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# Design and deployment of borehole observatories and experiments during IODP Expedition 336, Mid-Atlantic Ridge flank at North Pond[1]

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## Chapter contents



## Abstract

During Integrated Ocean Drilling Program (IODP) Expedition 336 to North Pond on the western flank of the Mid-Atlantic Ridge (8 Ma crust) in the late fall of 2011, borehole observatories were installed in IODP Holes U1382A and U1383C and Deep Sea Drilling Project Hole 395A. These borehole observatories are designed for long-term (multiyear) coordinated hydrogeological, geochemical, and microbiological monitoring and experimentation to understand the nature of life, fluid flow, and fluid-rock interactions in young and cool oceanic crust. Additional related activities during Expedition 336 included recovery of an instrument string that was deployed within an earlier generation of a circulation obviation retrofit kit (CORK) observatory in Hole 395A and preparation of IODP Hole U1383B, which was drilled, cased, and left open during Expedition 336, for a future deployment of a borehole observatory. A streamlined CORK observatory was deployed in Hole U1383B during a remotely operated vehicle–supported cruise in April 2012. An additional CORK servicing cruise is scheduled for 2013. Here, we summarize the observatory project goals and provide an overview of the design, construction, and deployment of these CORKs and related instrumentation during Expedition 336. We also summarize the project goals, design, and construction for the CORK-lite installation in Hole U1383B and discuss plans for its deployment. CORK servicing plans for 2012 and 2013 also are presented.

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## Background, motivation, and overview

### Subseafloor observatories

Circulation obviation retrofit kits (CORKs) (Davis et al., 1992) have been used in recent decades to isolate igneous basement from overlying sediments and seawater, allowing the borehole to return to its native hydrological and biogeochemical state (Fisher et al., 2011). Initially, the principal function of CORKs was to monitor pressure and temperature in situ within single intervals within sealed boreholes (Davis et al., 1992). CORKs have evolved and become increasingly sophisticated, allowing fluid sampling for chemical analyses and biological sampling and experiments, all of which can be conducted at multiple sealed observatory intervals within basaltic basement (Wheat et al., 2011). Hence, CORKs have become powerful tools for studying in situ hydrological, geochemical, and biological process in igneous oceanic crust.

The principal driver for installation of CORK observatories during Integrated Ocean Drilling Program (IODP) Expedition 336 at North Pond was to study a section of young (8 Ma), cool (<20°C), "average" ridge flank in order to assess the role of microbiological processes in alteration of igneous oceanic crust. These observatories complement ongoing CORK observatory work being conducted in young and warm oceanic crust on the Juan de Fuca Ridge flank (Fisher et al., 2011) but target a crustal end-member that is more representative of global ridge flank conditions. Like the CORKs installed on the Juan de Fuca Ridge flank during IODP Expedition 327 (Fisher et al., 2011), the North Pond Expedition 336 CORK observatories are designed to target multiple horizons within upper oceanic crust for long-term in situ experimentation and monitoring (i.e., colonization experiments, fluid samplers; Orcutt et al., 2011; Wheat et al., 2010) and real-time formation fluid collection with seafloor sleds and submersible-supported systems (Cowen et al., 2012).

## North Pond setting, history of study, and initial characterization

To study the potential for life in relatively young and cool oceanic crust, Expedition 336 visited the legacy North Pond drilling site at 22°45′N on the western flank of the Mid-Atlantic Ridge (Expedition 336 Scientists, 2012a) (Fig. **F1**). North Pond is an isolated northeast-trending sediment pond bounded by basement ridges as tall as 2 km and a range of sediment thicknesses up to 300 m in the southernmost part of the basin. This site was a drilling target during Deep Sea Drilling Project (DSDP) Leg 45 (Site 395) in 1974/1975 to examine crustal properties to characterize the geology of young oceanic crust (8 Ma). This relatively young and permeable crust is affected by vigorous seawater circulation that allows warming of circulating fluids to only 10°–15°C before they are discharged from the crust. Since initial drilling, the site has been revisited seven times for logging, hydrogeological studies, and other survey work (mapping, seismics, shallow coring, and heat flow): twice during DSDP and the Ocean Drilling Program (ODP) for logging and downhole experiments (DSDP Leg 78B and ODP Leg 109); a second time during ODP for logging and CORK installation (ODP Leg 174B); once with the submersible *Nautile* for logging by wireline reentry; and once by the R/V *Atlantis* and submersible *Alvin* for detailed heat flow, coring, and pore pressure surveys (Becker, Malone, et al., 1998). North Pond was revisited again with the R/V *Maria S. Merian* for additional survey work in 2009 and 2012. Borehole observatories and experiments were installed and sediment and volcanic rocks were cored during Expedition 336 in the fall of 2011, with a focus on subseafloor microbial systems.

Hydrologically, North Pond is characteristic of areas where volcanic crustal rocks are exposed across large areas, and continuous cover by sediment is the exception rather than the rule (Becker et al., 1984; Langseth et al., 1992). Drilling, coring, logging, and limited borehole experiments suggest that the upper crust in this area is highly porous and permeable (Bartetzko et al., 2001; Becker, 1990; Gable et al., 1992; Hickman et al., 1984). Samples and data collected during a heat flow and sediment coring expedition in 2009 suggest a crustal fluid having considerable dissolved oxygen and seawater-like concentrations for most major and trace ions and nutrients, indicating a short residence time for fluids within basaltic basement (Ziebis et al., 2012). Because temperatures are low, sluggish abiotic rates of reaction favor alteration by kinetically enhanced biotic reactions (Knab and Edwards, in press). These reactions could support microbial communities that alter the crust directly. North Pond was selected for new drilling and CORK installation during Expedition 336 in part because of the contrasts it provides with the Juan de Fuca Ridge flank environment—the only other dedicated site for deep crustal microbiology studies (Cowen et al., 2012; Fisher et al., 2011; Orcutt et al., 2011; Wheat et al., 2010). Namely, there is extensive, vigorous circulation of relatively cold fluids in the crust of North Pond (Fig. **F2**), likely more circulation per unit of basement rock than observed where fluids are hotter and more altered on the eastern flank of the Juan de Fuca Ridge. Delineating fluid flow pathways from recharge to discharge around North Pond is challenging, however, because of the large expanses of exposed rocky seafloor.

## North Pond upper oceanic crust, borehole conditions, and CORK overview

The primary objective of Expedition 336 was the installation of several single- and multilevel CORKs targeting upper oceanic crust within the North Pond study site (Fig. **F2**). At the conclusion of Expedition 336, two observatories were installed in the southern region of North Pond (DSDP Hole 395A and IODP Hole U1382A) and two observatories were initiated in the northeastern region of the study site (IODP Holes U1383B and U1383C; Expedition 336 Scientists, 2012a) (Figs. **F1**, **F2**). Here, we describe conditions of the upper oceanic crust in these holes directly related to the deployment of borehole observatories.

The original drilling at Site 395 proceeded smoothly despite several rubbly intervals, with core recovery of ~25% and ~50 m of fill/rubble in the base of the 664 m deep Hole 395A. Subsequent logging on several cruises documented a consistently clean and open hole to just deeper than 600 meters below seafloor (mbsf), including during the most recent Expedition 336. The original CORK installed in Hole 395A during Leg 174B consisted of a fairly simple thermistor string (603 m long internal string with 10 thermistors, a data logger, and pressure sensors) within the sealed hole. Hole 395A was an underpressured hole and drew down bottom seawater at a rate of roughly 1000 L/min for 21 y after its initial drilling (Becker, Malone, et al., 1998) prior to installation of a CORK. Subsequent logging and initial CORK results suggested that 21 y of downhole flow through Hole 395A prior to CORKing had a negligible effect on the hydrology of the North Pond area (Becker, Malone, et al., 1998). A new multilevel observatory was deployed in Hole 395A during Expedition 336; however, the observatory was not successfully installed, as described in more detail below.

Site U1382 includes a basement-penetrating hole (U1382A) located ~50 m west of Hole 395A (Figs. F1, F2; Expedition 336 Scientists, 2012a). Basement (encountered at 90 mbsf) was cored in Hole U1382A and wireline-logged (105.6 m of open hole in basement); rotary core barrel (RCB) coring recovered basement from 110 to 210 mbsf (Cores 336-U1382A-2R through 12R). Core recovery in basement was 32%, yielding a number of volcanic flow units with distinct geochemical and petrographic characteristics. A unit of sedimentary breccia containing clasts of basalt, gabbroic rocks, and mantle peridotite was found intercalated between two volcanic flow units and was interpreted as a rock slide deposit (Expedition 336 Scientists, 2012a). Downhole hydrologic (packer) tests failed because ship heave up to 3 m prevented the packer from remaining set in the casing for >10 min. A single-level CORK was installed in order to sample/monitor upper basement between 110 and 210 mbsf.

Site U1383 is located 5.9 km north-northeast of Site U1382 (Figs. F1, F2); Holes U1383B and U1383C with observatory components are ~25 m apart at this site (Expedition 336 Scientists, 2012a). Our strategy for Hole U1383B was to install 20 inch casing through sediments (53 mbsf) followed by installation of 16 inch casing into uppermost basement. We then planned to deepen the hole with a 14¾ inch tricone bit to install 10¾ inch casing to ~140 mbsf. However, this operation was not completed because a cone on the tricone bit broke off in the hole at 89.8 mbsf. A decision was made not to fish the lost component but to start over with a new hole. Nevertheless, this hole remained open and we planned to deploy a modified CORK with downhole experiments during a remotely operated vehicle (ROV)-based cruise in April of 2012, as described in more detail below. A landing platform was installed in order to facilitate the future work. We then initiated Hole U1383C, where we jetted in 16 inch casing before drilling into basement and sealing the sediment section with 10¾ inch casing to 60.4 mbsf. This hole was then RCB cored to 331.5 mbsf, logged, and completed with a three-level CORK that spans a zone of thin basalt flows with intercalated limestone (~70–146 mbsf), a zone of glassy, thin basaltic flows and hyaloclastites (146–200 mbsf), and a lowermost zone (~200–331.5 mbsf) of more massive pillow flows with occasional hyaloclastites in the upper part (Expedition 336 Scientists, 2012a). Drill string packer experiments were attempted in Hole U1383C but again were not successful (Expedition 336 Scientists, 2012a).

# Expedition 336 CORKs: mechanical and hydraulic features overview

The overall design, shipboard assembly, and installation of the Expedition 336 CORKs generally followed the plans outlined in detail elsewhere (Fisher et al., 2011, 2005) with some notable exceptions as outlined below. An overall schematic of a CORK observatory as shown in figure F2 in Fisher et al. (2011), applies well to the North Pond CORK observatories. For detailed step-by-step CORK installation details, see the operations summary presented in the Expedition 336 *Preliminary Report* (Expedition 336 Scientists, 2012a).

Expedition 336 CORKs were initiated by jetting in conductor casing with a steel reentry cone into the uppermost sediments. These components are described in more detail elsewhere (Graber et al., 2002). The conductor casing is installed to hold the reentry cone in position, thereby preventing the cone from sinking in unconsolidated sediments until a longer casing string can be cemented at depth. The conductor casing deployed in Holes U1382A and U1383C has a 16 inch outside diameter (OD). Hole U1383B has a conductor casing with a 20 inch OD. Once the cone and conductor casing were jetted in to the seafloor to support the reentry cone and deeper casing and keep them from sinking in unconsolidated sediments, a hole was drilled (without coring) through the underlying sediment and into the top few meters of basement. For the 20 inch OD conductor casing, an 18½ inch tricone bit was used; 16 inch casing spanning the thickness of the sediment column was then installed (i.e., the top was latched into the reentry cone casing hangers and the bottom was cemented below the sediment/basement interface). Basement was then drilled with a 14¾ inch tricone bit to allow installation of a second (in the case of 16 inch casing being the largest) or third (in the case of 20 inch casing being the largest) steel casing string (10¾ inch OD) within the upper basement. Holes were deepened by RCB coring once the 10¾ inch casing string was installed and cemented into place.

The remaining 4½ inch OD casing and wellhead (i.e., the section of the CORK that extends above the reentry cone above the seafloor) portions of the CORK were then assembled together before installation with the rest of the CORK system at the seafloor. The wellhead portion of the CORK was constructed from concentric 4½ and 10¾ inch steel casing sections, with parts of the larger casing omitted or cut away between horizontally oriented 30 inch OD bulkheads that house the sampling bays (Fig. F3). Seafloor sampling and valve manifolds, sensor packages, data loggers, and samplers are arranged within three bays, offset by 120°, and separated by vertical gussets. The gussets are intended to provide strength to the wellhead and help to guide the ship's camera system and the submersible platform around the bays during CORK installation and later operations, protecting instrumentation and valves. One bay is dedicated to monitoring pressure data, the second to fluid sampling, and the third for a flowmeter and microbiological sampling or auxiliary pressure monitoring or other experiments (Fig. F3). Cutouts on the bulkheads and gussets are designed to allow a submersible or ROV to hold on for stability and leverage, and signs attached to the gussets indicate the directions that valves should be turned during operations. The Expedition 336 CORK wellhead gussets were strengthened by welding 1 inch thick × 3 inch wide steel plates along their length; this was done to improve resistance to strain induced by pressure applied to the CORK during installation and unlatching the running tool.

The interior CORK casing strings, which spanned the length from the seafloor to the bottom of each CORK observatory, were composed of various combinations of resin-coated steel casing and drill collars (perforated and unperforated), crossover stubs, fiberglass casing (perforated and unperforated), packer elements, and external umbilicals terminating at miniscreens. The composition of each CORK string was dependent on the depth of the borehole and the placement of the monitoring sections within horizons of interest (Fig. F3), as discussed in the following sections.

## CORK sealing and isolation elements

CORK systems are intended to hydraulically isolate intervals of interest within the formation at depth from the overlying ocean. This requires the use of multiple seal components (see figs. F2, F4 in Fisher et al., 2011). The 10¾ inch OD casing systems deployed in Holes U1382A and U1383C included three independent mechanisms for sealing the formation inside 16 inch casing:

1. O-rings in a ring-shaped tapered seat, welded to the bottom of the 10¾ inch casing hanger, provided a seal between the 10¾ and 16 inch casing hangers. Casings were designed so that the 10¾ inch casing would be sealed against the 16 inch casing immediately upon installation, using rubber O-rings and metal sealing surfaces in the casing hangers held in place by gravity and a mechanical latch (see fig. F4A in Fisher et al., 2011).
2. Swellable packer elements were bonded to the outside of a single section of 10¾ inch casing in each hole (see fig. F4B in Fisher et al., 2011). These elements use a Freecap FSC-11 elastomer (developed by TAM International, www.tamintl.com/) that expands in seawater. They have an initial external diameter of 14¾ inches. Full expansion of the swellable packer elements to the inside diameter (ID) of the 16 inch casing (15 inch ID) requires several weeks to months and, hence, does not provide a seal immediately following casing installation but should provide a reliable casing seal over subsequent months to years.
3. Both the 16 and 10¾ inch casing strings in both Holes U1382A and U1383C were cemented. Cellophane cut in 1 inch square pieces was used as a lost circulation material and added to the cement to clog pores and fractures adjacent to the borehole. Cement was deployed around the shoe of the 10¾ inch casing without a cement retainer by backfilling the hole after the casing was landed and latched mechanically into place. Although this cement may not have formed a complete hydrologic seal between the 10¾ inch casing and the formation, the cement should have helped to separate the main borehole area from the dead (annular) space outside the 10¾ inch casing, and this should improve the quality of future geochemical and microbiological samples. Postinstallation monitoring of pressure within the annular gap of the cased interval should allow for quantitative assessment of the quality of the cement seal at depth.

The main CORK seal (see fig. F4C in Fisher et al., 2011) is located at the base of the CORK wellhead, where it seals against the 10¾ inch casing hanger in the throat of the reentry cone. Holes were drilled and tapped through the CORK landing seal ring for packer inflation, pressure monitoring, and fluid sampling lines. Below the landing seal ring are crossover subs and 4½ inch casing that extends to depth below the seafloor. Hydraulic packers were used to isolate observatory intervals. The hydraulic packer was inflated using pumped seawater after the CORK had been lowered into position. The final CORK seal component employs the weight of the top plug, instrument string, and a sinker bar to hold an O-ring seal against a tapered area in the top of the wellhead and additional landing seals within the borehole that define hydraulic zones of interest (see figs. F2, F4F in Fisher et al., 2011).

### CORK sampling components

Expedition 336 CORKs included multiple perforated and screened components to permit pressure monitoring and fluid sampling while protecting downhole instrumentation from basement collapse. Perforated resin-coated steel drill collars (6¾ inch OD) were deployed above a bullnose and below the deepest hydraulically inflatable packer in each hole, with lines of 2 inch holes separated by 9 inches running vertically up four sides of the collars (Figs. **F3, F4;** also fig. F5 in Fisher et al., 2011). The collars provide weight in order to pull and guide the lower end of the CORK into the hole during deployment of the CORK string, keeping the string in tension should it "hang up" on a ledge during deployment. At shallower sampling horizons, either perforated resin-coated steel 4½ inch casing or perforated fiberglass casing was used to span the region of interest (Figs. **F3, F4**).

Formation pressure is monitored and borehole fluids are sampled at the CORK wellheads via the umbilicals terminating at wire-wrap miniscreens installed at depth (Fig. **F5**). Stainless steel screens are used for pressure monitoring and standard geochemical sampling, whereas microbiological sampling is conducted through titanium screens. Three forms of tubing umbilicals were used during Expedition 336: (1) plastic-jacketed "flatpack" containing three ¼ inch OD stainless steel tubes for pressure monitoring, along with a single ½ inch OD hydraulic packer inflation line; (2) plastic-jacketed flatpack containing three ⅛ and three ¼ inch OD stainless steel tubes, mainly for geochemical sampling; and (3) plastic and woven metal–jacketed umbilical constructed around a ½ inch OD polytetrafluoroethylene (PTFE) tube specifically for microbiological sampling (Fig. **F6**). Umbilical tubes for each CORK were deployed with the tubes being passed through the inflatable and swellable packers, as required (Fig. **F7**). Final connections were made at the top of the CORK casing, connecting sampling and monitoring lines to tubes that were preinstalled to pass through the seafloor CORK seal.

Each CORK installed in Holes U1382A and U1383C included a lateral 4½ inch casing section that extended at a ~15° angle up from below the lower bulkhead (i.e., "lateral CORK" [L-CORK]; Fig. **F8**). The angled lateral casing penetrated the lower bulkhead with an offset of 9¼ inches from the CORK centerline, terminating at the top with a large-diameter (4 inch) ball valve. The ball valve was modified to include welded valve handle stops, and holes were drilled through the valve body to avoid trapping air in dead space around the ball, which could lead to development of a large differential pressure and damage during deployment. A custom ring clamp on top of the ball was deployed with a dust cover to prevent fouling of the valve.

### CORK component surface treatments

To minimize microbiological and geochemical perturbation of the borehole environment by corrosion of "standard" CORK components, specialized components and coatings were used during Expedition 336 (see **Orcutt et al.,** 2012). Specifically, steel components deployed within the borehole sampling environments were coated with various resins and epoxies to minimize rusting (Fig. **F4**), and fiberglass casing (Fig. **F9**) was used in some locations as a replacement for steel casing. Table **T1** lists the coatings that were used on different components of the downhole assembly, and **Orcutt et al.** (2012) and Orcutt et al. (2010) provide detailed descriptions of the properties of these materials. During Expedition 336, uncoated steel and scratches on steel were touched up manually during assembly (Fig. **F4**). Other specialized components like greases (thread lubricant, or "dope" as it is commonly referred to in drilling) (Table **T2**) and sealants, were also used (see **Orcutt et al.,** 2012 for more details). In part, running fiberglass casing for the first time in the drilling program's history drove the selection of new lubricants and sealants.

## Expedition 336 CORKs: detailed configuration

This CORK geometry description provides the reader with a fairly detailed picture of the overall CORK configuration. Many variables have to be considered when configuring a CORK installation and virtually every CORK installation to date has been different (for recent summaries see Fisher et al., 2011; Wheat et al., 2011). CORKs are configured to meet the specific science needs for a given borehole to be instrumented.

Expedition 336 CORKs had some unique features, which are outlined in more detail below.

## CORK wellhead

The CORK wellhead (Fig. F8) geometry is defined by several factors. The maximum wellhead OD is limited by the requirement to pass the wellhead through the vibration-isolated television (VIT) camera system guide sleeve over the wellhead for reentering a borehole (Figs. F10, F11). The VIT frame guide sleeve clamps around the drill string, which acts as a guide during deployment of the VIT for reentry. The VIT must pass over the wellhead, all the way to the bottom of the stinger, to be able to see the reentry cone. The minimum ID of the VIT guide sleeve is 32 inches. Thus, the maximum OD of the wellhead has been limited to 30 inches to allow the VIT guide sleeve to easily pass over.

The wellhead inner mandrel OD is kept small to allow as much room as possible for attaching instruments to the wellhead (Figs. F12, F13). Note that all instruments attached to the wellhead must reside within a 28 inch OD cylinder, centered on the inner mandrel, to allow the VIT frame to pass over.

The wellhead ID is intended to be "full open" (i.e., having the same or larger ID to the drill string). However, typically, a landing shoulder is incorporated into the CORK wellhead for landing a top plug, which reduces the minimum wellhead ID to ~3⅝ inches.

The distance from the top of the instrument bays to the top of the wellhead is somewhat fixed in an effort to keep it as short as possible while providing an adequate guide for the VIT frame guide sleeve and a stable connection point for the running tool. The distance from the bottom of the instrument bays to the bottom of the wellhead is fixed, based on landing the wellhead on top of the casing hanger inside the reentry cone throat, and positioning the instrument bays just above the reentry cone rim for easy access. Thus, the only length variable is the height of the instrument bays. The cross section of the wellhead instrument bays is an area bounded by a 30 inch diameter circle circumscribed around a 4½ inch diameter circle and divided into three equal sections by vertical panels positioned 120° apart. The CORK bodies deployed during Expedition 336 have 96 inch long bays.

## CORK stinger

The term "CORK stinger" refers to the part of the CORK that is suspended below the wellhead (Fig. F14). The stinger is composed of various casings (some perforated and some not), packers, various crossover subs, landing seats, sampling screens, umbilicals, and so on.

### CORK stinger casing selection and considerations

Two primary considerations have to be addressed when choosing the casing for making up a CORK stinger. The first consideration is geometry of the borehole and the stinger elements to be included (packers, umbilicals, screens, etc.). The second consideration is strength of the materials.

In terms of geometry, the maximum OD of the casing is dictated by the hole diameter that the stinger will be deployed in. Typically, open holes for CORK stingers are cored, or drilled, with a 9⅞ inch OD bit. Thus, the maximum stinger component OD that can be deployed is 8¼ inches. The minimum casing ID is generally chosen to match that of the drill sting, 4 inches, to be completely open to the drill string.

The second important geometry consideration for choosing a casing size is the inclusion of elements on the outside of the casing, which will restrict the outer diameter size. The most common elements to consider are packers (Figs. F7, F9), miniscreens (Figs. F5, F15), centralizers (Figs. F5, F14), and umbilical sampling lines (Figs. F5, F6). For example, if packers are to be installed in the stinger to seal hydrological horizons, they will limit the outer diameter because of the thickness of the packer mandrels and sealing material. CORK packers, whether inflatable or swellable, utilize a dual mandrel design that allows pass-throughs to be installed. Pass-throughs are stainless steel or titanium tubes that pass under the packer sealing element and are sealed within the packer body. This provides for a continuous sampling line to pass through the packer without defeating the overall packer borehole seal. The maximum number of pass-throughs is achieved with an inner mandrel that is 4½ inch OD × 4 inch ID inside a 7 inch OD outer mandrel. Thus, even if larger diameter casing is used in the stinger, they must be crossed over to mate with the 4½ inch OD packer inner mandrel. Geometry considerations are also important for the selection of umbilicals and miniscreens to be attached to the outside on the casing, which may further restrict the diameter of the tubing. For example, the umbilicals used during Expedition 336 range in size from ⅛ to ½ inch OD (Table T3).

Finally, if a casing with an ID >4 inches is used to make up the stinger, landing seats with IDs small enough to land the internal instrument string components on must be installed (Fig. F14). If the internal instrument string is to be deployed or recovered through the drill string, then the maximum OD of the internal instrument string components is limited by the drill string ID. Thus, the landing seats installed in the stinger must have a small ID.

The second primary consideration to be addressed when choosing casing for making up a CORK stinger is strength, compressive strength more so than tensile strength. When the stinger is lowered into the borehole, the possibility exists for the stinger to hang up and stop moving downhole. When this happens, the only indication the driller has is a slight decrease in the total load supported by the ship. If the drill string continues to be lowered after the stinger stops moving, the stinger casing will be placed in compression and can quickly become overstressed to the point of failure. Tables T4 and T5 present comparisons of the strength and stretch characteristics of various casing suitable for use in CORK stingers. As shown, the thick wall 5½ inch OD drill pipe has the highest area moment of inertia and thus is the stiffer of the standard casing shown. However, all of the casings have relatively low values for critical column loading, the load at which a particular casing is subject to begin buckling. Note that the critical column loads shown are conservative because they are based on the weight per unit length of the casing, a distributed load case, whereas the equation used to calculate the values applies to a point load at the top of the casing. Also note that the critical column load is not a function of the yield or tensile strength of the casing. The only mechanical property of the casing that enters into the critical column loading is the modulus of elasticity, which is virtually equal in all standard casing steels. However, how much a particular casing will buckle before it fails is a function of its yield and tensile strength.

To help prevent buckling of the stinger, a "plumb bob" is attached to the bottom of the stinger (Fig. F14). The plumb bob is simply a section of very thick walled, heavy casing. Drill collars with 8¼ and 6¾ inch OD have been used with good results. The plumb bob serves three purposes. First, it serves as a guide for the stinger as it is lowered into the borehole. A guide shoe, or bullnose, is attached to the bottom of the plumb bob to guide the bottom of the stinger through ledges or tight spots in the borehole. Second, the weight of the plumb bob helps keep the stinger in tension, thus preventing it from buckling. Third, the larger diameter and long length (tens of meters) keeps the stinger better aligned within the drilled hole.

### CORK stinger sampling and experimental umbilicals and screens

CORK umbilicals range from electrical wiring (or cables), to individual tubes (or hoses), to single elements containing multiple tubes (Fig. F14). The umbilicals are attached in three places: (1) to the wellhead at the top, (2) to the outside of the stinger along its length, and (3) to the downhole sampling ports. The umbilicals provide a means for sampling multiple zones within the borehole for pressure measurements, collecting geochemistry or microbiological samples, and also for transmitting electrical signals from downhole sensors or hydraulic signals to seafloor sensors. The materials used in fabricating the umbilicals range from stainless steel and/or titanium tubing of various ODs, to copper wires, to Teflon lined hoses (Tefzel), and more. However, no copper wire connectors were incorporated within Expedition 336 CORKs. Pass-throughs in the packers provide for a continuous umbilical path up the stinger. The umbilicals are connected at the wellhead to various valves and sampling ports. Umbilical size is limited by its effective diameter, which is the overall diameter created when the umbilical is attached to the stinger. The effective diameter cannot be any larger than the largest stinger component and should be slightly less for protection while being lowered into the borehole. Typical umbilical maximum OD is ~1 inch.

CORK screens are used to prevent the downhole sampling ports from clogging because of particulate infiltration. Historically, two screen configurations have been used with CORKs: full annular screens and miniscreens. Full annular screens are used when it is critical that an annulus has a large contact area with the formation. Full annular screens require severing the umbilical at the screen and then making up the ends to the screen pass-throughs during deployment. In contrast, only miniscreens were installed during Expedition 336 (Fig. F15). Miniscreens are easily installed and can be positioned anywhere along the stinger, except for over packers, the plumb bob, and pipe joints. Miniscreens are typically ~1 inch in diameter and ~1 m long and are fabricated from stainless steel or titanium.

## Expedition 336 CORKs: sensors and sampling

A variety of sensors, samplers, and sampling ports were deployed in the CORKs in Holes 395A, U1382A, and U1383C. Some of the sensors and samplers resided on the CORK wellheads, whereas others were placed internally (i.e., downhole) within the CORK casing. Wellhead configurations prior to deployment for Holes U1382A and U1383C are shown in Figures F5 and F9. A compilation of downhole deployed sampling systems and sensors is shown in Figure F16.

## Pressure sensors

Pressure monitoring in the North Pond CORKs is accomplished with wellhead-based pressure loggers monitoring hydrological horizons of interest via screened umbilicals. Pressure data from Expedition 336 CORKs can be downloaded during CORK servicing visits with a submersible or ROV using an underwater mateable connector.

Pressure measurement and logging systems deployed during Expedition 336 were built into frames designed to slide onto mounts within one of the three measurement and sampling bays in the CORK wellheads (Fig. F12). These systems share characteristics with those deployed following CORK installation during Expedition 327 (Fisher et al., 2011). Electronics and batteries are housed in a cylindrical pressure case, and communication with a computer for programming and data download is accomplished using an underwater mateable connector (Teledyne ODI). Instruments deployed during Expedition 336 include absolute pressure gauges (Paroscientific Model 8B7000-2) to monitor conditions at multiple depth intervals and the seafloor. The installation in Hole U1382A includes two gauges to monitor pressures at the seafloor and in the single formation zone; the installation in Hole U1383C includes four gauges to monitor pressures at the seafloor and in the three formation zones isolated downhole. The loggers can sample at time intervals as short as 1 s, and sensors have temperature-compensated pressure resolution on the order of 2 Pa (0.2 mm water), similar to those deployed on Expedition 327 CORK systems (Fisher et al., 2011). Loggers were configured to sample at a 2 min interval on deployment. Pressure gauges are connected with 1⁄16 inch OD stainless steel lines to hydraulic couplers attached near the base of the system frame, and the couplers are inserted into matching receptacles mounted near the base of the pressure bay. The receptacles are connected with ⅛ inch stainless steel lines to three-way valves mounted in the same wellhead bay, then down through the seafloor CORK seal and to ¼ inch stainless steel lines that extend to depth.

CORK data loggers communicate using an RS-422 protocol at speeds of up to 230 kbps. Several days prior to each Expedition 336 CORK deployment, pressure-monitoring lines were tested for hydraulic integrity from below the CORK seafloor seal up to the data loggers (similar testing was conducted for all lines and valves on the CORK body). For each CORK, the pressure measurement frame was installed in the wellhead, placing the hydraulic couplers in the receptacles. A fluid injection and pressure-monitoring manifold was connected to tubing pigtails below the CORK seal. The fittings connecting ⅛ inch monitoring lines to the pressure gauges were loosened, and the lines were de-aired by pumping freshwater through the lines for 10–20 min at 40–50 psi. The fittings were tightened, pressure was shut in at the testing manifold, and conditions were monitored using the data logger to verify that a complete seal was sustained. Once system integrity was verified, the data logger remained installed in the wellhead until the CORK was deployed. Additional de-airing of pressure monitoring lines was completed during the final stages of the CORK deployment after all monitoring line connections were complete. Screw-cap purge valves were installed at high points for each pressure line (when the CORK was positioned vertically), located behind the control valves in the wellhead. After each CORK wellhead was lowered through the rig floor, it was held over the moonpool and the purge valves were loosened; the wellhead was then lowered several meters below the water surface. After waiting 10 min for air in the pressure lines to escape, the wellhead was raised and the purge valves were tightened. Three-way valves in the wellheads are configured for each pressure gauge so that it can be set to monitor conditions either at the formation screens or the seafloor.

## Temperature sensors

Temperature measurements within the borehole are accomplished by autonomous temperature sensors and logger units placed within the CORK instrument string. Temperature data are acquired upon recovery of the instrument string (i.e., every few years).

Autonomous temperature sensors and data loggers deployed downhole within Expedition 336 CORKs are similar to those deployed during IODP Expeditions 301 and 327 and described in detail by Fisher et al. (2011, 2005). We elected to use autonomous loggers rather than a preinstrumented thermistor cable because (1) the Expedition 336 plan for multiple fluid and microbiological sampling zones would have required extensive expenses and minimal freedom in choosing zone location with a single thermistor cable and (2) we wanted to monitor temperatures at the depths of the OsmoSamplers because their sampling rates depend on the temperature-dependent viscosity of seawater.

As was used for the Expedition 301 and 327 CORKs, we deployed in the Expedition 336 CORKs a mix of two commercially available marine temperature logging tools. One was built by Antares Datensysteme GmbH (www.antares-geo.de/), with a 5 y lithium battery and thermistor type chosen to optimize resolution over the 0°–30°C temperature range expected at the North Pond sites. The other set was constructed by Onset Computer Corporation (www.onsetcomp.com/), HOBO Model U12-015-3, modified with a titanium pressure case and long-life battery for use to full ocean depth. The Onset tools have a working range of –40°–100°C but a lower resolution (0.02°–0.1°C) because of their greater working range and because they use Antares tools which use 12-bit rather than 16-bit analog to digital conversion. Both manufacturers provide factory calibrations for their temperature loggers, and we plan to recalibrate the loggers after the eventual recovery of the downhole sensor strings.

All of the temperature tools deployed in CORKs during Expedition 336 were housed inside polyvinyl chloride (PVC) housings containing OsmoSamplers and microbiological growth systems (Fig. **F16**). The distribution of individual temperature tools on CORK instrument strings is described in the **"Site 395," "Site U1382,"** and **"Site U1383"** chapters (Expedition 336 Scientists, 2012b, 2012c, 2012d).

## Oxygen

Oxygen measurements within the borehole are being taken by autonomous oxygen sensors and loggers placed within the borehole on the CORK instrument string. The oxygen sensor is a standard Aanderaa oxygen optode 4330. The sensor is connected to a custom RBR, Inc., data logger housed in a titanium body. The logger will power the sensor for 5 y, collecting data every 12 h. The logger and sensor package is housed in a stainless steel strength member (2⅞ inch OD) to allow the sensor to align with the OsmoSampler packages while being thin enough to pass through the 3 inch gravity seal. Oxygen concentration data will be acquired upon recovery of the instrument strings (i.e., in a few years).

## Fluid sampling for geochemical analyses

Fluid samples for geochemical analyses (major and minor ions, trace elements, gases, etc.) are collected continuously using both downhole (Fig. **F16**) and wellhead (Fig. **F12**) OsmoSamplers (Jannasch et al. 2004). The downhole OsmoSamplers sample fluid directly from the borehole and are based on a common design (Wheat et al., 2011). These samplers will be recovered in a few years during CORK instrument string recovery. The wellhead OsmoSamplers, which sample fluids pulled through the CORK umbilicals, can be recovered on a yearly basis during CORK servicing operations with a submersible or ROV. Wellhead OsmoSamplers have been used on other CORK systems (Wheat et al., 2011); however, these basic wellhead OsmoSamplers were uniquely connected during Expedition 336 to a new generation of "fast-flow" osmotic pumps (Fig. **F17**), which are described in more detail below.

In general, each downhole OsmoSampler consisted, in vertical orientation from top to bottom, of an osmotic pump, fluid sampling coils constructed of different materials (i.e., Teflon or copper) depending on the experimental design, and in some cases additional sampling materials, pumps, and coils. For each downhole sampling horizon, six different OsmoSampler packages were connected vertically to achieve fluid sampling and experimental objectives. The exact configurations are discussed in more detail below and in the **"Site 395," "Site U1382,"** and **"Site U1383"** chapters (Expedition 336 Scientists, 2012b, 2012c, 2012d). The borehole OsmoSampler packages were designed to pass through drill pipe and the inner CORK casing, and thus could have an outer diameter no larger than the smallest restriction imposed by the gravity plug seat through which it must pass. Two different sizes of OsmoSampler systems were used during Expedition 336. OsmoSampler packages deployed in the shallow horizons have a 2⅞ inch OD whereas the deepest OsmoSampler packages have a 2½ inch OD to pass through the 2⅞ inch gravity plug seat. The outer housing of the pumps and the protective sleeves surrounding the sampling coils was made of clear PVC to allow monitoring of the various components while the sleeve is installed, whereas most of the other pump parts were made of standard gray PVC. Each of the pump pieces was sealed with single O-ring seal, and the membranes were held in place with a single O-ring and a two-part epoxy (Hysol ES1902, **www.henkelna.com/**). Membrane configuration differed depending on the application: pumps contained one, five, or eight Alzet 2ML1 membranes (**www.alzet.com/**) to achieve desired flow rates. The salt gradient across the membrane was created using excess noniodized table salt (NaCl) supersaturated in water on one side of the membrane and deionized (18.2 MΩ) water on the other side (Fig. **F16**). The pumps were mounted on a central ½ inch OD stainless steel rod used to provide strength for the assembly, which consisted of threaded end-caps, the central rod, pump(s), sample coils, PVC connectors for stability, and in some cases temperature loggers, as described earlier. The OsmoSampler assemblies were connected in series using novel stainless steel connectors with cutouts for line handling and a stainless steel pin/plastic protector system to join the OsmoSampler package to the stainless steel connector.

Six kinds of downhole OsmoSamplers packages were deployed during Expedition 336: standard, gas-tight, acid addition, BioOsmoSampling System (BOSS), microbiological enrichment, and microbiological growth (MBIO). Each OsmoSampler package was intended for a deployment as long as 6 y. These instrument systems are described briefly in the rest of this section and in greater detail elsewhere (Wheat et al., 2011). Configurations and depths of individual instruments deployed during Expedition 336 are described in the **"Site 395," "Site U1382,"** and **"Site U1383"** chapters (Expedition 336 Scientists, 2012b, 2012c, 2012d).

A "standard" OsmoSampler package consists of a pump with either five or eight Alzet 2ML1 membranes for either the 2½ or 2⅞ inch OD packages, respectively. Fewer membranes are need in the deeper section (2½ inch OD) to acquire the same volume of fluid given the warmer conditions at depth (20°C versus 6° or 8°C, respectively) Three sampling coil units, each containing a spool of 305 m length PTFE sample coils (1.2 mm ID) are attached to the pump. Once recovered, fluids from the standard package will be analyzed for major and minor ions. The "gastight" package is similar to the standard package but uses three copper sample coils to eliminate diffusional gas exchange.

The "acid addition" package consists of (from bottom to top) a PTFE sample coil filled with deionized water, a single membrane pump, a PTFE coil filled with dilute acid (20 mL of subboiled 6N HCl in 500 mL 18.2 MΩ water), a T-connector with one branch open to borehole fluids and the other connected to three PTFE sample coils, and either a five or eight Alzet 2ML1 membrane pump. Thus, the lower pump, which has a pump rate of ⅕ or ⅛ that of the upper pump, forces dilute acid into the T-connector, where it mixes with borehole fluids that are subsequently stored in the three upper sample coils. This acid addition helps to stabilize redox-sensitive dissolved metals and reactive ions, ideal for shore-based measurements of trace elements in seawater and reacted formation fluids.

The fourth and fifth OsmoSampler packages have physical configurations similar to that of the acid addition assembly. The "BOSS" package has a PTFE coil that discharges a biological fixative solution (2 mL of saturated $HgCl_2$ in 75% RNAlater [Ambion]), rather than the dilute acid of the acid addition coil. The BOSS package is designed to arrest microbial metabolic processes while maintaining cell structure for shore-based microbial assays. The microbiological "enrichment" package injects a 1.2 mM nitrate solution in sterile seawater. The injection of nitrate-doped sterile seawater is designed to stimulate nitrate-reducing microorganisms. The enrichment package also contains a single microbial growth chamber, described below, so that microorganisms can be identified and quantified following shore-based analyses. The "MBIO" package consists of a series of microbial growth chambers (Orcutt et al., 2010, 2011), described in the next section, six PTFE sample coils, and two osmotic pumps with either five or eight Alzet 2ML1 membranes depending on where the packages are to be deployed within the borehole. By comparing this fluid to that collected with the standard package, researchers will be able to document compositional changes related to microbial and inorganic reactions within the microbial growth incubators.

Standard and MBIO OsmoSampler packages were also connected to a new fast-flow osmotic pumping system attached to stainless steel umbilical sampling lines at the CORK wellheads of Holes U1382A and U1383C (Fig. **F17**). Unlike regular OsmoSampler packages, which rely on small forward osmosis membranes with relatively low flow volumes (milliliters per day range) to drive fluid flow, the fast-flow osmotic pumps utilize a different forward osmosis membrane that allows larger flow volumes (hundreds of milliliters per day). Here, the membrane is sealed (with gaskets) within a PVC pump head, where one side of the membrane is exposed to seawater (to provide the salt gradient for pumping) and the other side is connected to a large reservoir of distilled water. The distilled water is contained within a PVC bag liner sealed inside a PVC reservoir. As distilled water moves across the membrane toward open seawater, the bag liner collapses, creating low pressure inside the PVC reservoir that enables the pumping of fluid up umbilical lines that are connected at the base of the reservoir.

During Expedition 336, the fast-flow OsmoSamplers consisted of two parallel 17 L volume PVC reservoirs connected jointly to a common umbilical sampling system constructed of ⅛ or ¹⁄₁₆ inch polyetheretherketone (PEEK) tubing. The size of the reservoirs during Expedition 336 was limited by the need for the wellhead pump systems to fit within the 28 inch diameter restriction of the wellheads for the VIT camera system. The membrane surface area was tailored to achieve pumping rates on the order of 150 mL/d, which should allow the 34 L pumping reservoir to last 7½ months until the fast-flow pumps would be replaced on a servicing cruise with an ROV. Two three-way T-connectors were added to the umbilical sampling line to allow connection of the standard and MBIO OsmoSampler packages, each consisting of one 12-membrane (Alzet) pump and a 300 m long Teflon fluid sampling coil. After assembly of the pumping systems but prior to deployment, the pump head was placed in seawater kept at 4°C to verify the pumping rate and check the condition of the membrane. The umbilical connector was kept in a bucket of cold distilled water until connection to the CORK wellhead in the moonpool immediately prior to CORK deployment. The system was attached to the wellhead via a network of zip ties and rubber bands so that the package would remain on the CORK during deployment but still be removable for ROV during servicing (by cutting with a knife). Future fast-flow osmotic pumps will have lessened size restrictions (because they will not need to pass under a VIT camera system), allowing for larger reservoirs and hence, faster pumping rates or longer pumping times.

Fluid samples can also be collected in real time using mechanical pumping systems connected to the fluid sampling umbilicals in the CORKs (Cowen et al., 2012; Wheat et al., 2011). This mechanism allows larger volume sampling than can be accomplished with OsmoSamplers but is dependent on battery- or submersible/ROV-powered pumping systems. The basic procedure is to attach a fluid sampling line from one side of a pump to the receptacle on the wellhead. The valve on the wellhead is opened to allow the pump to withdraw fluids from the umbilical that terminates at a hydrologic horizon of interest. The other side of the pump is attached to a series of sampler, sensors, filters, and inverted funnels to facilitate sampling using additional equipment. Such a mechanism allows collection of large volumes of water (hundreds of liters), measurement of ephemeral properties (e.g., dissolved hydrogen), and "redox" conditions.

The L-CORK design allows the borehole to be opened via a 4 inch ball valve to instruments such as pumps, flow meters, or tracer injection devices without disturbing downhole sampling and experimental systems. Although such experiments were not the focus for these initial downhole packages, the L-CORK design allows for future experimentation. The ball valve was replaced with a cap on the Hole U1382A CORK because of a crack that developed during the deployment procedure. A working ball valve system with attachment ring (e.g., Fisher et al., 2011) is on the Hole U1383C CORK.

### Microbial growth chambers

Microbial colonization chambers are another form of sampler deployed in Expedition 336 CORKs, both in wellhead and downhole configurations. The principle of these colonization devices, which consist of defined mineral growth substrates to encourage colonization by native planktonic (i.e., in fluids) borehole microorganisms, and which are referred to as Flow-through Osmo Colonization System (FLOCS), are described in more detail elsewhere (Orcutt et al., 2010, 2011). The wellhead FLOCS were deployed in tandem with the fast-flow OsmoSamplers (Fig. **F17**), while the downhole FLOCS (Fig. **F18**) were contained within the MBIO and enrichment OsmoSampler packages described above. The exact spacing of the downhole FLOCS experiments is described in the **"Site 395," "Site U1382,"** and **"Site U1383"** chapters (Expedition 336 Scientists, 2012b, 2012c, 2012d). The wellhead FLOCS can be serviced yearly, whereas the downhole packages are only retrieved when the instrument string is recovered (i.e., every few years).

Like the Expedition 301 and 327 passive colonization experiments and flow cells (Fisher et al., 2005; Orcutt et al., 2011; Smith et al., 2011), FLOCS contain series of presterilized chambers packed with colonization substrates (i.e., mineral coupons and fragments). Some chambers are connected to osmotic pumps that introduce a slow and steady flow of formation fluids, whereas other chambers are passively open to the formation. Microorganisms in the borehole fluids may preferentially colonize various rock and mineral substrates on the basis of favored mineral-fluid redox reactions (e.g., Edwards et al., 2003) such as has recently been observed from wellhead experiments conducted on the Juan de Fuca CORKs (Orcutt et al., 2011). Connection of the outflow of the chambers to an OsmoSampler sampling system provides a temporal record of chemical changes during deployment, and comparison of these fluids to those collected with standard OsmoSampler package may elucidate biogeochemical reactions occurring within the chambers. Modified FLOCS experiments were also deployed, coupled to an enrichment OsmoSampler package as described above.

# Expedition 336 CORKs: detailed summaries for each CORK installed

## Hole 395A

The configuration of the CORK as it was initially deployed in Hole 395A is summarized in Figure **F19** and is described in more detail in the **"Site 395"** chapter (Expedition 336 Scientists, 2012b). The Hole 395A CORK was designed to monitor four zones within igneous basement: a shallow interval just below the casing in uppermost basement, two intermediate intervals of basement, and a deep interval within the lowermost cased basement. These intervals were determined based on previous logging data, which defined an upper rubbly, high-flow zone, an intermediate high-flow zone, and a lower low-flow warmer basement regime at the bottom of Hole 395A. The upper crustal portion was intended to be sealed with a combination packer (inflatable and swellable) in the 11¾ inch casing, and the borehole was to be sealed with an inflation packer against the wall of the basaltic formation at the lower portion of the interval. In this interval, slotted casing was deployed from 114 to 140 mbsf. The middle zone ranges from 147 to 462 mbsf and has two sampling horizons from 211 to 282 mbsf and 409 to 436 mbsf. The deeper section of the borehole was to be sealed with an inflation packer set at 460 mbsf. Umbilicals with internal stainless steel or Tefzel tubing were strapped to the outside of the casing and connected to miniscreens located at ~120, 430, and 506 mbsf. At each depth, three stainless steel miniscreens were attached to stainless steel tubes (one with ⅛ inch diameter and two with ¼ inch diameter). A fourth miniscreen of titanium was attached to a Tefzel tube (½ inch diameter). An additional ½ inch stainless steel tube was used to inflate the packers, which have a check valve that opens at 25 psi.

Downhole OsmoSamplers, microbiological experiments, and temperature and oxygen sensors were all deployed in the Hole 395A CORK. Four sets of downhole OsmoSampler packages were deployed to target four sampling horizons. Sensors and experimental packages were deployed within slotted fiberglass casing within the top three intervals and within perforated, coated casing and drill collars in the lowermost interval.

The Hole 395A CORK instrument string contains eight FLOCS units (Fig. **F18**): four in the enrichment OsmoSampler packages and four in the MBIO packages. The enrichment OsmoSampler FLOCS units pull formation fluids mixed with enrichment solution through two serially connected chambers containing cassettes of different substrates (basalts, olivine, siderite, sphalerite, chalcopyrite, pyrrhotite, hematite, pyrite, and glass wool and beads). Separate osmotic pumps irrigate each chamber of the FLOCS unit in the MBIO OsmoSampler packages. One chamber contains basalts, olivine, siderite, sphalerite, chalcopyrite, pyrrhotite, and hematite; the other chamber contains larger volumes of glassy basalt and pyrite, plus glass wool and beads. All of the FLOCS have eight panels of rock chips (2–4 chips/panel, ~3 mm × 3 mm) mounted on one side of the FLOCS body to allow passive colonization on polished rock chips (as opposed to the slow advective pumped colonization in the chambers). The FLOCS used in the enrichment OsmoSampler package contains grids of barite, Hole 395A basalts collected during Leg 45, sphalerite, pyrite, goethite, and hematite. The FLOCS used in the MBIO OsmoSampler package contains grids of rhyolite, glassy basalt, Hole 395A basalts, olivine, chalcopyrite, pyrrhotite, and magnetite.

The assembly and installation of the CORK in Hole 395A proceeded well until the CORK head broke off during the final step of releasing the CORK running tool, as described in more detail in the **"Site 395"** chapter (Expedition 336 Scientists, 2012b). The CORK head experienced forces that bent the wellhead and severed its 5 inch pipe ~4 m below the top of the reentry cone (Fig. **F20**), and knocked the landing seat from its original centralized position (Fig. **F21**). The Spectra rope and umbilicals were also severed, leaving the downhole tool string in place. Based on the portion of the CORK wellhead recovered, the upper end of the remaining 5 inch diameter cup packer subassembly near the seafloor (5 inch pipe mandrel) is not completely rounded but may be open enough to allow recovery of the internal downhole samplers (using fishing tools), sensors, and experiments in the future (Fig. **F20**). Several stainless steel tubes likely extend above the cup packers and the top of the 5 inch casing. Damage to stabilizing fins above the cup packers suggests that they may have been too large in diameter to enter the throat of the reentry cone (DSDP documentation indicated a 24 inch ID, but this is now thought to be less), which may have been the root cause of the installation failure. Similar damage was observed on the Leg 174B CORK that was recovered (it, too, did not fully land). The CORK pressure logging system was recovered along with the broken-off wellhead. The recorded data do not definitively resolve whether or not the downhole CORK packers inflated. A plan is being formulated to recover the downhole instrument string in the future with the aid of an ROV.

## Hole U1382A

The configuration of the primary parts of the subseafloor CORKed observatory installed in Hole U1382A are depicted in Figure **F22.** The Hole U1382A CORK isolates one upper-basement interval for experiments and instruments, which are all deployed within coated perforated casing within the borehole. On the basis of drilling rate and core recovery, the screens and downhole instrument string targeted a single zone centered at 161 mbsf. Because of the need to keep the CORK in tension, heavy, perforated, resin-coated drill collars were used at the bottom of the CORK assembly. The monitoring section of the CORK comprises (from the bottom up) a bullnose that is not restricted (terminates at 188.7 mbsf), six perforated 6 inch OD drill collars, a crossover, a 15 m long section of perforated 5½ inch OD casing, a crossover to fiberglass, five nonslotted fiberglass (4½ inch; OD = 4.57 inches, ID = 3.89 inches, connection OD = 5¾ inches) casings, a crossover (5 inch OD, 4.05 inch ID), a landing seat (3.375 inch), and a combination packer (inflatable and swellable) that was set in casing with its base at 101.4 mbsf.

Downhole OsmoSamplers, microbiological experiments, and temperature and oxygen sensors were all deployed in the Hole U1382A CORK, identically to the systems described above for Hole 395A. One set of downhole OsmoSampler packages, an oxygen probe, and temperature probes were deployed to target the single sampling horizon. Sensors and experimental packages were deployed within slotted fiberglass and perforated steel casing (Fig. F16). The Hole U1382A CORK instrument string contains a total of four FLOCS units (Fig. F18): two in the enrichment OsmoSampler package and two in the MBIO packages. See above for further details on these downhole experimental packages (Hole 395A).

In addition to the downhole instrumentation packages, wellhead experimental packages were deployed in Hole U1382A as well. As described above, these packages consisted of a standard OsmoSampler package and an MBIO OsmoSampler package (each with a 12-membrane osmotic pump and a 300 m Teflon coil) connected to the sampling line of a fast-flow osmotic pump. The MBIO OsmoSampler package at the Hole U1382A wellhead consisted of FLOCS units containing siderite, rhyolite, chalcopyrite, pyrite, pyrrhotite, sphaelerite, basalts, olivine, goethite, hematite, and glass wool and beads.

### Hole U1383B

The configuration of the cone, casing, and potential CORK profile for Hole U1383B is depicted in Figure F23. A landing platform was also installed by free fall, which was slightly off center within the cone in Hole U1383B. Approximately 18 m of open hole is associated with U1383B, which was intended for future CORK installation (see below).

### Hole U1383C

The configuration of the primary parts of the subseafloor CORK observatory installed in Hole U1383C are depicted in Figure F24. Three observatory intervals were isolated at shallow, middle, and deep depths. Sensors and experimental packages were deployed within slotted fiberglass casing within the top two intervals and within perforated, coated steel casing and drill collars in the lowermost interval (Fig. F24). The CORK screens and downhole instrument string were selected on the basis of drilling rate, core recovery, and caliper logging data. The upper zone is isolated by a combination packer and landing seat in the casing (58.4 mbsf) and the first open-hole packer and landing seat at 145.7 mbsf. Within this section, the miniscreens are centered at 100 mbsf, with the slotted portion of the casing extending from 76 to 129 mbsf. The middle zone is isolated by the two open-hole packers and landing seats, with the bottom landing seat at 199.9 mbsf. Within this section, the screens are centered at 162 mbsf, with the slotted casing extending from 146 to 181 mbsf. The deep zone is defined as the bottom of the deepest landing seat (199.9 mbsf) to the bottom of the hole (331.5 mbsf), with miniscreens beginning at 203 mbsf.

The monitoring section of the CORK comprises (from the bottom up) a bullnose that is not restricted (terminates at 247.6 mbsf, leaving 83.9 m of open borehole for future open-hole logging), 10 perforated 6¼ inch OD drill collars, a crossover, a shortened 3.12 m long section of perforated 5½ inch OD casing to maximize the amount of open borehole below, a crossover to fiberglass, a landing seat (2⅞ inch), and an inflatable packer.

Downhole OsmoSamplers, microbiological experiments, and temperature and oxygen sensors were all deployed in the Hole U1383C CORK, identical to the systems described above for Hole 395A. The Hole U1383C CORK instrument string contains a total of six FLOCS units (Fig. F24): three in the enrichment OsmoSampler packages and three in the MBIO packages. See above (Hole 395A) for further details on these downhole experimental packages.

In addition to the downhole instrumentation packages, wellhead experimental packages were deployed in Hole U1383C, coupled to the fast-flow OsmoSampler systems described above and identical to the wellhead systems deployed in Hole U1382A.

## Future plans

At the time of this writing, two future visits are scheduled at North Pond, in the spring of 2012 and fall of 2013, using the ROV *Jason-II* and a German research vessel (*Maria S. Merian*).

### ROV dives

ROV dives are planned for North Pond in 2012 in order to service the wellheads in Holes U1382A and U1383C and to conduct operations in Holes 395A and U1383B. The following operations are planned for North Pond:

1. Pump fluids from each of the borehole observatory hydrological intervals in Holes U1382A (1 horizon) and U1383C (3 horizons).
2. Install two seafloor wellhead sleds (Cowen et al., 2012) in Holes U1382A and U1383C to sample one horizon each.
3. Inspect Hole 395A and possibly center or remove the ROV/submersible platform.
4. Install a simplified "CORK-lite" CORK plug system (described in more detail below) in Hole U1383B with a downhole OsmoSampler package and pressure recorder.

5. Collect rocks and sediments for geochemical and microbiological analyses.
6. Make heat flow measurements at the perimeter of the sediment pond.
7. Map rock outcrops that flank the pond using multibeam seismic surveys.
8. Exchange wellhead OsmoSampler fluid and microbiological experiments.

### CORK-lite

A major objective of the 2012 CORK servicing cruise will be the trial installation of a simplified CORK plug system into the abandoned cased basement borehole in Hole U1383B (Fig. F25). In brief, this simplified system termed CORK-lite is designed to connect a simplified wellhead sampling system and seafloor seal to the observatory reentry cone and casing existing in Hole U1383B, enabling this borehole to become a shallow basement observatory at Site U1383. If successful, the CORK-lite will enable monitoring of pressure in shallow basement and also the exchangeable deployment of a simplified downhole instrument string for sampling fluids and microbial material from upper basement. Furthermore, the CORK-lite may also be amenable to future adaptation of other legacy boreholes equipped with reentry cone and casing systems to become subseafloor observatories.

The CORK-lite consists of a 12 inch (ID) pipe with a gravity seal that will contact the 16 inch casing hanger. The 12 inch pipe extends ~2 m above the ROV platform and contains two ¼ inch OD stainless steel valves. These valves are intended to be connected to a pressure logger. The top of the CORK-lite has a removable cap with a rubber seal that is locked in place with a turnable latching mechanism. Also on the cap is a valve to vent borehole pressure to remove the cap should the borehole be under or over pressured. Inside the bottom of the cap is an eyebolt for attaching a shackle connected to Spectra line, a series of OsmoSampler packages, a lowered intake, and sinker bar.

For the CORK-lite deployment in Hole U1383B, a series of operations will be undertaken to install observatory components. Approximately 15 m of open hole extends below steel 10¾ inch casing in Hole U1383B, which is equipped with a reentry cone and ROV landing platform. The ROV platform may be slightly askew, based on VIT imaging during Expedition 336. Assuming that the landing platform skew can be corrected, the CORK-lite will be deployed from the support ship and maneuvered into place with the ROV *Jason-II*. Following installation of the CORK-lite, pressure loggers will be connected to the sampling valves, and an OsmoSampler instrument string will be latched into the cap. The OsmoSamplers will be designed to hang within open basement hole below casing, to be recovered during a subsequent ROV servicing cruise.

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**Figure F1.** Location maps of Expedition 336 study sites. **A.** Regional overview of North Pond location on the western flank of the Mid-Atlantic Ridge, south of the Kane Fracture Zone, in the North Atlantic Ocean. **B.** Local bathymetric map of North Pond and the adjacent Long Pond. Red circles = Expedition 336 sites in North Pond, gray circles = former sampling locations. Contours every 100 m. **C.** Detailed view of the bathymetry and orientation of holes at Site U1383. Red circles = borehole observatories, gray circles = other drilled sites. **D.** Detailed view of the bathymetry and orientation of holes at Sites 395 and U1382. Red circles = borehole observatories, gray circles = other drilled sites.

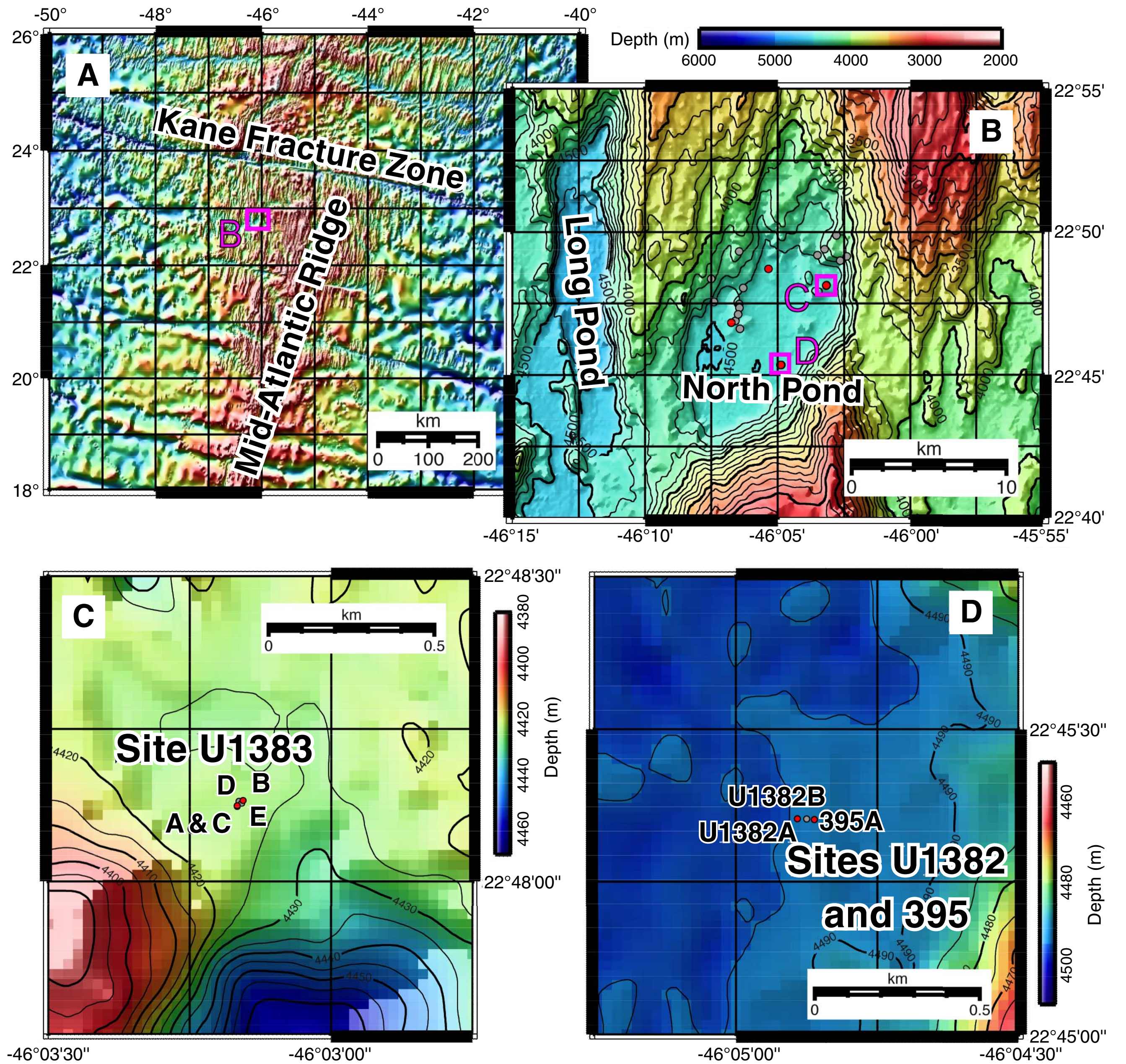


**Figure F2.** Cartoon schematic overview of the borehole configuration at North Pond. Three observatory intervals were installed during Expedition 336 in Holes 395A and U1383C, and one observatory interval was installed in Hole U1382A. CORK = subseafloor borehole observatory, CORK-lite = simplified CORK plug system.

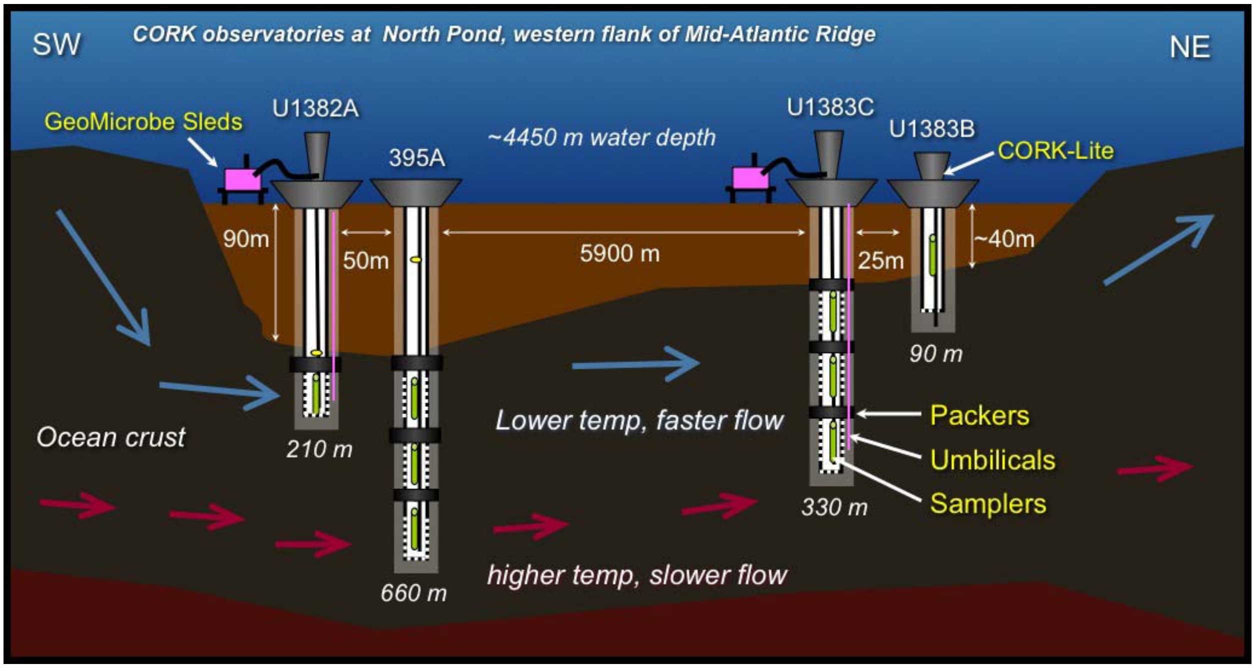


**Figure F3.** Photograph of Expedition 336 subseafloor borehole observatory (CORK) wellheads at the start of the expedition. The tops of the CORK wellheads are shown at the bottom of the photograph. The left CORK was prepared for deployment in Hole 395A, and the longer cup packer extension at the base of this wellhead is indicated. The configuration of each of the three wellhead bays (i.e., chemistry, microbiology [MBIO], and pressure bays) is also shown. Final configurations of these wellheads prior to deployment are shown in Figures F12 and F13. Photo courtesy of Bill Crawford/TAMU.

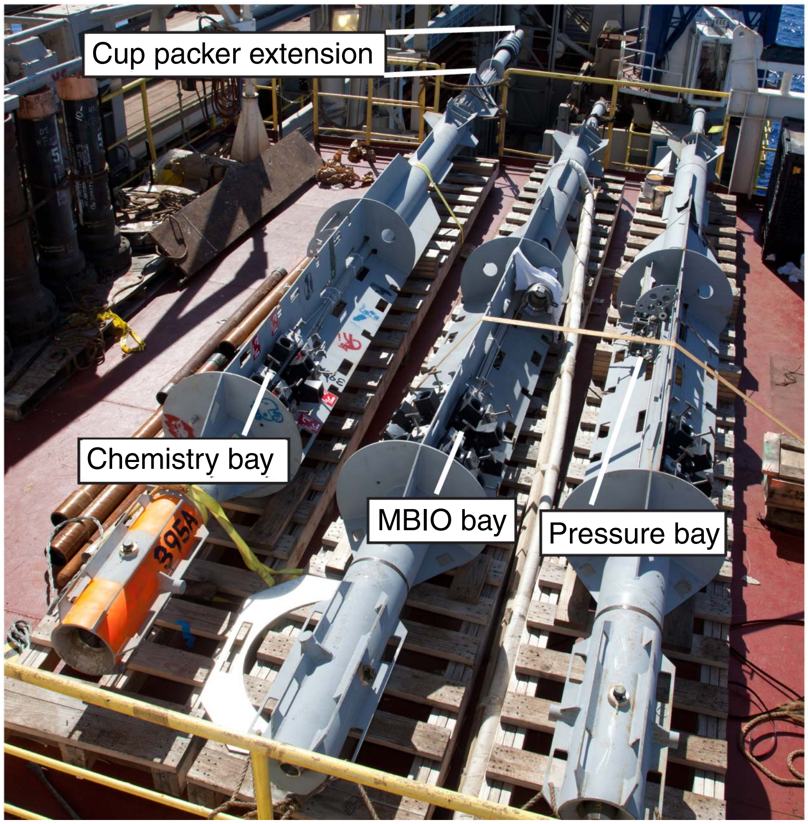


**Figure F4.** Coatings and sealants used on CORK casing during Expedition 336. **A.** Application of Alocit 28 paint on Amerlock- (exterior) and TK-34XT-coated (interior) drill collars. **B.** Application of Alocit 28 paint on Xylan-coated drill collars. **C.** Application of Amerlock epoxy to packer mandrel. **D.** Application of APT 3 sealant between fiberglass-to-steel connections. **E.** Cleaning of Xylan-coated drill collars with ethanol prior to application of Amerlock epoxy coating. Photos by Bill Crawford/TAMU (A, D, and E) and Geoff Wheat (B and C).

**Figure F5**. Umbilicals, miniscreens, and centralizers used during Expedition 336. **A.** Upper termination of umbilical lines to CORK wellhead run past a stainless steel centralizer. Note that centralizers in the 10¾ casing are not coated. **B.** Umbilicals secured with Smartbands. Note that lines coming from black flatpack are ⅛ and ¼ inch stainless steel umbilicals for chemistry, and the white and gray tubes are Tefzel umbilicals for microbiology connected to titanium fittings. **C.** Umbilicals connected to packer pass-throughs and secured with Smartbands. **D.** Umbilicals secured to fiberglass around plastic Kwik-zip centralizer (30 cm in length). **E.** Moonpool set-up for running umbilicals from reels through banana sheaves around the CORK casing. **F.** Close-up view of miniscreens (1 m in length). **G.** Miniscreen attached to outside of Amerlock-coated drill collar and secured between Xylan-coated steel centralizers with Smartbands and tape. Photos by Beth Orcutt (A, B, and F), Bill Crawford/TAMU (C, D, and E), and Geoff Wheat (G).

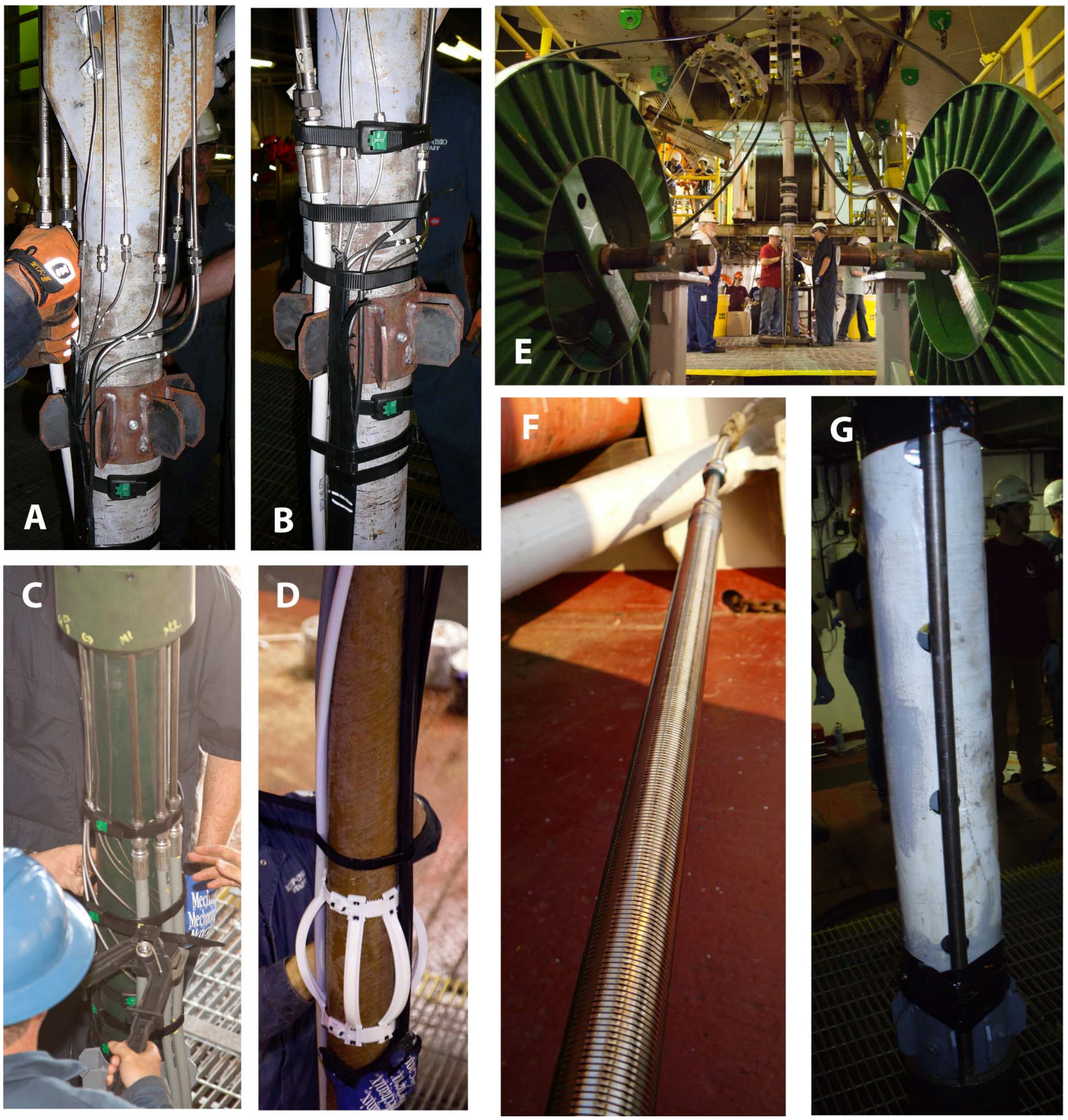


**Figure F6.** CORK umbilical–flatpack. OD = outside diameter.

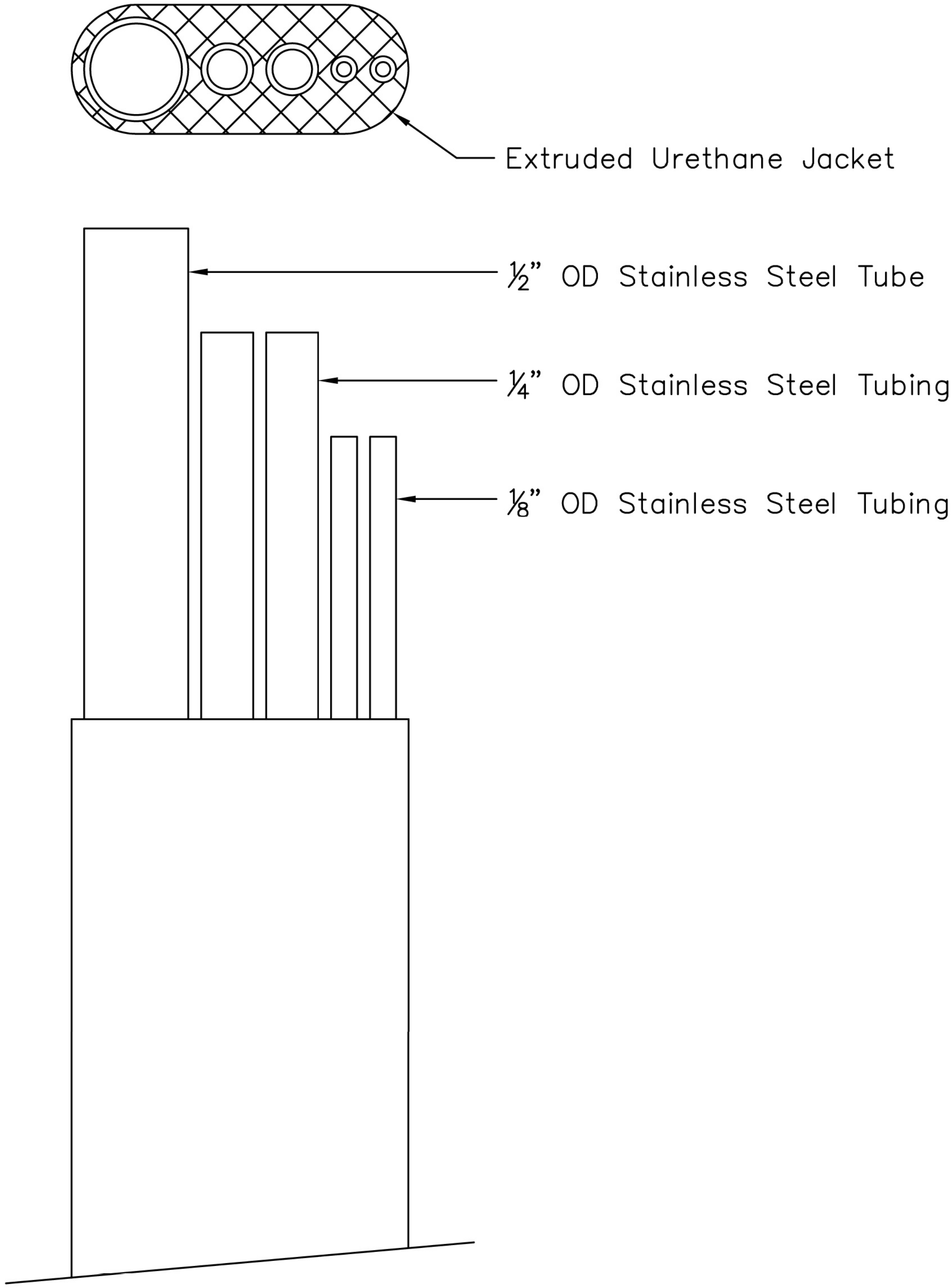
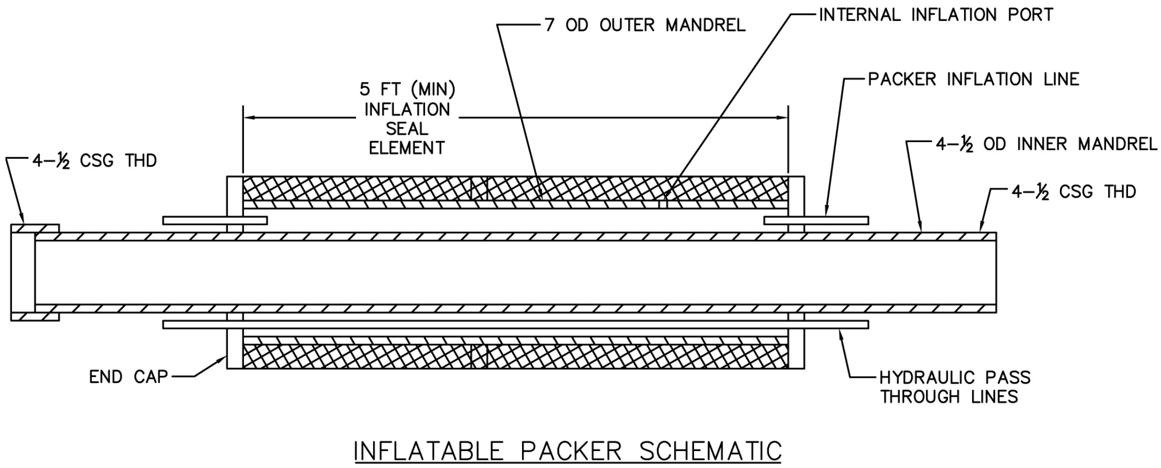


**Figure F7.** CORK packer configurations. csg = casing, THD = thread, OD = outside diameter.



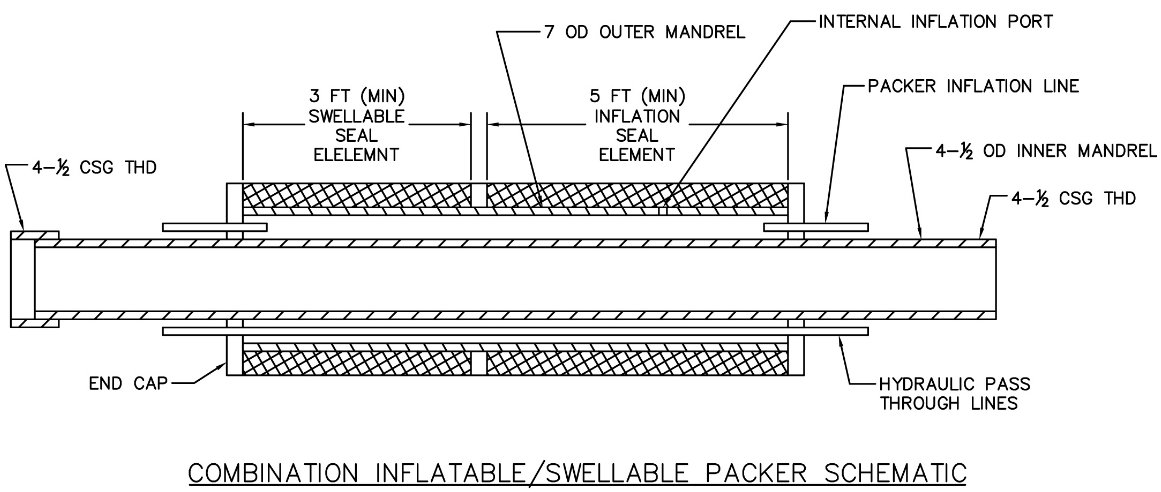



**Figure F8.** L-CORK wellhead general configuration. ROV = remotely operated vehicle.

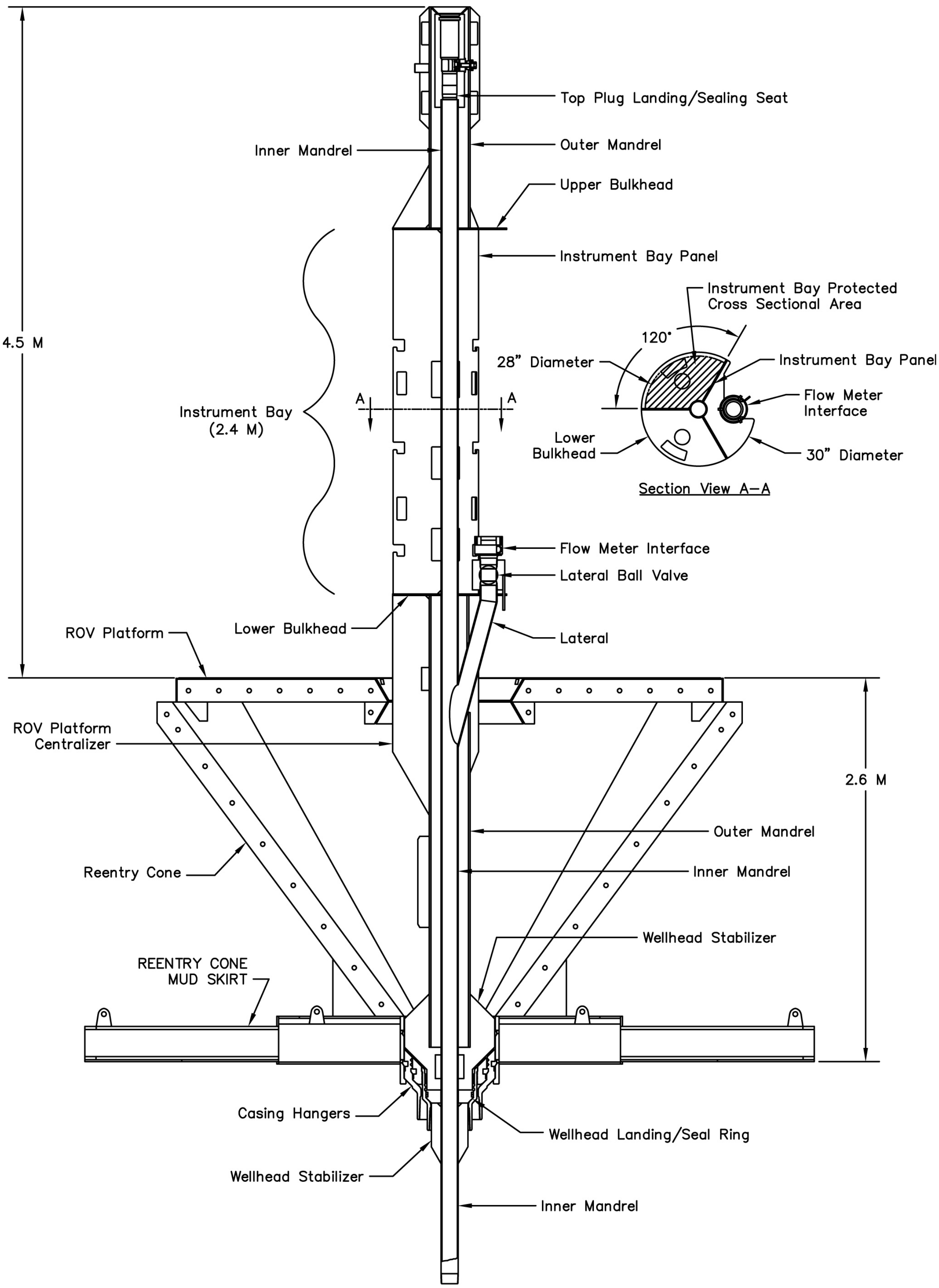


**Figure F9.** Fiberglass casing and packers used during Expedition 336. **A.** Connection of fiberglass pipe to steel crossover with nylon straps. **B.** Fiberglass-crossover-packer element in pipe stabber. Note the yellow oversized fiberglass elevator. **C.** Close-up of slotted fiberglass casing with umbilicals. **D.** Combination packer element from TAM International, showing umbilical pass-through connections. Photos by Bill Crawford/TAMU (A–C) and Beth Orcutt (D).

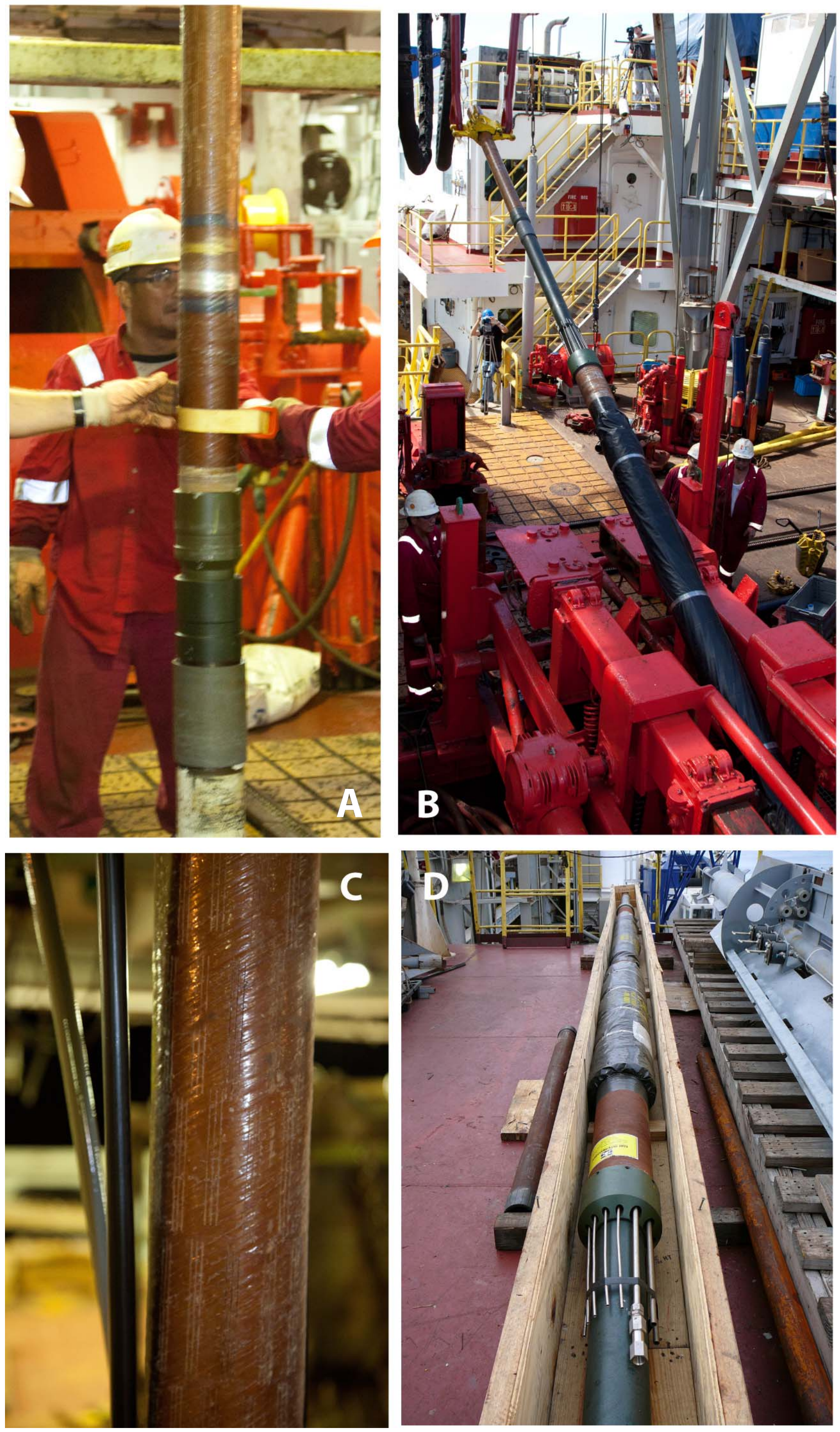


**Figure F10.** Instrument bay protected cross sectional area. VIT = vibration-isolated television.

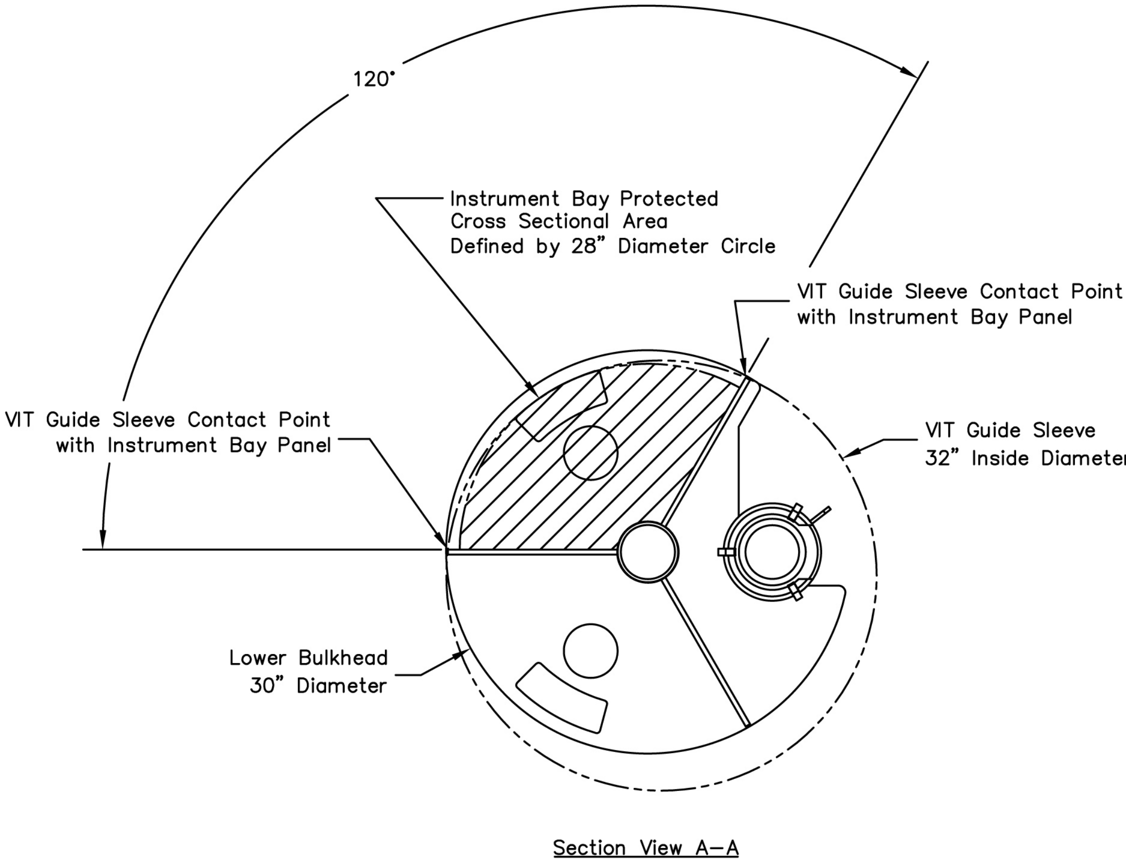


**Figure F11.** VIT camera system, Expedition 336.

**Figure F12.** Wellhead bays of CORK in Hole U1382A prior to deployment. **A.** Chemistry bay, with fast-flow OsmoSampler attached to opened upper left valve, all other valves closed. **B.** Microbiology bay, with all valves deployed closed. Note that flow valve has been removed from 4½ inch lateral pipe at base. **C.** Pressure bay with attached pressure sensor package connected to opened valve. Photos by Bill Crawford/TAMU.

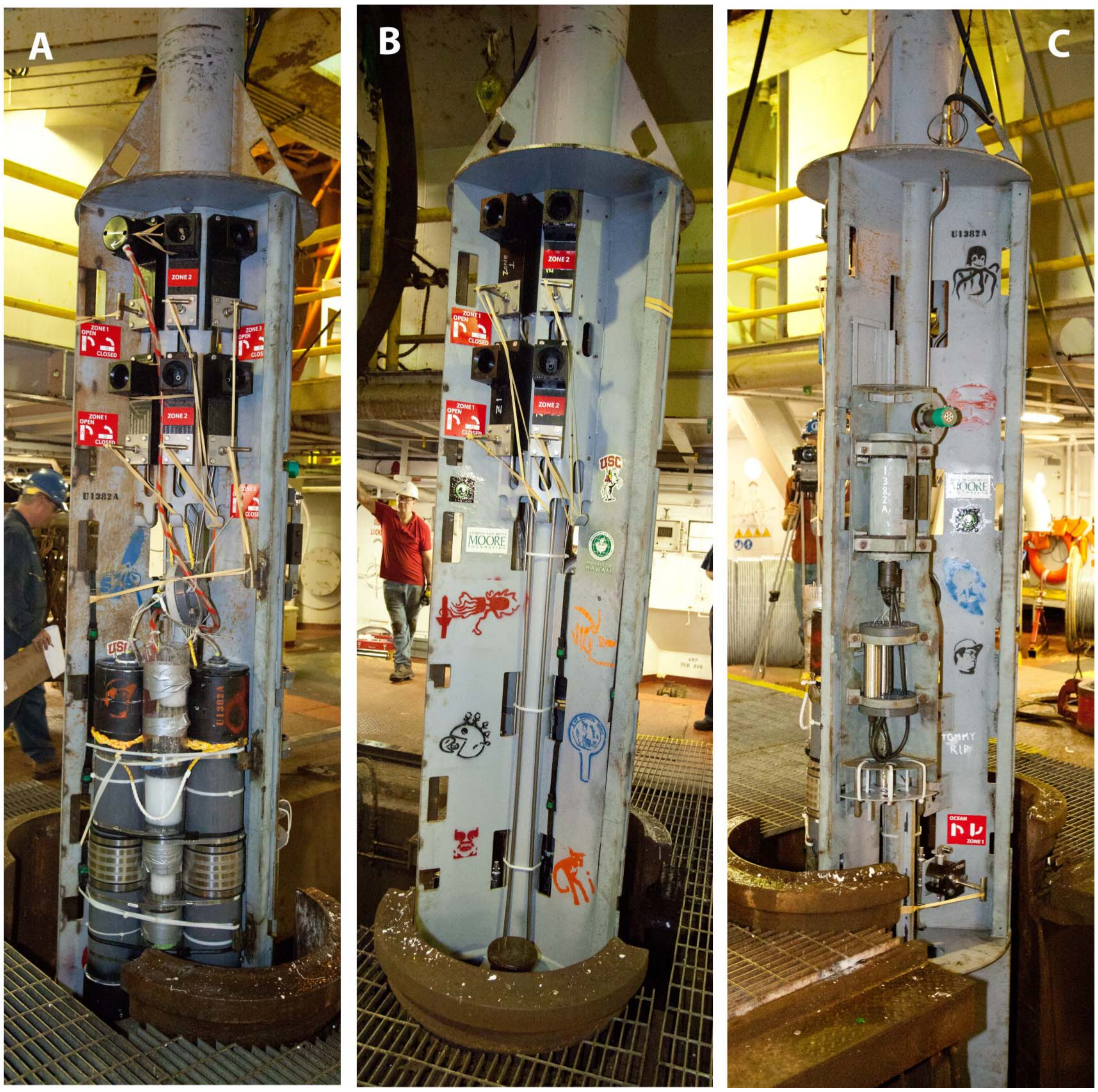


**Figure F13.** Wellhead bays of CORK in Hole U1383C prior to deployment. **A.** Chemistry bay, with fast-flow OsmoSampler attached to opened upper middle valve, all other valves closed. **B.** Microbiology bay, with all valves deployed closed. Note dust cap placed in flow valve at base, with handle closed. **C.** Pressure bay with attached pressure sensor package connected to opened valve. Photos by Bill Crawford/TAMU.

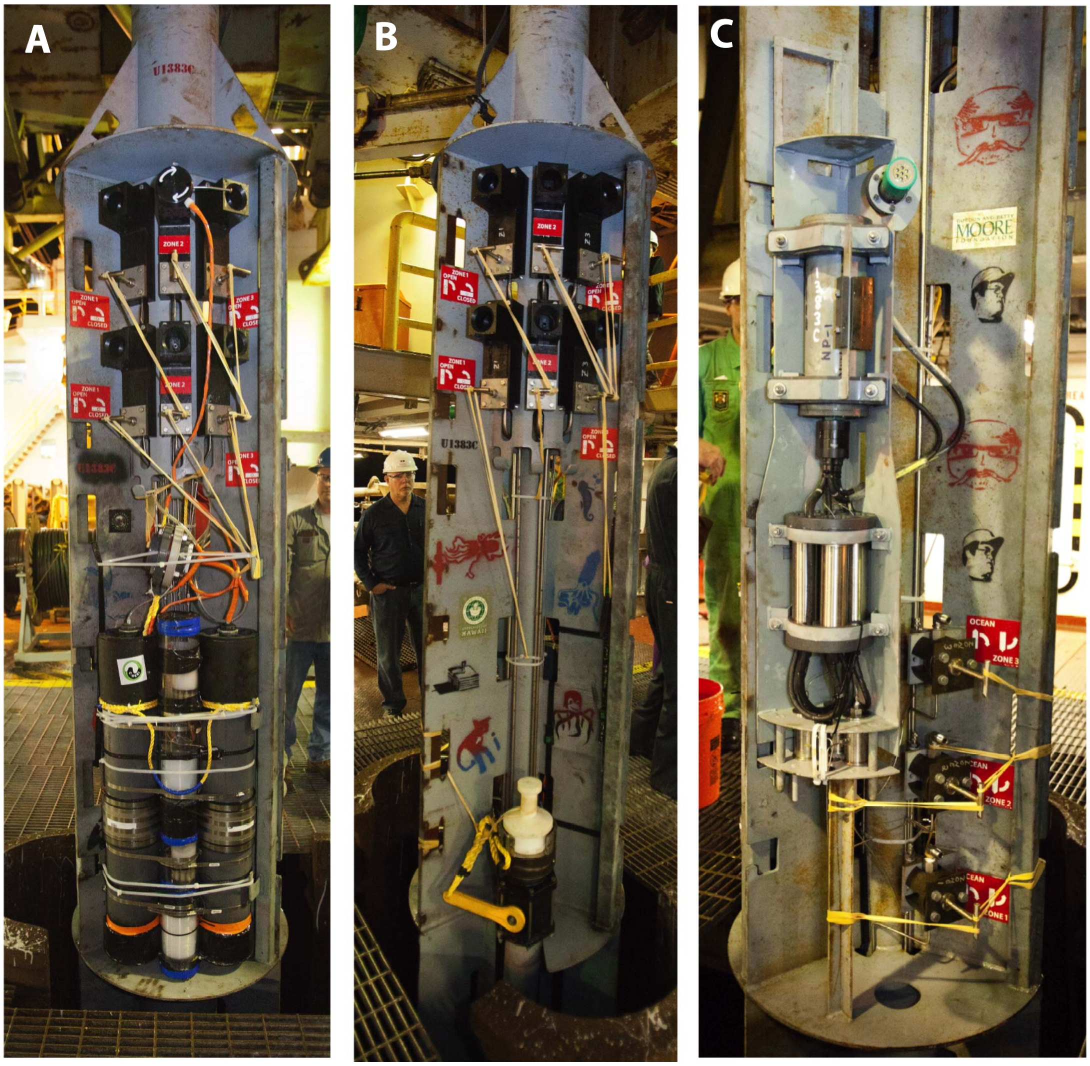


**Figure F14.** CORK stinger typical components. OD = outside diameter, ID = inside diameter.

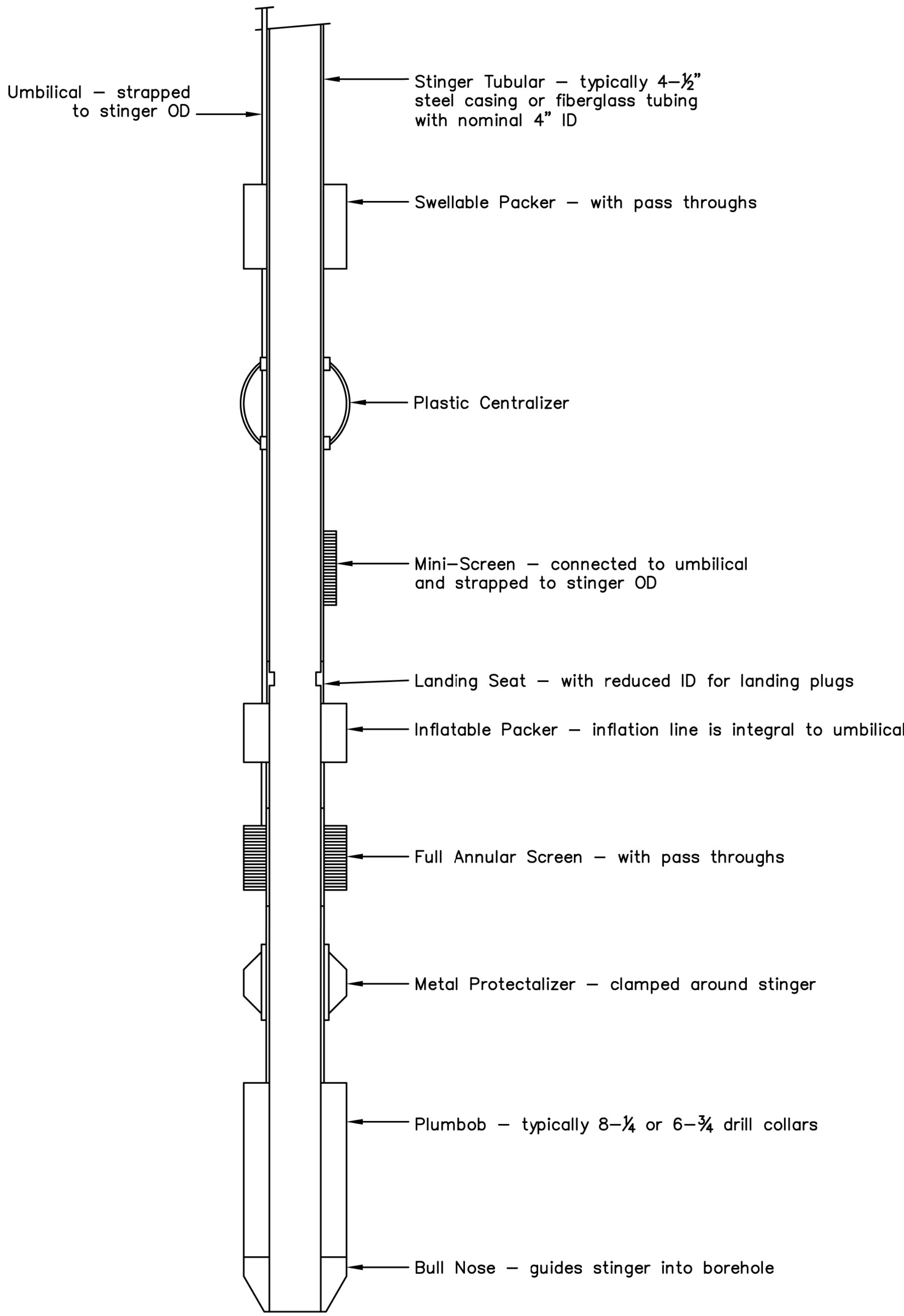


**Figure F15.** CORK miniscreens.

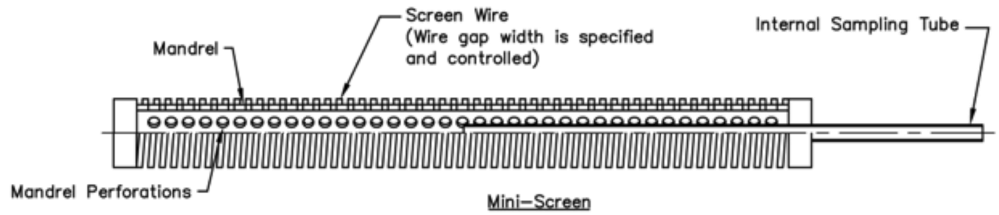


**Figure F16.** CORK downhole instrument strings with OsmoSampler packages, Expedition 336. **A.** Close-up of copper coils for gas OsmoSamplers. **B.** Stainless steel coupler in MBIO OsmoSampler, showing placement of Teflon tube in support-rod groove and set screws. **C.** Spectra rope spliced with eyes. **D.** Filled osmotic pumps connected to plastic couplers. **E.** Connection of oxygen probe to OsmoSampler packages on the rig floor. **F.** Insertion of OsmoSamplers into top of CORK in the rotary table on rig floor. Note that the gloved hand touches a clear PVC tube that protects the underlying Teflon tubing. **G.** Landing seat on instrument string. **H.** Top plug of instrument string connected to Spectra (with 1 m hydraulic hose protection). Photos by Beth Orcutt (A–C), Bill Crawford/TAMU (E, F, and H), and Geoff Wheat (D and G).

**Figure F17.** Fast-flow wellhead OsmoSamplers. **A.** Inside of the distilled water reservoirs of the fast-flow OsmoSamplers, showing the plastic liner used for holding the distilled water. **B.** Assembly of umbilical Y-connection to the base of the distilled water reservoirs. **C.** Continued assembly of the umbilical T-connections to the OsmoSampler intakes. **D.** Assembled fast-flow wellhead OsmoSamplers prior to deployment in the moonpool, with MBIO OsmoSampler and standard OsmoSampler in the middle of the distilled water reservoirs. Pump head and umbilical connection are held in the orange buckets in the back of the picture, with the pump head submerged in seawater and the umbilical connector submerged in distilled water. **E.** OsmoSampler attached to Hole U1382A CORK wellhead in the chemistry bay, with umbilical connected to opened upper left valve. Photos by Sam Hulme (A), Beth Orcutt (B–D), and Bill Crawford/TAMU (E).

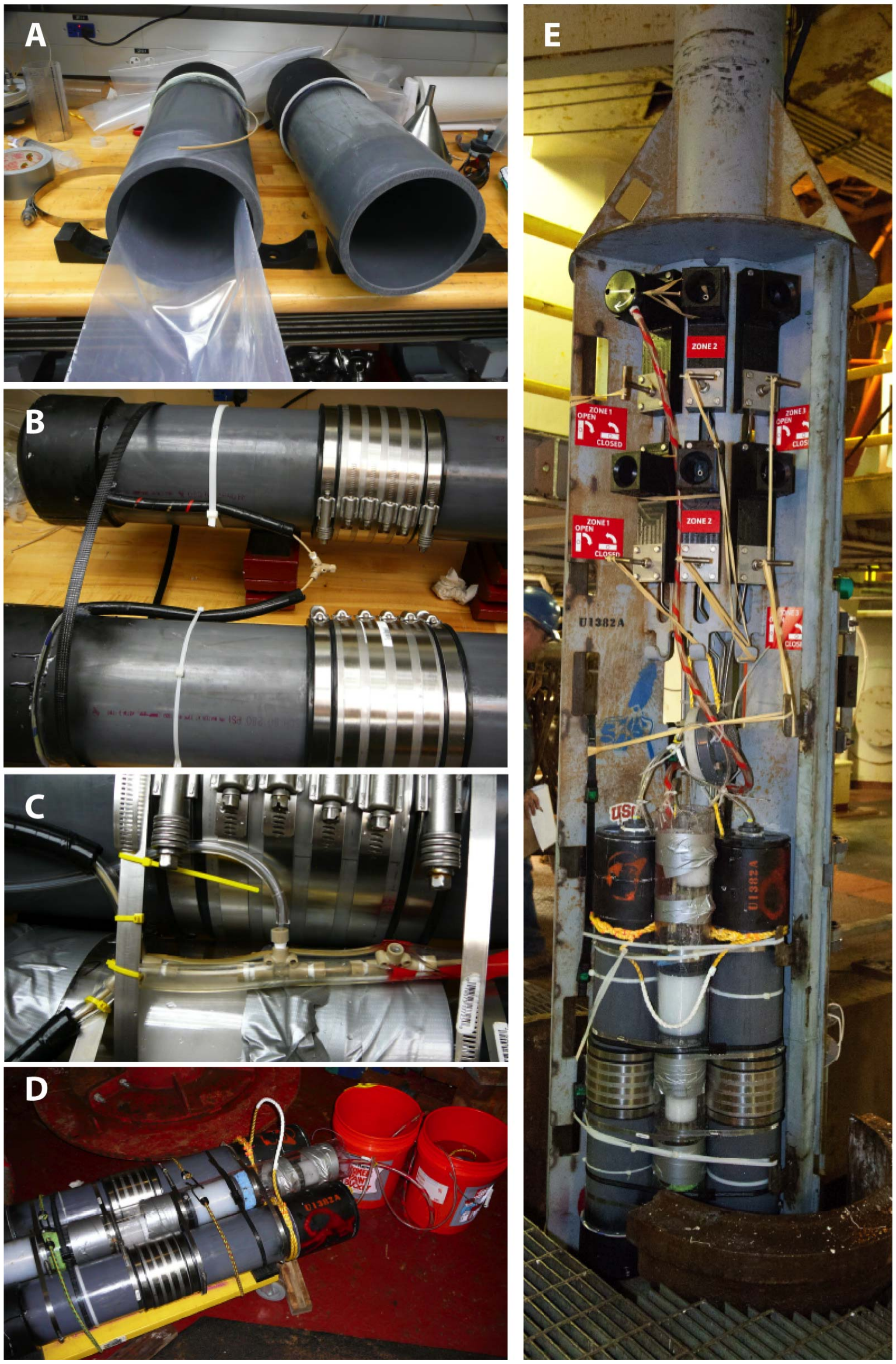


**Figure F18.** Example of FLOCS microbial colonization experiment for deployment on CORK downhole instrument string, Expedition 336. **A.** One side of the FLOCS with polished mineral coupons for passive colonization. **B.** Other side of the FLOCS unit showing the cassettes of mineral fragments for the flow-through colonization experiment. For scale, the FLOCS units are 25.4 cm (10 inches) on the long axis and 5.46 cm (2.15 inches) in diameter on the small axis. Photo by Beth Orcutt.

**Figure F19.** Configuration of the primary parts of the new subseafloor borehole observatory (CORK) deployed in Hole 395A. Red X indicates the portion of the CORK head that broke off during the final step of installation.

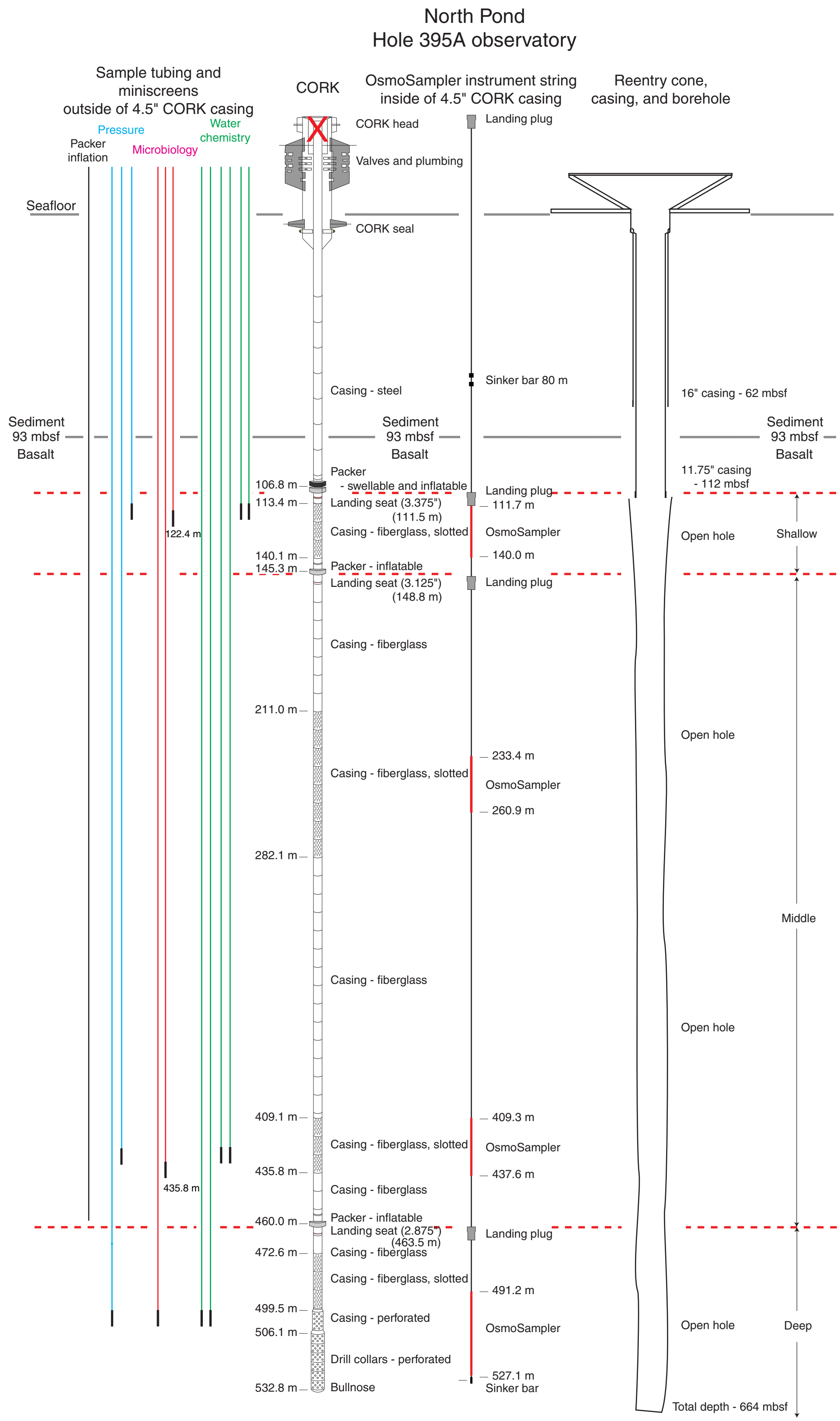


**Figure F20.** Overview of damage to CORK wellhead during deployment in Hole 395A. **A.** Cracked ball valve. **B.** Open free-flow pipe where ball valve broke off. **C.** Top latch of instrument string riding high upon removal of running tool. **D.** Buckled wellhead panel before equipment removed. **E.** Close up on buckled panel, showing damage to pressure sensor mount. **F.** Sheared pipe at the base of the wellhead and broken umbilicals. **G.** Overview of bent CORK wellhead in the moonpool. Photos by Adam Klaus (A–C) and Bill Crawford (D–G).

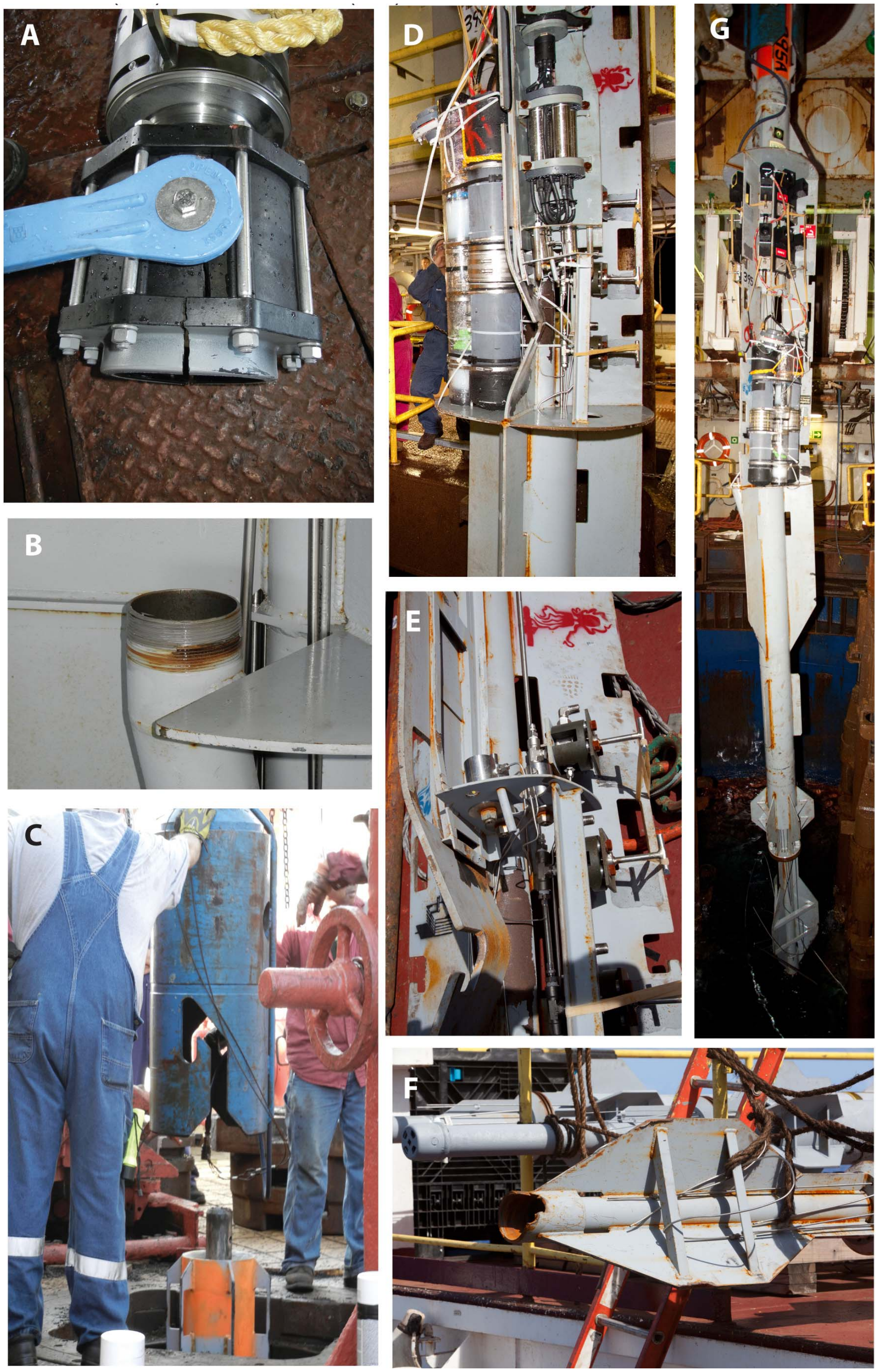


**Figure F21.** Still images from VIT camera footage of ROV platform on Hole 395A reentry cone after CORK wellhead snapped off. **A.** Image showing the skewed ROV platform and two of the three sonar targets on the reentry cone. **B.** TV still of VIT video, showing a suggestion of the 5 inch casing in the throat of the cone (barely visible in hole in ROV platform). Photo by Beth Orcutt (B).

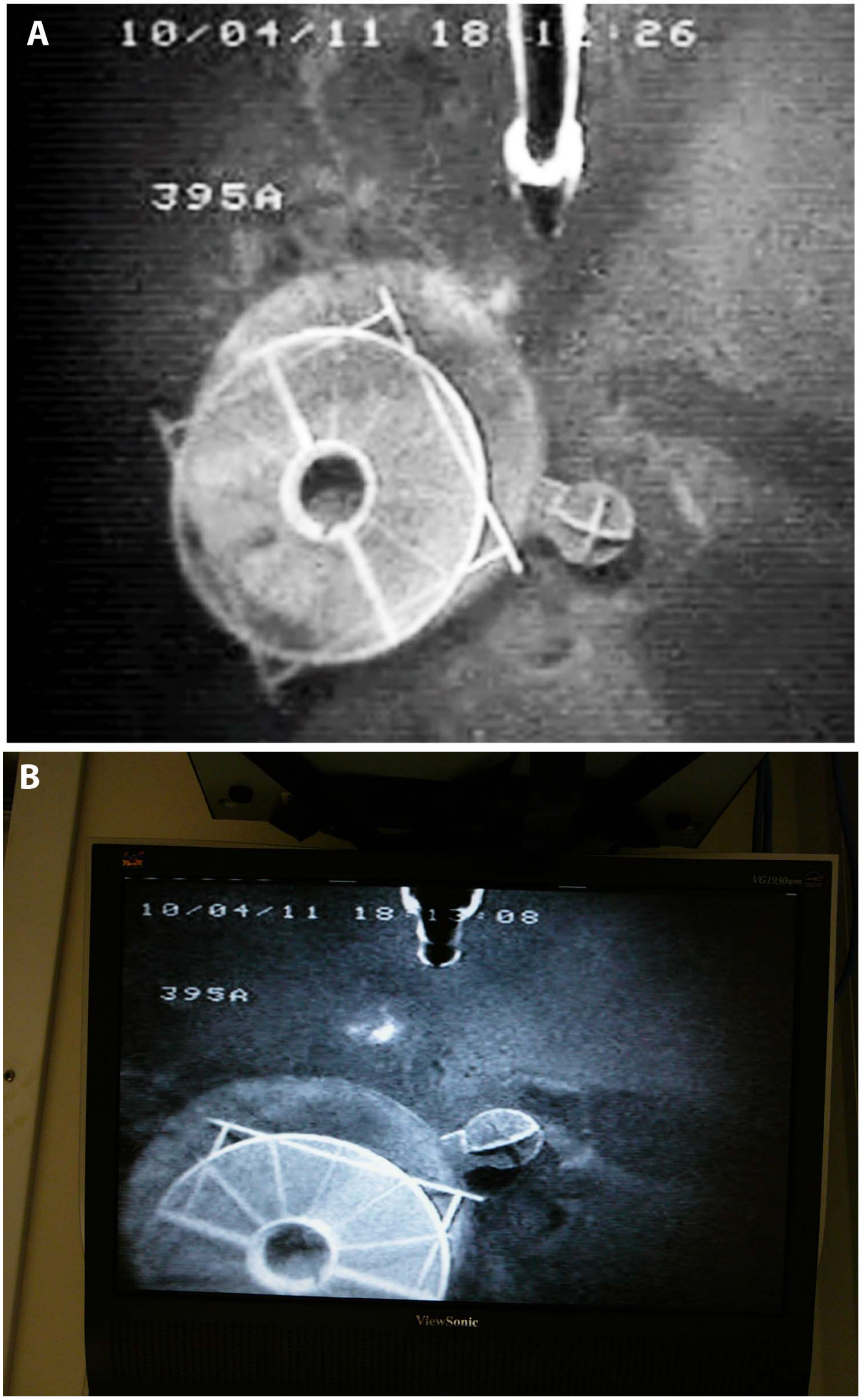


**Figure F22.** Configuration of the primary parts of the subseafloor borehole observatory (CORK) installed in Hole U1382A.

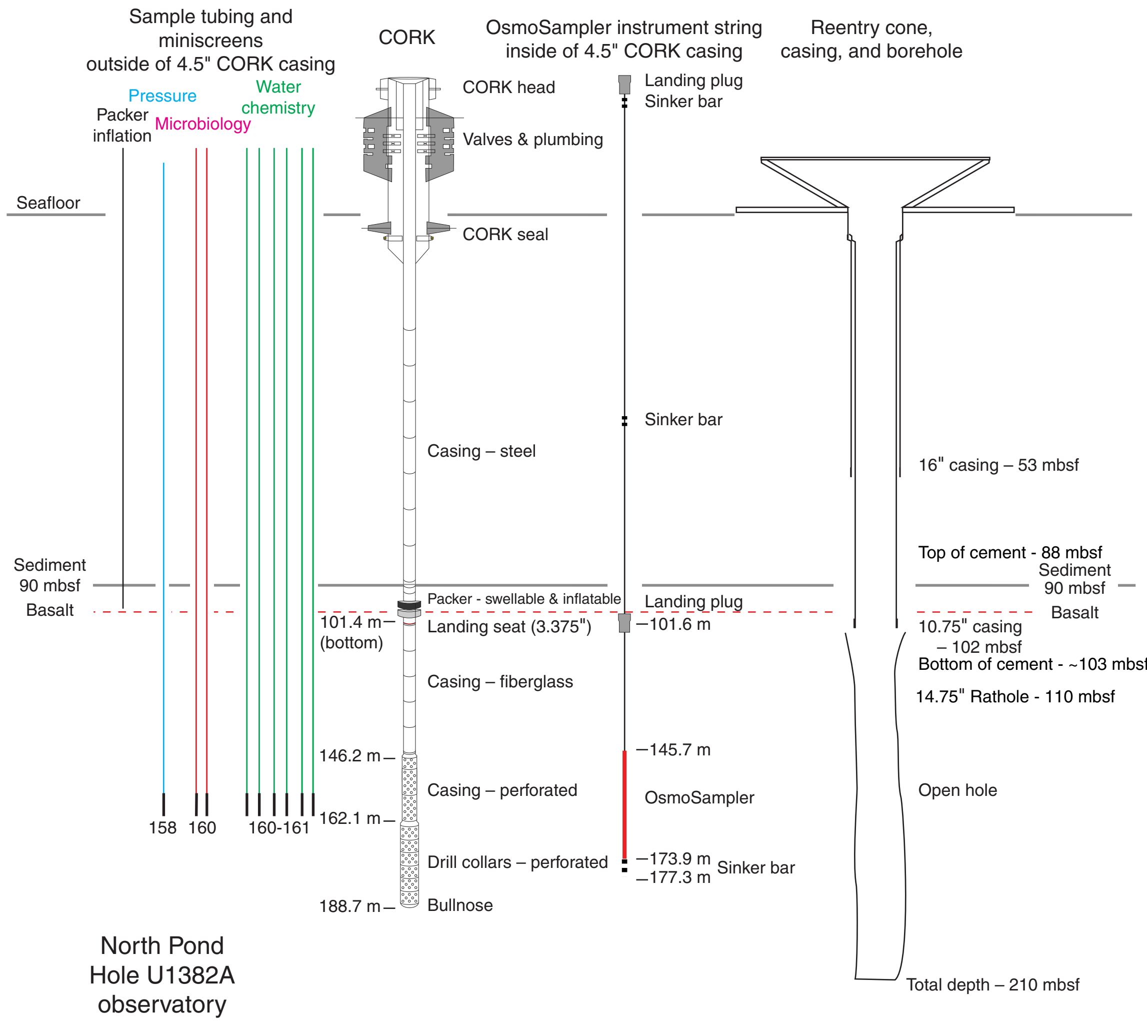


**Figure F23.** Schematic of the reentry cone and casing installed in Hole U1383B. CSG = casing, TD = total depth.

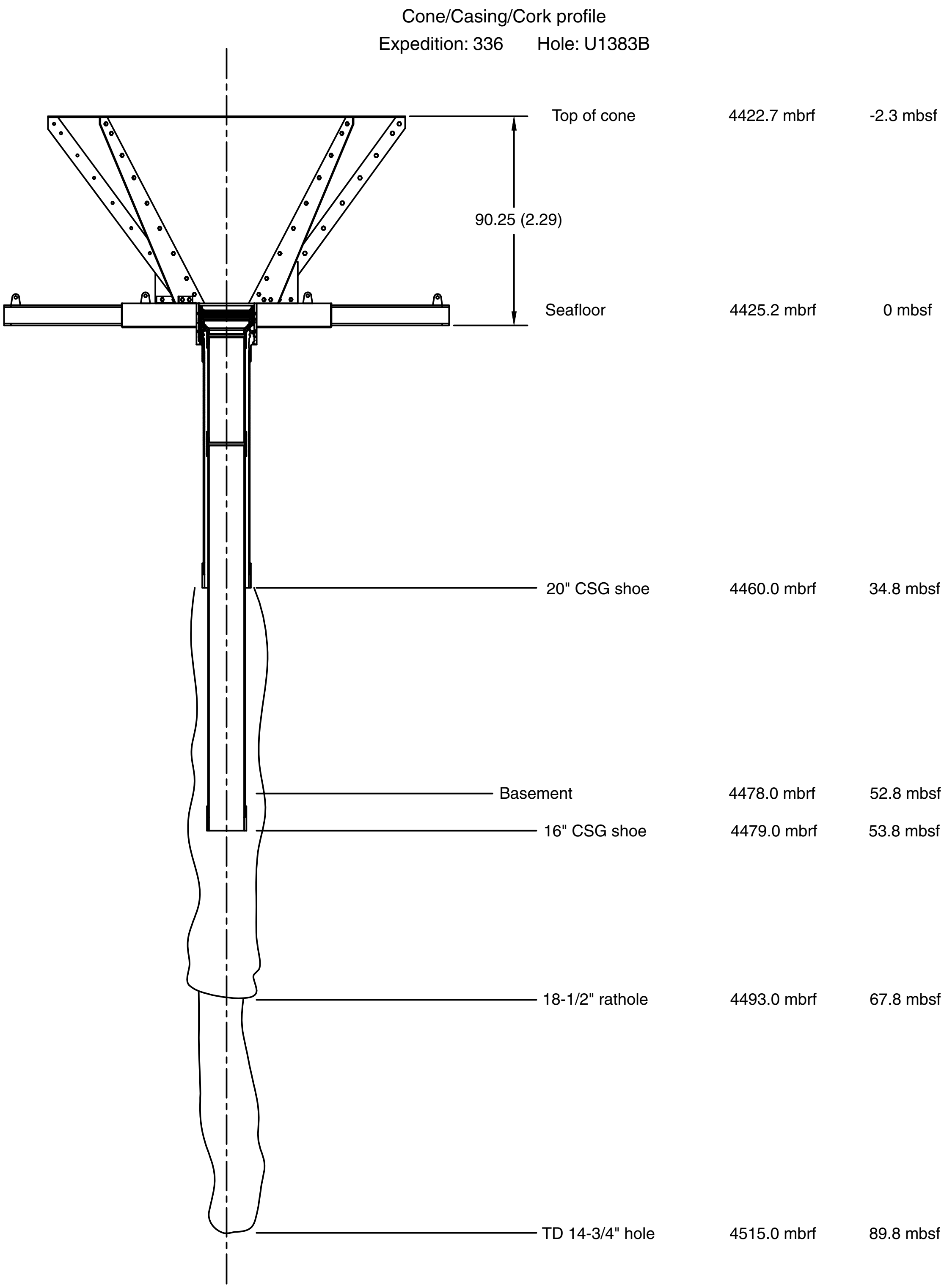


**Figure F24.** Configuration of the primary parts of the subseafloor borehole observatory (CORK) installed in Hole U1383C.

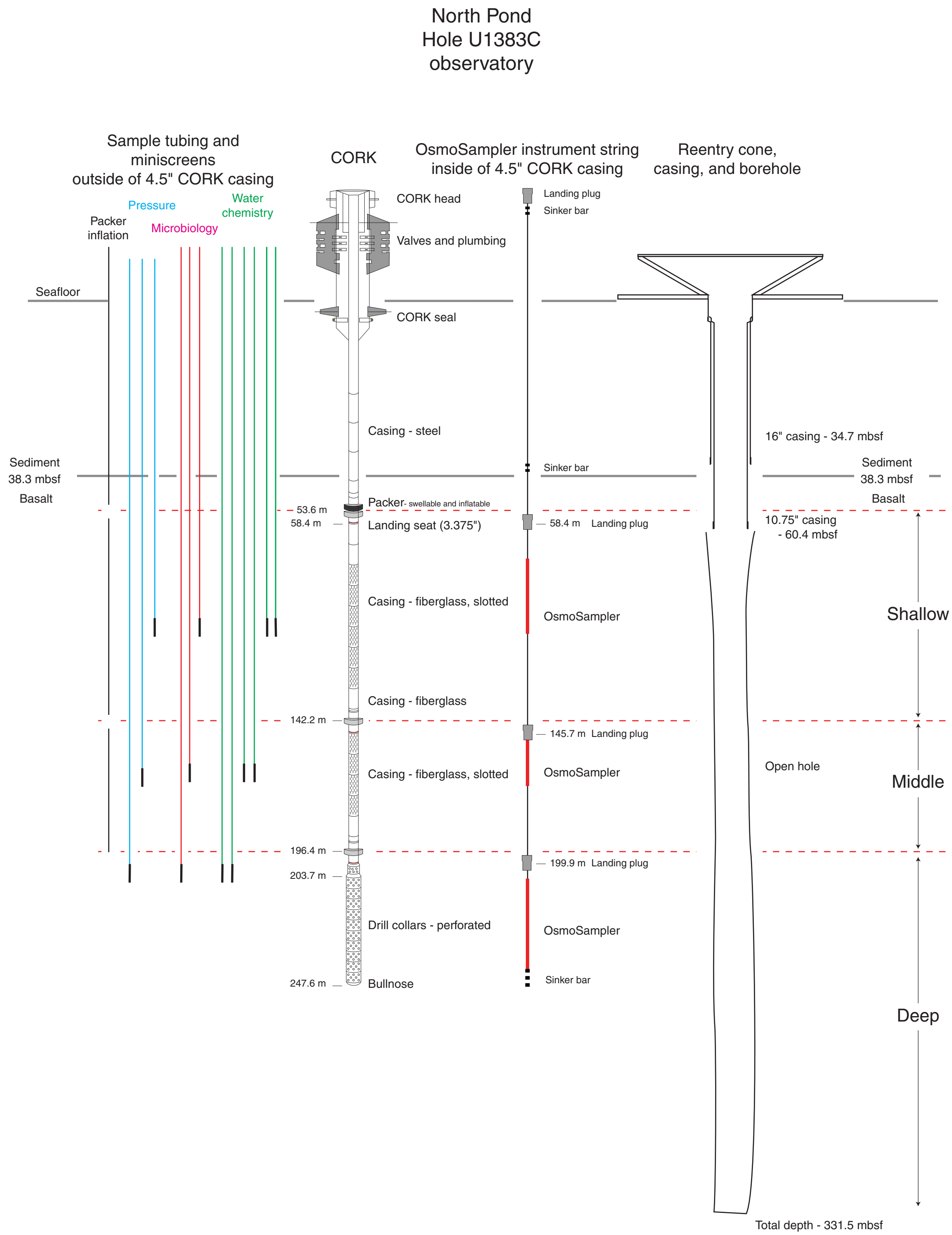


**Figure F25.** Schematic of the CORK body to be installed in Hole U1383B. The boot is used during deployment as a landing surface for the CORK body.

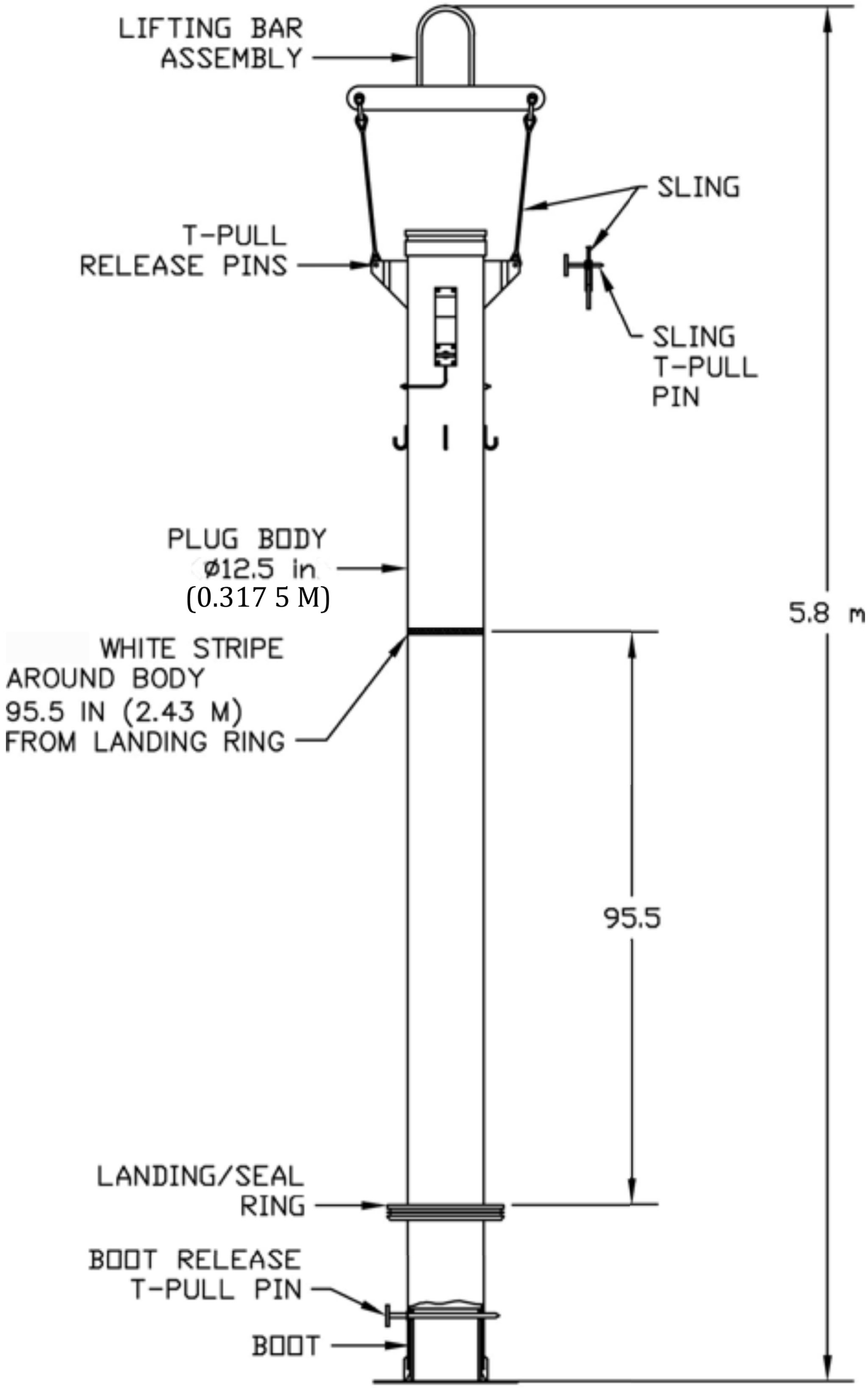


**Table T1.** Coatings used on different materials during Expedition 336.

| Item | Coating ID | Coating OD | Notes |
|---|---|---|---|
| Packers | Tubes - TK-34XT | Tubes - TK-34XT | Pressure mandrel - Amerlock |
| Landing seats | Amerlock | Amerlock | |
| Crossovers | TK-34XT | TK-XT | |
| Drill collars | Xylan | Xylan | OD painted with Alocit (as per Orcutt et al., 2012) on Hole 395A and Amerlock on Holes U1382A and U1383C |
| Bullnose | TK-34XT | TK-34XT | OD painted with Alocit on Hole 395A and Amerlock on Holes U1382A and U1383C |
| Crossovers from steel casing to fiberglass | Xylan | Xylan | |
| 5-1/2 inch casing, old | OD - Amerlock | ID - TK-34XT | |
| 5-1/2 inch casing, new | OD - TK-34XT | ID - TK-34XT | |
| Sinker bars | | Xylan | |
| Landing plugs | | Xylan | |
| Steel centralizers | Xylan | Xylan | |

See Orcutt et al. (2012) for more details. ID = inside diameter, OD = outside diameter.

**Table T2.** Lubricants used during Expedition 336 as per Orcutt et al. (2012).

| Grease | Where used | Why used | Manufacturer |
|---|---|---|---|
| Loctite 30561 thread sealant with PTFE | Metal-to-metal casing connections | Provides good lubrication and excellent sealing; does not contain zinc | Loctite/Henkel |
| APT 3 joint adhesive | Metal-to-fiberglass casing connections | Permanently bonds the metal to the fiberglass | APT Sealant |
| TF-15 thread sealant | Fiberglass-to-fiberglass connections | Recommended and approved by fiberglass casing supplier | Jet-Lube |

PTFE = polytetrafluoroethylene.

**Table T3.** Umbilical materials used during Expedition 336.

| Hole / Umbilical: | Tubing sizes (inch) Qty | Size | Material | OD (inch) | ID (inch) |
|---|---|---|---|---|---|
| 395A | | | | | |
| Pressure/Inflate | 1 | 1/2 | SST | 0.500 | 0.402 |
| | 3 | 1/4 | SST | 0.250 | 0.180 |
| Chem | 3 | 1/4 | SST | 0.250 | 0.180 |
| | 3 | 1/8 | SST | 0.125 | 0.085 |
| MBIO | 3 | 1/2 | Tefzel | 1.000 | 0.500 |
| | 3 | 1/2 | Titanium | 0.500 | 0.430 |
| U1382A | | | | | |
| Pressure/Inflate | 1 | 1/2 | SST | 0.500 | 0.402 |
| | 2 | 1/4 | SST | 0.250 | 0.180 |
| Chem | 3 | 1/4 | SST | 0.250 | 0.180 |
| | 3 | 1/8 | SST | 0.125 | 0.085 |
| MBIO | 2 | 1/2 | Tefzel | 1.000 | 0.500 |
| | 2 | 1/2 | Titanium | 0.500 | 0.430 |
| U1383C | | | | | |
| Pressure/Inflate | 1 | 1/2 | SST | 0.500 | 0.402 |
| | 3 | 1/4 | SST | 0.250 | 0.180 |
| Chem | 3 | 1/4 | SST | 0.250 | 0.180 |
| | 3 | 1/8 | SST | 0.125 | 0.085 |
| MBIO | 3 | 1/2 | Tefzel | 1.000 | 0.500 |
| | 3 | 1/2 | Titanium | 0.500 | 0.430 |

OD = outside diameter, ID = inside diameter. SST = stainless steel. MBIO = microbiology.

**Table T4.** CORK stinger tubular strength comparison, Expedition 336.

| Nominal pipe size (inches) | Weight (lb/ft) | OD (inches) | ID (inches) | Area ($inch^2$) | Area of moment of inertia ($inch^4$) | Critical column load (lb) | Critical column length (m) | Joint strength (lb) | Modulus of elasticity (lb/$inch^2$) | Yield or tensile strength (lb/$inch^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 4-1/2 csg | 10.5 | 4.500 | 4.052 | 3.009 | 6.884 | 1,152 | 33.4 | 132,000 | 30,000,000 | 55,000 |
| 5-1/2 csg | 17.0 | 5.500 | 4.892 | 4.962 | 16.775 | 2,136 | 38.3 | 229,000 | 30,000,000 | 55,000 |
| 5 DP | 22.1 | 5.000 | 4.250 | 5.449 | 14.639 | 2,432 | 33.5 | 735,576 | 30,000,000 | 135,000 |
| 5-1/2 DP | 31.9 | 5.500 | 4.500 | 7.854 | 24.745 | 3,700 | 35.4 | 1,060,290 | 30,000,000 | 135,000 |
| 4-1/2 FG | 3.5 | 4.570 | 3.980 | 3.962 | 9.078 | 421 | 36.7 | 118,859 | 10,000,000 | 30,000 |

OD = outside diameter, ID = inside diameter. csg = casing, DP = drill pipe, FG = fiberglass. Area = $(OD^2 – ID^2) \times (\pi/4)$. Area of moment of inertia = $(\pi/64) \times (OD^4 – ID^4)$. Critical column load = critical column length × weight per foot. Critical column length = $[(\pi^2 \times \text{modulus of elasticity} \times \text{area of moment of inertia})/(\text{weight per foot}/12 \text{ inches/ft})]^{0.3}$. Joint strength = published data or calculated – area × yield or tensile strength.

**Table T5.** CORK stinger tubular stretch per 1,000 lb load and 100 m length comparison, Expedition 336.

| Nominal pipe size (inches) | Weight (lb/ft) | OD (inches) | ID (inches) | Area ($inch^2$) | Load (lb) | Length (m) | Change in length (m) | Joint strength (lb) | Modulus of elasticity (lb/$inch^2$) | Yield or tensile strength (lb/$inch^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 4-1/2 csg | 10.5 | 4.500 | 4.052 | 3.009 | 1,000 | 100 | 0.0011 | 132,000 | 30,000,000 | 55,000 |
| 5-1/2 csg | 17.0 | 5.500 | 4.892 | 4.962 | 1,000 | 100 | 0.0007 | 229,000 | 30,000,000 | 55,000 |
| 5 DP | 22.1 | 5.000 | 4.250 | 5.449 | 1,000 | 100 | 0.0006 | 735,576 | 30,000,000 | 135,000 |
| 5-1/2 DP | 31.9 | 5.500 | 4.500 | 7.854 | 1,000 | 100 | 0.0004 | 1,060,290 | 30,000,000 | 135,000 |
| 4-1/2 FG | 3.5 | 4.570 | 3.980 | 3.962 | 1,000 | 100 | 0.0025 | 118,859 | 10,000,000 | 30,000 |

OD = outside diameter, ID = inside diameter. csg = casing, DP = drill pipe, FG = fiberglass. Change in length or stretch = (load × length)/(modulus of elasticity × area). Values for critical column load are based on a distributed load (weight per foot) rather than a point load applied at the top of the column.