INTERNATIONAL OCEAN DISCOVERY PROGRAM

International Ocean Discovery Program Expedition 405 Scientific Prospectus

Tracking Tsunamigenic Slip Across the Japan Trench (JTRACK)

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Abstract

The 11 March 2011 M 9.0 Tohoku-oki earthquake was one of the largest earthquakes ever recorded and was accompanied by a devastating tsunami. Slip during the earthquake was exceptionally large at shallow depth on the plate boundary fault, which was one of the primary factors that contributed to the extreme tsunami amplitudes that inundated the coast of Japan. International Ocean Discovery Program Expedition 405 aims to investigate the conditions and processes that facilitated the extremely shallow slip on the subduction interface in the 2011 Tohoku-oki earthquake. Proposed work includes coring and logging operations at two sites in a transect across the trench. The first site, located within the overriding plate, will access the fault zone in the region of large shallow slip, targeting the plate boundary décollement, overlying frontal prism, and subducted units cut by the décollement. The second site, located on the Pacific plate, will access the undisturbed sedimentary and volcanic inputs to the subduction zone. A borehole observatory will be installed into the décollement and surrounding rocks to provide measurements of the temperature in and around the fault over the following several years. Sampling, geophysical logs, and the observatory temperature time series will document the compositional, structural, mechanical, and frictional properties of the rocks in the décollement and adjacent country rock, as well as the hydrogeologic structure and pore fluid pressure of the fault zone and frontal prism—key properties that influence the effective stress to facilitate earthquake slip and potential for large slip. Results from Expedition 405 will address fundamental questions about earthquake slip on subduction zones that may directly inform earthquake and tsunami hazard assessments around the world.

Plain language summary

The magnitude 9.0 earthquake that occurred off the coast of northeast Japan on 11 March 2011 was one of the largest ever recorded and caused a devastating tsunami. The earthquake happened because two tectonic plates meet and are pushing past one another in a subduction zone under the ocean offshore Japan. During the earthquake, there was a lot of slip at a shallow depth along the subduction fault where the two tectonic plates meet. This shallow slip played a major role in generating the large tsunami waves that inundated the Japanese coast. The International Ocean Discovery Program Expedition 405 aims to investigate the conditions and processes that led to this shallow fault slip during the 2011 earthquake by collecting samples of the materials that are in and around the shallow fault and by installing sensors to monitor temperature and subseafloor fluids. These data will provide critical information about the composition, structure, mechanics, and fluids within the subduction fault and surrounding rocks that will help us understand the conditions that allow large shallow slip to occur. The findings from Expedition 405 will address fundamental questions about how earthquakes occur in subduction zones and can provide valuable insights for assessing earthquake and tsunami risks worldwide.

1. Schedule for Expedition 405

International Ocean Discovery Program (IODP) Expedition 405 is based on IODP drilling Proposal 835-Full (available at **https://docs.iodp.org/Proposal_Cover_Sheets/835-Full_Kodaira_cover.pdf**). Following evaluation by the IODP Scientific Advisory Structure, the expedition is scheduled for the D/V *Chikyu*, operated under contract with the Japanese Implementing Organization, The Institute for Marine-Earth Exploration and Engineering (MarE3). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled in 2024, starting 12 September 2024 and ending 7 December 2024. A total of 87 days will be available for the transit, drilling, coring, and downhole measurements described in this report. Further details on *Chikyu* can be found at **https://www.jamstec.go.jp/mare3/e/ships/research_vessel/chikyu.html**.

2. Introduction

Subduction zones host the world's largest earthquakes, which can have devastating effects on human life and infrastructure, particularly when accompanied by tsunamis that inundate coastal regions. Earthquakes with a range of magnitudes and hypocentral depths have been observed to cause tsunamis, but it is clear from recent earthquakes such as the 2004 M9.1 Sumatra–Andaman earthquake, which caused the worst tsunami damage in history (Fujii and Satake, 2007), and the 2011 M9.0 Tohoku-oki earthquake (Satake et al., 2013) that large coseismic slip at shallow depth on the fault is a major contributing factor toward tsunami generation. This is because earthquakes can cause tsunamis by displacing the seafloor relatively quickly (i.e., over the duration of the earthquake), which perturbs the water column and results in gravitational waves spreading out from the source. Seafloor displacement is enhanced when a subduction zone earthquake propagates to the Earth's surface at the trench and large slip occurs at shallow depth. Key factors that contribute to the tendency of a shallow fault zone to generate large slip include the mechanical and frictional properties of the materials in the fault and the pore fluid pressure in and around the fault, which influence both the effective stress conditions to initiate slip and potential for large slip. Although recent work has informed the changes to the stress conditions caused by shallow slip in the 2011 Tohoku-oki earthquake (Brodsky et al., 2020), more information is needed to determine the mechanical properties and deformation processes of the rocks in the fault zone and to inform the details of the hydrogeologic structure and how it varies temporally. Determining the controls on the magnitude of shallow earthquake slip is a major goal for the geoscience community to help mitigate the hazard from future tsunamigenic earthquakes, both at the Japan Trench and other subduction zones globally.

The Japan Trench presents an unparalleled opportunity to fully characterize a system that is known to generate great earthquakes and where there is a documented history of large, destructive tsunamis. Ocean drilling uniquely provides access to the subsurface in order to determine the characteristics of the fault zone that control the mechanical behavior. The feasibility of accessing the fault zone, despite the extreme ocean depth, is demonstrated by the success of Integrated Ocean Drilling Program Expedition 343/343T. Expedition 405 will drill, sample, and log the fault zone beneath the frontal prism and the sedimentary rock-to-oceanic crust section outboard of the trench for an undisturbed reference. A long-term borehole observatory will be installed to capture a time series of measurements of the subsurface temperature field, which will describe the hydrogeologic structure at high spatial and temporal resolution. Through integration of the results from each of these distinct methods, the mechanical behavior of the Japan Trench subduction zone and how it varies over time will be constrained. Because the focus of the work is on fundamental processes, the results from the expedition will help us to understand other subduction zones around the world, which may have similar earthquake and tsunami hazards. This project is directly aligned with the Natural Hazards Impacting Society strategic objective, the Assessing Earthquake and Tsunami Hazards flagship initiative, and the Technology Development and Big Data Analytics enabling elements of the IODP 2050 Science Framework.

3. Background

On 11 March 2011, the Mw9.0 Tohoku-oki earthquake ruptured a large portion of the Japan Trench subduction zone (Figure **F1**), where the Pacific plate is subducted beneath Japan, resulting in a devastating tsunami that caused thousands of fatalities and billions of dollars of damage. Bathymetric surveys show direct evidence for >50 m of lateral and 10 m of vertical motion near the trench where seismological and geodetic data suggest the slip was largest (Fujiwara et al., 2011; Kodaira et al., 2012). These are the largest fault displacements ever recorded for an earthquake. The shallow depth of the enormous slip caused substantial motion of the seafloor during the earthquake, which was a primary driver of the huge accompanying tsunami (Satake et al., 2013). The Tohoku-oki earthquake was the first great subduction event where the entire activity was recorded by modern dense geophysical, seismological, and geodetic networks located near the rupture zone. However, despite the significant instrumentation for earthquake monitoring, the magnitude of the 2011 earthquake and the amount of the co-seismic slip and size of the accompanying tsunami were largely unexpected by the geoscience community. In particular, the unprecedentedly large shallow slip during the 2011 Tohoku-oki earthquake demonstrated that the widely held assumption that the shallow portion of the megathrust behaves predominantly aseismically (e.g., Scholz, 1998) is not universally applicable.

Expedition 405, JTRACK, will drill into the Japan Trench subduction zone with the goal of establishing the fundamental controls on shallow slip during great earthquakes. The expedition is motivated by key questions regarding the mechanical and hydrogeologic behavior of the fault zone—properties thought to control the ability of a subduction zone to generate earthquakes with large, shallow slip. These questions include the following:

- What is the current stress state 13 years after the Mw9.0 Tohoku-oki earthquake at the site in the rocks surrounding the fault zone?
- Have the rocks around the plate boundary fault zone already started to store elastic strain energy after the 2011 earthquake?
- What are the dominant fault zone structures, rock physical properties, and deformation and healing properties that control slip?
- Can we extend the paleoseismic record back in time to evaluate the longer term seismic behavior of the margin?
- What are the formation hydrogeologic properties that control fluid flow and pore pressure variations in space and in time during the seismic cycle?
- How does fluid flow contribute to the stress state and mechanical behavior of the décollement?

Expedition 405 builds from the results of Expedition 343/343T, the rapid-response JFAST project, and will revisit Integrated Ocean Drilling Program Site C0019. Results from Expedition 343/343T

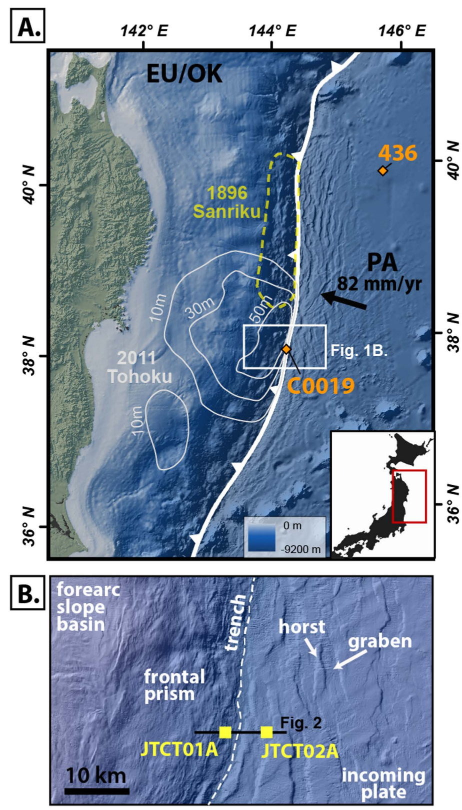

Figure F1. Location maps for the study area. A. Map showing the tectonic configuration at the Japan Trench, the rupture area of the 2011 Tohoku-oki rupture (slip contours in white, after Iinuma et al., 2012), and the locations of existing Sites C0019 and 436. EU/OK = Eurasian or Okhotsk plate. PA = Pacific plate B. Inset map showing major physiographic features of the Japan Trench, the locations of proposed dill Sites JTCT-01A and JTCT-02A, and the approximate location of seismic lines in Figure F2.

show that the plate boundary fault system in the region of large slip of the 2011 Tohoku-oki earthquake is clearly defined geologically and can be accessed by scientific drilling. By revisiting the JFAST site, Expedition 405 has the unique opportunity to evaluate temporal variations between 2012 and 2024. Specifically, this expedition provides the opportunity to identify changes in stress state, fluid flow, and the physical properties of the plate interface in the decade following a great earthquake.

3.1. Geologic setting

The Japan Trench subduction zone is located off the east coast of Japan where the Pacific plate subducts beneath Japan and is characterized by an ~8 km deep trench with a shallowly dipping (~8°) décollement separating the subducting (Pacific) and overriding (Eurasia/Okhotsk) plates (von Huene et al., 1982). The convergence rate between the Pacific and overriding plates is 85 mm/y (DeMets et al., 2010; Argus et al., 2011). This relatively rapid convergence results in a high rate of seismic activity, and historical records for the margin include 13 M7 and 5 M8 earthquakes over the last 400 years in addition to the 2011 Mw9 event and its aftershock sequence (e.g., Hashimoto et al., 2009; Kanamori et al., 2006). Inversions of seismic, geodetic, bathymetric, and tsunami data combined with repeat seismic reflection and bathymetric survey data across the Japan Trench indicate that the 2011 event produced up to ~40–60 m of coseismic displacement at the latitude of Site C0019 (Fujiwara et al., 2011; Romano et al., 2012; Sun et al., 2017; Lay, 2018; Kodaira et al., 2020). Furthermore, paleoseismic evidence indicates that the central Japan trench has hosted numerous past large-magnitude earthquakes in the past 4 ky (Ikehara et al., 2016; Usami et al., 2018; Kioka et al., 2019), and past earthquakes appear to have slipped to the trench (Rabinowiz et al., 2020).

The composition and thickness of units on the incoming Pacific plate have been determined through a combination of coring at Deep Sea Drilling Project (DSDP) Leg 56/57 Site 436 and high-resolution multichannel seismic reflection profile data (Shipboard Scientific Party, 1980; Nakamura et al., 2013) (Figure **F2**). The incoming plate consists of basaltic crust overlain by <100–160 m of Cretaceous to Oligocene chert, ~20–50 m of Eocene to early Miocene smectite-rich clay, and ~200–350 m of Miocene to Quaternary diatomaceous mudstone (Shipboard Scientific Party, 1980; Nakamura et al., 2013; Moore et al., 2015; Rabinowitz et al., 2015). Trench fill sediments are thin (<50–100 m) and spatially discontinuous (Fujie et al., 2020; Nakamura et al., submitted). Outer rise normal faults offset both basaltic crust and overlying sediments and form networks of horsts and grabens that extend ~120 km seaward of the trench axis. Normal faults have spacings of ~5–10 km and increase in total offset toward the trench from ~100 to ~500 m (Boston et al., 2014). Subducted horsts and grabens have been imaged in the subducted plate under the frontal prism to at least 50 km landward of the trench axis (Tsuru et al., 2000; Kodaira et al., 2017; Nakamura et al., 2020). Portions of the incoming Pacific plate contain petit-spot volcanic deposits, which consist of young (0–8 Ma) volcanic deposits that are <300 m tall by <5 km wide (Hirano et al., 2006; Fujie et al., 2020). These volcanic deposits are thought to form as a result of subduction-related plate flexure outboard of the trench axis and may locally metamorphose and alter the incoming plate sediments (Hirano et al., 2006, 2019; Fujie et al., 2020). Both outer rise faults and petit-spot volcanism produce physical roughness and compositional heterogeneity on the surface of the subducting plate that have major impacts on décollement development and heterogeneity that may be linked to the occurrence of shallow slip (Fujie et al., 2020; Nakamura et al., 2020; Scottenfels et al., submitted).

The frontal prism composition and structures are informed by the combination of high-resolution multichannel seismic reflection profile data and the geophysical logging and coring operations from Expedition 343/343T (Expedition 343/343T Scientists, 2013; Nakamura et al., 2013) (Figure **F3**). The frontal prism consists of a low-velocity (2–3.5 km/s *P*-wave), seismically chaotic, ~20–30 km-wide sedimentary wedge (Kodaira et al., 2017; Tsuru et al., 2002). The prism consists of highly disrupted biogenic and siliciclastic mudstones that appear to be deformed by a series of reverse-sense and normal-sense faults occurring at spacings of 1–10 m in core from Site C0019. Sediments recovered from the lower ~380 m of the frontal prism range in age from 0 to 9.1 Ma, with >50% of the material ranging 0–3 Ma (Expedition 343/343T Scientists, 2013; Rabinowitz et al., 2015; Regalla et al., 2019). These sediments have been interpreted to be derived predominantly from accretion of offscraped sediments on the incoming plate in the past ~25 ky to 1 My (Chester et al., 2013; Nakamura et al., 2013; Rabinowitz et al., 2015; Regalla et al., 2019).

The décollement is imaged in seismic reflection lines across the Japan Trench as a high-amplitude, semi-continuous reflection that separates undeformed, shallowly dipping strata in the subducting plate from deformed material in the overriding plate (Nakamura et al., 2013, 2020) (Figure **F2**). At the position of Site C0019, the décollement occurs above a subducted host block and separates deformed mudstones of the frontal prism from relatively undeformed pelagic clays and chert on the downgoing plate (Chester et al. 2013; Nakamura et al. 2013; Kirkpatrick et al., 2015). Both updip and downdip of this horst block, seismic reflection images indicate that the décollement steps down into graben (Nakamura et al., 2013, 2020). Cores recovered from Site C0019 indicate that the décollement zone is ~5 m wide and consists of intensely deformed clays with scaly fabric and several planar, sharp faults surrounded by a few tens of meters of highly fractured mudstones (Chester et al., 2013; Kirkpatrick et al., 2015; Keren and Kirkpatrick, 2016) (Figure **F3**). Deformed clays and mudstones within this zone have been lithologically and geochemically correlated to pelagic clays and clayey mudstones at the base of the incoming sediment section (Chester et al., 2013; Kameda et al., 2015; Rabinowitz et al., 2015).

Several lines of evidence suggest that the frontal prism and lower plate are likely mechanically decoupled across the décollement. The orientation and magnitude of the anisotropy of magnetic susceptibility indicates horizontal shortening above and vertical uniaxial strain below the décollement (Yang et al., 2013), which reflects a change in the deformation across the décollement over geological timescales. Estimates of the stress field in the prism and décollement support this inference. For example, Sh_{max} directions determined from borehole breakouts in image logs collected during Expedition 343 in 2012 have a preferred azimuth of 319° ± 23°, ~30° away from the plate convergence direction of 292°, and then become largely absent below the décollement (Expedition 343/343T Scientists, 2013; Lin et al., 2013; Brodsky et al., 2020). This could indicate either a rota-

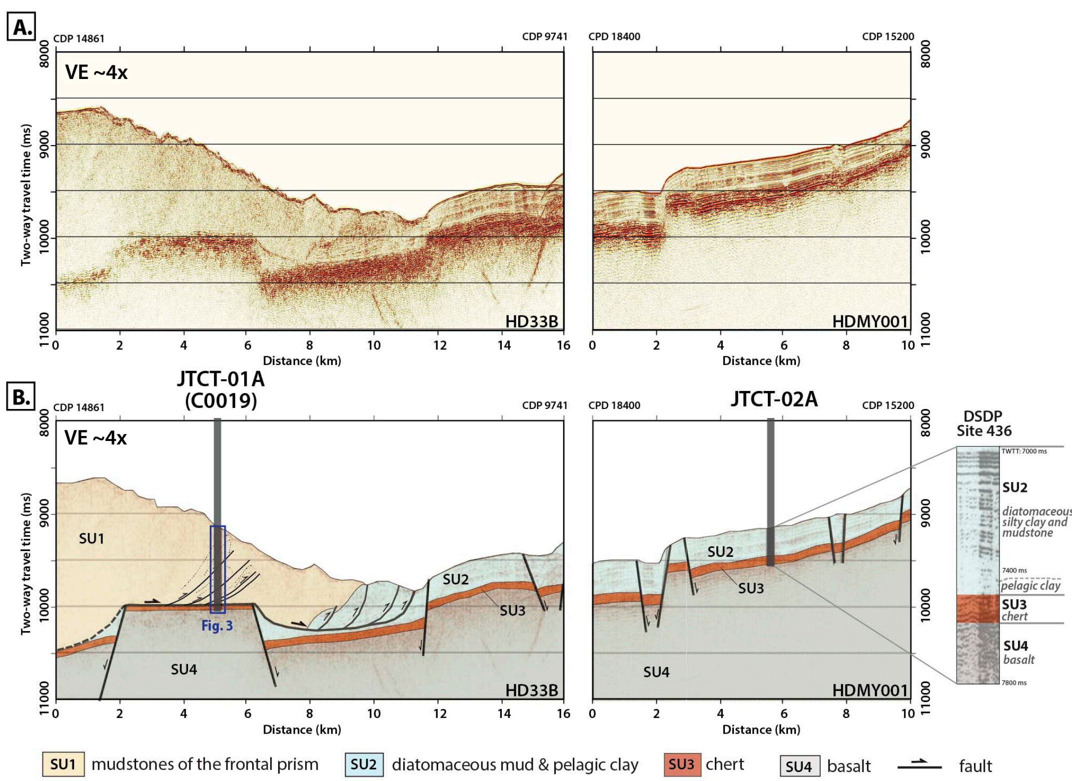

Figure F2. A. Unannotated high-resolution multichannel seismic reflection Profiles HD33B and HDMY001 showing the locations of proposed Sites JTCT-01A and JTCT-02A. B. Interpreted seismic line from A showing the structure of the incoming and overriding plate. Seismic units defined after Nakamura et al., 2013 and 2020 and their correlation to Site 436 (Shipboard Scientific Party, 1980). CDP = common depth point, TWTT = two-way traveltime.

tion of the principal stress axes from the prism down into the décollement zone or a change in the mechanical properties of the sediments as they approach the fault. Overall, stress modeling on the fault suggests a low shear stress after the 2011 earthquake (Fulton et al., 2013; Brodsky et al., 2020).

The coseismic slip zone during the 2011 Tohoku-oki earthquake may not have been recovered during Expedition 343, due to limited core recovery. However, based on inferences from the recovered core, the 2011 slip zone was thin (i.e., less than a few millimeters to a few centimeters), similar to coseismic slip zones in exhumed subduction complexes (Ujiie and Kimura, 2014), and was hosted in the frictionally weak smectite-rich clays with anomalous cationic composition that constituted the décollement zone (Chester et al., 2013; Sawai et al., 2014; Kirkpatrick et al., 2015; Kameda et al., 2016). Friction experiments indicate these clays have a static friction coefficient (μ_s) of <0.2–0.6 and a dynamic friction coefficient (μ_d) of 0.05–0.1, significantly lower than that of surrounding mudstones ($\mu_s \geq 0.5$ $\mu_d < 0.1$) (Ujiie et al., 2013, 2016; Ikari et al., 2015a, 2015b; Remitti et al., 2015). The dynamic friction values of the clays are consistent with coseismic friction values of 0.05–0.19 determined from borehole temperature measurements ~1 y following the Tohoku-oki earthquake (Fulton et al., 2013) and of 0.08–0.19 determined from drilling torque acquired at seismic slip rates of 0.8–1.3 m/s (Ujiie et al., 2016). However, as many as eight faults have been identified based on core and logging-while-drilling (LWD) observations (Expedition 343/343T Scientists, 2013), biostratigraphic and ^{10}Be chronologic inversions (Regalla et al., 2019), and zones of elevated fluid flow (Fulton and Brodsky, 2016) occurring in four lithologic subunits including

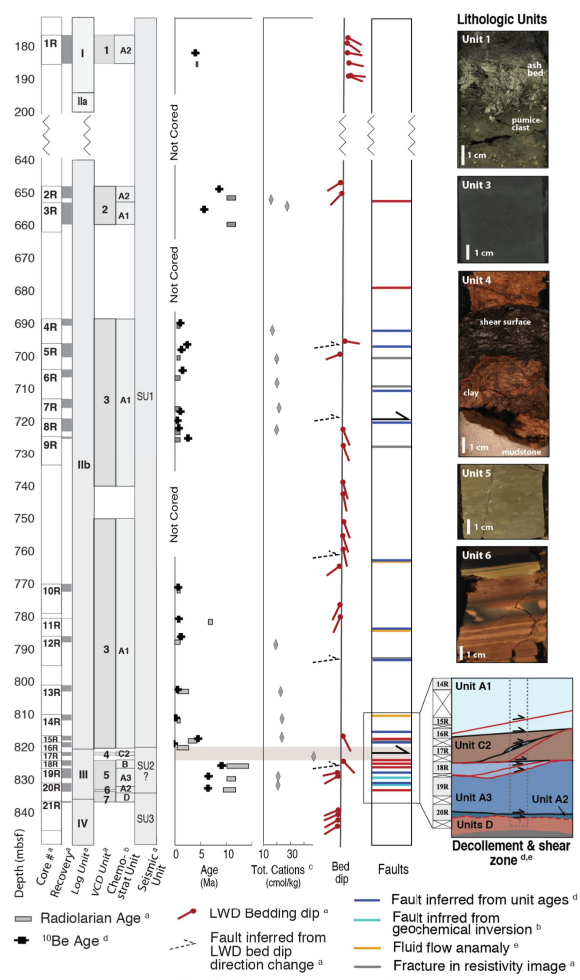

Figure F3. Frontal prism composition and structures interpreted from the combination of the geophysical logging and coring operations from Expedition 343/343T and high-resolution multichannel seismic reflection profile data. a: Expedition 343/343T Scientists, 2013; b: Rabinowitz et al., 2015; c: Kameda et al., 2016; d: Regalla et al., 2019; e: Fulton et al., 2016; f: Rabinowitz et al., 2020. VCD = visual core description.

both pelagic clays and mudstones. Thermal maturity of organic biomarker indexes indicate that five of these faults may have hosted shear heating associated with past large magnitude (≥10M) earthquakes (Rabinowitz et al., 2020).

3.2. Seismic studies/site survey data

High-resolution seismic lines were collected close to the targeted drilling sites by the Japan Agency for Marine Earth-Science and Technology with Deep Sea Research Vessel *KAIYO* (Figure **F2**). Data were collected during the KY11-E05 and KY14-E02 cruises using a cluster gun array with volumes of 320 and 380 in^3, respectively, 37.5 m shot interval, 6.25 m receiver interval, and a 1300 m-long streamer cable. This high-resolution survey results show that the seismic structure of the near-trench area is classified into four major Seismic Units SU1–SU4 (following Nakamura et al., 2013) (Figure **F2**). The uppermost unit (SU1) is restricted to the landward trench slope. SU1 is characterized by a seismically chaotic structure with few continuous reflections and has previously been interpreted as a frontal accretionary prism (von Huene et al., 1994). SU2 is situated below SU1 in the trench and at the seafloor seaward of the trench. It is characterized by generally well stratified, parallel, continuous reflections with relatively weak amplitude seaward of the trench that become disrupted at the trench axis (Figure **F2**). SU3 directly underlies SU2 on the seaward trench slope and in the trench axis but is in contact with SU1 along the subducting Pacific plate under the landward trench slope. SU3 is characterized by relatively strong reflections, and the base of this unit is marked by a high-amplitude semicontinuous reflection. The lowermost unit (SU4) is the basement, which is interpreted as the igneous crust of the Pacific plate.

Paleontological, geochemical, and mineralogical data can be used to define the stratigraphy at DSDP Site 436, located ~200 km north-northeast of proposed Site JTCT-01. In combination with seismic units described above, they can be used to assess the stratigraphy of the incoming Pacific plate and predict the likely composition of the frontal prism and accretionary wedge beneath the inner-trench slope of the Japan Trench. Cores from Site 436 contain a sequence of undeformed pelagic and hemipelagic sedimentary rocks deposited on the Pacific plate from Cretaceous to Holocene times (Shipboard Scientific Party, 1980) (Figure **F2**). The total thickness of the recovered section during DSDP Leg 56/57 was ~380 m, with the total depth during coring ending within the chert, so the basaltic basement was not penetrated. The section was divided into three primary lithologic units during DSDP Leg 56/57 (Figure **F2**). The upper unit is diatomaceous silty clay and mudstone that is subdivided based on degree of lithification, minor differences in lithology, and age into two subunits, Units 436-1 and 436-2 (Shipboard Scientific Party, 1980). Cretaceous chert was sampled as cobbles in the two lowermost cores and underlies a dark brown pelagic clay. Together these rock types compose Unit 436-3 (Shipboard Scientific Party, 1980).

The seismic images at proposed Site JTCT-02 show the incoming Pacific plate section contains a comparable stratigraphy to Site 436 (Chester et al., 2013; Nakamura et al., 2013) (Figures **F2**, **F3**, **F4**). Seismic Unit 2 (SU2) correlates with Units 436-1, 436-2, and the pelagic clay of 436-3. SU3 is a package with relatively strong amplitude reflectors with one continuous reflector at the top, inferred to correlate with chert at the base of Unit 436-3. SU4 is the acoustic basement, interpreted as basalt. In addition, seismically chaotic rock landward of the trench above SU3 and SU4 was interpreted to represent the frontal prism (SU1).

The input section on the Pacific plate is composed predominantly of hemipelagic/pelagic mud/mudstone and basal pelagic clay as recovered at Site 436, which correlates to SU2. The internal structure of SU2 on the incoming plate is generally well stratified, but it shows small-scale internal deformation in addition to the large-scale offset by the horst and graben normal faults (Figure **F2**). Parts of SU2 are intensively deformed in the vicinity of the trench axis (Figures **F2**, **F3**). The deformation of SU2 in the trench is characterized by imbricate thrusts and folds produced by trench-normal horizontal compressional stress. Within the deformed sequence in the trench axis, the seismic sections show that the detachment surface is likely located within the lowermost part of the SU2, slightly above the top of SU3.

The supporting site survey data for Expedition 405 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select 835 for proposal number).

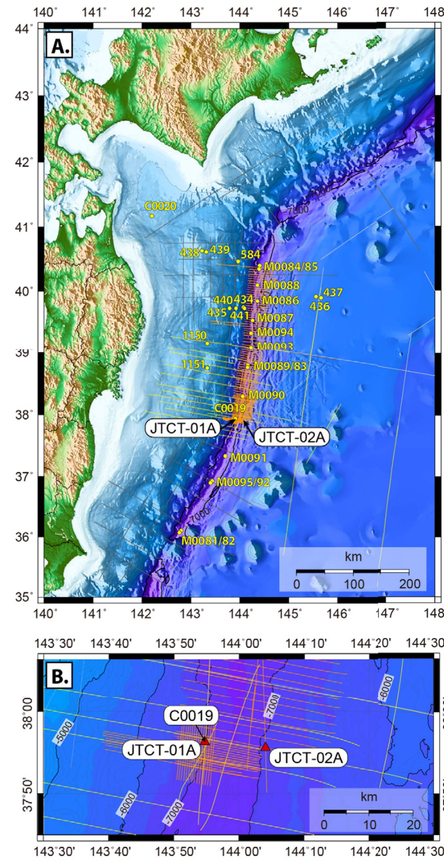

Figure F4. Locations of prior seismic reflection and drill data in the Japan Trench. Data from prior ocean drilling expeditions can be accessed through **https://iodp.tamu.edu/scienceops/maps.html**. Data from prior seismic surveys can be accessed through **https://www.jamstec.go.jp/obsmcs_db/e/index.html**. A. Seismic reflection profiles collected by JAMSTEC and DSDP, ODP, and IODP drill sites. B. High-resolution multichannel seismic reflection profiles near Site C0019 and proposed Sites JTCT-01A and JTCT-02A.

4. Scientific objectives

The overall goal of Expedition 405 is to establish the properties, processes, and conditions within subduction zones that promote large slip to the trench and contribute toward the generation of large tsunamis. To meet this goal, Expedition 405 will undertake a coordinated strategy of LWD, coring, and observatory installation to achieve a series of objectives that together will develop a comprehensive description of the mechanical properties and conditions relevant to earthquake slip: (1) the stress and strain conditions within and around the fault zone and their variation over space and time, (2) the subsurface geology including the physical rock properties affecting fault slip behavior and strain localization, as well as the geologic record of past earthquakes and tsunami, (3) the hydrogeology of the fault zone—including the hydrogeologic structure of faults, fractures, and permeable zones around the plate boundary and their influence on effective stress and earthquake mechanics and the variation of conditions over time.

Expedition 405 will visit two sites that will access the fault zone in the region of large slip during the 2011 earthquake and sample the input section to the subduction zone. The operations at these two sites are intended to provide a complete transect across the frontal prism, plate boundary décollement, and subducted oceanic crust and provide a basis for evaluating the mechanical and compositional changes from the initial condition outboard of the subduction zone into the shallow portion of the subduction zone. These data will provide critical information on the composition, structure, stress state, fluid properties, and thermal conditions and provide repeat measurements from Expedition 343/343T to quantify changes in physical/chemical properties and stress state in the more than a decade following the Tohoku-Oki rupture.

The science objectives are closely aligned with the 2050 science framework (**https://www.iodp.org/2050-science-framework**), particularly the Natural Hazards Strategic Objective, the Assessing Earthquake and Tsunami Hazards Flagship Initiative, and the Broader Impacts and Outreach and the Technology Development and Big Data Enabling Elements.

Specifically, the science objectives and strategies for achieving them are as follows:

4.1. Objective 1

Characterize the stress state within and around the fault zone that experienced large co-seismic slip during the 2011 Tohoku-oki earthquake.

This objective will provide insights into the potential accumulation of elastic strain energy and changes in the stress state within the shallow plate boundary fault zone since the last in situ measurements in 2012. This objective is key to evaluating the mechanical conditions in the active fault zone and constraining strain localization, fault strength, and healing rates that are fundamental to earthquake mechanics.

Key questions regarding the state of the system include:

1A. What is the present-day state of stress in and around the décollement, and has the stress state changed since last measured in situ in 2012?
1B. Over what timescales do damage and healing processes operate? Has the fault zone reacquired strength over the past 12 years since the 2011 earthquake? Is there evidence for elastic strain build up or fault healing in the shallow plate boundary fault zone?
1C. Can the frictional resistance to slip during the 2011 earthquake be confirmed as a constraint on the cause of extreme slip?

The present-day stress state will be determined through a combination of strain and rock strength measurements on core samples combined with analyses of borehole breakouts and drilling-induced tensile fractures identified in borehole image logs acquired through logging while drilling. Effective stress conditions will be evaluated by integrating logging data along with hydrogeologic characterization described below as part of Objective 3 and postexpedition work to measure the hydraulic properties of the fault and surrounding rocks. Other types of analyses enabled by core samples, such anelastic strain recovery tests, will also help provide stress state characterization.

Analysis of the borehole temperature data offers a promising avenue to estimate the co-seismic shear stress on the fault. In 2012, the JFAST observatory data deployed during Expedition 343T and recovered 9 months later revealed a 0.31°C temperature anomaly centered around 819 meters below seafloor (mbsf), which was interpreted to be the frictional heat signature of the 2011 M9 earthquake (Fulton et al., 2013). By deploying a new borehole temperature observatory sensor string in a new observatory hole, it may be possible, even after more than a decade, to potentially detect a smaller yet resolvable anomaly. If successful, interpretation of the temperature measurements will provide valuable constraints on the co-seismic frictional heat generation and stress conditions and establish a baseline from which the temporal changes since 2012 can be determined.

4.2. Objective 2

Characterize the geologic composition and structure of the frontal prism, décollement, and subducted oceanic crust to determine how these materials and structures control fault mechanics or reveal evidence of past earthquakes and deformation.

Understanding how and why strain becomes localized is important for understanding why fault slip during some megathrust earthquakes propagates all the way to the trench rather than terminating at depth or dissipating through distributed deformation. It is also important for understanding how the processes controlling slip to the trench vary over space and time. Geologic evidence of large tsunamigenic earthquakes in the past can be used to constrain the paleohistory and recurrence time of large earthquakes and tsunamis. It can also be used to determine which fault structures host co-seismic slip and the magnitude of slip they have hosted.

Key questions regarding the geologic controls on slip to the trench include:

2A. What is the influence of fault zone and host rock structures, rock physical properties, and deformation processes on controlling slip and deformation? How do fault zone deformation mechanisms vary over time?
2B. What is the history of past earthquakes and tsunami as recorded in the rock record? How many past events occurred at this location that hosted slip to the trench? Along how many fault zones can this occur?
2C. How much variation is there in the units that host shallow slip? Is there a lithologic preference for hosting seismogenic slip to the trench? Does seafloor roughness (e.g., horst and graben structures, petit-spot volcanics) impact slip localization and propagation potential?

Answering these questions requires analysis of the mechanical, geochemical, and physical properties of country rocks and deformation structures sampled from cores, deformation experiments on incoming plate and fault zone materials; lithostratigraphic, structural, and physical property characterization from logging data; and core-log-seismic integration. The complete sampling of the upper plate will provide the basis to determine whether slip is distributed across multiple surfaces other than the décollement, and the degree to which different structures accommodate plate convergence during the interseismic period.

Exploration of past earthquakes and tsunami is possible through analysis of core samples for geologic/geochemical signatures (e.g., thermal maturity changes, mineralogic anomalies, etc.) of past frictional heating localized within fault slip zones and sedimentary and structural features indicative of paleoearthquakes.

4.3. Objective 3

Characterize the hydrogeology of the plate boundary fault zone and frontal prism.

The hydrogeology of fault systems controls the distribution of pore fluid pressure, which has a direct influence of the effective stress and the strength of faults and fractures. Pore pressure therefore plays a critical role in earthquake mechanics by modulating the effective normal stress resolved on the fault, which controls the static strength and overall amount of slip by varying the potential stress drop. In addition, permeable zones can also act as pathways for large-scale heat and chemical transport, which can affect hydrologic, thermal, diagenetic, and mechanical conditions at much deeper parts of the megathrust. Thus, characterization of the hydrogeologic structure of faults, fractures, and permeable zones around the plate boundary is of particular interest toward developing a better understanding of the relationship between fluids and earthquake physics.

Key questions regarding the fault zone hydrogeology to addressed include:

3A. What is the hydrogeologic structure around the fault zone controlling fluid flow and pore fluid pressure distribution? To what extent does the permeability structure differ between the primary plate boundary fault, the fault damage zone, downgoing basaltic crust, and the intrinsic properties of the frontal prism and subducted sediments?
3B. Where is fluid flow presently concentrated and where has it been concentrated in the past? How does the hydrogeology and flow system vary over time?
3C. How does the fault zone hydrogeology respond to external perturbations such as regional earthquakes and what are the controls on transient fluid flow? Over what timescales does hydrologic healing occur and what processes control healing within the shallow subduction zone?

The questions will be addressed through a combination of analysis of geochemistry of interstitial pore water obtained from core samples along with core analysis of water-rock interactions, fracture density, and petrophysical variations determined from LWD and core analysis, indicators of active flow or permeable zones in LWD logs, and long-term monitoring of temperature with a new borehole observatory that will have total depth extending below the main plate boundary fault and very densely spaced sensors.

5. Operations plan/Coring strategy

Expedition 405 will visit two sites that comprise a transect across the trench from undisturbed sedimentary rocks on the Pacific plate (Site JTCT-02A) to a site within the overriding plate that will access the fault zone in the region of large, shallow slip in the 2011 Tohoku-oki earthquake (Site JTCT-01A) (see **Site summaries**). Site JTCT-01A is located ~6 km landward of the trench, in the frontal prism, and is co-located with Expedition 343 Site C0019 (Figure **F2**). Site JTCT-02A is located on the incoming plate, ~8 km seaward of the trench. LWD and coring operations at this site will provide critical information on the physical, chemical, and mechanical properties of input materials to the subduction zone, as well as on the amount of fluids entering into the subduction zone.

The general operations plan and time estimates are provided in Table **T1** and Figure **F5**. The operations strategy is to conduct LWD first to acquire comprehensive geological information to total depth (TD) to guide the sequential coring plan. The LWD and coring results will also be used to refine the placement depth of the sensors along the borehole for the planned observatory. Since the budgetary impact of the LWD program is a significant portion of the entire drilling project, LWD will be conducted at Sites JTCT-01A and JTCT-2A in series to minimize the onboard tool rental period. In a similar fashion, the coring operations will also be conducted at Sites JTCT-01A and JTCT-2A in series. The observatory implementation and deployment is planned only for Site JTCT-01A.

The operational sequence to be completed during IODP Expedition 405 consists of the following:

1. Drilling an 8½ inch hole with LWD/measurement while drilling (MWD) to TD, currently planned for 950 mbsf at Site JTCT-01A and 450 mbsf at Site JTCT-02A.
2. Coring a 10⅝ inch hole with the rotary core barrel (RCB) system to 950 mbsf at Site JTCT-01A and to 450 mbsf at Site JTCT-02A.
3. Jetting in 20 inch casing and wellhead, drilling a 10⅝ inch hole to 950 mbsf, and installing 4½ tubing with multisensor temperature measurement string at Site JTCT-01A.

5.1. Proposed drill sites

5.1.1. Inner-trench slope site (water depth = 6930 m, anticipated TD = 950 mbsf)

Proposed Site JTCT-01A is located on the lower continental slope near the trench and is selected to revisit JFAST Site C0019 in the region of large slip of the 2011 Tohoku-oki earthquake. This site is located above the frontal prism, which overlies a horst in the subducted Pacific plate. At this proposed site we intend to drill the entire section of Seismic Unit SU1 and to the depth of refusal in the underlying chert and basalt, including the plate boundary fault zone, which is expected at ~820 mbsf (Figures **F2**, **F3**). Two holes will be drilled to continuously core and continuously log (LWD) the frontal prism, fault zone, and subducted plate to oceanic basement. A long-term borehole observatory will be installed to monitor subseafloor temperature. Drilling is expected to encounter complexly deformed mudstones of the frontal prism (SU1), highly sheared pelagic clay and mudstone at the décollement, and mudstone, chert, with interbedded claystone deposited on the Pacific plate (SU2, SU3), and basaltic volcanic rocks of the oceanic crust (SU4) beneath the décollement.

The key scientific objectives at Site JTC-01A are to define the deformation structures, lithologies, rock mechanical properties, and interstitial fluid geochemistry of the plate boundary décollement and surrounding rocks in both hanging wall and footwall. The borehole observatory is designed to collect a long-duration (years) time series of temperature measurements in and around the plate boundary décollement, which will be used to characterize the fault zone hydrogeology and monitor hydrogeologic transients. Coring results will be combined with analyses of LWD data to confirm the location and architecture of the plate boundary fault, define the stress field in the frontal prism and potentially around the fault zone, and to identify faults and fractures that may act as permeable pathways in and around the décollement or be active either co-seismically or during the interseismic period. These results will also inform the interpretation of the time series data

Table T1. Operations and time estimates for primary sites, Expedition 405. Water depth at Site JTCT-01A = 6,930 m. Water depth at Site JTCT-02A = 6,945 m. DP = dynamic positioning. LWD = logging while drilling. BHA = bottom-hole assembly. UWTV = underwater television. POOH = pull out of hole. HPCS = hydraulic piston coring system. RCB = rotary core barrel. RIH = run in hole.

Operation	Depth (mbsf)	Section length (m)	Daily progress (m/days)	Days	Subtotal (days)	Total (days)
Transit						
Transit from port to Site JTCT-01A.				2.50	2.50	2.50
Rig up guide horn						
Rig up guide horn. Deploy transponders, DP calibration.				0.50	0.50	3.00
LWD hole to 950 mbsf at Site JTCT-01A						
Make up and run LWD BHA w/UWTV.				2.25	2.25	
Tag seabed and recover UWTV prior to starting drilling.						
Drill 8-1/2 inch LWD from 0 to 950 mbsf.	950	950	270	3.75	6.00	
POOH, lay out LWD BHA.				1.25	7.25	10.25
Transit to Site JTCT-02A.						
LWD hole to 450 mbsf at Site JTCT-02A						
Make up and run LWD BHA w/UWTV.				2.25	2.25	
Deploy transponders, DP calibration.						
Tag seabed and recover UWTV prior to starting drilling.						
Drill 8-1/2 inch LWD from 0 to 450 mbsf.	450	450	129	3.50	5.75	
POOH, lay out LWD BHA.				1.00	6.75	17.00
Transit to Site JTCT-01A.						
HPCS and RCB core 0–950 mbsf at JTCT-01A						
Make up and run HPCS coring BHA.				2.00	2.00	
Set DP mode.						
Cut core from 0 to 180 mbsf (until refusal).	180	180	51	3.50	5.50	
POOH HPCS coring BHA.				1.00	6.50	
Make up and run RCB coring BHA.				2.00	8.50	
Drill down w/center bit to 180 mbsf.	180	180	240	0.75	9.25	
Cut core from 180 to 950 mbsf.	950	750	34	21.75	31.00	
POOH RCB coring BHA.				1.00	32.00	49.00
Transit to Site JTCT-02A.						
HPCS and RCB core 0–450 mbsf at Site JTCT-02A						
Make up and run HPCS coring BHA.				2.00	2.00	
Set DP mode.						
Cut core from 0 to 180 mbsf (until refusal).	180	180	51	3.50	5.50	
POOH HPCS coring BHA.				1.00	6.50	
Make up and run RCB coring BHA.				2.00	8.50	
Drill down w/center bit to 180 mbsf.	180	180	240	0.75	9.25	
Cut core from 180 to 450 mbsf.	450	270	27	10.00	19.25	
POOH RCB coring BHA.				1.00	20.25	
Recover transponders; Possible to recover transponders during daytime.				0.50	20.75	69.75
Transit to Site JTCT-01A.						
Set wellhead and casing at JTCT-01A						
Make up and run wellhead, casing and drill ahead BHAw/UWTV.				2.00	2.00	
Set DP mode.						
Tag seabed and recover UWTV prior to starting jetting.						
Jetting casing.				1.25	3.25	73.00
Unlock drill ahead tool. Recover UWTV.						
Drill observatory hole to 950 mbsf at Site JTCT-01A						
Drill 10-5/8 inch hole to 950 mbsf.	950	950	290	3.75	3.75	
Wiper trip.						
POOH drilling BHA.				1.25	5.00	78.00
Run completion assembly at Site JTCT-01A						
Make up and run 4-1/2 inch tubing w/Thermistor rope to 950 mbsf.				3.25	3.25	
Run UWTV, enter wellhead.				0.50	3.75	
RIH to 950 mbsf.				1.25	5.00	
Set completion assembly. Unlock running tool. Recover UWTV.						
POOH drill string.				1.00	6.00	
Recover transponders; Possible to recover transponders during daytime.				0.50	6.50	84.50
Rig down guide horn.						
Transit						
Transit from Site JTCT-01A to port.				2.50	2.50	87.00
			Total:			87.00

from the borehole observatory. To achieve these objectives, priorities for postexpedition will work include (but are not limited to) the following:

1. The interpretation of deformation structures and microstructures to inform coseismic, post-seismic, and interseismic deformation processes, styles, and mechanisms;
2. Evaluation of fault and wall rock rheology and frictional behavior to test hypotheses linking fault constitutive properties to slip behavior and magnitude;
3. Geomechanical measurements to define poroelastic, hydrologic, and strength properties that control hydromechanical behavior and effective stress conditions and to provide context for the interpretation of borehole failures as indicators of in situ stress magnitude;
4. Geochemical measurements to assess fluid circulation and budget; and
5. Retrieval of and analysis of borehole observatory time series data.

5.1.2. Reference site (water depth 6945 m, anticipated TD 450 mbsf)

Proposed site JTCT-02A is located ~8 km seaward of the trench where sedimentary rocks of the Pacific plate overlie basaltic oceanic crust. Site JTCT-02A lies between seismically resolvable normal faults that offset sedimentary and volcanic rocks and that represent faults accommodating extension associated with flexure at the outer rise. Drilling at proposed Site JTCT-02A will target the entire undeformed section of sedimentary rocks that comprise Seismic Units SU2 and SU3 as well as the oceanic crust (SU4), to characterize the input section corresponding to the region of large slip. Based on interpretation of the seismic section at this site, drilling is expected to encounter a well-stratified sedimentary package (SU2) down to ~300 mbsf, slightly inclined toward the trench. Below ~300 mbsf, a strong reflection that is interpreted as a chert layer (SU3) is imaged (Figure **F2**). DSDP Site 436 ~250 km north of proposed Site JTCT-02A showed Holocene to Miocene diatomaceous mudstones overlying Miocene–Eocene pelagic clay (~30 m thick) above a chert layer at 400 mbsf (Figure **F2B**), and the lithology may be similar at proposed Site JTCT-02A.

Drilling at Site JTCT-02A is motivated by the need to characterize the properties of the input materials to the subduction zone. The primary objective at Site JTCT-02A is to describe and measure the composition, mechanical, and hydrologic properties of the rocks and interstitial fluids in the input section that are critical to understanding the controls of shallow slip and to provide a basis to evaluate their evolution as they enter the subduction zone. Late Neogene to Cretaceous pelagic clay in the input section is inferred to be a mechanically weak layer that localizes the plate boundary deformation (Chester et al., 2013; Kameda et al., 2015), and the distribution of the clay on the incoming plate appears to correlate positively with the locations of tsunamigenic earth-

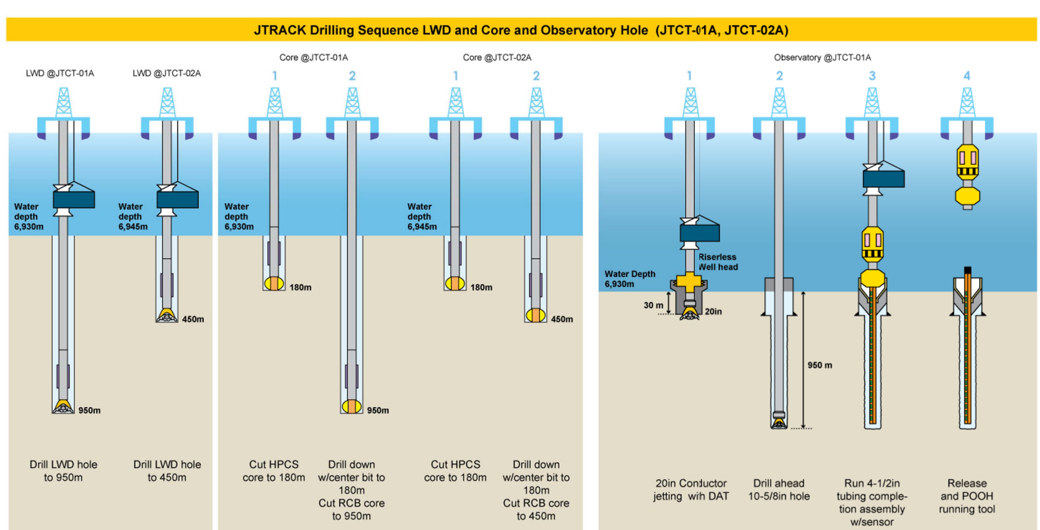

Figure F5. Operations plan for IODP Expedition 405. From left, LWD operations for Sites JTCT-01A and JTCT-02A, coring operations at the same sites (middle), and observatory installation at Site JTCT-01A (on right). HPCS = hydraulic piston coring system, DAT = drill ahead tool, POOH = pull out of hole.

quakes (Moore et al., 2015). However, seismic survey data show that the stratigraphy of the Pacific plate is nonuniform along the Japan Trench (Nakamura et al., submitted; Fujie et al., 2020), and the nearest reference drilling site in the incoming plate, DSDP Leg 56 Site 436 (Shipboard Scientific Party, 1980), is located >250 km from Site C0019/JTCT-01A. Results from DSDP Site 436 have been used as a basis for interpreting the lithologic origin of lithologic units at Site C0019/JTCT-01A (e.g., Rabinowiz et al., 2015), but Site JTCT-02A provides a reference section closer to the location of Site JTCT-01A that can reduce uncertainty in these interpretations and additionally provides constraints on the regional-scale variability of the mechanical and hydrologic properties of input material. Priorities for postexpedition analysis of cores include, but are not limited to, measurements of the mechanical, elastic, frictional, and hydrologic properties of the incoming sediment and basement, along with detailed analyses of sediment and top oceanic crust composition, stratigraphy (e.g., via biostratigraphy or chemostratigraphy), alteration/diagenesis, and fluid composition.

6. Wireline logging/Downhole measurements strategy

See **http://iodp.tamu.edu/tools** and **http://iodp.tamu.edu/tools/logging** for information about downhole tools.

Logging-while-drilling technologies will be utilized to monitor real-time drilling conditions and assess the downhole lithological and structural properties. The following tools from SLB (formerly Schlumberger Logging Services) will be selected for Expedition 405 (note that last-minute changes and substitutions may occur).

6.1. TeleScope: measurements while drilling

The TeleScope MWD tool provides electrical power for and transmits data from other downhole measurements and also provides real-time data on board while drilling. It also provides operational and drilling mechanics data, including collar rotation rate (rpm), drilling fluid turbine rpm, stick and slip, annular pressure while drilling (APWD), weight on bit, torque on bit, and axial and torsional vibration, which can be used to assure safe, stable, and successful drilling. Those measurements are also important for scientific purposes such as stress analysis, fluid pressure estimates, and assessment of rock property variations along the borehole.

6.2. MicroScope: at-bit resistivities and borehole resistivity images

The MicroScope resistivity tool is designed to provide real-time at-bit resistivity data and a high-resolution array of laterolog resistivity measurements for detailed geological mapping and imaging capabilities. The sensors include bit resistivity and four azimuthally oriented focused button electrodes that are ~0.4 inch in diameter and are longitudinally spaced along the axis of the tool. The spacing provides multiple depths of investigation for quantifying invasion profiles. These azimuthal measurements enable full borehole images for detailed geological imaging of the borehole wall, including bedding planes, fractures, and borehole breakouts. For environmental correction of the resistivity measurements, drilling fluid resistivity and temperature are also measured.

6.3. ArcVISION: resistivity measurements, gamma ray, and annulus pressure measurements

The arcVISION tool (array-resistivity compensated) measures propagation resistivity. Electromagnetic waves are both attenuated and phase-shifted when they propagate in an electrically conductive medium; the degree of attenuation and phase shift depends on the resistivity of the formation. Phase-shift resistivity has relatively high vertical resolution and a shallow depth of investigation, whereas attenuation resistivity has lower vertical resolution and a greater depth of investigation. The dual-frequency (2 MHz and 400 kHz) array of coils in the arcVISION tool makes 10 phase shifts and 10 attenuation measurements at 5 transmitter-receiver separations of 16, 22, 28, 34, and 40 inches (40.6, 55.9, 71.1, 86.4, and 101.6 cm), which correspond to several depths of investigation. In addition to the resistivity tools, arcVISION measures natural gamma radioactivity of the formation. The gamma ray sensor has a measurement range of 0–250 gAPI, with an accuracy of ~3%. The arcVISION tool also measures the pressure and temperature of the borehole fluid in the annulus, which are converted to equivalent circulating density (ECD) (density of circulating drilling fluid when pumping). Downhole pressure is a crucial parameter for detecting any inflow from the formation into the borehole or obstruction of the borehole because of collapse of the borehole walls, characterized by an increase in pressure. Monitoring of downhole pressure also allows us to detect pressure decreases associated with loss of circulation to permeable formations or faults.

6.4. SonicVISION: sonic velocity measurements

The sonicVISION sonic-while-drilling tool delivers real-time interval transit time data for compressional waves. Measurement range is between 40 and 230 s/ft (1.3 and 7.6 km/s) depending on mud type, but intensive processing is required to obtain reliable sonic velocity measurements in the relatively slow formations. In LWD operations the sonic processing parameters are conventionally set at the surface, before the tool is run in the hole. This results in possible mislabeling of arrivals (especially for slow formations) and limited confidence levels, as only the end result of downhole processing is seen uphole in the real-time log. Full-waveform data are recorded in memory, however. Advanced onboard postprocessing should allow fine tuning of sonic acquisition parameters and so extend the range of measurement out to the mud velocity, a key feature for achieving the scientific objectives of this cruise, including log-seismic ties.

7. Borehole observatory

A borehole observatory will be installed at Site JTCT-01A. The observatory will measure high-resolution temperature over time at multiple depths within the fault zone. This observatory builds upon the success of the JFAST temperature observatory at the co-located Site C0019.

One of the primary objectives of the JFAST observatory was to measure the remaining frictional heat signal from ~50 m of co-seismic slip at these shallow depths along the megathrust during the M9 Tohoku-oki earthquake (Fulton et al., 2013). In addition to successfully resolving a 0.31°C frictional heat anomaly around the plate boundary fault at 819 mbsf, data from the JFAST temperature observatory have also enabled characterization the fault zone hydrogeologic structure, properties, and conditions and revealed evidence of low-level background fluid flow through discrete fractures and transient fluid pulses in response to regional earthquakes (Figure **F6**) (Fulton et al., 2013; Fulton and Brodsky, 2016).

Analysis of the JFAST observatory temperature data has illustrated the incredible value and potential of high-resolution, spatially dense time series measurements of borehole temperature for the purposes of characterizing hydrogeologic structure, properties, and conditions and observing transient fluid advection and the hydrogeologic response to earthquakes and other perturbations (Fulton et al., 2013; Fulton and Brodsky, 2016, 2023; Purwamaska and Fulton, 2022) (Figures **F3**, **F4**). In particular, advanced analytical approaches demonstrate how near-field permeability structure can be constrained by thermal recovery from drilling perturbations (Fulton et al., 2013; Purwamaska and Fulton, 2022) and how cross-correlation between sensors can constrain hydrogeologic properties, as well as when and where fluid advection is occurring (Fulton and Brodsky, 2016).

The sensor string in the JFAST observatory consisted of 55 independent, autonomous temperature sensors—each with their own data logger encased in titanium to withstand the extreme pressures in deep water. The position of the bottommost sensor at 820.6 mbsf is interpreted to be just below the primary plate boundary fault and peak in the frictional heat signal at 819 mbsf (Fulton et al., 2013).

The new JTRACK observatory will go deeper than the JFAST observatory and include many more (hundreds) densely spaced temperature sensors (Figure **F7**). This is ideal for the experiments it is designed to address, namely the following:

1. Characterize the low-amplitude frictional heat anomaly from the 2011 Tohoku-oki earthquake, still expected to be resolvable, both above and below the plate boundary,
2. Characterize the fault zone hydrogeologic structure, also including down below the plate boundary fault,
3. Monitor hydrologic transients, and
4. Characterize spatial variations by comparing and contrasting observations with those previously obtained within the nearby JFAST observatory.

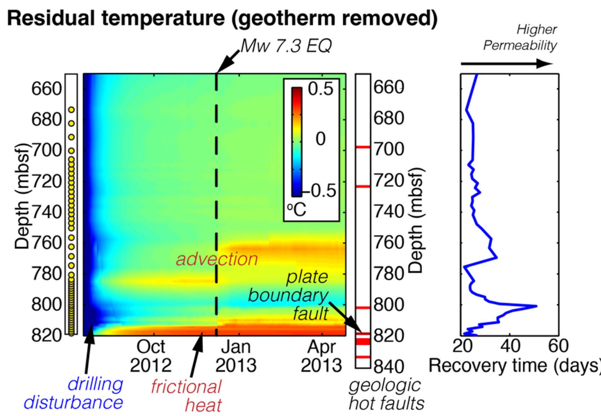

Figure F6. Adapted after Fulton and Brodsky, 2016, and Fulton et al., 2019. Borehole temperature records in the JFAST borehole observatory reveal several insights into the near-field hydrogeology. Colors represent residual temperature after the background geotherm is removed, as a function of time and space. Data show the signature of frictional heat from the 2011 Mw9.0 Tohoku-oki (Japan) earthquake, fluid advection, and drilling disturbance. Least-squares approximation of characteristic diffusion time of drilling disturbance recovery at each depth (right) provides a qualitative measure of permeability variations downhole (Fulton et al., 2013). Yellow dots (left) mark sensor positions in the observatory and red lines (center) indicate faults identified from geologic signatures of frictional heating in core samples from Hole C0019E (Fulton et al., 2019; Rabinowitz et al., 2020; Yang et al., 2018).

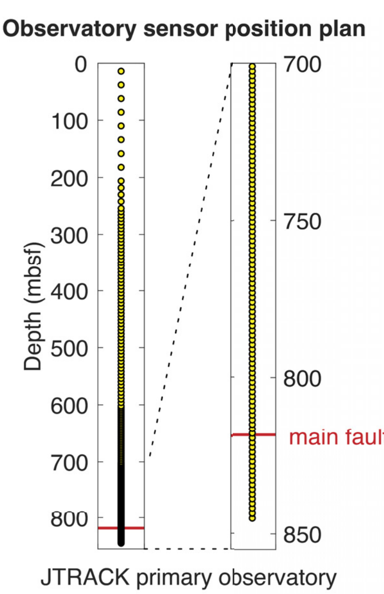

Figure F7. Diagram of preliminary plan for temperature sensor positions within the Site JTCT-01A observatory assuming 150 sensors. Sensor spacing will ideally be ~1.5 m apart along the lowermost portion of the sensor string starting ~25 m below the primary plate boundary fault, estimated to be roughly ~819–820 mbsf. Sensor spacing will remain dense within the fault the bottommost 150 m of sensor string, which covers the main damage zone around the fault and previously identified permeable fracture zones in Hole C0019E (Fulton et al., 2013; Fulton and Brodsky, 2016). Sensor spacing will progressively expand to 3, 6, 12, and 24 m to obtain full depth coverage while providing spatial resolution focused on areas of particular hydrogeologic interest around the fault and damage zone.

Going deeper than the JFAST observatory allows investigation of the hydrogeologic structure below the primary plate boundary fault and assessment of any potential hydrologic or frictional heating signals across deeper faults that have since been identified to have chemostratigraphic evidence of large total displacement or signatures of past frictional heating evident in the rock record (Rabinowitz et al., 2015, 2020; Fulton et al., 2019). More sensors will enable finer scale characterization of the depth-varying hydrogeologic structure of the fault and damage zone through analysis of the depth-varying borehole thermal recovery (e.g., Fulton et al., 2013). Characterization of where and when fluid advection is occurring 13 years after the M9 Tohoku-oki earthquake enables a comparison with observations of transient fluid flow identified 12 years prior in the JFAST observatory.

Similar to the JFAST observatory, the JTRACK observatory will consist of a 4.5 inch diameter steel tubing (i.e., casing) that extends beneath a seafloor wellhead to a depth ~850 mbsf, 20+ m deeper. The tubing will contain a check valve at the bottom allowing circulation out the bottom during installation, but together with a top seal/hanger at the top of a sensor string, prevents fluid flow into and along the inside of the observatory. Both the small diameter of the tubing and the volume occupied by the wrapped sensors help to inhibit free convection. The sensor string will be deployed through drill pipe and into the hole via core line. Recovery of the instrument string is needed to obtain the measured data; this will be done during a return visit of *Chikyu* at least a year after deployment by mating drill pipe to the wellhead and connecting to and retrieving the instrument string via core line.

8. Risks and contingency

8.1. LWD drilling and coring

From the experience of past operations in the area, if the geology is similar, we do not anticipate any high risk from LWD drilling. On the other hand, coring operations might entail some risk from poor hole conditions, since the plan is full coring to TD. Continuous RCB operation will require 25 days at Site JTCT-01A. If hole conditions worsen, ceasing coring operations and drilling a new adjacent hole to the depth of coring cessation and continuing coring operations is recommended. Hole cleaning operations in riserless holes are not usually effective to improve hole conditions, if the proper routine hole cleaning had been performed while coring. Otherwise, the hole will become fully deteriorated by seawater invasions and collapse.

8.2. Dual elevator

During Expedition 343/343T (JFAST), the dual elevator was used to handle >7000 m of drill pipe. However, the complicated hydraulic controls caused frequent downtime. During Expedition 405 JTRACK operations, MarE3 will mobilize enhanced types of drill pipes, such as 5½ inch DP UD-165 and 6⅝ inch DP UD-165 to avoid the need for the dual elevator.

8.3. Underwater television (UWTV)

Expedition 343 experienced significant downtime with the UWTV due to umbilical cable drum collapse and cable failure. The cable drum collapse required the core cable to be cut in the bottom layer of the drum, therefore requiring paying out the entire length of the umbilical cable to reterminate. Another problem resulting from the drum collapse was irregular winding of the umbilical cable. The drum was rebuilt and used during IODP Expeditions 370 (T-limit) and 380 (LTBMS) Site C0006 operations; these deployments confirmed that the previous issues encountered during Expedition 343 have been solved. Cable retermination will be carried out just before Expedition 405.

Because the current UWTV control system will be replaced with a common JAMSTEC control system in 2023, this system will be tested at the 7000 m water depth site in October 2023.

8.4. Sensor installation and retrieval through drill pipe

During Expedition 343 (JFAST), the JAMSTEC-owned ROV *Kaiko* retrieved the sensors from the borehole observatory. *Kaiko* is now limited to 4500 m, leaving no option to retrieve the sensors from the planned 7000 m water depth observatory. JAMSTEC is planning instead to use the core line and CBRT (core barrel retrieving tool) to recover the Expedition 405 sensor installation via drill pipe. JAMSTEC is planning a field test of this system during the UWTV test in October 2023.

8.5. Contingency

The following operations are being considered as contingency options as needed:

- Targeted RCB coring in specific intervals of interest, in the event of limited remaining operation time,
- Drilling a new observatory hole in the event failure is experienced during observatory installation or completion assembly running.

9. Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted on the Web at **http://www.iodp.org/top-resources/program-documents/policies-and-guidelines**. This document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of the Co-Chief Scientists, Staff Scientist, and IODP Curator on shore and curatorial representative on board the ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Shipboard scientists are expected to submit sample requests (at **http://iodp.tamu.edu/curation/samples.html**) ~6 months before the beginning of the expedition. Based on sample requests (shore based and shipboard) submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by core recovery and cruise objectives. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. Modification of the strategy during the expedition must be approved by the Co-Chief Scientists, Staff Scientist, and curatorial representative on board the ship.

The minimum permanent archive will be the standard archive half of each core. All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the cruise objectives. Some redundancy of measurement is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

If some critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling by a single investigator. A sampling plan coordinated by the SAC may be required before critical intervals are sampled.

10. Expedition scientists and scientific participants

A list of participants for Expedition 405 will be added to the JAMSTEC *Chikyu* Expedition 405 website when available (**https://www.jamstec.go.jp/chikyu/e/exp405**).

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Site summaries

Site JTCT-01A

Priority:	Primary
Position:	37.9389°N, 143.9135°E
Water depth (m):	6930
Target drilling depth (mbsf):	950
Approved maximum penetration (mbsf):	TBD
Survey coverage (track map; seismic profile):	Inline: HD33B, Xline HS41B
Objective(s):	• Continuously core the frontal prism, fault zone and subducted plate to oceanic basement in large slip area of the 2011 Tohoku-oki earthquake to obtain representative fault and surrounding rock samples and logging data for structural analyses and laboratory experiments. • Install a long-term fault zone observatory to monitor pore pressure and temperature near the previous JFAST temporary temperature observatory. • Investigate the role of fluids in slip with geochemical and physical property data from continuous cores. • Measure the prism stress state from borehole and sediment property measurements and long-term observatory monitoring.
Coring program:	10-5/8 inch hole with the rotary core barrel (RCB) system to TD.
Downhole measurements program:	8-1/2 inch hole with logging while drilling (LWD)/measurement while drilling (MWD) to total depth (TD). Jet a 20 inch casing and wellhead, drilling 10-5/8 inch hole to 950 mbsf and installing 4-1/2 inch tubing with multisensor temperature measurement string at Site JTCT-01A.
Nature of rock anticipated:	Based on existing data from Site C0019, we anticipate encountering the following units, listed below in order from deep to shallow: (1) basaltic crust of the Pacific plate (SU4), (2) <100–160 m of Cretaceous yellow to red radiolarian chert and interbedded pelagic clay (SU3), (3) ~10 m of minorly deformed to subhorizontally stratified Eocene to Miocene pelagic clay and mudstone (basal portion of SU2), (4) ~5 m of highly sheared pelagic clay and mudstone at the décollement, and (5) ~820 m of highly deformed, faulted, and folded, brown to blue-gray mudstones of the frontal prism (SU1). The uppermost portion of this unit may consist of subhorizontally bedded mudstones with minor deformation (Expedition 343/343T Scientists, 2013; Nakamura et al., 2013 and 2020).

Site JTCT-02A

Priority:	Primary
Position:	37.9267°N, 144.0688°E
Water depth (m):	6945
Target drilling depth (mbsf):	450
Approved maximum penetration (mbsf):	TBD
Survey coverage (track map; seismic profile):	Inline: HDMY001, Xline: JTXC02
Objective(s):	• Obtain sample and logging data of a reference section on the incoming plate seaward of the large slip area of the 2011 Tohoku-oki earthquake as a baseline for comparison with sediments in the prism, plate-boundary décollement and underthrust section. • Investigate the role of fluids in the reference input section with geochemical and physical property data from continuous cores. • Measure the stress state in the incoming sediment section from borehole and sediment property measurements and measure geophysical characteristics of the input section for correlation with the logs at Site JTCT-01A.
Coring program:	10-5/8 inch hole with the rotary core barrel (RCB) system to TD.
Downhole measurements program:	8-1/2 inch hole with logging while drilling (LWD)/measurement while drilling (MWD) to total depth (TD)
Nature of rock anticipated:	We anticipate encountering four lithologic units, listed below in stratigraphic order from old to young: (1) basaltic crust of the Pacific plate (SU4), (2) <100–160 m of Cretaceous yellow to red radiolarian chert and interbedded pelagic clay (SU3), (3) ~20–50 m of Eocene to Early Miocene A to B age brown pelagic clay (basal portion of SU2), and (4) ~200–250 m of Miocene to Holocene, brown to blue-gray, diatomaceous silty clay and biogenic mudstone (SU2) (Shipboard Scientific Party, 1980; Moore et al., 2015; Nakamura et al., 2013 and 2020).