International Ocean Discovery Program
Expedition 375 Scientific Prospectus

Hikurangi Subduction Margin Coring and Observatories: unlocking the secrets of slow slip through drilling to sample and monitor the forearc and subducting plate

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Abstract

Slow slip events (SSEs) at the northern Hikurangi subduction margin, New Zealand, are among the best-documented shallow SSEs on Earth. International Ocean Discovery Program Expedition 375 aims to investigate the processes and in situ conditions that underlie subduction zone SSEs at northern Hikurangi through coring of the frontal thrust, upper plate, and incoming sedimentary succession and through installation of borehole observatories in the frontal thrust and upper plate above the slow slip source area. Logging-while-drilling (LWD) data for this project will be acquired as part of Expedition 372 (beginning in November 2017; see the Expedition 372 *Scientific Prospectus* for further details on the LWD acquisition program).

Northern Hikurangi subduction margin SSEs recur every 2 years and thus provide an excellent setting to monitor deformation and associated chemical and physical properties surrounding the SSE source area throughout the slow slip cycle. Sampling material from the sedimentary section and oceanic basement of the subducting plate and from the primary active thrust in the outer wedge near the trench will reveal the rock properties, composition, and lithologic and structural character of the material transported downdip to the known SSE source region. A recent seafloor geodetic experiment shows the possibility that SSEs at northern Hikurangi may propagate all the way to the trench, indicating that the shallow fault zone target for Expedition 375 may lie within the SSE rupture area.

Four primary sites are planned for coring, and observatories will be installed at two of these sites. Expedition 375 (together with the Hikurangi subduction component of Expedition 372) is designed to address three fundamental scientific objectives: (1) characterize the *state* and *composition* of the incoming plate and shallow plate boundary fault near the trench, which comprise the protolith and initial conditions for fault zone rock at greater depth; (2) characterize material properties, thermal regime, and stress conditions in the upper plate above the SSE source region; and (3) install observatories at the frontal thrust and in the upper plate above the SSE source to measure temporal variations in deformation, fluid flow, and seismicity. The observatories will monitor deformation and the evolution of physical, hydrological, and chemical properties throughout the SSE cycle. Together, the coring, logging, and observatory data will test a suite of hypotheses about the fundamental mechanics and behavior of slow slip events and their relationship to great earthquakes along the subduction interface.

Schedule for Expedition 375

Expedition 375 is based on International Ocean Discovery Program (IODP) drilling Proposals 781A-Full and 781A-Add2 (available at **http://iodp.tamu.edu/scienceops/expeditions/hikurangi_subduction_margin.html**). Following ranking by the IODP scientific advisory structure, the expedition was scheduled for the research vessel (R/V) *JOIDES Resolution*, operating under contract with the *JOIDES Resolution* Science Operator (JRSO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Wellington, New Zealand, on 8 March 2018 and to end in Auckland, New Zealand, on 5 May 2018. Accounting for 5 days of port call and 3 days of transit, a total of 50 days will be available for the coring, logging, and observatory program described in this report (for the current detailed schedule, see **http://iodp.tamu.edu/scienceops**). Further details about the facilities aboard the *JOIDES Resolution* and the JRSO can be found at **http://iodp.tamu.edu/labs/ship.html**.

Introduction

Slow slip events (SSEs) involve transient aseismic slip on a fault (lasting weeks to months) at a rate intermediate between plate boundary displacement rates and that required to generate seismic waves. Only since the advent of dense, plate boundary–scale geodetic networks in the last decade has the importance of these events as a significant mode of fault slip been recognized. The observation of SSEs and associated seismic phenomena (e.g., tremor and low-frequency earthquakes) along subduction megathrusts worldwide (see review in Schwartz and Rokosky, 2007) has ignited one of the most dynamic fields of research in seismology (e.g., Rubenstein et al., 2010; Peng and Gomberg, 2010; Wech and Creager, 2011). Although SSEs appear to bridge the gap between typical earthquake behavior and aseismic creep at plate rate, the physical mechanisms that lead to SSEs and their relationship to destructive seismic slip on subduction thrusts are poorly known. This deficiency in our understanding of SSEs is partly due to the fact that most well-studied subduction zone SSEs (Cascadia and southwest Japan) occur too deep for high-resolution imaging or direct sampling of the source region. A notable exception is the northern Hikurangi margin, New Zealand, where well-characterized SSEs occur every 2 years over a period of 2–3 weeks at depths <5–15 km below the seafloor (Wallace and Beavan, 2010) (Figure **F1**). The close proximity of SSEs to the seafloor makes it feasible to drill into and sample, collect downhole logs, and conduct monitoring within and around the source area in the near-field. The regularity and well-characterized short repeat interval of the SSEs allow monitoring over multiple SSE cycles, with the potential to document the spatial and temporal distribution of strain accumulation and release, as well as any associated hydrogeologic phenomena.

Coring and monitoring above and surrounding the shallow SSE source area are key goals of Expedition 375. We plan to drill at four sites within the overriding and subducting plates to recover sediments, rocks, and pore fluids; collect geophysical logs; and make downhole measurements (logging objectives will be undertaken partly during Expedition 372). Borehole observatories will be installed at two of the drill sites to monitor physical, hydrological, and chemical changes throughout the SSE cycle. The objectives of the Expedition 375 program (and allied Expedition 372) are three-fold: (1) to document the physical, hydrogeological, and chemical properties, lithology, geometry, microstructure, and thermal state of the most active frontal thrust, as well as the inputs of sediment and upper igneous crust of the subducting Pacific plate, with an emphasis on intervals that will eventually host SSEs; (2) to characterize the stress regime, thermal structure, porosity, permeability, lithology, pore fluid pressure state, fluid chemistry, flow pathways, and structural geology of the upper plate overlying the SSE source region; and (3) to install two observatories in the upper plate and frontal thrust that span the entire SSE source region to monitor changes in deformation, temperature, and hydrogeology related to SSEs.

Background

Geological setting

In the region of proposed drilling, the Pacific plate subducts westward beneath the North Island of New Zealand along the Hikurangi Trough at a convergence rate of 4.5–5.5 cm/y (Wallace et al.,

2004) (Figure **F1**). The subducting plate is composed of the Hikurangi Plateau, a Cretaceous oceanic plateau (large igneous province). The plateau sequence is overlain by a ~1 km thick Cenozoic to Mesozoic sedimentary sequence (Figure **F2**) that increases to >5 km thickness at southern Hikurangi (e.g., south of ~40°S). The northern part of the margin is currently largely nonaccretionary and locally exhibits frontal tectonic erosion associated with subducting seamounts (Lewis et al., 1998; Collot et al., 2001; Pedley et al., 2010). Where accretion does occur at northern Hikurangi, the margin is characterized by a narrow, steep (>10° taper angle) wedge geometry (Barker et al., 2009). A number of seamounts are present on the Pacific plate approaching the deformation front (e.g., Tūranganui Knoll and Puke Seamounts). The subduction thrust is identified as a décollement between a relatively less deformed subducting sequence below and a highly deformed imbricated thrust wedge above. Barker et al. (2009) show that the interface lies <5–6 km below the seafloor in the portion of the profile 15–40 km from the trench.

SSEs at the northern Hikurangi margin occur offshore Gisborne every 18–24 months and typically involve 1–2 cm of southeastward surface displacement at continuously operating GPS (cGPS) sites (Figure **F1**) along the coast near Gisborne (Wallace and Beavan, 2010). The portion of the subduction interface that undergoes slow slip is largely locked between the SSEs, and this slip deficit is recovered by the repeating SSEs (Wallace and Beavan, 2010). Inversion of cGPS displacements from SSEs near Gisborne indicates that the equivalent moment magnitudes are typically Mw 6.5–7.0, with average slip of ~7–20 cm on the plate interface. These larger SSEs are punctuated by more frequent smaller events (one or more per year) that are not as well characterized (see GPS time series inset in Figure **F1**). SSE slip near Gisborne predominantly occurs beneath the offshore region, with the downdip limit of slip near the coastline, and the SSEs appear to rupture similar areas of the interface repeatedly (Wallace and Beavan, 2010). A recent seafloor geodetic experiment has shown that slow slip occurs to within at least 2 km of the seafloor beneath the Expedition 375 drilling transect, and it is possible that slow slip continues all the way to the trench (Wallace et al., 2016).

Multichannel seismic (MCS) data reveal regions where the interface (between <5 to >10–16 km depth) follows the top of a thick high-amplitude reflectivity zone (HRZ) that coincides with the source areas of some SSEs (Figures **F1**, **F2**) (Bell et al., 2010). The high-amplitude reflectivity has been hypothesized to result from high fluid pressures within sediments entrained between downgoing seamounts that lead to undercompaction and low seismic impedance. Alternatively, the reflectors may occur within altered basaltic lavas and volcaniclastic sediments. If the former interpretation is correct, then the correlation between HRZ and a subset of the SSEs would support the idea that fluid pressure plays a key role in the generation of slow slip by reducing effective stress (e.g., Kodaira et al., 2004; Liu and Rice, 2007; Audet et al., 2009; Song et al., 2009; Saffer and Wallace, 2015).

Previous drilling

There has been no previous scientific drilling at the Hikurangi subduction margin. There have been 44 industry exploration wells drilled onshore and 3 offshore the east coast of the North Island, targeting the East Coast Basin, which constitutes much of the inner Hikurangi forearc. These wells range in depth from <100 to 4352 m. None of them are commercially productive. The wells do provide some constraints on the expected stratigraphy and physical conditions at proposed Sites HSM-01A and HSM-18A.

Previous Ocean Drilling Program (ODP) drilling during Leg 181 targeted the eastern portion of the Hikurangi Plateau (Sites 1123 and 1124), ~900 and ~600 km (respectively) east of the coast of the North Island of New Zealand. These data allow a preliminary correlation of seismic stratigraphy on Line 05CM-04 (Figure **F2**) with regional seismic lines interpreted by Davy et al. (2008). The correlations suggest the following Hikurangi Plateau stratigraphy: (1) a basal sequence of high-velocity (>4 km/s) basaltic rocks deepening from ~6 km below sea level (bsl) beneath Tūranganui Knoll Seamount to ~7.5 km bsl beneath the Hikurangi Trough; (2) an overlying 3 km thick Hikurangi Basement Sequence (HKB), interpreted to comprise 120 Ma volcaniclastics and/or chert/limestone; (3) an upper late stage (100–90 Ma) volcanic cone and seamount constructional sequence (VB); (4) a highly reflective, 150–230 m thick infilling sedimentary cover sequence beneath the Hikurangi Trough, comprising an upper sequence (70–32 Ma) of nannofossil chalks and mudstones and a possible lower sequence (100–70 Ma) of clastic sedimentary rocks (MES on Figure **F2**); and (5) a 1000–1200 m thick trench-fill cover sequence of late Cenozoic turbidites, mudstones, and debris flows, the lower ~290 m of which is characterized by sediment waves. At the deformation front, beneath Puke Ridge (Figure **F2**), the subduction décollement is developed at about 5 km bsl and about 2 km below the seabed in the upper part of the HKB sequence of volcaniclastics and/or chert/limestone.

Seismic studies and site survey data

Supporting site survey data for Expedition 375 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P781 for the proposal number). The northern Hikurangi margin has undergone significant active source seismic investigation in the last decade (see Barker et al. [2009] and Sutherland et al. [2009]). The NIGHT (2001) and 05CM (2005) surveys both acquired deep high-quality seismic reflection data in the region of the Hikurangi SSEs (Henrys et al., 2006; Barker et al., 2009). The New Zealand Ministry of Economic Development's 05CM survey was conducted to assess petroleum prospects and consisted of ~2800 km of 2-D seismic reflection data including 33 dip and 6 strike profiles (Figure **F3**). Data were acquired by Multiwave Geophysical onboard the motor vessel (M/V) *Pacific Titan* using a 4140 in^3, 2000 psi air gun source. Streamer length varied between lines from 12 to 4 km, with varying record lengths of 12 to 8 s two-way traveltime (TWT) and shot intervals of 37.5 to 25 m. Line 05CM-04 (Figure **F2**) was recorded with a 12 km (960 channel) streamer to 12 s TWT. Data were processed by GNS Science and Fugro, and prestack time migrated with 12.5 m common depth point bins. Additional shallow penetration (1–3 s TWT), low-fold seismic surveys, rock dredge and shallow sediment core samples, and swath bathymetry provide details of seafloor geomorphology, shallow structure, and stratigraphy (Figure **F3**) (e.g., Mountjoy et al., 2009; Pedley et al., 2010; Mountjoy and Barnes, 2011). Bathymetry data include SIMRAD EM300 30 kHz multibeam data acquired by the National Institute of Water and Atmospheric Research (NIWA). Additional data in the drilling transect area were acquired in October 2011 during a New Zealand–funded cruise aboard the R/V *Tangaroa*. Approximately 400 km of seismic reflection data were collected during Surveys TAN1114 and TAN1213 with a seismic source consisting of two 45/105 generator-injector (GI) guns (total volume = 300 in^3) operated at 140 bar pressure, a typical shot interval of 25 m (10.8 s), and a 600 m long Geometrics Geoeel 48-channel streamer with a receiver group interval of 12.5 m. Seismic data were processed to poststack, time-migrated (finite-difference migration) sections, with a 6.25 m common depth point (CDP) bin spacing resulting in 12-fold stacks. The depth conversion of these sections at drilling site locations is based on the high-density velocity analysis derived from Line 05CM-04.

Scientific objectives

Coring, downhole logging, and long-term observatories installed at the Expedition 375 drill sites will resolve competing hypotheses and address key questions regarding the generation of slow slip and the mechanics of subduction megathrusts. Major hypotheses that will be tested are as follows:

1. SSEs propagate to the trench. They are not confined to a specific (narrow) pressure or temperature range.
2. Pore fluid pressure is elevated in the source region of SSEs. The elevated pore pressures are driven by a combination of compaction disequilibrium and mineral dehydration reactions that occur as sediments and altered igneous crust on the incoming plate are buried during subduction.
3. SSEs occur in regions of conditional frictional stability. A single SSE fault patch can fail by multiple slip behaviors depending on in situ conditions and state (e.g., steady creep, episodic slow slip, and seismic slip).
4. There is a continuum of duration and magnitude characteristics of SSEs and slow seismic behavior along the shallowest reaches of the subduction megathrust.
5. Slow slip events drive fluid flow along faults and throughout the upper plate.

To test these hypotheses, Expeditions 375 and 372 will undertake a coordinated strategy of LWD, coring, and observatory installation to accomplish three primary scientific objectives, outlined here and addressed in further detail below:

1. Document the in situ conditions, material properties, and composition of the subduction inputs and the shallow plate boundary near the trench. These rocks comprise the protolith and reveal the initial conditions for fault rocks that are transported into the SSE source zone at greater depth. In the case of the shallow fault zone, these materials may in fact host SSEs if the events propagate to the trench (e.g., Wallace et al., 2016).
2. Characterize the stress regime, temperatures, rock physical properties, lithologies, fluid pressures, fluid geochemistry, flow pathways, and structure of the upper plate above the SSE source.
3. Monitor hydrogeology, seismicity, temperature, and deformation related to SSEs via a pair of borehole observatories.

1. *Objective 1: characterize the compositional, thermal, hydrogeological, frictional, geochemical, structural, and diagenetic conditions associated with the SSE rupture area.*

To achieve this goal, characterization of the incoming stratigraphy and upper oceanic basement rocks, together with the shallow, most active strand of the frontal thrust system, is essential. This characterization involves a combination of coring, downhole measurements, and logging at proposed Sites HSM-13B, HSM-08A, and HSM-18A, followed by a strategy of carefully coordinated sampling and postexpedition laboratory analyses (e.g., Screaton et al., 2009; Underwood et al., 2010). Proposed Site HSM-13B (or HSM-05A) targets the entire sediment package on top of the Hikurangi Plateau and, if drilling conditions allow, will penetrate into the top of the basaltic lava and volcaniclastic sequence. Proposed Site HSM-08A will drill a relatively short distance (<150 m) into the Tūranganui Knoll seamount to capture a representative section of the upper, altered, basaltic basement. Proposed Site HSM-18A will provide access to material from the frontal thrust in the up-dip region of the plate interface early in its evolution, at low temperature and low effective stress. LWD during Expedition 372 at proposed Sites HSM-18A and HSM-05A (which targets a similar section to proposed Site HSM-13B) will document continuous downhole trends in sediment properties and structure and characterize stress conditions through analysis of wellbore failures (e.g., Chang et al., 2010). After LWD, continuous coring during Expedition 375 will provide key samples and data sets for sediment/rock physical properties, mineral composition, pore fluid composition, and downhole temperature, with a focus on hydrogeology and fault mechanical processes. These data are also critical for refined depth conversion of the existing 2-D and planned 3-D seismic data and, most importantly, to quantitatively extend knowledge of in situ conditions (stress, fault zone properties, and pore pressure) away from the boreholes over a broader region (Bangs and Gulick, 2005; Tobin and Saffer, 2009). Overall, this objective will constrain (1) the composition and frictional properties of subduction inputs and the shallow plate interface, (2) the hydrologic and thermal conditions of the incoming plate and shallow fault, and (3) the structural character, stress conditions, and mechanical properties of the main active thrust and subduction inputs.

2. *Objective 2: characterize the properties and conditions in the upper plate overlying the SSE source region.*

The LWD resistivity-at-the-bit (RAB) imaging data acquired during Expedition 372 at proposed Site HSM-01A will provide key information about fracture and faulting patterns and will allow us to evaluate the relationship between fractured intervals and any geochemical or thermal evidence of fluid flow (e.g., Kopf et al., 2003). The RAB data will also document wellbore failures if present (borehole breakouts and/or drilling induced tensile fractures) to determine maximum and minimum horizontal stress orientations. In combination with rock physical properties data, these data will be used to constrain stress magnitudes that may reflect variations in absolute strength of the plate boundary below (e.g., Zoback et al., 2007; Lin et al., 2010; Chang et al., 2010). Core samples from proposed Site HSM-01A will enable measurements of rock elastic and physical properties needed to confidently interpret observatory data and wellbore failures. Pore fluid analysis will help to evaluate the source of fluids above and surrounding the region of SSE that may flow upward and escape through the fractured and structurally disrupted hanging wall (e.g., Kopf et al., 2003; Hensen et al., 2004; Ranero et al., 2008). Downhole temperature measurements will constrain thermal models of the margin needed to estimate the temperature structure and its relationship to slow slip and ultimately to estimate the loci of thermally driven dehydration reactions relative to SSE source regions (e.g., Saffer et al., 2008; Peacock, 2009). Core samples and downhole data from proposed Site HSM-01A will provide critical physical and elastic properties information for refined depth conversion of the existing and proposed seismic data.

3. *Objective 3: monitor deformation, hydrogeology, and chemistry via borehole observatories.*

Borehole observatories will be installed at the proposed frontal thrust site (HSM-18A) and the proposed hanging wall site above the source of large SSE slip (HSM-01A). The CORK observatory at proposed Site HSM-18A will involve multilevel pressure sensing above, within, and below the fault zone, as well as distributed temperature sensing using a string of autonomous miniature temperature loggers (MTLs) (Figure **F4**). Fluid flow rates and fluid geochemical sampling within the fault zone interval will be achieved using OsmoSamplers and an OsmoFlowmeter (Jannasch et al., 2004; Solomon et al., 2009). The CORK at proposed Site HSM-01A involves a simpler design (Figure **F5**) with two levels of formation pressure sensing and a distributed string of MTLs. Both CORKs will have pressure sensing at the wellhead to provide a seafloor reference for the downhole pressure sensors; the wellhead sensors will also provide critical data to resolve pressure changes due to vertical deformation of the seafloor during SSEs (e.g., Wallace et al., 2016). LWD acquired during Expedition 372 at proposed Sites HSM-01A and HSM-18A will be used in combination with coring results from those sites to identify target zones for observatory monitoring.

The main goals of the proposed observatories are as follows:

1. Monitor temporal variations in pore fluid pressure, temperature, fluid geochemistry, and flow rate within the shallow fault zone (near the trench; proposed Site HSM-18A), hanging wall, and footwall, as well as pressure and temperature in the hanging wall further landward (proposed Site HSM-01A), through several SSE cycles. These data will quantify ambient pore pressure, provide information about potential links between hydraulic and geochemical transients and SSEs, and constrain the source region of fluids associated with SSEs (e.g., Solomon et al., 2009; Davis et al., 2011).
2. Determine ambient temperatures to better constrain the thermal regime of slow slip.
3. Determine formation hydraulic and elastic properties using tidal loading.
4. Integrate pore pressure changes (as a direct proxy for volumetric strain) within a broader framework of deformation monitoring from an existing onshore cGPS network (Figure **F1**) and several seafloor sensors planned for northern Hikurangi to constrain the spatial and temporal distribution of slip during SSEs.

Drilling and coring strategy

Expedition 375 will include coring, logging, and installation of borehole observatories along a transect of boreholes spanning the incoming Pacific plate seaward of the subduction trench (proposed Sites HSM-08A and HSM-13B/HSM-05A), a site penetrating the frontal thrust near the trench (proposed Site HSM-18A), and a site on the upper slope above a clearly defined patch that slips in repeating SSEs (proposed Site HSM-01A). The proposed primary drill sites, alternate sites, and drilling and coring strategy for each are described further below (Tables **T1**, **T2**, **T3**). At all sites, wireline logging will be conducted following coring if hole conditions permit (see **Downhole measurements strategy**). Several of the proposed primary sites and alternates are the same as those planned for LWD operations during Expedition 372, and these are also described in the *Scientific Prospectus* for that expedition (Barnes et al., in press).

The final detailed operations plan will depend on drilling conditions encountered during LWD operations at the primary sites and on timing constraints and weather conditions (Tables **T1**, **T2**). Two "end-member" operations plans are outlined here, representing (1) a conservative model in which observatory casing is lowered into the holes after drilling and (2) a more aggressive model in which casing is drilled in. In the first model, lowering the observatory casing requires considerably more time but eliminates the risk of torque accumulation and "stick-slip" of the casing while drilling it into the formation, which could damage the hydraulic umbilical outside of the casing. In the more conservative operations plan, the added time for observatory installations will require elimination of other operations, including coring of the upper ~740 m of the subduction inputs and wireline logging at most sites (Table **T2**). This operations model would also require coring of a proposed shallower subduction inputs site (HSM-05A, described below) where LWD will have penetrated the section during Expedition 372, rather than an expanded section at proposed Site HSM-13B. In contrast, the more aggressive operations plan would potentially allow time for coring of the entire section at proposed Site HSM-13B and wireline logging at most of the primary sites (Table **T1**). On the basis of time or operational constraints, it is also likely that the actual operations plan will include elements of both models; for example, the more conservative casing installation may be adopted at proposed Site HSM-18A, whereas we may opt to drill in the casing at proposed Site HSM-01 where the formation is expected to be softer and the total depth is shallower.

Proposed primary and alternate sites

Upper slope site

Proposed Site HSM-01A is located on the upper continental slope ~38 km from shore at a water depth of 994 m at the landward edge of a midslope sedimentary basin (Figure **F4**; Table **T1**). On the basis of regional stratigraphic and seismic interpretations, the hole is expected to penetrate ~440 m of Quaternary deposits, including mass transport deposits and interlayered muds, sands, and ash. The base of this sequence is marked by an erosional unconformity underlain by seismically reflective landward-dipping strata of likely Miocene age, although Pliocene sediments may be present as well. On the basis of correlation with the Tolaga Group onshore, the sequence below the unconformity is expected to include sandy and muddy turbidites, with possible calcareous sandstone/mudstone and breccia intervals. A bottom-simulating reflector (BSR) is identified at ~570 meters below seafloor (mbsf).

Planned drilling at proposed Site HSM-01A includes coring from the seafloor to 650 mbsf with the advanced piston coring (APC)/extended core barrel (XCB) systems. Coring will provide key information about rock physical properties, composition, and structural geology and deformation in the upper plate above the SSE source region. Pore fluid geochemistry data will provide insights into diagenetic processes and potential sources and flow pathways of fluid sampled in the hanging wall. In conjunction with LWD data collected during Expedition 372, coring data will guide the selection of casing screen depths for pressure monitoring in the planned observatory.

One key focus for postexpedition studies on core samples will be geomechanical measurements to define poroelastic and strength properties of the formation. These data will be essential for interpretation of observatory data, such as calibrating the use of pore pressure as a proxy for volumetric strain (e.g., Davis et al., 2009). Similarly, measurements of strength, permeability, and elastic moduli will provide important context for the interpretation of borehole failures as indicators of in situ stress magnitude (e.g., Chang et al., 2010; Huffman and Saffer, 2016), parameterization of hydrological models, and core-log-seismic integration.

Three alternate sites for proposed Site HSM-01A have been identified to achieve the key scientific objectives in the event that operations at proposed Site HSM-01A are unsuccessful or are not possible. These include proposed Sites HSM-21B, HSM-22B, and HSM-23B (Figures **F4**, **F5**; Table **T3**). These sites lie within the same sedimentary basin, within 1–3 km from proposed Site HSM-01A, and are characterized by comparable seismic stratigraphy.

Frontal thrust site

Proposed Site HSM-18A is located on the lower continental slope near the trench and ~73 km from shore in 3168 m water depth (Figure **F6**; Table **T1**). This site is located on the forelimb of an anticline formed by the frontal thrust; note that seismic Profile TAN1114-05 crosses the thrust obliquely and therefore shows an apparent dip shallower than the true dip of the frontal thrust. Planned drilling at proposed Site HSM-18A will penetrate ~450 m of the hanging wall of the frontal thrust, the frontal thrust fault, and ~250 m into the footwall. Drilling is expected to encounter accreted Pleistocene trench-fill sediments comprising sand and mud turbidites, ash, and possibly mass transport deposits in both the hanging wall and footwall of the thrust.

Drilling at proposed Site HSM-18A will include APC/XCB coring from the seafloor to 700 mbsf. The highest priority targets for coring at the site are the lower ~200 m of the hanging wall (>250 mbsf), the fault zone at ~450 mbsf, and the footwall of the thrust. Thus, if time constraints are a consideration and LWD operations at the site are successful during Expedition 372, it is possible that the upper ~250 m of the section could be drilled without recovery, with coring beginning at ~250 mbsf.

The key scientific objectives of coring at proposed Site HSM-18A are to define the structures and deformation, physical properties, lithology and composition, and interstitial fluid geochemistry of the frontal thrust fault and surrounding country rock. Coring results will be used in combination with LWD data to identify the fault zone in order to accurately define the depth for observatory pore pressure monitoring and geochemical sampling (see **Observatory Installation**) and to select optimal locations (minimally disturbed mud-rich and presumably low-permeability zones) for the pressure monitoring in the hanging wall and footwall.

The key foci for postexpedition studies on core samples include (but are not limited to) (1) structural analysis of fractures and faults to define deformation behavior, style, and orientations (e.g., Byrne et al., 2009); (2) studies of fault and wall rock rheology and friction to test hypotheses linking fault constitutive properties to slip behavior (e.g., Saffer and Wallace, 2015; Leeman et al., 2016); (3) geomechanical measurements to define poroelastic and strength properties of the formation to guide interpretation of observatory data as described above for proposed Site HSM-01A (e.g., Davis et al., 2009); and (4) measurements of strength, permeability, and elastic moduli to provide context for the interpretation of borehole failures as indicators of in situ stress magnitude, parameterization of hydrological models, and core-log-seismic integration.

Three alternate sites have been selected for the proposed frontal thrust site (Figure **F7**; Table **T3**): proposed Sites HSM-19B, HSM-16B, and HSM-15A. Proposed Sites HSM-15A and HSM-16B lie on the hanging wall of another major out-of-sequence thrust fault west of the deformation front. Proposed Site HSM-15A has been approved to 600 mbsf and is expected to encounter the thrust fault at 325 m. Proposed Site HSM-16B has been approved to 1350 mbsf and is expected to encounter the major thrust fault at 1055 mbsf. Proposed Site HSM-19B lies about 5 km north of proposed Site HSM-18A on the same frontal thrust, has been approved to 1100 mbsf, and is expected to encounter the frontal thrust and an imbricate fault between 887 and 964 mbsf. Of these three sites, proposed Site HSM-15A is the first alternate, largely because it would intersect a major thrust fault at a comparably shallow depth (325 mbsf) below the seafloor to that of proposed Site HSM-18A. All alternate sites are expected to penetrate the accreted trench turbidites and possibly some cover slope sediments. Proposed Sites HSM-16B and HSM-19B would also likely penetrate some of the subturbiditic pelagic sequence in the hanging wall of the respective thrust faults.

Subduction inputs

Drilling and coring of subduction inputs will focus on two objectives at two primary sites: sampling of an expanded sediment section associated with a basement low at proposed Site HSM-13B (or proposed Site HSM-05A in the more conservative operations plan outlined above) and sampling of a thin sediment section and basement on the Tūranganui Knoll seamount at proposed Site HSM-08A (Figures **F8**, **F9**; Table **T1**). Proposed Site HSM-13B lies on a turbidite plain ~92 km from shore in 3508 m water depth and 7 km south of proposed Site HSM-05A (a primary Expedition 372 LWD site; see Barnes et al., in press). Proposed Site HSM-08 is located ~10 km southeast of proposed Site HSM-13B in 2908 m water depth atop the western flank of the Tūranganui Knoll.

The primary objective at proposed Site HSM-13B is to sample the sedimentary sequence on the subducting Pacific plate in order to provide insight into the lithologies and conditions expected deeper down the subduction interface and within the SSE source area. Drilling at proposed Site HSM-13B is expected to encounter sediments and rocks of late Quaternary to Cretaceous age (see bottom panel in Figure **F8**), based on regional seismic stratigraphic interpretation of stratigraphy of the Hikurangi Plateau and Hikurangi Trough (Barnes et al., 2010; Davy et al., 2008). Beneath the seafloor, a succession of clastic trench turbidites and related sediments are interpreted to overlie the older pelagic sedimentary and volcanic sequence of the subducting Hikurangi Plateau. The upper ~730 m of the section is expected to consist mainly of mud and sand turbidites, hemipelagic sediment, debris flow material, and minor ash, of predominantly Pliocene–Quaternary age. The package between 730 and 1245 mbsf is interpreted to correlate with Late Cretaceous, Paleogene, and Miocene sedimentary rocks of the Hikurangi Plateau cover sequence and may include nannofossil chalk, mudstone, tephra, and possible sandstone, with possible unconformities. The lower sequence below 1245 mbsf is strongly reflective and is expected to include basalts, volcaniclastic sediments, and breccia, with possible intervals of pelagic chert and/or limestone (Davy et al., 2008). Proposed Site HSM-08 will penetrate a veneer of sediment overlying the basement of the Tūranganui Knoll (Figure **F9**). Drilling is expected to encounter ~20 m of fine-grained sediment of unknown age overlying altered basalt.

Priorities for coring at proposed Site HSM-13B are to sample the entire inputs section, with a highest priority on recovering the materials below ~700 mbsf. In order to maximize the likelihood of successfully coring the deep portion of the section, the drilling strategy includes APC/XCB coring to 750 mbsf or to refusal, followed by drilling in casing to this depth in a second hole and rotary core barrel (RCB) coring below the casing as deep as possible (to a maximum of 1500 mbsf).

Because sampling the lower portion of the succession is the top priority, if there are operational or timing constraints, or in the case of the "conservative" operations plan described above, inputs coring may be moved to proposed Site HSM-05A (described briefly below; Barnes et al., in press). If necessary for time or operational reasons, and if LWD data are available for the upper part of the succession at proposed Sites HSM-05A or HSM-13B, the coring plan may also be modified to drill the casing in to ~740 mbsf and begin RCB coring below the casing. At proposed Site HSM-08, coring will target the basement of the knoll to characterize its composition, extent of alteration and hydration, and structure and hydrology prior to transport into the SSE source region at greater depth.

At both inputs sites, the scientific objectives of coring are to define any structures and deformation, physical properties, lithology and composition, and interstitial fluid geochemistry of the incoming material in its "presubduction" state. At proposed Site HSM-13B, coring will also be used to correlate with LWD data collected at proposed Site HSM-05 during Expedition 372 (Barnes et al., in press) and for core-log-seismic integration regionally across the Hikurangi Trough. Priorities for postexpedition analysis of cores include but are not limited to measurement of the mechanical, elastic, frictional, and hydrological properties of the incoming sediment and basement, along with detailed analyses of composition and alteration.

Two alternate sites have been identified for each of the primary inputs sites. Alternates for proposed Site HSM-13B include proposed Sites HSM-05A and HSM-14A (Figures **F8**, **F10**, **F11**; Tables **T2**, **T3**). Proposed Site HSM-05A is a primary site for Expedition 372 LWD operations and is located ~7 km north of proposed Site HSM-13B and adjacent to the Tūranganui Knoll, where the lower part of the section is condensed relative to that at proposed Site HSM-13B, with the Miocene to Cretaceous section of the succession spanning from ~689 to 890 mbsf. Coring at this site would span from the seafloor to a maximum of 1200 mbsf if conditions and time permit. Proposed Site HSM-14A lies about 1 km southwest of proposed Site HSM-05A and includes a nearly identical stratigraphic sequence. Proposed Site HSM-14A is approved for drilling to 1350 mbsf and is expected to encounter the top of the Hikurangi Plateau volcanics at about 987 mbsf.

Alternates for Proposed Site HSM-14A Site HSM-08 include Proposed Site HSM-14A Sites HSM-11A and HSM-12A, located ~2 km south and <1 km west-southwest of Proposed Site HSM-14A Site HSM-08A, respectively (Figures **F8**, **F11**; Table **T3**). Both alternate sites would penetrate the same thin sediment cover sequence overlying basement.

Downhole measurements strategy

As part of APC/half-length APC (HLAPC) coring, formation temperature measurements will be made using the advanced piston corer temperature tool (APCT-3). If time, sea state, and hole conditions permit, we also anticipate conducting pressure and temperature measurements with the temperature-dual pressure (T2P) or sediment temperature pressure (SETP) tools, with a priority for pressure measurements at proposed Sites HSM-18A and HSM-01A. The key targets for these sites will be the hanging wall and thrust fault (proposed Site HSM-18A) and the lower part of the Quaternary sequence (proposed Site HSM-01A).

Logging operations for the Hikurangi margin science program are distributed across Expeditions 372 and 375 (Tables **T1**, **T2**). LWD data will be acquired at proposed Sites HSM-01A, HSM-05A, and HSM-18A during Expedition 372 (Barnes et al., in press). Wireline logging data are planned after coring at all primary sites as part of Expedition 375 (time and hole conditions permitting). Planned wireline logging includes multiple runs and will include some combination of the triple combo, Formation MicroScanner (FMS), and sonic tool strings (Table **T1**).

Observatory installation

Borehole observatory installations are planned for proposed Sites HSM-01A and HSM-18A. The observatory at proposed Site HSM-18A (frontal thrust site) includes three levels of pore pressure monitoring, distributed temperature monitoring, a fluid flow meter, and geochemical time-series sampling (Figure **F12**). The observatory at proposed Site HSM-01A is similar in overall design, as described below, but will include only two pore pressure monitoring intervals and distributed temperature monitoring (Figure **F13**). Pore pressure monitoring will be conducted via hydraulic tubing that terminates in screens outside of casing, except in the fault zone interval at proposed Site HSM-18A. Geochemical sampling will be conducted using sampling coils driven by osmotic pumps (Jannasch et al., 2004; Solomon et al., 2005). Distributed temperature monitoring will be conducted using distributed autonomous MTLs suspended in the interior of the casing.

Both observatories consist of an outer 10¾ inch casing string with an ACORK head with a CORK-II head nested inside of it (Figures **F12**, **F13**). For both sites, the outer 10¾ inch casing will be drilled in using an underreamer and mud motor, with a mud skirt and ACORK head attached to the casing. A hydraulic release tool (HRT) will be used to release the assembly after it is drilled in.

Flat-pack hydraulic lines (0.25 inch diameter) will be strapped to the outside of the 10¾ inch casing as it is assembled and run through the moonpool. These lines will terminate in casing screens in the target intervals at depth (at their bottom) and will be connected to valves and the pressure sensing unit at the ACORK head. Pressure monitoring will take place in two intervals at proposed Site HSM-01A, located at approximately 200 and 360 mbsf. Pressure monitoring at the proposed fault zone Site HSM-18A will take place in the hanging wall (~300 mbsf), fault zone (~450 mbsf), and footwall (~500 mbsf). LWD data (from Expedition 372) and coring results from these sites will be used to refine the locations of the target intervals prior to the observatory installation. The CORK-II will be lowered into the ACORK and latched into the ACORK once lowered. Inside of the CORK-II at proposed Site HSM-18A is a titanium landing seat for the OsmoSampler and OsmoFlowmeter (see below).

To undertake temperature monitoring at proposed Sites HSM-01A and HSM-18A, MTLs will be attached to a rope (7⁄16 inch spectra line) with sinker bars at various depths to hold the rope taut. The string will consist of 15 MTLs at proposed Site HSM-01A and will be lowered into the CORK-II head and seated with a landing plug. A total of 28 MTLs will be used at proposed Site HSM-18A, with denser spacing within the fault zone interval compared to the hanging-wall and footwall intervals. OsmoSamplers and an OsmoFlowmeter will be lowered as part of the MTL string at proposed Site HSM-18A (Figure **F12**) and will land on the titanium seat inside the CORK-II casing to take position within the fault zone interval (~450 mbsf). Perforated casing (7 m high) at the fault zone monitoring interval will allow flow of formation fluids across the OsmoSamplers and OsmoFlowmeter. LWD data acquired during Expedition 372 and coring data acquired at proposed Site HSM-18A will be used to define the location of the fault zone monitoring interval.

To complement the borehole observatories, we also plan to place two seafloor instrument packages near the frontal thrust site. One of these will be a tilt meter package ~500–1000 m landward of the frontal thrust observatory at proposed Site HSM-18A to help resolve the trenchward limit of SSE propagation. The second package will be a bottom pressure recorder (BPR) placed on the subducting Pacific plate ~1000 m seaward of proposed Site HSM-18A. The BPR will act as an oceanographic reference site to enable resolution of pressure changes due to centimeter-level vertical deformation with the observatory seafloor reference pressure data. The seafloor instruments will be deployed at the end of proposed Site HSM-18A operations using the subsea camera vibration isolated television (VIT) frame and a manipulator arm.

Risks and contingency strategy

A number of challenges are associated with coring, logging, and observatory installations through thick sedimentary sections and fault zones.

Weather is always a potential issue, as sea state and the resulting heave can have adverse effects on drilling operations. The mean annual wave height is 2.3 m (4.0 m at 95% and 5.1 m at 99%). There is monthly variability, with New Zealand summer months having generally lower wave conditions compared to winter months. The mean annual wind speed is 14 kt (27 kt at 95% and 32 kt at 99%). Our operations are taking place in late summer and early fall, and weather conditions are considered unlikely to have a major impact on most coring operations. However, weather could be of particular concern for the complex sequence of observatory installations, which require relatively calm seas. The expedition could experience some weather delays depending on conditions during critical operations. Casing and reentry system deployment and RCB basement coring could also be impacted. There are no perceived drilling operational hazards associated with oceanographic currents in the region.

The primary concerns of the IODP Environmental Protection and Safety Panel during evaluation of the planned sites were related to possible overpressures and highly reflective dipping strata at the upper plate site (proposed Site HSM-01A) and, to a lesser extent, at the frontal thrust sites (proposed Sites HSM-18A, HSM-15A, HSM-16B, and HSM-19B). Continuous monitoring of annular pressure during LWD operations during Expedition 372 will address this concern prior to Expedition 375. Overpressured conditions experienced by previous industry drilling in the East Coast Basin are highly variable and strongly influenced by lithologies, primarily located in the Miocene and older sequences, so are mainly of concern at proposed Site HSM-01. Routine headspace gas analyses will be conducted for all cores that come on deck to avoid drilling into hydrocarbon or gas accumulations. The JRSO safety protocol is designed to suspend operations before any substantial hydrocarbons or gas are encountered.

There is always risk during coring operations, and the risk is higher when there are longer sections of open (uncased) hole. Poor hole conditions, such as loose unconsolidated material (e.g., sands) or collapsing holes, can prevent our ability to reach total depth at any of the planned sites. To address potential hole stability issues at proposed Sites HSM-13B and/or HSM-05A, we will drill in casing prior to RCB coring from 740 mbsf to the target of 1500 mbsf (Table **T1**). Fault zone rocks can also pose problems for drilling operations. Enhanced horizontal stresses are also likely at proposed Sites HSM-01A and HSM-18A and could lead to borehole breakouts. These stresses, in combination with highly fractured and unstable formations, may compromise hole stability. Routine drilling procedures to maintain hole conditions such as circulating drilling mud and wiper trips are included in the plan; however, more time for these procedures may be required to achieve the objectives. Hole stability will also pose a risk to completing planned wireline logging at all sites.

Contingencies

Two main contingency operations have been identified for Expedition 375 in the event that time is available either from operations being completed more quickly than expected at the primary sites or if some of the planned primary operations are not possible and there is remaining time for operations at other sites. The first of these is APC/HLAPC coring at proposed Site HSM-15A as deep as 600 mbsf to collect samples of the hanging wall, fault zone at ~325 mbsf, and footwall of the imbricate thrust (Figures **F6**, **F7**; Table **T3**). This process will provide valuable materials for postexpedition analyses of fault and wall rocks, as well as a second set of observations to characterize the materials, structural architecture, and physical properties of shallow fault zones in and near the upper extent of SSE slip.

A second main contingency option is to core at either proposed Site HSM-05A or HSM-13B (depending on the operations plan implemented during the expedition, one of these two will not be drilled as part of primary operations; see above). The goal will be to collect samples and further characterize the subduction inputs (Table **T2**). This process will provide an important tie between the two proposed primary inputs Sites HSM-13B and HSM-05A (Figure **F10**). Proposed Site HSM-05A is a primary Expedition 372 LWD site (Barnes et al., in press). In tandem, characterization of these two sites will yield an improved understanding of spatial variations in the lithology and physical properties of subduction inputs and will contribute significantly to core-log-seismic integration. If time is limited for operations at proposed Site HSM-05A, the upper part of the section may be drilled without coring, with RCB coring starting at ~650 mbsf.

In addition to these two main contingency options, operations may also be conducted at any of the alternate sites discussed above to further the overall expedition objectives (Table **T3**).

Sample and data sharing strategy

Because the objectives and original proposals for Expeditions 372 and 375 are tightly linked, sample/data requests and research plans will be shared and coordinated across both expeditions. Shipboard scientists on either expedition will be considered as part of the combined shipboard science party and will be able to request data and samples from either expedition as part of their requests.

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines (**http://www.iodp.org/policies-and-guidelines**). This document outlines the policy for distributing IODP samples and data. The document also defines the obligations that scientists incur if they receive samples and data. The Sample Allocation Committee (SAC) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postexpedition sampling. The SAC is composed of the Co-Chief Scientists, Expedition Project Manager/Staff Scientist, and IODP Curator on shore or curatorial representative on board the ship. In the case of Expeditions 372 and 375, the four Co-Chief Scientists, two Expedition Project Managers/Staff Scientists, and IODP curatorial representatives will make up a combined SAC that will oversee the distribution of samples across both expeditions.

Every member of the science party is obligated to carry out scientific research for the expedition and publish the results. All shipboard scientists, and any potential shore-based scientists, are required to submit a research plan and associated sample and data request. These will be due at least 6 months before Expedition 372 (for both expeditions) using the IODP Sample and Data Request Database (**http://www.iodp.tamu.edu/sdrm**). Based on the shipboard and shore-based research plans submitted, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and expedition 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. The SAC must approve modifications of the strategy during the expedition. Given the mutual objectives of both expeditions, care will be taken to maximize shared sampling to promote integration of data sets and enhance scientific collaboration among members of both scientific parties. 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 expedition objectives.

Shipboard sampling will include samples taken for shipboard analyses and samples needed for personal postexpedition research. We expect a large number of shipboard and personal whole-round samples to be taken for geochemical, petrophysical, and possibly microbiological measurements. 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 or reduced sample size and frequency. The SAC may require an additional formal sampling plan to be developed for critical intervals. All archive halves will be designated as permanent archives and will not be sampled.

The cores from both Expeditions 372 and 375 will be delivered to the IODP Gulf Coast Repository in College Station, Texas (USA), for permanent storage. All Expedition 372 and 375 data and samples will be protected by a 1 year moratorium period that will start at the end Expedition 375. During this moratorium, all data and samples will be available only to the expedition shipboard scientists and approved shore-based participants.

Expedition scientific participants

The current list of scientific participants for Expedition 375 can be found at: **http://iodp.tamu.edu/scienceops/expeditions/hikurangi_subduction_margin.html**.

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Table T1. Operations plan for primary sites, Expedition 375. * = hole may include sediment temperature/pressure tool (SETP)/temperature dual-pressure tool (T2P) deployments not included in time estimate. EPSP = Environmental Protection and Safety Panel, LWD = logging while drilling, APC = advanced piston corer, XCB = extended core barrel, APCT-3 = advanced piston corer temperature tool, FMS = Formation MicroScanner, TD = total depth, RCB = rotary core barrel.

Proposed site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations	Transit (days)	Drilling, coring (days)	Logging (days)
Wellington, New Zealand			Begin expedition	5.0	Port call days	
			Transit ~270 nmi to HSM-18A at 10.5 kt	1.4		
HSM-18A	38.87191°S	3179	Hole A: LWD to 700 mbsf to be completed during Expedition 372		0.0	
Depth approved	178.93993°E		Hole B: APC/XCB to 700 mbsf with orientation and APCT-3 measurements*		5.4	
by EPSP			Hole B (continued): Log with triple combo and FMS-sonic			1.6
to 800 mbsf			Hole C: ACORK/CORK-II observatory installation to 535 mbsf (550 mbsf TD)		7.7	
			Hole C (continued): seafloor deployment of tilt meter and pressure recorder			
			Subtotal days on site: 14.8			
			Transit ~13 nmi to Site HSM-13B at 10.5 kt	0.1		
HSM-13B	39.03881°S	3519	Hole A: APC/XCB to 750 mbsf with orientation and APCT-3 measurements*		6.1	
Depth approved	179.12806°E		Hole B: Drill in reentry system to ~740 mbsf; RCB to ~1500 mbsf		12.1	
to 1500 mbsf			Hole B (continued): Log with triple combo and FMS-sonic			2.5
			Subtotal days on site: 20.7			
			Transit ~31 nmi to Site HSM-01A at 10.5 kt	0.2		
HSM-01A	38.72728°S	1005	Hole A: LWD to 650 mbsf to be completed during Expedition 372		0.0	
Depth approved	178.61423°E		Hole B: ACORK/CORK-II observatory installation to 400 mbsf (415 mbsf TD)		6.1	
to 1180 mbsf			Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 measurements*		3.3	
			Hole C (continued): Log with triple combo-sonic			0.9
			Subtotal days on site: 10.2			
			Transit ~35 nmi to HSM-08A at 10.5 kt	0.3		
HSM-08A	39.02200°S	2919	Hole A: RCB to ~150 mbsf; log with triple combo		3.9	
Depth approved	179.24600°E					0.4
to 400 mbsf			**Subtotal days on site: 4.3**			
			Transit ~297 nmi to Auckland at 10.5 kt	1.2		
Auckland, New Zealand			**End expedition**	**3.1**	**44.5**	**5.4**

Port call:	**5.0**	**Total operating days:**	**53.0**
On-site subtotal:	**49.9**	**Total expedition:**	**58.0**

Table T2. Alternate operations plan for primary sites, Expedition 375. * = hole may include sediment temperature/pressure tool (SETP)/temperature dual-pressure tool (T2P) deployments not included in time estimate. EPSP = Environmental Protection and Safety Panel, LWD = logging while drilling, APC = advanced piston corer, XCB = extended core barrel, APCT-3 = advanced piston corer temperature tool, TD = total depth, RCB = rotary core barrel.

Proposed site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations	Transit (days)	Drilling, coring (days)	Logging (days)
Wellington, New Zealand			**Begin expedition**	**5.0**	**Port call days**	
			Transit ~270 nmi to HSM-18A at 10.5 kt	1.4		
HSM-18A	38.87191°S	3179	Hole A: LWD to 700 mbsf to be completed during Expedition 372		0.0	
Depth approved	178.93993°E		Hole B: APC/XCB to 700 mbsf with orientation and APCT-3 measurements*		5.4	
by EPSP			Hole C: ACORK/CORK-II observatory installation to 535 mbsf		12.1	
to 800 mbsf			Hole C (continued): seafloor deployment of tilt meter and pressure recorder			
			Subtotal days on site: 17.5			
			Transit ~11 nmi to Site HSM-05A at 10.5 kt	0.1		
HSM-05A	38.96940° S	3549	Hole A: LWD to 750 mbsf to be completed during Expedition 372*		0.0	
Depth approved	179.13225° E		Hole B: Drill in reentry system to ~740 mbsf; RCB to ~1200 mbsf		9.2	
to 1500 mbsf			Hole C: APC/XCB to 750 mbsf with orientation and APCT-3 measurements		6.1	
			Subtotal days on site: 15.3			
			Transit ~28 nmi to Site HSM-01A at 10.5 kt	0.1		
HSM-01A	38.72728°S	1005	Hole A: LWD to 650 mbsf to be completed during Expedition 372		0.0	
Depth approved	178.61423°E		Hole B: ACORK/CORK-II observatory installation to 400 mbsf (415 mbsf TD)*		9.6	
to 1180 mbsf			Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 measurements		3.3	
			Subtotal days on site: 12.9			
			Transit ~35 nmi to HSM-08A at 10.5 kt	0.3		
HSM-08A	39.02200°S	2919	Hole A: RCB to ~150 mbsf; log with triple combo		3.9	
Depth approved	179.24600°E					0.4
to 400 mbsf			**Subtotal days on site: 4.3**			
			Transit ~297 nmi to Auckland at 10.5 kt	1.2		
Auckland, New Zealand			**End expedition**	**3.1**	**49.5**	**0.4**

Port call:	**5.0**	**Total operating days:**	**53.0**
On-site subtotal:	**49.9**	**Total expedition:**	**58.0**

Table T3. Time estimates for alternate sites, Expedition 375. Logging time not included; see primary sites in Table T1 for logging time estimates. RCB = rotary core barrel, LWD = logging while drilling, APC = advanced piston corer, XCB = extended core barrel, APCT-3 = advanced piston corer temperature tool.

Proposed site	Location (latitude, longitude)	Seafloor depth (mbrf)	Corresponding primary site	Operations	Drilling, coring (days)	Total time on site (days)
HSM-11A Depth approved to 400 mbsf	39.03002°S 179.26885°E	2788	HSM-08A	Hole A: RCB core to 150 mbsf	3.7	3.7
HSM-12A Depth approved to 400 mbsf	39.02788°S 179.24374°E	2980	HSM-08A	Hole A: RCB core to 150 mbsf	3.8	3.8
HSM-14A Depth approved to 1300 mbsf	38.97492°S 179.12154°E	3542	HSM-13B, HSM-05A	Hole A: LWD to ~1300 mbsf (Expedition 372 alternate site) Hole B: APC/XCB to ~750 mbsf with APCT-3 measurements Hole C: Drill in reentry system to ~740 mbsf; RCB to ~1300 mbsf	0.0 6.1 10.1	16.1
HSM-15A Depth approved to 600 mbsf	38.85894°S 178.89601°E	2735	HSM-18A	Hole A: LWD to ~600 mbsf (Expedition 372 alternate site) Hole B: APC/XCB to ~600 mbsf with APCT-3 measurements Hole C: ACORK/CORK-II observatory installation to ~600 mbsf	0.0 4.3 8.1	12.4
HSM-16B Depth approved to 1350 mbsf	38.91341°S 178.90684°E	2443	HSM-18A	Hole A: LWD to ~1350 mbsf (Expedition 372 alternate site) Hole B: APC/XCB to ~600 mbsf with APCT-3 measurements Hole C: ACORK/CORK-II observatory installation to ~600 mbsf Hole D: Drill in reentry system to ~600 mbsf; RCB to ~1350 mbsf	0.0 4.1 7.8 9.3	21.2
HSM-19B Depth approved to 1100 mbsf	38.83610°S 178.94390°E	3035	HSM-18A	Hole A: LWD to ~1100 mbsf (Expedition 372 alternate site) Hole B: APC/XCB to ~600 mbsf with APCT-3 measurements Hole C: ACORK/CORK-II observatory installation to ~600 mbsf Hole D: Drill in reentry system to ~600 mbsf; RCB to ~1100 mbsf	0.0 4.5 8.2 7.6	20.4
HSM-21B Depth approved to 1200 mbsf	38.72006°S 178.61857°E	1022	HSM-01A	Hole A: LWD to ~650 mbsf (Expedition 372 alternate site) Hole B: ACORK/CORK-II observatory installation to ~400 mbsf Hole C: APC/XCB to ~650 mbsf with APCT-3 measurements	0.0 5.4 3.3	8.7
HSM-22B Depth approved to 1200 mbsf	38.71823°S 178.64254°E	1052	HSM-01A	Hole A: LWD to ~650 mbsf (Expedition 372 alternate site) Hole B: ACORK/CORK-II observatory installation to ~400 mbsf Hole C: APC/XCB to ~650 mbsf with APCT-3 measurements	0.0 5.4 3.3	8.7
HSM-23B Depth approved to 1300 mbsf	38.71705°S 178.64956°E	1056	HSM-01A	Hole A: LWD to ~650 mbsf (Expedition 372 alternate site) Hole B: ACORK/CORK-II observatory installation to ~400 mbsf Hole C: APC/XCB to ~650 mbsf with APCT-3 measurements	0.0 5.4 3.3	8.7

Figure F1. Tectonic setting (upper left inset) and location of slip on the interface in the January/February (green contours) and the March/April (orange contours) 2010 SSEs (Wallace and Beavan, 2010) and the reflective properties of the subduction interface (Bell et al., 2010) at northern Hikurangi. Black dashed line shows the location of the drilling transect (see Figure F2); pink ellipses are the planned drill sites. Blue dots are locations of triggered seismicity during the January/February 2010 SSE. Red stars are locations of two tsunamigenic subduction interface earthquakes (Mw 6.9–7.1) in March and May of 1947. Lower left inset shows the east component of the position time series for a cGPS site near Gisborne to demonstrate the repeatability of SSEs since they were first observed in 2002.

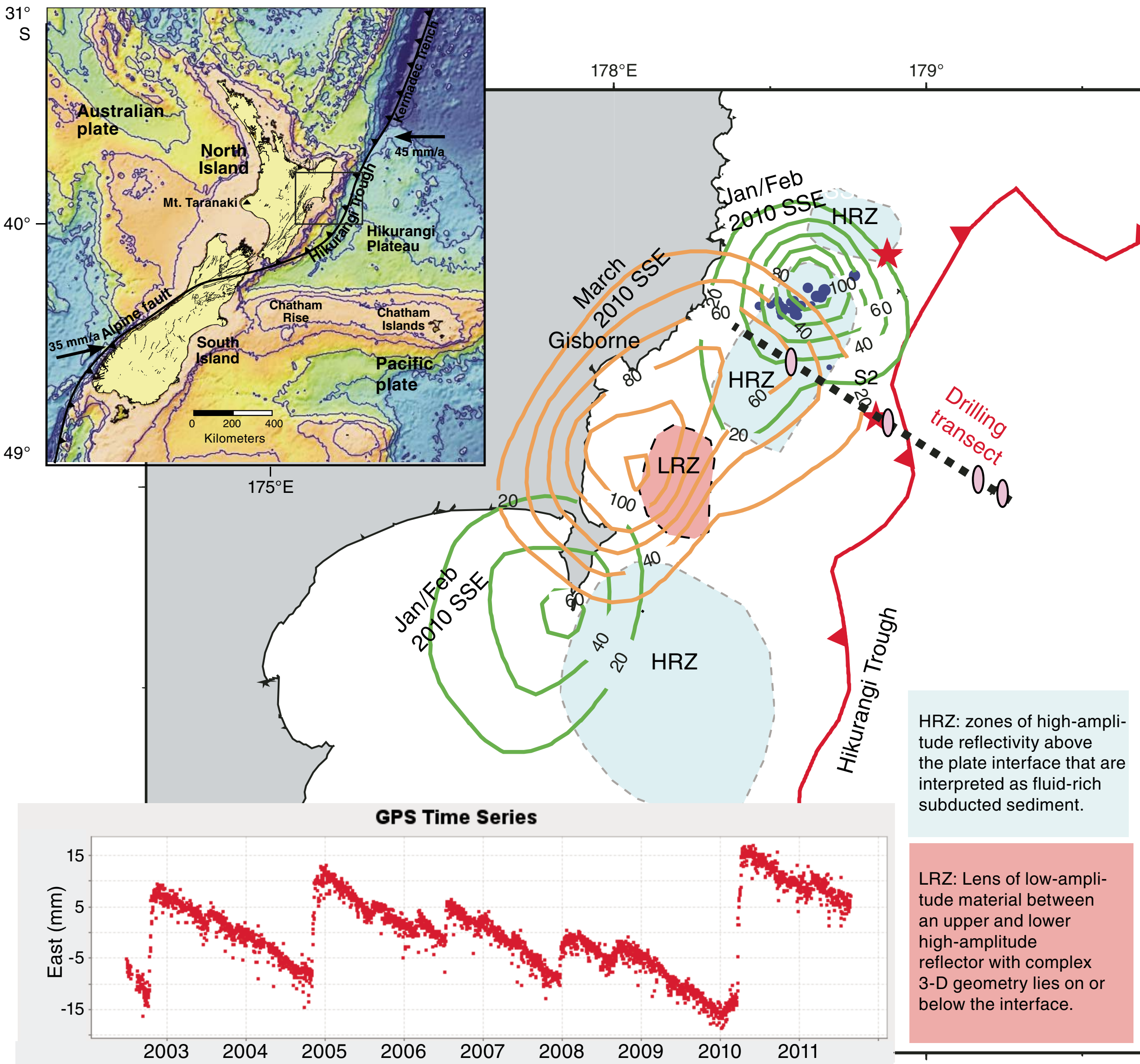


Figure F2. Depth converted seismic Profile 05CM-04 showing the locations and depths of several of the planned primary and alternate sites, as well as stratigraphic and structural interpretation. Red star = projected location of March 1947 tsunami earthquake. Location of the profile coincides with the drilling transect shown in Figure **F1**.

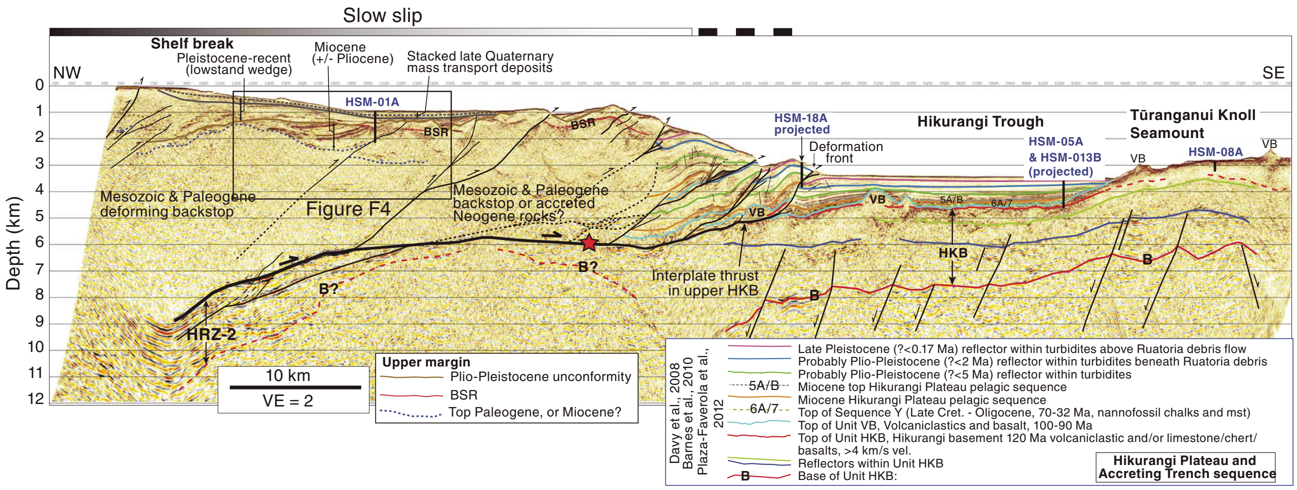


Figure F3. Bathymetry and location of seismic lines (05CM-04 in black, other lines in white) in the region of Expedition 375. Approved primary (yellow) and alternate (red) drill sites are shown.

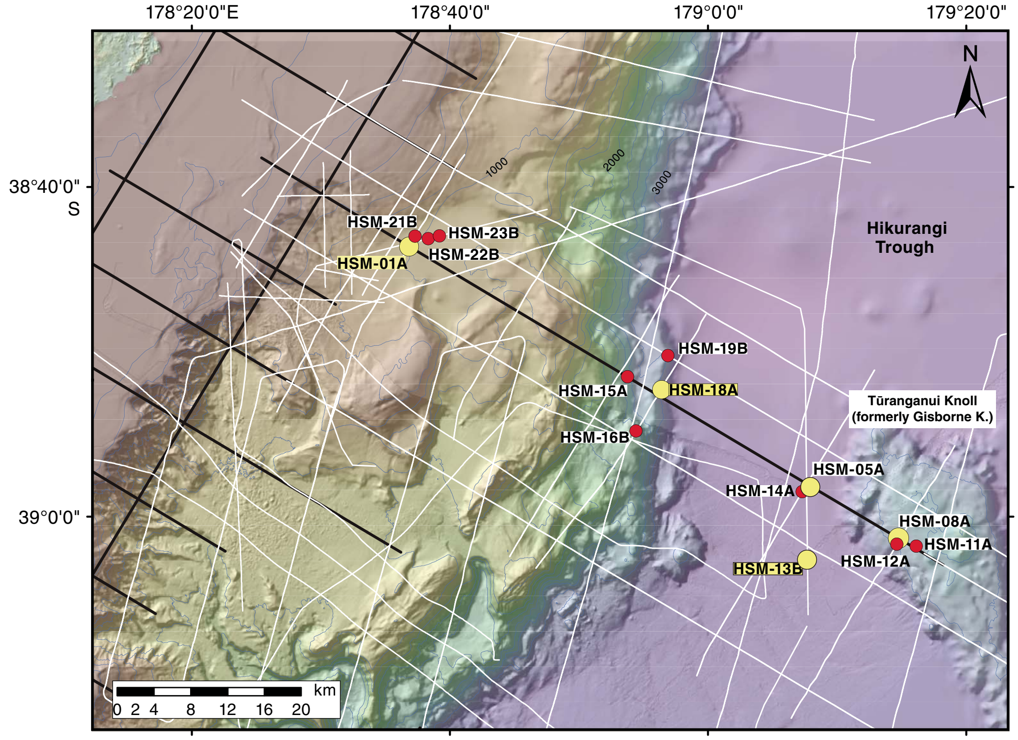


Figure F4. Top: Bathymetry map showing locations of upper slope proposed primary Site HSM-01A and alternate Sites HSM-21B, HSM-22B, and HSM-23B with seismic crossing lines. Bottom: Detailed seismic image for proposed primary Site HSM-01A. Black bar shows EPSP approved depths; red bar shows planned depths in current operations plan.

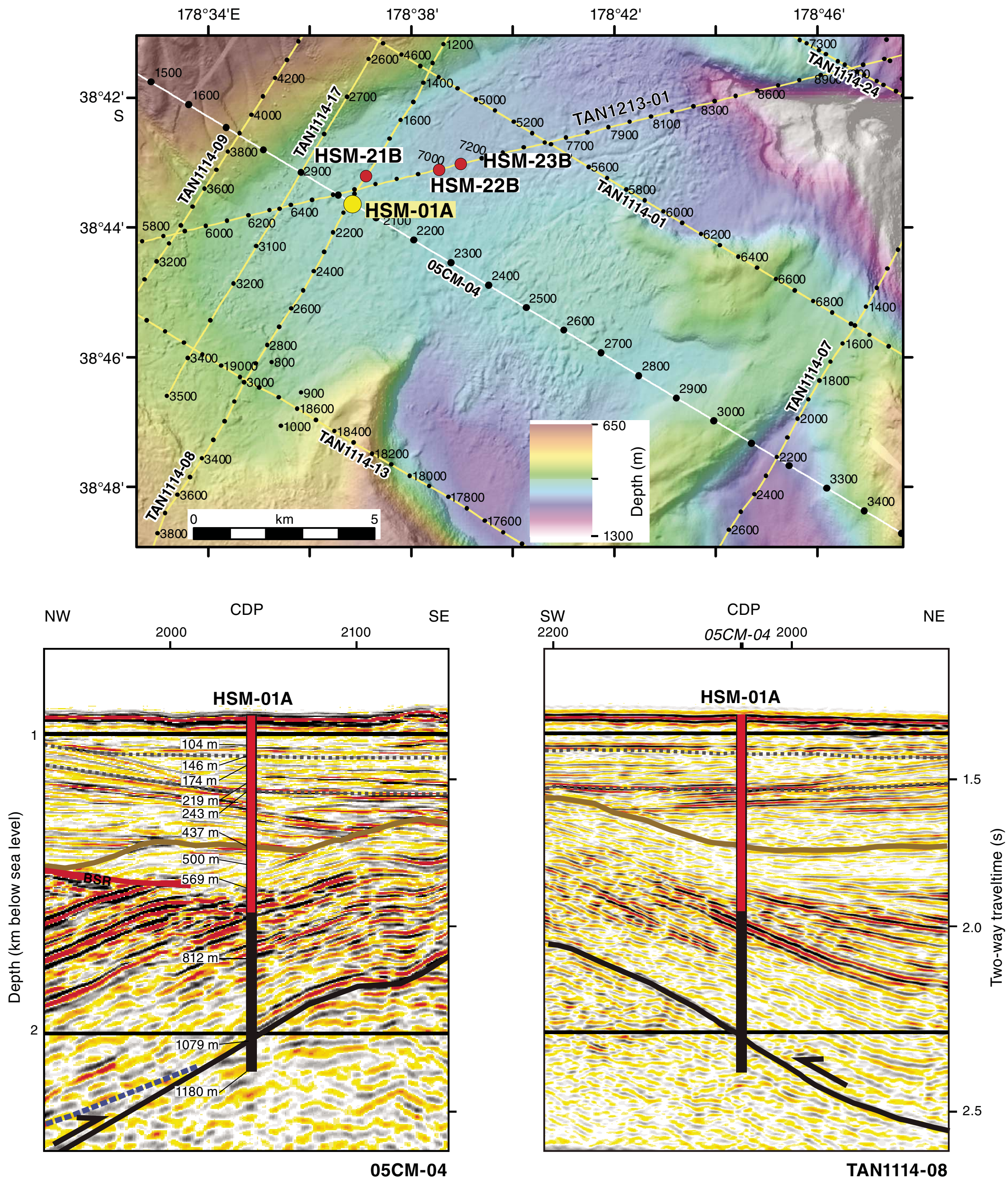


Figure F5. Detailed seismic images for proposed alternate Sites HSM-21A, HSM-22A, and HSM-23A. Locations shown in Figure **F4**. Black bar shows EPSP approved depths; red bar shows planned depths in current operations plan.

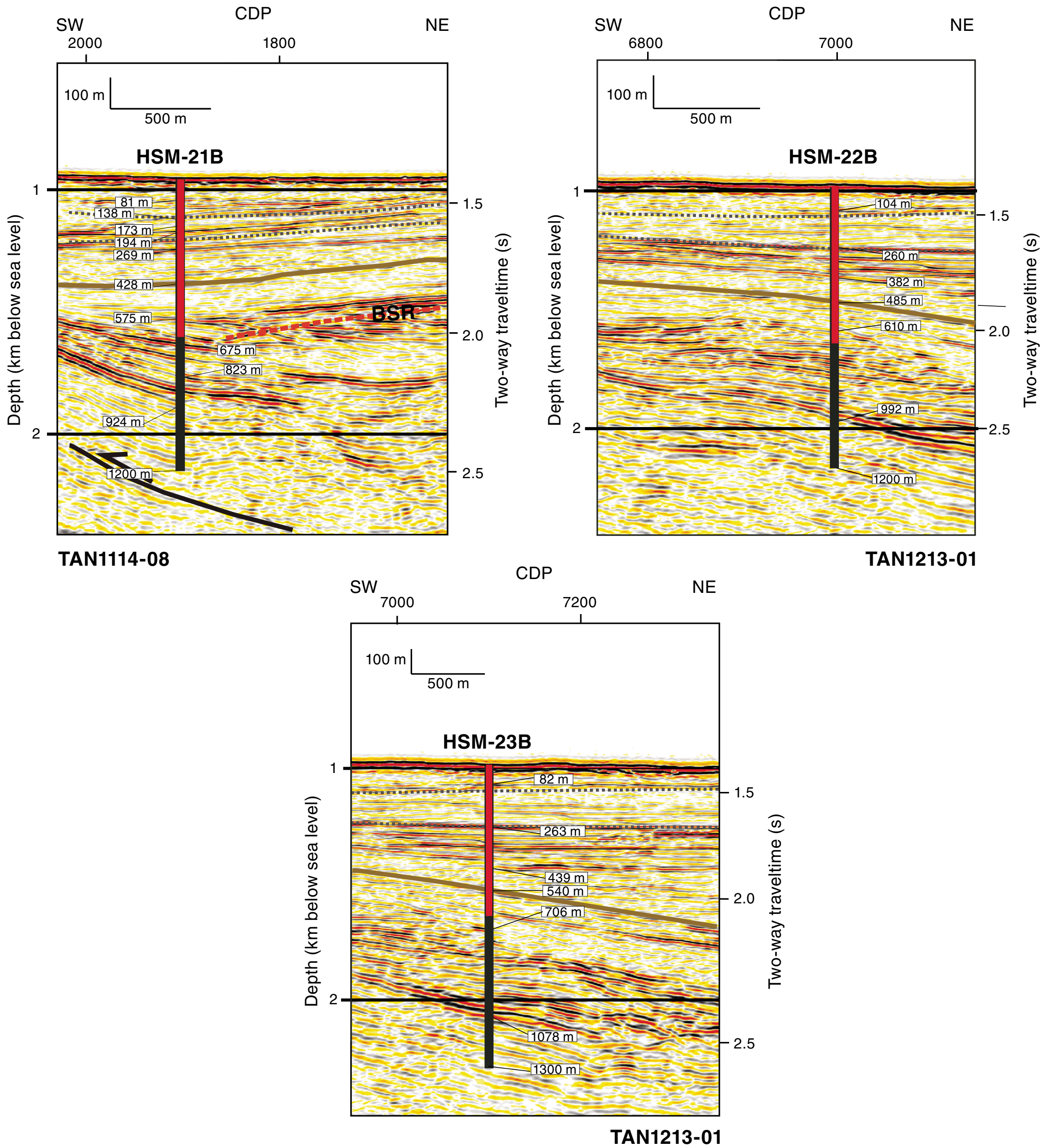
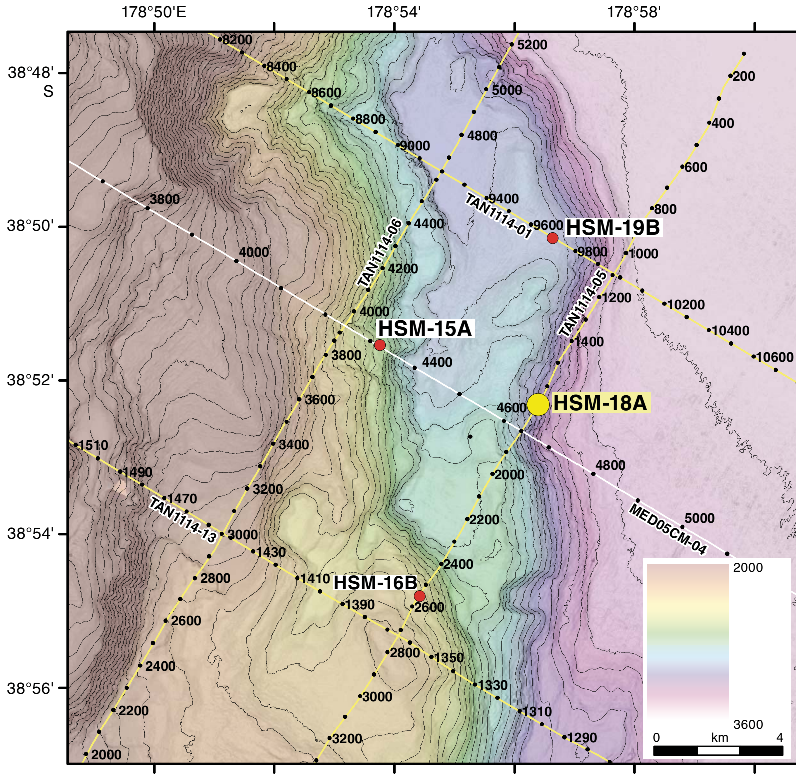


Figure F6. Top: Bathymetry map showing locations of frontal thrust proposed primary Site HSM-18A and alternate Sites HSM-15A, HSM-16B, and HSM-19B with seismic crossing lines. Bottom: Detailed seismic image for proposed primary Site HSM-18A. Black bar shows EPSP approved depths; red bar shows planned depths in current operations plan.



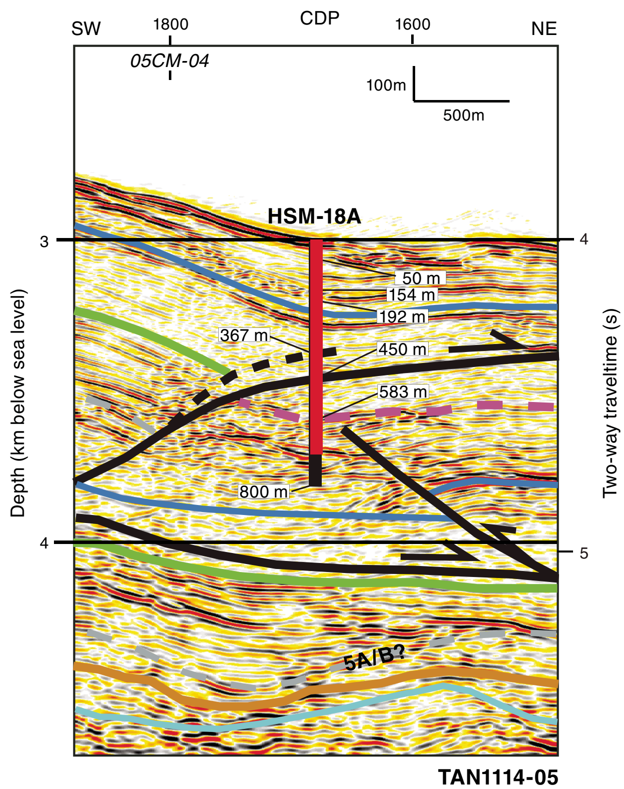


Figure F7. Detailed seismic images for proposed alternate Sites HSM-15A, HSM-16B, and HSM-19B. Locations shown in Figure **F6**.

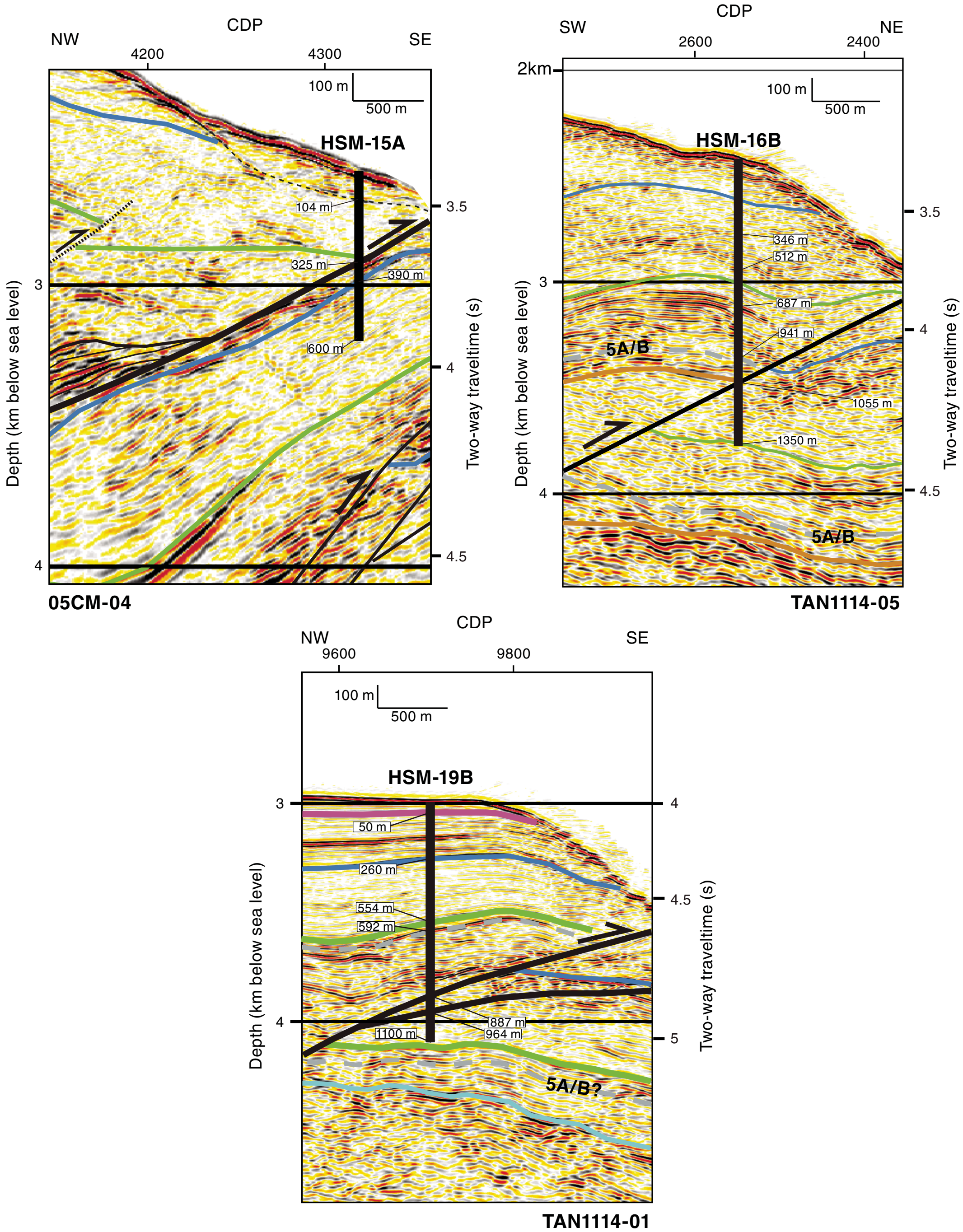


Figure F8. Top: Bathymetry map showing locations of proposed primary subduction inputs Sites HSM-13B (HSM-05A) and HSM-08A and alternate Sites HSM-14B, HSM-11A, and HSM-12A with seismic crossing lines. Bottom: Detailed seismic image for proposed primary Site HSM-13B.

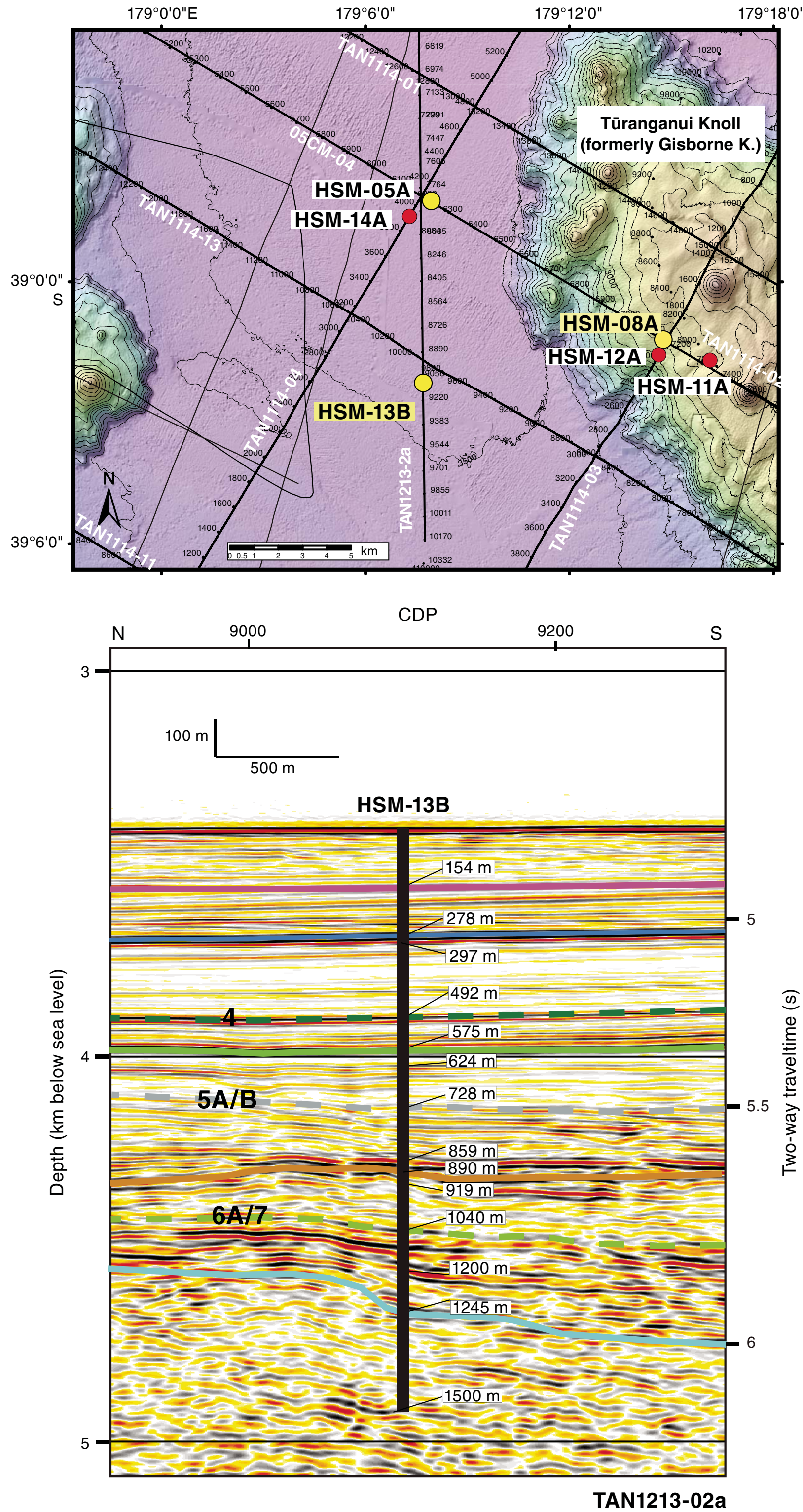


Figure F9. Detailed seismic image for proposed primary subduction inputs Site HSM-08A. Location shown in Figure **F8**. Black bar shows EPSP approved depths; red bar shows planned depths in current operations plan.

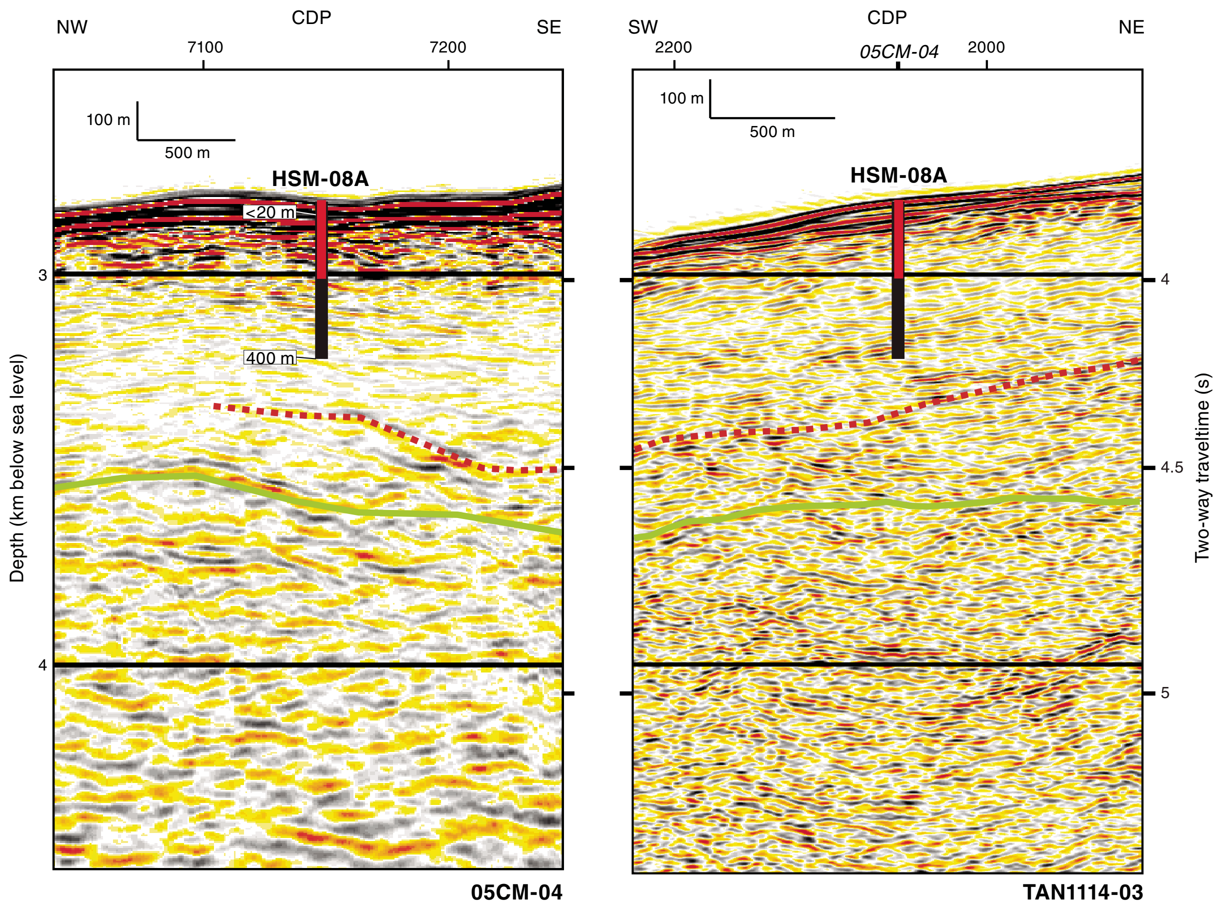


Figure F10. Seismic lines showing proposed primary Site HSM-13B (HSM-05A). Locations shown in Figure F8.

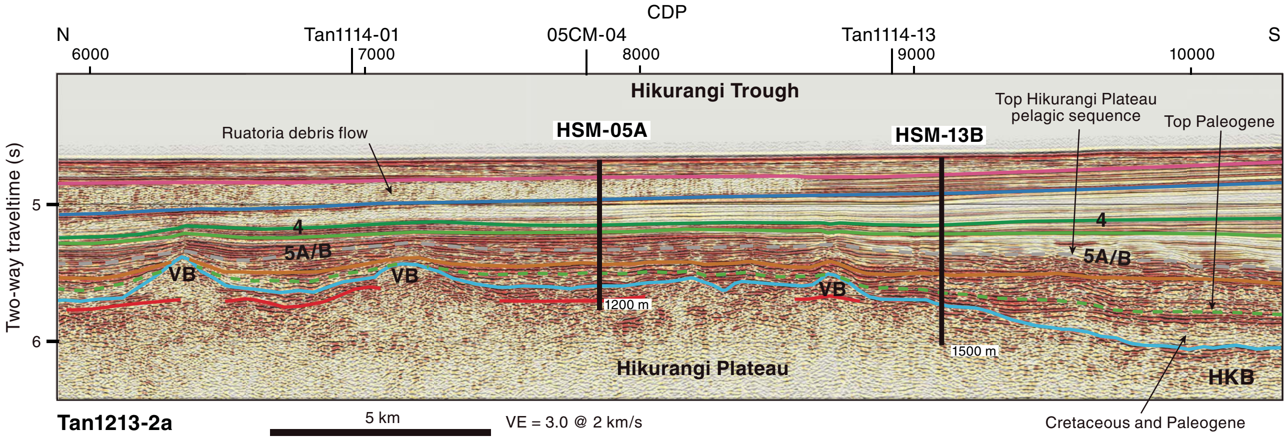


Figure F11. Detailed seismic images for proposed alternate subduction inputs Sites HSM-11A, HSM-12A, and HSM-14A. Locations shown in Figure **F8**. Black bar shows EPSP approved depths; red bar shows planned depths in current operations plan.

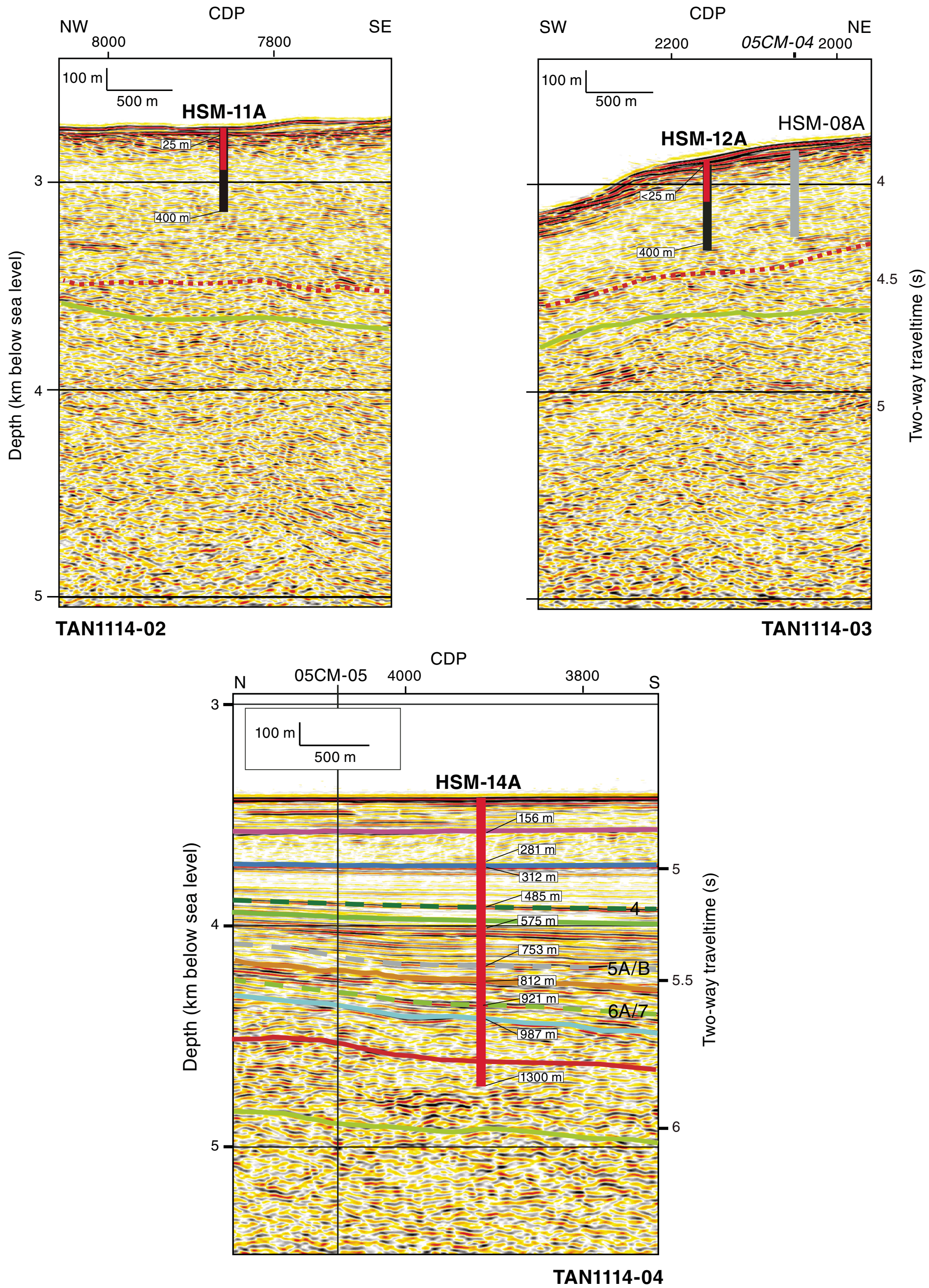


Figure F12. Schematic of plan for proposed frontal thrust observatory Site HSM-18A. The observatory concept involves an ACORK with a CORK-II head nested inside. HRT = hydraulic release tool, ROV = remotely operated vehicle, OD = outer diameter, ID = inner diameter, MLT = miniature temperature logger.

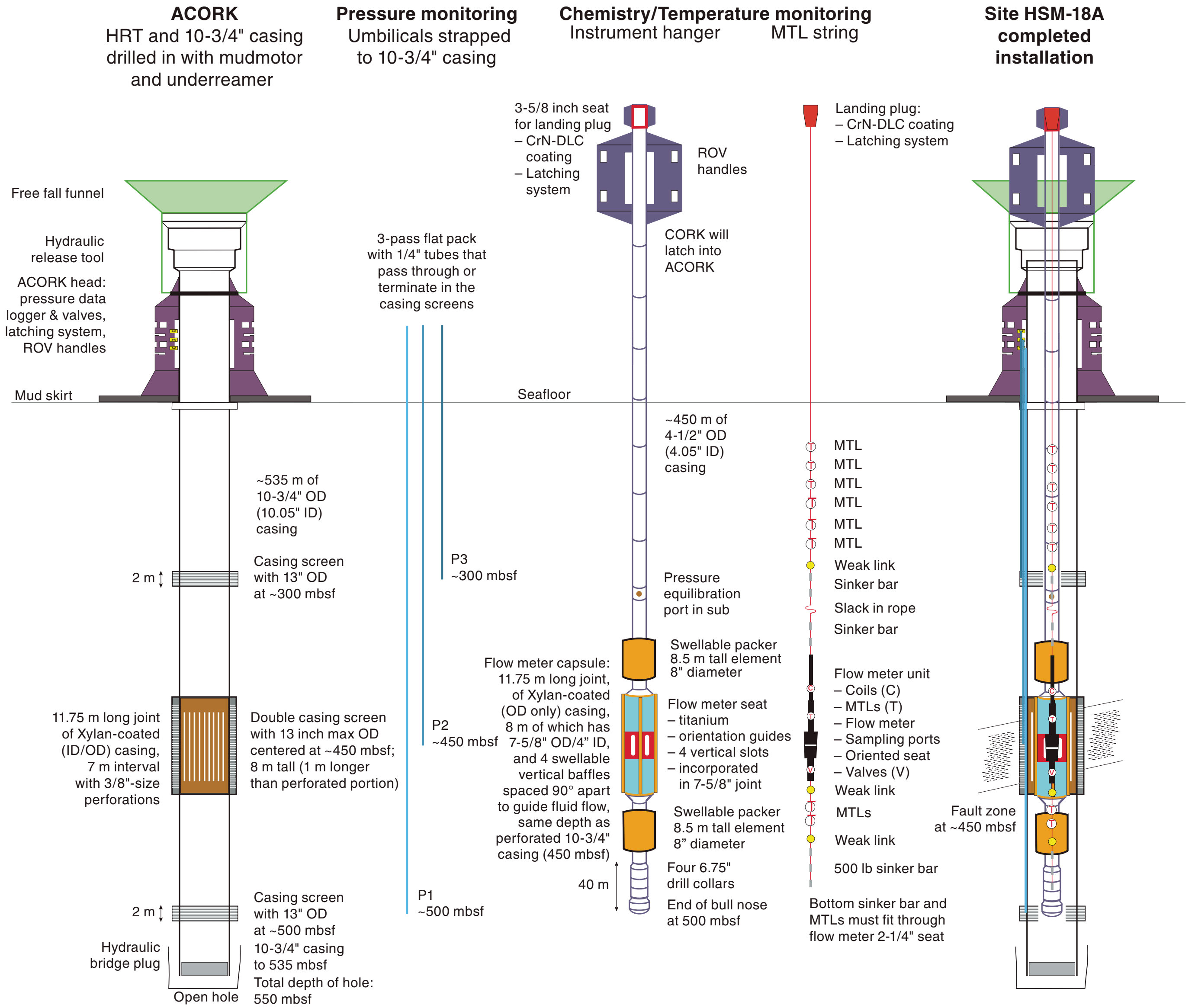
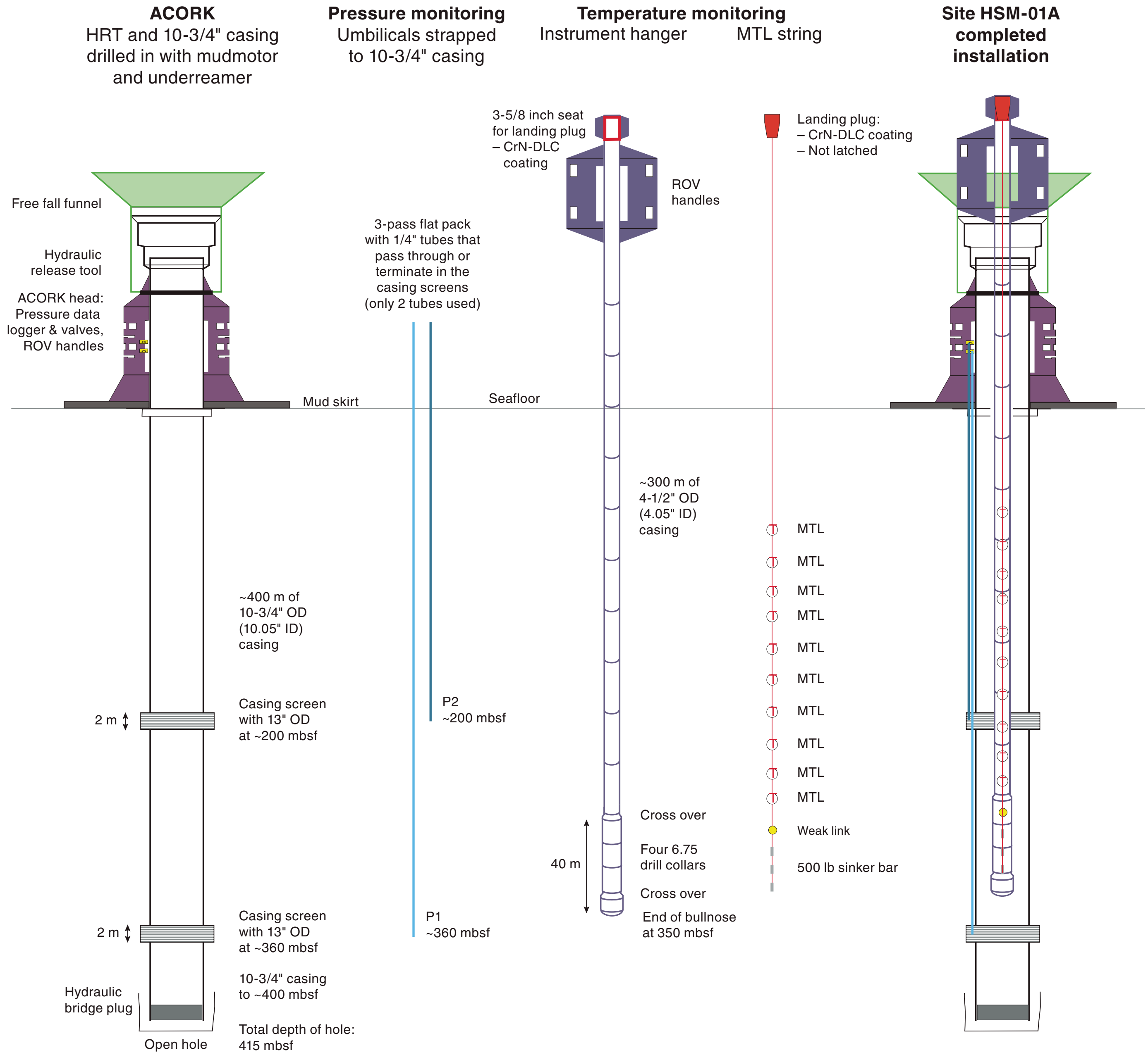


Figure F13. Schematic of plan for the upper plate observatory at proposed Site HSM-01A. The observatory concept involves an ACORK with a CORK-II head nested inside. Note that this observatory is simpler (pressure and temperature only) than the frontal thrust observatory shown in Figure F12.



Site summaries

Site HSM-18A

Priority:	Primary (Expedition 372 primary site)
Position:	38.87191°S, 178.93993°E
Water depth (m):	3168
Target drilling depth (mbsf):	700
Approved maximum penetration (mbsf):	800
Survey coverage:	MCS Profile TAN1114-05, CDP 1678 • Track map (Figure F6) • Seismic profile (Figure F6)
Objective(s):	Establish shallow fault zone properties, composition, and conditions. Inform selection of stratigraphic target for observatory installation. Thrust fault at 450 mbsf.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 700 mbsf (Expedition 372) • Hole B: APC/XCB to 700 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole B: log with triple combo and FMS-sonic (not present in alternate operations plan) • Hole C: ACORK/CORK-II observatory to 535 mbsf
Nature of rock anticipated:	Lower slope sediments over accreted trench-fill turbidites and hemipelagic sediment; sandstone, siltstone, mudstone, and ash. Possibly mass transport deposits.

Site HSM-15A

Priority:	Alternate for HSM-18A (Expedition 372 alternate site)
Position:	38.85894°S, 178.89601°E
Water depth (m):	2724
Target drilling depth (mbsf):	600
Approved maximum penetration (mbsf):	600
Survey coverage:	MCS Profile 05CM-04, CDP 4319 • Track map (Figure F6) • Seismic profile (Figure F7)
Objective(s):	Establish shallow fault zone properties, composition, and conditions. Inform selection of stratigraphic target for observatory installation. Thrust fault at 325 mbsf.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 600 mbsf (Expedition 372) • Hole B: APC/XCB to 600 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole B: log with triple combo and FMS-sonic (not present in alternate operations plan) • Hole C: ACORK/CORK-II observatory
Nature of rock anticipated:	Lower slope sediments over accreted trench-fill turbidites and hemipelagic sediment; sandstone, siltstone, mudstone, and ash. Possibly mass transport deposits.

Site HSM-16B

Priority:	Alternate for HSM-18A (Expedition 372 alternate site)
Position:	38.91341°S, 178.90684°E
Water depth (m):	2432
Target drilling depth (mbsf):	1350
Approved maximum penetration (mbsf):	1350
Survey coverage:	MCS Profile TAN1114-05, CDP 2550 • Track map (Figure F6) • Seismic profile (Figure F7)
Objective(s):	Establish shallow fault zone properties, composition, and conditions. Inform selection of stratigraphic target for observatory installation. Thrust fault at 1055 mbsf.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 1350 mbsf (Expedition 372) • Hole B: APC/XCB to 600 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: ACORK/CORK-II observatory • Hole D: drill in reentry system to 600 mbsf and RCB to 1350 mbsf • Hole D: log with triple combo and FMS-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Lower slope sediments over accreted trench-fill turbidites and hemipelagic sediment; sandstone, siltstone, mudstone, and ash. Possibly mass transport deposits.

Site HSM-19B

Priority:	Alternate for HSM-18A (Expedition 372 alternate site)
Position:	38.83610°S, 178.94390°E
Water depth (m):	3024
Target drilling depth (mbsf):	1100
Approved maximum penetration (mbsf):	1100
Survey coverage:	MCS Profile TAN1114-01, CDP 9700 • Track map (Figure F6) • Seismic profile (Figure F7)
Objective(s):	Establish shallow fault zone properties, composition, and conditions. Inform selection of stratigraphic target for observatory installation. Thrust faults at 890-960 mbsf.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 1100 mbsf (Expedition 372) • Hole B: APC/XCB to 600 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: ACORK/CORK-II observatory • Hole D: drill in reentry system to 600 mbsf and RCB to 1100 mbsf • Hole D: log with triple combo and FMS-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Lower slope sediments over accreted trench-fill turbidites and hemipelagic sediment; sandstone, siltstone, mudstone, and ash. Possibly mass transport deposits.

Site HSM-13B

Priority:	Primary (may be replaced by HSM-5A depending on time available; Expedition 372 alternate site)
Position:	39.03881°S, 179.12806°E
Water depth (m):	3508
Target drilling depth (mbsf):	1500
Approved maximum penetration (mbsf):	1500
Survey coverage:	MCS Profile TAN1213-02a, CDP 9100 • Track map (Figure **F8**) • Seismic profile (Figs. **F8**, **F10**)
Objective(s):	To characterize the age, lithology, physical and thermal properties of the sedimentary sequence and underlying volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: APC/XCB to 750 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole B: drill in reentry system to 740 mbsf and RCB to 1500 mbsf • Hole B: log with triple combo and FMS-sonic
Nature of rock anticipated:	Sandstone–mudstones turbidites, mass transport deposits, ash, and hemipelagic sediment over nannofossil-rich pelagic mudstones, chalk, ash, possibly siliceous chert, and volcanic rocks of the Hikurangi Plateau.

Site HSM-05A

Priority:	Primary (may replace HSM-13B depending on time available; Expedition 372 primary site)
Position:	38.96940°S, 179.13225°E
Water depth (m):	3538
Target drilling depth (mbsf):	1200
Approved maximum penetration (mbsf):	1400
Survey coverage:	MCS Profile 05CM-04, CDP 6229, and TAN1114-04, CDP 4076 • Track map (Figure **F8**) • Seismic profile (Figure **F10**)
Objective(s):	To characterize the age, lithology, physical and thermal properties of the sedimentary sequence and underlying volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 1200 mbsf (Expedition 372) • Hole B: drill in reentry system to 740 mbsf and RCB to 1200 mbsf • Hole C: APC/XCB to 750 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements)
Nature of rock anticipated:	Sandstone–mudstones turbidites, mass transport deposits, ash, and hemipelagic sediment over nannofossil-rich pelagic mudstones, chalk, ash, possibly siliceous chert, and volcanic rocks of the Hikurangi Plateau.

Site HSM-14A

Priority:	Alternate for HSM-13B (Expedition 372 alternate site)
Position:	38.97492°S, 179.12154°E
Water depth (m):	3531
Target drilling depth (mbsf):	1300
Approved maximum penetration (mbsf):	1300
Survey coverage:	MCS Profile TAN1114-04, CDP 3915 • Track map (Figure **F8**) • Seismic profile (Figure **F11**)
Objective(s):	To characterize the age, lithology, physical and thermal properties of the sedimentary sequence and underlying volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 1300 mbsf (Expedition 372) • Hole B: APC/XCB to 750 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: drill in reentry system to 740 mbsf and RCB to 1300 mbsf • Hole C: log with triple combo and FMS-sonic
Nature of rock anticipated:	Sandstone–mudstones turbidites, mass transport deposits, ash, and hemipelagic sediment over nannofossil-rich pelagic mudstones, chalk, ash, possibly siliceous chert, and volcanic rocks of the Hikurangi Plateau.

Site HSM-01A

Priority:	Primary (Expedition 372 primary site)
Position:	38.72728°S, 178.61423°E
Water depth (m):	994
Target drilling depth (mbsf):	650
Approved maximum penetration (mbsf):	1180
Survey coverage:	MCS Profiles 05CM-04, CDP 2037, and TAN1114-08, CDP 2040 • Track map (Figure **F4**) • Seismic profile (Figure **F5**)
Objective(s):	Coring and logging to assess physical properties and rock composition in the upper plate above SSE source region. Inform selection of stratigraphic target for observatory installation.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 650 mbsf (Expedition 372) • Hole B: ACORK/CORK-II observatory to 400 mbsf • Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: log with triple combo-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Upper slope and slope basin marine sandstone, siltstone, mudstone, mass transport deposits, ash, and possibly calcareous sandstone and/or mudstone. Breccia intervals possible.

Site HSM-21B

Priority:	Alternate for HSM-01A (Expedition 372 alternate site)
Position:	38.72006°S, 178.61857°E
Water depth (m):	1011
Target drilling depth (mbsf):	650
Approved maximum penetration (mbsf):	1200
Survey coverage:	MCS Profile TAN1114-08, CDP 1900 • Track map (Figure **F4**) • Seismic profile (Figure **F5**)
Objective(s):	Coring and logging to assess physical properties and rock composition in the upper plate above SSE source region. Inform selection of stratigraphic target for borehole observatory installation.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 650 mbsf (Expedition 372) • Hole B: ACORK/CORK-II observatory to 400 mbsf • Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: log with triple combo-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Upper slope and slope basin marine sandstone, siltstone, mudstone, mass transport deposits, ash, and possibly calcareous sandstone and/or mudstone. Breccia intervals possible.

Site HSM-22B

Priority:	Alternate for HSM-01A (Expedition 372 alternate site)
Position:	38.71823°S, 178.64255°E
Water depth (m):	1041
Target drilling depth (mbsf):	650
Approved maximum penetration (mbsf):	1200
Survey coverage:	MCS Profile TAN1213-01, CDP 7000 • Track map (Figure **F4**) • Seismic profile (Figure **F5**)
Objective(s):	Coring and logging to assess physical properties and rock composition in the upper plate above SSE source region. Inform selection of stratigraphic target for borehole observatory installation.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 650 mbsf (Expedition 372) • Hole B: ACORK/CORK-II observatory to 400 mbsf • Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: log with triple combo-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Upper slope and slope basin marine sandstone, siltstone, mudstone, mass transport deposits, ash, and possibly calcareous sandstone and/or mudstone. Breccia intervals possible.

Site HSM-23B

Priority:	Alternate for HSM-01A (Expedition 372 alternate site)
Position:	38.71705°S, 178.64956°E
Water depth (m):	1045
Target drilling depth (mbsf):	650
Approved maximum penetration (mbsf):	1300
Survey coverage:	MCS Profile TAN1213-01, CDP 7100 • Track map (Figure **F4**) • Seismic profile (Figure **F5**)
Objective(s):	Coring and logging to assess physical properties and rock composition in the upper plate above SSE source region. Inform selection of stratigraphic target for borehole observatory installation.
Coring, downhole measurements, and observatory program:	• Hole A: LWD to 650 mbsf (Expedition 372) • Hole B: ACORK/CORK-II observatory to 400 mbsf • Hole C: APC/XCB to 650 mbsf with orientation and APCT-3 formation temperature measurements (may include SETP/T2P pressure measurements) • Hole C: log with triple combo-sonic (not present in alternate operations plan)
Nature of rock anticipated:	Upper slope and slope basin marine sandstone, siltstone, mudstone, mass transport deposits, ash, and possibly calcareous sandstone and/or mudstone. Breccia intervals possible.

Site HSM-08A

Priority:	Primary
Position:	39.02200°S, 179.24600°E
Water depth (m):	2908
Target drilling depth (mbsf):	200
Approved maximum penetration (mbsf):	400
Survey coverage:	MCS Profile 05CM-04, CDP 7145, and TAN1114-03, CDP2057 • Track map (Figure **F8**) • Seismic profile (Figure **F9**)
Objective(s):	To characterize the age, lithology, and physical properties of the volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: RCB to 150 mbsf • Hole A: log with triple combo
Nature of rock anticipated:	Hemipelagic/pelagic sediment veneer over volcanic seamount rocks of Tūranganui Knoll (formerly Gisborne Knoll), Hikurangi Plateau.

Site HSM-11A

Priority:	Alternate for HSM-08A
Position:	39.03002°S, 179.26885°E
Water depth (m):	2777
Target drilling depth (mbsf):	200
Approved maximum penetration (mbsf):	400
Survey coverage:	MCS Profile TAN1114-02, CDP 7860 • Track map (Figure **F8**) • Seismic profile (Figure **F11**)
Objective(s):	To characterize the age, lithology, and physical properties of the volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: RCB to 150 mbsf • Hole A: log with triple combo
Nature of rock anticipated:	Hemipelagic/pelagic sediment veneer over volcanic seamount rocks of Tūranganui Knoll (formerly Gisborne Knoll), Hikurangi Plateau.

Site HSM-12A

Priority:	Alternate for HSM-08A
Position:	39.02788°S, 179.24374°E
Water depth (m):	2969
Target drilling depth (mbsf):	200
Approved maximum penetration (mbsf):	400
Survey coverage:	MCS Profile TAN1114-03, CDP 2160 • Track map (Figure **F8**) • Seismic profile (Figure **F11**)
Objective(s):	To characterize the age, lithology, and physical properties of the volcanic basement on the subducting plate.
Coring, downhole measurements, and observatory program:	• Hole A: RCB to 150 mbsf • Hole A: log with triple combo
Nature of rock anticipated:	Hemipelagic/pelagic sediment veneer over volcanic seamount rocks of Tūranganui Knoll (formerly Gisborne Knoll), Hikurangi Plateau.