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Expedition 332 Preliminary Report

NanTroSEIZE Stage 2: Riserless Observatory

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Abstract

One primary objective of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) complex drilling project is to drill and instrument a series of holes across the seismogenic subduction system offshore the Kii Peninsula, Japan. Integrated Ocean Drilling Program (IODP) Expedition 332 followed up on initial observatory operations begun during IODP Expedition 319 in 2009. This expedition focused mainly on engineering work, including (1) retrieval of a temporary observatory instrument installed during Expedition 319 at IODP Site C0010, which penetrates the shallow "megasplay" fault in the midforearc, and installation of a new suite of temporary sensors; (2) deployment of an upgraded temporary observatory at Site C0010; and (3) installation of a permanent observatory at IODP Site C0002 in the outer Kumano Basin, at the location of planned future deep riser drilling.

Expedition 332 began on 25 October 2010 and ended on 11 December 2010. During the first few weeks, the focus was on exchanging the SmartPlug temporary observatory with an upgraded GeniusPlug, both attached to a retrievable casing packer above the screened megasplay fault zone at Site C0010. The SmartPlug recovery was successful despite the strong Kuroshio Current, which can be attributed to an efficient reduction of vortex-induced vibration (VIV) on the drill string by attaching ropes. Times series data recovered from the self-contained instrument include seafloor and formation pressure as well as four independent temperature records from the fault zone and the overlying seafloor reference. Tentative analysis of the data proves the effective seal of the bridge plug; dampened pressure amplitudes in the tight, slightly overpressured formation; and identification of prominent earthquake and tsunami events in the 15 month record (23 August 2009–7 November 2010). The SmartPlug was replaced with a GeniusPlug, which is similar in geometry and equally self-contained but with an addendum that hosts an OsmoSampler for collecting fluids for geochemical analysis and a flow-through osmotic colonization system for microbiological study. The system was installed at a depth that placed the addendum in the center of the 22 m wider screened cased section across the megasplay fault.

At Site C0002, somewhat upslope of Site C0010, a new hole was drilled with logging while drilling (LWD) and cased for placement of a long-term borehole monitoring system. The monitoring system comprises a circulation obviation refrofit kit (CORK) assembly with a hydrogeological unit measuring pressure at four depth levels as well as a broadband seismometer, volumetric strainmeter, tiltmeter, geophones, and a thermistor string. The key goals include pore pressure monitoring in the upper accre-

tionary prism (Unit IV), a series of measurements in the homogeneous sediments of Unit III (strain, tilt, seismicity, and pressure) in the transition zone, and temperature and pressure monitoring in the overlying Kumano Basin sediments of Unit II. The string of the CORK assembly had a total length of 965 m and was carefully secured during deployment with centralizers, bands, and straps to withstand the strong current. VIV was minimized using ropes, and acceleration was monitored during deployment. The lower portion of the assembly is isolated against the overlying ocean body by a swellable packer at 746 meters below seafloor (mbsf). Part of the instrument string below was cemented (~780–935 mbsf) to couple the strainmeter and seismometer to the formation/casing. The CORK head was revisited prior and after cementing for system tests of the borehole instruments using the remotely operated vehicle (ROV), and all of these experiments were successful. The CORK was left with minimum battery power after the expedition and will be revisited in spring 2011 by ROV to connect an additional seafloor unit for power and data storage. In winter 2011/2012, the unit is anticipated to be connected to the real-time seafloor cabled network Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET).

Introduction

Overview of the NanTroSEIZE complex drilling project

Subduction zones account for the majority of global seismic moment release, and slip along subduction megathrusts generate both damaging earthquakes and tsunamis (e.g., Lay et al., 2005). Understanding the processes that govern the distribution, mechanics, and style of slip along subduction and other plate boundary fault systems is essential to earthquake and tsunami hazard assessment. To this end, several recent and ongoing drilling programs have targeted portions of active plate boundary faults that have either slipped coseismically during large earthquakes or nucleated smaller events. These efforts include the San Andreas Fault Observatory at Depth (SAFOD) (Hickman et al., 2004), the Taiwan-Chelungpu Drilling Project (Ma, 2005), and Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) drilling (Tobin and Kinoshita, 2006a, 2006b).

NanTroSEIZE is a multiexpedition, multistage IODP drilling project focused on understanding the mechanics of subduction plate boundary faults. The drilling program includes a coordinated effort to characterize, sample, and instrument the plate boundary system at several locations offshore the Kii Peninsula (Fig. **F1**), culminating in drilling, sampling, and instrumenting the plate boundary fault system near the updip limit of inferred coseismic slip, at 5~7 km below seafloor (Tobin and Kinoshita, 2006b) (Fig. F2) and installation of a distributed network of integrated borehole observatories to monitor strain and seismological, thermal, and hydrological processes. The main scientific objectives of drilling and monitoring are to understand and test

- Hypothesized mechanisms controlling the transition from predominantly aseismic creep at shallow depths and near the trench to seismic slip and interseismic locking at greater depths along the megathrust fault system;
- Frictional and hydrologic processes governing the mode of fault slip, strain accumulation, and release;
- The absolute mechanical strength of the plate boundary fault; and
- The potential role of a major upper plate fault system (termed the "megasplay" fault) in seismogenesis and tsunamigenesis.

In the NanTroSEIZE study area, high-resolution seismic reflection profiles across the outer rise clearly document a major out-of-sequence thrust fault system (megasplay fault, after Park et al., 2002) that branches from the décollement close to the updip limit of inferred coseismic rupture in the 1944 Tonankai M 8.2 earthquake (Fig. F2). Several lines of evidence indicate that the megasplay system is active, may accommodate a significant fraction of plate boundary motion, and may slip coseismically; these are discussed in more detail in **"Geological setting"** below (Moore et al., 2007; Strasser et al., 2009). However, the partitioning of strain between the lower plate interface (the décollement zone) and the megasplay system and the nature and mechanisms of fault slip as a function of depth and time on the megasplay are not understood. Thus, the megasplay and the region near its updip terminus comprise one of the primary drilling and monitoring targets for NanTroSEIZE.

In late 2007 through early 2008, NanTroSEIZE Stage 1 was conducted as a unified program of drilling, comprising IODP Expeditions 314, 315, and 316 (Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009). Drilling during Stage 1 included riserless drilling along a transect of eight sites that targeted the frontal thrust region near the trench, the megasplay fault region, and the Kumano forearc basin region (Fig. F2). One of these sites, IODP Site C0002, also serves as a preparatory pilot hole for planned future deep riser drilling. The other drill sites primarily targeted fault zones and accretionary prism sediments in the shallow, presumed aseismic portions of the accretionary complex (Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009). Expedition 314 was dedicated to in situ measurement of physical properties and borehole imaging through a comprehensive logging-while-drilling (LWD) program (Kinoshita et al., 2008). Expedition 315 focused on coring and downhole temperature measurements at one site in the megasplay region (IODP Site C0001) and one in the forearc basin (Site C0002) (Ashi et al., 2008). Expedition 316 cored and conducted downhole temperature measurements across the frontal thrust and megasplay fault near their updip termini (Kimura et al., 2008).

NanTroSEIZE Stage 2, begun during the summer of 2009, has included two expeditions to date (IODP Expeditions 319 and 322), with the aims of building on the results of Stage 1 and preparing for later observatory installations. Expedition 319 investigated the properties, structure, and state of stress within the hanging wall above the locked plate boundary at IODP Site C0009 and across the shallow megasplay fault at IODP Site C0010. In addition, the first temporary long-term borehole observatory, a SmartPlug, was successfully installed at Site C0010 in an interval of screened casing across the megasplay fault (Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010). Expedition 322 sampled and characterized the properties of sediments entering the subduction zone on the subducting Philippine Sea plate (Saito, Underwood, Kubo, and the Expedition 322 Scientists, 2010).

IODP Expedition 332 continued NanTroSEIZE Stage 2 operations, using data generated during previous expeditions in Stages 1 and 2 as well as infrastructure provided by the cased Hole C0010A to continue riserless observatory operations along the NanTroSEIZE transect.

Background

Geological setting

The Nankai Trough is formed by subduction of the Philippine Sea plate underneath southwestern Japan at a rate of ~4.1–6.5 cm/y along an azimuth of 300°–315°N (Seno et al., 1993; Miyazaki and Heki, 2001) down an interface dipping 3°–7° (Kodaira et al., 2000). The Nankai Trough subduction zone forms an end-member sediment-dominated accretionary prism similar to the Mediterranean Ridge (Kopf et al., 2003). In the toe region, a sedimentary section ~1–1.5 km thick is accreted to or underthrust below the margin (Moore, Taira, Klaus, et al., 2001; Moore et al., 2009).

The three major seismic stratigraphic sequences identified in the northern Shikoku Basin are the lower and upper Shikoku Basin sequences and the Quaternary turbidite sequences. The upper Shikoku Basin facies off Kumano slightly decrease in thickness toward the north, whereas the lower Shikoku Basin facies displays a much more complicated geometry as a result of the effects of basement topography (Le Pichon et al., 1987a, 1987b; Mazzotti et al., 2000; Moore, Taira, Klaus, et al., 2001). Seismic thickness decreases above larger basement highs, and a more transparent acoustic character indicates local absence of sand packages that characterize most other parts of the lower Shikoku Basin. The mechanical differences between subducting basement highs and subducting basement plains could be significant for fault zone dynamics and earthquake rupture behavior.

The deformation front behavior off Kumano is fundamentally different than it is at previous targets of Ocean Drilling Program (ODP) drilling off Muroto and Ashizuri, ~200–300 km to the southwest. Seismic reflection data off Kumano clearly delineate the frontal fault near the prism toe; however, there is little evidence for seaward propagation of the décollement within the deeper Shikoku Basin strata (see Proposal 603A-Full2 at **www.iodp.org/600/**). One interpretation of the seismic profile is that the décollement steps up to the seafloor, thereby thrusting older accretionary prism strata over the upper Quaternary trench-wedge facies (Fig. **F2**). Manned submersible observations also indicate that semilithified strata of unknown age have been uplifted and exposed along a fault scarp at the prism toe (Ashi et al., 2002). Farther inboard, the fault ramps down into the lower Shikoku Basin facies (Park et al., 2002).

The lower forearc slope consists of a series of thrust faults that have shortened the accreted sedimentary units of the accretionary prism. A combination of swath bathymetric and multichannel seismic data show a pronounced continuous outer ridge (outer arc high) of topography extending >120 km along strike, which may be related to megasplay fault slip, including the 1944 Tonankai M 8.2 earthquake and repeated previous earthquakes (e.g., Moore et al., 2007; Strasser et al., 2009). Remotely operated vehicle (ROV) and manned submersible diving surveys along this feature reveal a very steep slope on both sides of the ridge (Ashi et al., 2002; J. Ashi et al., unpubl. data). The outer arc high coincides with the seaward edge of the splaying system of thrust faults that branch from the megasplay.

The megasplay is a major structural boundary within the accretionary wedge, traverses the entire wedge, and has had a protracted history as shown by the thick forearc basin trapped behind its leading edge (Moore et al., 2007). The megasplay is also hypothesized to represent a discontinuity in rock physical properties and fault mechanical boundary between the inner and outer accretionary wedge and between aseismic and seismogenic fault behavior (Wang and Hu, 2006). At depth, the megasplay is imaged in seismic reflection data as a high-amplitude reflector (Bangs et al., 2009) (Fig. F2), and it branches into a family of smaller splays in the upper few kilometers below the seafloor, including the fault penetrated at IODP Sites C0004 and C0010. The most direct evidence for recent megasplay fault activity comes from stratigraphic relationships at the tips of the faults in young slope sediments. Direct fault intersections with the seafloor are not observed (Moore et al., 2007; Strasser et al., 2009); however, the thrust sheets wedge into these deposits, causing tilt and slumping of even the deposits nearest to the surface. Evidence for mass wasting complexes is consequently found at IODP Sites C0004, C0008, and C0010. The latter, as well as Site C0002 further landward, were the target areas of Expedition 332.

Site C0010, located 3.5 km north of previously completed Site C0004, was first drilled during Expedition 319 (Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010). Operations during that expedition included drilling through the megasplay fault zone and into its footwall using LWD, setting casing with screens across the fault zone, and installing a simple and temporary borehole observatory (a SmartPlug) to monitor fluid pressure and temperature in the shallow megasplay. Major lithologic boundaries as well as the location of the megasplay fault at ~407 mbsf were identified in LWD data and were used to select a depth interval spanning the fault for placement of the two screened casing joints. Three distinct lithologic packages were observed at Site C0010: slope deposits (Unit I, 0–182.5 mbsf), thrust wedge (Unit II, 182.5–407 mbsf), and overridden slope deposits (Unit III, 407 mbsf to total depth [TD]) (Fig. F3). Unit I is similar to Unit I described previously at Site C0004 and was interpreted as hemipelagic slope sediments composed primarily of mud with minor distal turbidite interbeds. The thrust wedge (Unit II) is clayey and characterized by high and variable gamma ray and resistivity values compared with the units above and below. Unit III is composed of hemipelagic muds with minor turbidite interbeds and rare volcanic ash layers.

Site C0002 is located near the southeastern edge of the Kumano Basin (Fig. F2). The Kumano Basin has a generally flat bathymetry, with a water depth of ~2000 m. The sediments in the southern part of the Kumano Basin are tilted northward, truncated by a flat erosional surface, and subsequently cut by normal faults (Park et al., 2002; Ashi et al., 2008; Moore et al., 2009). Lithostratigraphy at Site C0002 (Fig. F3) is characterized by turbiditic sediments to ~830 mbsf, underlain by older rocks of the accretionary prism and/or early slope basin sediments deposited prior to the development of the megasplay fault, which were drilled and partly cored during Expeditions 314 and 315. Expedition 332 revisited Site C0002, drilling with a limited suite of LWD/measurement-while drilling (MWD) tools, for reconnaissance and to identify the most suitable depth intervals to place sensors of the long-term borehole monitoring system (LTBMS) (see **"Site C0002 riserless observatory"**).

Seismic studies/site survey data

The Kii and Kumano Basin region is among the best-studied subduction zone forearcs in the world. A significant volume of site survey data has been collected in the drilling area over many years, including multiple generations of two-dimensional seismic reflection (e.g., Park et al., 2002), wide-angle refraction (Nakanishi et al., 2002; Nakanishi et al., 2008), passive seismicity (e.g., Obana et al., 2001), heat flow (Yamano et al., 2003), side-scan sonar, and swath bathymetry as well as submersible and ROV dive studies (Ashi et al., 2002). In 2006, a joint, three-dimensional (3-D) seismic reflection survey was conducted by Japanese and U.S. scientists over a ~11 km × 55 km area, acquired under contract by Petroleum GeoServices, an industry service company (Fig. **F1**) (Moore et al., 2007). The poststack trace spacing is 12.5 m in the in-line direction and 18.75 m in the cross-line direction. This 3-D volume—the first deep-penetration, fully 3-D marine survey ever acquired for basic research purposes—has been used to refine the selection of drill sites and targets in the complex megasplay fault region and define the regional structure and seismic stratigraphy (Moore et al., 2009). As NanTroSEIZE drilling proceeds, the 3-D seismic data will continue to be used to refine drilling and operational strategies, to analyze physical properties of the subsurface through seismic attribute studies, to extend findings in the boreholes to wider areas, and to assess drilling safety.

Scientific objectives and operational strategy

Long-term monitoring within a network of boreholes along the Kii drilling transect is one of the central objectives of NanTroSEIZE and is critical in order to shed light on potential changes in mechanical and hydrologic properties through the seismic cycle, define the upper transition from aseismic to seismic deformation and distribution of interseismic strain accumulation, and assess the role of the megasplay in accommodating slip. Therefore, Expedition 332 Riserless Observatory-2 followed up on the riserless observatory installations begun during Expedition 319 in summer 2009. Our activities focused on two sites:

- Site C0010, drilled and cased across the shallow megasplay fault and into its footwall, has been identified as a high-priority target for permanent long-term monitoring. However, because no LTBMS was available for Expedition 319, a simple temporary pore pressure and temperature observatory (SmartPlug) was installed in 2009 (Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010). The objectives for Expedition 332 included recovering the SmartPlug and replacing it with the upgraded temporary observatory that also includes geochemical sampling capability and in situ microbiological culturing media, termed a "GeniusPlug."
- Site C0002 is also identified as a high-priority target for permanent long-term monitoring. Ultimately, observatory instruments at this location will be installed in two boreholes: one ~1 km deep riserless LTBMS and one deep riser completion at ~5–7 km below seafloor. The main goal of Expedition 332 was to drill and case a borehole at Site C0002 and install an integrated LTBMS that combines thermal, hydrologic, and geodynamic sensors to monitor pore fluid pressure, temperature, strain, tilt, and seismicity. The installation contains four major components: bottom-hole instruments and hydraulic screens, tubing to provide mechanical support for downhole cables and hydraulic tubes, a swellable packer to provide hydraulic isolation between the formation below and the overlying ocean, and a wellhead similar to those used for previous circulation obviation retrofit kit (CORK) installations during ODP and IODP (Becker and Davis, 2005). The wellhead is designed to land at the casing hanger and suspend the tubing, packer, and instruments below. The latter include a broadband seismometer, a tiltmeter combo, a thermistor string, and a strainmeter (see **"Site C0002 riserless observatory"**).

Our operation summary for Expedition 332 is shown in Table **T1.** After departure from Shingu, Japan, port on 27 October 2010, we evacuated from Typhoon Chaba, carried out additional loading of equipment at sea, and started drilling operations at Site C0010 on 2 November. At Site C0010, operations began with an ROV dive to place transponders on the seafloor and recalibrate the dynamic positioning (DP) system. The D/V *Chikyu* then moved to a low-current area (LCA) on 3 November to start lowering the casing packer retrieving assembly and running tool. While lowering the string, two accelerometer packages to monitor vortex-induced vibration (VIV) were attached to the drill string at two depth levels while passing through and in the Kuroshio Current. In parallel, ropes were attached the upper 500 m of the drill string, where current velocities are highest. Once the bottom-hole assembly (BHA) neared the seafloor, the ROV was launched to assist reentry into Hole C0010A, which took place around noon on 5 November. The assembly latched onto the retrievable bridge plug 5 h later, and the bridge plug and SmartPlug were pulled out of the hole in the early morning of 6 November. At 1400 h on 7 November, the bridge plug and SmartPlug were recovered on the rig floor. We detached the SmartPlug and downloaded and processed the stored data. Hole C0010A was covered with the corrosion cap and transponders were recovered before moving to Site C0002.

At Site C0002, transponders were already in place from drilling during IODP Expedition 326 (NanTroSEIZE Stage 3: plate boundary deep riser: top hole engineering) in summer 2010 (Expedition 326 Scientists, 2011). The *Chikyu* moved upstream of Site C0002 on 13 November and prepared to run the drilling BHA into the water. Anti-VIV ropes were attached to the string and the vessel started to drift toward the site. Jetting in began on 15 November. After completing additional loading via supply boat, reaming of the hole and drilling using the LWD/MWD BHA commenced on 17 November. We first drilled a 12¼ inch hole to 892 meters below seafloor (mbsf) and collected logging data with a limited suite of LWD/MWD tools (MWD PowerPulse/TeleScope, annular pressure while drilling [APWD], and arcVISION array resistivity compensated tool with natural gamma radiation detection and attenuation resistivity). After pulling the drill string, we ran into the hole with a 10⅝ inch BHA in order to deepen the hole to a TD of 980 mbsf. This was mostly done to maintain a small hole diameter and minimize disturbance in the anticipated target depth for the cemented instruments. LWD data were collected during drilling of the 10⅝ inch hole from 892 to 980 mbsf, with a section of the hole relogged because of failure in the live streaming of LWD data. After a wiper trip and some reaming, the hole was found to be in good condition and casing (including screened casing joints set for 757–780 mbsf) was lowered on 22 November. During casing operations, the accelerometer packages as well as anti-VIV ropes were run again. Casing operations were completed early on 25 November, and the BHA was pulled out of the hole in order to have a short port call at Shimizu, Japan, on 27 November.

Once back at the site of Hole C0002G, drilling out the cement started on 29 November before the hole was swept and spotted with high-density brine and gel for later reentry and LTBMS hole completion. Early on 30 November the CORK running tool was picked up, running in the hole began, and the flatpack umbilical, three cables for CORK instruments, and the thermistor string were terminated and connected. From 1 December, joints of 3.5 inch tubing were slowly run down with four centralizers per joint, with tie wraps and metal bands securing the cables, thermistor, and flatpack regularly. From 2 December onward, the number of centralizers per joint was reduced from four to two, with a corresponding increase in speed and efficiency. The swellable packer was slit and the cables were fed through its body seal a day later before lowering tubing commenced. Both prior and after packer operations, the CORK instruments were tested via an interface and extension leads to a container unit in the moonpool area. From late on 2 December into the morning of 3 December, the CORK head was picked up on the rig floor, latched to the CORK running tool, and lowered into the moonpool area. The electrical cables and flatpack umbilical were measured, cut, and terminated thereafter and tested prior to and after mounting them to the CORK-head assembly. All tests were successful so the ROV platform could be attached, and the CORK-head assembly finally entered the water in the evening of 5 December. Three more CORK component tests were carried out: before drifting to the site (CORK head at 350 meters below sea level), after drifting (above the hole), and after landing of the CORK head in the well. The last of these tests was successfully completed late on 8 December. Cementing through a cement port at 937 mbsf took place on the morning of 9 December, and a final check of the hydrogeologic unit at the CORK head took place by ROV 15 h later before the transponders were recovered. Expedition 332 ended at sea on 11 December, and scientists were exchanged via helicopter.

Site summaries

Site C0010 riserless observatory

Hole C0010A = 32°12.5981′N, 136°41.1924′E
Water depth = 2523.7 m
Drilling depth = 555 mbsf (Table **T1**)

Site C0010 is one of the key observatory sites because it intersects a branch of the megasplay fault at ~410 mbsf (see Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010) (Figs. **F3, F4**). During Expedition 332, the site was revisited about 15 months after the hole was drilled and cased. The two major objectives this time were (1) to recover the SmartPlug temporary observatory installed in 2009 and (2) to replace it with a GeniusPlug temporary observatory. No drilling, LWD/MWD, or other operations were performed at this site, which—in the future—will be a location for a LTBMS.

A number of science objectives for Site C0010 were achieved during Expedition 319 in 2009, including drilling with LWD/MWD across the megasplay fault to TD of

560 mbsf, casing the borehole (with casing screens at the fault), and installation of a simple pore pressure and temperature monitoring system (SmartPlug). It was possible to (1) define major lithologic unit boundaries of the shallow megasplay fault zone and (2) determine the preferred placement of the screened joints interval within the fracture zone interval for the temporary observatory. Through comparison with previously drilled Site C0004 located only 3 km along strike (Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009) these data also provide insights into along-strike differences in the architecture of the megasplay fault and hanging wall.

Although the SmartPlug is a relatively simple mini-CORK instrument, it marks the first observatory placement during the NanTroSEIZE project. The instrument contains a cylindrical steel hull with an internal metal frame that hosts the electronics and transducers (see Fig. **F5**). The inner section is cushioned against shock and is therefore suitable for installation in the Kuroshio Current and other high-current and violent VIV areas. The instrument package includes a data logger, a temperature sensor within the data logger housing, a self-contained temperature sensor, and two pressure gauges (one “upward looking” and one “downward looking”). These sensors monitor pressure (1) below the packer seal in a screened interval that is open to the fault zone and (2) above the packer seal to serve as a hydrostatic reference open to the overlying water column. Apart from the thermistors onboard the pressure transducers, two independent temperature sensors are included in the SmartPlug. These two temperature sensors are at a depth just below the packer in the upward-looking section of the casing packer. The retrieval of the SmartPlug allows the collection of the first observatory data (pressure and temperature) from the shallow section of the megasplay fault, as well as the evaluation of the observatory installation procedures in the rough Kuroshio Current. These data will be invaluable in planning for the permanent observatory, which is due for installation before 2013.

After reentry into Hole C0010A, the latching tool connected to the retrievable bridge plug without much effort, and the bridge plug and SmartPlug package was safely pulled out of the hole only a few hours after reentry (Fig. **F6**). On a long but careful recovery trip through the water column, the SmartPlug remained undamaged and was recovered safely on deck on 7 November (Fig. **F6**). Once the tack-welding points of the SmartPlug-to-bridge plug connection were cut, the SmartPlug was unscrewed; corrosion was found on the outside and inside of the instrument, most likely a result of the rusted inner casing of the borehole.

The SmartPlug sensor carrier with the pressure transducers, miniature temperature logger (MTL), and pressure housing containing the data logger was cleaned prior to hooking it to a computer via the AQW connector for data download. A full record of the deployment period (23 August 2009–7 November 2010) plus some extra time prior to that was recovered from all transducers and the MTL, attesting to the robust design of the instrument. Full-time series records are shown for the upward-looking (hydrostatic reference) and downward-looking (megasplay fault zone) pressure (Fig. **F7**) and the platinum chip and MTL temperature (Fig. **F8**). The full records clearly show an increase in pressure and decrease in temperature as the instrument entered the water and was lowered toward and into the seafloor. Thereafter, equilibration began, but both records suggest that the borehole had not fully equilibrated by the time we recovered the instrument (see Figs. **F7, F8**). At the same time, data also attest that the bridge plug effectively sealed the borehole because upon reentry of the drill string and latching onto the device during Expedition 332, the upward-looking pressure sensor shows a strong fluctuation owing to displacement of borehole fluid, whereas the downward-looking pressure sensor encounters no such interference and remains at a near-constant value (Fig. **F9**).

In order to illustrate some of these findings, we provide a few preliminary data examples of pressure and temperature. Figure **F10** provides an example of the tidal forcing seen in the upward- and downward-looking pressure transducers. As is consistent with the expectation from a pressurized formation, the tidal signature of the formation has a diminished amplitude and small phase shift when compared to the seafloor, or hydrostatic pressure.

A cursory review of the data identified multiple pressure and—to a lesser extent—temperature excursions that may be related to seismic events, although further detrending and processing of the data are required to filter the tidal signal and resolve pressure anomalies. Nevertheless, some of the prominent earthquakes that took place during the deployment period were imaged by the SmartPlug despite its rather low temporal resolution during the recording (i.e., 60 s sampling interval). Figure **F11** shows the sinoidal records of the seafloor and formation pressure data, with the M 8.8 Maule (Chile) event imaged on the left. About 24 h later, the associated tsunami had crossed the Pacific Ocean and loaded the formation at Site C0010 for several days. Many similar examples are found in the time series record (A. Kopf et al., unpubl. data). In contrast to the pressure responses recorded, temperature signals are less pronounced and, thus, more ambiguous. There are numerous examples where temperature remains unchanged while pressure shows excursions related to seismic or wave loading. On the other hand, significant changes in temperature were recorded on one occasion on 29 May 2010 (Fig. **F12**). Interestingly, no significant change in the pressure data was observed around that time. Also, it remains unresolved why three thermistors show an increase in temperature while the platinum chip temperature drops slightly. At this point, neither a seismic event nor any other natural explanation for the observed shifts in temperature can be provided. Also, artifacts such as settling of the instrument or violent fluid circulation may help explain the temperature changes but would have ultimately caused the pressure to vary as well (which is not the case).

The SmartPlug record contains a number of events seen in both the pressure and temperature data, which will be studied in more detail after Expedition 332. At first glance, however, the following summary statements can be made:

1. The plug apparently settled about 50 cm over the first 2 months, or some of the thread grease or anticorrosion additive to the borehole fluid was mucking the inside of the instrument (and hence the upward-looking pressure transducer) and loaded the seafloor sensor.
2. The formation appears to be very weakly overpressured and is still recovering at the end of the record.
3. The temperature records are well resolved but show yet-to-be-explained offsets, which may either have something to do with a change in the thermal insulation around the sensors or the instrument pressure case, the changing nature of heat dissipation, or hydrogeologic events such as earthquake loading of the formation. Postcruise research may shed light on the observed problem of opposite temperature trends from the different sensors during the same event (Fig. **F12**).
4. The pressure records show abundant earthquake events and associated Rayleigh and tsunami waves. The tsunami waveform related to the M 8.8 Maule, Chile, earthquake is similar to existing records from, for example, the NEPTUNE seafloor cabled network (E. Davis, pers. comm., 2010) but has larger amplitude and a more persistent pressure signal lasting 3–4 days (A. Kopf et al., unpubl. data).
5. The loading efficiency at the tsunami frequency is very similar to that at tidal frequency. Rayleigh waves are much larger in the formation relative to the water column, whereas in the tidal signal the formation has the lower magnitude signal when compared to the seafloor reference port (Fig. **F10**).

More information regarding both the instrument and the data set and the interpretation of the results can be found in a manuscript included in the Expedition 332 Proceedings (A. Kopf et al., unpubl. data).

One additional data record collected during the SmartPlug deployment at Site C0010 is triaxial accelerometer data monitoring drill string VIV. This measurement was taken after the problems associated with some of the observatory installation procedures tested during Expedition 319 (for details see Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010). In 2009, an instrument carrier was damaged and two borehole instruments were lost while another's internal circuitry was destroyed by drill string VIV-induced shocks. As a result, from fall 2009 to spring 2010 Japan Agency for Marine-Earth Science and Technology tested various techniques on land to minimize/reduce VIV and demonstrated that VIV related to strong current and wave action can be efficiently reduced by attaching ropes along the axis of the drill string. This was tested in the field during a *Chikyu* shakedown cruise in March 2010, so this technique was made a routine part of observatory operations in the high-velocity regions of the Kuroshio Current.

During Expedition 332, a set of four ropes was attached in the moonpool area when the drill string was passing from the rig floor into the water (Fig. **F13**). The attachment was carried out in the upper 500 m portion of the drill string where the current velocities are the highest. Figure **F14** demonstrates how the ropes serve to reduce VIV along the drill string where the sensitive observatory instruments are located. VIV in the upper part increased slightly when compared to a deployment free of ropes; however, such vibrations are tolerable given that no electronics or other sensitive parts are housed there. During drifting for SmartPlug retrieval at Site C0010 (see Fig. **F14**), we encountered accelerations of ~0.5 g or less. This value was even lower during slower drift speeds at Site C0002, where 0.2 g was not exceeded. The angle between drifting direction and sea current was ~45°, which also helps reduce VIVs. This finding has important repercussions for safe future observatory installations.

Once the SmartPlug and accelerometer instruments were safely recovered, the final step of the temporary instrumentation operations was the first deployment of a GeniusPlug (Fig. **F15**) in IODP history. In essence, the observatory is similar to the SmartPlug except that the instrument is ~30 cm longer. This extension includes the added OsmoSampler for fluid storage over time as well as the osmotically driven microbiology chambers of the flow-through osmotic colonization system (FLOCS) unit and also means that final placement needs to be much closer to the active fault zone than the SmartPlug. Therefore, the bridge plug assembly was adjusted to include two joints of 3.5 inch tubing, which were added between the instrument and the bridge plug (Fig. F4). The GeniusPlug was set up to be capable of sampling fluids for up to 24 months and was deployed after a short drifting period with ropes but no accelerometer instruments attached to the drill string. The wellhead was protected using a corrosion cap and will be revisited in 2011 or 2012 for instrument recovery.

Site C0002 riserless observatory

Hole C0002G = 33°18.0126′N, 136°38.1488′E
Water depth = 1937.5 m
Drilling depth = 980 mbsf (Table T1)

Site C0002 is the centerpiece of the NanTroSEIZE project, intended to access the plate interface fault system at a location where it is believed to be capable of seismogenic locking and in a zone thought to have slipped coseismically in the 1944 Tonankai earthquake. The primary targets include both the basal décollement at ~6200 mbsf and the megasplay fault (Tobin and Kinoshita, 2006b). The megasplay fault reflector lies at an estimated depth of 5000~5200 mbsf, and the top of the subducting basement is estimated to lie at 6800~7000 mbsf (Figs. F1, F2).

At Site C0002, a large number of scientific objectives have been covered during previous expeditions, during which a total of six holes have been drilled within a 100 m radius (Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009). Operations included drilling and logging with a full suite of LWD/MWD to 1400 mbsf during Expedition 314 and coring two intervals from 0 to 204 mbsf and 475 to 1057 mbsf during Expedition 315 (Fig. F3). The succession explored comprises four units, the upper three of which were different lithofacies in the Kumano forearc basin. From ~920 to 936 mbsf, the transition zone to the underlying accreted strata was found. The primary objective at Site C0002 during Expedition 332 was to install the first permanent borehole observatory system during the NanTroSEIZE project into the basal forearc basin (Unit III, dominated by condensed mudstone) and the upper accretionary prism (Unit IV, containing interbeds of mudstone, siltstone, and sandstone) (Fig. F16).

The suite of sensors for the downhole portion of the observatory includes (1) pressure ports, (2) a volumetric strainmeter, (3) a broadband seismometer, (4) a tiltmeter, (5) three-component geophones, (6) three-component accelerometers, and (7) a thermometer array (Fig. F16). For practical reasons, downhole components 4–6 are incorporated into one pressure housing, so the observatory includes

- The hydrogeological component with a pressure unit at the CORK head and a flat-pack umbilical with three stainless steel hydraulic lines running into the hole and terminated at a certain depth,
- The strainmeter,
- The broadband seismometer,
- The tilt-combo instrument, and
- A thermistor string.

The set of sensors is designed to collect, as a whole, multiparameter observations in a wide period ranging from months to 1/100 s and a wide dynamic range covering events from local microearthquakes, very low frequency earthquakes, to the largest earthquake slips of the Tonankai plate boundary 6 km below the sensors. The hydrogeologic component of the sensor set is further laid out to monitor formation pressures at three downhole levels and further records data from a seafloor pressure port for reference.

In order to set the stage for the LTBMS installation, Hole C0002G was drilled without coring but with three LWD runs (once with a 12¼ inch assembly and twice with a 10⅝ inch assembly). The speed was limited to a maximum rate of penetration of 20–30 m/h in order to achieve a high data resolution in order to identify the most promising locations for LTBMS instrument locations. Both resistivity and natural gamma ray were measured to confirm the anticipated depths of lithologic boundaries identified during drilling of nearby Hole C0002A (Expedition 314; see Kinoshita, Tobin, Ashi, Kimura, Lallemant, Screaton, Curewitz, Masago, Moe, and the Expedition 314/315/316 Scientists, 2009). Changes in composition and texture were identified by variations in natural gamma values that coincided with amplitude changes in the electrical resistivity data. LWD data confirm that both the depth and character of the transition were broadly consistent with previous logging. In particular, a marked decrease in the resistivity fluctuations coupled with an increase in natural gamma values defined the Unit II/III boundary. The lower boundary of Unit III was identified in the same manner in order to position the strainmeter in a relatively continuous zone of elevated gamma ray and resistivity values.

A 20 inch conductor pipe was jetted in to 41 mbsf, and then 9 inch casing was run to 887 mbsf. To ensure good coupling of the strainmeter to the formation and to eliminate local fluid motion around the seismic sensors and the tiltmeter, the sensors were cemented in the open-hole section below the 9 inch casing shoe in Unit III. One pressure port was installed in Unit IV below the strainmeter to sample pore fluid pressure in the accretionary prism. This pressure port is protected by miniscreens so that cement or clay-rich material does not hamper conductivity of the hydraulic tubing (Fig. **F17**). Above the cemented sensors in the open hole, the 9 inch casing has screened casing joints from 757 to 780 mbsf (Fig. **F16**) to sample pore fluid pressure in Unit II below a swellable packer to isolate the interval from the seafloor (Fig. **F18**). The downhole sensors are digitally connected to the seafloor where power is supplied and data are recovered, whereas pore fluid pressure is transmitted through hydraulic tubing to be recorded in the seafloor recorder (Fig. **F19**).

The nonhydraulic components of the observatory are all located in the deeper portion of the CORK assembly string (Fig. **F16**). The location of the strainmeter, tiltmeter, seismometers, and pressure ports for pore fluid pressure monitoring are determined based on LWD information. In the lowermost portion, above the bullnose, the strainmeter is implemented in a fracture-free zone. It is a volumetric system with a small sensing volume (Fig. **F20**). Above the strainmeter is the instrument carrier (Fig. **F21**) mounting a Guralp broadband seismometer and tilt-combo package (tiltmeter, geophone, accelerometer, and thermometer string digitizer). Depths of each of the five thermometer nodes of the thermistor string were determined automatically from the depth of the instrument carrier where the bottom of thermistor string is terminated at the digitizer. Figure **F22** shows one thermometer node protected by polyurethane and tie-wrapped to the 3.5 inch tubing. The thermistor has a total length of 146 m, with five nodes irregularly spaced over its length. It is terminated at the bottom by a digitizing unit that is mounted to the top of the instrument carrier.

In total, three cables plus the flatpack umbilical were guided upward from the instrument carrier together with the thermistor. Apart from the latter, everything was fed through four slits in the swellable packer's rubber compound mantle. Further above, centralizers, tie wraps, and steel bands secure the cables and umbilical to the string and feed all lines into the CORK head (Fig. **F23**).

Figures **F23, F24,** and **F25** illustrate the arrangement of seafloor part of the observatory (CORK head and ROV platform), showing the orientation of the pressure recorder and Teledyne Ocean Design, Inc. (ODI) connectors. Before lowering the completion string into water, all the hydraulic tubes were equilibrated to seawater pressure by opening two-way valves on Bay 1 of the CORK head to allow fluid to enter the tube and displace trapped air (see also Fig. **F19**). All the pressure transducers were connected to ocean by three-way valves to protect the transducer from excess pressures and damage. After landing on the borehole but prior to cementing, all two-way valves were closed to inhibit borehole fluid flow in the hydraulic tubes, and they remained closed after the cementing operation. When the cementing was completed and the completion string was released at the running tool, we switched the three-way valves to connect the three pressure transducers to start observation of borehole formation pressure. By ROV communication, we obtained the record of the initial ~15 h after observation had started as well as all pressure readings prior to switching the valves from the seawater port (i.e., hydrostatic pressure) to the lines from the pressure gauge to the ports at depth. The record obtained (Fig. **F26**) clearly shows tidal variations with the pressure disturbance during circulation and cementing before the valves were closed. After switching the valves after cementing was finished, we observed a shift in pressure and different tidal response from ocean especially for the bottom pressure port (P1) below the cemented section near the strainmeter, suggesting that the cement column successfully isolates the bottom section from the upper sections.

Before the ROV left the CORK head, the observatory was set to standby mode until it is visited again by ROV in March 2011. One exception is the CORK head–mounted pressure sensor unit, which was set to record prior to deployment into the seafloor, so that by March 2011 a 4 month record at four levels (3× formation pressure plus seafloor reference) will be available. In summary, the health of all observatory components installed with the LTBMS can be confirmed. In March 2011, we will download pressure data and start long-term observation with all instruments by data recorder installed in the seafloor. The data recorder has a stack of batteries that can power the whole system for 1 y. We plan to connect the observatory to the undersea Dense Oceanfloor Network System for Earthquakes and Tsunamis (DONET) submarine cable observatory network so that measurements can be observed in real time from a shore-based monitoring station during the next visit to the Site C0002 observatory in November 2011 or later.

Preliminary scientific assessment

The data collected from the recovered SmartPlug proved to be complete time series data over >15 months and validates the concept of cheap, durable, replaceable CORK-like observatories. The upgraded version, the GeniusPlug, also adds another dimension:

expandable. Data is still being evaluated from the SmartPlug, and it is anticipated that the geochemical and biological supplementary sampling systems will be as successful when the GeniusPlug is recovered.

The LTBMS CORK is one of the most ambitious CORK deployments ever. With the wide array of sensors successfully deployed and tested, we feel fairly confident that the Hole C0002G LTBMS will provide a wealth of valuable data and observations once it is tied into the DONET undersea network. The stringent and repetitive testing regime before, during, and after deployment went a long way to establishing the feasibility of deploying complex and sensitive permanent observatory systems in the NanTroSEIZE study area and give the entire project greater confidence that the future planned 7000 mbsf observatory can be successfully deployed.

These operations marked great strides forward in the NanTroSEIZE project and have provided the tools to ensure the future success of the complex drilling project.

Operations

Shingu, Japan port call

Expedition 332 began at port in Shingu, Japan, on 25 October 2010. We remained in port conducting cargo loading until 1700 h on 27 October, when the *Chikyu* left port to anchor 1 nmi southeast of Shingu. Plans were to continue loading operations via supply boat (*Kaiyu*), but due to deteriorating weather conditions with the approach of Typhoon Chaba, the *Chikyu* left anchorage off Shingu to evacuate from the typhoon at 1200 h on 28 October. The *Chikyu* set a course for the region around Torishima Island, ~300 nmi to the southeast, planning to arrive around 1500 h on 30 October. The *Chikyu* reached 29°52′N, 144°40′E at 0500 h on 30 October, near Soufugan rock, when it was decided to reverse course and return to the Site C0010 region to rendezvous with the supply boat because Typhoon Chaba reached the Shingu area earlier than predicted.

Site C0010

The *Chikyu* arrived back at the rendezvous point at 0545 h on 1 November 2010, 6 nmi north of the planned position to avoid the main Kuroshio Current. Loading continued from 0700 to 1500 h, after which the *Chikyu* moved to 1 nmi north of Site C0010 to install the ROV cursor at 1900 h, preparatory to the ROV diving at 0145 h on 2 November. After deploying one transponder, the ROV was recovered on deck to troubleshoot telemetry problems with the ROV camera. After the problems were solved, the ROV dove again at 1400 h to set the three remaining transponders and at 2045 h the ROV removed the corrosion cap and set it on the seafloor. The ROV was recovered to the surface at 2130 h, and the *Chikyu* resumed drifting to the well center for DP calibration from 2300 h on 2 November. DP calibration was completed at 0300 h on 3 November, whereupon the *Chikyu* moved to the LCA 28.5 nmi northwest of Site C0010, arriving at 1230 h. The casing packer retrieving assembly was run into the hole at that time, stopping at 1445 h to attach Accelerometer 1 ~460 m from the bottom of the BHA. The *Chikyu* continued running drill pipe into the hole to 1400 m drilling depth below rig floor (DRF). Meanwhile, the supply boat *Kaiyu* rendezvoused with the *Chikyu* at 1400 h to resume loading of cargo and supplies, finishing at 1600 h, after which the supply boat was released. Drifting continued while the BHA was run to 1800 m DRF, pausing to attach Accelerometer 2 to the drill pipe at ~1600 m DRF. No significant VIV was observed, even while drifting in 6.0 kt current. The ROV was launched on 0215 h on 5 November when the *Chikyu* reached a position 1 nmi upstream of Hole C0010A, and the *Chikyu* reentered the hole on 1215 h. The BHA was run down in the cased hole to latch on to the bridge plug at 1730 h and then was pulled out of the hole, leaving the wellhead at 0220 h on 6 November. The BHA was pulled up to 1777 m DRF, whereupon drifting to the southeast commenced while being monitored by the ROV. Drifting continued until 1030 h, 5 nmi southeast of Hole C0010A, when the ROV was recovered and back on deck by 1200 h. Drifting to the southeast resumed in 3.6 kt current. Pulling out of the hole resumed at 0700 h on 7 November; Accelerometer 2 was removed from the drill pipe at 0821 h and Accelerometer 1 at 1245 h. The SmartPlug was recovered on deck at 1403 h, removed from the bridge plug, and opened at 1500 h. Pressure data were downloaded in the Core Processing Deck laboratory at 1620 h. Once the SmartPlug was on deck, the *Chikyu* ended drifting and began moving to upstream of Site C0010 to begin the casing scraper run. At 2215 h, the *Chikyu* resumed drifting back to Site C0010 while running the scraper BHA to 480 m DRF. By 0215 h on 8 November, the scraper BHA reached 1526 m DRF; however, to avoid a slight seafloor rise, the BHA was pulled to 1000 m DRF. Running drill pipe resumed at 0700 h, reaching 2283 m DRF by 1030 h, stopping running at 1 nmi upstream of Site C0010 to dive the ROV. Drifting resumed again at 1130 h, but an ROV camera malfunction (data transmission cable came loose and was cut by the ROV thruster) caused another delay while the ROV was recovered on deck, fixed, and relaunched at 2200 h. In the meantime, drill pipe was pulled back to 2000 m DRF until the ROV was back in the water. At that point, running drill pipe continued until the BHA was at 2400 m DRF (at 2330 h). At 2400 h, the scraper BHA reentered Hole C0010A, reaching 2542 m DRF (10 m above the wellhead), stabbing in and performing two scraper runs to 2933 m DRF by 0115 h on 9 November. The scraper BHA was pulled out of the hole to clear the wellhead while the ROV tried but failed to recover the corrosion cap. The decision was made to leave the present cap on the seafloor near the wellhead and install a new corrosion cap when Site C0010 operations were finished. The scraper BHA was recovered on deck at 1020 h on 9 November, whereupon the *Chikyu* moved to the LCA at 1302 h to begin running the GeniusPlug replacement into the hole. The GeniusPlug was connected to two joints of 3.5 inch tubing, and then the retrievable bridge plug and the entire BHA and running tool were rigged up and set to run into the rotary table at 1905 h. The tubing had bent while lying down, so after straightening the tubing it entered the moonpool at 1930 h on 9 November. At 0800 h on 10 November the ROV dove, and at 0952 h it inspected the BHA and GeniusPlug at 2359 m DRF. The *Chikyu* continued drifting toward Hole C0010A, and at 0904 h on 11 November was ready to reenter the wellhead. At 0930 h the ROV once again examined the BHA, including the GeniusPlug and the casing packer assembly. At 1035 h the GeniusPlug was run into the wellhead, and by 1100 h the entire BHA had been run into the wellhead. The drill pipe continued to be run into the hole, and at 1710 h the bridge plug was set and latched at 2928 m DRF (packer element center) and the running tool was released. Suspension fluid pumping (20 cm^3) began at 1724 h, after which the running tool BHA was pulled out of the hole to 2550 m DRF. The anti-VIV ropes were removed as the BHA was pulled out of the hole to 1900 m DRF while the ROV was recovered on deck with the suspension cap at 0200 h on 12 November. The running tool BHA was recovered on deck at 1100 h on 12 November while the ROV was prepared to dive with the replacement corrosion cap. The ROV dove at 1500 h to set the corrosion cap and recover the transponders, recovering the last one (of four) and returning to the cage at 2135 h, and was on deck at 2330 h. The well was completed and the *Chikyu* moved off to Site C0002.

Site C0002

The *Chikyu* moved toward Site C0002 after midnight on 12 November 2010, moving upstream of the site to prepare the 20 inch casing and jetting-in BHA with the mudmat and wellhead assembly connected. At 1830 h on 13 November, the BHA was run into the water ~15 nmi upstream of Site C0002. The ROV dove at about the same time, and the BHA was run into the water, with 40 m of the 20 inch casing hanging below, until it reached 1441 m DRF, whereupon anti-VIV ropes were attached to the upper portion of the drill pipe as it continued being run. By 0330 h on 14 November, the BHA reached 1861 m DRF while the *Chikyu* continued to drift to Site C0002. The *Chikyu* reached 2.5 nmi from Site C0002 by 0600 h on 15 November while the ROV continued monitoring the BHA and running tool for signs of VIV. At 1247 h the BHA position was confirmed by ROV and the ship's DP systems, and the seafloor was tagged at 1256 h. Hole C0002G was began at 33°18.0126′N, 136°1488′E in water depth of 1966 m DRF (1937.5 m mud depth below sea level). Jetting in with the 20 inch casing began at 1307 h. The cart was released by the ROV at 1630 h, and beginning at 1700 h the running tool was picked up to 1970 m DRF while ropes were removed from the drill string. The BHA was pulled out of the hole to the surface and was laid down at 0330 h on 16 November. Once recovered, there was a short stop at 0710 h as the *Chikyu* moved to a LCA to rendezvous with the *Heisei maru* to backload the CORK running tool for transport ashore. At 1230 h the guidehorn was moved to the moonpool for assembly and was completed by 1815 h, after which the 12¼ inch drilling LWD/MWD BHA was made up and run into the hole at 1900 h. By 0618 h on 17 November, the BHA had reached 1787 m DRF as the *Chikyu* drifted along with the current, reentering the wellhead at 0945 h. Reaming to the bottom of the 20 inch casing at 2007 m DRF began, and drilling with LWD to 2267 m DRF commenced at 1030 h. Drilling reached 2573 m DRF at 1145 h on 18 November, when a short trip to the casing shoe to circulate and clean the hole was run from 1230 to 1430 h. The run back to the bottom resumed at 1630 h, and drilling resumed from 2573 to 2675 m DRF at 1830 h. The BHA reached 2858 m DRF, an initial 9⅝ inch casing shoe target depth, at 1045 h on 19 November when cleaning and sweeping of the hole was resumed. The BHA was pulled out of the hole to 1810 m DRF with no overpull and then resumed pulling out of the hole to the rig floor. The ROV was recovered at 1640 h as the *Chikyu* drifted along the current and continued to pull the BHA out of the hole. The LWD/MWD BHA was laid down at 0100 h on 20 November, and 10⅝ inch BHA was made up and run into the hole at 0130 h. At 0800 h, 1 nmi from Hole C0002G, the ROV dove and the BHA run in hole was paused, resuming at 1030 h, and the BHA reentered the hole at 1130 h. By 1145 h the BHA was at 2785 m DRF, where a short relogging trip began from 2785 to 2804 m DRF and again from 2830 to 2858 m DRF, first to overlap the proposed casing shoe depth and also to confirm the suitability of the proposed strainmeter depth and sensor carrier positioning. At 1900 h, drilling with the 10⅝ inch BHA LWD assembly began from 2858 m DRF to TD (2946 m DRF), which was reached 0230 h on 21 November when circulation to clean to hole began, sweeping with 10 m^3 of Hi-Vis mud. After sweeping was completed at 0445 h, the BHA was pulled out of the hole to 2862 m DRF to relog from 2859 to 2830 m DRF because the live-streaming LWD data were missing two resistivity channels and did not appear in ply back after TD was reached. Relogging finished at 0600 h, after which the BHA made a short trip to 2500 m DRF. The BHA was run down to the bottom at 0715 h for circulation. There was some concern about hole conditions deteriorating below 2934 m DRF, as the BHA began experiencing pack-off. Circulation began at 0900 h, and a wiper trip to the 20 inch casing shoe was completed at 1200 h. A run back to bottom, starting at 1500 h, showed no more trouble with hole conditions, as reaming slowly to 2945 m DRF had no problems. Hi-Vis mud was spotted at 1900 h, pulling out of the hole to 1870 m DRF began at 2015 h, and the BHA was clear of the wellhead at 2330 h. By 0615 h on 22 November, the 10⅝ BHA was laid down, and then the 9⅝ inch casing was readied to be run in the hole while moving to the LCA. At 0845 h the guidehorn was rigged down, and at 1130 h the casing was rigged up and ready to run. At 1330 h the casing was run in, reaching 130 m DRF by 1730 h. The casing screen joints were run in the hole from 1330 to 1945 h, followed by the rest of the casing, while the *Chikyu* began drifting back to Hole C0002G. Anti-VIV ropes were deployed on the drill pipe from 1360 m DRF at 0600 h on 23 November until 1830 m DRF was reached at 2000 h that evening. Once the ropes were securely tied off (terminated) on the drill string, the guidehorn was reinstalled again and completed by 2300 h. From that point, drifting back to reenter Hole C0002G continued all day on 24 November, reaching 1.5 nmi from location at 2300 h, whereupon the ROV dove. No VIV was observed throughout the entire time the drill string was hung while drifting back to Hole C0002G. The casing BHA reached 10 m above the wellhead at 0300 h on 25 November, and the ROV stood by to observe reentry into the wellhead. The casing was run into the wellhead, reaching the planned setting depth (2853 m DRF) by 0530 h. Cementing the casing began at 0930 h on 25 November, after which the casing hanger tool was released and pulled out of the hole while the drill string was cleared. The ROV was recovered on deck by 1330 h, and the casing hanger was recovered on deck by 0200 h on 26 November. The cement stand and head were examined, and the wiper plug was found trapped above the drop indicator inside the cement head. The *Chikyu* began moving to Shimizu, Japan, for port call, arriving by 0700 h on 27 November.

The *Chikyu* stayed quayside, loading and unloading tools and equipment, leaving port at 2000 h and making way back to Site C0002. The *Chikyu* reached 7 nmi upstream of Site C0002 at 1730 h on 28 November, went into DP mode, and installed the ROV cursor rail at 2030 h. The drill-out cement BHA was run into the hole to 1860 m DRF by 0130 h on 29 November while drifting back toward Hole C0002G. The ROV dove at 0315 h on 29 November, and at 0830h the BHA was run into the hole to 2826 m DRF to begin drilling out cement. After a short trip to the 9⅝ inch float shoe, the BHA was run to 2943 m DRF, the hole was swept, and high-density brine and protect zone were spotted into hole at 1530 h. After spotting, the BHA was pulled out of the hole from the wellhead at 1715 h, and then the *Chikyu* drifted as the drill pipe continued to be recovered. Taking position 20 nmi northwest of Site C0002, the CORK running tool was picked up and makeup began at 0500 h on 30 November. The upper guidehorn was rigged down at 0730 h, and the completion assembly was prepared for running into the hole. Running into the hole began at 2300 h on 30 November, with stopping for connection and termination of three cables, the flatpack, and thermister string on the sensor carrier instruments at 0700 h on 1 December. Joints of 3.5 inch tubing were run with four centralizers per joint up to the swellable packer at 1400 h on 2 December. The electrical cables, flatpack, and hydraulic lines were run through the packer body seal by 1630 h on 2 December, after which the electrical cables were tested at 2215 h to ensure that the connections to the sensors were still viable after working them through the packer. Running continued from 2300 h on 2 December to 948 m DRF on 3 December, when the CORK head was readied for attachment to the completion assembly. The CORK running tool was picked up and mated to the CORK head by 0045 h on 4 December and run through the rotary table by 0200 h. The electrical cables were again tested at 0400 h, after which the cables were measured for cutting and termination. Termination by ODI engineers began at 0730 h on 4 December, and the terminated cables were installed on the CORK head at 0830 h on 5 December. The ROV platform was lowered to the moonpool in preparation for assembly and attachment to the CORK head at 1645 h. Stands of drill pipe were fixed to the CORK running tool and run into the hole to 1300 m DRF by 2230 h on 5 December while the ROV entered the water. The completion assembly was run to 1417 m DRF, where the ROV tested the underwater mateable connectors on the CORK head at 0200 h on 6 December. All connections passed inspection, and the completion assembly continued being run into the hole to 1897 m DRF by 0045 h on 8 December. The underwater mateable connectors were successfully checked again by ROV at 0430 h on 8 December before running the CORK assembly into the wellhead. The *Chikyu* approached and shifted position before running the CORK completion assembly into the wellhead at 0845 h. The assembly was run to 2904 m DRF, and the CORK head was landed on the wellhead at 2015 h on 8 December. One more systems check was performed on the tiltmeter and strainmeter underwater mateable connectors only because the broadband seismometer connector was in danger of being damaged by the ROV arm. All checks were successfully completed by 2200 h. Cementing was finished by 0230 h on 9 December, and the unjay stopper and CORK running tool were released at 0330 h. The running tool was pulled out of the hole to the surface by 1355 h on 9 December.

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Table T1. Hole operation summary. (**See table notes.**)

Hole	Latitude	Longitude	Water depth (m MSL)	Operations	Drilled interval (m)	Cased interval (m)	Total penetration (m)	Time on site (days)
C0002G	33°18.0130′N	136°38.1500′E	1936	Set casing, MWD, LWD, LTBMS deployment	980.0	887.0	980.0	27
C0010A	32°12.5981′N	136°41.1924′E	2552	SmartPlug recovery, GeniusPlug deployment	0.0	0.0	0.0	12
C0018A	32°49.730′N	136°52.890′E	4049	Coring	0.0	0.0	0.0	2
				Expedition 332 totals:	980.0	887.0	980.0	41

Notes: MWD = measurement while drilling, LWD = logging while drilling. LTBMS = long-term borehole monitoring system.

Figure F1. Map of Nankai accretionary complex off Kumano, showing NanTroSEIZE drill sites. Yellow arrows = computed far-field convergence vectors between the Philippine Sea plate and Japan (Seno et al., 1993; Heki, 2007), stars = epicentral location of great earthquakes, red circles = Expedition 332 sites, green circles = previous NanTroSEIZE drill sites. Inset shows location of Nankai Trough region in relation to Japan.

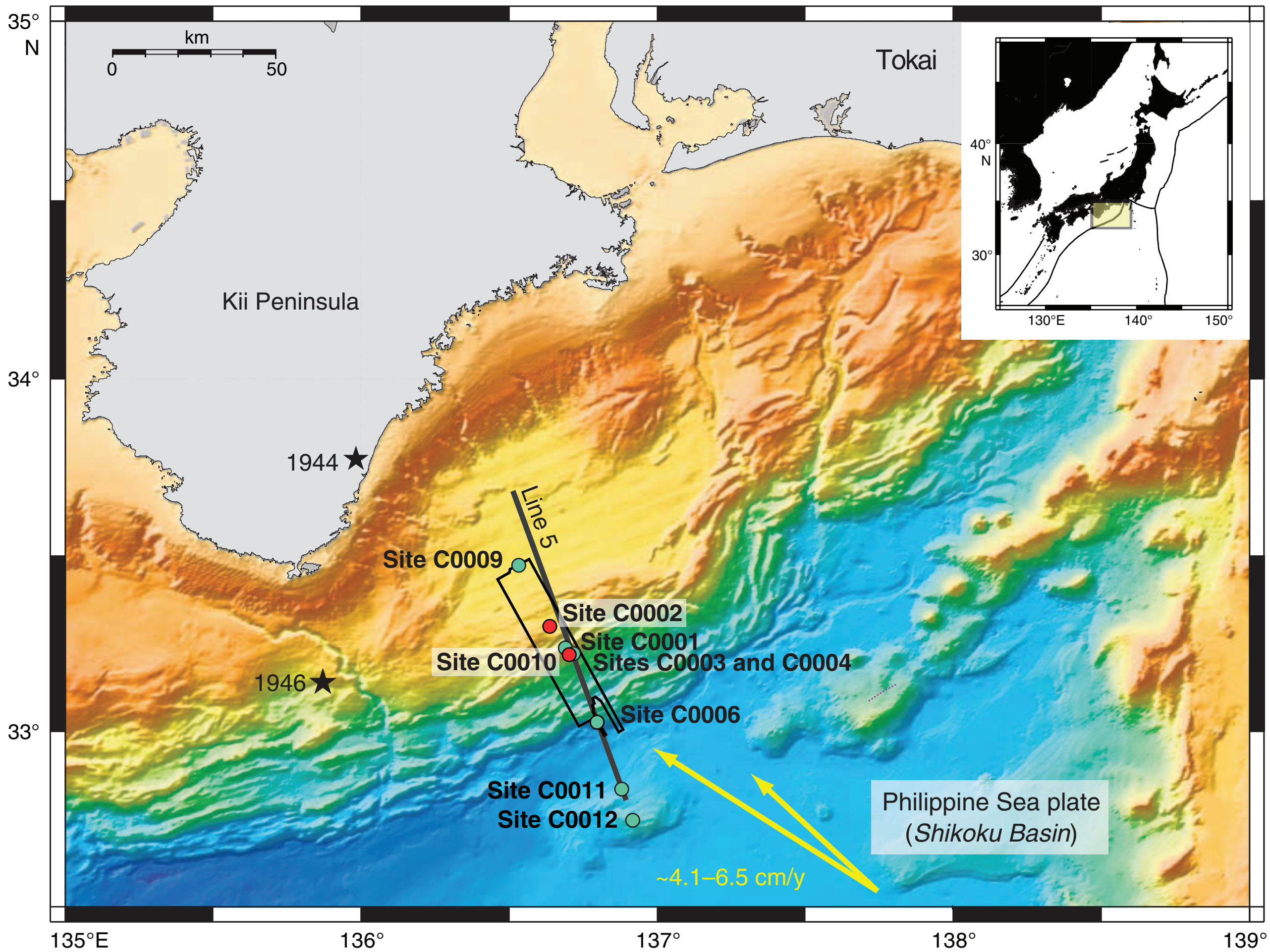

Figure F2. Spliced composite profile of a representative depth section from the NanTroSEIZE 3-D seismic data volume (Moore et al., 2009) and Line 95 from IFREE mini-3-D seismic survey (Park et al., 2008). Projected positions of Stage 1 and 2 drilling sites, including Sites C0009, C0010, C0011, and C0012.

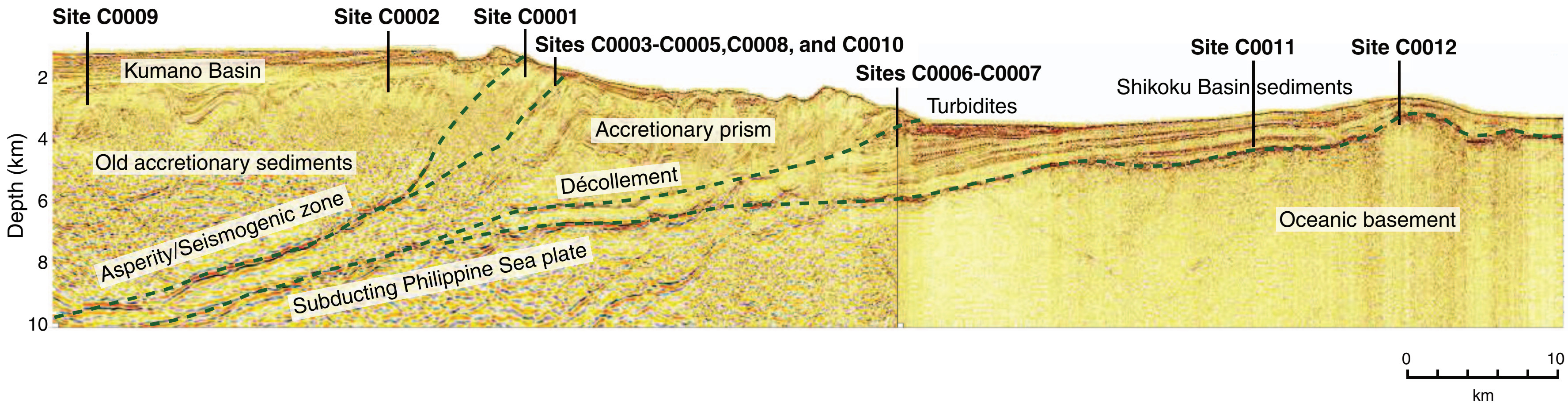

Figure F3. Seismic data for Site C0010 summarizing interpreted LWD information from Expedition 319 (Saffer, McNeill, Byrne, Araki, Toczko, Eguchi, Takahashi, and the Expedition 319 Scientists, 2010). See text. Key elements of casing and hole suspension are shown at right: blue = casing screens, black = casing shoe, thin black = retrievable packer, thin red = SmartPlug.

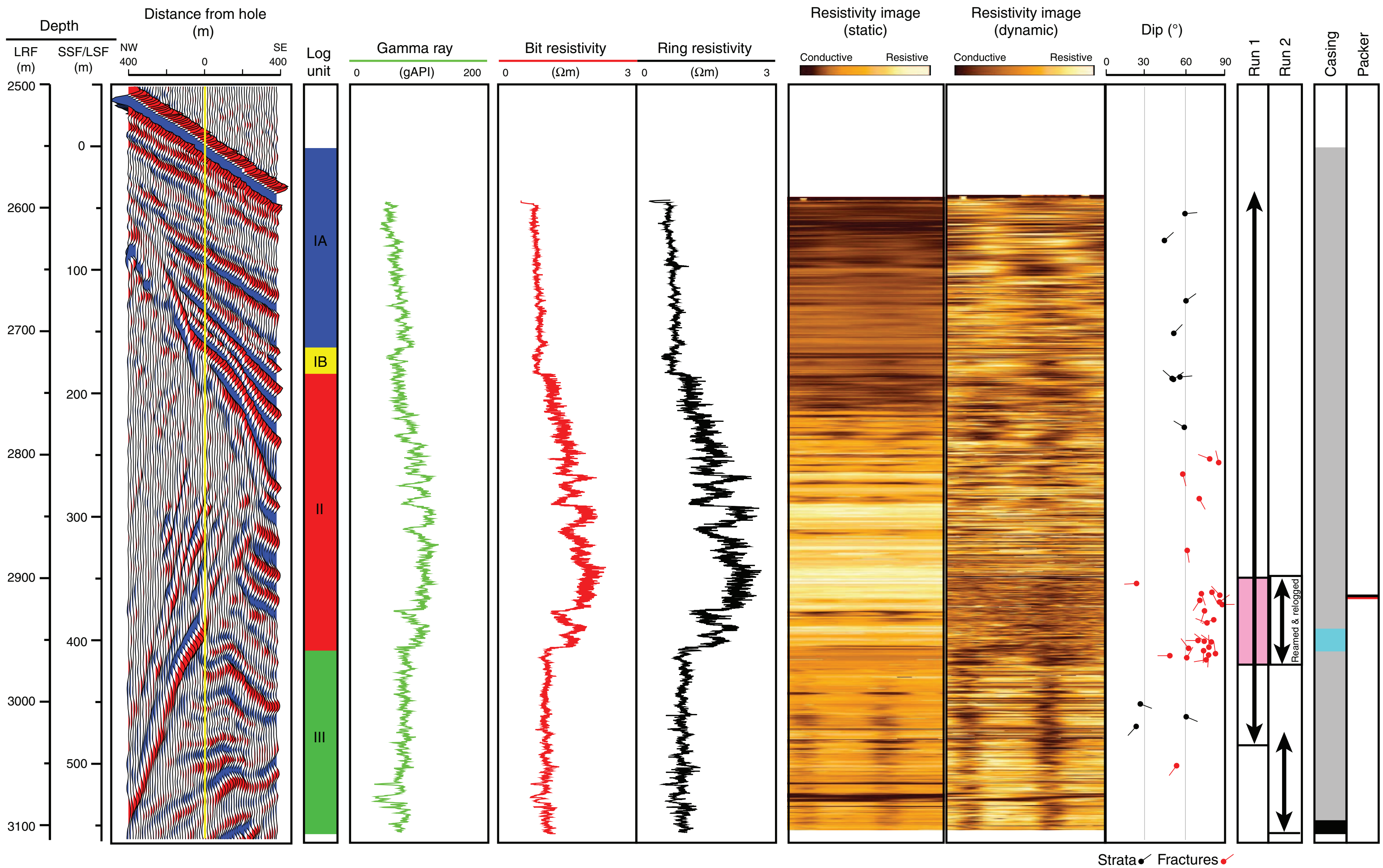

Figure F4. Hole completion at Site C0010, Expedition 319 (SmartPlug) vs. Expedition 332 (GeniusPlug). Packer depth for Expedition 332 changed.

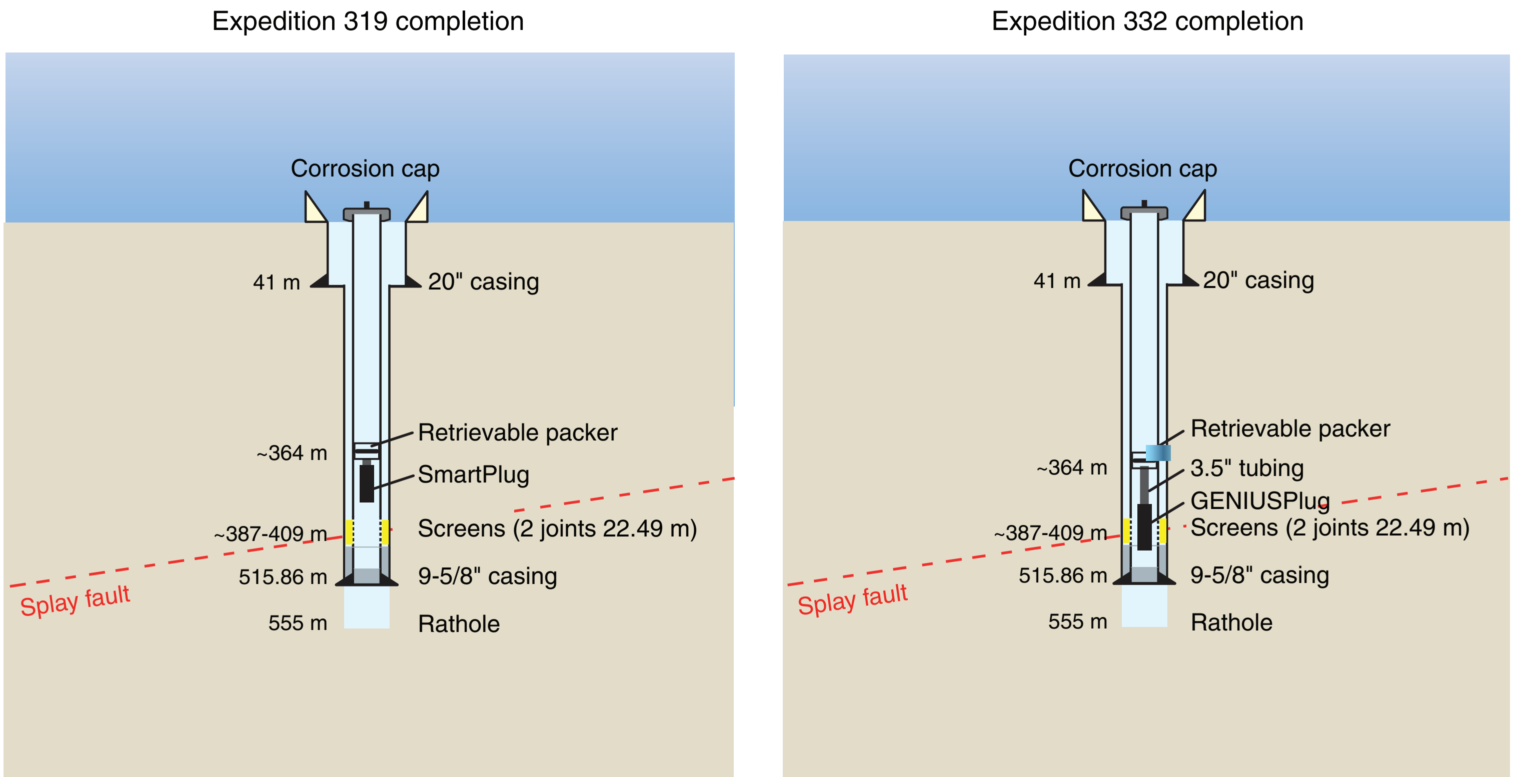

Figure F5. SmartPlug diagram as deployed in 2009.

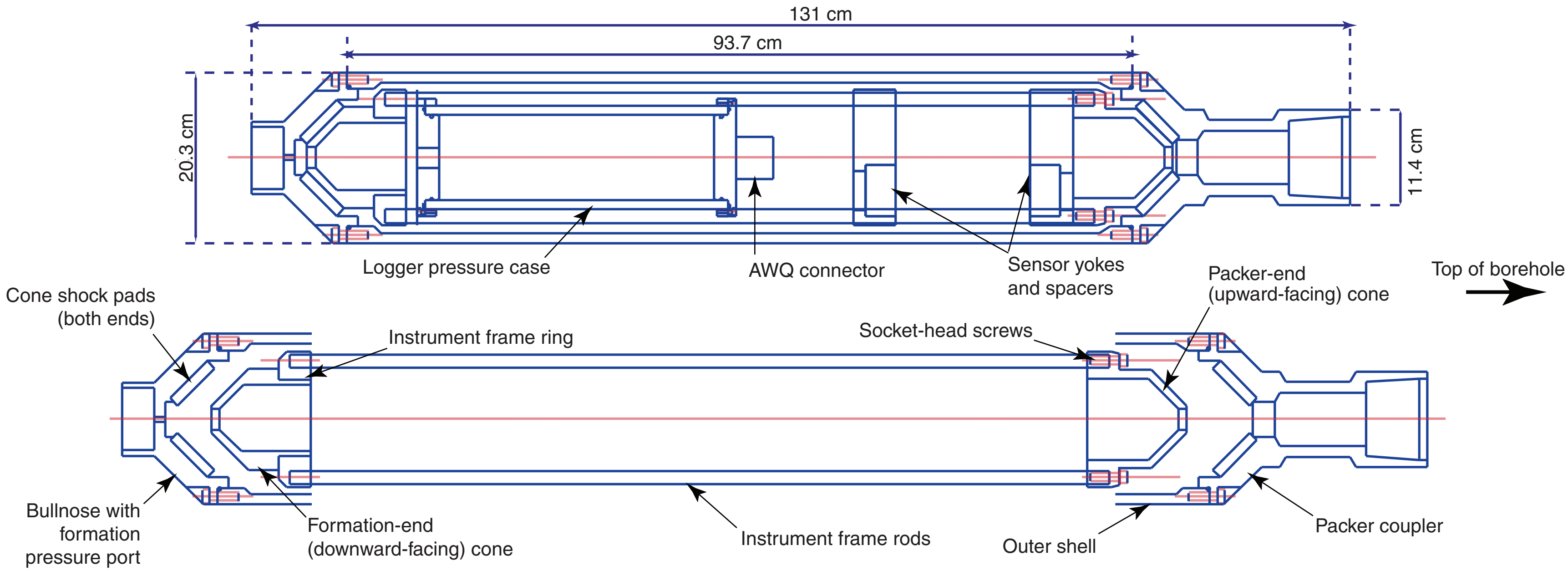

Figure F6. SmartPlug after recovery on deck.

Figure F7. Pressure data from SmartPlug.

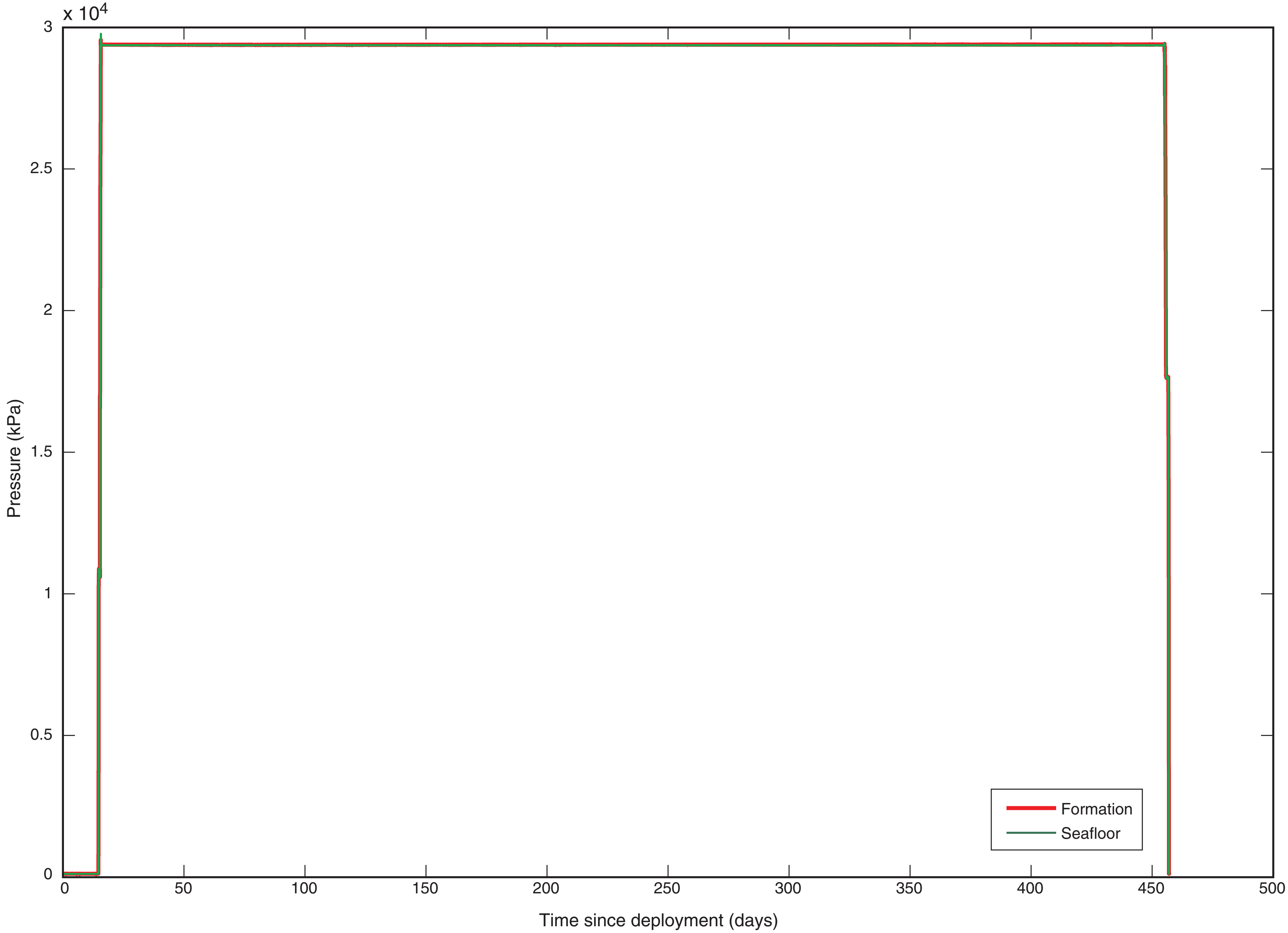

Figure F8. Temperature data from SmartPlug.

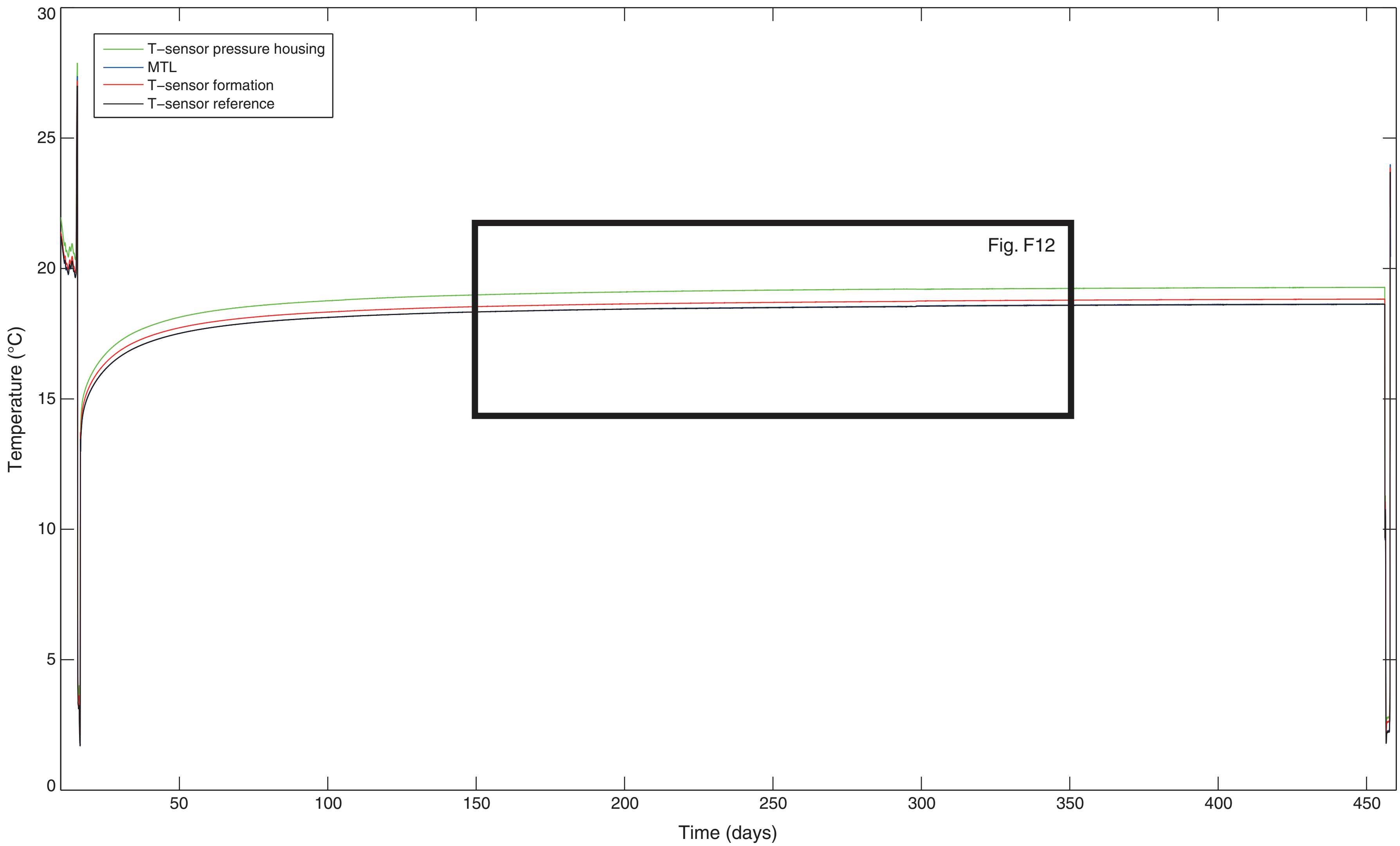

Figure F9. Pressure record from SmartPlug prior to retrieval. Note that the perturbations in the upward-looking sensor and the stable signal in the downward-looking sensor attest that the bridge plug sealed the hole effectively.

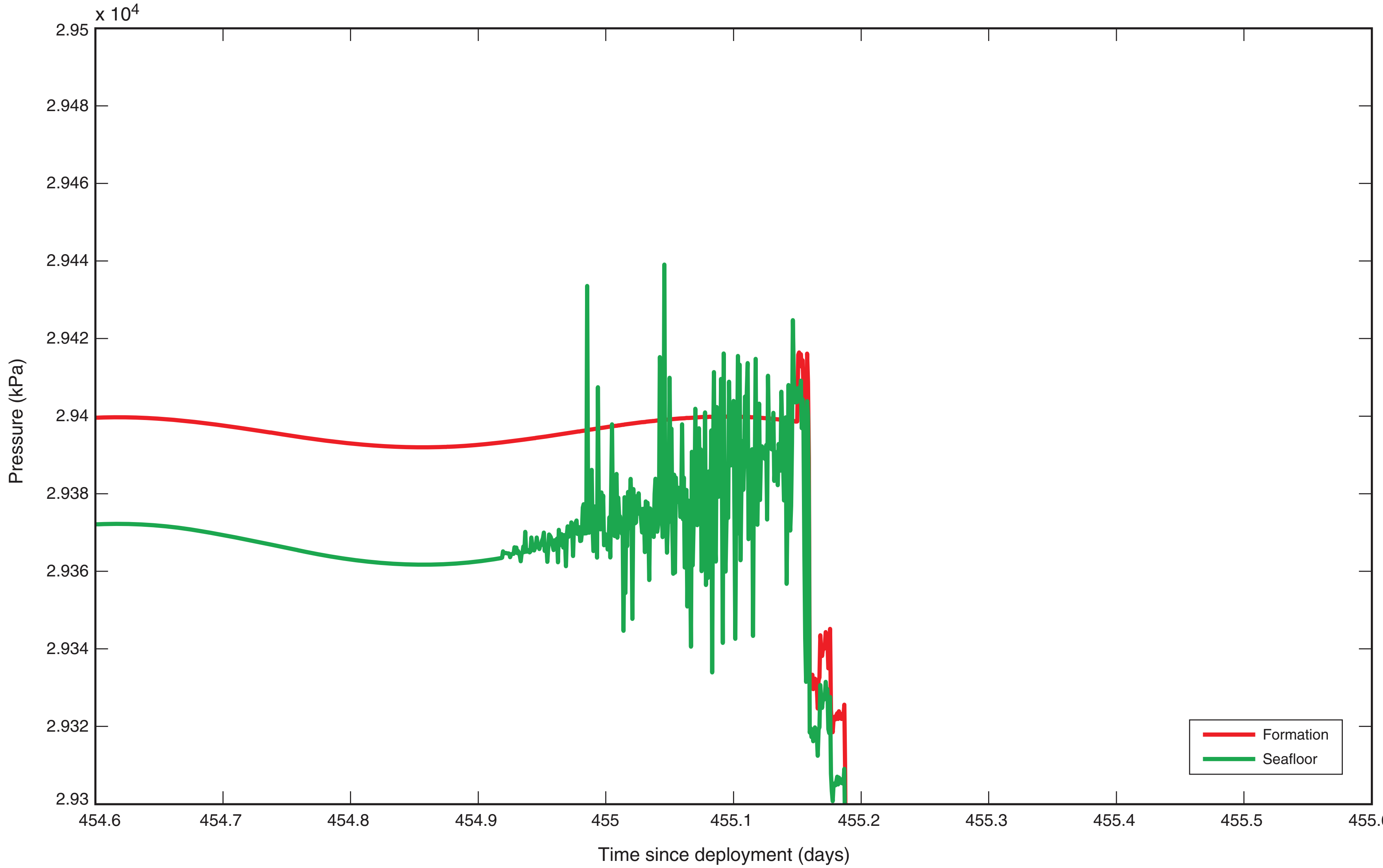

Figure F10. Extracted detail from the pressure record of the SmartPlug illustrating the tidal forcing to the formation. See text.

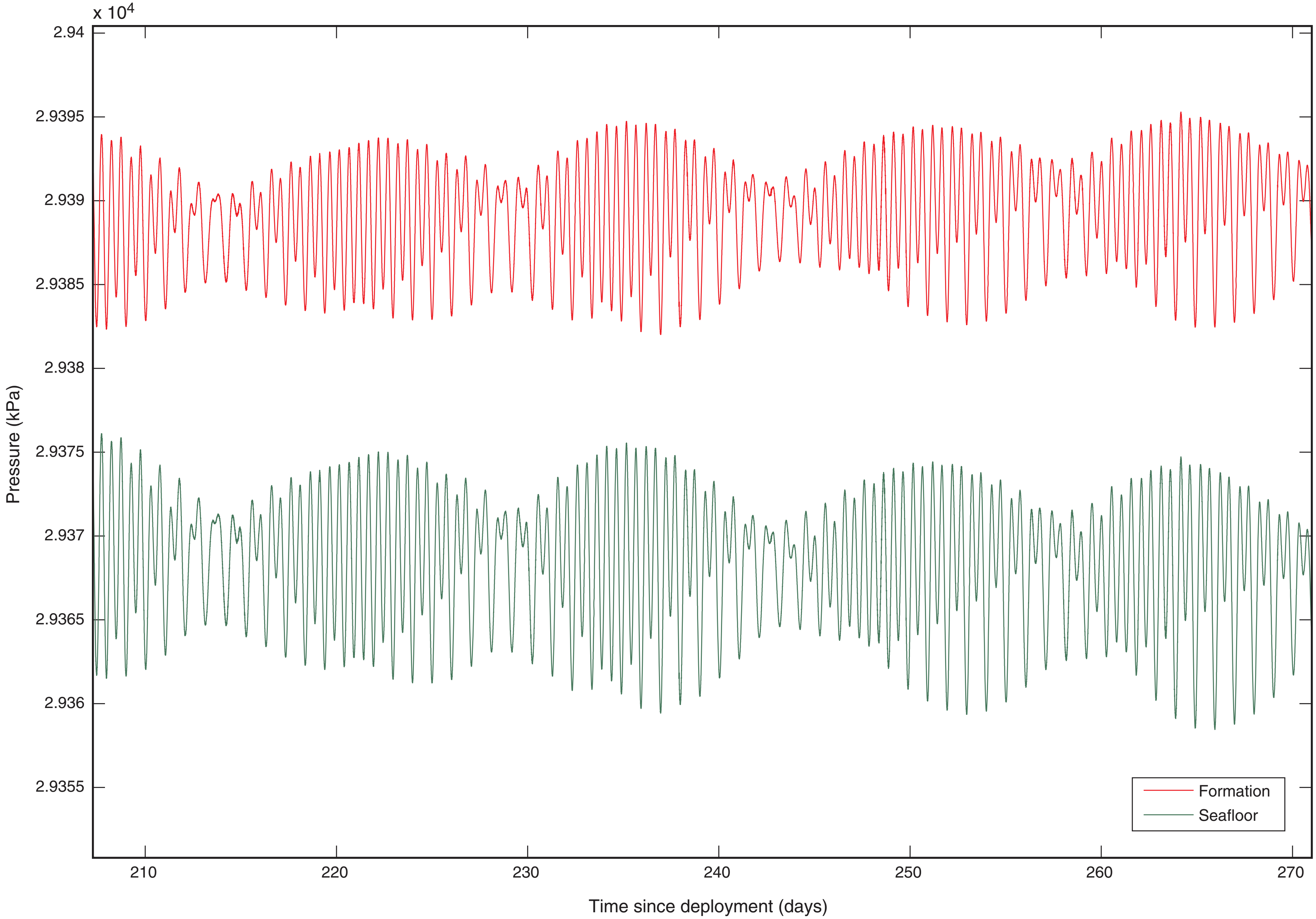

Figure F11. Example of loading to formation by the Chile M 8.8 earthquake (EQ) on 27 December 2010, followed by a tsunami approximately one day later. See text.

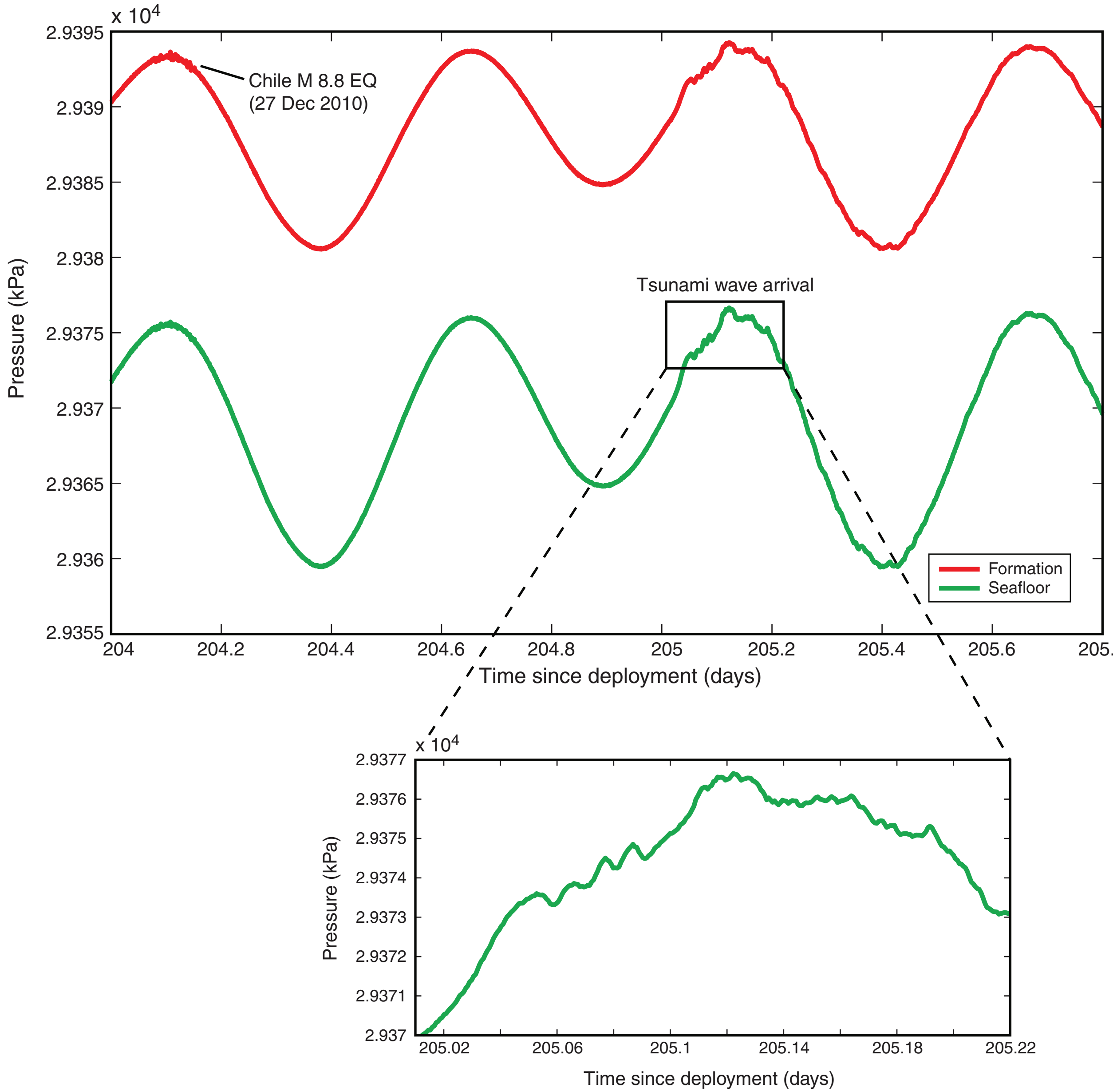

Figure F12. Example of temperature perturbations in late May 2010. It remains unresolved why three thermistors show a systematic increase by ~0.03°C whereas one drops gently at the same time. MTL = miniature temperature logger.

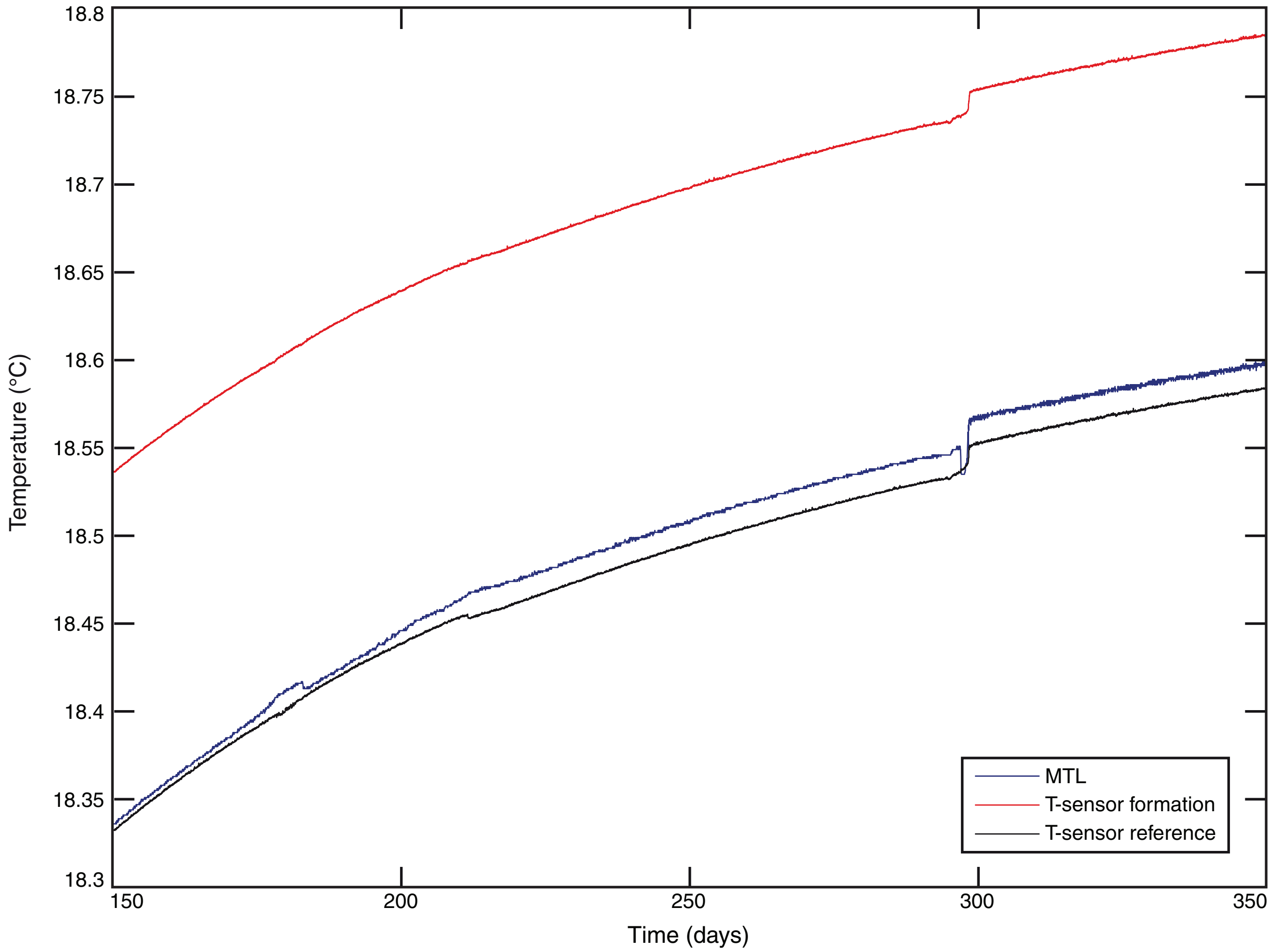

Figure F13. Photograph of ropes attached to the drill string in order to suppress VIV.

Figure F14. Example of accelerometer data illustrating the effect of the ropes on VIV on the drill string.

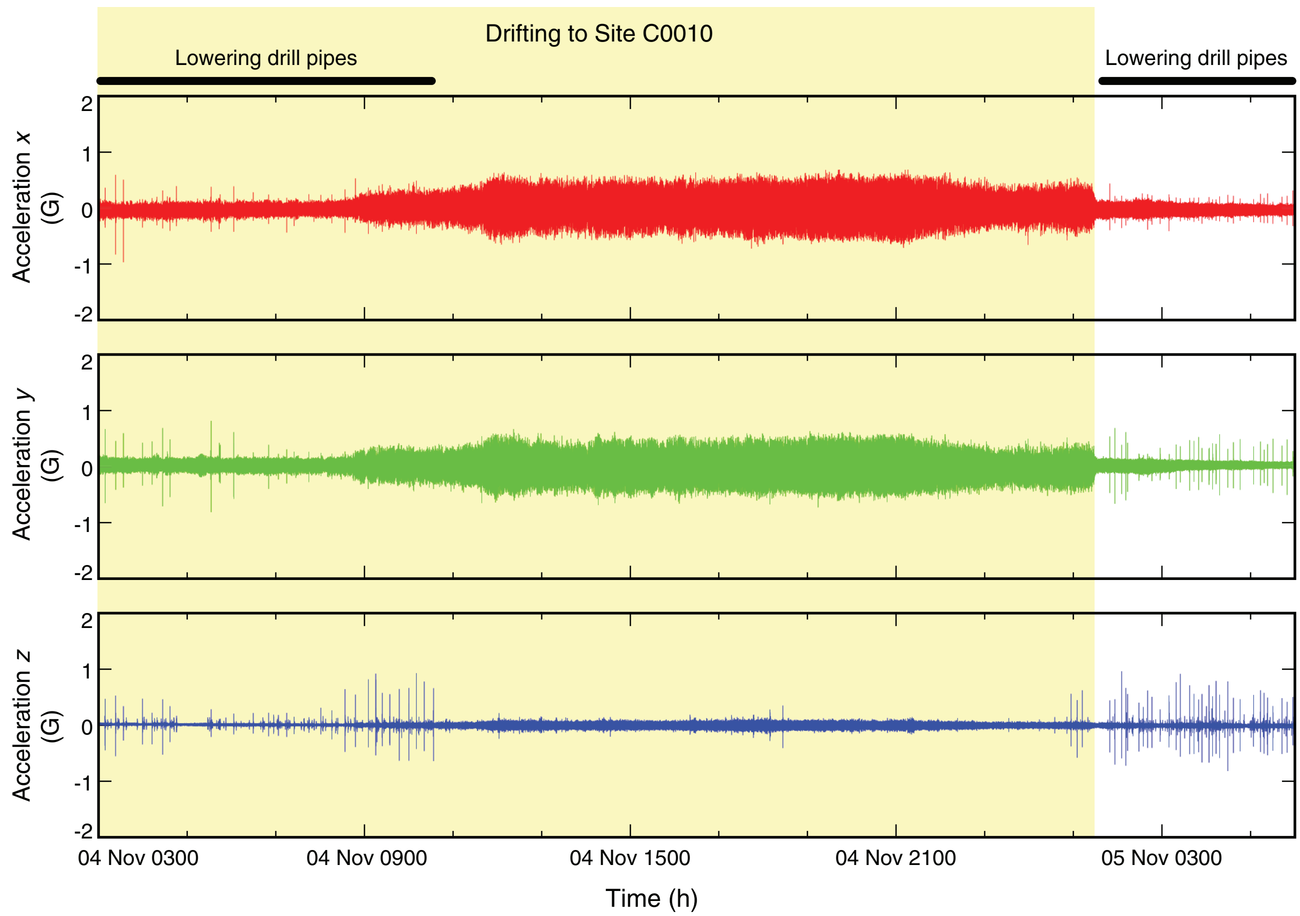

Figure F15. A. Schematic diagram of the extension unit that transformed the SmartPlug into a GeniusPlug. (**Continued on next page.**)

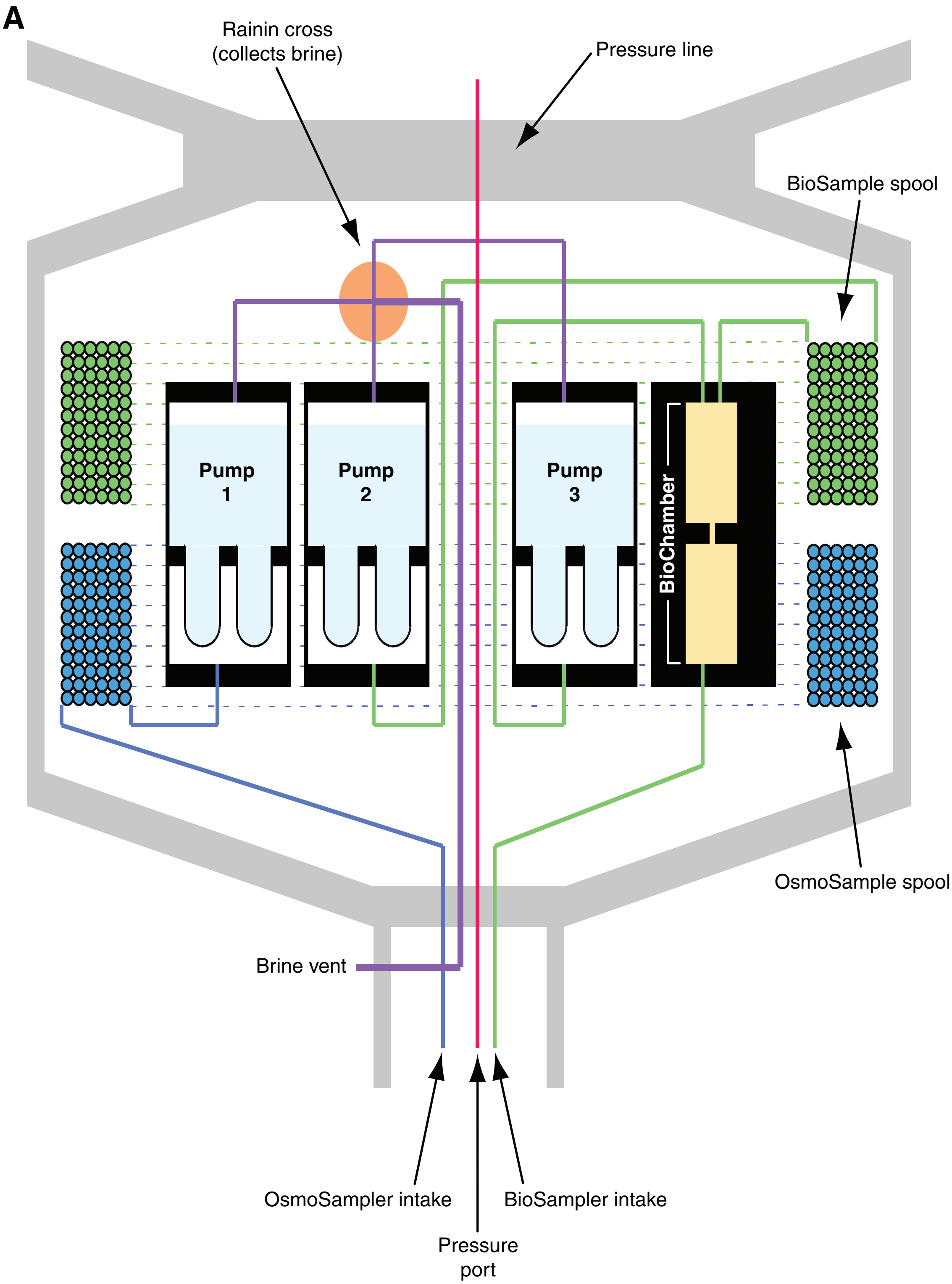

Figure F15 (continued). B. Photograph of the components hosted in the extension unit. FLOCS = flow-through osmotic colonization system.

B

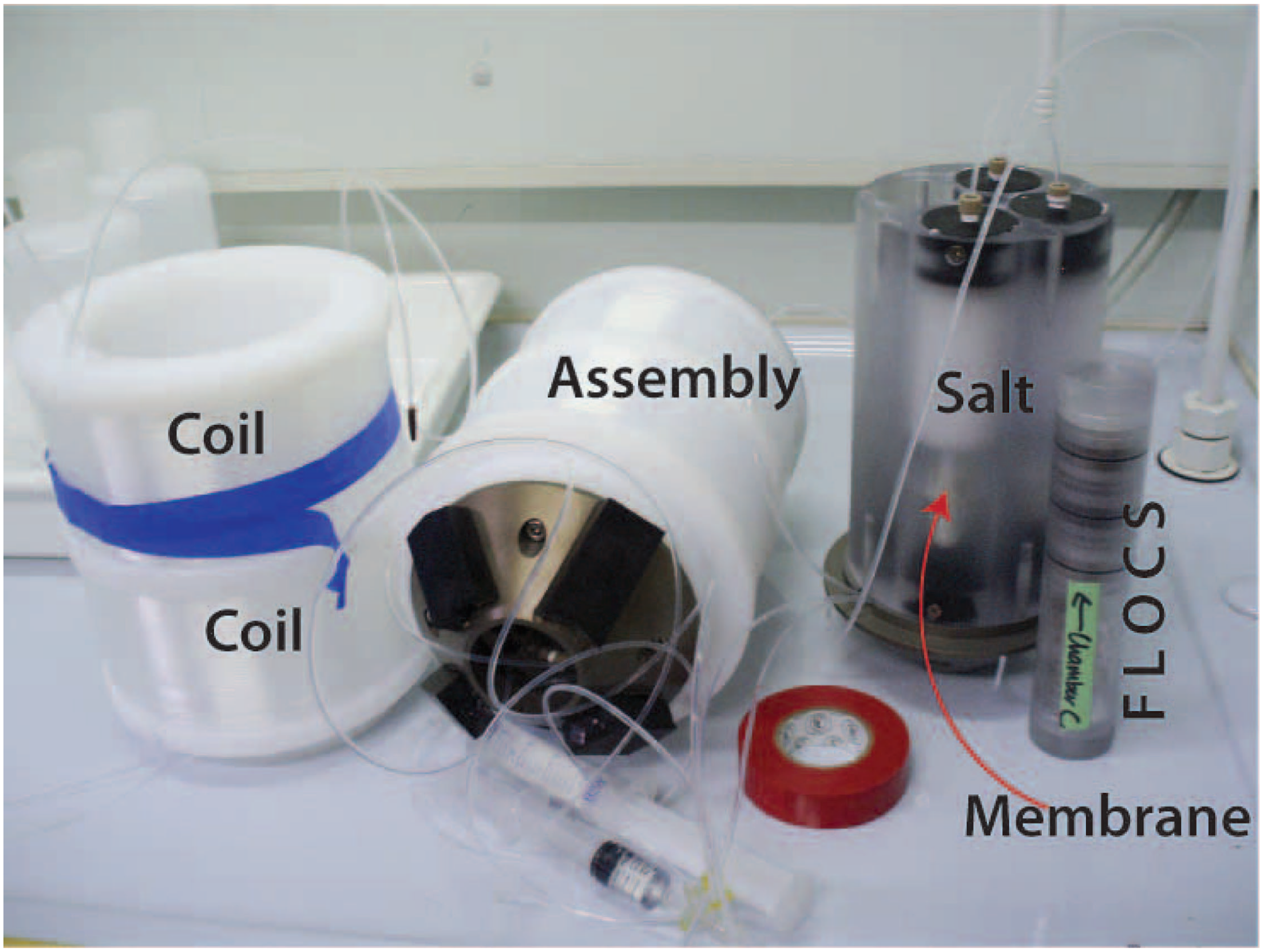

Figure F16. Hole C0002G completion assembly.

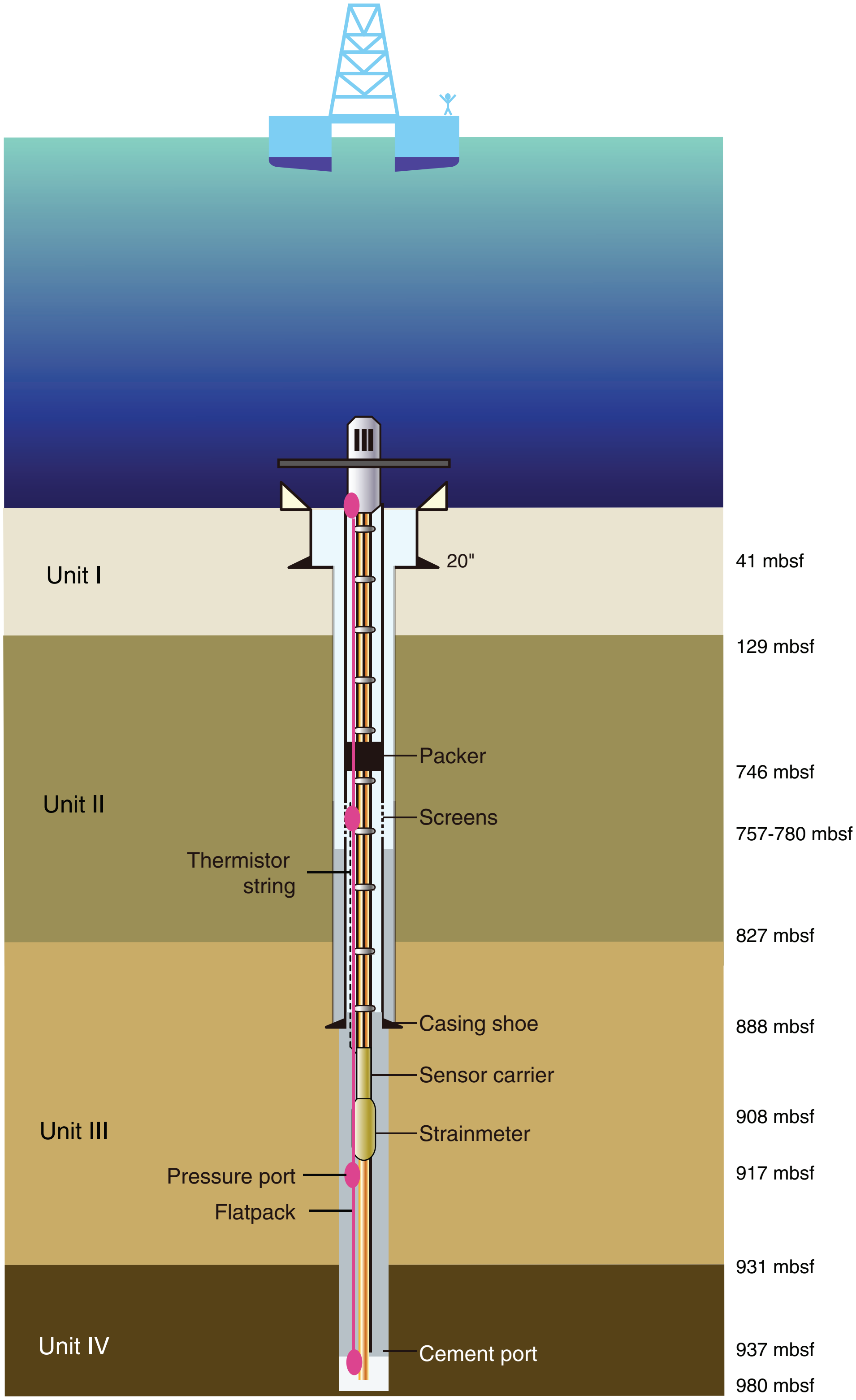

Figure F17. Miniscreen arrangement above bullnose on 3.5 inch tubing.

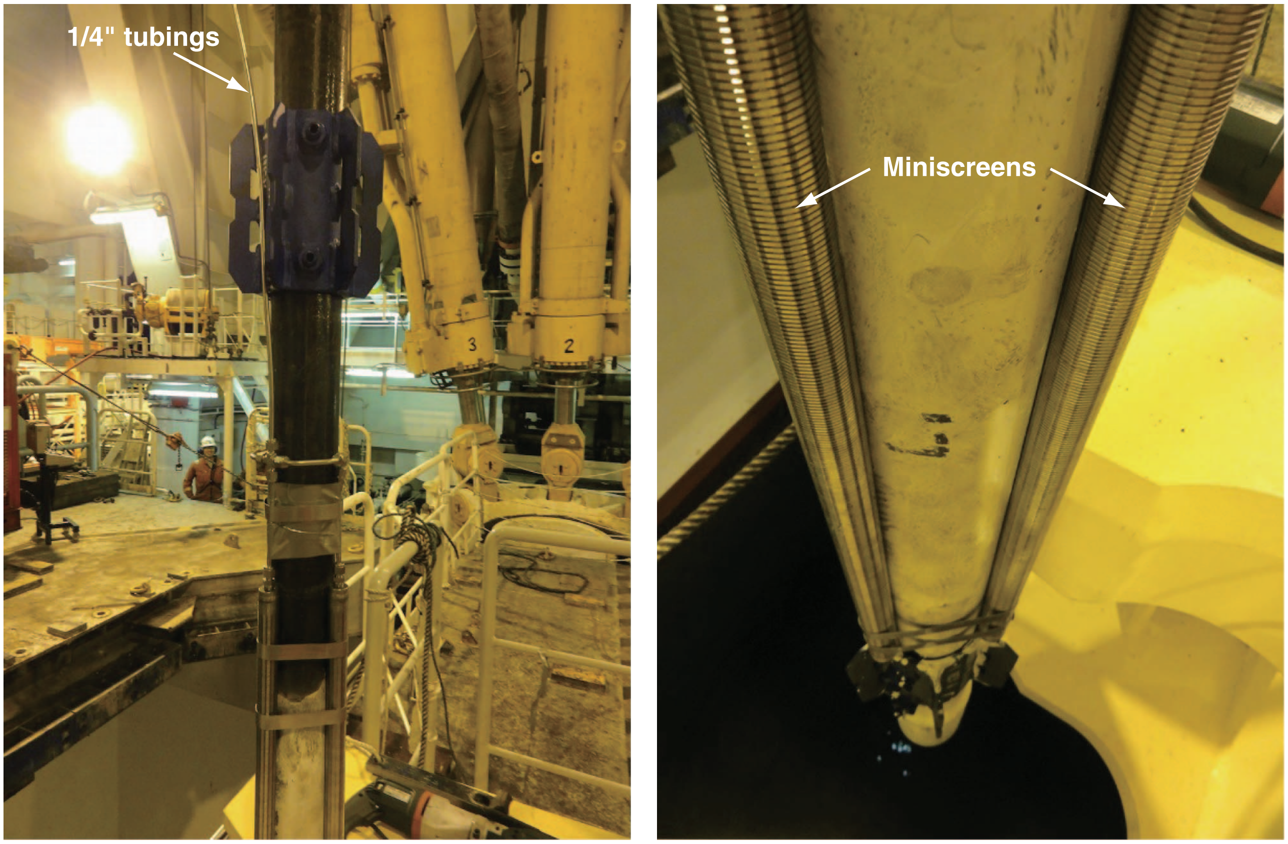

Figure F18. Swellable packer in moonpool area.

Figure F19. Pressure unit carrier on CORK head.

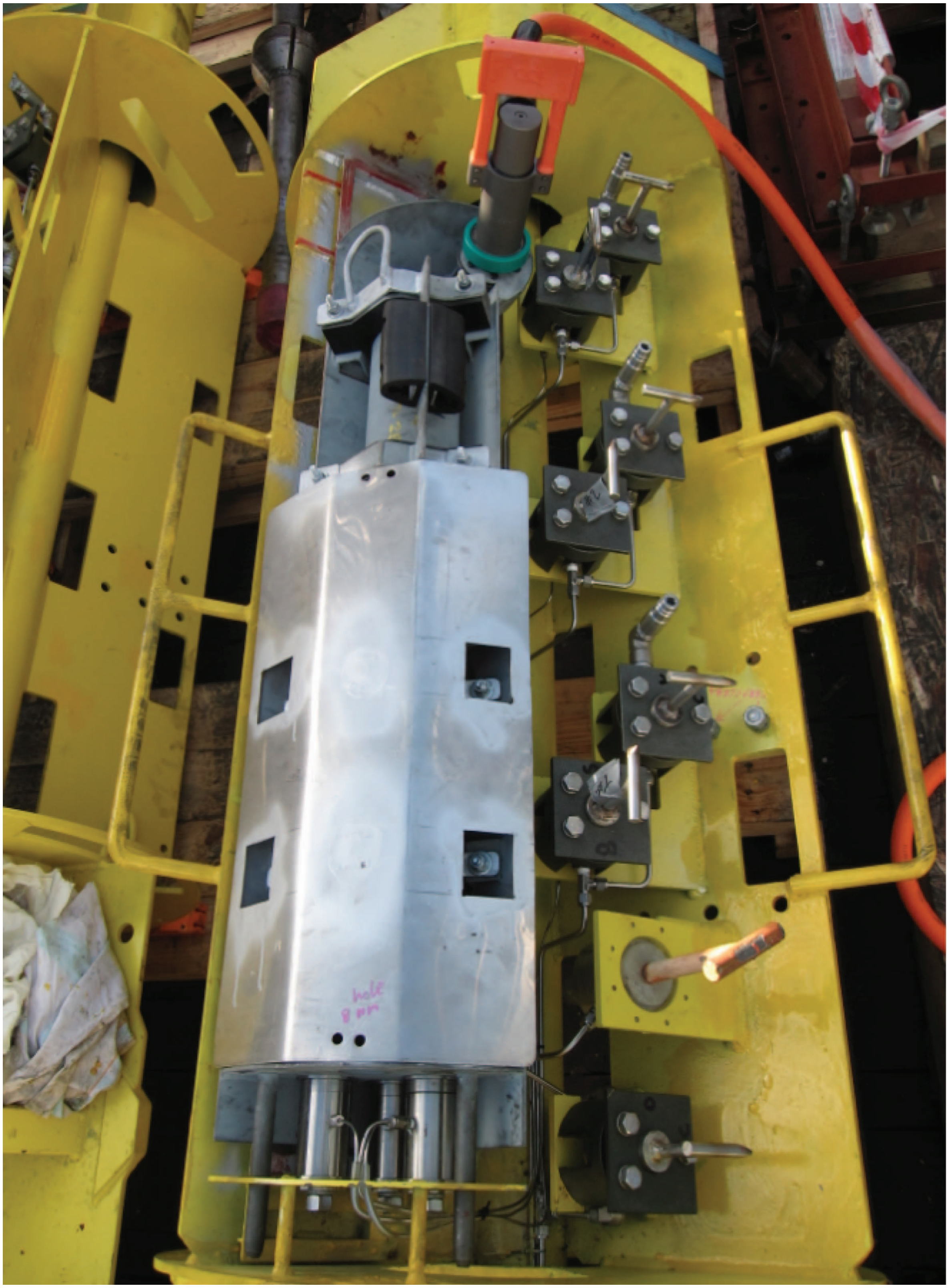

Figure F20. Strainmeter on completion string being run into the moonpool.

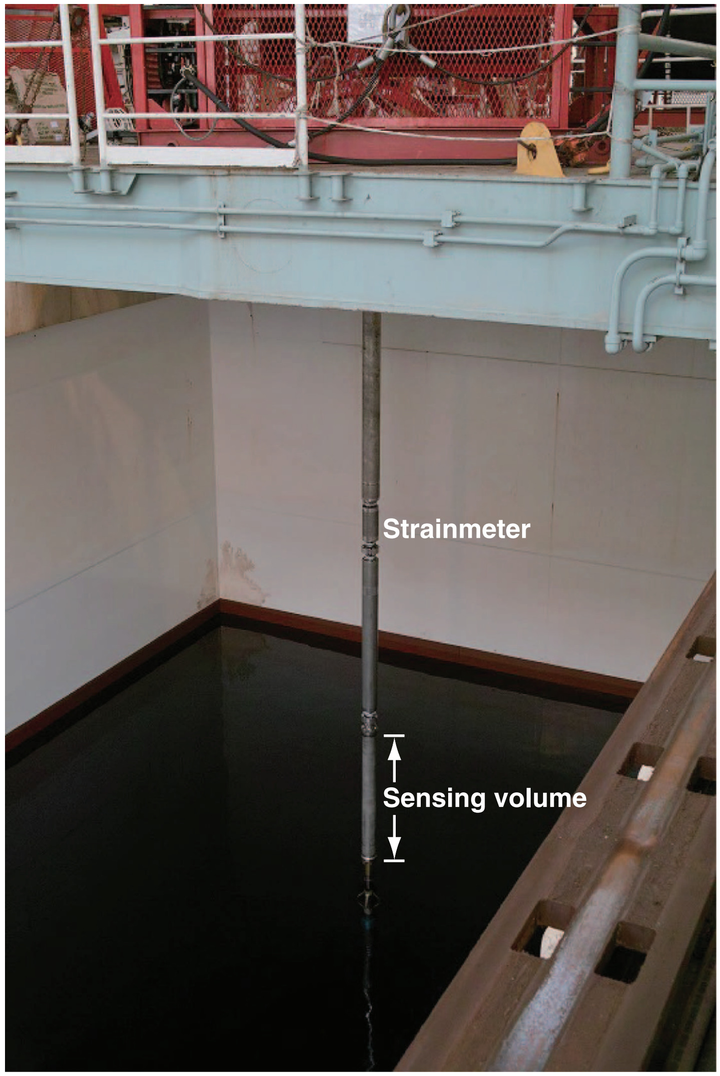

Figure F21. Instrument carrier, showing (attached from the bottom up) Guralp broadband seismometer, LILY tiltmeter, SAHF digitizer, and geophone and accelerometer module.

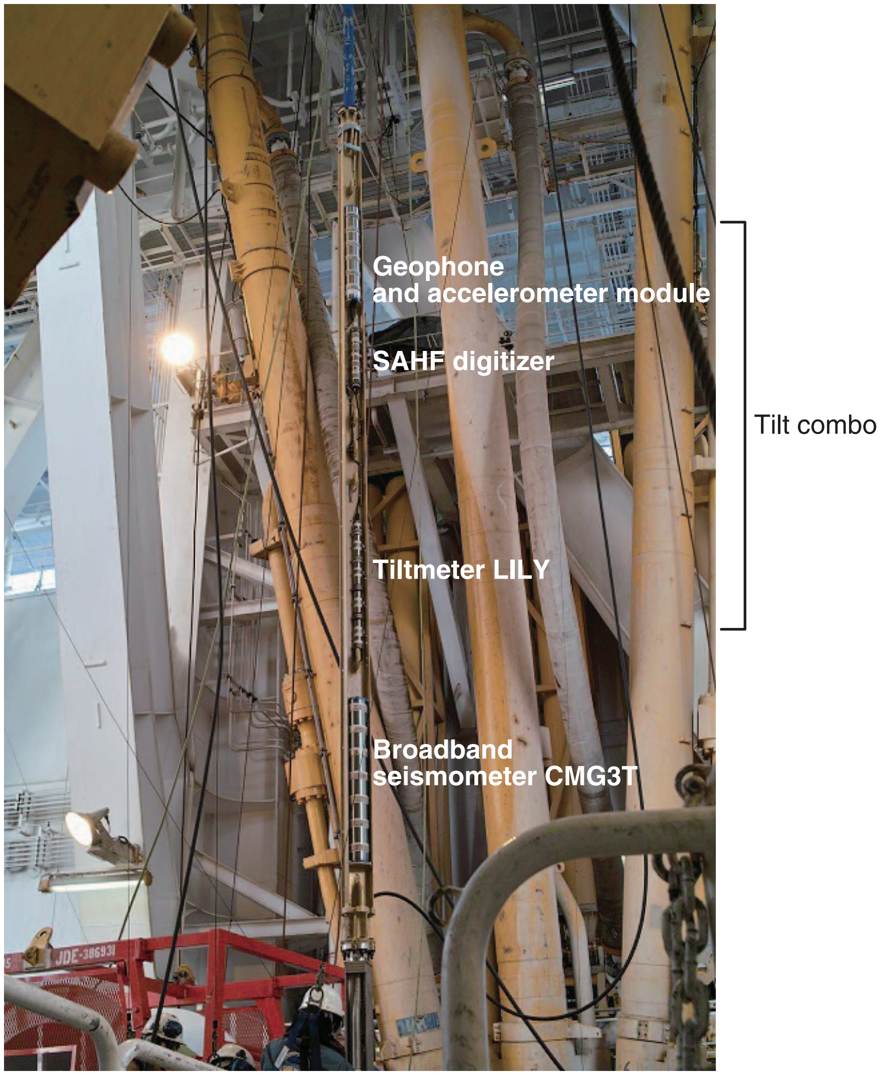

Figure F22. One of the thermometer nodes on the thermistor string. White cable ties keep it secured to the completion string.

Figure F23. CORK head photographs. **A.** Pressure data logger bay. **B.** Ocean Design, Inc. (ODI) underwater mating connectors for borehole instruments. ROV = remotely operated vehicle.

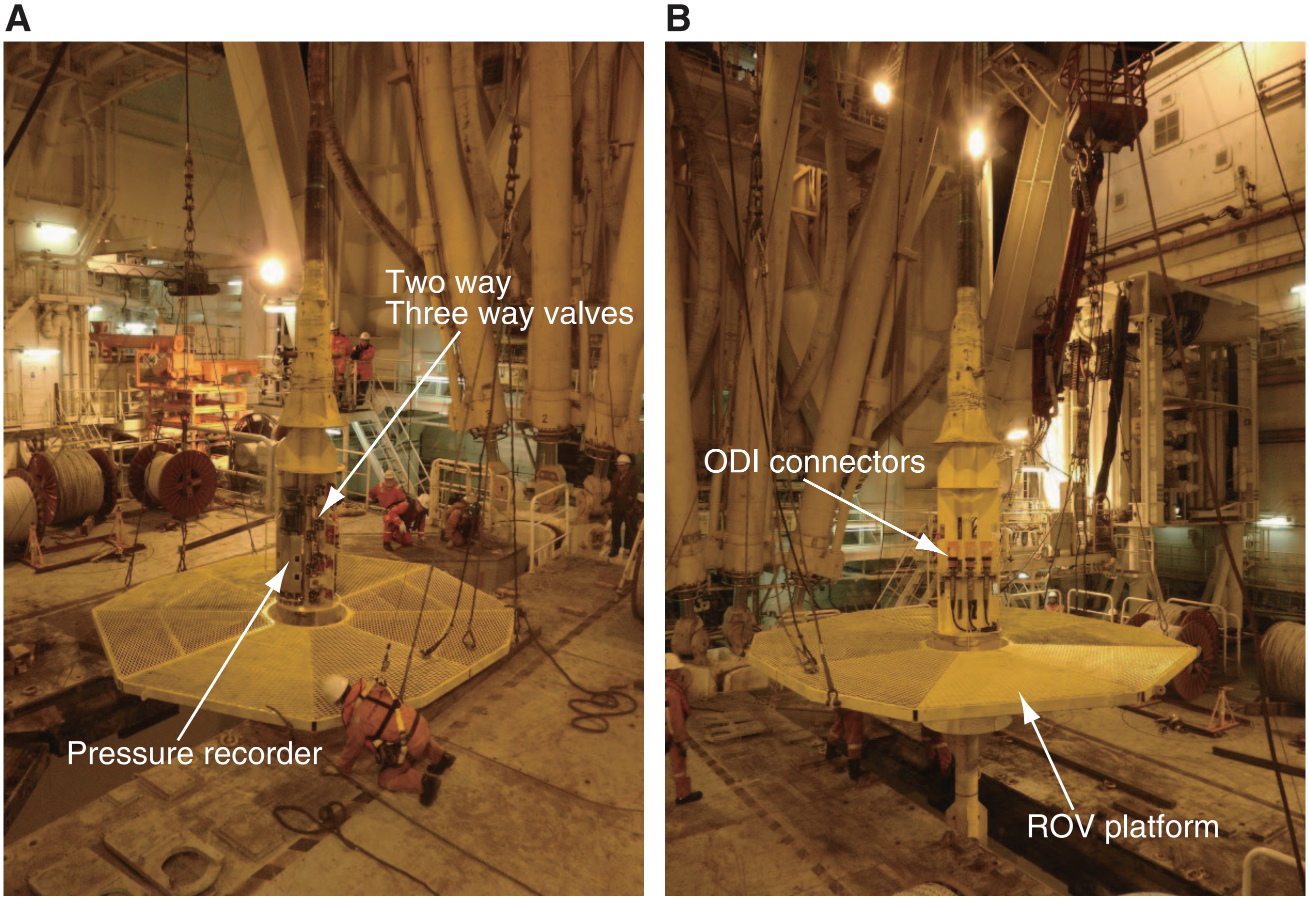

Figure F24. Schematic drawing of the CORK head with ROV platform viewed from above.

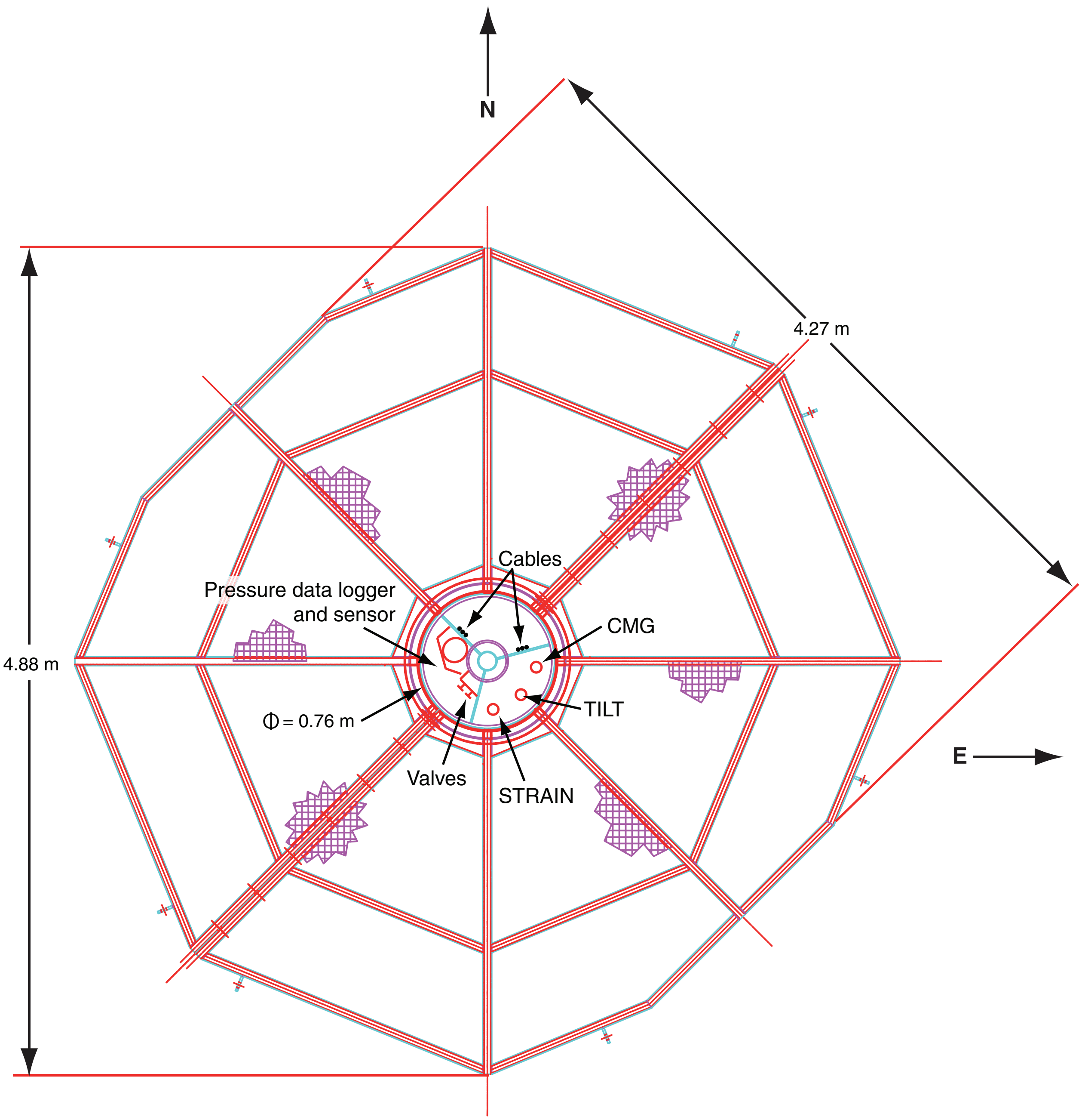

Figure F25. Remotely operated vehicle (ROV) video snapshots of the CORK head, showing (**A**) CORK head and ROV platform as they are lowered through the water column and (**B**) downloading pressure data from the sensor carrier in the pressure bay of the CORK head after cementing.

A

B

Figure F26. Initial pressure data from Site C0002 CORK LTBMS during cementing and after starting observation. UTC = Universal Time Coordinated.