Integrated Ocean Drilling Program
Expedition 348 Scientific Prospectus

NanTroSEIZE Stage 3: NanTroSEIZE plate boundary deep riser 3

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Abstract

The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) program is a coordinated, multiexpedition drilling project designed to investigate fault mechanics and seismogenesis along subduction megathrusts through direct sampling, in situ measurements, and long-term monitoring in conjunction with allied laboratory and numerical modeling studies. The fundamental scientific objectives of the NanTroSEIZE project include characterizing the nature of fault slip and strain accumulation, fault and wall rock composition, fault architecture, and state variables throughout the active plate boundary system.

Drilling during Integrated Ocean Drilling Program (IODP) Expedition 348 will comprise riser drilling with the primary objective of deepening existing Hole C0002F to 3600 meters below seafloor (mbsf). These operations will extend drilling conducted during IODP Expeditions 326 and 338. The entire expedition will cover a period of 130 days, beginning on 13 September 2013 and ending on 20 January 2014.

Site C0002 is located in the Kumano forearc basin above the seismogenic, and presumably locked, portion of the plate boundary thrust system. The Kumano Basin sedimentary sequence and uppermost part of the accretionary prism were drilled, logged, and sampled during IODP Expeditions 314 (logging while drilling [LWD] to 1401.5 mbsf), 315 (coring to 1057 mbsf), and 338 (LWD to 2005 mbsf and coring to 1120 mbsf). During Expedition 348, drilling to 3600 mbsf or deeper will access the deep interior of the Miocene inner accretionary prism and will allow characterization of a unique tectonic environment that has never before been sampled in situ by ocean drilling. The primary goals include LWD, casing to a target depth of 3600 (or 4400) mbsf, and analyses of cuttings, mud gases, and limited cores to address the four primary scientific objectives: (1) determine the composition, stratigraphy, and deformational history of the Miocene accretionary prism; (2) reconstruct its thermal, diagenetic, and metamorphic history; (3) determine horizontal stress orientations and magnitudes; and (4) investigate the mechanical and hydrological properties of the upper plate of the seismogenic plate boundary. After Expedition 348, current plans call for the hole to be deepened to cross and sample the megasplay fault at ~5200 mbsf during a later expedition in 2015.

This *Scientific Prospectus* outlines the scientific rationale, objectives, and operational plans for drilling during Expedition 348 and describes the main contingency options.

Schedule for Expedition 348

The operations schedule for Integrated Ocean Drilling Program (IODP) Expedition 348 is derived from the original IODP drilling Proposals 603-CDP3, 603B-Full2, and 603C-Full (available at **www.iodp.org/600/**). Following ranking by the IODP Scientific Advisory Structure, the IODP Operations Task Force charged the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Project Management Team (PMT) with formulating a strategy to achieve the overall scientific objectives outlined in all of the NanTroSEIZE program proposals. The overarching goals and multistage implementation strategy are described in Tobin and Kinoshita (2006a, 2006b).

Expedition 348 is the third expedition of NanTroSEIZE Stage 3 and is scheduled to begin at Shimizu, Japan, on 13 September 2013. Details of the operational schedule, updates to the drilling schedule, and operational and layout details of the D/V *Chikyu* (operating under contract with the Japanese Implementing Organization, the Center for Deep Earth Exploration [CDEX]) can be found at **www.jamstec.go.jp/chikyu/eng/CHIKYU/index.html.**

The Science Party will be on board for only the latter part of riser drilling operations, when we anticipate that collection of cuttings, core, and logging data will be ongoing and/or complete and shipboard analysis can begin. To ensure a scientific presence during the entire expedition, PMT members acting as Operations Liaisons will be on board during operations to drill and case IODP Hole C0002F from 860 to 2300 meters below seafloor (mbsf), prior to embarkation of the main science party. The schedules for the Operations Liaisons, Co-Chief Scientists, Expedition Project Managers (EPMs), and science party are listed in Table **T1.** The entire expedition comprises a total of 130 days, including 41 days of contingency time (Table **T2**).

Introduction

Overview of the NanTroSEIZE drilling project

Subduction zones account for 90% of the global seismic moment release and generate damaging earthquakes and tsunamis with potentially disastrous effects on heavily populated coastal areas (e.g., Lay et al., 2005; Moreno et al., 2010; Simons et al., 2011). Understanding the processes that govern the strength, nature and distribution of slip along these plate boundary fault systems is a crucial step toward evaluating earthquake and tsunami hazards. More generally, characterizing fault slip behavior and mechanical state at all plate boundary types through direct sampling, near-field geophysical observations, measurement of in situ conditions, and shore-based laboratory experiments is a fundamental and societally relevant goal of modern earth science. To this end, several recent and ongoing drilling programs have targeted portions of active plate boundary faults that have either slipped coseismically during large earthquakes or nucleated smaller events. These efforts include the San Andreas Fault Observatory at Depth (SAFOD) (Hickman et al., 2004), the Taiwan-Chelungpu Drilling Project (Ma, 2005), IODP NanTroSEIZE drilling (Tobin and Kinoshita, 2006a, 2006b), and the Japan Trench Fast Drilling Project (Mori et al., 2012).

NanTroSEIZE is a multiexpedition, multistage IODP drilling project focused on understanding the mechanics of seismogenesis and rupture propagation along subduction plate boundary faults. The drilling program includes a coordinated effort to sample and instrument the plate boundary system at several locations offshore the Kii Peninsula (Tobin and Kinoshita, 2006a) (Figs. **F1, F2**). The main objectives are to understand

- The mechanisms and processes controlling the updip aseismic–seismic transition of the megathrust fault system, including fault processes associated with very low frequency (VLF) earthquakes and tremor (e.g., Sugioka et al., 2012);
- Processes of earthquake and tsunami generation;
- Mechanics of strain accumulation and release;
- The absolute mechanical strength of the plate boundary fault; and
- The potential role of a major upper plate fault system (termed the "megasplay" fault) in seismogenesis and tsunamigenesis.

The drilling program will evaluate a set of core hypotheses through 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 thrust faults.
2. Subduction megathrusts are weak faults.
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 (including the fault system and its hanging wall and footwall) change with time during the earthquake cycle.

5. A significant, laterally extensive upper plate fault system (the megasplay fault; Park et al., 2002) slips in discrete events that may include tsunamigenic slip during great earthquakes. It remains locked during the interseismic period and accumulates strain.

An additional hypothesis has been developed following the emergence of observations of tremor and VLF earthquake modes of fault activity in the outer forearc:

- Shallow tremor, VLF earthquakes, and/or slow-slip events occur by faulting under conditional frictional stability conditions facilitated by elevated pore fluid pressure.

Sediment-dominated subduction zones such as the East Aleutian, Cascadia, Sumatra, and Nankai margins are characterized by the repeated occurrence of great earthquakes of Mw ~8.0+ (Ruff and Kanamori, 1983). Although the causal mechanisms are not well understood (e.g., Byrne et al., 1988; Moore and Saffer, 2001; Saffer and Marone, 2003) and great earthquakes are also known to occur within sediment-starved subduction zones such as the Japan Trench, the updip limit of the seismogenic zones at these margins is thought to correlate with a topographic break, often associated with the outer rise (e.g., Byrne et al., 1988; Wang and Hu, 2006). Along the Nankai margin, high-resolution seismic reflection profiles across the outer rise clearly document a large out-of-sequence-thrust fault system (the megasplay fault, after Park et al., 2002; Tobin and Kinoshita, 2006a) that branches from the plate boundary décollement close to the updip limit of inferred coseismic rupture in the 1944 Tonankai Mw 8.2 earthquake (Fig. **F2**). Several lines of evidence indicate that the megasplay system is active; however, the partitioning of strain between the lower plate interface (the décollement zone) and the megasplay system and the nature and mechanisms of fault slip as a function of depth and time on the megasplay are not fully understood (e.g., Strasser et al., 2009; Kimura et al., 2011). Therefore, documenting the role of the megasplay fault in accommodating plate motion (both seismically and interseismically) and characterizing its mechanical and hydrologic behavior constitute an important goal for NanTroSEIZE and, more generally, toward understanding subduction zone megathrust behavior globally.

In late 2007 through early 2008, IODP Expeditions 314, 315, and 316 were carried out as a unified program of drilling collectively known as NanTroSEIZE Stage 1 (Tobin et al., 2009). A transect of eight sites was selected for riserless drilling to target the frontal thrust region, the midslope megasplay fault region, and the Kumano forearc basin region (Figs. **F1, F2**). Two of these sites are preparatory pilot holes for planned deeper riser drilling operations, whereas the other sites primarily targeted fault zones in the shallow, presumed aseismic, portions of the accretionary complex (Tobin et al., 2009). Expedition 314 was dedicated to in situ measurement of physical properties and borehole imaging through logging while drilling (LWD) in holes drilled specifically for that purpose, including Site C0002 (Expedition 314 Scientists, 2009). Expedition 315 was devoted to core sampling and downhole temperature measurements at a site in the megasplay region and Site C0002 in the forearc basin (Expedition 315 Scientists, 2009b). Expedition 316 targeted the frontal thrust and megasplay fault in their shallow, aseismic portions (Screaton et al., 2009).

Stage 2 of NanTroSEIZE comprised four IODP expeditions (319, 322, 332, and 333), with the aims of defining the state of stress, composition, and mechanical properties of the inner accretionary wedge at Site C0009, characterizing the subduction inputs on the Philippine Sea plate, and preparing for later observatory installations for long-term monitoring of deformation, seismicity, and hydrological processes (Saito, Underwood, Kubo, and the Expedition 322 Scientists, 2010; Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010).

Stage 3 operations in Hole C0002F, the main NanTroSEIZE riser hole, began with the installation of a riser wellhead and shallow casing string to 860 mbsf during IODP Expedition 326 (Kinoshita et al., 2012). IODP Expedition 338 deepened the hole to ~2005 mbsf in 2012, collecting a complete set of logs and cuttings (Moore et al., 2013). Expedition 338 also drilled and cored several riserless holes at Site C0002 near Hole C0002F. The primary objective of Expedition 348 is to log, core, and case this hole to 3600 (or 4400) mbsf, as conditions permit. Riser expeditions after 2015 will focus on deepening this hole to penetrate the megasplay fault at ~5200 mbsf and installing a long-term observatory at the fault zone (Figs. **F2, F3**).

Site C0002 is the centerpiece of the NanTroSEIZE project, and Hole C0002F will access the plate interface at a zone where the fault system is believed to be capable of interseismic locking (and therefore coseismic slip) and to have slipped in the 1944 Tonankai earthquake (e.g., Ichinose et al., 2003). This zone also coincides broadly with the locations of VLF earthquake swarms observed in 2004–2005 (Ito and Obara, 2006) and 2009 (Sugioka et al., 2012) and with tectonic tremors in the outer accretionary prism (Obana and Kodaira, 2009).

Background

Geological setting

The Nankai Trough is formed by subduction of the Philippine Sea plate to the northwest beneath the Eurasian plate at a rate of ~40–60 mm/y (Seno et al., 1993; Miyazaki and Heki, 2001). The convergence direction is oblique to the trench, and sediments of the Shikoku Basin are actively accreting at the deformation front. The Nankai Trough is among the most extensively studied subduction zones in the world, and great earthquakes during the past 1300 or more years are well documented in historical and archeological records (e.g., Ando, 1975). The Nankai Trough has been one of the focus sites for studies of seismogenesis by both IODP and the U.S. MARGINS initiative, based on the wealth of geological and geophysical data available. A better understanding of seismic and tsunami behavior at margins such as Nankai is highly relevant to heavily populated coastal areas.

Subduction zones like the Nankai Trough, where most great earthquakes (Mw > 8.0) occur, are especially favorable for study because the entire downdip width of the seismogenic zone ruptures in each event, suggesting that the zone of coseismic rupture in future large earthquakes may be more predictable than for smaller earthquakes. The Nankai Trough region has a 1300 y historical record of recurring great earthquakes that are typically tsunamigenic, including the 1944 Tonankai Mw 8.2 and 1946 Nankaido Mw 8.3 earthquakes (Ando, 1975; Hori et al., 2004). The rupture area and zone of tsunami generation for the 1944 event (within which Site C0002 is located) are now reasonably well understood (Ichinose et al., 2003; Baba et al., 2005). Land-based geodetic studies suggest that currently the plate boundary thrust 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., 2001) implies significant interseismic strain accumulation. However, recent observations of VLF earthquakes within or just below the accretionary prism in the drilling area (Obara and Ito, 2005; Sugioka et al., 2012) demonstrate that interseismic strain is not confined to slow elastic strain accumulation. Slow slip phenomena, referred to as episodic tremor and slip, including episodic slow slip events and nonvolcanic tremor (Schwartz and Rokosky, 2007), are also widely known to occur in the downdip part of the rupture zone (Ito et al., 2007). In the subducting Philippine Sea plate mantle below the rupture zone, weak seismicity is observed (Obana et al., 2005). Seaward of the subduction zone, deformation of the incoming ocean crust is suggested by microearthquakes as documented by ocean-bottom seismometer (OBS) studies (Obana et al., 2005).

The region offshore the Kii Peninsula on Honshu Island was selected for seismogenic zone drilling for several reasons. First, the rupture area of the most recent great earthquake, the 1944 Mw 8.2 Tonankai event, is well constrained by recent seismic and tsunami waveform inversions (e.g., Tanioka and Satake, 2001; Kikuchi et al., 2003). Slip inversion studies suggest that only in this region 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 has been identified and targeted (Figs. **F2, F3**). Second, OBS campaigns and onshore high-resolution geodetic studies (though of short duration) indicate significant interseismic strain accumulation (e.g., Miyazaki and Heki, 2001; Obana et al., 2001). Third, the region offshore the Kii Peninsula is generally typical of the Nankai margin in terms of heat flow and sediment on the incoming plate. This is in contrast to the area offshore Cape Muroto, previously drilled during the Deep Sea Drilling Project and the Ocean Drilling Program (ODP), where both local stratigraphic variation associated with basement topography and anomalously high heat flow have been documented (Moore et al., 2001, 2005). Finally, the drilling targets are within the operational limits of riser drilling by the *Chikyu* (i.e., maximum of 2500 m water depth and 7000 m subseafloor penetration). In the seaward portions of the Kumano Basin, the seismogenic zone lies ~6000 m beneath the seafloor (Nakanishi et al., 2002).

The position of the plate boundary décollement fault or faults (sometimes called the "plate interface") is the subject of ongoing debate. Most previous NanTroSEIZE publications (e.g., Tobin and Kinoshita, 2006a; Moore et al., 2007; and many others) have followed the general interpretation of Park et al. (2002), showing a branching point with the prominent megasplay reflector above a deeper décollement horizon that continues seaward as the outer wedge décollement. However, recent imaging, including the 3-D seismic volume and wide-angle OBS inversion (Kamei et al. 2013), have led to an alternative hypothesis that at Site C0002 the megasplay is the main plate boundary reflector and shallows into the outer décollement. In this scenario, the splay fault branching occurs seaward of and shallower than the reflector at ~5000 mbsf at Site C0002 (Figs. **F2, F3**), and the section beneath the reflector is composed primarily of subducting sediments underlain by down-going plate basement. It seems to be clear in the 3-D seismic imaging that the top of ocean crust is not likely to be the décollement at this location (Bangs et al., 2009), but a décollement could lie somewhere between 5000 and 7000 mbsf. In either interpretation of the décollement geometry, coseismic plate boundary slip during events like the 1944 Tonankai earthquake may have occurred on the megasplay fault reflector in addition to any deeper décollement

(Ichinose et al., 2003; Baba et al., 2006). That reflector is therefore a primary drilling target.

Seismic studies/Site survey data

A significant volume of site survey data has been collected in the drilling area over many years, including multiple generations of 2-D seismic reflection (e.g., Park et al., 2002), wide-angle refraction (Nakanishi et al., 2002; Kamei et al., 2013), passive seismicity (e.g., Obara and Ito, 2005; Sugioka et al., 2012), heat flow (Yamano et al., 2003), side-scan sonar, swath bathymetry, and submersible and remotely operated vehicle dive studies (Ashi et al., 2002). In 2006, Japan and the United States conducted a joint 3-D seismic reflection survey over a ~11 km × 55 km area, acquired by PGS Geophysical, an industry service company (Moore et al., 2009). This 3-D data volume is the first deep-penetration, fully 3-D marine survey ever acquired for basic research purposes and has been used to (1) refine selection of drill sites and targets in the complex megasplay fault region, (2) define the 3-D regional structure and seismic stratigraphy, (3) analyze physical properties of the subsurface through seismic attribute studies, and (4) assess drilling safety (Moore et al., 2007, 2009; Kitajima and Saffer, 2012). These high-resolution, 3-D data will be used in conjunction with physical properties, petrophysical, and geophysical data obtained from core analyses and both wireline and LWD logging to allow extensive and high-resolution integration of core, logs, and seismic data.

The supporting site survey data for Expedition 348 are archived at the **IODP Site Survey Data Bank.**

Scientific objectives

Site C0002 background

The primary drilling plan for Expedition 348 is to extend Hole C0002F to ~3600 mbsf (or deeper) through riser drilling. The hole will be suspended after casing is installed and cemented at the 11¾ inch casing set point (Fig. **F3**). During Expedition 326 in 2010, the wellhead was installed and a 20 inch casing string was cemented in place to 860 mbsf. During Expedition 338, the riser hole was extended to 2005 mbsf; however, the hole was not cased because of operational difficulties.

The uppermost 1400 mbsf at Site C0002 was previously logged with a comprehensive LWD program during Expedition 314 (Expedition 314 Scientists, 2009). The intervals 0–204 and 475–1057 mbsf were cored during Expedition 315 (Expedition 315 Scientists, 2009b). During Expedition 338, riser operations extended the hole from 842 to 2005.5 mbsf, collecting a full suite of LWD and measurement-while-drilling (MWD), mud gas, and cuttings data (Moore et al., 2013). Additional cores were collected at adjacent holes during Expedition 338 with riserless drilling to 1120 mbsf (Moore et al., 2013). The Kumano forearc basin sedimentary package comprises the interval from 0 to 940 mbsf, and it is underlain by the inner accretionary wedge. The entire interval from ~940 mbsf to the megasplay reflector at ~5200 mbsf exhibits few coherent seismic reflections that would indicate intact stratal packages, which is in contrast to the outer accretionary wedge seaward of the Kumano Basin region (Figs. **F2, F3**) (also see Moore et al., 2009). This seismic character is thought to indicate complex deformation within the inner wedge, perhaps best characterized as a subduction mélange or protomélange. The anticipated lithology to be encountered during Expedition 348 is Miocene age hemipelagic mudstone and sand/silt turbidites with sparse volcanic ash, based on cores and logs obtained during Expeditions 314, 315, 319, and 338. Whether the deeper accreted strata represent trench-wedge deposits, Shikoku Basin deposits, or both remains to be determined.

Site C0002 objectives

The main research objectives for Expedition 348 are to (1) sample the interior of the accretionary complex in the midslope region beneath the Kumano forearc basin by collection of both cores and drill cuttings and (2) collect an extensive suite of LWD logs to characterize the formation. Sampling this previously unsampled interval will allow (1) determination of the composition, age, stratigraphy, and internal style of deformation of the Miocene accretionary complex; (2) reconstruction of its thermal, diagenetic, and metamorphic history and comparison with present pressure-temperature conditions; (3) determination of horizontal stress orientations and potentially magnitudes within the deep interior of the inner accretionary wedge; (4) investigation of the mechanical and hydrological and behavior of the wedge; and (5) characterization of the overall structural evolution of the Nankai accretionary prism and the current state of the upper plate above the presumed locked seismogenic plate boundary thrust.

The interval from 860 mbsf to target depth (3600–4400 mbsf, depending on drilling conditions) will be drilled with continuous LWD resistivity, azimuthal resistivity imaging, sonic transit time, gamma radiation, and annular pressure data. During this riser drilling, mud return will allow for a comprehensive analysis of drill cuttings and mud gas, as was performed at Site C0009 and Hole C0002F and described by Expedition 319 Scientists (2010) and Moore et al. (2013), respectively. Coring (100 m total) is also planned to sample the inner wedge but is restricted to one interval from 2300 to 2400 mbsf, just below the 13⅜ inch casing shoe. The overall target depth planned for the expedition depends on operational time, hole stability, and weather conditions. If these are all favorable and drilling proceeds smoothly with sufficient time remaining, the goal will be to drill to 4400 mbsf (instead of 3600 mbsf) and to case the hole to that depth with a 9⅝ inch liner (instead of the 11¾ inch casing). The decision between these options will be made as the expedition progresses.

Site C0002 drilling will access the interior of the landward region of an active accretionary wedge for the first time by scientific ocean drilling, testing hypotheses for the transition from aseismic wedge growth to a strong hanging wall regime defining the outer edge of the geodetically locked or partially locked seismogenic plate boundary. Additionally, it will shed light on the nature of wedge formation and evolution. The data collected will also define the physical properties of the sediments that create the observed discontinuous seismic signature across the megasplay (e.g., Park et al., 2002; Moore et al., 2009; Kamei et al., 2013). At the end of Expedition 348, the borehole will be suspended for reentry and further deepening to the planned plate boundary target during 2015.

Specific questions to be addressed by drilling into the deep interior of the inner wedge include

- What is the thermal, diagenetic, and metamorphic history of the sedimentary rock below the Kumano Basin?
- What is the budget for hydrous minerals (e.g., smectite group clays) and the extent of dehydration reaction progress as a function of depth?
- What is the mechanical and structural evolution of the inner wedge?
- Are there indicators of low effective stress, high pore pressure zones related to deformation?
- How do the properties of the inner wedge sediments compare with the Shikoku Basin sediments that are input to the wedge?
- What are the horizontal stress orientations and magnitude within the deep interior of the inner wedge? How does the stress orientation relate to the current state of the earthquake cycle?

- What is the mechanical state and behavior of the formation and how does it relate to the current state of the upper plate above the seismogenic plate boundary thrust?
- What are faulting processes and mechanisms and how do they vary with depth in the inner accretionary wedge?

Answering these questions will allow for inferences on the structural style (subduction mélange or protomélange, deformed former outer wedge, or some unanticipated lithology and fabric), connections between sediment dewatering and fluid pressure, and thus the long-term evolution of the Nankai accretionary complex. The answers also provide a robust characterization of the inner wedge, which will ultimately be related to the deep section near the plate boundary fault.

Performing experiments using cuttings at presumed in situ conditions, we can constrain mechanical and hydrological properties of the inner wedge materials. Analyses of continuous series of cuttings, even with poor resolution from mixing, would also provide information on the lithologic constituents and their variation with depth in the inner accretionary wedge and also compare them with those properties estimated by LWD.

Drilling strategy, operations plan, and downhole measurements

To meet the scientific and engineering objectives, primary operations in Hole C0002F will comprise drilling using LWD/MWD to ~2300 mbsf, followed by setting 13⅜ inch casing (Fig. F3). Cuttings and mud gas will be collected and analyzed during riser drilling from 860.3 (bottom of 20 inch casing) to 2300 mbsf (see below regarding the 860–2005 mbsf section). Wireline coring will be conducted from 2300 to 2400 mbsf using a rotary core barrel (RCB) to obtain the highest quality and most complete core samples. Currently, plans call for drilling and LWD/MWD logging and cuttings and mud gas analysis to then continue to ~3600 mbsf, where the 11¾ inch casing shoe will be set. An alternative plan if conditions and time allow, is to drill with the same LWD string ~4400 mbsf and install a 9⅝ inch liner, as described above.

Operations plan

The operations plan and time estimate (Table T2) are based on formations and depths inferred from seismic and regional geological interpretations combined with data from previous drilling operations at nearby sites. We will use these operations and data to guide the operations described during Expedition 348. The primary operational plan is to conduct riser operations in Hole C0002F (Fig. F3).

Hole C0002F

During Expedition 326 in 2009, 36 inch conductor casing was run and cemented to 54 mbsf. Following this, a 26 inch hole was drilled to 860.3 mbsf, cased with 20 inch casing, and then cemented. During Expedition 338, the hole was deepened to 2005 mbsf in preparation for casing, but operations were terminated before the casing could be installed. Hole C0002F was suspended with a series of cement plugs and high-density mud: the section between 910 and 2007.5 mbsf was filled with 1.12 sg KNPP mud, above which was an ~72 m thick cement plug (1; 838.2–910.5mbsf); another section was filled with high-density mud (1.12 KNPP) to another ~50 m thick cement plug (2; 350–400 mbsf), above which more high-density KNPP mud (1.12 sg) filled the space between it and the corrosion cap on the wellhead. During Expedition 348, we will begin drilling a sidetrack hole from within the cement plug below the 20 inch casing shoe, running LWD/MWD tools behind a 12¼ inch bit. The first drilling interval will be from 860.3 to 2300 mbsf to set and cement the 13⅜ inch casing (Fig. F3). After a leak-off test, we will perform RCB drilling and coring from 2300 to 2400 mbsf. A second LWD/MWD interval will extend the hole to 3600 mbsf, after which the 11¾ inch casing will be set and cemented. If time is available after setting the 11¾ inch casing, additional coring beyond 3600 mbsf may be included.

Logging/Downhole measurements strategy

Hole C0002F

During drilling in Hole C0002F, LWD/MWD tools will be run between 860.3 and 3600 (or 4400) mbsf. Annular pressure while drilling, gamma ray, and resistivity logs will be collected in the 860.3–2300 mbsf section. The complete LWD string will be used below 2400 mbsf. This provides the ability to monitor drilling parameters and conditions and to collect gamma ray, sonic, and resistivity logs to define major lithologic changes in real time (MWD) as well as record high-resolution borehole and formation conditions (LWD). The MWD tool suite (Fig. **F4**) will include annular pressure while drilling, weight on bit, torque, azimuth, rate of penetration, hole inclination, and gamma radiation. The LWD tool suite will include laterolog resistivity at bit, azimuthal and sonic imaging (azimuthal focused resistivity), and compressional and shear sonic velocity and ultrasonic caliper (bimodal acoustic XBAT). LWD azimuthal resistivity data and borehole resistivity images will be obtained in order to further define stratigraphic boundaries and to characterize bedding, minor faults, and any wellbore breakouts or tensile fractures induced by drilling.

Sampling and sample coordination

Expedition 348 will sample cuttings and mud gas from all riser drilling intervals, including those that are not cored (860–2300 and 2400–3600 mbsf), as well as a limited number of sediment cores (2300–2400 mbsf). Previously (during Expedition 338), cuttings and mud gas were collected for analysis from the interval 860–2005 mbsf; because much of this interval will be redrilled, cuttings samples will be collected from this interval and stored for analysis (if desired) by the science party when they board the *Chikyu*. Sampling and sample coordination for cuttings and mud gas will involve a combination of shipboard analysis, sample collection, and sample archiving based on the approach that was first used in Hole C0009A (Expedition 319 Scientists, 2010) and refined for previous work in Hole C0002F (Expedition 338) (see the Cuttings Cookbook). This approach is built on experience transferred from the oil industry and from the SAFOD drilling program. The core and cuttings sampling strategy was developed by the PMT and Specialty Coordinators in consultation with the Sample Allocation Committee (SAC) (see **"Sample requests and coordination"** below) to best meet the drilling project's objectives and the needs of the science party. Sampling of cores will include whole-round and discrete sampling following traditional IODP sample policies. Basic shipboard sampling, community samples (see below), and individual sample requests will be coordinated by the SAC with exact numbers and location of samples based on core recovery. A short review of core sampling and archiving is provided below, followed by a more detailed discussion of sampling and archiving of cuttings. Shipboard and shore-based researchers should also refer to the IODP Sample, Data, and Obligations Policy (**www.iodp.org/program-policies/**) for additional details about obtaining and using samples.

Sampling sediment cores

Prior to any whole-round or discrete sampling of cores, all cores will be imaged with X-ray computed tomography (CT). Time-sensitive whole-round samples (e.g., interstitial water, microbiology, and anelastic strain recovery) will then be subsampled (Fig. **F5**). Whole-round core sections will then be nondestructively analyzed in the multisensor core logger. After nondestructive logging, nontime-sensitive whole-round samples (e.g., community whole rounds and science party research samples) will be taken as approved by the Co-Chief Scientists. Then cores will be split into a "working half" and "archive half," with the working half being available for sampling by shipboard and shore-based scientists. Although the archive half is also available for sampling in certain circumstances, it is primarily used for stratigraphic and structural characterization and archived to preserve retrieved material while providing flexibility and broader access to important material postexpedition.

The unique multiexpedition nature of the NanTroSEIZE project has also required the modification of traditional IODP sampling policy and routines in sampling sediment cores. Specifically, these include (1) community whole-round samples that are archived (at the Kochi Core Center [KCC]) for postexpedition distribution as approved by the SAC and (2) cluster samples taken for a suite of basic scientific measurements collected onboard and shore-based from a much smaller (1–2 cm thick) whole-round core sample. These basic measurements consist of carbonate content, moisture and density (MAD), grain size, bulk X-ray fluorescence (XRF), bulk X-ray diffraction (XRD), and clay-size XRD. Community whole-round cores and sample clusters are typically adjacently located and collected approximately one or two per core. We note that, due to the well-lithified core expected at these depths, high-pressure squeezing will probably not yield usable pore water samples, so fluid chemistry will have to follow the ground rock interstitial normative determination (GRIND) method (Expedition 315 Scientists, 2009a).

Community whole-round core samples

As is usual practice in IODP, individual scientists will be permitted to collect samples for shipboard analyses and their postexpedition research in accordance with approved sample requests. In addition, we intend to collect "community" archive samples, especially whole-round samples. These community samples will augment and/or provide redundancy for whole-round core samples requested by shipboard and shore-based scientists. The goal is to preserve a wide range of sample material for geotechnical characterization to help achieve the overall science objectives after the expedition and over the duration of the NanTroSEIZE project. Community whole-round cores are typically collected from each core after X-ray CT imaging as determined by the Co-Chief Scientists.

Cluster samples

To ensure achievement of overall NanTroSEIZE scientific objectives and maximize the ability to correlate different shipboard and shore-based data sets, it is essential to co-locate suites of essential data types (pore water, calcium carbonate content, MAD, bulk XRD, grain size, bulk chemistry, cation exchange capacity, and clay mineral XRD). This will be done with appropriate and consistent sample spacing throughout each site's stratigraphic succession. Sample clusters are normally collected from each section. In addition, a cluster sample is taken adjacent to each whole-round sample.

Sampling and archiving drill cuttings

During riser drilling, the unwashed drill cuttings are delivered continuously to the shale shaker, where samples are collected (by a Mantle Quest Japan [MQJ] roustabout) at a frequency equivalent to every 10 m of drilling penetration (Fig. **F6**). The roustabout then divides the cuttings into two splits: one for the Mud Logger (Geoservices) and the second for scientific analysis. The "science cuttings" sample (volume depends on volume of total sample requests) is transferred to the Core Cutting Area on the Laboratory Roof Deck (by a MQJ roustabout), where it is again split into two portions: a 400 cm^3 portion for archiving ("archive portion") and a 1000 cm^3 portion for analysis and sampling ("working portion"). The working portion is available for scientific sampling and analysis at any stage of the cleaning, sieving, and preliminary analysis shown in Figure **F6** (diamonds indicate potential sampling intervals). A portion of the archived cuttings (designated as a "temporary archive") is also available for sampling and analysis after the moratorium and approval of the SAC. Shipboard analysis of the working portion normally includes gamma radiation, MAD, lithologic and structural (microstructures) descriptions (through smear slides and thin sections, respectively), XRD and XRF analyses, magnetic susceptibility, total carbonate (using carbonate analyzer), and total carbon and nitrogen (using CHNS/O elemental analyzer). When possible, pore fluids will also be extracted from cuttings using the GRIND method (Expedition 315 Scientists, 2009a). The archive portion will be separated into an unwashed split and a washed split, both of which will be archived at KCC. Samples will be sorted, when possible, by lithology after sieving with magnets and seawater.

Sample requests and coordination

Because NanTroSEIZE is a long-term, multiexpedition drilling project that includes multiple linked expeditions over several years that share overarching scientific objectives, sampling and coordination of individual samples and data requests are somewhat different than for single expeditions. These differences include the recognition of the role of Specialty Coordinators, unique data sharing opportunities, and a more integrated sample and data request program. Key aspects of these differences are described below.

Specialty coordinators

Unlike traditional, stand-alone ODP/IODP legs and expeditions, unusual amounts of coordination and collaboration must occur among science parties across expeditions and within the framework of the overall NanTroSEIZE goals. Specialty Coordinators, in collaboration with Co-Chief Scientists, are responsible for facilitating collaborations between all of the participants of Expedition 348, as well as identifying research or sampling gaps or collaborations across the entire NanTroSEIZE project that are needed to achieve the overall scientific goals. They also provide technical and scientific guidance to each science party before, during, and after the expedition to ensure uniform and consistent data sets and nomenclature. The NanTroSEIZE PMT has identified six specific research areas that require special effort over the project's duration; these areas and the Specialty Coordinator for each are

- Lithostratigraphy and sedimentary petrology (Michael Underwood, University of Missouri);
- Structural geology (Gaku Kimura, University of Tokyo);
- Geotechnical properties, hydrogeology, and observatories (Demian Saffer, the Pennsylvania State University);
- Geochemistry (Geoff Wheat, University of Alaska Fairbanks;
- Core-log-seismic integration (Greg Moore, University of Hawaii); and
- Paleomagnetism and biostratigraphy (Toshiya Kanamatsu, Japan Agency for Marine-Earth Science and Technology).

Data/Sample sharing

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, planned, or ongoing expedition. In this context, all Expedition 348 scientists are required to submit a request for data/samples from other IODP expeditions, including Expeditions 315 and 338 (both of which cored the shallower portions of the section at Site C0002), if they are interested in conducting postexpedition research that requires samples from those expeditions. Expedition 348 participants are also encouraged to review the postexpedition science of NanTroSEIZE Stages 1 and 2 to identify potential collaborative projects or research gaps that they can help address. In the broader scientific context of NanTroSEIZE, it is also possible that drilling or scientific objectives will overlap across two or more expeditions and science parties to such an extent that the expeditions will be treated as one project in terms of shipboard data and samples. In cases of formal merger of expeditions by the PMT, 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 PMT in consultation with the SAC and the Co-Chief Scientists of the involved expeditions. This is somewhat different than most previous ODP and IODP expeditions but will follow the precedent and procedures defined during NanTroSEIZE Stage 1 drilling (Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009).

Sample and data requests (research proposals)

All shipboard scientists must submit at least one data or sample request in advance of the drilling expedition. Additional requests also may be submitted before, during, or after the expedition as necessary to acquire samples or data that will help address fundamental questions of Expedition 348 or individual research projects. Requests may also be submitted by shore-based participants; in cases of overlap or potential conflict, the shipboard scientists will be given higher priority. The initial sample requests provide the basis for the SAC and Specialty Coordinators to develop an integrated sampling program of both shipboard and shore-based sample requests to meet all of the essential postexpedition research objectives and to avoid unnecessary duplication of effort. The initial sampling plan, of course, will be subject to modification depending upon the actual material/data recovered and on collaborations that may evolve between scientists before and during the expedition(s). Modifications to the sampling plan during the expedition require the approval of the SAC. To provide time for the

SAC and Specialty Coordinators to develop a detailed and integrated sampling strategy, sample requests are due by 20 September 2013.

The IODP Sample, Data, and Obligations Policy (**www.iodp.org/program-policies/**) outlines the policy for distributing IODP samples and data and defines the obligations incurred by both shipboard and shore-based scientists. All scientists submitting sample requests must read the IODP Access Data and Samples webpage (**www.iodp.org/access-sample-data/**). Sample requests need to be submitted using the Sample/Data request form (**smcs.iodp.org/**).

Additional sampling guidelines

The SAC is composed of the expedition Co-Chief Scientists, EPMs, the shipboard curatorial representative, and the IODP Curator on shore. Specialty Coordinators provide advice to the SAC, but the SAC is responsible for all decisions. The SAC for the expedition(s) must approve access to data and core/cuttings samples requested during the expedition and during the 1 year moratorium, which starts at the end of the drilling expedition.

All sample frequencies and sizes must be justified on a scientific basis and will depend on core/cuttings recovery, the full spectrum of other sample/data requests, the expedition objectives, and project-wide NanTroSEIZE objectives. When critical or volumetrically limited intervals are recovered, there may be considerable demand for samples because of the 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' postexpedition research may be conducted during the expedition or may be deferred to postexpedition.

Contingency plans

Contingency operational options

Details of possible operational priorities or contingencies will be decided by the Co-Chief Scientists, EPMs, and Operation Superintendents according to operational realities aboard ship. To date, the NanTroSEIZE PMT has defined three viable contingency options; the first two options are described above as part of the riser operations strategy:

- Recovering temporary monitoring instruments and redeploying replacement sensors (GeniusPlug) in IODP Hole C0010A;
- Coring Hole C0002F beyond 3600 mbsf; and
- Logging, cuttings, mud gas analysis, and casing to 4400 mbsf in Hole C0002F.

Site C0010 is located 3.5 km north of IODP Site C0004 and was first drilled during Expedition 319 (Expedition 319 Scientists, 2010). Operations during that expedition included drilling through a shallow branch of the megasplay fault zone and into its footwall using LWD, setting casing with screens spanning the fault zone, and installing a temporary suite of pressure and temperature sensors (a SmartPlug) to monitor within the fault zone. Major lithologic boundaries as well as the location of the splay fault at ~407 mbsf were identified in LWD data and were used to select a depth interval spanning the fault for placement of the two screened casing joints. During Expedition 332 (Expedition 332 Scientists, 2011), the SmartPlug was recovered and replaced with a modified instrument package (the GeniusPlug), which includes a set of geochemical and biological experiments in addition to the pressure and temperature sensors. If conditions and time allow during Expedition 348, this temporary instrument package will be recovered and replaced with a new GeniusPlug.

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Table T1. IODP Expedition 348 staffing and boarding schedule.

Staff	Time period	Duration	Operation	People
EPMs	13 Sep 2013–20 Jan 2014	130 days	Entire	Sean Toczko, Lena Maeda, Yusuke Kubo
OL 1	27 Sep 2013–11 Oct 2013	2 weeks	13-3/8 inch LWD, csg	Gaku Kimura
OL 2	11 Oct 2013–25 Oct 2013	2 weeks	13-3/8 inch LWD, csg or 11-3/4 inch (9.5) LWD, csg	Greg Moore
OL 3	25 Oct 2013–1 Nov 2013	1 week	11-3/4 inch (9.5) LWD, csg	Kyu Kanagawa
OL 4	1 Nov 2013–15 Nov 2013	2 weeks	11-3/4 inch (9.5) LWD, csg	Mike Underwood
CC "A"	12 Nov 2013–6 Dec 2013	24 days	11-3/4 inch (9.5) LWD, csg	Demian Saffer
CC "B"	15 Nov 2013–10 Jan 2014	56 days	11-3/4 inch (9.5) LWD, csg	Takehiro Hirose
CC "C"	26 Nov 2013–10 Jan 2014	45 days	11-3/4 inch (9.5) LWD, csg	Harold Tobin
SP	26 Nov 2013–10 Jan 2014	45 days	11-3/4 inch (9.5) LWD, csg	Science party

Expedition Project Manager (EPM) schedules will cover entire operation. OL = Operations Liaison, CC = Co-Chief Scientist, SP = science party. LWD = logging while drilling. csg = casing.

Table T2. Expedition 348 operations plan.

Operation	Base ROP (m/day)	Days	Subtotal (days)	Total (days)
1. Transit, deploy transponders, retrieve corrosion cap, preparation for spud			4.5	4.5
Transit from Shingu to the site		0.5		
Deploy 10 transponders/calibration		1		
Wellhead survey and recover corrosion cap		1		
Preparation for run BOP and riser		2		
2. Run and set BOP and riser			11	15.5
Run BOP and riser w/fairing at low-current area		7		
Drift from low-current area to the site		2		
Test BOP		2		
3. Set 13-3/8 inch casing			19	34.5
Run 17 inch bit w/MWD/LWD BHA, DOC inside 20 inch casing		2		
Kick off from 880 m, 880–1170 mbsf	100	3		
Drill 17 inch hole w/LWD, 1170–2300 mbsf	180	7		
Run and cement 13-3/8 inch casing		5		
Test BOP		2		
4A. Set 11-3/4 inch casing			43	77.5
DOC and LOT		2		
Cut 10-5/8 inch RCB core 100 m interval, 2300–2400 mbsf	25	4		
Drill 12-1/4 inch hole w/LWD to 3600 mbsf, 2300–3600 mbsf	100	13		
Open hole to 14-1/2 inch w/underreamer, 2300–3600 mbsf	100	13		
Run and cement 13-3/8 inch casing		5		
Test BOP (3 times)		6		
4B. Set 9-5/8 inch casing			38	72.5
DOC and LOT		2		
Cut 10-5/8 inch RCB core 100 m interval, 2300–2400 mbsf	25	4		
Drill 12-1/4 inch hole w/LWD, 2300–4400 mbsf	100	21		
Run and cement 9-5/8 inch casing		5		
Test BOP (3 times)		6		
5. Suspend hole			8	85.5 (80.5)
Set cement plug or bridge plug in hole		2		
Retrieve BOPs and marine risers		6		
6. Set corrosion cap, retrieve transponders, transit		2.5	2.5	88 (83)
7. Contingency			41	129 (124)
Mechanical downtime (operation time × 4%)		4		
Wait on weather (operation time × 15%)		13		
Typhoon evacuation (2 times × 12 days)		24		
Total:				129 (124)

ROP = rate of penetration. BOP = blowout preventer. MWD = measurement-while-drilling, LWD = logging-while-drilling, BHA = bottom-hole assembly. DOC = drill out cement. LOT = leak-off test. RCB = rotary core barrel. Green shading = optional Operation 4.

Figure F1. Map of NanTroSEIZE region, showing all Stage 1, 2, and 3 drilling sites. Diamond = Expedition 348 site, circles = Stage 1, 2 and 3 sites, black stars = 1944 and 1946 earthquake epicenters, yellow arrows = range estimates of plate motion vector between Philippine Sea plate (PHS) and Eurasian plate (EP). PAC = Pacific plate.

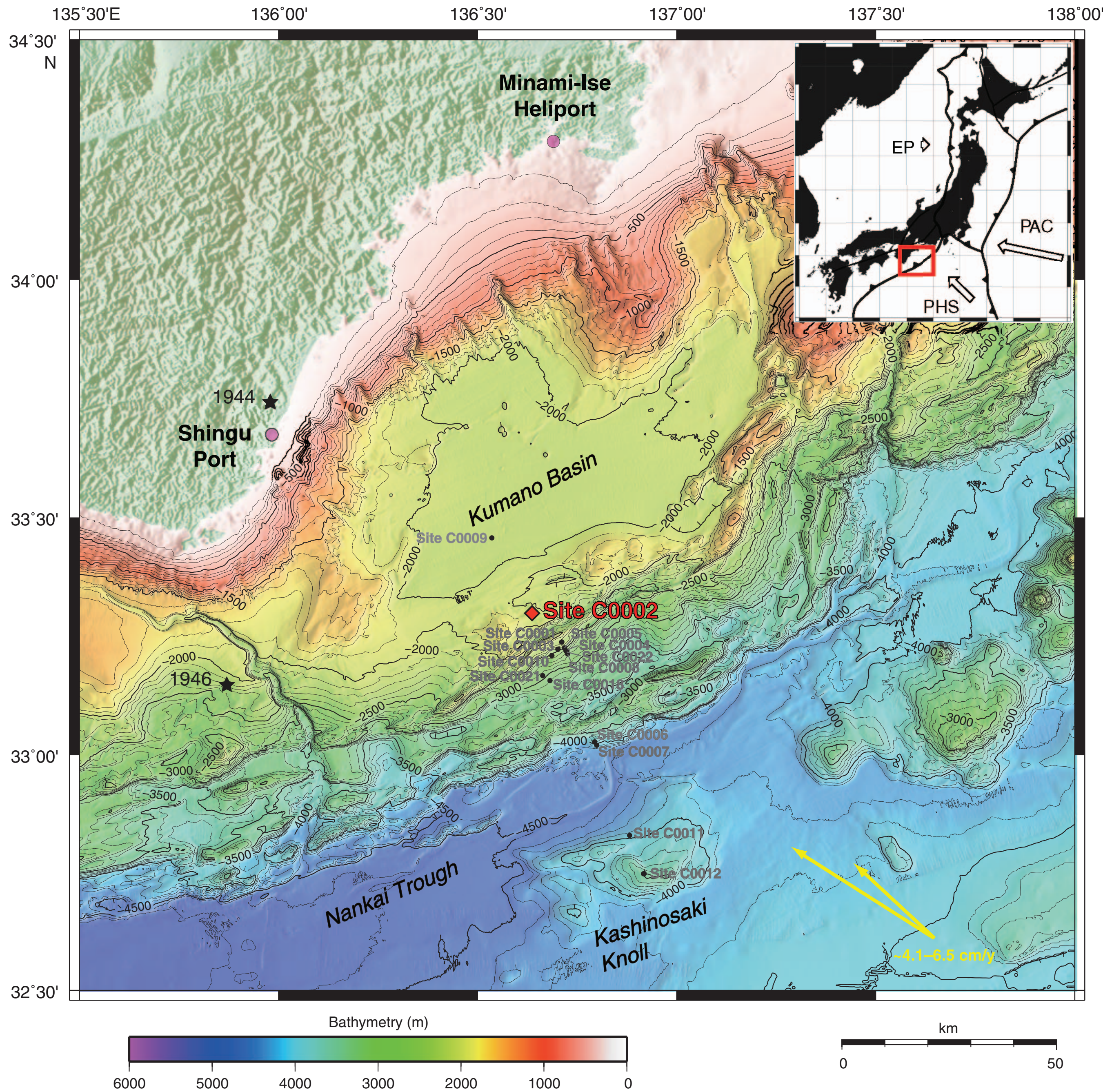


Figure F2. In-line (IL) 2529 extracted from 3-D seismic volume, showing Hole C0002F in relation to Stage 1 Sites C0001, C0003, and C0004. Dashed extension below the colored boxes = future planned oceanic plate basement interception at ~7000 mbsf, red box = 20 inch casing to 860 mbsf; yellow, green, and blue boxes = planned casing set points for $13\frac{3}{8}$ inch, $11\frac{3}{4}$ inch, and $9\frac{5}{8}$ inch casing at 2300, 3600, and 4400 mbsf, respectively. Target depth for Expedition 348 is ~3600 mbsf (possibly to ~4400 mbsf with good conditions), with open hole coring (black) shown from the 2300 mbsf casing shoe (also beyond the planned $9\frac{5}{8}$ inch casing shoe position at 4400 mbsf). VE = vertical exaggeration.

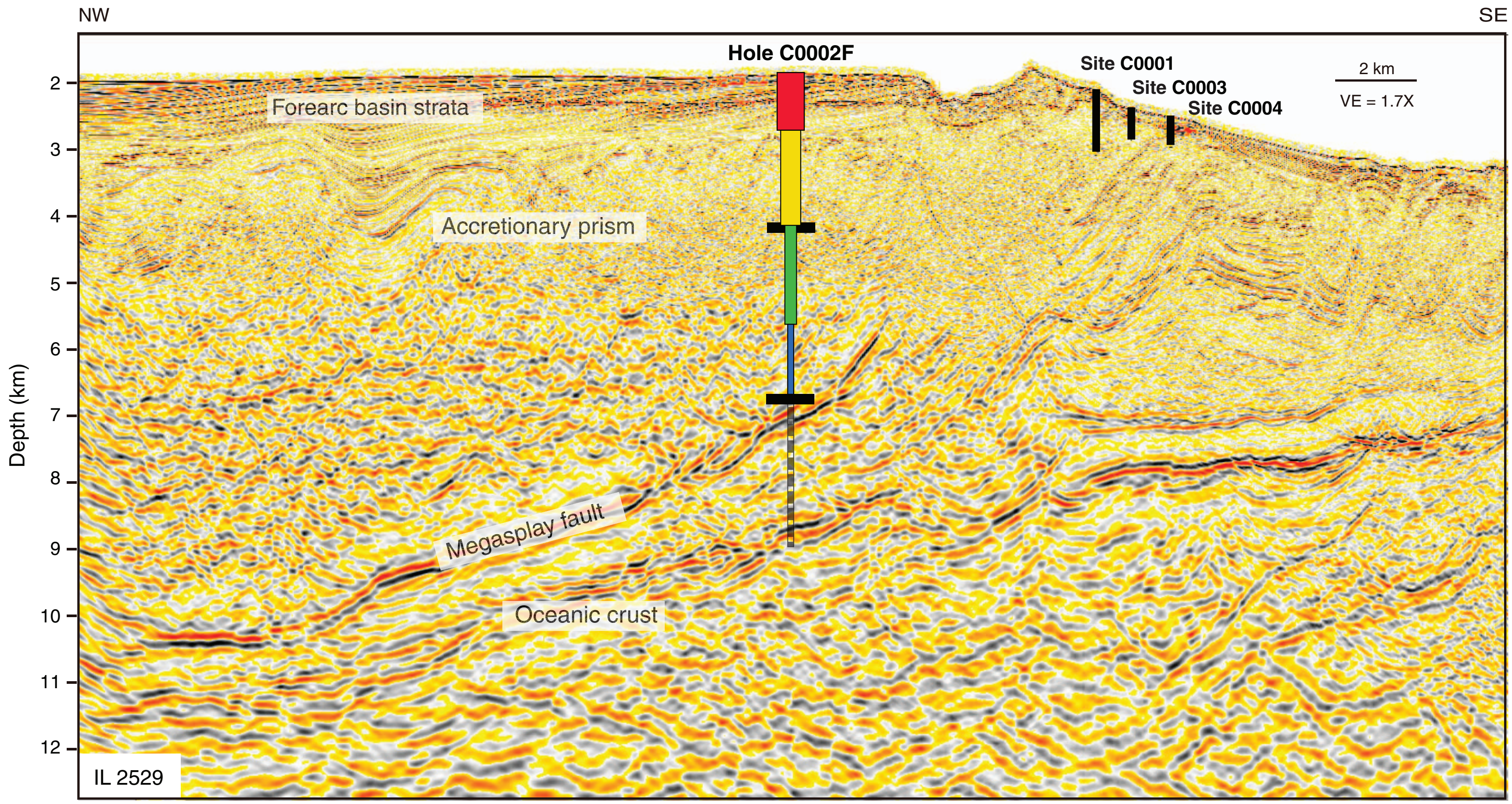


Figure F3. Schematic diagram of planned operations in Hole C0002F. The ultimate total depth of Hole C0002F is planned for ~5200 mbsf, with the megasplay reflector depth (green dashed line) assumed at ~5000 mbsf. Expedition 348 targets are (1) 13⅜ inch casing shoe at 2300 mbsf (red) and either (2A) 11¾ inch casing shoe depth at ~3600 mbsf (red) or (2B) 9⅝ inch casing shoe to ~4400 mbsf (red and black striped). Open hole coring (blue) will extend below the planned casing depth. Future operations include deepening the hole (black) to the top of oceanic crust (blue dashed line) and coring. Green = previously drilled and cased sections. LTBMS = long-term borehole monitoring system, BSR = bottom-simulating reflector, IL = in-line, VE = vertical exaggeration.

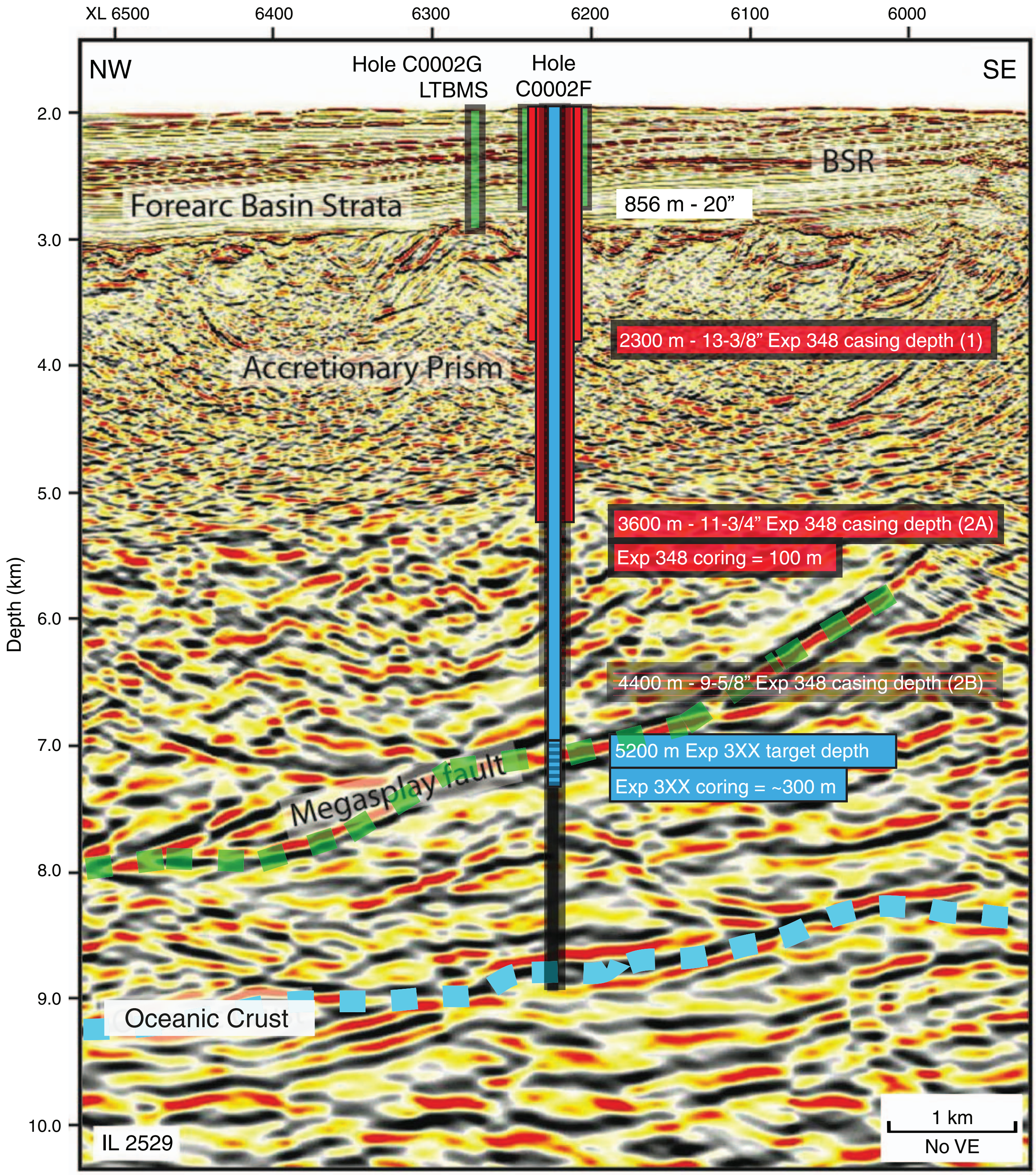


Figure F4. Logging-while drilling (LWD) tools proposed for use during Expedition 348. BHA = bottom-hole assembly, PDC = polycrystalline diamond compact.

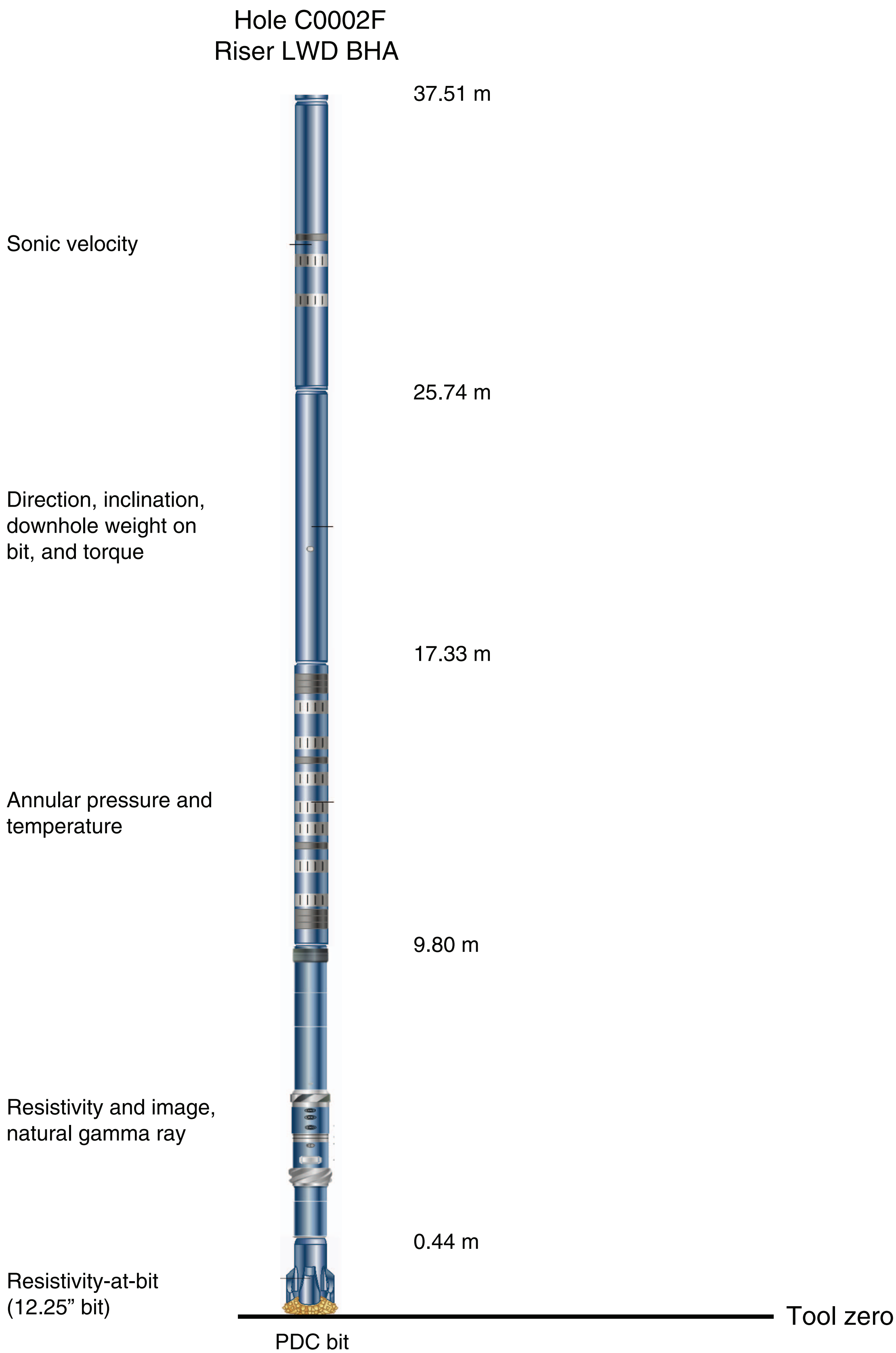


Figure F5. Schematic diagram of proposed core flow (based on Expedition 338). PPE = personal protective equipment, HS = headspace, GC-FID = gas chromatograph–flame ionization detector, HC = hydrocarbon, IW = interstitial water, MBIO = microbiological sample, ASR = anelastic strain recovery, DeepBIOS = deep biosphere sample, CT = computed tomography, WR = whole round, MSCL-W = whole-round multisensor core logger, GRA = gamma ray attenuation, MS = magnetic susceptibility, PWV = *P*-wave velocity, NCR = noncontact resistivity, NGR = natural gamma radiation, MSCL-I = photo image logger, VCD = visual core description, MSCL-C = color spectroscopy logger, SRM = superconducting rock magnetometer, MAD = moisture and density, UCS = unconfined compressive strength, SEM-EDS = scanning electron microscope–energy dispersive spectrometry, GRIND = ground rock interstitial normative determination, ICP-AES = inductively coupled plasma–atomic emission spectroscopy, ICP-MS = inductively coupled plasma–mass spectrometry, IC = ion chromatography, UV = ultraviolet, XRD = X-ray diffraction, XRF = X-ray fluorescence, CA = carbonate analyzer, CHNS = carbon-hydrogen-nitrogen-sulfur analyzer. Black figures = Marine Works Japan Laboratory Technicians, white figures = scientists.

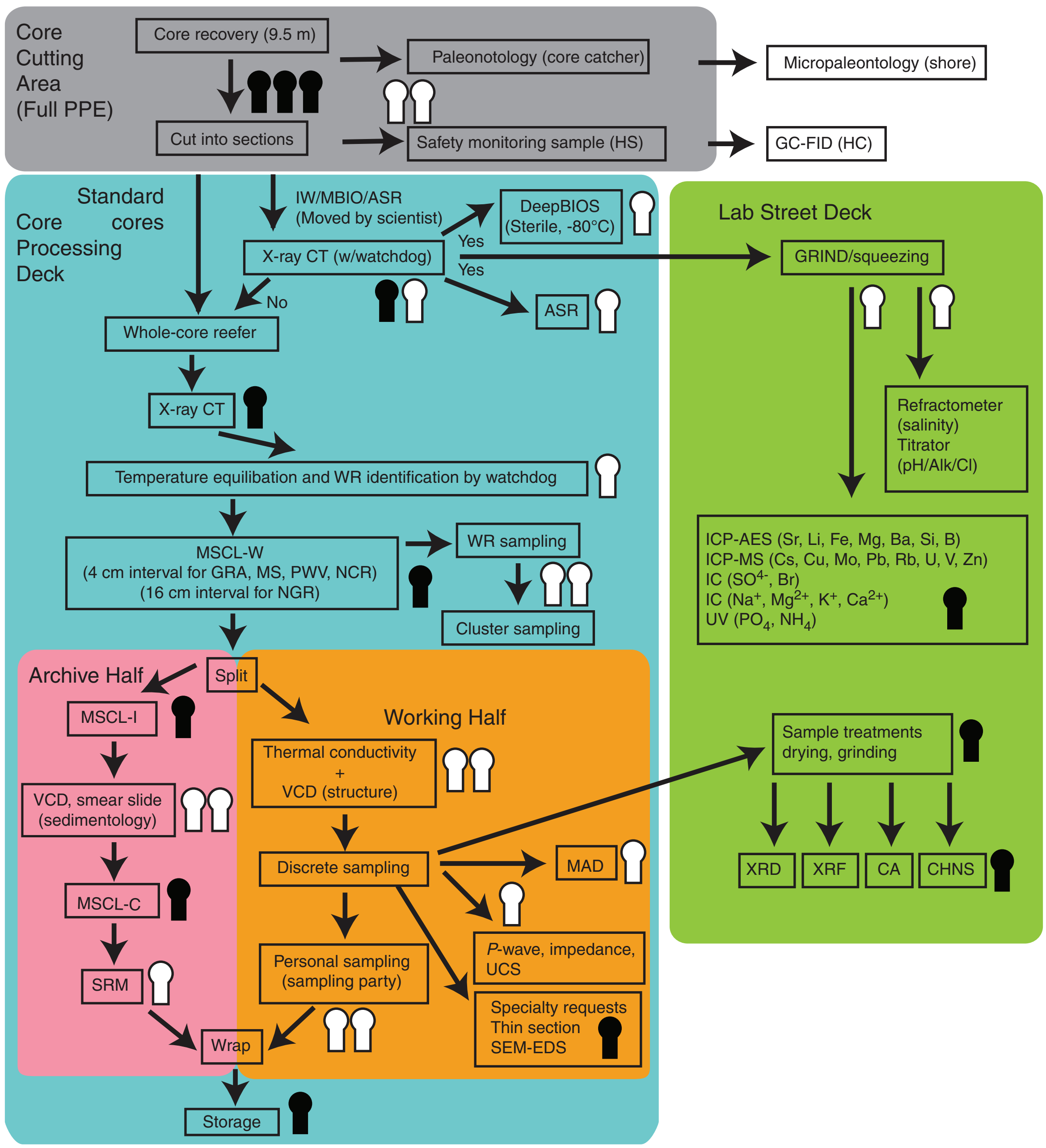
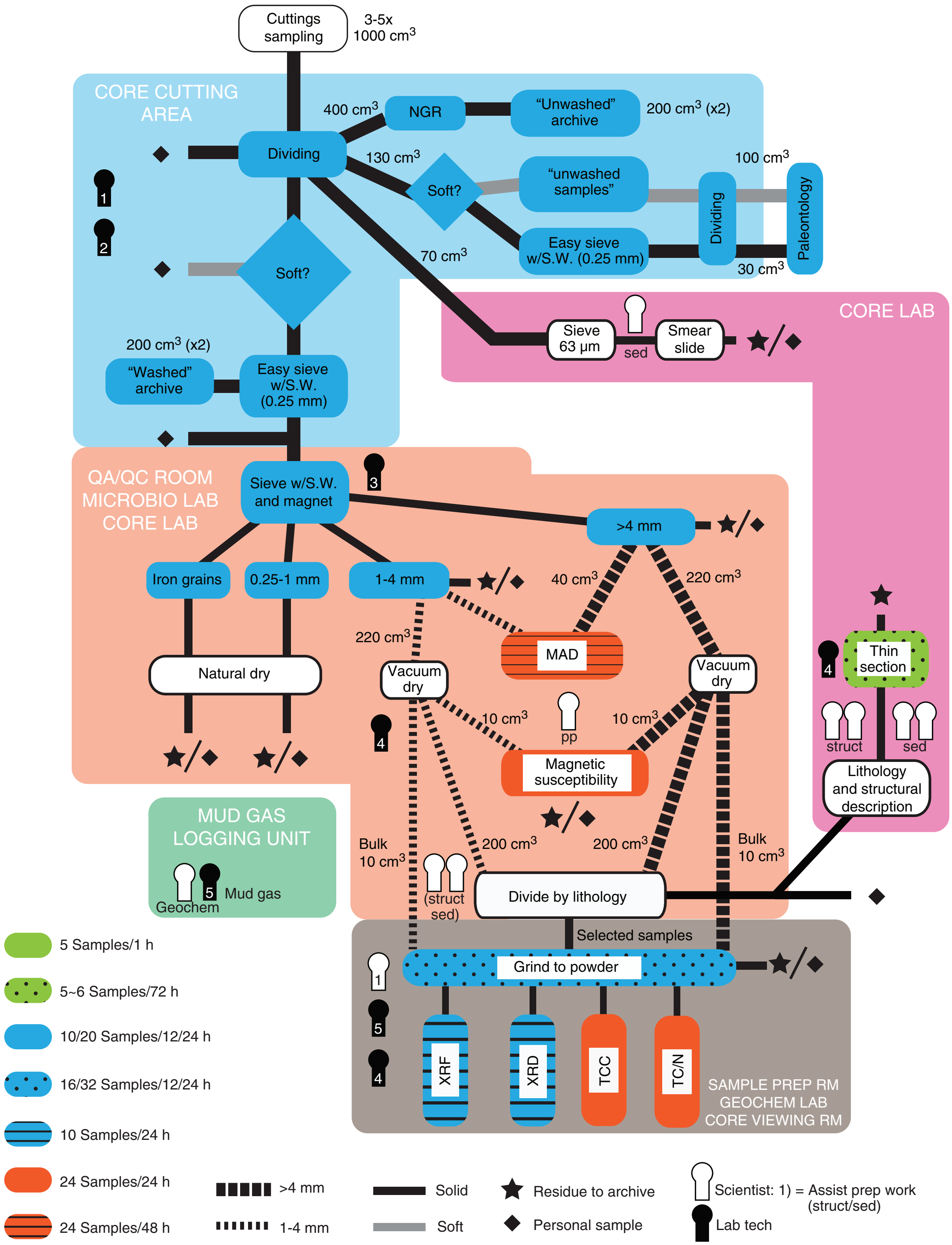


Figure F6. Schematic diagram of proposed cuttings sorting and sampling plan (based on Expeditions 319 and 338). NGR = natural gamma radiation, S.W. = seawater, QA/QC = quality assurance/quality control, MAD = moisture and density, XRF = X-ray fluorescence, XRD = X-ray diffraction, TCC = total carbonate content, TC/N = total carbon/nitrogen.



Site summaries

Hole C0002F

Priority:	Primary: *Chikyu* Expedition 348 (riser)
Position:	33°18.507′N, 136°38.2029′E
Water depth (m):	1968
Target drilling depth (mbsf):	3600
Approved maximum penetration (mbsf):	7000
Survey coverage: (track map; seismic profile):	Extensive data from 3-D seismic data: • In-line 2553 • Cross Line 6228
Objective(s):	• Drill and case hole • Take cuttings and core samples to define lithostratigraphy, physical properties, and composition • Constrain in situ stress and pore pressure • Prepare hole for future expedition
Drilling, coring, and downhole measurement program:	*Chikyu* Expedition 348: • RCB coring (2300–2400 mbsf) • LWD/MWD • Cuttings analysis • Mud gas analysis
Anticipated lithology:	Hemipelagic mud, mudstone, and siltstone/sandstone

Site summaries (continued)

Hole C0010A

Priority:	Contingency: *Chikyu* Expedition 348 (riserless)
Position:	32°12.5981′N, 136°41.1924′E
Water depth (m):	2552
Target drilling depth (mbsf):	600
Approved maximum penetration (mbsf):	550
Survey coverage: (track map; seismic profile):	Extensive survey data from 3-D seismic data: • In-line 2489 • Cross Line 5342
Objective(s):	Recover and replace GeniusPlug
Drilling, coring, and downhole measurement program:	None
Anticipated lithology:	Hemipelagic mud with turbidite sand, sedimentary breccia, and hemipelagic mudstone

Expedition scientists and scientific participants

The current list of participants for Expedition 348 can be found at **www.jamstec.go.jp/chikyu/eng/Expedition/.**