

What is the role of the Nankai Frontal prism in tsunamigenic earthquakes & slow slip?

A Core-Log-Seismic Integration Investigation at Sea: Synthesis and New Directions in research building on NanTroSEIZE Stage 1

D/V Chikyu

The Nankai Accretionary Prism is one of the most intensively researched accretionary prisms in the world, with over 10 scientific drilling expeditions by *D/V Chikyu* alone. Recent findings from the 2011 Tohoku-Oki mega earthquake in the Japan Trench have refocused attention on the role that co-seismic tsunamigenic slip to the trench plays in the development of devastating tsunamis. Here, tsunamigenic slip was found to continue from the locked portion of the subduction plate boundary all the way out to the trench (IODP Exp. 343 JFAST; Chester et al 2013). Evidence for similar behavior had previously been described at NanTroSEIZE Sites C0004 and C0007 from Exp. 316 research (Sakaguchi et al., 2011; see Kinoshita et al., 2009, for more details for NanTroSEIZE Stage 1).

This investigation at sea will focus on further investigations of the role of the Nankai Frontal Prism in past tsunamigenic earthquakes and slow slip, using Exp. 314 logs from Site C0006 and Exp. 316 cores from Sites C0006 and C0007 in the frontal ramp thrust portion of the prism. It will be held onboard *Chikyu*, concurrently with IODP Expedition 380, NanTroSEIZE Stage 3: Frontal Thrust Long-Term Borehole Monitoring Systems (LTBMS). The investigation at sea will offer participants the opportunity to build on existing data and sample analysis and conduct comprehensive, high-density sampling from the cores previously collected from Sites C0006 and C0007. The research targets are likely to include three main units from the seafloor to the top of the subducting plate: (1) the shallow turbidite sequences and record of uplift in the upper section, (2) fault gouges and extensive fracture zone in the middle section, and (3) hemipelagic sediments in the deepest section. In particular, Site C0006 provides us with the opportunity to examine cores from the Pliocene and Miocene sections almost down to the décollement.

Balanced cross-section profiling shows that the total horizontal shortening of the frontal prism is ~500 m, and this is inferred to have occurred in the last ca. 0.5 Ma from the onset of the wedge-top deposits. Vertical uplift inferred from the anticlinal geometry

requires a similar amount of vertical displacement in the same time period. Using recent recurrence intervals of 3-7 hA for Nankai tsunamigenic earthquakes (Okamura et al., 2012), it is estimated that average slip for each tsunamigenic earthquake has been ~0.5 m, even greater if recurrence intervals were longer in the geological past. This would have been partitioned with the slip along the basal décollement. In that context, we offer research questions that could be addressed by the investigation and fieldwork at sea:

- What is the geological record of earthquakes and tsunamis since ca. 0.5 Ma?
- What can the thrust fault gouges reveal about fault mechanisms in tsunamigenic frontal ramp thrusts?
- What can the contrasts at the plate boundary tell us about the hanging wall and footwall?
- What are the geomechanical, frictional and physical properties of the fault zones and wall rock? How are these related to the in situ stress state?
- How do rock properties vary spatially in the volume of rock away from the borehole, as sampled by 3-D seismic data? What are the implications for fault zone processes, architecture, evolution, and slip behavior?

Participants will have the opportunity to articulate and pursue additional questions based on their expertise and individual interests. Pre-proposals to outline research interests will be part of the application package. Participants will submit more detailed proposals before the end of the first week of the session.

Structure:

There are two options: an abbreviated vs. full investigation session. The full session will be for the length of the expedition (ca. 40 days); the short will be 2 weeks. Participants choosing the 2-week program will require helicopter underwater escape training (HUET) certification from an approved OPTIO training center. Costs for this certification would be a responsibility of the participant's Program Member Office (PMO), where applicable.

The program will comprise:

- A. "Big picture" lectures and discussion of the current state of understanding in Nankai, facilities introduction and training phase,
- B. Thematic break-out sessions to identify and focus discussion on unanswered scientific questions,
- C. Fieldwork laboratory work and data analysis, including new drilling parameter data, presentations, discussions, and writing.

A. "Big picture" & facilities:

Overview of the current state of research into the Nankai region and other accretionary complexes, review of current journal papers, introduction to laboratories, analytical tools and techniques, and ship facilities. Review and discussion of the NanTroSEIZE long-term borehole monitoring system (LTBMS) observatories and DONET cabled seafloor network, and other CORK systems.

Review lectures and discussion summarizing results to date and emerging questions will include:

- Gaku Kimura – Introduction of the tectonic plate framework around Japan & an overview of Sites C0006 & C0007,
- Greg Moore – Evolution and deformation of the Nankai accretionary prism,
- Michael Strasser - Deposition, Erosion, and the Evolution of the Nankai Frontal Thrust complex,
- *Harold Tobin** – *Seismogenic and other fault processes in subduction zones,*
- *Mike Underwood** – *Lithostratigraphy of the Nankai region,*
- Kyu Kanagawa – A discussion and summary of core-scale structures,
- Keir Becker – Introduction to CORKS and review of observatory systems at subduction zones,
- Kiyoshi Suyehiro – Understanding earthquakes from modeling and observations,
- Masa Kinoshita – The goals of the NanTroSEIZE LTBMS network, Geothermal processes in subduction zones,
- *Demian Saffer** – *Physical, mechanical, and hydrological properties of fault rocks.*

**Indicates mentor will support activities from shore via telepresence.*

There will also be relevant paper reviews presented by participants, and hands on training on lab techniques, software, and analytical tools in the labs.

B. Break-out sessions:

The investigation mentors will help organize teams to attack specific research topics as identified by the participants during break-out sessions. Such teams could be interdisciplinary or highly focused, depending on the objectives. Teams will draft research proposals to articulate their science plans.

C. Fieldwork and lab work:

Interwoven with the “big picture” introduction and overview, focus will be on advancing collaborative research. The complete archive and working half core sections from IODP Sites C0006 and C0007, along with whole round X-ray CT 3D scanning data, will be on board for examination and sampling. All expedition measurement data from IODP Exp 314 and 316 will be on board. All logging data from Site C0006, seismic data from the frontal wedge, drilling data from both LWD and coring holes will be available. One focus will be on new data and sample collection from these cores. The opportunity for high density and comprehensive sampling of specific stratigraphic or structural intervals,

accented by access to the entire D/V *Chikyu* laboratory and lab support staff, will be a hallmark of the program.

This program will focus on collaboration, discussion, and drafting journal publications for submission to international journals. Primarily, a complete integrated paper draft overview paper summarizing the investigation at sea is desired. Additional papers might address details related to work performed aboard and additional sample/analysis requests on shore.

On a usual IODP expedition, core samples and data would be under a 1-year moratorium; however, these cores and data are out of moratorium. For investigation participants, research paper drafts for journal submission should be prepared within 8-12 months post disembarkation. Depending on the need, a science meeting may be scheduled at that time to discuss publication and research updates. Successful publications will be included in the NanTroSEIZE Stage 1 science results (see publications.iodp.org for details on the IODP Exp 314, 315, 316 *Proceedings* volume).

Research Mentors/Group Leaders

Scientists with extensive experience in IODP and the NanTroSEIZE project will guide discussions and research planning with participants. These group leaders include Keir Becker (observatory specialist)*, Masa Kinoshita (hydrogeology, thermal systems)*, Greg Moore (geophysics), Michael Strasser (sedimentology), Kyuichi Kanagawa (structural geology), Harold Tobin (geophysics, structural geology), Demian Saffer (physical properties), Gaku Kimura (structural geology), Mike Underwood (lithostratigraphy), and Kiyoshi Suyehiro (seismology).

*Expedition 380 co-Chief Scientists.

An introduction to *Chikyu* and the facilities aboard can be found at the *Chikyu* wiki:

http://cdex-science.jamstec.go.jp/chikyu-wiki/index.php/Main_Page

Applications

To apply for the investigation program, please submit to the relevant PMO your CV, a short 1 page outline of proposed research targets, and a letter of endorsement from your advisor or supervisor. Successful applicants will be notified by your PMO.

References

Chester, F.M., Mori, J., Eguchi, N., Toczko, S., and the Expedition 343/343T Scientists, 2013. *Proc. IODP*, 343/343T: Tokyo (Integrated Ocean Drilling Program Management International, Inc.). [doi:10.2204/iodp.proc.343343T.2013](https://doi.org/10.2204/iodp.proc.343343T.2013)

Kinoshita, M., Tobin, H., Ashi, J., Kimura, G., Lallemand, S., Screatton, E.J., Curewitz, D., Masago, H., Moe, K.T., and the Expedition 314/315/316 Scientists, 2009. *Proc. IODP*,

314/315/316: Washington, DC (Integrated Ocean Drilling Program Management International, Inc.). [doi:10.2204/iodp.proc.314315316.2009](https://doi.org/10.2204/iodp.proc.314315316.2009)

Okamura, M., Matsuoka, H. Mega-earthquake recurrences recorded in lacustrine deposits along the Nankai Trough. 2012. Paper presented at the Fall Meeting, American Geophysical Union, San Francisco, California.

Sakaguchi, A., Chester, F., Curewitz, D., Fabbri, O., Goldsby, D., Kimura, G., Li, C-F., Masaki, Y., Screatton, E.J., Tsutsumi, A., Ujiie, K., and Yamaguchi. A., 2011. Seismic slip propagation to the updip end of plate boundary subduction interface faults: Vitrinite reflectance geothermometry on Integrated Ocean Drilling Program NanTroSEIZE cores. *Geology*, 39(4):395–398. doi: 10.1130/G31642.1

Figure 1.

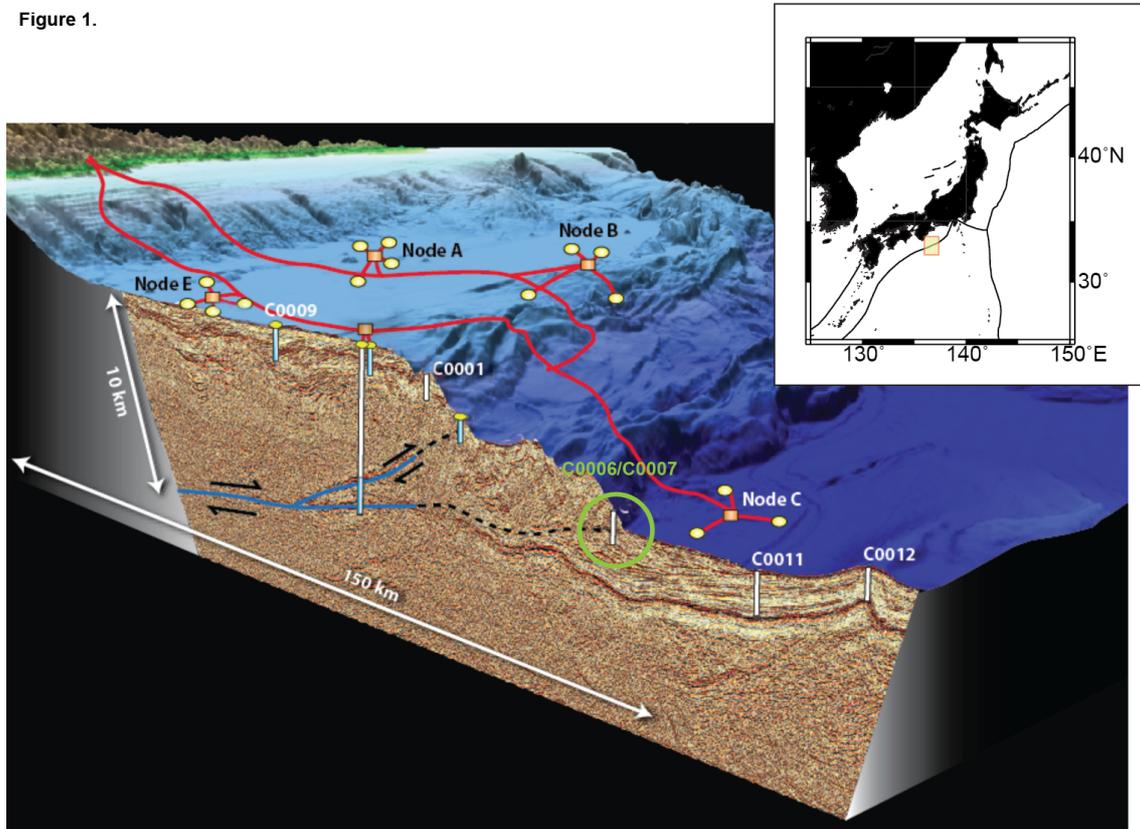


Figure 1. Site location of NanTroSEIZE study area off Japan (inset), and 3D image of NanTroSEIZE transect with seismic image showing major accretionary wedge structures. The megasplay fault is shown in blue, with the extension of the plate boundary and frontal thrust shown by the dashed black line. Site C0006/C0007 are in green, with the previous drilled interval shown by the white vertical bar. The red line on the sea floor shows the DONET undersea cabled network.

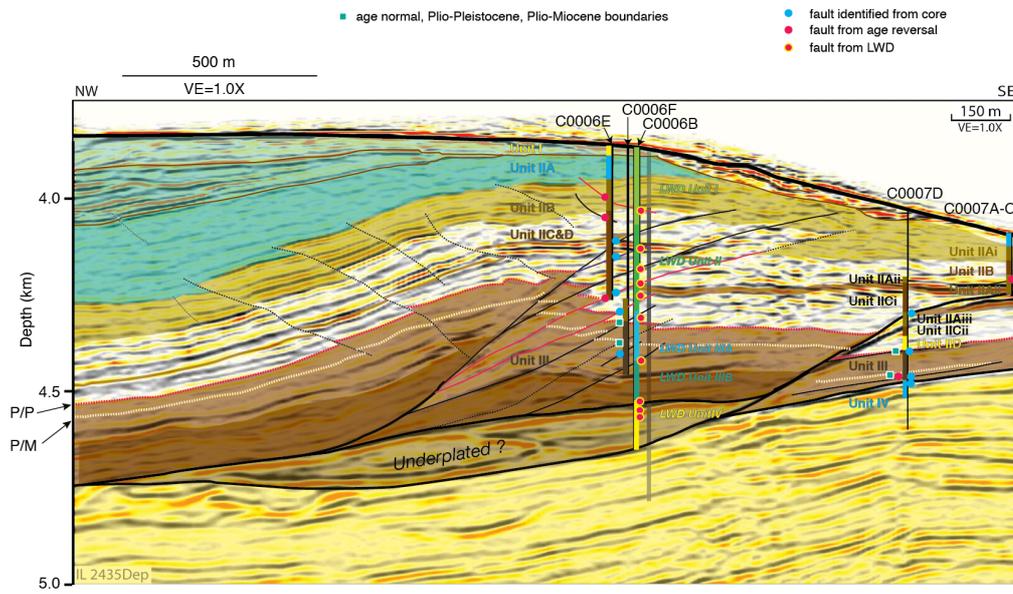
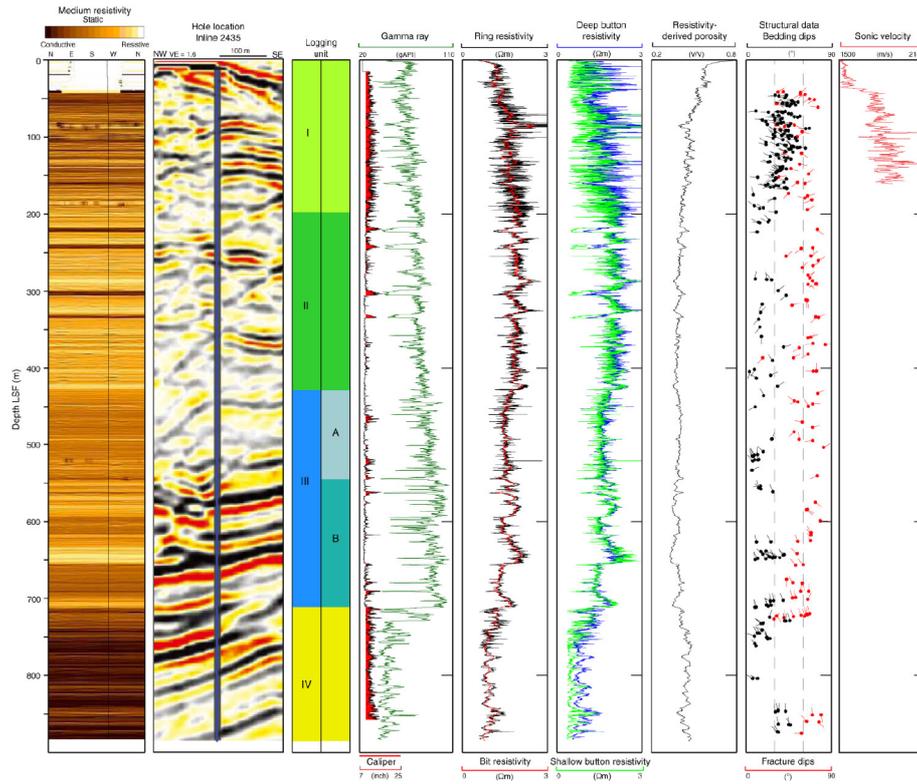


Figure 2. Interpretive diagram of the Nankai accretionary toe, specifically Sites C0006 and C0007, from logging-while-drilling (LWD) and coring results. Lithological interpretation overlaid upon seismic image. Faults and age boundaries as indicated.



From IODP Exp 314 Proceedings, Site C0006 Figure F1

Figure 3. Summary log diagram, Site C0006. Bedding (black tadpoles) and fracture (red tadpoles) dip from resistivity at bit image. VE = vertical exaggeration, LSF = LWD depth below seafloor. From IODP Exp 314 *Proceedings*, Summary Chapter.

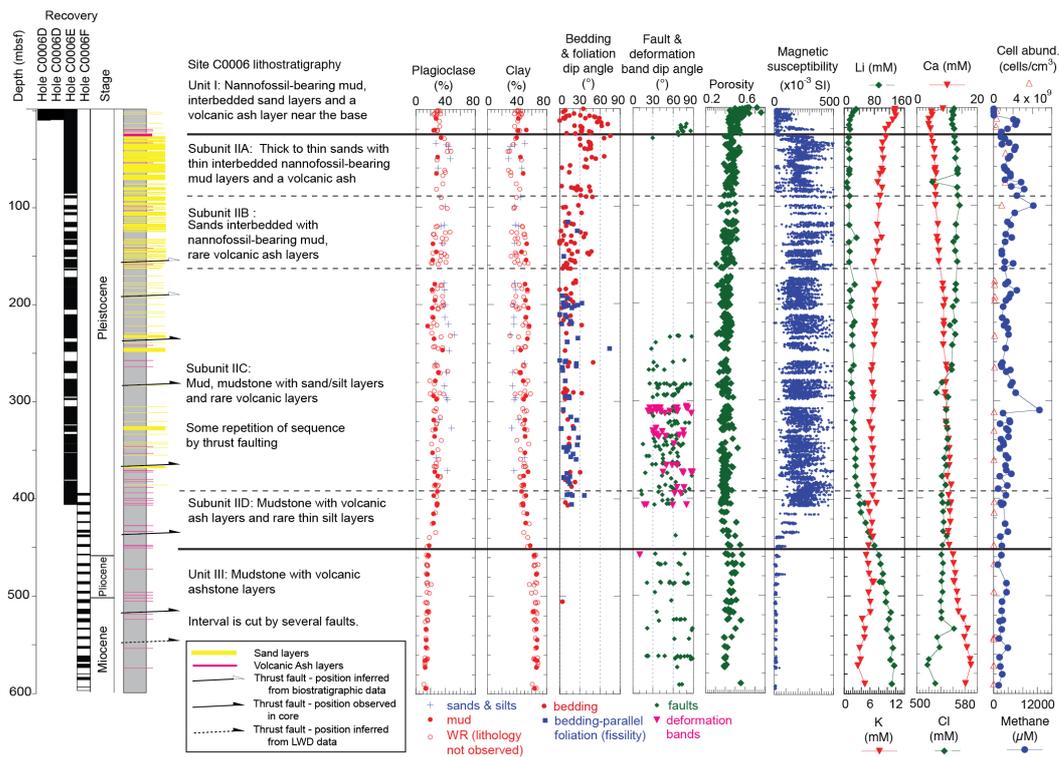


Figure Summary-F6

Figure 4. Site C0006 summary results, Holes C0006C–C0006F. CSF = core depth below seafloor, LWD = logging-while-drilling, WR = whole-round. From IODP Exp 316, *Proceedings*, Summary Chapter.

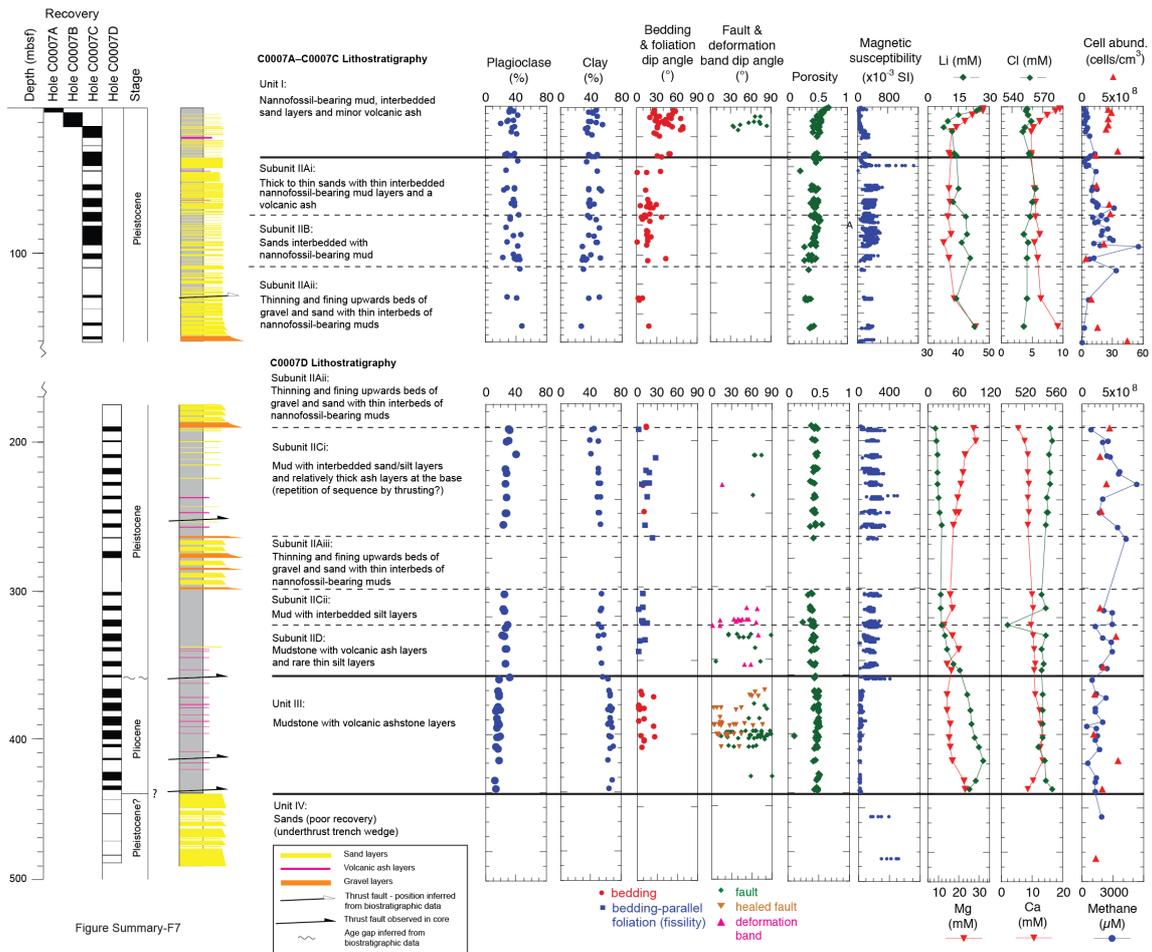


Figure Summary-F7

Figure 5. Site C0007 summary results. Because of the distance (185 m) and prism thickening between Holes C0007A–C0007C and C0007D, they are not combined. CSF = core depth below seafloor. From IODP Exp 316, *Proceedings*, Summary Chapter.