International Ocean Discovery Program
Expedition 380 Scientific Prospectus

NanTroSEIZE Stage 3: Frontal Thrust Long-Term Borehole Monitoring System (LTBMS)

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IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

Publisher's notes

This publication was prepared by the D/V Chikyu Science Operator, the Center for Deep Earth Exploration (CDEX), at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the *JOIDES Resolution* Science Operator (JRSO) at Texas A&M University (TAMU) as an account of work performed under the International Ocean Discovery Program (IODP). Funding for IODP is provided by the following international partners:

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)
Australia-New Zealand IODP Consortium (ANZIC)
Ministry of Earth Sciences (MoES), India
Coordination for Improvement of Higher Education Personnel (CAPES), Brazil

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This IODP *Scientific Prospectus* is based on precruise discussions by the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Project Coordination Team and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists, the Staff Scientist/Expedition Project Manager, and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus.

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Citation

Becker, K., Kinoshita, M., and Toczko, S., 2017. *Expedition 380 Scientific Prospectus: NanTroSEIZE Stage 3: Frontal Thrust Long-Term Borehole Monitoring System (LTBMS).* International Ocean Discovery Program. https://doi.org/10.14379/iodp.sp.380.2017

ISSN
World Wide Web: 2332-1385

August 2017

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 drilling 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.

International Ocean Discovery Program (IODP) Expedition 380 will deploy a permanent long-term borehole monitoring system (LTBMS) in a new cased hole at Site C0006 above the frontal thrust, where previous expeditions have conducted logging-while-drilling and coring operations. This deployment will be the third borehole observatory deployed as part of the NanTroSEIZE program, and it will extend the existing NanTroSEIZE LTBMS network seaward to include the frontal thrust region of the Nankai accretionary prism. This expedition will cover a period of 40 days, beginning on 12 January 2018 and ending on 24 February.

The LTBMS sensors will include seafloor reference and formation pressure sensors, a thermistor string, a broadband seismometer, a tiltmeter, a volumetric strainmeter, geophones, and accelerometers. The casing plan does not include a screened interval for this LTBMS; the monitoring zone will be isolated from the seafloor by a swellable packer (inside the casing) and cement at the casing shoe. This LTBMS will be later linked to the Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) submarine network. This *Scientific Prospectus* outlines the scientific rationale, objectives, and operational plans for Site C0006.

A congruent “NanTroSEIZE Investigation at Sea” will convene researchers aboard the D/V *Chikyu* to use the latest techniques and equipment to reexamine cores, shipboard measurement data (including X-ray computed tomography scans), and logging-while-drilling data collected during NanTroSEIZE Stage 1 in 2007.

Schedule for Expedition 380

The operations schedule for International Ocean Discovery Program (IODP) Expedition 380 is derived from the original Integrated Ocean Drilling Program drilling Proposals 603-CDP3 (cover sheet is available at **https://docs.iodp.org/Proposal_Cover_Sheets/603-CDP3_Kimura_cover.pdf**) and 603D-Full2 (cover sheet is available at **https://docs.iodp.org/Proposal_Cover_Sheets/603D-Full2_Screaton_cover.pdf**). The Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Project Coordination Team (PCT) works with the Japan Agency for Marine-Earth Science and Technology’s (JAMSTEC’s) Center for Deep Earth Exploration (CDEX) to ensure that the scientific targets remaining from the Integrated Ocean Drilling Program are achieved. The overarching goals and implementation strategy are described in Tobin and Kinoshita (2006a, 2006b).

Expedition 380 is the fifth NanTroSEIZE Stage 3 expedition and will focus on installation of an long-term borehole monitoring system (LTBMS) at IODP Site C0006. It is scheduled to begin on 12 January 2018 and end on 24 February at Shimizu port, Japan. Details of the operational schedule and updates to scheduling can be found at **http://www.jamstec.go.jp/chikyu/e/nantroseize/expedition_380.html**. A description of the D/V *Chikyu* and the facilities available on board can be found at **http://cdex-science.jamstec.go.jp/chikyu-wiki/index.php/Main_Page**.

Site C0006 is located at the toe of the accretionary prism (Figure **F1**) near the trench axis of the Nankai Trough off the Kii Peninsula, Japan. Previous drilling at this site included logging while drilling (LWD) to 885.5 meters below seafloor (mbsf) and coring to 603 mbsf during Integrated Ocean Drilling Program NanTroSEIZE Stage I Expeditions 314 (Expedition 314 Scientists, 2009; Figure **F2**) and 316 (Expedition 316 Scientists, 2009; Table **T1**), respectively.

Planned operations during Expedition 380 include

- Riserless drilling to ~495 mbsf at Site C0006 and setting 9⅝ inch casing to ~389 mbsf,
- Running and setting the LTBMS, and
- Conducting a shipboard “NanTroSEIZE Investigation at Sea.”

Further background information about the NanTroSEIZE drilling transect and the goals for the observatory network can be found in IODP Proposal 603D-Full2 (cover sheet is available at **https://docs.iodp.org/Proposal_Cover_Sheets/603D-Full2_Screaton _cover.pdf**).

Introduction

Subduction zones account for 90% of 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. Characterizing fault slip behavior and mechanical state at convergent plate boundaries 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 current earth science. To this end, several recent and ongoing drilling programs have targeted portions of convergent plate boundary faults that have slipped either during large earthquakes, smaller events, or slow earthquakes. These efforts include the San Andreas Fault Observatory at Depth (Hickman et al., 2004), the Taiwan-Chelungpu Drilling Project (Ma, 2005), Integrated Ocean Drilling Program drilling in the Nankai Trough (NanTroSEIZE; Tobin and Kinoshita, 2006a, 2006b) and in the high slip region of the March 2011 Tohoku earthquake (Japan Trench Fast Earthquake Drilling Project [JFAST]; Expedition 343/343T Scientists, 2013; Ito et al., 2013), and the IODP Hikurangi Subduction Margin project (Saffer et al., 2017).

Recent geological studies at the Nankai margin (Sakaguchi et al., 2011; Yamaguchi et al., 2011), direct observational evidence from the 2011 Tohoku earthquake, and new results from both a seafloor cabled network and LTBMS installations ~25–35 km landward of the trench along the NanTroSEIZE transect all suggest that the décollement or frontal thrust are capable of storing and releasing elastic strain and may participate in both periodic slow slip events (SSEs) and megathrust earthquakes. New observations along the drilling transect include a family of repeating SSEs, as well as very low frequency (VLF) earthquakes and tremor. Together, these observations indicate that the shallow megathrust is highly active and may present a greater tendency for coseismic slip than previously recognized. Monitoring of this region is therefore a high priority to detect interseismic strain accumulation and release to better understand outer wedge megathrust processes.

Background

Geological setting of the Nankai Trough

The Nankai Trough is formed by subduction of the Philippine Sea plate to the northwest beneath the Eurasian plate at a rate of ~65 mm/y (Miyazaki and Heki, 2001). The convergence direction is slightly oblique to the trench, and trench wedge turbidites and underlying Shikoku Basin hemipelagic sediments accrete at the deformation front. The Nankai Trough is among the most extensively studied subduction zones in the world. It has been one of the focus sites for studies of seismogenesis by the U.S. MARGINS initiative, the Integrated Ocean Drilling Program, and IODP, based on the wealth of geological and geophysical data available. A better understanding of seismic and tsunami behavior at the Nankai margin is highly relevant for the assessment of their societal impacts in heavily populated coastal areas in the world.

The Nankai Trough region has 1300 y of historical and archaeological records 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 the site of Expedition 380 is located) are now reasonably well understood (Ichinose et al., 2003; Baba et al., 2005). Land-based offshore geodetic studies suggest that the plate boundary thrust is currently strongly locked (Miyazaki and Heki, 2001; Yokota et al., 2016). Similarly, the lower microseismicity near the updip edge of the rupture area of the 1940s earthquakes (Obana et al., 2001) implies significant interseismic strain accumulation on the megathrust.

However, observations of VLF earthquakes and tremor within or just below the accretionary prism in the drilling area (Obara and Ito, 2005; Obana and Kodaira, 2009; Sugioka et al., 2012) demonstrate that interseismic strain is not confined to slow elastic strain accumulation. New observations from two LTBMS systems installed at IODP Site C0010 and Integrated Ocean Drilling Program Site C0002, located ~25–35 km from the trench, reveal repeating SSEs that extend to <25 km from the trench, are accompanied by low-frequency tremor, and recur approximately every 12–18 months (Araki et al., 2017). These SSEs may accommodate as much as 50% of the plate convergence budget, indicating that quasiperiodic accumulation and release of strain on the shallowest megathrust via slow slip plays an important role in the earthquake cycle. Slow slip phenomena, including 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). Seaward of the subduction zone, deformation of the incoming ocean crust is suggested by microearthquakes as revealed through 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. Notably, coseismic slip during events like the 1944 Tonankai earthquake may have occurred on the megasplay fault in addition to the plate boundary décollement (Ichinose et al., 2003; Baba et al., 2006; Sakaguchi et al., 2011). The megasplay fault is therefore a primary drilling target equal in importance to the basal décollement. 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; Yokota et al., 2016). 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, in contrast to the area offshore Cape Muroto (the location of previous scientific ocean drilling), where both local stratigraphic variations associated with basement topography and anomalously high heat flow have been documented (Moore et al., 2001, 2005; Moore and Saffer, 2001). 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 ~4700–6000 m beneath the seafloor (Nakanishi et al., 2002).

Site C0006 was successfully drilled with LWD during Expedition 314 (Figure **F2**) and successfully cored during Expedition 316 (Tobin et al., 2009). Core samples (to 603 m core depth below seafloor [CSF]; Expedition 316 Scientists, 2009) were divided into three lithologic units (Figure **F3**; Table **T1**). Unit I extends from the seafloor to ~27 m CSF and comprises trench to slope transition facies. Unit II is mainly trench deposits, divided into four subunits. Subunit IIA comprises mainly sand-dominated trench wedge deposits, Subunit IIB comprises mixed sand-mud trench wedge deposits, Subunit IIC comprises mud-dominated trench wedge deposits, and Subunit IID comprises deep marine basin to mud-dominated trench transition deposits. Unit III comprises deep marine basin deposits.

Seismic studies and 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), passive seismicity (e.g., Obara et al., 2004), heat flow (Yamano et al., 2003), side-scan sonar, swath bathymetry, and submersible and remotely operated vehicle (ROV) dive studies (Ashi et al., 2002). As a joint project between Japan and the United States in 2006, a 3-D seismic reflection survey was conducted over a ~11 km × 55 km area, acquired by PGS Geophysical, an industry service company (Moore et al., 2009). This 3-D data volume has been used to (1) refine selection of drill sites and targets in the complex plate boundary fault system, (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). These high-resolution, 3-D data were 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 (Figure **F4**). These data were recently reprocessed using newer advanced techniques (Shiraishi et al., 2016; Kinoshita et al., 2017).

The supporting site survey data for Expedition 380 are archived at the IODP Site Survey Data Bank (**http://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P603D or P603CPD for the proposal number).

Borehole observatories

A series of permanent borehole observatories were installed in the NanTroSEIZE transect, beginning with Site C0002 (Expedition 332; Expedition 332 Scientists, 2011) and Site C0010 (Expedition 365; Kopf et al., 2017). Expedition 380 will extend this array to Site C0006 (Figure **F1**). This transect includes locations within and above regions of contrasting behavior of the megasplay fault zone and plate boundary as a whole. Note that recent studies and discussion suggest that the "megasplay" below Site C0002 is more likely to be the active plate boundary (which can mechanically connect either to the décollement or to the shallow out-of-sequence trusts), whereas the underlying reflector (top of oceanic crust) is probably not active (see Moore et al., 2007; Strasser et al., 2009). The observatory sites include a site above the updip edge of the "locked" zone (Site C0002), a shallow site in the splay fault zone and its footwall side (Site C0010), and a site at the tip of the accretionary prism (this expedition; Site C0006), motivated by observed slip in the 11 March 2011 Tohoku earthquake, indicating that at some margins coseismic rupture may propagate along the late boundary all the way to the trench (e.g., Fujiwara et al., 2011). The importance of the last is emphasized by newly observed repeating slow slip events within <25 km of the trench (Araki, et al., 2017). The suite of NanTroSEIZE observatories has the potential to capture in unprecedented detail seismic and microseismic activity, slow slip, and interseismic strain accumulation across a transect from the near trench to the seismogenic zone. Such temporally continuous and spatially distributed observations are necessary to understand how each part of the plate boundary functions through the seismic cycle of megathrust earthquakes.

The planned observation system for Site C0006 consists of an array of sensors designed to monitor slow crustal deformation (e.g., strain, tilt, and pore pressure as a proxy for strain), seismic events including VLF earthquakes, hydrologic transients associated with strain events, ambient pore pressure, and temperature. To ensure the long-term and continuous monitoring necessary to capture events that occur over a wide range of timescales, the borehole observatory will be connected to a submarine cabled observation network called Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) (**http://www.jamstec.go.jp/donet/e**) after the drilling expedition in order to provide power and allow for higher sampling rates than can be achieved in a standalone mode (Kopf et al., 2017). The Site C0002 and C0010 LTBMSs are already connected to this network, and the data can be viewed and downloaded at two open-access observatory data portals (**http://join-web.jamstec.go.jp/join-portal/en** and **http://offshore.geosc.psu.edu/about**).

Specific Expedition 380 scientific plans

Prior results at Site C0006

The primary plan for Expedition 380 is to drill a new 9⅞ inch hole to 495 mbsf at Site C0006, install 9⅝ inch casing to 398 mbsf, and install the LTBMS. This site was originally drilled during Expedition 314 with measurement while drilling/LWD to 885.5 mbsf in two holes and was cored in four holes during Expedition 316 to a maximum of 409.4 mbsf.

The Expedition 314 science party identified four primary logging units (Figure **F2**), based on differing trends and LWD log responses (Expedition 314 Scientists, 2009). Logging Unit I (0–197.8 m LWD depth below seafloor [LSF]) was interpreted as sandy and muddy deposits. Logging Unit II (197.8–428.3 m LSF) was interpreted as mud with occasional thick sand layers; the base of Unit II was interpreted as a possible fault zone. Logging Unit III (428.3–711.5 m LSF) was identified as alternating beds of mud and sand and is divided into two subunits. Logging Unit IV (711.5 m LSF to total depth) was interpreted as underthrust, coarse, trench-fill sediments. The main frontal trust was identified by a sudden decrease in gamma ray values (from ~90 to 20–50 gAPI) across the Unit III/IV boundary.

The Expedition 316 science party identified three lithologic units (Figure **F3**; Table **T1**) from Site C0006 core examination (Expedition 316 Scientists, 2009). Unit I (0–27.2 m CSF) comprises trench to slope deposits dominated by greenish gray silty clay containing clay, feldspar, lithic fragments, vitric fragments, and calcareous nannofossils. Unit II (27.2–406.95 m CSF in Hole C0006E; 395.0–449.7 m CSF in Hole C0006F) is trench deposits. Unit II is divided into four subunits, mainly based on variations in silt and sand content (a general coarsening upward with progressive increase in sand and silt upsection), with no real correlation between cores and subunit divisions. Numerous thrust faults cause significant repetition of sequences. Subunit IIA (Hole C0006E; 27.2–72.1 m CSF) contains mainly sand-dominated trench wedge deposits. Subunit IIB (Hole C0006E; 72.1–163.3 m CSF) is mixed sand-mud trench wedge deposits composed of almost equal abundances of fine-grained sand, silty sand, and silty clay. Subunit IIC (Hole C0006E; 163.3–391.3 m CSF) is mud-dominated trench wedge deposits primarily composed of greenish gray silty clay. Subunit IID (391.3–406.5 m CSF in Hole C0006E; 395.0–449.7 m CSF in Hole C0006F) comprises deep marine basin to mud-dominated trench transition deposits. Unit III (Hole C0006F; 449.7–603.0 m CSF) is deep marine basin deposits composed of greenish gray to grayish silty clay with some interbedded volcanic tuff and shows a transition from Pleistocene to late Miocene.

Site C0006 observatory design

Site C0006 will be the third LTBMS installation during NanTroSEIZE. The observatory will be equipped with (1) pressure sensors, (2) a strainmeter, (3) a broadband seismometer, (4) a tiltmeter, (5) geophones, (6) accelerometers, (7) a thermistor string, and (8) an acoustic modem. The LTBMS will be deployed into a cased borehole (no screened intervals), with the main sensor carrier and strainmeter (Figure **F5**) positioned below 400 mbsf in a zone that LWD data (Figure **F2**) indicates is relatively homogeneous and with pore pressure access to the formation in the open hole below the strainmeter. The pressure sensors will operate in standalone mode with data loggers via battery power. Pore pressure will be monitored (1) in the formation via hydraulic tubing extending through the cemented strainmeter and instrument carrier interval to the open hole and (2) at the seafloor to provide a reference pressure necessary to remove common mode noise due to tidal and other oceanographic forcing. The LTBMS will be fitted with an acoustic modem for data transmission until the observatory is linked to the DONET network during a future JAMSTEC cruise.

Drilling strategy and operations plan

The primary operations drilling plan and time estimate (Table **T2**) for Expedition 380 is to drill and case a new riserless hole at Site C0006 for the LTBMS installation. Previous LWD logs, coring records, and seismic images were used to determine casing shoe depth and identify a suitable lithologic interval for setting and cementing the sensor carrier and related instruments (Figure **F5**). There are no plans for either new LWD drilling or coring during this expedition. Connection of the LTBMS to the DONET undersea cabled network is currently planned for ~2 months after the drilling expedition. Once the LTBMS is successfully deployed, the expedition will end. There are no contingency operations planned.

Expedition scientists and scientific participants

The current list of participants for Expedition 380 can be found at **http://www.jamstec.go.jp/chikyu/e/nantroseize/expedition_380.html**.

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Table T1. Summary of lithologic units, Holes C0006E and C0006F. From Expedition 316 Scientists (2009).

Unit	Hole, core, section, interval (cm) Top	Hole, core, section, interval (cm) Bottom	Depth CSF (m) Top	Depth CSF (m) Bottom	Thickness (m)	Stratigraphic age	Lithologic description	Processes of formation
	316-	316-						
I	C0006E-1H-1, 0	C0006E-4H-3, 20	0.00	27.23	27.2	Pleistocene	Nannofossil-bearing mud, interbedded sand layers, and a volcanic ash layer near the base	Hemipelagic settling, turbidites, and a volcanic ash layer
IIA	C0006E-4H-3, 20	C0006E-12H-2, 10	27.23	72.06	44.8	Pleistocene	Thick to thin sands with thin interbedded nannofossil-bearing mud layers and a volcanic ash layer	Turbidites, hemipelagic settling, and a volcanic ash layer
IIB	C0006E-12H-2, 10	C0006E-24X-1, 0	72.06	163.33	91.3	Pleistocene	Sands interbedded with nannofossil-bearing mud, rare volcanic ash layers	Turbidites, hemipelagic settling, and rare volcanic ash layers
IIC	C0006E-24X-1, 0	C0006E-48X-1, 0	163.33	391.33	228	Pleistocene	Mud with sand/silt layers and rare volcanic layers	Hemipelagic settling, thin-bedded turbidites, and rare volcanic ash falls
IID	C0006E-48X-1, 0	C0006F-7R-CC, 33.5	391.33	449.67	58.3	Pleistocene	Mud with volcanic ash layers and rare thin silt layers	Hemipelagic settling, volcanic ash layers, and rare thin-bedded turbidites
III	C0006F-7R-CC, 33.5	C0006F-23R-CC, 21	449.67	603.00	153.3	Pleistocene to Miocene	Mud with tuff layers	Hemipelagic settling and rare volcanic ash layers

Table T2. Expedition 380 operations plan and schedule. BRT = below rotary table. PDM = positive displacement motor, BHA = bottom-hole assembly, UWTV = underwater television, POOH = pull out of hole, RIH = run in hole.

Operation	Start depth (mbsf)	Start depth BRT (m)	Days	Subtotal (days)	Total (days)
Transit and deploy transponders					
Transit from Shimizu to Site C0006	0	3902	1.0		
Deploy transponders, preparation	0	3902	1.0	2.0	2.0
Jet-in 20 inch casing to 56 mbsf					
Run 20 inch casing with PDM BHA in low-current area	0	3902	2.0		
Jetting 20 inch casing to 56 mbsf	56	3958	1.0		
Run UWTV and release drill-ahead tool	56	3958	2.0	5.0	7.0
Drill ahead 12-1/4 inch hole to 399 mbsf					
Drill ahead to 399 mbsf	399	4301	2.0		
POOH to surface	399	4301	2.0	4.0	11.0
Run 9-5/8 inch casing to 389 mbsf					
Make up and run 9-5/8 inch casing	399	4301	2.0		
Cementing	399	4301	1.0		
POOH to surface	399	4301	1.0	4.0	15.0
Drill out cement and drill 9-7/8 inch with bicenter bit to 495 mbsf					
Make up and RIH drill out cement assembly	399	4301	1.0		
Drill to 495 mbsf	495	4397	1.0		
Spot protect zone	495	4397	0.5		
POOH to surface	495	4397	1.0	3.5	18.5
Run 9-5/8 inch casing scraper					
Make up and run 9-5/8 inch scraper assembly	495	4397	1.5		
POOH to surface	495	4397	1.0	2.5	21.0
Run completion					
Make up and run 3-1/2 inch tubing	495	4397	7.0		
Run completion assembly	495	4397	2.0		
Run UWTV, reenter hole, and set completion assembly	495	4397	1.0		
Cementing	495	4397	1.0		
POOH to surface	495	4397	1.0	12.0	33.0
Recover transponders	495	4397	2.0	2.0	35.0
Transit to Shimizu					
Transit from site to Shimizu	495	4397	1.0	1.0	36.0
Contingency					
Mechanical downtime, wait on weather, etc.	495	4397	4.0	4.0	40.0
				Total days:	43.0

Figure F1. Map showing location of Site C0006 (solid red circle). Red-outlined circles = LTBMS Sites C0002 and C0010. Inset shows region in relation to Japan. Yellow arrows = computed far-field convergence vectors between Philippine Sea plate and Japan (Seno, 1993; Heki, 2007).

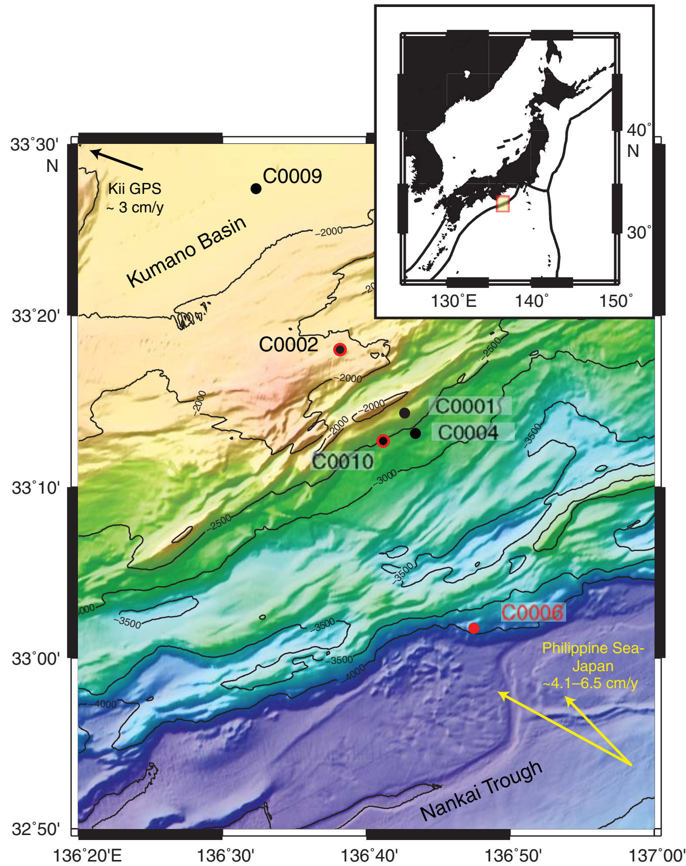

Figure F2. Summary LWD diagram, Expedition 314 Site C0006. From Expedition 314 Scientists (2009). LSF = LWD depth below seafloor. VE = vertical exaggeration. From top to bottom, blue symbols on In-line 2435 indicate planned depths of reference (hydrostatic) pressure sensor, packer, sensor carrier, and pressure Sensor 1. Black tadpoles = bedding, red tadpoles = fracture, tadpole line = dip direction of plane.

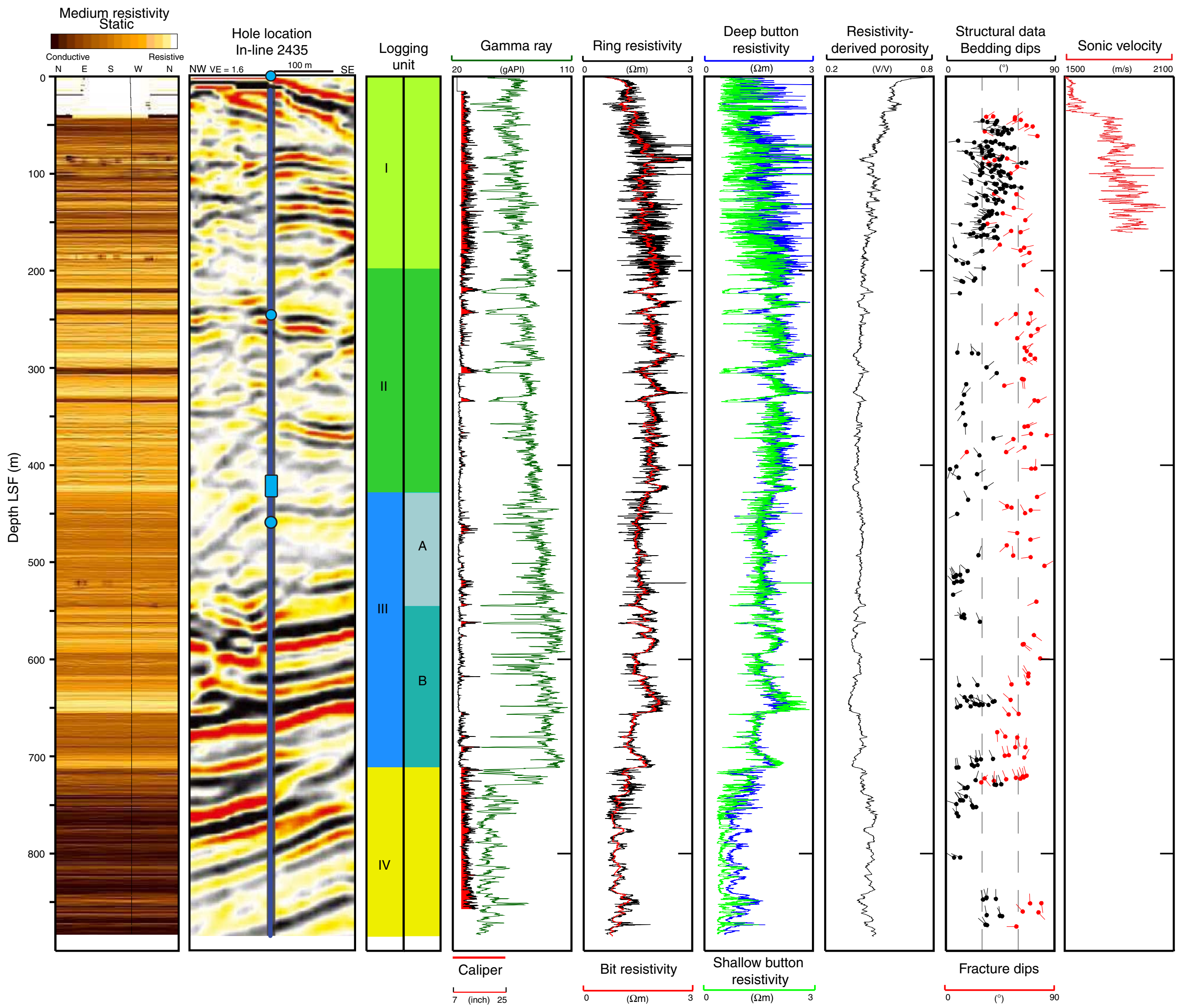

Figure F3. Expedition 316 Site C0006 summary results. From Screaton et al. (2009). WR = whole round. From top to bottom, blue symbols in recovery column indicate planned depths of reference (hydrostatic) pressure sensor, packer, sensor carrier, and pressure Sensor 1.

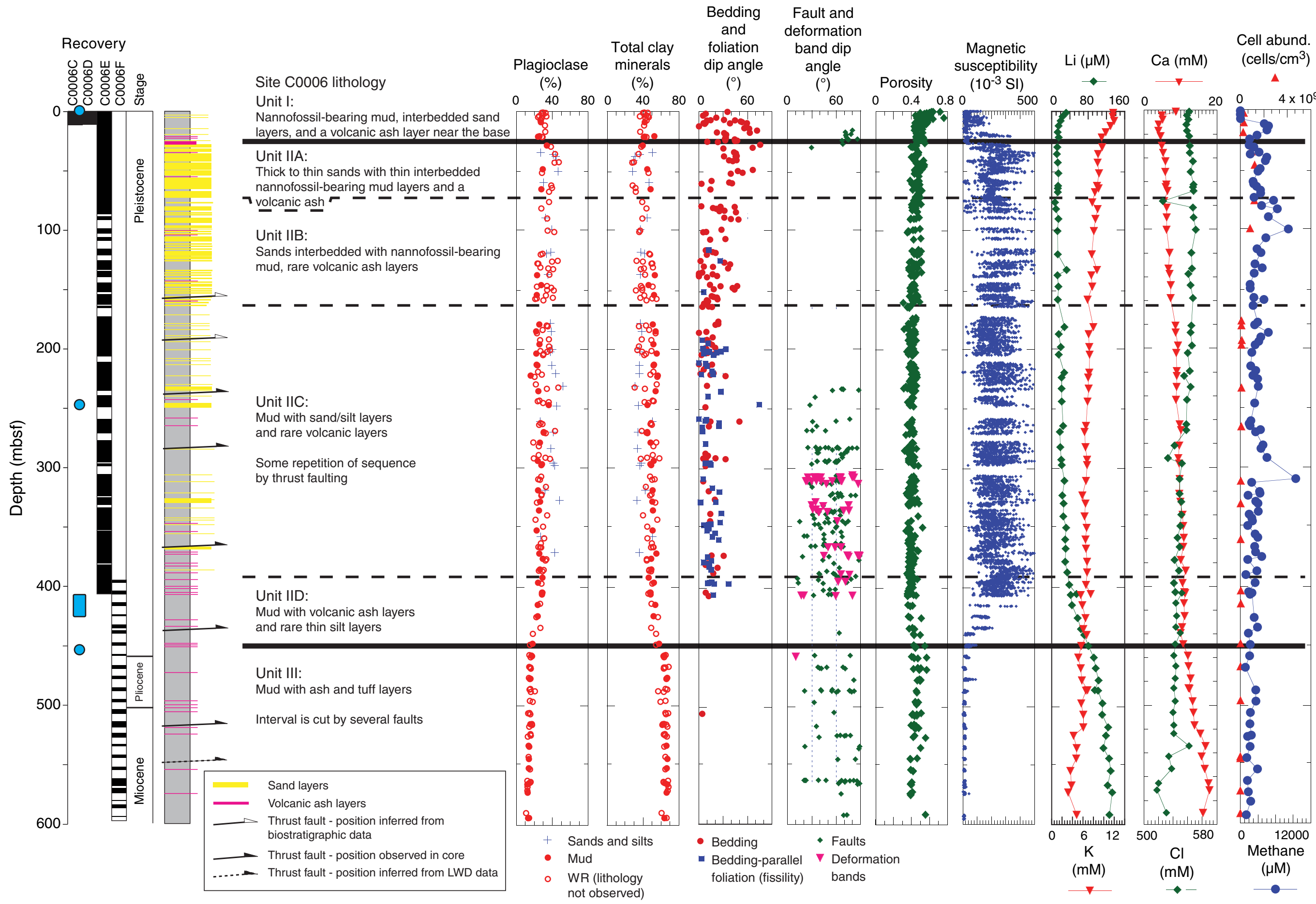

Figure F4. Interpreted seismic reflection depth section (In-line 2435) around Sites C0006 and C0007, based on integrated interpretation of core and log data from the boreholes with the seismic imaging. P/P = Pleistocene/Pliocene boundary, P/M = Pliocene/Miocene boundary.

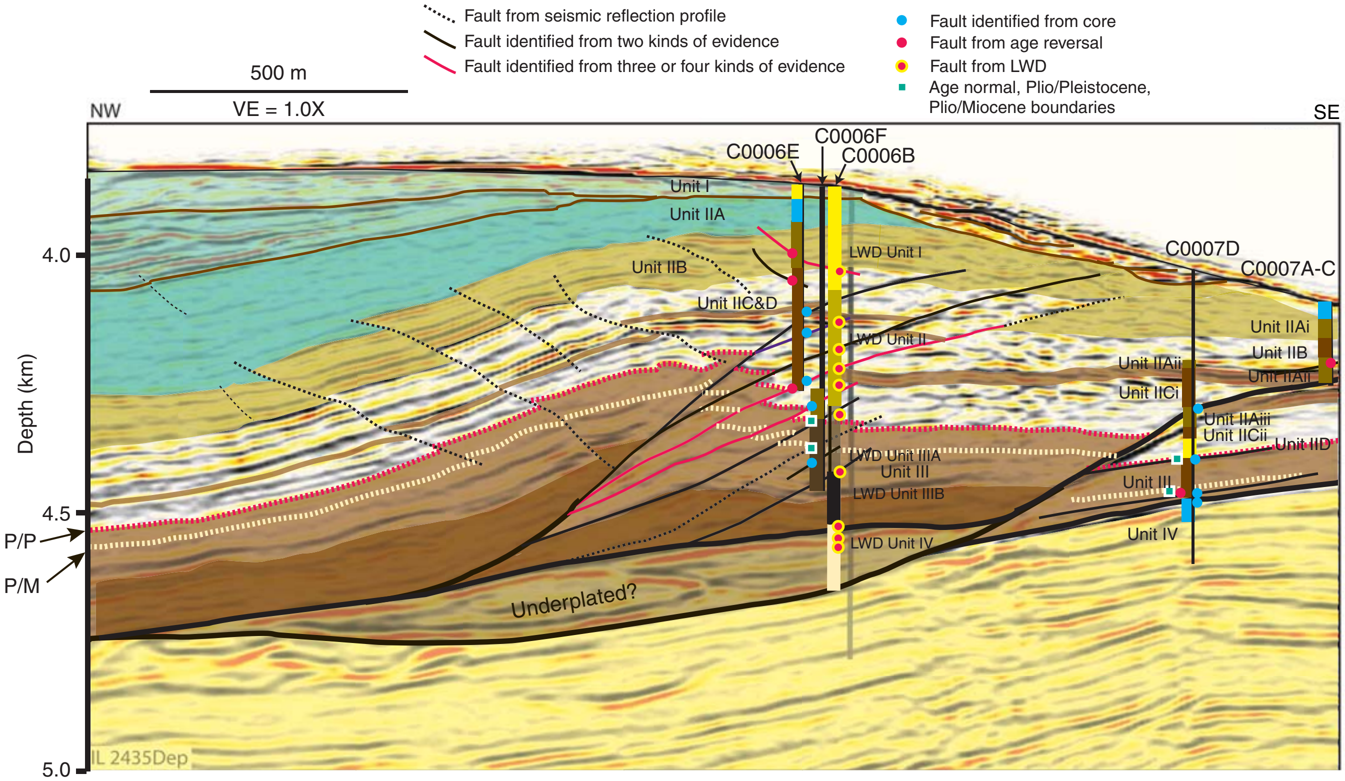

Figure F5. Diagram of Site C0006 LTBMS with depth targets for total depth, sensors, and casing. BRT = below rotary table. TBD = to be determined.