International Ocean Discovery Program
Expedition 358 Scientific Prospectus

NanTroSEIZE Plate Boundary Deep Riser 4: Nankai seismogenic/slow slip megathrust

Harold Tobin
NanTroSEIZE Chief Project Scientist
Department of Geoscience
University of Wisconsin-Madison
USA

Masataka Kinoshita
NanTroSEIZE Project Coordination Team Member
University of Tokyo
Earthquake Research Institute
Japan

Gaku Kimura
NanTroSEIZE Chief Project Scientist
Department of Marine Environment and Resources
Tokyo University of Marine Science and Technology
Japan

Sean Toczko
NanTroSEIZE Project Coordination Team Member
Center for Deep Earth Exploration
Japan Agency for Marine-Earth Science and Technology
Japan

Lena Maeda
NanTroSEIZE Project Coordination Team Member
Center for Deep Earth Exploration
Japan Agency for Marine-Earth Science and Technology
Japan

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)

Portions of this work may have been published in whole or in part in other IODP documents or publications.

This IODP *Scientific Prospectus* is based on precruise *JOIDES Resolution* Facility advisory panel discussions 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.

Disclaimer

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

Copyright

Citation

Tobin, H., Kimura, G., Kinoshita, M., Toczko, S., and Maeda, L., 2018. *Expedition 358 Scientific Prospectus: NanTroSEIZE Plate Boundary Deep Riser 4: Nankai Seismogenic/Slow Slip Megathrust*. International Ocean Discovery Program. https://doi.org/10.14379/iodp.sp.358.2018

ISSN
World Wide Web: 2332-1385

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.

Site C0002 is 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 Integrated Ocean Drilling Program Expeditions 314 (logging while drilling [LWD] to 1401.5 mbsf), 315 (coring to 1057 mbsf), 338 (LWD to 2005 mbsf and coring to 1120 mbsf), and 348 (LWD to 3058.5 mbsf, with limited coring from 2163-2218.5 mbsf).

International Ocean Discovery Program (IODP) Expedition 358 aims to reach and sample the megasplay fault/plate boundary fault at Site C0002 by extending the riser borehole (Hole C0002P) established during previous Integrated Ocean Drilling Program NanTroSEIZE expeditions. Evidence suggests that the drilling target at the megasplay will reach a region where megathrust seismogenic processes are active. A new borehole will be "kicked off" from Hole C0002P and will be extended to ~5000 meters below seafloor (mbsf) and then across the high-amplitude seismic reflector identified as the main plate boundary fault. Continuous LWD with drilling mud gas analysis and limited coring at the anticipated plate boundary fault depth, will leave the cased borehole completed at ~5200 mbsf. A suite of analyses on cuttings, mud gases, and limited cores will 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.

The main scientific objective is to log and sample the hanging wall, the fault zone, and into the footwall. The main contingency plan is to leave a cased borehole in good condition for future installation of a long-term borehole monitoring system (LTBMS). These operations will extend drilling conducted during Integrated Ocean Drilling Program Expeditions 326, 338, and 348. The entire expedition will cover a period of 164 days, beginning on 7 October 2018 and ending on 21 March 2019.

Summary of planned operations

International Ocean Discovery Program (IODP) Site C0002 (Figure **F1**) is the deep centerpiece of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Project (Tobin and Kinoshita, 2006; Tobin, Hirose, Saffer, Toczko, Maeda, Kubo, and the Expedition 348 Scientists, 2015), intended to access the plate interface fault system at a location where it is believed to be capable of seismogenic locking and slip and to have slipped coseismically in the 1944 Tonankai earthquake (e.g., Ichinose et al., 2003). This drilling target is also in close proximity to the location where a cluster of very low frequency (VLF) seismic events and the first tectonic tremor recorded in any accretionary prism setting was found (summarized in Obara and Kato, 2016), all of which suggest fault processes related to the updip limit of megathrust seismogenic mechanics are active here.

Previous major riser drilling efforts during IODP Expeditions 338 and 348 advanced the main riser hole at Site C0002 (Hole C0002F/N/P) to 3058.5 meters below the seafloor (mbsf), and casing was installed in that hole to 2922.5 mbsf (Figure **F2**). Extensive downhole logging data, continuously sampled drill cuttings, and limited intervals of core were collected during those expeditions, and the results are documented in Strasser, Dugan, Kanagawa, Moore, Toczko, Maeda, and the Expedition 338 Scientists (2014) and Tobin, Hirose, Saffer, Toczko, Maeda, Kubo, and the Expedition 348 Scientists (2015), which include details of the discoveries at this site so far.

The objectives of the upcoming planned Expedition 358 operations are to extend Hole C0002P to and across the high-amplitude seismic reflector we believe to be the main plate boundary fault at approximately 5000 mbsf (±200 m), crossing and sampling the main fault plane reflector (the "megasplay" fault), completing the hole, and installing casing at a final total vertical depth of ~5200 mbsf. The principal strategy is to rely on drilling with continuous real-time logging while drilling/measurement while drilling (LWD/MWD), analysis of drill cuttings and mud gases, a series of downhole measurements and tests, and a very limited coring program of ~100 m or as much as time allows. The hole will start by "kicking off" from the previous casing depth of 2922.5 mbsf and then sidetrack drill and case incrementally with three new casing strings. The planned final configuration is to leave the hole cased and capped but without a permanent long-term borehole monitoring system (LTBMS) installed.

The main scientific objective is to log and sample the hanging wall, the presumed fault zone, and up to ~50 m of the footwall of this structure, which is believed to be the main active detachment zone of the plate boundary within the accretionary prism. Additional key objectives include drilling through the overlying lower accretionary prism interval with LWD and cuttings analysis. The contingency plan's emphasis is on achieving as much of the total depth objective as possible and leaving the hole in good condition for future use, and the use of time will be optimized for that. Should additional time become available as the expedition proceeds, the focus will be on conducting more coring.

The expedition is currently scheduled to take place from 7 October 2018 through 21 March 2019 (164 days). The riser drilling operations are complex and time-intensive, but the coring plan is severely limited, so a standard scientific party will not be on board for the entire expedition.

Summary of planned operations (Table **T1**) for Expedition 358:

- Employing riser drilling technique, kick-off from at or above the existing 11¾ inch casing shoe at 2922.5 mbsf (Figure **F3**) and open new hole to ~5200 mbsf or the maximum achievable depth within time and budget limits, setting 9⅝ inch (expanded to 11¾ inch), 9⅜ inch steel liner, and 7⅝ inch (expanded to 9⅜ inch) to ~4700 mbsf and open-hole drilling with a 8½ inch diameter below that to total depth.
- Use a suite of LWD/MWD tools and measurements to be determined, but which are anticipated to include gamma, sonic, and resistivity logs and images; downhole fluid pressure while drill-

ing; and others. Sample and analyze lithology, physical properties, and geochemistry of cuttings from the entire drilled interval at a suitable spacing (nominally every 5 m).
- At casing set points and other opportunities, conduct downhole tests: formation integrity test (FIT), extended leak-off tests (XLOT), leak-off tests (LOT), and other formation tests to evaluate the in situ stress, pore fluid pressure, permeability, and rock strength conditions.
- Core about 100 m: ~50 m from 4650 mbsf and ~50 m from 5150 mbsf or at a depth selected as we penetrate the fault zone.

Anticipated geology and conditions

The primary drilling plan for Expedition 358 is to extend Hole C0002F/N/P by ~2000 m vertically through riser drilling with the D/V *Chikyu*. Based on findings from previous expeditions, the material from 3000 to 5000 mbsf is anticipated to be increasingly well lithified and potentially metamorphosed deep-water mudrocks (derived from original pelagic, hemipelagic, and turbiditic sediments): siltstones, sandstones, and claystones, variably cemented. Samples from the overlying interval between 2000 and 3000 mbsf were bedded and well-lithified mudstones, variably deformed cemented, and commonly dipping steeply (45°–90°) to the northwest. Seismic velocity analysis of wide-angle refraction data and 3-D seismic reflection data (Kamei et al., 2012; Tsuji et al., 2014; Shiraishi et al., unpubl. data) all suggest that between ~4000 and 5000 mbsf, the hanging wall has a zone of high seismic velocity up to ~5 km/s, suggesting a "slab" of strong, low porosity material is present. Beneath this high-velocity zone is a rapid reduction of velocity with depth, presumably forming the impedance contrast associated with the strong negative-polarity reflector at the fault zone. Crossing this boundary is the principal target for drilling.

Near the maximum planned depth, the main target for coring and log acquisition is the lowermost portion of the hanging wall, the fault zone itself, and into the footwall, which we anticipate will be marked by a pronounced velocity inversion and other log-detected features, as well as possible (though not certain) lithologic contrasts. The pore pressure regime in the fault zone and footwall may also be markedly different from that in the hanging wall. The region surrounding the reflector is expected to be dominated by brittle fault zone structures and complex lithologic architecture typical of large offset plate boundary fault zones. We will prioritize taking the maximum number of cores possible in this zone but will likely be severely limited by time constraints.

In summary, Site C0002 drilling during Expedition 358 aims to access a subduction plate boundary fault system and its wall rocks at likely seismogenic depths for the first time anywhere, testing hypotheses for the mechanics and geological/geochemical evolution of these megathrust faults and determining the cause of the prominent seismic reflector. Additionally, it will shed light on the nature of accretionary prism formation and evolution, underplating processes, and other open questions in active margin tectonics. At the end of this expedition, the borehole will be suspended for possible future reentry and installation of instrumentation. No permanent LTBMS is planned for Expedition 358.

Scientific staffing needs

This expedition is planned for more than 5 months at sea, with variable needs for real-time scientific analysis of the limited samples and log data and considerable uncertainty in the timing of specific operations during the offshore period. Therefore, it will not be staffed in the standard expedition Shipboard Scientific Party model.

A series of time windows for different scientific expertise needed on board will be developed (Table **T2**), with contingency for operational schedule changes. The Leadership Team (similar to Co-Chief Scientists and the Expedition Project Managers) will identify members of the science party to embark as needed, potentially for periods of as little as a week or two to over a month. Scientists will be asked to commit to potential time windows during the expedition (not the entire time) when they may be asked to go on board on short notice, rather than given a fixed schedule.

We solicit applicants for the scientific party who can commit to two activities:

1. Making themselves available for time windows of 2–3 months, during which they will likely be asked to board the *Chikyu* for one or more 2-4 week "shifts." The shipboard tasks of cuttings, log, and downhole experiment analysis will take place in these concentrated efforts during the expedition. The exact timing of these boarding periods for shipboard team work (within the broader time windows) will be determined by the science leadership team as operations develop. Members of the scientific party will be asked to maintain flexible schedules to accommodate this need. For the expedition, the science leadership will form teams based on scientific specialty to board for up to two shifts.
2. Participating in a final analysis and sampling meeting at the end of the entire expedition (anticipated to require several weeks in March or April of 2019). All members of the scientific party will be expected to participate.

Participants will require helicopter underwater escape training (HUET) certification from an approved OPTIO training center. Costs for this certification will be the responsibility of each participant's Program Member Office (PMO), where applicable.

Scientists with interest and expertise in fault zone structure and mechanics, accretionary complex geology and evolution, lithostratigraphy, physical and hydrogeological properties, diagenetic/metamorphic processes and effects, micropaleontology, microbiology, rock magnetism, and core-log-seismic integration (CLSI) in structurally complex settings are all invited to apply. Because of the nature of the drilling operation and need for near-real-time analysis, expertise in the use of drill cuttings, mud gas, and modern well logging to address sedimentary petrology, structure, physical properties, and geomechanics are all especially useful.

A total science party size of ~30 scientists, organized into five teams of about six scientists each, is anticipated.

References

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. *Journal of Geophysical Research: Solid Earth,* 108(B10):2497. **https://doi.org/10.1029/2003JB002393**

Kamei, R., Pratt, R.G., and Tsuji, T., 2012. Waveform tomography imaging of a megasplay fault system in the seismogenic Nankai subduction zone. *Earth and Planetary Science Letters,* 317–318:343–353. **https://doi.org/10.1016/j.epsl.2011.10.042**

Moore, G.F., Bangs, N.L., Taira, A., Kuramoto, S., Pangborn, E., and Tobin, H.J., 2007. Three-dimensional splay fault geometry and implications for tsunami generation. *Science,* 318(5853):1128–1131. **https://doi.org/10.1126/science.1147195**

Obara, K., and Kato, A., 2016. Connecting slow earthquakes to huge earthquakes. *Science,* 353(6296):253–257. **https://doi.org/10.1126/science.aaf1512**

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. **https://doi.org/10.1126/science.1074111**

Strasser, M., Dugan, B., Kanagawa, K., Moore, G.F., Toczko, S., Maeda, L., and the Expedition 338 Scientists, 2014. Proceedings of the Integrated Ocean Drilling Program, 338: Yokohama (Integrated Ocean Drilling Program). **https://doi.org/10.2204/iodp.proc.338.2014**

Tobin, H., Hirose, T., Saffer, D., Toczko, S., Maeda, L., Kubo, Y., and the Expedition 348 Scientists, 2015. *Proceedings of the Integrated Ocean Drilling Program,* 348: College Station, TX (Integrated Ocean Drilling Program). **https://doi.org/10.2204/iodp.proc.348.2015**

Tobin, H.J., and Kinoshita, M., 2006. NanTroSEIZE: the IODP Nankai Trough Seismogenic Zone Experiment. *Scientific Drilling*, 2:23–27. **https://doi.org/10.2204/iodp.sd.2.06.2006**

Tsuji, T., Kamei, R., and Pratt, R.G., 2014. Pore pressure distribution of a mega-splay fault system in the Nankai Trough subduction zone: insight into up-dip extent of the seismogenic zone. *Earth and Planetary Science Letters,* 396:165–178. **https://doi.org/10.1016/j.epsl.2014.04.011**

Table T1. Operations plan, Expedition 358. BOP = blowout preventer. CMT = cement. CSG = casing. RIH = run in hole, TOL = top of liner, POOH = pull out of hole. LOT = leak-off test. LWD = logging while drilling. UR = underreamer. RCB = rotary core barrel. TD = total depth. OD = outside diameter.

Operation					Days	Sub Total (d)	Total (d)
1) Transit, Deploy Transponders, Recover corrosion cap, Preparation						3.5	3.5
Transit from Shimizu to site					1.5		
Deploy transponders / calibration					1.0		
Well head (WH) survey and recover corrosion cap					1.0		
2) Run & set BOP and Riser						11.0	14.5
Run BOP and Riser w/fairing in low current area (LCA)					7.0		
Drifting from LCA to site, Land BOP onto WH					2.0		
Test BOP					2.0		
3) CBL/USIT, Sidetrack from original well						29.0	43.5
Run 12-1/4-inch Bit, Drill out CMT (DOC) inside 13-3/8-inch CSG, RIH and cleaning 11-3/4-inch TOL, POOH					2.0		
Wireline logging for temp survey					1.5		
Tie back operation; Run polish mill assy, Set 11-3/4-inch Tie back string to top of 11-3/4-inch liner for prevention of Casing wear					3.0		
Run Drilling 10-5/8-inch Bit, Circ.and Conditioning mud, CSG Pressure test for 11-3/4-inch Shoe with 3000 psi					4.0		
DOC shoe, SBT&LOT, POOH					2.0		
Scraping with 11-3/4-inch Scraper					1.5		
Run CBL/USIT					1.0		
Run 10-5/8-inch Slick assy, DOC, Ream 70 m below shoe, POOH					2.0		
Run Diverter, Spot kick off plug, Run Kick off assy, Kick off					10.0		
Test BOP					2.0		
4) Set 9-5/8-inch x 11-3/4-inch Expandable Liner, Tie back operation						15.0	58.5
Drill 8-1/2-inch x 12-1/4-inch Hole w/**LWD to 3500 mbsf**	2922	-	3500 mbsf	(578 m)	7.0		
Run 9-5/8-inch x 11-3/4-inch Expandable open hole liner, Cementing					6.0		
Test BOP					2.0		
5) Set 9-3/8-inch Liner						16.0	74.5
Run 9-1/2-inch Bit, DOC, extended leak-off test (**ELOT**)					2.0		
Drill 9-1/2-inch x 11-3/8-inch Hole w/**LWD and UR to 4100 mbsf**	3500	-	4100 mbsf	(600 m)	7.0		
Run & Cement 9-3/8-inch Liner *Cover 9-5/8-inch expandable casing section					5.0		
Test BOP					2.0		
6) Set 7-5/8-inch x 9-3/8-inch Expandable Liner						21.0	95.5
Run 7-3/8-inch Bit, DOC, **ELOT**					2.0		
Drill 8-1/2-inch x 9-1/2-inch Hole w/**LWD to 4650 mbsf**	4100	-	4650 mbsf	(550 m)	9.0		
Make up and Run 8-1/2-inch RCB Coring assy, **cut Core**	**4650**	**-**	**4700 mbsf**	**(50 m)**	2.0		
Run & Cement 7-5/8-inch x 9-3/8-inch Expandable Open hole Liner					6.0		
Test BOP					2.0		
7) DOC, Drill 7-3/8-inch x 8-1/2-inch hole with LWD and UR to 5200 mbsf (TD)						23.0	118.5
Make up and Run 6-3/4-inch LWD assy, DOC, **ELOT**					2.0		
Drill 7-3/8-inch x 8-1/2-inch hole w/**LWD to 5150 mbsf**	4700	-	5150 mbsf	(450 m)	10.0		
Run 6-3/4-inch OD core barrel, **Cut core from 5150 to 5200 mbsf**	**5150**	**-**	**5200 mbsf**	**(50 m)**	9.0		
Test BOP					2.0		
8) Suspend hole						7.0	125.5
Set cement plug or Bridge plug in hole					2.0		
Recover BOP and Riser					5.0		
9) Set corrosion cap, Recover Transponders, Transit					2.0	2.0	127.5
10) Mechanical Down, Wait on Weather, Cold Front Evacuation Time					33.0	33.0	160.5
Mechanical Down Time (Operation Time x 4%)	6 day						
Wait on Weather (Operation Time x 8%)	11 day					(5.3 months)	
Cold Front Evacuation	16 day						

Table T2. Scientific operations time windows, Expedition 358. LWD = logging while drilling.

Science Operations	Estimated Start	Duration (days)	Potential end date*
LWD from kick-off (ca. 2900) to 3500 mbsf	19-Nov-18	7	29-Dec-18
LWD from 3500 - 4100 mbsf	6-Dec-18	7	15-Jan-19
LWD from 4100 - 4700 mbsf	22-Dec-18	9	2-Feb-19
Coring from 4750 - 4800 mbsf	8-Jan-19	5	15-Feb-19
LWD from 4800 to 5150 mbsf	15-Jan-19	10	27-Feb-19
Coring - from 5150 to 5200 mbsf	25-Jan-19	6	5-Mar-19

Figure F1. A. Interpreted deep-penetration seismic section of Line 5 (Park et al., 2002), showing major tectonic elements and NanTroSEIZE sites drilled between 2007 and 2014. Site C0002 to present total depth of ~3000 mbsf is shown. PSP = Philippine Sea plate. B. Location map of NanTroSEIZE transect. Irregular polygon outline = 3-D seismic survey footprint (Moore et al., 2007).

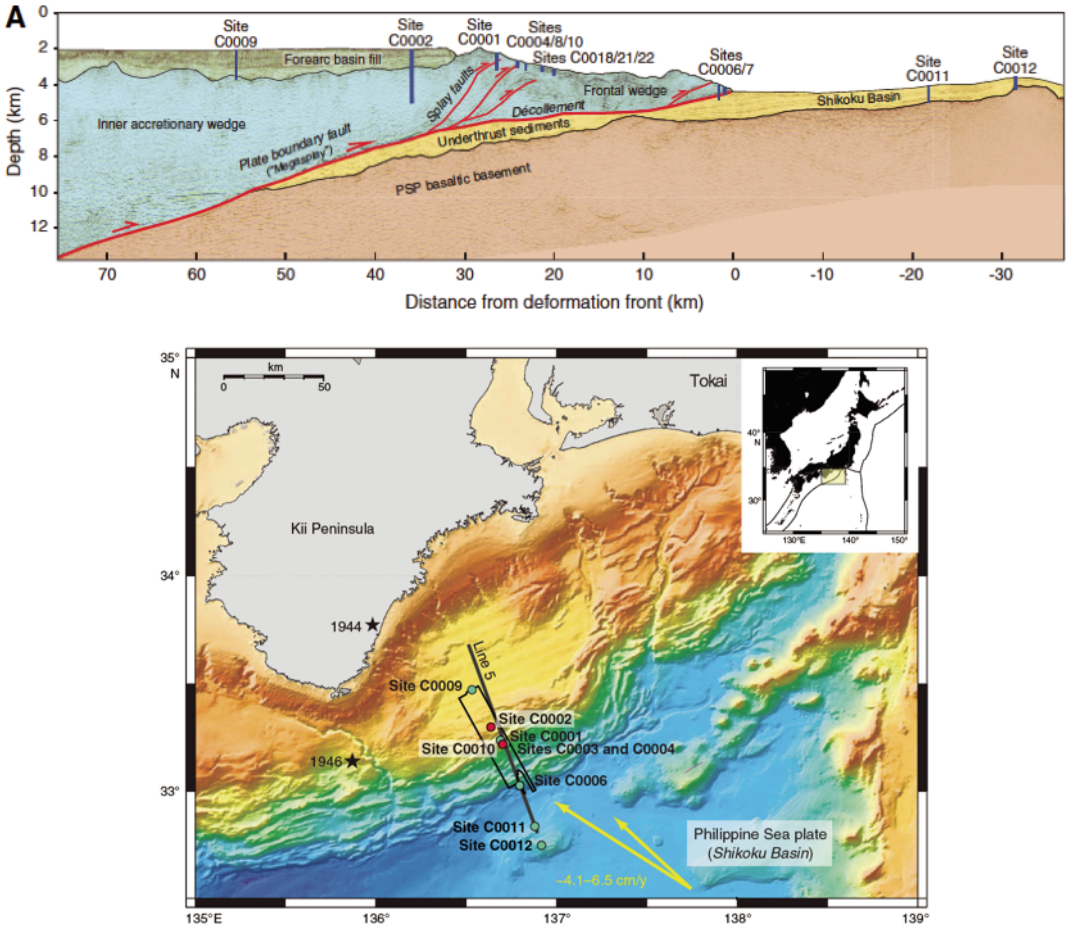

Figure F2. Detail of the 3-D survey (In-line [IL] 2529) around Site C0002. Current hole configuration and casing depth set points are shown. The plate boundary fault zone target reflector is indicated. mbsl = meters below sea level.

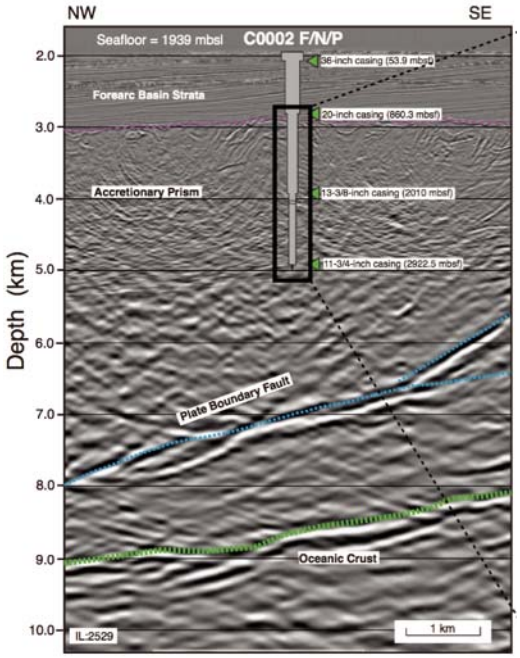

Figure F3. Riser drilling operations sequence for Site C0002. Operations are depicted as each operation stage is completed, in sequence, from left to right. Depths and operational highlights are described for each phase of drilling. The final completion setting is shown at far right. BRT = below rotary table, MSL = from mean sea level. WH = wellhead. TD = total depth.