition will lead to subsequent installation of a pore pressure and strain monitoring system in Stage 2.

The shipboard scientific party for this expedition will be focused on scientists with interest and expertise in lithostratigraphy and structure, physical properties and hydrogeology, geochemistry, and age-depth relations (micropaleontology and paleomagnetism).

USIO Expedition 1 (Subduction Inputs)

Inputs to the seismogenic zones: Shikoku Basin drilling (Sites NT1-01, NT1-07)

The purpose of this expedition is to sample at two reference sites within Shikoku Basin: NT1-01 and NT1-07 (Figs. **F2, F6**). The program of coring and downhole measurements will quantify initial conditions in the material that is tectonically delivered to the subduction system; this material ultimately is what enters the seismogenic zone and hosts fault slip. There is significant preexisting relief on the Shikoku Basin igneous crust that has affected the distribution of sediments, and therefore the lithostratigraphy and fluid content of the sediment column vary spatially. In particular, seismic reflection analysis shows that most of the basin area includes a large proportion of turbidites in the deeper part of the stratigraphic column, but basement highs lack much or all of this deep turbidite section. Presence or absence of these facies and attendant fluid and smectite clay content may strongly affect downdip physical properties and initial conditions as sediments enter the seismogenic zone; basement highs have been suggested to act as asperities in earthquake slip.

Our plan is to drill proposed Site NT1-01 on a basement high and Site NT1-07 in a thicker section off that high, in order to show how basement relief influences the presubduction geometry of sedimentary facies, temperature, permeability, sediment and basement alteration, and fluid flow. Key scientific themes will include deepwater turbidite depositional system and facies architecture, heat flow, diagenesis and fluid chemistry of mixed terrigenous and oceanic sediments, volcanic ash stratigraphy, physical properties of hemipelagic and turbidite sediments, and igneous petrology, alteration, and hydrology of the uppermost oceanic crust. On this expedition, complete coring and wireline logging of the sedimentary section is planned at both sites, plus 100 m penetration into the igneous basement at Site NT1-01 only. Casing of Site NT1-07 is planned, with packer testing for hydrologic properties of the lower Shikoku Basin turbidites.

The shipboard scientific party for this expedition will be focused on scientists with interest and expertise in lithostratigraphy, physical properties and hydrogeology, geochemistry, and age-depth relations (micropaleontology and paleomagnetism).

USIO Expedition 2 (Kumano Basin Observatory)

Kumano Basin coring and observatory (Site NT3-01)

The plan for this expedition is to core, perform downhole measurements, and install a long-term monitoring observatory at proposed Site NT3-01 to a depth of up to 1340 mbsf, for both scientific and engineering reasons (Figs. **F2, F5, F7**). This is the site slated for deep drilling across the entire plate boundary system to 5500+ mbsf during Stage 3 riser drilling. Scientifically, the Stage 1 drilling at this site will (a) document the depositional and uplift history of outer Kumano Basin sediments which will shed light on the long-term slip history of the megasplay fault system and deformation in the accretionary wedge; (b) sample the interior of the accretionary wedge in the mid-slope region; (c) establish a thermal structure at the position of the updip limit of co-seismic slip; and (d) monitor strain, tilt, seismicity, and pore fluid pressure in this key position above the aseismic–seismic transition zone, where VLF earthquakes have recently been observed (Obara and Ito, 2005; Ito and Obara, 2006).

Plans include continuous coring of the entire sedimentary section through the Kumano Basin and as much of the underlying older accretionary wedge rocks as possible to 1340 mbsf. Downhole temperature and pressure measurements will be performed, and a VSP will be acquired, possibly as an offset VSP with a second ship shooting to the borehole seismometers. Installation of casing and a CORK-style system will follow; current plans for the borehole observatory include monitoring systems for pore fluid pressure at several depths, tensor volumetric strain, borehole tilt, and temperature. All components of the long-term monitoring package are subject to availability of funds and equipment at the time of this writing.

As with Site NT2-03, this site will serve as a primary hole for subsequent Stage 2 riser drilling to much greater depth. Complete characterization of seismic velocity, density, porosity, thermal conductivity, rock strength parameters, and pore pressure gradient are high priority, and the data will be merged with LWD logs from *Chikyu* Expedition 1. Additionally, the observatory systems to be installed here will serve in part as a prototype and testbed for strategies that might be applied to conduct multiple measurements efficiently in a single cased borehole.

The shipboard scientific party for this expedition will be focused on scientists with interest and expertise in the long-term observatory science, downhole measurements, physical properties, lithostratigraphy, geochemistry, and age-depth relations (micropaleontology and paleomagnetism).

Applying for scientific participation

Shipboard and shore-based opportunities exist across all Stage 1 expeditions for interested researchers. Besides the central fault-zone objectives, diverse geological environments will be sampled, including the interior of an actively developing accretionary wedge, gas hydrates, oceanic crust, abyssal plain turbidite systems, and a major forearc basin sequence. Opportunities include sedimentology, structural geology, physical properties, geochemistry, rock magnetism, borehole geophysics, seismology, microbiology, hydrogeology, crustal deformation, and other disciplines.

Applications to participate in the Stage 1 expeditions (Table **T1**) should be made through the scientists' national IODP program member office (PMO). Links to these PMOs and information about applying are available at **www.iodp.org/apply to-sail/.**

References

Ando, M., 1975. Source mechanisms and tectonic significance of historical earthquakes along the Nankai Trough, Japan. *Tectonophysics,* 27(2):119–140. **doi:10.1016/0040-1951(75)90102-X**

Araki, E., Shinohara, M., Sacks, S., Linde, A., Kanazawa, T., Shiobara, H., Mikada, H., and Suyehiro, K., 2004. Improvement of seismic observation in the ocean by use of seafloor boreholes. *Bull. Seismol. Soc. Am.,* 94:678–690.

Ashi, J., Kuramoto, S., Morita, S., Tsunogai, U., Goto, S., Kojima, S., Okamoto, T., Ishimura, T., Ijiri, A., Toki, T., Kudo, S., Asai, S., and Utsumi, M., 2002. Structure and cold seep of the Nankai accretionary prism off Kumano—outline of the off Kumano survey during YK01-04 Leg 2 cruise. *JAMSTEC J. Deep Sea Res.,* 20:1–8.

Baba, T., and Cummins, P.R., 2005. Contiguous rupture areas of two Nankai Trough earthquakes revealed by high-resolution tsunami waveform inversion. *Geophys. Res. Lett.,* 32(8):L08305. **doi:10.1029/2004GL022320**

Becker, K., and Davis, E.E., 2005. A review of CORK designs and operations during the Ocean Drilling Program. *In* Fisher, A.T., Urabe, T., Klaus, A., and the Expedition 301 Scientists, *Proc. IODP,* 301: College Station TX (Integrated Ocean Drilling Program Management International, Inc.). **doi:10.2204/iodp.proc.301.104.2005**

Hori, T., Kato, N., Hirahara, K., Baba, T., and Kaneda, Y., 2004. A numerical simulation of earthquake cycles along the Nankai Trough in southwest Japan: lateral variation in frictional property due to the slab geometry controls the nucleation position. *Earth Planet. Sci. Lett.,* 228(3–4):215–226. **doi:10.1016/j.epsl.2004.09.033**

Ichinose, G.A., Thio, H.K., Somerville, P.G., Sato, T., and Ishii, T., 2003. Rupture process of the 1944 Tonankai earthquake (Ms 8.1) from the inversion of teleseismic and regional seismograms. *J. Geophys. Res.,* 108(B10):2497. **doi:10.1029/2003JB002393**

International Working Group, 2001. *Earth, Ocean, and Life: Scientific Investigation of the Earth System Using Multiple Drilling Platforms and New Technologies—Integrated Ocean Drilling Program Initial Science Plan, 2003–2013:* Washington, DC (International Working Group Support Office).

Ito, Y., and Obara, K., 2006. Very low frequency earthquakes within accretionary prisms are very low stress-drop earthquakes. *Geophys. Res. Lett.,* 33(9):L09302. **doi:10.1029/2006GL025883**

Kinoshita, M., Goto, S., Hamamoto, H., and Yamano, M., 2003. Heat flow distribution and thermal regime across the Nankai accretionary complex. *Eos, Trans. Am. Geophys. Union,* 84(46) (Suppl.):T42C-06 (Abstract).

Miyazaki, S., and Heki, K., 2001. Crustal velocity field of southwest Japan: subduction and arc-arc collision. *J. Geophys. Res.,* 106(B3):4305–4326. **doi:10.1029/2000JB900312**

Nakanishi, A., Takahashi, N., Park, J.-O., Miura, S., Kodaira, S., Kaneda, Y., Hirata, N., Iwasaki, T., and Nakamura, M., 2002. Crustal structure across the coseismic rupture zone of the 1944 Tonankai earthquake, the central Nankai Trough seismogenic zone. *J. Geophys. Res.,* 107(B1):2007. **doi:10.1029/2001JB000424**

Obana, K., Kodaira, S., and Kaneda, Y., 2004. Microseismicity around rupture area of the 1944 Tonankai earthquake from ocean bottom seismograph observations. *Earth Planet. Sci. Lett.,* 222(2):561–572. **doi:10.1016/j.epsl.2004.02.032**

Obara, K., and Ito, Y., 2005. Very low frequency earthquake excited by the 2004 off the Kii Peninsula earthquake: adynamic deformation process in the large accretionary prism. *Earth Planets Space,* 57:321–326.

Park, J.-O., Tsuru, T., Kodaira, S., Cummins, P.R., and Kaneda, Y., 2002. Splay fault branching along the Nankai subduction zone. *Science,* 297(5584):1157–1160. **doi:10.1126/science.1074111**

Saffer, D.M., and Marone, C., 2003. Comparison of smectite- and illite-rich gouge frictional properties: application to the up-dip limit of the seismogenic zone along subduction megathrusts. *Earth Planet. Sci. Lett.,* 215(1–2):219–235. **doi:10.1016/S0012-821X(03)00424-2**

Tobin, H., and Kinoshita, M., 2006. NanTroSEIZE: the IODP Nankai Trough seismogenic zone experiment. *Sci. Drill.,* 2:23–27. **doi:10.2204/iodp.sd.2.06.2006**

Wells, R.E., Blakely, R.J., Sugiyama, Y., Scholl, D.W., and Dinterman, P.A., 2003. Basin-centered asperities in great subduction zone earthquakes: a link between slip, subsidence, and subduction erosion? *J. Geophys. Res.,* 108(B10):2507. **doi:10.1029/2002JB002072**

Figure F1. A. Nankai Trough region of southwestern Japan is the locus of subduction of the Philippine Sea plate (PSP) beneath Honshu and Shikoku islands. Shaded boxes are the generalized slip areas of the last two great subduction earthquakes (stars represent epicenter locations for earthquake nucleation). Red line shows the location of seismic reflection Line 5, portions of which are shown in Figures **F3, F4,** and **F5.** Arrow shows convergence direction of PSP and Japan. Inset shows location of Nankai Trough. EP = Eurasian plate, PP = Pacific plate, NAP = North American plate. (Continued on next two pages.)

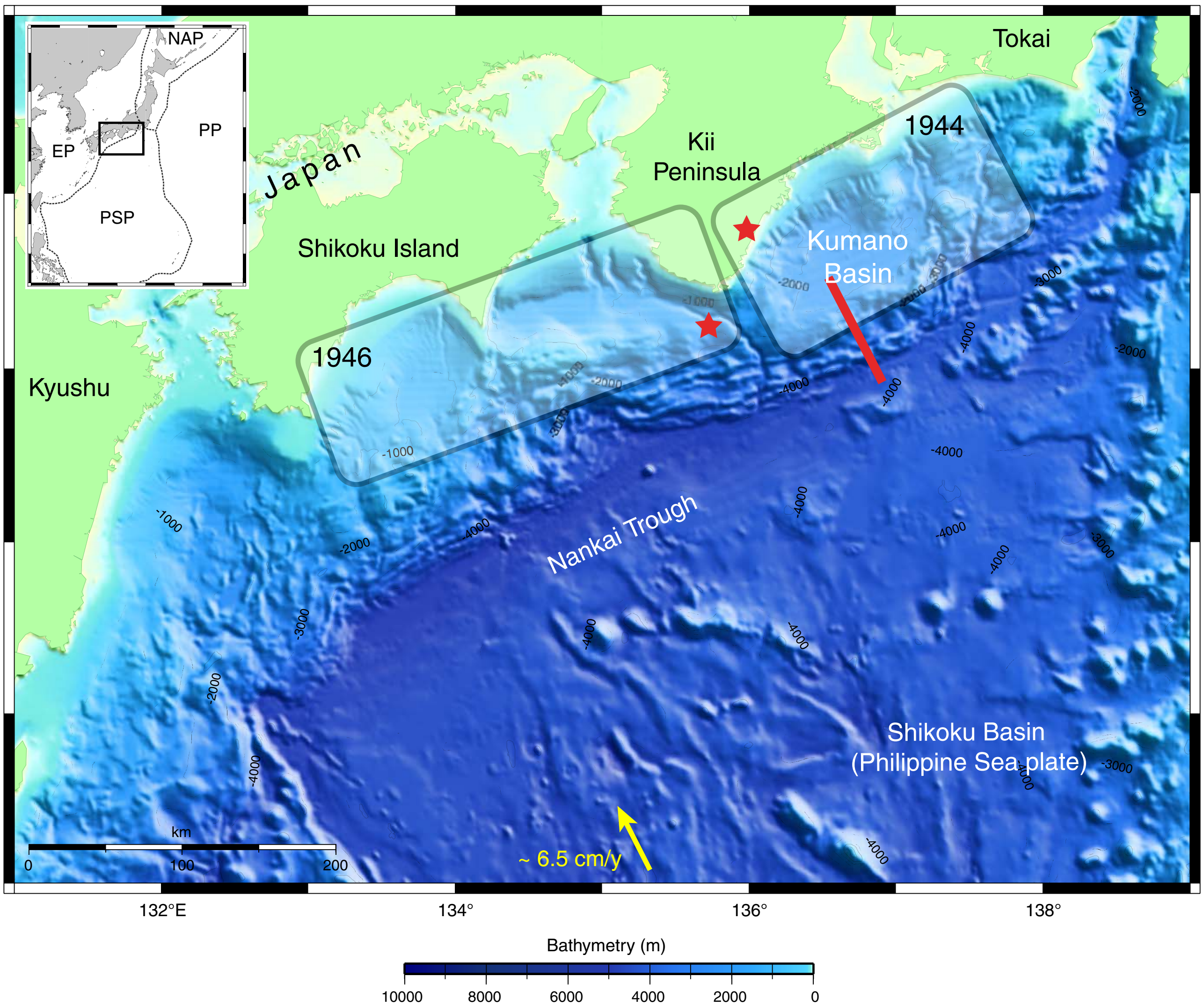

Figure F1 (continued). B, C. Coseismic slip (B) and (C) tsunami source inversions of the 1944 Tonankai earthquake by Ichinose et al., (2003) and Baba and Cummins (2005), respectively. Both maps show that the coseismic displacement had a large component of shallow slip (seismic asperity) updip of the nucleation region. The NanTroSEIZE drilling transect targets this apparent asperity region. The shallow high-slip zone corresponds to the location of the megasplay fault (see Fig. F3), suggesting that it may have been the locus of coseismic slip. Stars indicate epicentral location of great earthquakes. Gray shaded boxes = spatial distribution of slip in centimeters during the 1944 Tonankai earthquake. Red = planned riser drilling sites, yellow = riserless only sites. (Continued on next page.)

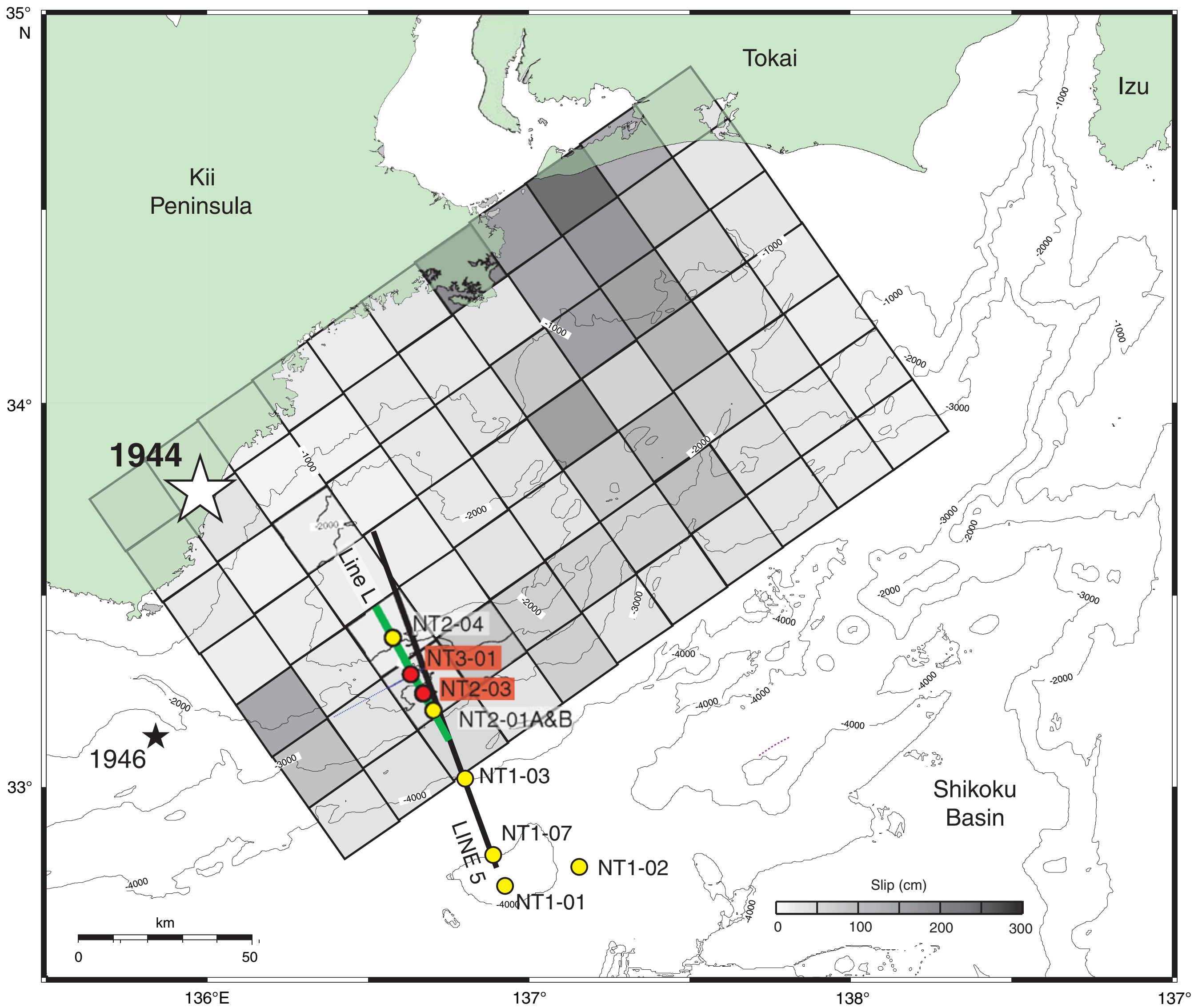

Figure F1 (continued). **C.** Blue and red boxes slip in meters from tsunami inversion of the 1940s Tonankai and Nankai-do earthquakes, respectively. Triangles = locations of tide gauge stations used in inversion.

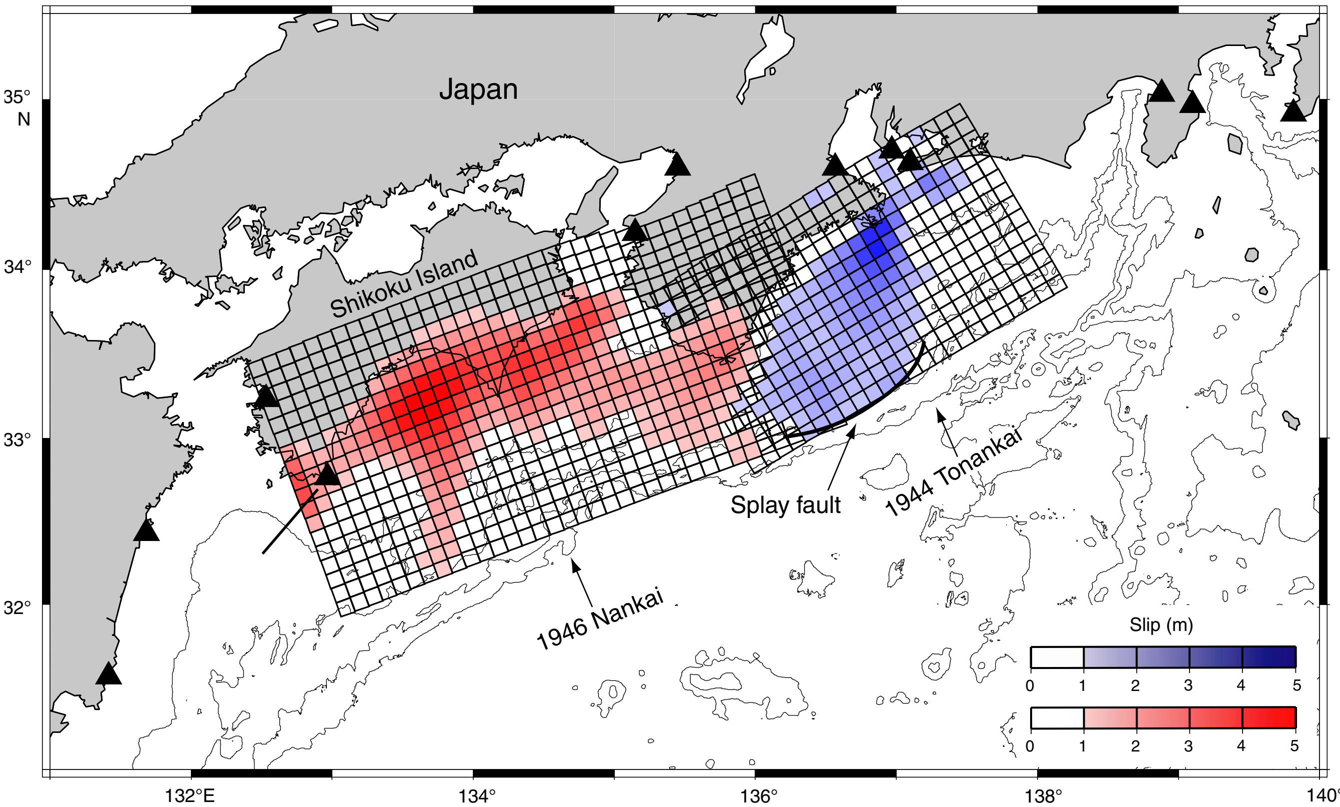

Figure F2. Bathymetric map of Kumano Basin region, with all multichannel seismic (MCS) profile locations and planned drill sites located. White barbed line = position of deformation front of accretionary prism. Portions of Line L (bold blue), Line 5 (bold black), and Line KR9806-2 (white dashed) are shown in Figures F3, F5, F6, and F7. Proposed Site NT1-02 is an alternate for Site NT1-07. Yellow = convergence vector between Philippine Sea plate and Japanese Islands (Eurasian plate). Red = planned riser drilling sites, yellow = riserless sites.

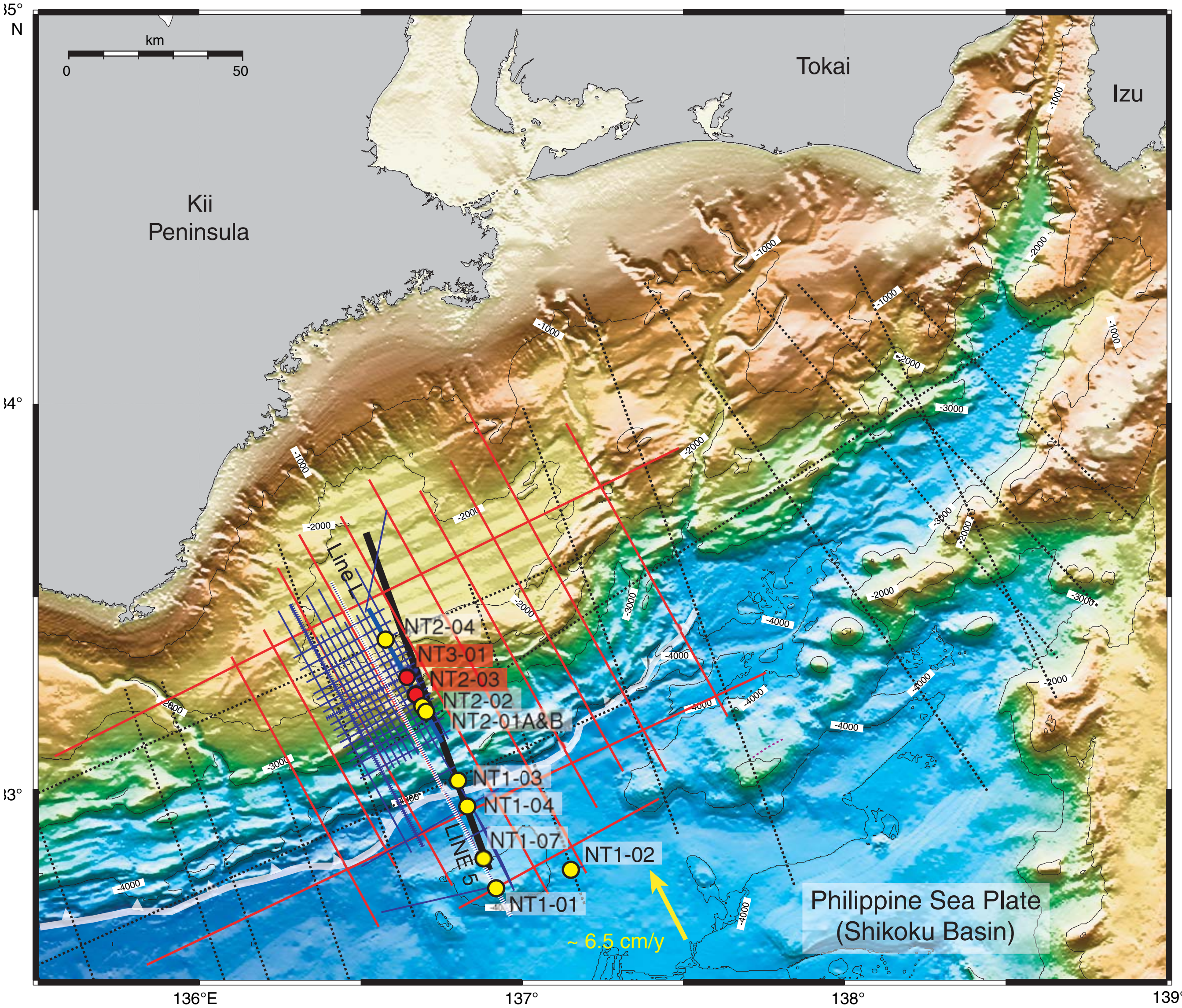

Figure F3. Prestack depth-migrated seismic line of Park et al. (2002), with locations of planned drill sites. Red and blue arrows = seaward extent of co-seismic slip inferred from tsunami and seismic data, respectively. Location of seismic profile is shown in Figures F1B and F2. Vertical exaggeration = 2X. PSP = Philippine Sea plate. Red line shows planned riser boreholes.

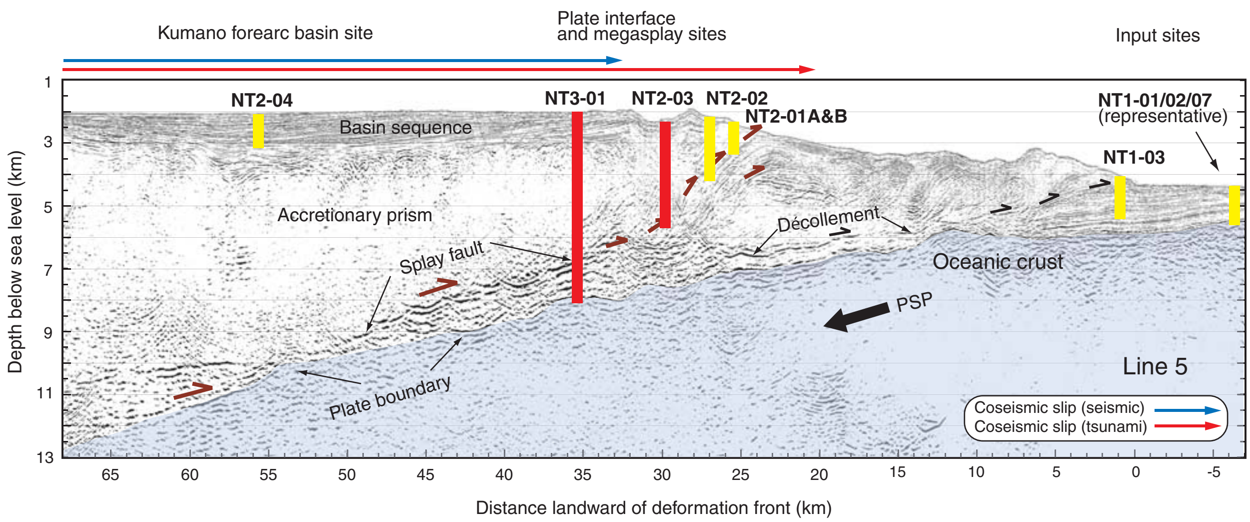

Figure F4. Conceptual drilling and long-term observatory plan for the deepest site, NT3-01. Drilling is planned to proceed with a mix of logging while drilling (LWD) and coring with casing to total depth, followed by sidetracking to core the prime fault targets and install monitoring instrumentation. Sensors shown here are positioned schematically. A number of sensor elements are not shown for clarity, including temperature arrays and fluid pressure sensors. Packers isolate perforated zones for fluid communication to the formation above, below, and inside each of the two target fault zones. Depths are based on seismic profile Line 5 shown in Figure F3. The borehole deviation is shown conceptually and is not meant to represent true angle or scale.

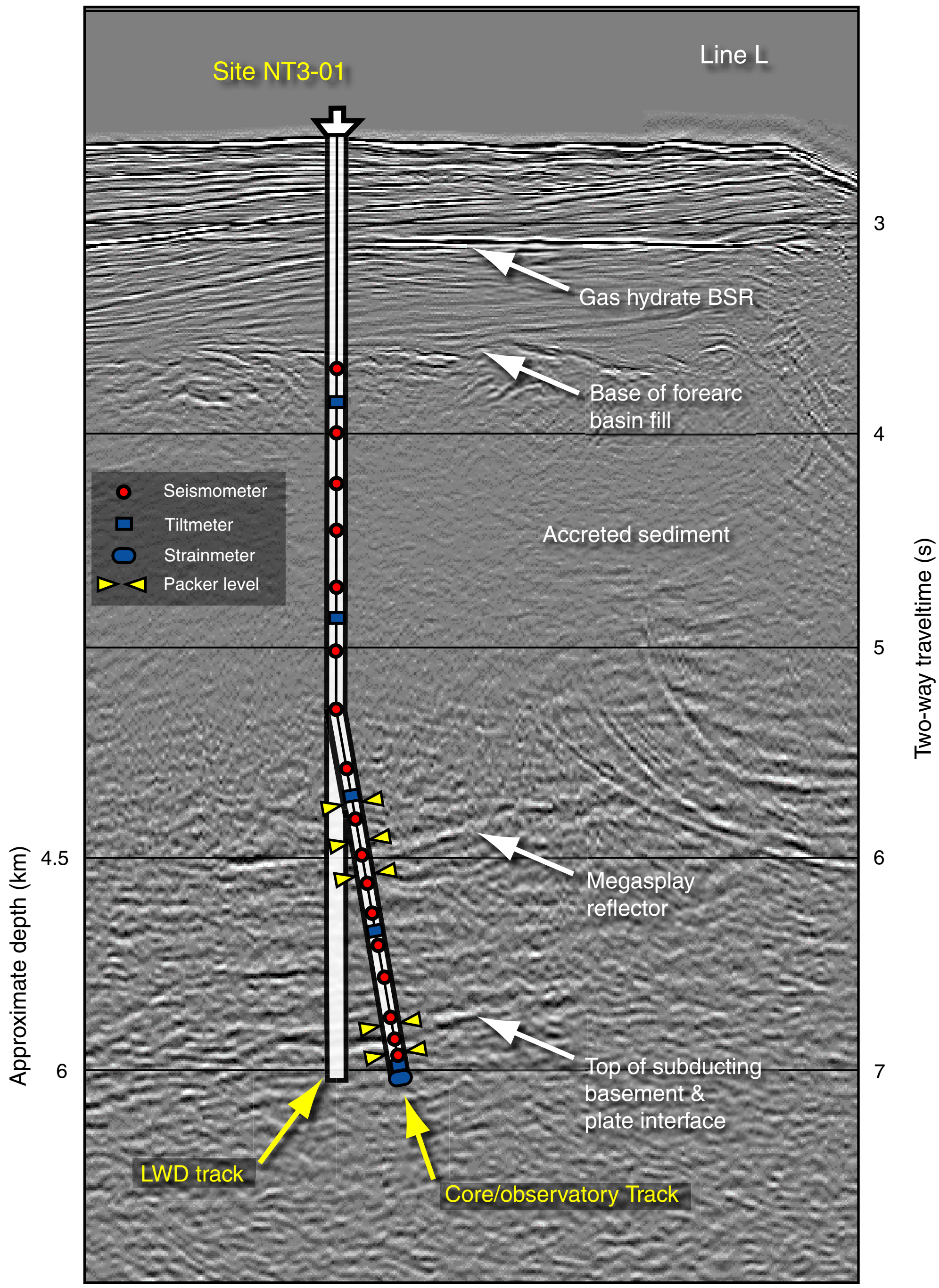

Figure F5. Overview of Stage 1 sites and projected Stage 1 drilling penetration. See text for detailed description of operations to be conducted at each location. Location of seismic profile is shown in Figures **F1B** and **F2.** Vertical exaggeration = 2X. PSP = Philippine Sea plate.

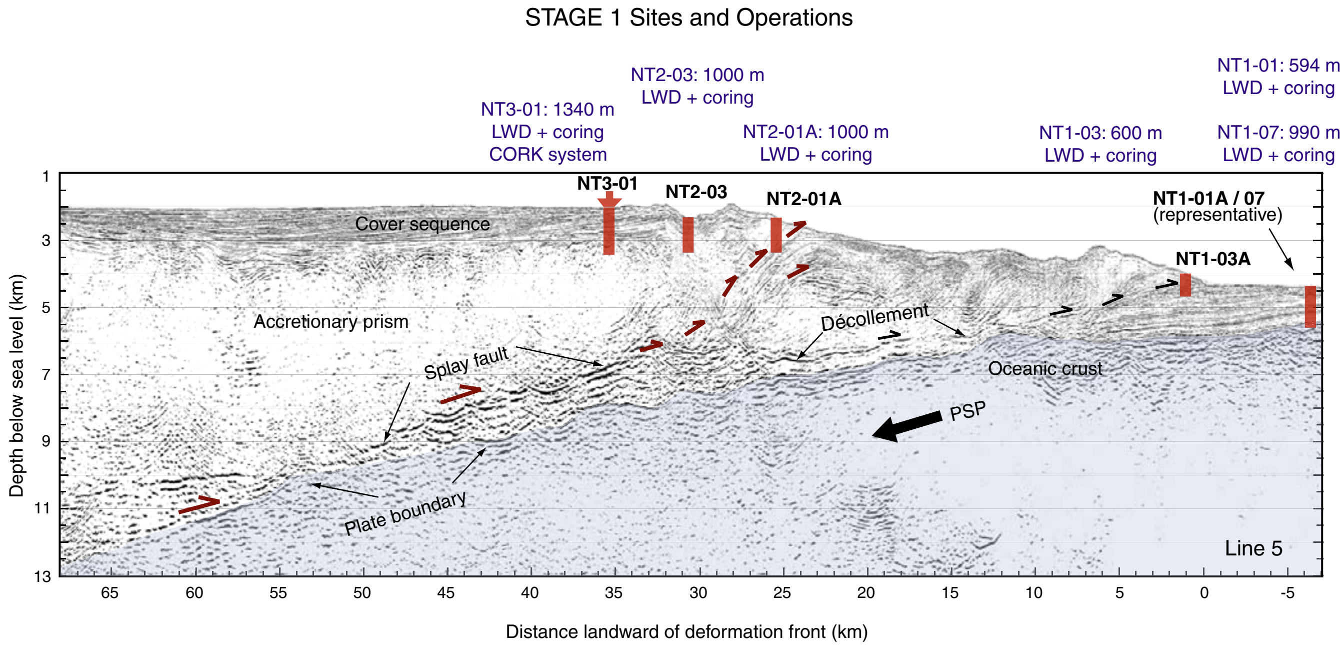

Figure F6. Seismic Line KR9806-2, showing locations of proposed Sites NT1-01, NT1-07, and NT1-03. The location of this seismic profile is shown in Figure F2.

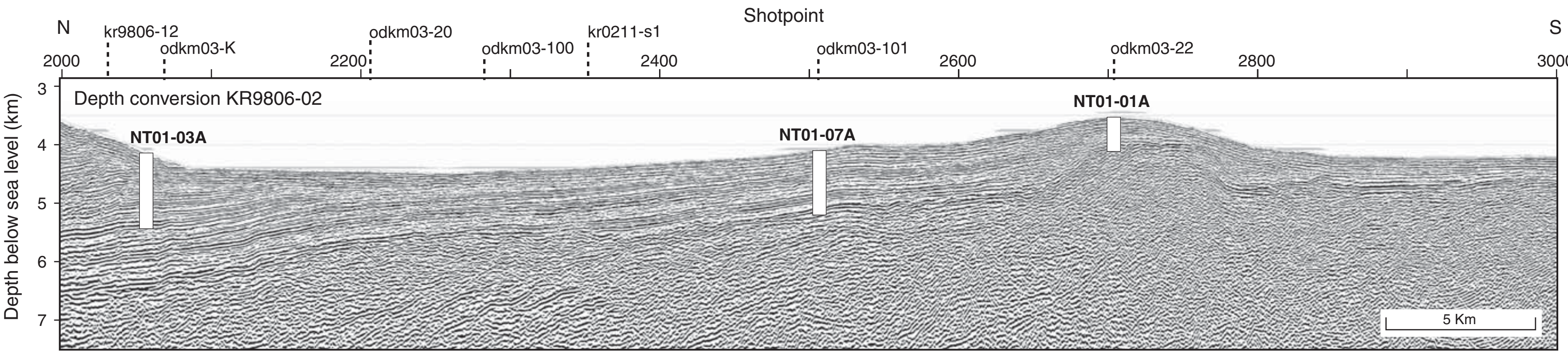

Figure F7. Locations of proposed Sites NT2-01, NT2-03, and NT3-01 on interpreted CDEX seismic Line L (see Fig. F2 for location). The Stage 1 borehole penetration depths are shown in white for Sites NT2-03 and NT3-01; drilling to greater depths (red) will be completed by riser drilling in subsequent stages of the NanTroSEIZE project. Site NT2-02 has been deferred to a later stage. The locations of Sites NT2-01 and NT2-03 may shift once the newly acquired 3-D seismic data are interpreted in coming months. Location of Line L is shown in Figures F1A and F2. Vertical exaggeration = ~1.5X. CMP = common midpoint.

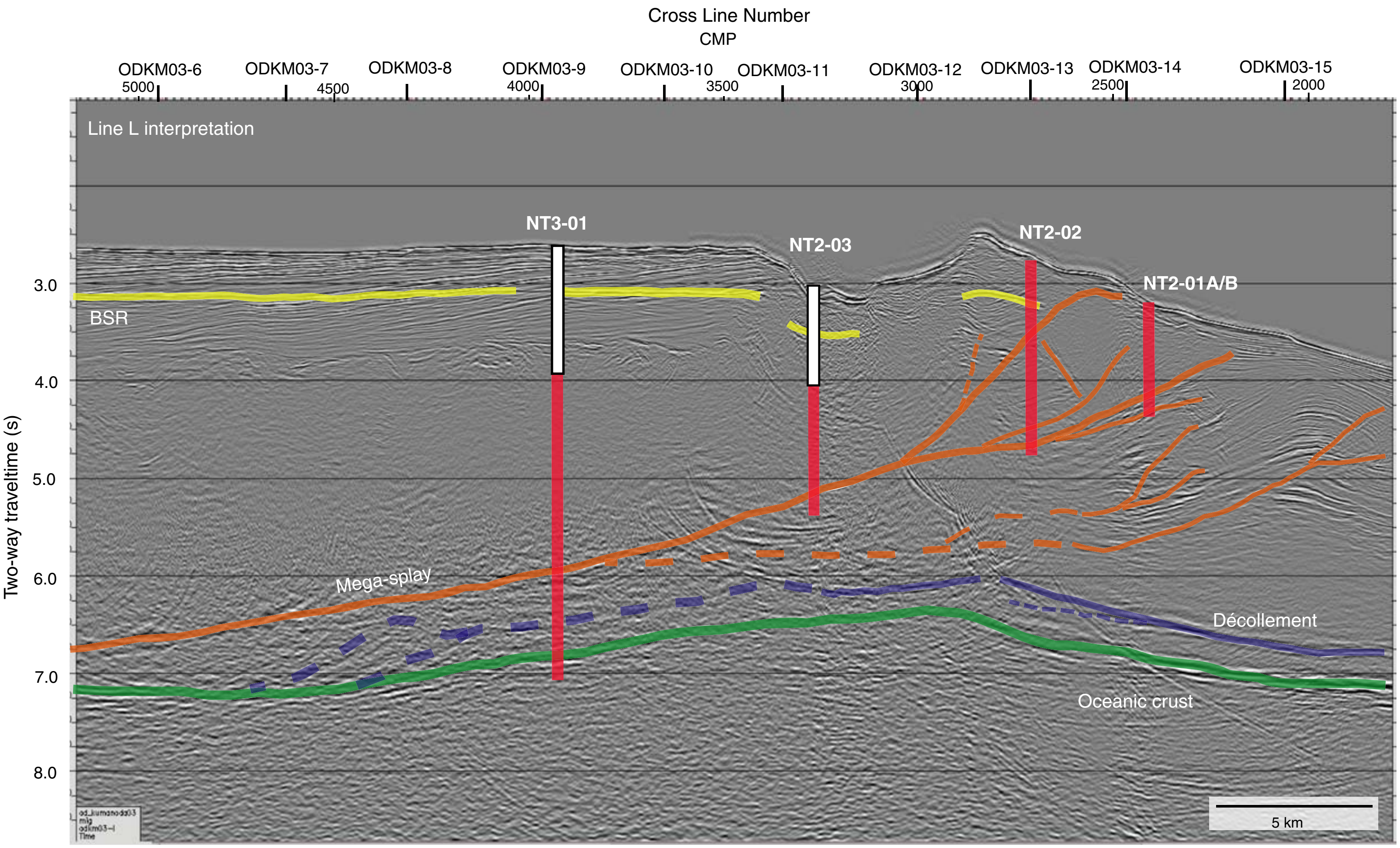

Table T1. Stage 1 riserless drilling expeditions.

Expedition	Estimated duration (days)*	Expedition name	Expedition objectives	Invited Co-Chief Scientists
Chikyu 1	53	NanTroSEIZE Logging-While-Drilling (LWD) Transect	Riserless drilling using LWD technology (no coring) at all six Stage 1 sites (NT1-01, NT1-07, NT1-03, NT2-01, NT2-03, NT3-01)	Masataka Kinoshita JAMSTEC-IFREE Japan **masa@jamstec.go.jp** Harold Tobin University of Wisconsin–Madison USA **htobin@wisc.edu**
Chikyu 2	54	NanTroSEIZE Megasplay Riser Pilot	Riserless coring at Site NT2-03 to sample forearc basin sediments and deformed prism with fault zones derived from a megasplay fault system Preparatory site for intermediate-depth (~3.5 kmbsf) Stage 2 riser site	Juichiro Ashi University of Tokyo ORI Japan **ashi@ori.u-tokyo.ac.jp** Siegfried Lallemant University Cergy-Pontoise France **Siegfried.Lallemant@u-cergy.fr**
Chikyu 3	57	NanTroSEIZE Thrust Faults	Riserless coring of frontal thrust (Site NT1-03) and splay fault targets (Site NT2-01)	Gaku Kimura University of Tokyo Japan **gaku@eps.s.u-tokyo.ac.jp** Elizabeth Screaton University of Florida USA **screaton@ufl.edu**
SODV 1	54	NanTroSEIZE Subduction Inputs	Coring of Shikoku Basin sediments to define inputs to the seismogenic zone (Sites NT1-01 and NT1-07)	Achim Kopf Bremen University Germany **akopf@uni-bremen.de** Michael Underwood University of Missouri USA **underwoodm@missouri.edu**
SODV 2	53	NanTroSEIZE Kumano Basin Observatory	Coring entire forearc basin section and upper portion of underlying prism Installation of observatory to monitor seismicity, strain, pressure, and temperature Preparatory site for deep (~5.5–6.0 km) riser drilling	Demian Saffer Penn State University USA **dsaffer@geosc.psu.edu** Wonn Soh JAMSTEC Japan **soh@jamstec.go.jp**

Notes: * = expedition durations are subject to change. Please check **www.iodp.org/expeditions** for official expedition schedule.