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Expedition 336 Preliminary Report

Mid-Atlantic Ridge microbiology

Initiation of long-term coupled microbiological, geochemical, and hydrological experimentation within the seafloor at North Pond, western flank of the Mid-Atlantic Ridge

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Abstract

Integrated Ocean Drilling Program (IODP) Expedition 336 successfully initiated subseafloor observatory science at a young mid-ocean-ridge flank setting. All of the drilled sites are located in the North Pond region of the Atlantic Ocean (22°45′N, 46°05′W) in 4414–4483 m water depth. This area is known from previous ocean drilling and site survey investigations as a site of particularly vigorous circulation of seawater in permeable 8 Ma basaltic basement underlying a <300 m thick sedimentary pile. Understanding how this seawater circulation affects microbial and geochemical processes in the uppermost basement was the primary science objective of Expedition 336.

Basement was cored and wireline-logged in Holes U1382A and U1383C. Upper oceanic crust in Hole U1382A, which is only 50 m west of Deep Sea Drilling Project (DSDP) Hole 395A, recovered 32 m of core between 110 and 210 meters below seafloor (mbsf). 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. From Hole U1383C we recovered 50.3 m of core between 69.5 and 331.5 mbsf (19%). The basalts are aphyric to highly plagioclase-olivine-phyric tholeiites that fall on a liquid line of descent controlled by olivine fractionation. They are fresh to moderately altered, with clay minerals (saponite, nontronite, and celadonite), Fe oxyhydroxide, carbonate, and zeolite as secondary phases replacing glass and olivine to variable extents. In addition to traditional downhole logs, we also used a new logging tool for detecting in situ microbial life in ocean floor boreholes—the Deep Exploration Biosphere Investigative tool (DEBI-t).

Sediment thickness was ~90 m at Sites U1382 and U1384 and varied between 38 and 53 m at Site U1383. The sediments are predominantly nannofossil ooze with layers of coarse foraminiferal sand and occasional pebble-size clasts of basalt, serpentinite, gabbroic rocks, and bivalve debris. The bottommost meters of sections cored with the advanced piston corer feature brown clay. Extended core barrel coring at the sediment/basement interface recovered <1 m of brecciated basalt with micritic limestone. Sediments were intensely sampled for geochemical pore water analyses and microbiological work. In addition, high-resolution measurements of dissolved oxygen concentration were performed on the whole-round sediment cores.

Major strides in ridge-flank studies have been made with subseafloor borehole observatories (CORKs) because they facilitate combined hydrological, geochemical, and microbiological studies and controlled experimentation in the subseafloor. During Expedition 336, two fully functional observatories were installed in two newly drilled holes (U1382A and U1383C) and an instrument and sampling string were placed in an existing hole (395A). Although the CORK wellhead in Hole 395A broke off and Hole U1383B was abandoned after a bit failure, these holes and installations are intended for future observatory science targets. The CORK observatory in Hole U1382A has a packer seal in the bottom of the casing and monitors/samples a single zone in uppermost oceanic crust extending from 90 to 210 mbsf. Hole U1383C was equipped with a three-level CORK observatory 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.

Introduction

The uppermost ~500 m of basaltic ocean crust is fractured and permeable, harboring the largest hydrologically active aquifer on Earth. The oceanic crust is hydrologically active beneath at least 60% of the seafloor (Fisher, 2005), with a fluid flux through the crust that rivals global riverine input to the oceans (Wheat et al., 2003). Solutes and colloids (including microbes) circulate actively through the crustal aquifer, but the extent to which microbes colonize, alter, and evolve in subsurface rock is not known. A large fraction of ocean crust remains uncovered by sediments for millions of years on the flanks of mid-ocean ridges before being blanketed in the abyssal plains of the ocean and eventually subducted at trenches. These basement outcrops serve as “breathing holes” through which seawater can ventilate the ocean crust. Fluid flow in the crust is focused in specific areas where permeability is increased—usually at the contacts of lava flows or in brecciated zones. In these intervals, the extent of rock alteration is increased, suggesting elevated intensity of seawater–rock interaction. It is well known that the geochemical changes associated with basalt alteration in the uppermost oceanic crust play an important role in setting ocean chemistry. It is unknown, however, what role microorganisms play in mediating this seawater–ocean crust exchange.

Laboratory studies, field examinations, and in situ field colonization and alteration experiments have shown that microbes are abundantly present and play an active role in rock alteration of exposed outcrops at the seafloor at low temperatures (e.g., Wirsen et al., 1993, 1998; Eberhard et al., 1995; Rogers et al., 2003; Edwards et al., 2003a, 2003b). In the subseafloor, the extent of direct participation in alteration by extant communities is not as clear. Abundant petrographic observations show that crust older than 100 Ma may harbor biological communities (e.g., Fisk et al., 1998). However, studies suggest that young subseafloor ocean crust may be the most redox active—and thereby the most likely to support active biological communities. Furnes et al. (2001) compared the degree of alteration in ocean crust aged 0–110 Ma. These data suggest that the majority of alteration features are established early and change little thereafter. Bach and Edwards (2003) compiled data concerning the oxidation state of the upper ocean crust. These data also suggest that oxidative ocean crust alteration occurs during the first 10 m.y. of ocean crust evolution. We therefore expect that hydrologically active, young ridge-flank crust is undergoing progressive oxidative alteration. If microorganisms metabolize the energy associated with the oxidation of FeO in the basalt, a sizeable microbial biomass may be supported by these oxidative alteration reactions.

The principal science objective of Integrated Ocean Drilling Program (IODP) Expedition 336 was to address fundamental microbiological questions concerning the nature of the subseafloor deep biosphere in oceanic hydrological, geological, and biogeochemical contexts. Primarily, we planned to study the nature of subseafloor microbiological communities in young igneous ocean crust in order to understand the role of these communities in ocean crust alteration and their ecology in hydrological and biogeochemical contexts. Specifically, we wanted to test the hypothesis that microbes play an active role in ocean crust alteration, while also exploring broad-based ecological questions such as how hydrological structure and geochemistry influence microbial community structures. We also intended to study the biogeography and dispersal of microbial life in subseafloor sediments.

The primary operational goal of Expedition 336 was the installation of subseafloor borehole observatories (CORKs) for long-term coupled microbiological, geochemical, and hydrological experiments. The study site for Expedition 336 is North Pond, a sediment pond on the western flank of the Mid-Atlantic Ridge, which is underlain by hydrologically active upper oceanic crust (Figs. F1, F2). The observatories will enable us to monitor conditions and study processes in situ after the drilling-induced disturbance and contamination of the borehole environment have dissipated. Sampling for microbiological and geochemical studies was conducted on basement and sediment cores retrieved from the CORKed holes and their immediate vicinities.

Our specific operational goals were to

1. Drill a basement hole to ~565 meters below seafloor (mbsf) at prospectus Site NP-1, core the bottommost ~200 m of the basaltic crust, conduct downhole hydrologic (packer) tests and wireline logging, and install a multilevel CORK to conduct experiments in the deeper portions of the upper basement hydrological environment;
2. Drill a basement hole to ~175 mbsf at prospectus Site NP-2, core ~70 m of the basaltic crust, conduct downhole hydrologic (packer) tests and wireline logging, and install a single-level CORK to conduct experiments in the uppermost basement hydrological environment;
3. Recover the existing CORK in Deep Sea Drilling Project (DSDP) Hole 395A, conduct downhole wireline logging, and install a multilevel CORK to conduct experiments in the deeper portions of the upper basement hydrological environment; and
4. Recover the thin sediment covers of prospectus Sites NP-1 (64 m) and NP-2 (85 m), DSDP Hole 395A (93 m), and Ocean Drilling Program (ODP) Site 1074 (64 m) by drilling a single hole at each site with the advanced piston corer (APC).

The primary focus of operations during Expedition 336 was the installation of the initial CORK experiments and preparation of the boreholes for subsequent long-term monitoring, experimentation, and observations using remotely operated vehicle or submersible dive expeditions. CORKs are being used in perturbation and monitoring points for single- and cross-hole experiments using a recently developed novel in situ microbiological experimentation system, Flow-through Osmo Colonization Systems (FLOCS; Orcutt et al., 2010, 2011a; also see **www.darkenergybiosphere.org/resources/toolbox.html**).

Expedition 336 also included an enhanced education and outreach program intended to facilitate and communicate the excitement of scientific drilling and exploration to a broad audience, develop educational curricula, and generate products such as photographs, audio/visual media, and web-based materials to help achieve critical outreach goals.

Background

Geological setting

North Pond is an isolated, northeast-trending, ~8 km × 15 km sediment pond located on the western flank of the Mid-Atlantic Ridge at 22°45′N and 46°05′W (Figs. **F1, F2**). This area exhibits normal polarity that has been interpreted as magnetic Anomaly 4 (Melson, Rabinowitz, et al., 1979), suggesting a basement age between 7.43 and 8.07 Ma using the geomagnetic polarity timescale of Cande and Kent (1995). The sediment cover is as thick as 300 m at the southernmost part of the pond. North Pond is bounded to the east and west by basement ridges as high as 2 km. During DSDP Leg 45, two holes were cored with the rotary core barrel (RCB) at Site 395, penetrating the southeastern part of the sediment pond (Fig. **F2;** 22°45.35′N, 46°04.90′W; 4484 meters below sea level [mbsl]). A 93 m thick sediment sequence was cored in Hole 395, consisting of 89 m of foraminifer-nannofossil ooze underlain by 4 m of calcareous brown clays with manganese micronodules (Melson, Rabinowitz, et al., 1979). Basement penetration was 91.7 m (Hole 395) and 576.5 m (Hole 395A); a reentry cone and casing to basement were installed in Hole 395A. The basement lithology at this site is dominated by several units of massive and pillow lava flows (typically several tens of meters thick) that are separated by sedimentary breccia units, which resulted from mass wasting and contain cobbles of gabbro and serpentinized peridotite (Bartetzko et al., 2001; Melson, Rabinowitz, et al., 1979). A peridotite-gabbro complex several meters thick with brecciated contacts was cored in Hole 395 (Arai and Fujii, 1978; Melson, Rabinowitz, et al., 1979; Sinton, 1978).

Several expeditions have revisited Hole 395A for logging operations, packer testing, and borehole fluid sampling, including DSDP Leg 78B (Hyndman, Salisbury, et al., 1984), ODP Leg 109 (Detrick, Honnorez, Bryan, Juteau, et al., 1988), ODP Leg 174B (Becker, Malone, et al., 1998), and the French DIANAUT expeditions (Gable et al., 1992). Temperature and flow logs acquired during Leg 78B indicated rapid fluid flow (~1000 L/h) into Hole 395A (Becker et al., 1984) and low formation pressures, and this flow apparently continued for many years after drilling (Becker et al., 1998; Gable et al., 1992). Despite more than two decades of recharge into and through Hole 395A, the hydrology of the North Pond system has not been significantly affected. Geothermal (temperature and heat flow) surveys indicate that recharge occurs dominantly in the southeastern part of the basin, which is consistent with basement fluid flow generally directed to the northwest (Langseth et al., 1984).

Comparison of lithologic and downhole electrical resistivity logs for Hole 395A suggests a series of distinct basalt flows (Bartetzko et al., 2001; Matthews et al., 1984). Each flow unit is characterized by an uphole decrease in electrical resistivity and an increase in gamma ray counts. Many of the low-resistivity intervals at the tops of the flow units correspond to recovery of cobbles or breccia, although recovery of the uppermost few hundred meters of basement was low. These results indicate that breccias developed between major flow units likely have high present-day permeability. These zones also exhibit high gamma ray counts, suggesting high K and U concentrations indicative of increased oxidative alteration. The correlation between alteration chemistry and permeability indicates that the basalt flow boundaries acted as fluid conduits throughout the hydrological history of the basement at Site 395.

Downhole logging and packer results suggest that permeability at Site 395 decreases below 400 meters subbasement (msb) (Hickman et al., 1984), where temperature increases. In 1998, bulk density, temperature, and spontaneous potential (SP) downhole logs were collected in Hole 395A during Leg 174B (Becker, Malone, et al., 1998; Becker et al., 1998). The SP log is used in the petroleum industry to infer the locations of intervals in a borehole that receive or produce fluids. Deflections in the SP log also correspond to the tops of individual resistivity sequences, suggesting that these thin intervals, interpreted independently on the basis of resistivity and lithologic data to have higher porosity and permeability, are indeed the most hydrologically active. The typical ratio in thicknesses of the most and least hydrologically active sections of this borehole is on the order of 1:10 to 1:100, suggesting that most of the fluid that entered the formation surrounding Hole 395A passed through a small fraction of the exposed rock (Bach et al., 2004; Fisher and Becker, 2000).

During Leg 174B, Hole 1074A was cored near the northwestern margin of North Pond (Fig. **F2**). Temperature and geochemical profiles are diffusive, indicating there is no upward advection of basement fluids through the sediments, even in an area of local high heat flow (Becker, Malone, et al., 1998). This observation is consistent with the hydrologic model of Langseth et al. (1992, 1984), which indicates fluid flow is predominantly lateral beneath all of North Pond and recharge/discharge is taking place through basement outcrops that surround the basin. Most of the seawater recharge in Hole 395A is accommodated by aquifers in the uppermost 300 m of basement. Below this depth, temperature increases (Becker et al., 1998) and borehole fluid chemistry indicates significant chemical exchange with the rocks in the borehole walls (Gieskes and Magenheim, 1992; McDuff, 1984), which indicates a hydrological regime below 300 msb that is less permeable and conducive to seawater circulation.

Site survey data: seismic, bathymetric, heat flow, and sediment coring

Seismic, sediment echo sounding, bathymetry, and heat flow measurements were recorded during R/V *Maria S. Merian* Cruise 11/1 in February/March of 2009 (Villinger and Cruise Participants, 2010). A 12 kHz swath-bathymetry multibeam echo sounding system (Kongsberg EM120) was used to conduct a detailed bathymetric survey. Fourteen seismic lines with spacings between <1 and 3 km were collected across North Pond using a generator-injector gun and a 100 m long, 16-channel streamer. Eleven of these profiles are oriented southwest–northeast and three run southeast–northwest. All heat flow measurements and sediment gravity coring were conducted on these seismic lines. Seismic two-way traveltime was used to estimate sediment thickness. The seismic record is poor at the boundaries of North Pond because the steep slopes of the bounding basement outcrops caused severe side echoes. In addition, it can be difficult to identify the exact basement/sediment interface because the rough basement topography does not produce a clear reflection pattern. Migrating the seismic data improves the imaging, and accurate sediment thicknesses for existing drill holes (395A and 1074B) can be calculated using a sediment velocity of 1700 m/s.

Fourteen gravity cores (up to 9.5 m in length) have been collected from North Pond between 4040 and 4480 mbsl in areas of high heat flow in the northern and northwestern part of the basin. Preliminary interpretation is that the recovered sedimentary sequences represent pelagic sedimentation of clay-size particles interrupted by abrupt deposition of foraminiferal sand layers. The presence of sharp, irregular bottom contacts and normal-graded bedding may indicate that these coarse-grained intervals are the result of gravity flows supplied from the surrounding slopes. Consistent with this interpretation, sand layers are commonly found at the deepest parts of the basin (>4300 mbsl) and are absent in cores retrieved from the less sedimented slopes of the basin.

Oxygen is the terminal electron acceptor in all gravity cores and hence the most sensitive indicator of microbial activity and fluid flow in the North Pond sediments. Dissolved oxygen permeates all of the cores recovered at all coring sites. A number of dissolved oxygen profiles appear to be affected by a deep secondary source of dissolved oxygen, causing them to increase toward the base of the core. Flow variability in the underlying basalt is hypothesized to cause these deeper increases in dissolved oxygen. This affect appears to be greatest in the northern part of the basin, which is why the sites for new subseafloor borehole observatories (CORKs) were located there and not in the Site 1074 area, as proposed in the original drilling proposal.

Scientific objectives

Our objectives for Expedition 336 were to recover sediment and basement cores and to install new CORKs to address two major scientific questions:

1. *Where do deep-seated microbial communities come from?*

Viable, diverse, and distinct microbiological communities occur in deeply buried marine sediments, but the origin of these communities is currently unknown. One possibility is that microorganisms from overlying bottom seawater are a steady source of inoculum that seeds microorganisms (particle attached and free living) to sediments, allowing each sediment layer, no matter how deeply buried, to harbor (in principle) a population that derives from this initial deepwater inoculum. A second possibility is that microbial inoculum is provided by active transport (e.g., by vertical advective transport from the basement [passive transport] or by lateral active transport [swimming] from adjacent, older sediments following redox gradients). The latter hypothesis is consistent with known mechanisms (i.e., swimming by chemotactic response to chemical gradients or advective flow) and would explain how microbial communities persist in such nutrient-limited, deeply buried sedimentary sequences—that is, they evolved very specifically for this niche. However, this mechanism implies that sediments need to be in physical contact for effective inoculum transfer in order for these specialized niches to be exploited. Hence, an isolated sedimentary sequence may be inactive, dormant, or harbor evolutionarily distinct populations of microorganisms compared to sedimentary communities that receive the "ancient inoculum." North Pond is the ideal location to test these opposing hypotheses, which have important mechanistic implications concerning dispersal mechanisms in the deep biosphere and evolutionary consequences for microbial life on Earth. We will analyze the microbial communities in both deep sediments (obtained from cores taken during the expedition) and basement crustal fluids (obtained with the CORKs post-expedition).

2. *What is the nature of the microbial communities harbored in young ridge flanks, and what is their role in the ocean crust weathering?*

In the subseafloor, the extent of direct participation in weathering by extant communities is not clear. Abundant petrographic and geochemical data indicate that oxidative seafloor alteration occurs during the first 10–20 m.y. of crustal age and thereafter slows or ceases. These preliminary lines of evidence suggest that the most reasonable place to search for active subsurface microbial communities is in young ridge flanks

(<10 Ma). Most young ridge flanks lack a sediment cover, which presents difficulty for recovering intact upper ocean crust. One major exception is the Juan de Fuca Ridge flank. However, the high heat flow, rapid chemical reaction rates, and anaerobic conditions of this setting preclude using Juan de Fuca for our principal interest, which is to characterize more average, cold ridge flanks to reveal the role of microorganisms in promoting weathering on a global basis. Chemical reaction kinetics are inhibited at low temperatures, providing a window of opportunity for biological catalysts. The low heat flow ridge flank at North Pond represents an ideal model system for studying biologically mediated oxidative basement alteration. The work will also provide an excellent point of comparison for the studies taking place at the Juan de Fuca Ridge, which represents the warm, sedimented end-member in the global spectrum of ridge flanks.

Operations plan

The initial operations plan for Expedition 336 anticipated installation of subseafloor borehole observatories (CORKs) at three sites (DSDP Hole 395A and prospectus Sites NP-1 and NP-2), with basement recovery at Sites NP-1 and NP-2 and sediment coring at all three. The initial plan (detailed in the Expedition 336 *Scientific Prospectus*; Edwards et al., 2010) had to be modified because of unforeseen events. In adjusting the operations plan, the overall strategy was tailored to achieve three objectives (ranked in order of decreasing priority): (1) install CORK observatories, (2) recover and log basement, and (3) recover sediments.

Operations began in Hole 395A, where the old-style CORK and thermistor string were removed before logging and depth-checking to 610 mbsf, introducing minimal amounts of surface seawater. A summary of logging results in Hole 395A is shown in Figure **F3.** We then attempted to install a new multilevel CORK with downhole and surface experiments, as illustrated in Figure **F4.** The final installation step failed when the wellhead was broken off as we tried to unlatch the CORK running tool, so a new hole (U1382A) was set up and drilled 50 m west of Hole 395A to install a shallow, single-level CORK observatory. Hole U1382A was drilled to 210 mbsf, penetrating 90 m of sediment and 120 m of basement. After coring was completed, 105.6 m of open borehole was logged (Fig. **F5**), and the hole was sealed with a 189 m long CORK completion string (Fig. **F6**).

We then planned to install the deep (500 msb) CORK observatory in the northern part of North Pond at prospectus Site NP-2. Our strategy was to set up the hole with 20 inch casing in the sediment cover, followed by 16 inch casing in upper basement. We then planned to deepen the hole with a 14.75 inch tricone bit to install 10.75 inch casing to ~140 msb. This strategy had to be changed, however, when Hole U1383B, located 6 km north-northeast of Hole U1382A, was lost as a result of the destruction of the tricone bit. The configuration of Hole U1383B is shown in Figure **F7.** Although this hole could not be deepened, the seafloor infrastructure and open-hole basement section are entirely available for an observatory installation. A new hole, U1383C, was spudded into basement and cased with 10.75 inch casing to 60.4 msb. This hole was then RCB cored to 331.5 m, logged (Fig. **F8**), and installed with a three-level CORK (Fig. **F9**).

With our basement objectives largely achieved, we cored sediment with the advanced piston corer (APC) in the vicinity of the CORK observatories, drilling two holes at Site U1383, one at Site U1382, and one at Site U1384 (in the prospectus Site NP-1 area). We moved between locations without retrieving the drill string, APC cored to basement, and then extended core barrel (XCB) cored into basement for ~1 h. These cores were the focus of intensive microbiological and geochemical sampling.

Hydrologic (drill string packer) testing

In situ hydrogeologic testing is essential for quantifying crustal properties (transmissive and storage) that control ridge-flank hydrothermal circulation. We planned to use a drill string packer for hydrologic testing, which is reliable and relatively easy to integrate as part of a comprehensive program of basement drilling, sampling, and experiments. Tests in multiple depth intervals were to be conducted to discern the difference between test results at two depths and to quantify differences in hydrologic properties in discrete depth intervals.

The drill string packer was part of a bottom-hole assembly (BHA) that is compatible with logging so that a separate pipe trip was not required. Wireline logs were run before packer testing to assist with identifying zones suitable for packer element inflation (massive and in gauge). Tests followed the standard approach: (1) inflate and set the packer at the deepest setting point, (2) complete testing at that depth, and (3) deflate the packer, raise it to a shallower depth, and repeat the testing. The difference between test results at two depths can be used to quantify differences in hydrologic properties in discrete depth intervals. Tests are generally repeated at each testing depth, using two or more different pumping rates, to verify test response and formation properties.

Pressure data were generally collected using autonomous downhole pressure gauges that were suspended below a go-devil that was dropped into the packer when it was positioned at depth in the borehole. These gauges were recovered after the complete testing sequence had been run. The shipboard Rig Instrumentation System was used to record key pumping parameters: time, stroke rate, total number of strokes, BHA depth, and standpipe pressure, which is a backup for downhole pressure records.

Logging/Downhole measurements

Downhole measurements during Expedition 336 focused on characterizing crustal physical properties and defining structural and lithologic boundaries as a function of depth. In addition, wireline logging data were compared to results of laboratory analyses of discrete samples to help delineate alteration patterns, fracture densities, and structural orientations and determine how these correlate with fluid flow. These measurements complement core measurements by determining the thickness and structure of lithologic units in intervals where core recovery is poor. These logs were also critical for both shipboard hydrologic (packer) tests as well as for the precise depth placement of the CORK experiments.

Wireline tool strings were deployed in all basement holes and provided measurements including temperature, natural gamma ray, density, porosity, resistivity, sonic velocity, and microresistivity. Descriptions of the wireline tools and their applications are available at **iodp.ldeo.columbia.edu/TOOLS_LABS/index.html.**

We deployed adapted combinations of tool strings, including probes to measure borehole caliper, natural gamma ray (Hostile Environment Natural Gamma Ray Sonde), temperature (Modular Temperature Tool), and resistivity (Formation MicroScanner) (the latter not in Hole 395A). Additionally, we employed the Deep Exploration Biosphere Investigative tool (DEBI-t) in a tool string. This tool was specifically designed and built for Expedition 336 to image the natural fluorescence of microbial communities exposed on the borehole wall.

Summary of operational achievements

Our achievements in meeting our operational goals are summarized below:

1. *Drill a basement hole to ~565 mbsf at prospectus Site NP-1, core the lowermost 200 m, log the hole, and install a multilevel CORK.*

We drilled a 331.5 m deep hole (U1383C) in the NP-2 area and cored/logged the lowermost ~260 m. A summary of the coring and logging results for Hole U1383C is presented in Figures **F10** and **F11.** Further details will be provided in the "Site U1383" chapter of the Expedition 336 *Proceedings* volume. A three-level CORK observatory was installed in Hole U1383C, with packers centered at 56, 142, and 196 mbsf (Fig. **F9**). Hole U1383B was penetrated to 89 mbsf and was equipped with a reentry cone and remotely operated vehicle (ROV) landing platform for future observatory science objectives.

2. *Drill a basement hole to ~175 mbsf at prospectus Site NP-2, core ~70 m of the basaltic crust, conduct hydrologic tests and wireline logging, and install a single-level CORK.*

A shallow, single-level CORK was installed in Hole U1382A, and this CORK will sample/monitor upper basement between 101 and 210 mbsf. A summary of the coring and logging results for Hole U1382A is presented in Figure **F12.** Further details will be provided in the "Site U1382" chapter of the Expedition 336 *Proceedings* volume.

3. *Recover the existing CORK in Hole 395A, conduct downhole wireline logging, and install a multilevel CORK.*

The CORK installed in Hole 395A during ODP Leg 174B, including the entire thermistor string, was successfully recovered. The hole was successfully logged with the new in situ deep ultraviolet fluorescence tool for detecting microbial life in ocean floor borehole (the DEBI-t); other logging data obtained include spectral gamma ray and temperature. A new three-level observatory was lowered into the seafloor; however, the CORK wellhead broke off, which will preclude our ability to conduct any downstream wellhead operations. Nevertheless, there is no conclusive evidence that the downhole portion of the observatory operations was significantly compromised, so a 4 y experimental run followed by downhole experiment/instrument recovery is still planned. Options for future use of the instrumentation in Hole 395A will be explored during upcoming ROV dives.

4. *APC core the thin sediment cover in single holes at four sites (prospectus Sites NP-1 and NP-2, Hole 395A, and Site 1074).*

ACP coring of sediments at Sites U1383 (prospectus Site NP-2; two holes), U1382 (near Hole 395A), and U1384 (prospectus Site NP-1) was achieved, and XCB coring retrieved short sections of the sediment/basement interface from all locations. The sediments comprise nannofossil ooze, foraminiferal sand, and brown clay; Site U1382 also features layers with basalt and peridotite debris. The sediments were heavily sampled for microbiological and pore water analyses.

Principal results

Site 395

Investigating coupled geochemical and microbial processes in active aquifers in the upper oceanic crust is the main science goal of Expedition 336, and the primary objective was initiating multilevel subseafloor borehole observatory (CORK) experiments. We planned to install one observatory in the 664 m deep Hole 395A in the southeastern part of North Pond. Hole 395A was drilled during DSDP Leg 45 in 1975–1976, was logged repeatedly, and was equipped with a first-generation CORK in 1997 during ODP Leg 174B (Becker et al., 1998). Hole 395A is located in an area of exceptionally low conductive heat flow (Langseth et al., 1992), which results from the cooling of uppermost basement by cold seawater that recharges basement and is inferred to flow underneath the sediment cover in a northerly direction.

At the beginning of our operations at Site 395, the old Leg 174B CORK (including the entire 603 m long internal string with thermistors, a data logger, and pressure sensors) was successfully pulled out of Hole 395A and secured on board. The pressure and temperature data were downloaded, the thermistors were cut out of the string, and sections of the string were sampled for microbiological analyses. Further microbiological samples were obtained from the CORK remotely operated vehicle (ROV) platform and the CORK wellhead elements. The hole was then logged with a new in situ deep ultraviolet (UV) fluorescence tool for detecting microbial life in ocean floor boreholes—the Deep Exploration Biosphere Investigative tool (DEBI-t). Other logging data obtained include spectral gamma ray and temperature. A rock ledge in the borehole at ~180 mbsf had to be bridged by lowering the logging bit to ~198 mbsf, but then an open-hole section of 405.7 m was logged (total depth = 603.5 m). The lowermost ~50 m of the hole was not logged because Leg 174B found it filled with rubble. The logging results are consistent with the data obtained by Bartetzko et al. (2001) and allow the distribution of massive basalt, pillow basalts, altered lava flows, and rubble zones (sedimentary breccia and hyaloclastite) to be distinguished.

A 530 m long multilevel CORK was assembled to perform long-term coupled microbiological, biogeochemical, and hydrological experiments. Assembling the observatory entailed preparing osmotically driven fluid samplers, microbial incubation experiments, seven temperature sensors, and two oxygen sensors. Packers at 111, 149, and 463 mbsf were installed to isolate the borehole into three intervals characterized by different thermal and fluid flow regimes. Umbilicals containing fluid sampling lines attached to the outside of the CORK casing were designed to reach depths of 122, 220, 430, and 506 mbsf. OsmoSamplers for fluid geochemistry and microbiology were lowered on Spectra rope inside the slotted or perforated CORK casing to sample four intervals: 118–140, 240–261, 415–438, and 499–527 mbsf. The CORK wellhead was instrumented with sensors for monitoring pressures in the four zones isolated by packers and with OsmoSamplers for retrieving fluid samples from the lowermost zone.

The assembly and installation proceeded well until the CORK head broke off during the final step of releasing the CORK running tool. The CORK head experienced forces that bent the wellhead and severed its 5 inch pipe ~4 m below the top of the reentry cone. 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, sensors, and experiments in the future. 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 diameter, 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 actually inflated; however, no data suggest that the packers did not inflate as intended either. A plan is being formulated to recover the downhole instrument string in 4 y with an ROV.

Site U1382 (basement)

Hole U1382A was drilled 50 m west of Hole 395A at 22°45.353′N, 46°04.891′W, in 4483 m water depth. The primary objective for Hole U1382A was to install a CORK to perform long-term coupled microbiological, biogeochemical, and hydrological experiments in uppermost basaltic crust in this area of very low conductive heat flow. Coring and downhole logging of basement were also conducted.

After the reentry cone with 53 m of 16 inch casing was jetted in, the hole was deepened by drilling with a 14.75 inch tricone bit to 110 mbsf without coring. Basement was encountered at 90 mbsf, and 3 m of basement was penetrated in 30 min. The interval from 93 to 99 mbsf was drilled very quickly and is inferred to have been sediments; however, the underlying formation to 110 mbsf was drilled slowly (2–3 m/h) without significant torque. Casing (10.75 inch) was installed and successfully cemented to 102 mbsf. Rotary core barrel (RCB) coring recovered basement from 110 to 210 mbsf (Cores 336-U1382A-2R through 12R). In total, 32 m of core was retrieved, with recovery rates ranging from 15% to 63%. This succession resembles the lithostratigraphy encountered in DSDP Holes 395 and 395A and provided excellent sampling material for various microbiological and petrologic studies.

The shipboard petrologists divided the core into 8 lithologic units, comprising 17 subunits. Major unit boundaries are defined by contacts between massive and pillowed flows and interlayered sedimentary units. Each major lava flow unit consists of several cooling units, which are recognized by glassy or variolitic margins or changes in grain size. Results from thin section studies reveal a large range of grain sizes (glassy to medium grained) and diverse textures (aphanitic to subophitic or intersertal). Basalts are either aphyric or plagioclase-olivine-phyric and have <3% vesicles. Phenocryst contents range up to 25%, with plagioclase being more abundant than olivine. All of the basement volcanic rocks recovered from Hole U1382A are affected only by low-temperature alteration by seawater, manifesting as replacement of groundmass and phenocrysts, vesicle filling, glassy margin replacement, and vein formation with adjacent brown alteration halos. Chilled margins often show advanced palagonitization, which develops as blotchy alteration texture following the primary variolitic texture of the mesostasis. The extent of alteration ranges up to 20%, with clay (smectite and celadonite) being the most abundant secondary phase, followed by Fe oxyhydroxides and minor zeolites and carbonates. The recovered section has between 13 and 20 veins/m, with vein thickness being generally <0.2 mm. A sedimentary unit in Cores 336-U1382A-8R and 9R features a variety of clasts, including plutonic and mantle rocks. The peridotites are weakly serpentinized harzburgites and lherzolites with a protogranular texture. The intensity of deformation of the gabbroic lithologies ranges from undeformed to mylonitic. Minor cataclastic deformation of the peridotites has led to the development of carbonate-filled vein networks, along which the rocks have been subjected to oxidative alteration, resulting in the breakdown of olivine to clay, oxide, and carbonate.

Physical property measurements reveal typical *P*-wave velocities for these lithologies and a correlation between sonic velocity and porosity of the basalt. Elevated potassium and uranium concentrations in the oxidatively altered part of the core were revealed by natural gamma radiation core scanning. Thermal conductivity also reflected the typical values associated with basalt and peridotite and showed small variations with depth.

Whole-rock geochemistry analyses reveal systematic differences in compositions between aphyric and porphyritic basalt, which are due to plagioclase accumulation in the porphyritic basalt. The aphyric basalts show a liquid line of descent, which is controlled by the fractional crystallization of olivine. As the extent of alteration increases, loss on ignition values and potassium concentrations also increase. Immobile trace element ratios (Zr/Y and Ti/Zr) indicate that parental magma compositions for the basalts above and below the sedimentary unit are different from each other. Petrographically and geochemically, the basalts correspond to the uppermost lithologic units identified in Hole 395A. Likewise, a sedimentary unit with varied plutonic and mantle rocks was also observed in Hole 395A.

A primary objective of basement coring was to obtain samples for microbiological analysis. We collected 46 hard rock and 2 sediment whole-round samples for these studies (11% of core recovered). Samples were preserved for ship-based (deep UV fluorescence scanning, culturing and enrichment, and fluorescent microsphere analysis) and shore-based (DNA and RNA analysis, shore-based fluorescence in situ hybridization, cell counting analysis, and isotopic analysis) studies. Generally, 1–3 microbiology hard rock samples were collected from every core section. Hard rock samples span a range of lithologic units, alteration states, and presence of chilled margins, and some contain veins or fractures. Additionally, a few recovered plastic bags that held the fluorescent microsphere solutions in the core catcher were collected as a contamination checks via DNA analysis.

An open-hole section of 105.61 m was logged over a period of ~19.5 h with two tool strings (the adapted microbiology combination I [AMC I] and the Formation MicroScanner [FMS]–Hostile Environment Natural Gamma Ray Sonde [HNGS]). Downhole log measurements include natural total and spectral gamma ray, temperature, density, electrical resistivity, electrical images, and deep UV-induced fluorescence (acquired with the new DEBI-t). The borehole remained in good condition throughout logging, and no obvious tight spots were encountered in open hole. Integration of core and log measurements and observations showed excellent correspondence between potassium concentrations provided by shipboard natural gamma radiation, the spectral gamma ray logging tool, and whole-rock geochemical analyses. FMS data were combined with images of the external surfaces of whole-round cores. Prominent veins with alteration halos in cores from the massive flows can be matched up with fractures in the FMS images. Also, logging results constrain the depth of the peridotite interval from 165 to 167 mbsf (based on density and low K/U ratios).

Downhole hydrologic (packer) tests failed, because ship heave up to 3 m prevented the packer from sealing in the casing for more than 10 min.

A CORK to monitor and sample a single interval in uppermost basement was successfully installed in Hole U1382A. The 210 m deep hole was sealed with a 189 m long CORK completion string with nine external umbilicals and a retrievable internal instrument string. The umbilicals include one for pressure monitoring, two for microbiological sampling, and six for fluid sampling. The retrievable internal instrument string comprises several osmotic pump-driven samplers for basement fluids and microorganisms as well as enrichment experiments, an oxygen probe, and a thermistor with data recorder. The samplers and probes extend from 152 to 174 mbsf and are kept in position by a 150 lb sinker bar at 177 m. A pressure gauge and a fast-pumping OsmoSampler are situated in the wellhead and monitor/sample fluids from 161 mbsf.

Site U1383 (basement)

Site U1383 (prospectus Site NP-2) is located 5.9 km northeast of Site U1382 in an area of elevated conductive heat flow in 4414 m water depth. The primary objective at Site U1383 was to install a multilevel CORK for long-term coupled microbiological, biogeochemical, and hydrological experiments in uppermost basaltic crust. Basement coring, downhole logging, and hydrologic experiments were also planned.

Hole U1383B at 22°48.1328′N, 46°03.1556′W, was prepared for drilling 500 m into basement by installing a reentry cone with 20 inch casing extending to 35 mbsf. We then prepared the hole for 16 inch casing by drilling an 18.5 inch hole to 68 mbsf; the sediment/basement interface is at 53 mbsf. After installing and cementing the 16 inch casing to 54 mbsf, we started to prepare the hole for 10.75 inch casing by drilling a hole into basement with a 14.75 inch tricone bit. We decided to abandon

Hole U1383B after this tricone bit failed at 89.8 mbsf, resulting in large parts of the bit being left in the hole. Although we did not choose to deepen this hole, it remains a viable CORK hole because it has a completely functional reentry cone and casing system with ~35 m of accessible basement. An ROV landing platform was therefore installed in the reentry cone to facilitate future ROV operations, which will include installation of an instrumented plug in Hole U1383B.

Hole U1383C was started at 22°48.1241′N, 46°03.1662′W, at the site of the original jet-in test, 25 m southwest of Hole U1383B. The primary objective was installing a multilevel CORK in the uppermost ~300 m of basement. The ultimate configuration of the CORK in Hole U1383C was to be determined by the depth of basement penetration and the downhole logging results. A reentry cone with 16 inch casing was installed to 34.8 mbsf, and a 14.75 inch hole was drilled to 69.5 mbsf for the 10.75 inch casing string. The sediment/basement interface was encountered at 38.3 mbsf. After cementing the 10.75 inch casing at 60.4 mbsf, drilling in Hole U1383C proceeded with an RCB bit from 69.5 to 331.5 mbsf. From this 262 m long interval, 50.3 m of core was recovered (19.2%). Rocks are glassy to fine-grained basalts with variable phenocryst (plagioclase and olivine) contents. Three major lithologic units were distinguished on the basis of primary texture and phenocryst abundance. Down to 127 mbsf, the core consists of microcrystalline to fine-grained, sparsely plagioclase-phyric basalt with abundant glassy margins and numerous intervals of hard interflow limestone. From 127 to 164 mbsf, massive plagioclase-olivine-phyric basalts occurs, occasionally hosting limestone (with and without basalt clasts) as fracture fill. Below 164 mbsf, glassy to variolitic to cryptocrystalline basalts (most likely pillow flows) predominate, and limestone is largely missing. Each of these three main lithologic units is divided into numerous subunits on the basis of hyaloclastite layers and rare tectonic breccias. The overall abundance of glass is noticeably greater than that in Hole U1382A, and the extent of palagonitization ranges from weak to moderate. Basalts are avesicular to sparsely vesicular and show vesicle fills of clay, zeolite (mainly phillipsite), calcium carbonate, and Fe oxyhydroxide. Brownish alteration halos commonly track veins filled with clay or carbonate and zeolite. Within Unit 3, a gradational change from glassy, to variolitic with abundant hyaloclastite layers, to more massive microcrystalline, to fine-grained basalt with rare glassy margins can be observed.

Although the hyaloclastites are noticeably palagonitized throughout the hole, the extent of background alteration appears to decrease downsection. Vein densities average 33 veins/m and increase somewhat downsection to 50 veins/m. Zeolite veins are abundant in the upper section of the drilled interval, whereas carbonate veins predominate in the lowermost part. Sparse vesicles are filled with zeolite and clay.

Physical property measurements reveal tight correlations between sonic velocity, density, and porosity of the basalt. These correlations reflect changes in physical properties as a result of low-temperature alteration. In basalts with up to 40% alteration, *P*-wave velocities and bulk densities as low as 4750 m/s and 2.43 g/cm^3 were recorded. These most altered basalts also show exceptionally high porosities (up to 16.6%). Despite the locally high alteration intensity, natural gamma radiation core scanning reveled fairly low average potassium and uranium concentrations (e.g., 0.19 ± 0.05 wt% K). Fresh basalts show physical properties and K concentrations typical for mid-ocean-ridge basalt.

Whole-rock geochemistry shows that basalts from Units 1 and 2 systematically differ in Zr/Y and Zr/Ti ratios from basalts from Unit 3. The compositional variability in the different units is primarily due to fractionation of olivine, but some trends (gain of K, loss of Mg) are also related to increased alteration intensity. The porphyritic basalts do not show the distinct plagioclase accumulation signature revealed in similar basalts from Holes U1382A and 395A. Correlations between Site U1383 and Sites U1382 and 395 based on geochemical composition cannot be made for individual flow units, indicating that the sites belong to different volcanic centers that were fed by mantle sources with variable compositions.

Hard rock samples for microbiological analysis were collected from every RCB core from Hole U1383C. Roughly 12% (6.11 m total) of core recovered from Hole U1383C was taken as whole-round samples from the core splitting room and dedicated to microbiological analysis. The 79 hard rock microbiology samples span a range of lithologic units, alteration states, and presence of chilled margins, and some contain at least one vein or fracture. Additionally, a few background contamination samples were collected for shore-based DNA analysis, including recovered plastic bags that held the fluorescent microsphere solutions in the core catcher.

Samples recovered were preserved for shore-based DNA and RNA analysis, shore-based fluorescence in situ hybridization and cell counting analysis, ship-based culturing and enrichments, shore-based isotopic analysis, and ship-based fluorescent microsphere analysis. Microspheres were used during all coring operations to help in evaluating core contamination. The enrichment and cultivation experiments initiated include carbon fixation incubations; carbon and nitrogen cycling experiments;

enrichments for methanogens, sulfate reducers, sulfide oxidizers, and nitrate-reducing iron-oxidizing bacteria; and enrichments for heterotrophic metabolisms.

Deep UV scanning of hard rock materials was used to identify sample regions with concentrations of biomass and organic material. At this time, the exact biomass density on the sample is unknown, but studies are under way to investigate this.

Wireline logging data include natural total and spectral gamma ray, density, compressional velocity, electrical images, and deep UV-induced fluorescence (acquired with the new DEBI-t) of a 274.5 m section of open hole. Lithologic Unit 1 is characterized by variable caliper, density, and sonic velocity values. Gamma ray intensities are generally low but increase in the bottom part of the unit. Lithologic Unit 2 has a uniform caliper and high densities and apparent sonic velocities and shows high-resistivity massive flows with fractures in the FMS images. The upper section of lithologic Unit 3 (153–166 mbsf) is characterized by decreases in density, apparent resistivity, and velocity and an increase in gamma ray intensity. This interval corresponds to thin flows with interpillow/flow sediments and tectonic breccias. From 166 mbsf to the bottom of the hole, the logging data reveal fairly uniform values for density, velocity, and apparent resistivity. Areas with peaks in gamma ray intensity correspond to intervals with abundant hyaloclastite in the recovered core (in particular around 175 mbsf and from 220 to 250 mbsf).

Drill string packer experiments were attempted in Hole U1383C to assess the transmissivity and average permeability of open-hole zones bounded by the bottom of the hole at 331.5 mbsf and three different packer inflation seats at 53, 141, and 197 mbsf. The packer experiments were not successful.

In preparation for the CORK observatory, Hole U1383C was cased through the 38.3 m thick sediment section with 10.75 inch casing to a depth of 60.4 mbsf and through a 14.75 inch rathole to 69.5 mbsf. After the hole was RCB cored to 331.5 mbsf and cleaned in five wiper trips, there was no noticeable fill, which was verified during logging. The CORK screens and downhole instrument string targeted three zones, selected mainly on the basis of recovered core and the caliper log. An upper zone extends from the combination packer and landing seat at 58.4 mbsf in the casing to 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 extends to an open-hole packer and landing seat at 199.9 mbsf. Within this section the screens are centered at 163 mbsf, with the slotted casing extending from 146 to 181 mbsf. The deep zone reaches to the bottom of the hole (331.5 mbsf) with miniscreens centered at 203 mbsf. The miniscreens are connected to the wellhead by five umbilicals with stainless steel or Tefzel internal tubing that are strapped to the outside of the casing. The downhole tool string consists of six different OsmoSampler packages, two dissolved oxygen sensors and recorders (one in the shallow zone and one in the middle zone), two miniature temperature recorders, sinker bars, sealing plugs, and interspersed sections of ⅜ inch (0.95 cm) spectra line. The wellhead is instrumented with a pressure logger monitoring each of the three horizons and bottom seawater and a fast-flow OsmoSampler with both standard and microbiological sampling packages. The CORK extends to 247.6 mbsf, yet leaves the bottom portion of the hole open for future logging and access (247.6–331.5 mbsf).

Sediment and basement contact coring (Holes U1383D, U1383E, U1382B, and U1384A)

This section summarizes the results of advanced piston corer (APC) sediment coring and extended core barrel (XCB) coring of the sediment–basement transition at Sites U1383 (prospectus Site NP-2), U1382 (near Hole 395A), and U1384 (prospectus Site NP-1).

In Hole U1383D, 44.3 m of sediment was cored, of which the lowermost 1 m was XCB cored through basalt and limestone-cemented breccia (0.76 m of basement was recovered). At nearby Hole U1383E, 44.2 m of sediment and 1 m of basaltic basement was cored (0.3 m of basement was recovered). The basalts are aphyric and slightly to moderately altered. They are distinct from the uppermost basaltic flow that was RCB cored in Hole U1383C and hence represent a different lithologic unit.

Hole U1382B was drilled midway between Holes 395A and U1382A. A total of 90.0 m of sediment was APC cored, and another 8.8 m was cored with the XCB, recovering a piece of basalt and countless millimeter- to centimeter-sized pebbles of completely altered plutonic and ultramafic rocks at the basement/sediment interface. These rocks are interpreted to be part of the sedimentary breccia overlying the massive basalt of Unit 1 cored in Hole U1382A.

Coring in Hole U1384A recovered 93.5 m of sediment overlying 0.58 m of basalt and limestone-cemented breccia. The basalts are aphyric and sparsely vesicular with glassy to variolitic to microcrystalline groundmass. They are between 3% and 10% altered and display brown alteration halos along clay veins and fractures.

The sediments at all sites consist of foraminifer nannofossil ooze with layers of foraminiferal sand. The bottom several meters of the sedimentary pile are brown and appear rich in clay. Sediments from Hole U1382B show moderately rounded rock fragments concentrated in layers or dispersed in the ooze. These fragments range from coarse sand to pebble in grain size and consist of serpentinized mantle peridotite, gabbro, troctolite, and basalt. Both XCB cores from Hole U1382B also contain coarse sediment with predominantly serpentinite clasts, including soapstone and talc-tremolite schist. The occurrence of these rock fragments is consistent with the polymict sedimentary breccia recovered during basement drilling in Holes 395A and U1382A. The deformed and metasomatized lithologies encountered in Hole U1382B corroborate the hypothesis that this material was transported to the Site U1382 area in North Pond by mass wasting events and that its source is an oceanic core complex, probably in the southern rift mountains. Layers of foraminiferal sand are abundant in all holes, and many show erosional bases and normal-graded bedding, suggesting that they represent deposits of turbidity currents.

Each of the four holes cored was intensively sampled for microbiology and interstitial water analyses. The sampling program was similar for each hole. In total, we collected 167 whole-round samples for interstitial waters and 691 whole-round samples for microbiological analyses. Sampling density was increased in the bottom sections. Pore waters in these basal sediments are dominated by diffusion of components from the basement fluids into the sedimentary pile, and they allow estimation of basement fluid compositions by extrapolation. Whole-round cores were preserved for shore-based molecular analysis to provide a detailed description of the microbial community. Ship-based enrichment cultures were established to enrich for multiple metabolic functional groups. These cultures will be analyzed on shore for both metabolic activity and community composition. Sediment sections remaining after whole-round sampling were analyzed for oxygen using optodes. Hard rock samples were sectioned and allocated following previous strategies established during the hard rock drilling phase of the expedition. Multiple basalt samples were provided for RNA/DNA, geochemistry, and culture analysis.

An extensive, high-resolution physical property data set was obtained for all holes. This data set includes whole-round, split-core, and discrete measurements of magnetic susceptibility, velocity, density, porosity, natural gamma ray, and resistivity.

Atmospheric and surface-water microbiology studies

Investigations of atmospheric and surface-water microbiology were conducted by a shipboard atmospheric microbiologist during Expedition 336 for a project titled "Long-range transatlantic transport of microorganisms in clouds of African desert dust: a study of atmospheric microbiology, chemistry, and the influence of desert dust on surface-water microbial ecology."

Atmospheric samples were collected in transit and while on-station daily from 19 September to 11 November 2011 (54 sample days). As a result of incubation-period constraints, the resultant report included data collected from 19 September to 1 November (44 sample days). These data indicate that atmospheric particulate matter moving over the Atlantic Ocean from Europe and Africa carries culturable microorganisms and that colony-forming unit concentrations in these air masses correlate with particulate concentrations. Further, these data demonstrate a "fertilization affect," where surface-water prokaryote concentrations correlate to near-surface atmospheric particulate concentrations. Numerous episodes of African dust presence occurred in the near-surface atmosphere over the period of the study. Many of the high-volume membrane filter particulate/aerosol loads produced dark and light orange coloration similar to that of desert surface soils of the Sahara and Sahel. These samples will be evaluated postexpedition for chemical and biological composition. Dust deposition was so heavy at times that dust particles pooled into naturally occurring wind traps located on the roof of the R/V *JOIDES Resolution,* which enabled collection into resealable plastic bags. Particle count data and the strength of correlations with surface-water communities and atmospheric communities will be evaluated again after chemical analyses of the high-volume filters. These analyses will be needed to verify sources and to determine if the particulate loads on the light gray to dark gray filters are an artifact of diesel exhaust or biomass burning in Europe or Africa. These data, along with data such as wind speed, wind direction, and ship orientation, will be valuable in determining which air masses and their sources influenced these communities. Obviously, additional (shore-based) data and more careful interpretation are needed to accurately evaluate the true extent of the observed relationships outlined here and for those yet to be determined. Additional shore-based studies will include the identification of isolates and non-culture-based studies to determine community composition and the reaction of various species of bacteria to surface-water dust deposition.

Operations

Port call and transit to North Pond

Prior to Expedition 336, the *JOIDES Resolution* was berthed in Curaçao. Although Expedition 336 officially did not begin until 15 September 2011 in Barbados, all of the subseafloor borehole observatory (CORK) hardware and experiments were sent to Curaçao in advance of the expedition. In addition, a few scientists and engineers boarded the ship in Curaçao and used the 2-day transit to Barbados to start preparing the CORK observatories and a new in situ tool for detecting microbial life in ocean floor boreholes—the Deep Exploration Biosphere Investigative tool (DEBI-t).

Expedition 336 officially began with the first line ashore in Bridgetown, Barbados, at 0948 h on 15 September. Other than personnel transfers, only minor port call activities were planned; these began immediately after the early arrival of the ship. On Day 2 of the port call, the remaining scientists, engineers, technical staff, and crew boarded the ship in Barbados on 16 September. The vessel was then secured for sea and departed Bridgetown, Barbados, at 0742 h on 17 September. The pilot departed the vessel at 0812 h, and the vessel started the 986 nmi transit to Hole 395A. Times are presented in ship local time, which is Universal Time Coordinated (UTC) – 3 h for all drilling operations during this expedition. We arrived over Hole 395A at 2330 h on 20 September, having averaged 11.4 nmi/h. At 0012 h on 21 September, the vessel was placed in dynamic positioning mode over Hole 395A and operations began. All operational tasks, along with task start and end times, are listed in Table **T1.**

Hole 395A

Operations for Hole 395A began by picking up the CORK pulling tool for the Hole 395A CORK and making it up to a pony drill collar. The rest of the bottom-hole assembly (BHA) was attached and the drill string was tripped to just above the seabed. At 2166 meters below rig floor (mbrf), tripping operations were temporarily halted to install the vibration-isolated television (VIT) camera system to begin running the subsea camera. It quickly became apparent that there was a problem with the sonar system on the camera system, and it had to be retrieved for repair. Tripping continued to 2824 mbrf, where operations were again suspended to install the camera system. Tripping operations resumed as the camera system was carefully lowered toward the seafloor. Periodically, the camera system winch was stopped and the hoisting function was engaged. At ~3700 mbrf, it became clear that the winch did not have sufficient power to retrieve the camera system. Drill pipe tripping operations continued while mechanics and engineers diagnosed the winch problem. When tripping operations were complete, the top drive was installed. However, from 1630 h on 21 September until 1630 h on 22 September, diagnostics and repair were performed on the camera system winch. After both the hydraulic motor and the hydraulic pump were changed, the winch was restored to working condition. The camera system was deployed and lowered carefully to the seafloor. The Hole 395A reentry cone and CORK were located, and the pulling tool was lowered over the CORK and latched on. The CORK was then picked up ~7 m, and the core line was deployed to retrieve the data logger, which was attached to a 600 m long thermistor string. After running an overshot three times and attempting to jar onto the top of the data logger, attempts to pull the thermistor string were suspended and the CORK was pulled to the surface along with the data logger/thermistor string. After the CORK was landed and secured in the moonpool, the recess where the top of the data logger was located was cleaned and the overshot was installed. The data logger was then jarred loose and all 600 m of the thermistor string, including 10 thermistors and the sinker bar, was removed at the rig floor. The thermistors were cut out of the string, and portions of the string were sampled for microbiological analysis. A lifting sub was installed on top of the CORK, and it was pulled through the rig floor and then moved to the starboard aft main deck for sampling. Next, the stinger, made up of three joints of 5.5 inch drill pipe, was broken down and laid out for additional microbiological sampling. After the rig floor was cleared of CORK pulling tools, the logging bit and BHA were made up and the drill string was tripped back to seafloor. There was a break in tripping operations after running Stand 70 to deploy the camera system, which was lowered to the bottom, following the bit. Hole 395A was reentered after 19 min of maneuvering. After rigging up to log with the DEBI-t microbiology string (DEBI-t, natural spectral gamma ray, and temperature), the tool string was run into the hole to log Hole 395A. After a 45 min interval to repair the logging winch, the tools were run down into the hole. The logging tool was unable to pass a section of the hole at 4670 mbrf (~186 mbsf), and after repeated attempts the logging string was pulled back to the surface and rigged down. On the basis of previous logs, we inferred that the tool string could not pass this section because it was hanging up on a ledge. After the logging bit was lowered ~21 m below the ledge, we were able to make two runs with the microbiology logging string all the way to the depth objective of 600 mbsf. The logging string was not lowered farther to keep it from landing on the bottom of the hole and causing potential damage to the tools.

After logging was concluded, the drill bit was also lowered to 600 mbsf to check for obstructions and make sure the hole was ready for the new CORK to be installed. When no obstructions were encountered, the string was pulled out of the hole and tripped back to the surface. After the drill line was slipped and cut, assembly of the new Hole 395A lateral CORK (L-CORK) commenced. Around midnight on 26 September, all casing, packers, umbilicals, and the CORK were assembled from the bottom to the top. Although the perforated casing was coated with epoxy to minimize the amount of exposed steel, the coated steel casing was washed with 10% ethanol and painted with an underwater curable epoxy paint. The deepest umbilical screens were deployed at the transition between the drill collars and 5.5 inch perforated casing. Umbilicals were secured with stabilizers (two per joint, with additional stabilizers near packers and screens) and sturdy plastic zip ties. Duct tape was used near packers to secure fittings. The CORK included a combination of steel and fiberglass casing.

The CORK was then lowered ~10 mbrf to purge the pressure lines of air. The CORK was then raised to the moonpool and all of the purge valves were closed. All but one of the valves in the microbiology and geochemistry bays were closed. The open valve was attached to a fast-flow OsmoSampler with both standard and microbiology OsmoSamplers.

Next, we lowered the CORK ~100 mbrf to ensure the camera system sleeve would pass freely over the CORK head. The OsmoSampler instrument string was then assembled and lowered inside the CORK. An attempt to land and latch the top plug was made, but the top plug could not be latched. The CORK was pulled back and landed in the moonpool, and an attempt was made to latch the top plug at the rig floor level. After numerous attempts with two different top plugs, it was finally decided to run the top plug without the latch being engaged; however, the top plug will still work as a gravity seal given the underpressured hydrologic system. When the CORK was pulled to the surface to check the top plug, it was apparent that the lateral valve and flow meter interface had broken off the lateral port on the CORK body. The port was then sealed with a 4 inch cap. It is unclear how the breakage occurred, and this type of valve was deployed successfully on two CORKs during IODP Expedition 327, on the CORK at ODP Site 1200, and on four cement deep-sea delivery vehicles.

Finally, we started lowering the CORK to the seafloor. The camera system was installed during the deployment and lowered to the bottom following the CORK. When the casing string stinger was just above the seabed, the drill string was spaced out for reentry and Hole 395A was reentered at 2003 h. The casing was carefully lowered into

Hole 395A while observing the weight and carefully watching the string at known critical depths in the borehole (based on previous logging data). We then installed the top drive, and the drill string was spaced out to land the CORK. The CORK was apparently landed and over the next 2 h the packers were inflated to 1400 psi according to the inflation procedure and appeared to be holding pressure; however, there was no slight decrease in pressure, typical of the packers inflating. Simultaneously, the camera system was pulled to the surface, and we began putting together the remotely operated vehicle (ROV) platform. At 0800 h the ROV platform had reached the CORK head and released. The release was not smooth, with one side of the platform releasing before the other side. Eventually, the platform completely released and appeared to settle into position. An initial attempt was made to release the running tool from the CORK. After ~45 min of attempting to release the running tool, the camera was retrieved to remove the ROV platform release mechanism and slings in order to allow the camera to get a closer view of the CORK running tool. While the camera was being pulled to the surface, the driller lost the 10,000 lb of overpull that was being maintained on the CORK. At the time, we assumed that the running tool had released. However, when the camera system was lowered back to the seafloor to make a visual check of the CORK installation, we observed that the CORK head was no longer inside the reentry cone but was still attached to the running tool, offset from the reentry cone, and had broken off from the CORK casing below. We retrieved the camera system and drill string. Once the CORK head was back at the moonpool, we began to survey the damage. The CORK head was then raised up to the rig floor, the running tool was removed, and the CORK head was laid down.

The CORK head experienced forces that bent the body through the lower part of the instrument bays. Also, the welded connection between the cup packer subassembly and the L-CORK mandrel had failed ~4 m below the top of the reentry cone. This part of the assembly was a slip fitting that was not welded completely, and little of the connection was welded. When the 5 inch pipe was severed, the Spectra rope and umbilicals were also cut, leaving the downhole tool string in place. On the basis of recovered pieces of casing and the upper end of the remaining 5 inch diameter cup packer subassembly, the 5 inch pipe mandrel near the seafloor is not completely rounded but might not be closed enough to restrict the recovery of the downhole samplers, sensors, and experiments. Several stainless steel tubes likely extend above the cup packers and the top of the 5 inch casing. These tubes may impede recovery of the downhole instrument string.

After the 10.75 inch casing in Hole U1382A was released, a camera survey was made of the Hole 395A reentry system to provide initial data for formulating a plan to recover the downhole instrument string in 4 y with an ROV. The ROV platform was slightly offset from the center of the reentry cone, which made it nearly impossible to see down into the casing where the remainder of the CORK must be located. One of the three sonar reflectors appears to be missing, and some views of the ROV platform, which rests on the cone and is not latched, are suggestive of possible damage to the platform.

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 actually inflated. The seafloor gauge and three formation gauges show very similar slight increases in pressures after the time of attempted inflation, but the similarity to the seafloor gauge could be consistent with a tidal influence without inflation of the downhole packers. However, there may be no evidence that the packers did not inflate based on analysis of the overall volume of the system, inflated packers, packer setting line, drill string, and standpipe in relation to the pressure change observed. The inflated packer volume represents only ~0.1% of the total system volume. Thus, if the overall system is truly closed (i.e., there are no leaks), then no additional pumping would be required to inflate the packers after shutting in the inflation pressure. Also, the pressure change observed during the packer inflation process indicates, assuming a closed system, a volume change equal to ~25 times that of the total volume of the inflated packers. Some of this volume change is most likely leakage in the system. Thus, based on onboard data and initial analyses, we cannot say whether or not the packers are inflated; however, we have no reason to believe that they are not inflated.

Our next objective was to install a CORK in Hole U1382A (50 m west of Hole 395A) to monitor the uppermost basaltic crust. However, this plan was put on hold when we had to leave the area because of Tropical Storm Philippe. After the ship was secured for transit at 0215 h (29 September), we departed Hole 395A and headed to the northeast to avoid the approaching storm.

Engineering summary

The first North Pond objective, pulling the old CORK and thermistor string in Hole 395A, was successfully completed.

The new Hole 395A L-CORK, a design modified to fit DSDP reentry hardware, failed during the final stages of installation in the borehole. Preliminary analysis suggests that the bottom ~0.6 m of the L-CORK became hung up, indicated by damage to the leading edge of the lowermost stabilizer fins. This exposed the L-CORK—designed to be much longer and narrower than usual to fit the DSDP-style cone while still accommodating broader science objectives (i.e., extended height for the bays in which the scientific experiments are placed)—to much higher bending loads than anticipated. It is believed the system cracked at a weld just above the landing seat, which led to even higher loads and bending of the wellhead itself and then eventual failure at the weld. A final report will be prepared once the L-CORK, video evidence, and instrumentation data are further reviewed. However, examination of the recovered old Hole 395A CORK revealed damage to its stabilizer fins in the same area as the new Hole 395A L-CORK that failed. We also observed a noticeable lack of corrosion to its landing ring. Combine this with the inability of the old CORK to be latched-in during Leg 174B and one might assume it also landed high. The old CORK was shorter and more robust, especially in the area just above the landing ring, so it was exposed to much lower stress. As for why the CORKs landed high, we have very little information. One theory is that the interior diameter of the reentry cone's 24 inch transition pipe, through which the stabilizer fins must pass, is narrower than indicated on DSDP engineering diagrams. A final engineering report of this failure will be produced either during or shortly after the expedition, so these initial findings may be revised.

Site U1382

The primary objective for Hole U1382A was to install a CORK to perform long-term coupled microbiological, biogeochemical, and hydrological experiments in uppermost basaltic crust. We installed a reentry cone with 53 m of 16 inch casing, installed 102 m of 10.75 inch casing and cemented it a few meters into the basaltic basement, cored 100 m of basalt below the casing, conducted downhole logging and hydrologic (packer) experiments, and installed a CORK that extends to 188.7 mbsf.

After operations in Hole 395A, we intended to go directly to Hole U1382A (50 m west of Hole 395A). However, we had to leave the area because of Tropical Storm Philippe. After the ship was secured for transit at 0215 h on 29 September, we headed to the northeast to avoid the approaching storm. After Tropical Storm Philippe crossed over the North Pond drilling area, we returned to Hole U1382A at 1224 h on 1 October.

We assembled a reentry cone and 52.98 m of 16 inch casing and lowered it to the seafloor. The trip was temporarily suspended to install the camera system, which was lowered as the pipe trip continued to just above the seafloor. When the casing shoe was just above the seafloor, the top drive was picked up and the drill string was spaced out to start Hole U1382A. We started jetting in the reentry system at 0745 h on 2 October. After 2.75 h the reentry cone mud skirt was landed on the seafloor, verified with the camera system, and the casing running tool was released from the casing. The camera system was then pulled to the surface as the drill string and running tool were pulled back to the rig floor. The BHA was set back, and the running tool was detorqued at the rig floor. The BHA for drilling the 14.75 inch hole was assembled, and the drill string was tripped to just above the reentry system. During the pipe trip the camera system was installed and lowered as the drill string was tripped to bottom. After the drill string was spaced out for reentry, the bit reentered Hole U1382A at 0348 h on 3 October. The top drive was then picked up, and the drill string was run to the casing shoe and spaced out for drilling. The sediment section was drilled without coring from 4547 to 4584 mbrf (53–90 mbsf), at which point basement was contacted. Drilling parameters indicated a fairly hard formation from 90 to 93 mbsf, but drilling proceeded fairly quickly from 93 to 99 mbsf. From 99 to 110 mbsf, drilling parameters again were slow and consistent, indicating a hard formation. We decided to terminate the hole at 110 mbsf to allow 8 m of rathole below 10.75 inch casing that would extend to 102 mbsf. After the hole was conditioned, the bit was tripped above the casing shoe, the top drive was removed, and the drill string was tripped back to the rig floor. Before we could begin rigging up for running casing, we had to slip and cut 115 ft of drill line. We assembled 101.86 m of 10.75 inch casing that included a 14.75 inch outside diameter swellable packer one joint from the top and a casing hanger with a seal ring. We attached the casing running tool, lowered the entire casing string to the seafloor, and reentered Hole U1382A at 1355 h on 4 October. The casing was lowered smoothly into the hole until the last couple of meters, when we had to circulate to help clear the way so it could fully land. After the casing string was fully landed and latched, we cemented it in place with 20 bbl of cement blended with lost-circulation material (Cello-Flake). The cement displacement calculation was made to leave ~15 m of cement inside the casing above the casing shoe. Once we released the casing running tool from the casing hanger (1712 h on 4 October), we pumped seawater through the drill string to clean it of any remaining cement. Before we retrieved the casing running tool, we performed a 30 min survey of the Hole 395A reentry system (50 m to the west). The casing running tool arrived back on the rig floor at 0200 h on 5 October.

Our next step was rotary core barrel (RCB) coring, so we assembled a new C-7 RCB bit (with center bit) with a three-stand BHA and lowered it to the seafloor. A break in tripping pipe occurred around 1030 h to install the camera system, but the system was quickly retrieved when the subsea camera did not work. The pipe trip continued for another hour and was halted again to install the repaired camera system. At 1330 h the drill string was spaced out for reentry, and Hole U1382A was quickly reentered at 1337 h. The bit was carefully run into the hole, and cement was encountered 14 m above the casing shoe (1 m below the expected 15 m). The top drive was then picked up, and the cement was drilled from 88 mbsf to just below the casing shoe that had been positioned at 102 mbsf. We circulated mud to clean the hole, recovered the center bit by wireline, dropped an RCB core barrel, and RCB coring began. The first core on deck, Core 336-U1382A-2R, arrived at 2245 h on 5 October. Coring continued through Core 336-U1382A-12R, which was on board at 2320 h on 7 October. We cored 100 m of section from 110 to 210 mbsf and recovered 31.8 m (32%). After coring was completed, five wiper trips were made from total depth to the casing shoe and back to total depth. The first three trips revealed tight spots and circulation problems. The fourth and fifth trips were made with no evidence of drag or circulation problems, and no fill was found at the bottom of the hole. After hole cleaning and conditioning were completed, the drill string was tripped from the hole, clearing the seafloor at 0729 h on 8 October.

After the bit was back on the rig floor and before logging began, we assembled a stand of 6.75 inch perforated and coated drill collars for the lowermost portion of the CORK installation. We wanted to make up the drill collars before assembling the CORK to make it easier and more efficient to paint with epoxy prior to being deployed. Next, we assembled a logging BHA with a logging bit and the drill string packer, lowered it 64 m into Hole U1382A, and began deploying the logging tools. Logging proceeded with a modified triple combination tool string, with the DEBI-t on the bottom of the string. Log data were collected while the string was lowered to the bottom of the hole. However, while logging upward, the power failed ~20 m below the casing. The tool string was pulled to the surface, and the problem was found to be in the cable head. The cable head was re-terminated, and we decided to run the Formation MicroScanner (FMS)-sonic tool string next. After two successful passes, the lower portion of the FMS (calipers) would not enter the logging bit. After 2 h of working the string up and down, opening and closing the calipers, and pumping seawater, the entire tool string was able to pass through the logging bit; when it was recovered, one of the caliper arms had been damaged. We then spaced out the drill string for the hydrologic (packer) flow test and began attempting to inflate the packer. We made four attempts to set the packer inside the 10.75 inch casing; however, each time, high vessel heave (3 m) caused the packer to deflate, so the experiment was terminated. Before pulling out of the hole and installing the CORK, we lowered the entire BHA (including the deflated packer) until the logging bit reached the bottom of the hole to check that the hole was still open to full depth. We did not encounter any problem intervals and found only ~1.5 m of fill. The drill string was recovered, and the bit was back on board at 1328 h on 10 October. Before we could begin our next operation, we had to slip and cut 115 ft of drill line. We started assembling the CORK at 1500 h on 10 October.

The preassembled 6.75 inch coated, painted, and perforated drill collar stand was picked up and run through the rotary table. Epoxy paint was used to touch up rust marks, and 10% ethanol was used to wipe grease from all exposed steel between the bottom of the casing and the top of the combination packer. After a crossover was installed, we attached 15.35 m of 5.5 inch coated and perforated casing. Miniscreens were attached to the outside of the lowermost perforated 5.5 inch casing joint. The lowermost four miniscreens included one titanium microbiology screen (connected to a Tefzel umbilical) and three stainless steel miniscreens for chemistry (two connected to 0.125 inch stainless umbilicals and one attached to a 0.25 inch umbilical). The next set of four miniscreens, including a second titanium microbiology screen (connected to a Tefzel umbilical) and three stainless steel miniscreens for chemistry (one connected to a 0.125 inch stainless umbilical and two attached to 0.25 inch umbilicals) was placed just above the first set of miniscreens. The stainless steel miniscreen for pressure (connected to a 0.25 inch stainless umbilical) was strapped to the casing immediately above the second set of miniscreens. Crossovers to the 4.5 inch fiberglass casing were installed, and then 44.25 m of 4.5 inch fiberglass casing was made up. Umbilicals from the miniscreens and plastic Kwik-zip centralizers were installed on the outside of the casing as it was run. Next to be installed was a crossover from the fiberglass casing to the landing seat for the instrument string, followed by the joint with the swellable and inflatable packers. Umbilicals were terminated and connected to the bottom and top of the combination packer. Above the packers, ~91.01 m of uncoated and unperforated 4.5 inch steel casing was run, followed by the CORK head. All pressure and sampling lines were connected to the bottom of the CORK. It took us 10 h to complete assembly, and the bottom of the CORK string extends to 188.7 mbsf.

Our next step was to assemble and install the OsmoSampler string into the CORK at the rig floor. Modifications were made before and during installation (thicker springs were installed, and parts were ground off of the latching mechanisms so they would stick out further) so that it would latch into the CORK head; however, these modifications did not work. The CORK head was submerged for 10 min to clear the pressure line of air, and then the CORK head was raised through the moonpool. A fast-flow OsmoSampler system was attached, and all of the unused valves were closed. The used valves include one pressure valve and a 0.125 inch chemistry line attached to the fast-flow OsmoSampler. The CORK was then lowered to ~100 m. The camera system was then test fit over the CORK, and at 0630 h on 11 October, we began lowering the CORK package to the seafloor. The camera system was installed, and Hole U1382A was reentered for the last time at 1630 h on 11 October.

After carefully lowering the CORK into the hole, we landed the CORK at 1820 h on 11 October. The packer was inflated (to 1400 psi, which then bled off to ~1280–1300 psi), and the camera was pulled to the surface. Next, the ROV platform was assembled and rigged up with the ROV deployment tool attached below the camera system and then lowered back to the seafloor. The platform was released over the CORK at 0055 h on 12 October. The camera system was retrieved and after the ROV deployment system was removed, the camera was lowered back to the bottom to observe the final step of installing the Hole U1382A CORK—releasing the running tool from the CORK. This was successfully released at 0425 h on 12 October. The drill string with the CORK running tool was recovered back on board at 1145 h, ending Hole U1382A.

Site U1383

Our objective at Site U1383 was to install a multilevel CORK observatory to perform long-term coupled microbiological, biogeochemical, and hydrological experiments in deeper portions of the oceanic crust. Our first step was to use an 18.5 inch tricone drill bit to perform a jet-in test to determine the length of 20 inch casing to install with the reentry cone. While we assembled the BHA and lowered to the seafloor, we retrieved the seafloor beacon used for Hole 395A and transited ~5.8 km to Site U1383 in dynamic positioning mode. After arriving at Site U1383, we dropped a positioning beacon at 1812 h on 12 October. The jet-in test in Hole U1383A began at 2240 h on 12 October and reached 36 mbsf at 0200 h on 13 October. The penetration rate during the last 2 m was very slow. The 18.5 inch bit was back on board at 0930 h, ending Hole U1383A.

On the basis of the jet-in test, we deployed 34.84 m of 20 inch casing for Hole U1383B. The casing and reentry cone were run to the bottom, but our initial attempt jetted in the casing to only 29 mbsf. After trying to advance the casing for over 3 h with no progress, we pulled the string out of the seafloor and moved 50 m to the northeast. Our second attempt to start Hole U1383B began at 0810 h on 14 October. This time, we were able to fully land the reentry system and casing at 1015 h. We released the running tool at 1035 h and retrieved the drill string, with the bit arriving on the rig floor at 1915 h.

Our next job was to drill an 18.5 inch hole into uppermost basement for the 16 inch casing. After both drill collar pup joints and the casing running tool were laid out, the 18.5 inch bit was removed, the nozzles were changed, and the BHA was made up and run back to the bottom. During the trip into the hole we had to pause to slip and cut 115 ft of drill line and to start lowering the camera system for reentry. We reentered Hole U1383B at 0518 h on 15 October, began drilling at 0704 h, and encountered basement at 0723 h at 53 mbsf. Drilling continued to 68 mbsf at a penetration rate of ~2 m/h. We drilled to this depth to allow ~9 m of rathole for the 16 inch casing. Once 68 mbsf was reached, the hole was reamed and conditioned and the bit was retrieved.

After the bit was back on the rig floor at 0450 h on 16 October, the casing running tool was picked up and made up to the BHA and set back in the derrick. A total of 58.82 m of 16 inch casing, including the casing hanger, was assembled. The running tool was made up to the casing, and the casing was then run to the bottom, pausing only to deploy the camera system. Hole U1383B was reentered at 1524 h after ~20 min of maneuvering. The casing was then lowered into the open hole until the casing shoe contacted the sediment/basement interface. The casing shoe would not pass the interface after 1 h of attempts, even with rotation. The ship was offset, and repeated attempts were made until the shoe passed the basement contact. Unfortunately, the casing was unable to advance enough to successfully land the casing hanger in the reentry cone. The final position of the casing shoe was ~3 m short of landing. The 16 inch casing was retrieved at 1945 h on 16 October, arriving back on the rig floor at 0315 h on 17 October. The top two joints of casing were removed, and the length of the casing shoe joint was shortened by 5 m. A new casing shoe was welded onto the shoe joint, and at 0800 h the casing was lowered back into the hole. The running tool was reattached, and the casing was once again run back to the bottom. The camera system was installed 70 stands into the trip to the bottom. At 1537 h Hole U1383B was reentered with the 16 inch casing for the second time. The casing was successfully landed at 1630 h and cemented into place with 20 bbl of cement with lost-circulation material (Cello-Flake). The casing running tool was released at 1745 h, and the drill string was circulated out to remove any excess cement from the string. At 1845 h on 17 October the drill string was pulled back to the surface, stopping only so that the camera system could be removed. The running tool cleared the rotary table at 0130 h on 18 October and then was de-torqued and laid out.

The next stage of operations was to drill ~100 m of basement to install 10.75 inch casing. A new bit was made up to the BHA, and the drill string was tripped to the bottom. At 90 stands into the trip, the camera system was installed and run to the bottom behind the bit. The trip was suspended just above the seafloor to slip and cut 115 ft of drilling line from the drawworks winch. Hole U1383B was reentered at 1210 h on 18 October after 15 min of maneuvering. The bit was tripped to near the bottom, the top drive was picked up, and cement was tagged at 49 mbsf (5 m above the casing shoe). After 45 min of drilling, the bit reached the bottom of the cement at 57 mbsf (3 m below the casing shoe). From 1500 h on 18 October through 0515 h on 19 October, drilling proceeded to 89.8 mbsf. At this depth torque increased, RPM became erratic, and penetration rates dropped to zero. A wiper trip was performed from 89.8 mbsf to the 16 inch casing shoe at 54 mbsf and back to the bottom. Attempts to resume drilling were unsuccessful. At 1000 h, we decided to pull the bit and inspect it at the surface. The top drive was set back, and the drill string was pulled from the hole. The bit cleared the rotary table at 1750 h on 19 October. Inspection of the bit revealed that two of the three rotary cones and both shanks, including bearings and nozzles, had broken off the body of the bit. Only one cone remained on the bit, and it too had all the inserts broken off. After discussions with all of the operations staff on board, we decided that we would have a greater chance of achieving the expedition objectives by starting a new hole rather than trying to salvage Hole U1383B.

At 1830 h construction began on a reentry cone for Hole U1383C. Because of several factors, we decided to start the new reentry system with 16 inch casing jetted in to a depth of 34.58 m at the same location as the original jet-in test in Hole U1383A. Assembly of the Hole U1383C reentry cone was completed at 0630 h on 20 October. The reentry cone was moved to the moonpool and positioned on the moonpool doors, and then 35 m of 16 inch casing was picked up, landed, and latched into the reentry cone. The running tool was then released, and the stand was set back in the derrick. The stand with the 14.75 inch drill bit was then picked up, followed by another 5 m of 8.25 inch drill collar pup joints to space the bit out to the 16 inch casing shoe. The drill collar stand with the casing running tool was picked up and made up to the BHA and lowered and latched into the 16 inch casing hanger. The remainder of the BHA was assembled, and the reentry system and casing were lowered to just above the seafloor, stopping every 30 stands to fill the drill string. The camera system was installed 90 stands in and run to just above the reentry system. Hole U1383C was spudded at

1900 h on 20 October. The reentry system was jetted in ~35 m, and the casing running tool was released at 2130 h. The camera system and drill string were then pulled back to the surface, and the 14.75 inch bit cleared the rotary table at 0545 h on 21 October. After the nozzles on the bit were changed, the drilling BHA was assembled and run back to the bottom. The camera system was installed at Stand 70 and run to the bottom, following the bit to the seafloor. At 1130 h the vessel began maneuvering, and Hole U1383C was reentered at 1444 h. After the top drive was picked up, drilling began at 1635 h on 21 October. Contact was made with basement at 38 mbsf, just 3 m below the 16 inch casing shoe, after only 10 min of drilling. Basement drilling continued with slow penetration rates (0.5–2.5 m/h), reaching a total depth of 69.5 mbsf at 1840 h on 22 October.

We assembled 60.41 m of 10.75 inch casing with a swellable packer just below the casing hanger and lowered it to just above the seafloor, pausing about halfway to deploy the camera system. After ~30 min of maneuvering, we reentered Hole U1383C at 1626 h on 23 October. The casing string was landed at 1720 h, and we confirmed it was latched in with a 20,000 lb overpull. The casing was secured in place by pumping 25 bbl of cement with lost-circulation material (Cello-Flake). The casing running tool was released at 1940 h, the drill string was flushed clear of any remaining cement, and we started pulling out of the hole. With the casing running tool at 2336 mbrf, the trip was halted so we could slip and cut 115 ft of drill line. We also spent 2 h replacing a spool valve and repairing a hydraulic line on the 5 inch pipe racker. We then continued retrieving the casing running tool, which was back on board at 0825 h on 24 October.

We assembled an RCB bit and BHA, verified the core barrel space out, and lowered it to the seafloor. About halfway down, we paused to deploy the camera system. This reentry took us only ~10 min of maneuvering. After we retrieved the camera system, installed the top drive, and spaced out for drilling, we tagged the top of the cement at 43.8 mbsf (~16.6 m above the casing shoe). Once we drilled out the cement and cleaned out the rathole, we recovered the center bit. We dropped an RCB core barrel and started coring at 0000 h on 25 October. We cut Cores 336-U1383C-2R through 18R from 69.5 to 211.6 mbsf. After Core 15R had been cut, we performed a wiper trip back up to the casing shoe and encountered 20 m of fill while getting back to the bottom of the hole. Hole cleaning remained a priority, with mud sweeps being performed on average twice during each cored interval. A total of 142.1 m was cored, and 28.55 m was recovered (20%). Just as Core 18R began to be cut (with 45.8 h on the bit), the vessel began experiencing high heave. This heave made it almost impossible to keep sufficient weight on the bit to keep it on the bottom, so we circulated cuttings out of the hole with a final mud sweep and pulled the bit out of the hole. The RCB bit was back on board at 1720 h on 28 October. It was fortunate that we did not continue coring with this bit because it had experienced bearing failures on all four roller cones.

We conducted routine rig maintenance while we assembled a new C-7 RCB bit and inspected the float valve and support bearing assemblies. This maintenance identified a faulty air cylinder for the locking pin on the motion compensator that had to be repaired, which resulted in 9.25 h of rig downtime. During the repair we assembled the previous BHA and added three more drill collars. We installed a center bit so that the float valve would remain open during the trip, allowing the drill string to fill with seawater. At 0630 on 29 October we started tripping the BHA to the seafloor. The reentry cone was visible as soon as the camera system reached the seafloor, and the bit was almost directly over the cone. We reentered Hole U1383C in several minutes at 1231 h on 29 October. We retrieved the camera system and the center bit and lowered the bit to the bottom of the hole to check for tight spots and to circulate out any fill at the bottom before changing bits.

We assembled a second RCB bit to continue coring in Hole U1383C. After the bit was lowered to the bottom of the hole, it was circulated clean. An RCB core barrel was dropped, and coring resumed with Core 336-U1383C-19R. We decided to core with drilling knobbies because of high vessel motion and operating in deep water. RCB coring continued through Core 336-U1383C-23R, at which point we made a short wiper trip to both clean a short section of hole and to replace three drilling knobbies with a stand of 5.5 inch drill pipe. Once the bit was back on the bottom, we circulated a mud sweep and resumed coring. Two 20 bbl sweeps were pumped on every core to keep the hole clean. We decided to stop RCB coring at 4756.7 mbrf (331.5 mbsf) because of accumulating bit hours, minimal time left in the expedition, and because a sufficient depth was reached to achieve the CORK objectives. Thirty-one cores recovered 50.31 m of rocks from a 262.0 m interval. Overall recovery was 19%, varying from 8% to a maximum of 43%.

We conducted three wiper trips to prepare the hole for downhole logging, packer experiments, and CORK installation. At 1400 h on 1 November, the first wiper trip began, and hole cleaning continued until the following day. Three wiper trips were made from total depth to the 10.75 inch casing shoe and back. Tight spots were recorded at 4692, 4703, 4708, 4716, 4724, 4743, 4751, and 4752 mbrf (266.8, 277.8, 282.8, 290.8, 298.8, 317.8, 325.8, and 326.8 mbsf). These spots were reamed and rechecked during the first wiper trip. At the end of the first wiper trip, 4 m of fill was found on the bottom and cleaned out. We circulated a 70 bbl sweep of high-viscosity mud, and then the hole was displaced with salt water. The subsequent two wiper trips did not detect tight spots or fill on the bottom. At 0545 h on 2 November we started to pull the string out of Hole U1383C, and it cleared the seafloor at 0625 h. The RCB bit was back on the rig floor at 1315 h.

Before we started assembling the logging/packer BHA, we picked up and assembled six 6.75 inch perforated drill collars into a stand. The exterior of the stand was then completely coated with an epoxy paint and set back in the derrick to cure. This stand is the lowermost portion of the CORK completion string.

The logging and drill string packer BHA was then assembled and lowered to the seafloor. After ~3 min of maneuvering, we reentered Hole U1383C at 2342 h on 2 November. The logging bit was then positioned ~5 m from the base of the 10.75 inch casing shoe.

The logging equipment was rigged up to run the adapted microbiology combination II (AMC II) tool string, which included the DEBI-t deep UV-induced fluorescence, density/caliper (Hostile Environment Litho-Density Sonde [HLDS]), and spectral gamma ray (Hostile Environment Natural Gamma Ray Sonde [HNGS]) tools. During assembly the resistivity tool failed and had to be removed from the string. The tool string was run into the hole, and two full passes were conducted, tagging bottom and confirming drill pipe depth and lack of fill in the hole. After this first tool string was back on board, the FMS-sonic tool string was rigged up. This tool string included the spectral natural gamma ray, Dipole Shear Sonic Imager (DSI), and FMS tools. This second string also completed two successful passes; it was pulled out of the hole and rigged down at 2315 h on 3 November. Following logging, we picked up the top drive and prepared for the first of three scheduled packer tests. We were unable to set the packer in the casing, and the test at this level was abandoned. The packer was then moved to 4566 mbrf (140.8 mbsf) in open hole. The packer was inflated, and flow tests were completed as scheduled. The packer was then moved to the final position but was unable to hold pressure. The packer experiment was concluded, the top drive was set back, and the drill string was pulled out of the hole to just above the seafloor.

Before beginning CORK installation in Hole U1383C, we decided to deploy an ROV platform in Hole U1383B to facilitate a future borehole observatory installation by

ROV. We moved to Hole U1383B, deployed the camera system, and reentered the hole at 1350 h on 4 November. We retrieved the camera system, assembled a modified ROV platform around the drill pipe, and let it free fall down onto the reentry cone at the seafloor. The platform had been modified to self-center on the reentry cone because there was no CORK wellhead to help it center as designed. The camera was deployed, and the platform was observed to be sitting in the cone—although perhaps just slightly off-center. The bit was pulled out of the hole at 1818 h. After pulling the bit well above the seafloor, we paused operations to slip and cut the drill line. At 2015 h the trip out of the hole resumed, and the logging bit arrived back on the rig floor at 0300 h on 5 November. We observed that the drill string packer element had experienced a blowout. After we had the drill collars stored in the derrick, we began assembling the Hole U1383C CORK.

The observatory assembly started with lowering the preassembled 6.75 inch perforated drill collar stand below the rig floor. We picked up, assembled, and painted with epoxy four additional 15 ft long perforated drill collars, which we added to the top of the first stand to provide additional weight to the bottom of the CORK to hopefully ease the string past a ledge encountered during hole cleaning. We then started assembling the various pieces of the CORK, including (1) external umbilicals terminated at screens, (2) coated and perforated steel and slotted fiberglass tubing, (3) landing seats, (4) packers, and (5) a variety of required crossovers. Five external umbilicals allow access to these three zones for microbiological, geochemical, and pressure sampling. The CORK tubing (coated steel and fiberglass) extends to 247.6 mbsf and includes perforated and slotted intervals (67.4–129.4, 154.8–181.1, and 203.7–246.6 mbsf) that provide access to the three isolated intervals but leave the bottom portion of the hole open for future logging and access (247.6–331.5 mbsf). An internal OsmoSampler string extends the full length of the CORK and includes seals isolating the three zones and microbiological, geochemical, and temperature experiments.

At just after 1700 h on 5 November, we finished assembling the 247.6 m long CORK observatory and picked up the CORK head and attached it to the casing string. The last umbilical connections were made to the bottom of the CORK head. The CORK was then lowered to the moonpool and landed on the moonpool doors. The CORK running tool was then removed, and the OsmoSampler instrument string was assembled and lowered inside the CORK and casing. The CORK running tool was then reinstalled, and the packer inflation line was connected. The CORK was then lowered below the keel to flood the umbilicals to remove air from the pressure lines. The CORK was then raised to the moonpool, and the seafloor fast-flow OsmoSampler was installed. All valves except the geochemistry bay upper Zone 2 valve (which was connected to the seafloor fast-flow OsmoSampler) were closed and secured. The CORK was lowered to ~100 mbsl, and the camera frame was test fit over the CORK head. At 0000 h on 6 November 2011, after ~21 h of assembly, we started lowering the CORK assembly to the seafloor. During the trip in the hole, the drill pipe was filled with seawater every six stands, which lengthened the trip to a total of 8.25 h. At 0915 h the vessel began maneuvering to reenter Hole U1383C. The hole was reentered at 0941 h. After reentry, the CORK was slowly lowered into the hole while drill string weight was carefully monitored and the procedure was observed with the camera. Approximately 35 m above the landing point, the top drive was picked up, and the CORK was fully landed at 1127 h on 6 November. Afterward, the mud pumps were brought online to pump up the packers. We applied pressure to the packers for 30 min but were unable to get them to hold a sustained pressure. It was evident there was a small leak somewhere in the system between the standpipe on the rig floor and the bottom packer. We were unable to detect where the leak might be, and there are many possibilities or combinations depending on where the leak is—from all packers pressurized and sealing to only the top swellable packer sealing. After the camera was recovered, the ROV platform was assembled and hung from the camera frame and run to the bottom. The platform was released at 1630 h without incident. The camera was then pulled back to the surface, the slings and releasing tool were removed, and the camera was lowered back to the bottom to monitor the release of the running tool from the CORK head. The running tool was released at 2015 h on 6 November, ending the Hole U1383C CORK deployment. When the CORK running tool was released, the CORK wellhead also appeared to rotate. Several possibilities could account for this action, but it is likely the result of tightening the upper casing in excess of the manual tightening on the rig floor. A similar occurrence was noted with the Juan de Fuca CORKs. The camera and drill string were retrieved, with the CORK running tool arriving back on the rig floor at 0315 h on 7 November, ending Hole U1383C.

Sediment and basement contact coring (Holes U1383D, U1383E, U1382B, and U1384A)

The final operations of the expedition were focused on APC/XCB coring of the sediment above basement and the sediment/basement contact in four holes.

Hole U1383D

The advanced piston corer (APC)/XCB BHA was made up with a new APC/XCB bit and lowered to 4 m above seafloor. The vessel was positioned halfway between Holes U1383B and U1383C, offset 5 m to the northwest, and Hole U1383D was spudded at 1426 h on 7 November. Six APC cores were taken from 0 to 43.3 mbsf (Cores 336-U1383D-1H through 6H) and recovered 47.89 m of sediment. Core 6H only penetrated 0.2 m before hitting basement, so the majority of the recovery was sucked in when pulling the barrel out of the formation. After hitting basement with the last APC core, we penetrated 1 m with Core 336-U1383D-7X and recovered 0.76 m. Hole U1383D ended at 2350 h on 7 November when the bit cleared the seafloor.

Hole U1383E

The vessel was then offset 10 m to the southeast, and Hole U1383E was spudded at 0038 h on 8 November. APC Cores 336-U1383E-1H through 6H extended to 43.2 mbsf and recovered 50.38 m of sediment. Core 6H only penetrated 2.3 m before encountering basement, so the remaining 6.22 m of sediment recovered was likely sucked in when the barrel was pulled out of the formation. After the last piston core hit basement, the XCB core barrel was dropped, and the sediment/basement interface was cored for ~1 h to a depth of 44.2 mbsf. Core 336-U1383E-7X recovered 0.3 m. Hole U1383E ended at 1000 h on 8 November, when the bit cleared the seafloor.

Hole U1382B

After pulling out of Hole U1383E and raising the bit well above seafloor (4300 mbrf), we moved in dynamic positioning mode to Site U1382. After the 3.28 nmi transit was completed at 1445 h, the bit was lowered to just above the seafloor, and the top drive was picked up and spaced out for spudding. Hole U1382B was spudded at 1700 h on 8 November. APC Cores 336-U1382B-1H through 10H extended to 90.0 mbsf and recovered 83.70 m of sediment. Core 10H, the last APC core, encountered basement after penetrating ~8.5 m, so the lowermost portion of sediment recovered in this core is likely flow-in. Temperature measurements with the advanced piston corer temperature tool (APCT-3) were attempted on Cores 3H through 5H. The measurements were not good as a result of tool movement, and they were discontinued because they were thought to be disturbing the sediment cores. Subsequent splitting of the cores seemed to indicate that the disturbed cores could have been caused by the lithology of the cores—coarse sediments as large as pebble-size were found inside the cores. After basement was hit with the last piston core, the XCB core barrel was dropped, and the sediment/basement interface was cored. After a few minutes of XCB coring, the formation changed, and the XCB quickly advanced to the remainder of the kelly length (4.7 m). After Core 336-U1382B-11X was pulled, another core barrel was dropped, and XCB coring continued until hard formation was encountered around 98.8 mbsf. After 30 min of coring with no advance, Core 336-U1382B-12X was pulled. The XCB cutting shoe had lost all of its carbide teeth, and only 18 cm of core was recovered. Cores 336-U1382B-11X and 12X recovered a total of 0.58 m over an 8.8 m interval. Hole U1382B ended at 1315 h on 9 November when the bit cleared the seafloor.

Hole U1384A

After raising the bit above the seafloor (4400 mbrf), we moved in dynamic positioning mode to Site U1384. The 3.38 nmi transit was completed at 1815 h. We lowered the bit to just above the seafloor, picked up the top drive, and spaced out for spudding. Hole U1384A was spudded at 2130 h on 9 November. APC Cores 336-U1384A-1H through 11H extended to 94.7 mbsf and recovered 93.51 m of sediment. Core 11H was only a partial stroke, likely because basement was encountered. XCB Core 336-U1384A-12X advanced 1.5 m in ~40 min, where penetration stopped. When Core 12X was retrieved, 0.58 m of core had been recovered and the XCB cutting shoe had lost all of its carbide teeth. Hole U1384A ended at 0042 h on 11 November.

After the drill string was back on board, the BHA was disassembled and the drill floor was secured for transit. The transit to Ponta Delgada began at 0042 h on 11 November. The planned arrival time in Ponta Delgado is 0730 h on 17 November.

Education, outreach, and communication objectives

Expedition 336 sailed with one onboard education officer, but several of members of the science party also conducted education, outreach and communications (EOC) activities while on board. The education officer was an elementary school teacher with a background in marine biology, as well as a marine science web designer. Four shipboard microbiologists also initiated education and outreach activities.

The primary goals of the Expedition 336 EOC effort were to (1) connect shipboard scientific, technical, and engineering personnel with nonspecialists on shore; (2) develop K-12 curricula related to the expedition's scientific objectives and general science, technology, engineering, and math (STEM) topics; (3) create and distribute multimedia materials (written, photographic, and video) related to expedition objectives and accomplishments; (4) help Expedition 336 scientific personnel learn to communicate the excitement of their research and other activities to an audience of nonscientists; and (5) teach the onboard education officer about the scientific foundations of the mission and the technical tasks involved in deep-sea scientific drilling in order to create a solid understanding of the scientific process that can then be communicated through her own formal and informal education efforts.

Education, outreach, and communication summary

The shipboard EOC team advanced the scientific goals of the expedition and of IODP by communicating the importance of scientific ocean drilling to a broad external audience and engendering understanding and enthusiasm for scientific exploration, ocean drilling, and subseafloor observatories. This was accomplished in partnership with the science party. Toward this objective, the team worked with custom websites, blogs, up-to-the-minute social media, and live video interactions with schools and museums.

More than 43 blog posts in English, Spanish, and French were added to **joidesresolution.org/** (a United States Implementing Organization website oriented toward a nonscientific audience) by seven authors, including the onboard education officer, scientists, engineers, and technical staff. Subjects included shipboard life, operations and deep-sea drilling, engineering and CORK observatories, microbiology, and math. Blog posts were viewed an average of 288 times each. In addition, four outside blogs/websites were published by onboard scientists. Katrina Edwards wrote about our expedition on the Expeditions blog at Scientific American (**blogs.scientificamerican.com/expeditions/**); this blog was also published on the Center for Dark Energy Biosphere Investigations (C-DEBI) website (**www.darkenergybiosphere.org/return-to-northpond/**). Beth Orcutt wrote about microbiology on the Adopt-a-Microbe project website (**aam.darkenergybiosphere.org/**), Amanda Haddad wrote for a special needs audience on the Classroom Connection website (**www.darkenergybiosphere.org/classroom-connection/**), and Heath Mills wrote a blog about Mid-Atlantic Ridge microbiology hosted on Texas A&M's College of Geosciences website (**georesearch.tamu.edu/blogs/microbiology/**). Altogether, more than 115 blog posts were published about Expedition 336.

Visits to the *JOIDES Resolution* website and page views within the site both increased significantly during Expedition 336. During the 6 weeks prior to the expedition there were 4,632 visits, resulting in 15,651 page views. During the first 6 weeks of the expedition, there were 11,044 visits (a 138% increase) and 42,217 page views (a 170%

increase). Website viewership has increased since last year as well, possibly indicating that each expedition retains some followers and that networking has resulted in increased awareness. During the same 6-week period during 2010 (mid-September through October), there were 8,448 visits and 34,867 page views. Viewership during this expedition demonstrated a 31% increase in visits and a 21% increase in page views compared to last year (Fig. **F13**).

The expedition page on the *JOIDES Resolution* website contained information about the scientific background and objectives of the expedition, videos about different aspects of the instrumentation and operations, links to microbiology news articles, information about participants, and a daily math problem related to the expedition. Teachers and other participants in EOC activities were directed to this page for general information on the expedition prior to videoconferences. As a result, this page received over 3,165 views during the first 6 weeks of the expedition, which is 7.5% of the total 42,217 page views.

The onboard education officer, with the assistance of scientific, technical, and engineering staff, conducted 47 live ship-to-shore video interactions, reaching more than 1800 participants ranging from third grade through university (Table **T2**). The majority of these interactions were 30–45 min conferences with individual or combined elementary, middle, and high school classes ranging in size from 5 to 300 students. Schools were located across the United States in 13 states, as well as in France, Spain, England, Australia, and the Virgin Islands. Thirteen of the broadcasts were arranged on board with groups that had a direct connection to scientists on board. Four live seminars were broadcast from the ship to scientists' home universities and conferences in France, England, and the United States (Texas and Florida). A total of 20 scientists, engineers, and technical staff members participated in the live broadcasts, both as hosts and as guests during the question-and-answer portion of the videoconferences.

Further information will be collected through user surveys, but initial responses from participating teachers indicate a generally positive response to the fast-paced virtual tours of shipboard laboratories and interviews with scientific, technical, and engineering staff. Teachers indicated that through participation in the videoconferences, their students learned more about geoscience content, marine careers, the *JOIDES Resolution*, and how science works.

Social media sites Facebook and Twitter were used to communicate up-to-the-minute information from the *JOIDES Resolution*. Increased traffic on both sites indicated a following of the expedition. In the month prior to the expedition, the *JOIDES Resolution* Facebook page had an average daily reach of 245 unique users, and an average of 20 users who engaged with the page on a daily basis. During the first 7 weeks of Expedition 336, this increased to an average daily reach of 835 unique users, including an average of 62 users engaging daily. During the expedition, more that 135 posts were made to the Facebook page, with an average viewership of 641 unique users. Photos were consistently the posts that engaged the most users, whereas posts tagged with other organizations' pages (such as those made during Earth science week that were connected to the "Earth Science Week" Facebook page with a tag) had the most reach. A number of short videos were produced during the expedition, posted to YouTube and Vimeo, and shared via social networks. Subjects varied, but included shipboard life, expedition progress, drilling operations, and sampling procedures.

The Adopt-A-Microbe project, which was initially developed during IODP Expedition 327 to engage learners in microbiology research at the bottom of the ocean (Orcutt et al., 2011b), was rerun during Expedition 336. In this project, scientists on board the *JOIDES Resolution*, led by microbiologist Beth Orcutt, interacted with shore-based students and teachers through the project website, which is the location of a virtual "adoption center" for different notable microbes from the deep biosphere and for blogs announcing different weekly science and art activities and news from the expedition. Several shipboard scientists also contributed articles about their favorite microbe to the project website. The Adopt-A-Microbe project was also the portal for an art contest for decorating the subseafloor observatories installed during Expedition 336, representing the world's deepest art installation.

Thirty-five different school groups, after-school programs, and families from around the United States and Spain officially registered to participate in the 10-week project. Participants received a free kit of materials for using in the weekly projects—including samples of sand, clay, basalt, pyrite, calcite, and materials for growing microbes—which was supplied from the Deep Earth Academy. The participants varied in age, with high school marine science and biology classes making up a large proportion. Several participating teachers developed their own class projects using the Adopt-A-Microbe weekly activities as a base, and these are now available for sharing with other programs. For the first time, a Spanish-language section was also incorporated into the project website, translated by scientist Tania Lado Insua, to engage with elementary school students in Spain.

This online interactive project was hosted on the website for C-DEBI at **aam.darkenergybiosphere.org/,** with promotion through Facebook, Twitter, the *JOIDES Resolution* website and C-DEBI email listservs.

During Expedition 336, four special education classrooms in the Phoenix, Arizona, metro area interacted with shipboard scientists via weekly activities, blogs, question-and-answer sessions and Skype calls revolving around ocean exploration as part of the Classroom Connection initiative. The initiative was inspired by informal ship-to-classroom interactions during Expedition 327, during which one special education classroom in the Phoenix metro area read blogs and interviews written by shipboard scientists and submitted questions for the shipboard scientific party.

The Classroom Connection participants interacted with the shipboard scientific party via a web page hosted on the C-DEBI website (**www.darkenergybiosphere.org/classroomconnection/**) for a total of 10 weeks (9 weeks at sea plus 1 introductory week before the expedition). Each week followed a different theme (e.g., life on the *JOIDES Resolution*, coring/drilling, logistics, data collection, etc.), and each day of the week involved a different type of interaction—hands-on activities posted on Mondays, answers to student questions on Tuesdays, SciMath Career series interview on Wednesdays, blog on Thursdays, and WebDay Friday activities on Fridays—all revolving around the theme of the week. Each interaction addressed one or more Arizona state-mandated curriculum standards in one or more subjects (math, reading, writing, science, and social studies). The activities were designed to be easily adaptable to include every student in the classroom regardless of ability, and thus included several modes of assessment from reading and writing to pictorial representation, tactile models, and kinetic learning.

In addition to the classroom activities created for the Adopt-a-Microbe and Classroom Connection programs, three classroom activities were created for the *JOIDES Resolution* website. These activities focused on the process of deep-sea scientific drilling and combined art, math, creative thinking, technology, and the scientific process. The activities are ready to be tested in the classroom and will be added to the educational resources at Deep Earth Academy.

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Table T1. Summary of holes occupied during Expedition 336.

Site	Hole	Latitude	Longitude	Seafloor depth (mbrf)	Number of cores	Interval cored (m)	Length recovered (m)	Percent recovered (%)	Section drilled without coring (m)	Total penetration (m)	Total depth of hole (mbrf)	Time on hole (h)	Time on hole (d)	Number of holes	Operations conducted
395	395A	22°45.3519′N	46°4.8609′W	4484.0	0	0.0	0.00	—	0.0	0.0	5084.0	194.00	8.1	—	Retrieved Leg 174 CORK, logged, installed CORK (failed wellhead)
U1382	U1382A	22°45.3531′N	46°4.8911′W	4494.0	11	100.0	31.79	32	110.0	210.0	4704.0	263.25	11.0	1	Cored basement, logged, installed CORK
	U1382B	22°45.3528′N	46°4.8748′W	4494.0	12	98.8	84.28	85	0.0	98.8	4592.8	22.00	0.9	1	Cored sediment and basement contact
			Site U1382 totals:		23	198.8	116.07	58	110.0	308.8	—	285.25	11.9	2	
U1383 (NP-2)	U1383A	22°48.1229′N	46°3.1661′W	4425.2	0	0.0	0.00	—	36.0	36.0	4461.2	21.75	0.9	1	Jet-in test
	U1383B	22°48.1328′N	46°3.1556′W	4425.2	0	0.0	0.00	—	89.8	89.8	4515.0	152.25	6.3	1	Installed cone and casing; bit lost in hole, 35 m open hole, ROV platform deployed
	U1383C	22°48.1241′N	46°3.1662′W	4425.2	31	262.0	50.31	19	69.5	331.5	4756.7	441.50	18.4	1	Cored basement, logged, installed CORK
	U1383D	22°48.1316′N	46°3.1628′W	4425.2	7	44.3	48.65	110	0.0	44.3	4469.5	20.50	0.9	1	Cored sediment and basement contact
	U1383E	22°48.1283′N	46°3.1582′W	4425.2	7	44.2	50.28	114	0.0	44.2	4469.4	10.25	0.4	1	Cored sediment and basement contact
			Site U1383 totals:		45	350.5	149.24	43	195.3	545.8	—	646.25	26.9	5	
U1384 (NP-1)	U1384A	22°48.7086′N	46°5.3464′W	4475.9	12	96.2	94.09	98	0.0	96.2	4572.1	30.50	1.3	1	Cored sediment and basement contact
			Site U1384 totals:		12	96.2	94.09	98	0.0	96.2	—	30.50	1.3	1	
			Expedition 336 totals:		80	645.5	359.40	56	305.3	950.8		962.00	40.11	8	

— = not applicable. CORK = subseafloor borehole observatory. ROV = remotely operated vehicle.

Table T2. Summary of educational videoconferences during Expedition 336.

Date (2011)	Grade level/Class	Number of students	Venue	City	State	Country
23 Sept	11–12th grade	6	Erindale College	Canberra	ACT	Australia
26 Sept	11–12th grade elective	24	St. Joseph's Academy	St. Louis	MO	USA
28 Sept	5th grade gifted students	10	Maclary Elementary	Oxford	PA	USA
30 Sept	11–12th grade Astronomy	40	North Hollywood Zoo Magnet	Los Angeles	CA	USA
3 Oct	8th grade	32	St. Anne School	Lancaster	PA	USA
4 Oct	11–12th grade elective	24	St. Joseph's Academy	St. Louis	MO	USA
5 Oct	12th grade Marine Biology	40	Animo Leadership High School	Inglewood	CA	USA
5 Oct	9–12th grade Marine Biology Club	40	Animo Leadership High School	Inglewood	CA	USA
6 Oct	11–12th grade	40	River Ridge High School	New Pt. Richey	FL	USA
7 Oct	6th grade	60	Marina del Rey Middle School	Los Angeles	CA	USA
10 Oct	Naval and Ocean Engineering	20	University of La Coruña	A Coruña		Spain
11 Oct	5th grade	40	Polo Road Elementary School	Columbia	SC	USA
11 Oct	5th grade	40	Polo Road Elementary School	Columbia	SC	USA
12 Oct	6th grade	32	South Gate Middle School	South Gate	CA	USA
13 Oct	University	50	Institut Universitaire Européen de la Mer	Plouzané		France
14 Oct	10th grade Biology	24	St. Joseph's Academy	St. Louis	MO	USA
14 Oct	University	40	University of the Virgin Islands	St. Thomas	VI	VI
18 Oct	Form 8	20	St Philip's School	London		United Kingdom
18 Oct	University	300	Colorado State University	Niwot	CO	USA
19 Oct	8th grade	30	Quibbletown Middle School	Piscataway	NJ	USA
19 Oct	8th grade	30	Quibbletown Middle School	Piscataway	NJ	USA
20 Oct	8th grade	30	Quibbletown Middle School	Piscataway	NJ	USA
20 Oct	6–8th grade	50	The International School of Monterey	Seaside	CA	USA
21 Oct	8th grade	30	Quibbletown Middle School	Piscataway	NJ	USA
21 Oct	HS special needs	20	Challenger Middle School	Glendale	AZ	USA
24 Oct	7–8th grade	40	Nobel Middle School-Marine Science	Calabasas	CA	USA
25 Oct	6–8th grade	60	Providence Englewood Charter School Middle School	Chicago	IL	USA
26 Oct	8–9 year olds	20	La escuela Manuela Rial en Cee	A Coruña		Spain
26 Oct	11–12th grade	5	AIM (Academy in Manayunk)	Philadelphia	PA	USA
27 Oct	7–8th grade	40	Nobel Middle School-Marine Science	Calabasas	CA	USA
28 Oct	University	50	Texas A&M University	College Station	TX	USA
31 Oct	9th grade Earth/Environmental Science	30	Croatan High School	Newport	NC	USA
1 Nov	4–12th grade club	14	CyberExplorers 4H Club	Cape May	NJ	USA
1 Nov	5th grade	30	Arroyo Vista Elementary School	South Pasadena	CA	USA
2 Nov	7th grade Life Science	30	Trinity Lutheran School	Newport News	VA	USA
3 Nov	6th grade Life Science + 7th grade Earth Science	44	Allen Academy	Bryan	TX	USA
3 Nov	5th grade	30	Arroyo Vista Elementary School	South Pasadena	CA	USA
4 Nov	7th grade	25	Pound Middle School	Lincoln	NE	USA
4 Nov	7th grade	25	Pound Middle School	Lincoln	NE	USA
4 Nov	9th grade Biology	15	Allen Academy	Bryan	TX	USA
8 Nov	3rd grade	25	Arroyo Vista Elementary School	South Pasadena	CA	USA
9 Nov	6th grade	60	Mayport Coastal Sciences Middle School	Atlantic Beach	FL	USA
10 Nov	6–8th grade	60	Providence Englewood Charter School Middle School	Chicago	IL	USA
11 Nov	University	30	University of Leicester	Leicester		United Kingdom
11 Nov	9th grade	38	Eastern Mennonite High School	Harrisonburg	VA	USA
11 Nov	9th grade	38	Eastern Mennonite High School	Harrisonburg	VA	USA
15 Nov	Adults	40	Association of Earth Science Editors	Tallahassee	FL	USA

Figure F1. Location map of North Pond area on the western flank of the Mid-Atlantic Ridge.

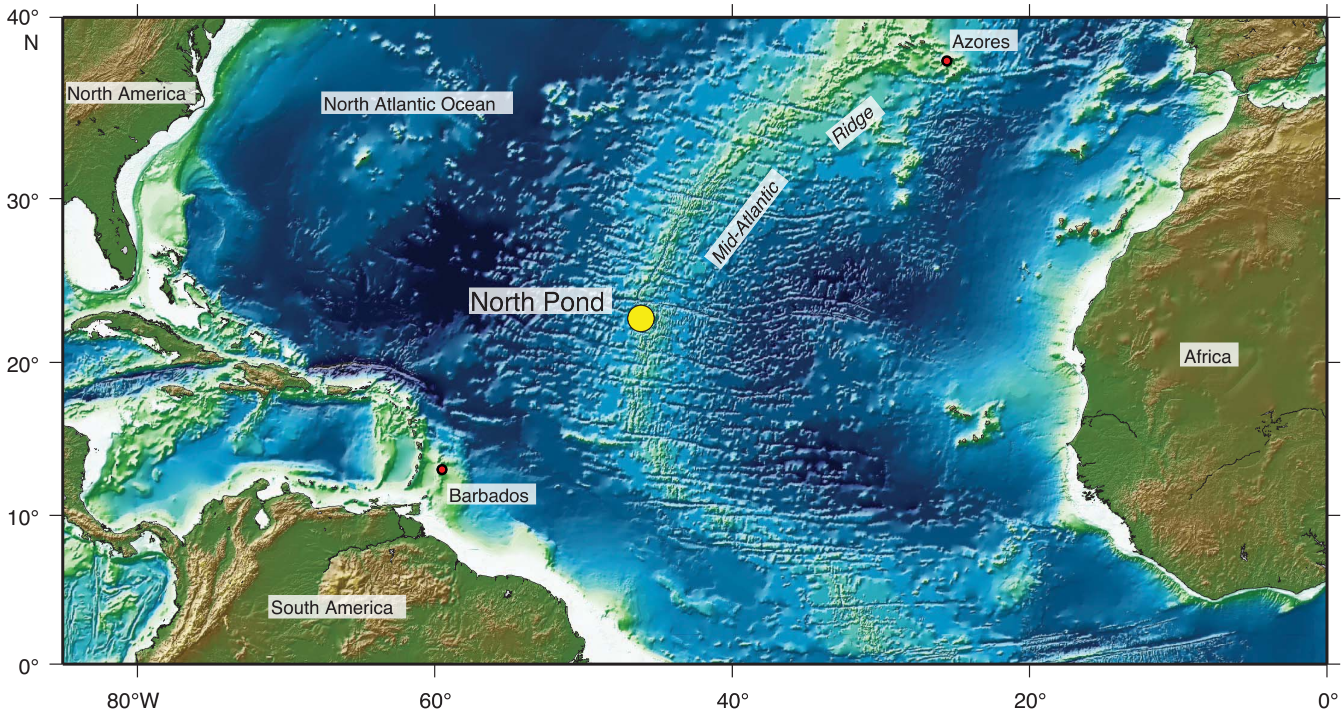

Figure F2. Bathymetric map of North Pond showing locations of DSDP Hole 395A, ODP Hole 1074A, and Sites U1382, U1383 (proposed Site NP-2), and U1384 (Proposed Site NP-1). Bathymetric data are from Villinger and Cruise Participants (2010).

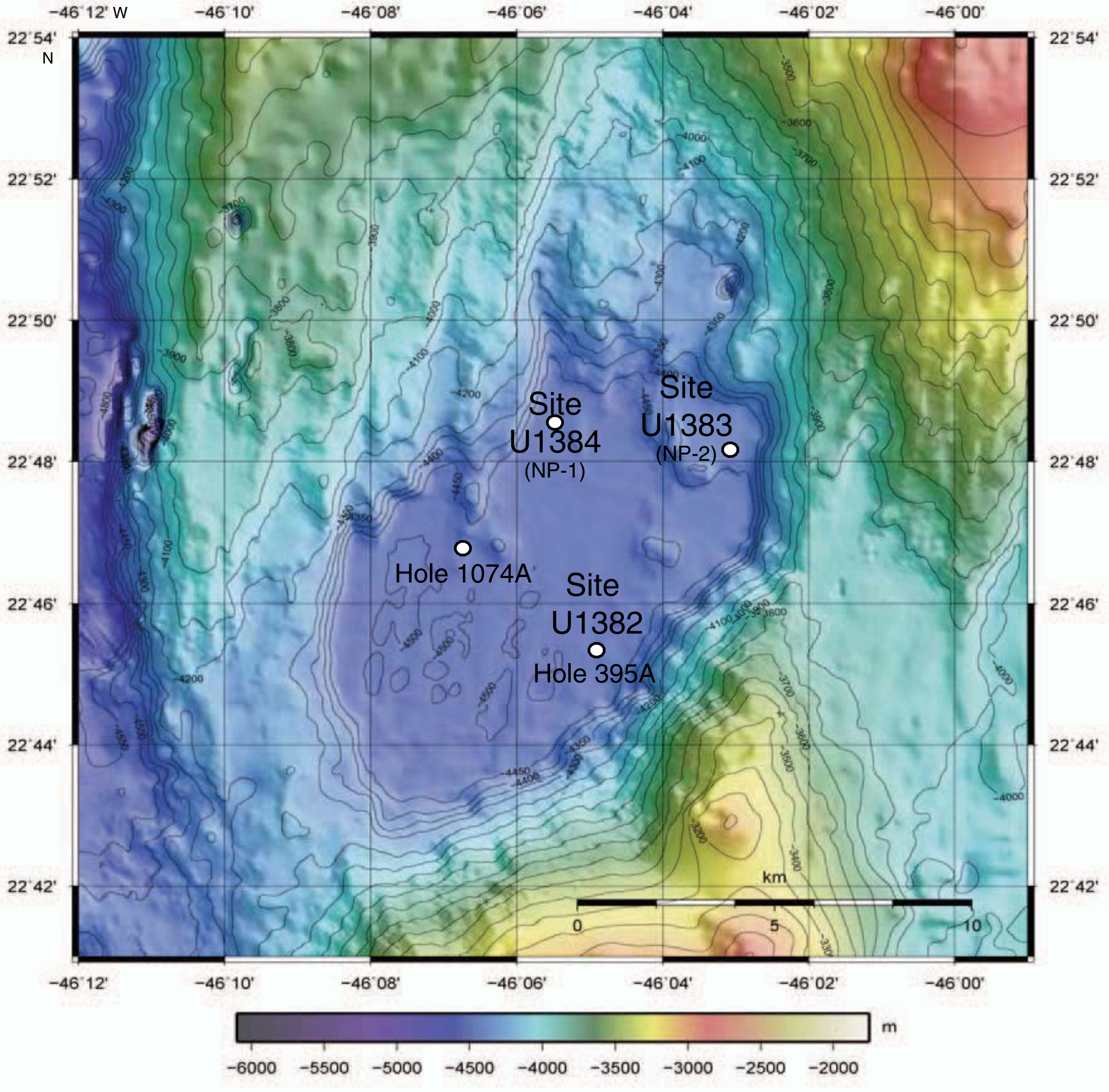

Figure F3. Summary of Hole 395A logging results. Blue lines = eruptive unit divisions (after Bartetzko et al., 2001), black lines = limits of casing and pipe for Expedition 336 operations. Arrows mark trends in gamma ray and resistivity. Measurements include borehole diameter (C1, C2 = FMS pass [ODP Leg 174B]), gamma ray (TGR 174B ARI = total gamma ray counts from Azimuthal Resistivity Imager tool string [Leg 174B]; TGR 174B DIT = total gamma ray counts from Dual Induction Sonde tool string [Leg 174B]; TGR 395A 2U2 = total gamma ray counts from Microbiology Combination tool string Run 2, Uplog 2 [Expedition 336]; TGR 395A 2D1 = total gamma ray counts from the Microbiology Combination tool string Run 2, Downlog 1 [Expedition 336]), bulk density (Leg 174B), resistivity (174B IMPH = medium induction phasor-processed resistivity, 174B IDPH = deep induction phasor-processed resistivity [both Leg 174B]), and *P*-wave velocity (174B V_P = compressional wave velocity measured with downhole sonic sonde [Leg 174B]). A summary of core recovery and lithologic units is provided at far left (after Shipboard Scientific Party, 1979, fig. 9). DSDP = Deep Sea Drilling Project. Electrofacies log after Bartetzko et al. (2001).

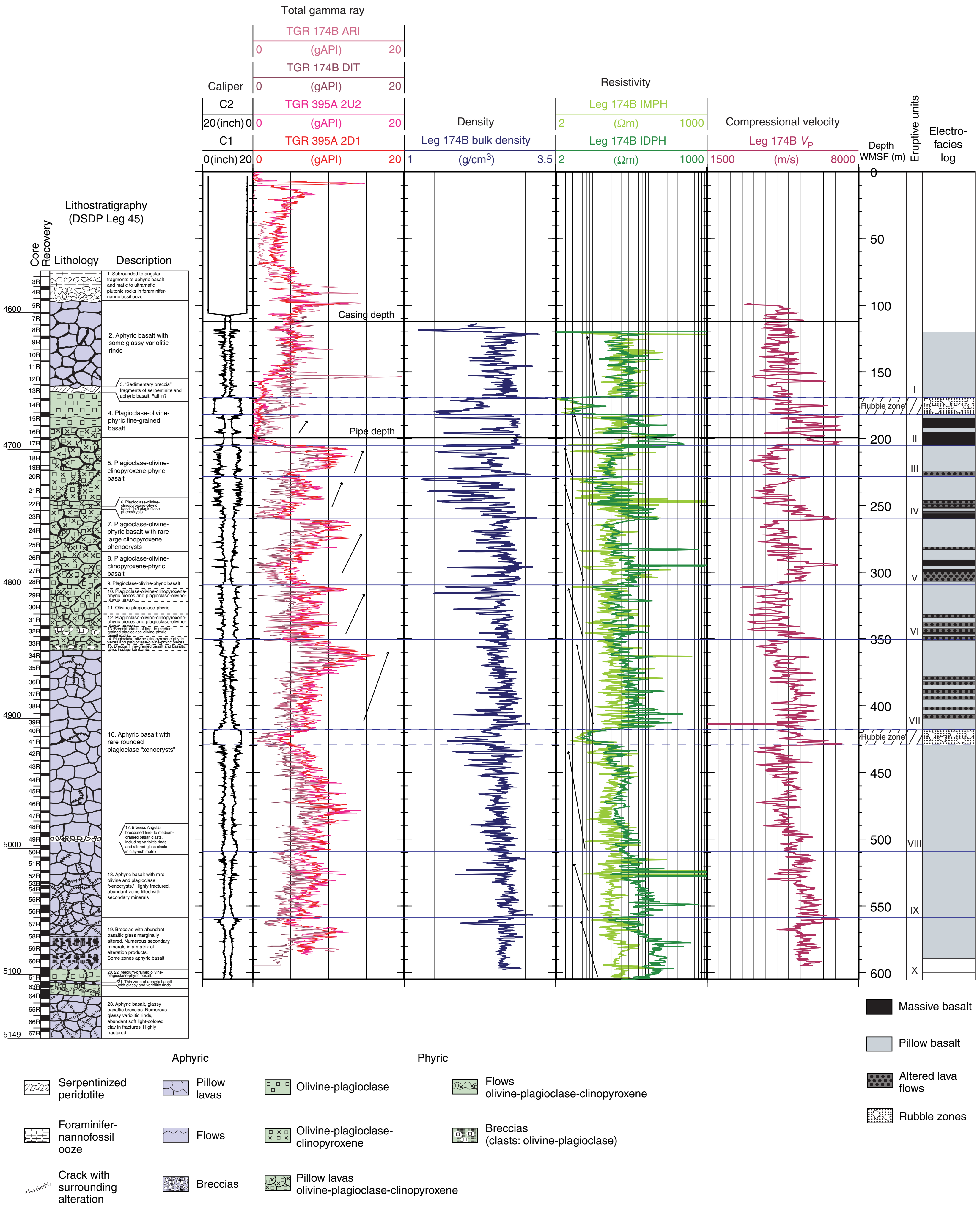

Figure F4. Configuration of the primary parts of the new subseafloor borehole observatory (CORK) deployed in Hole 395A.

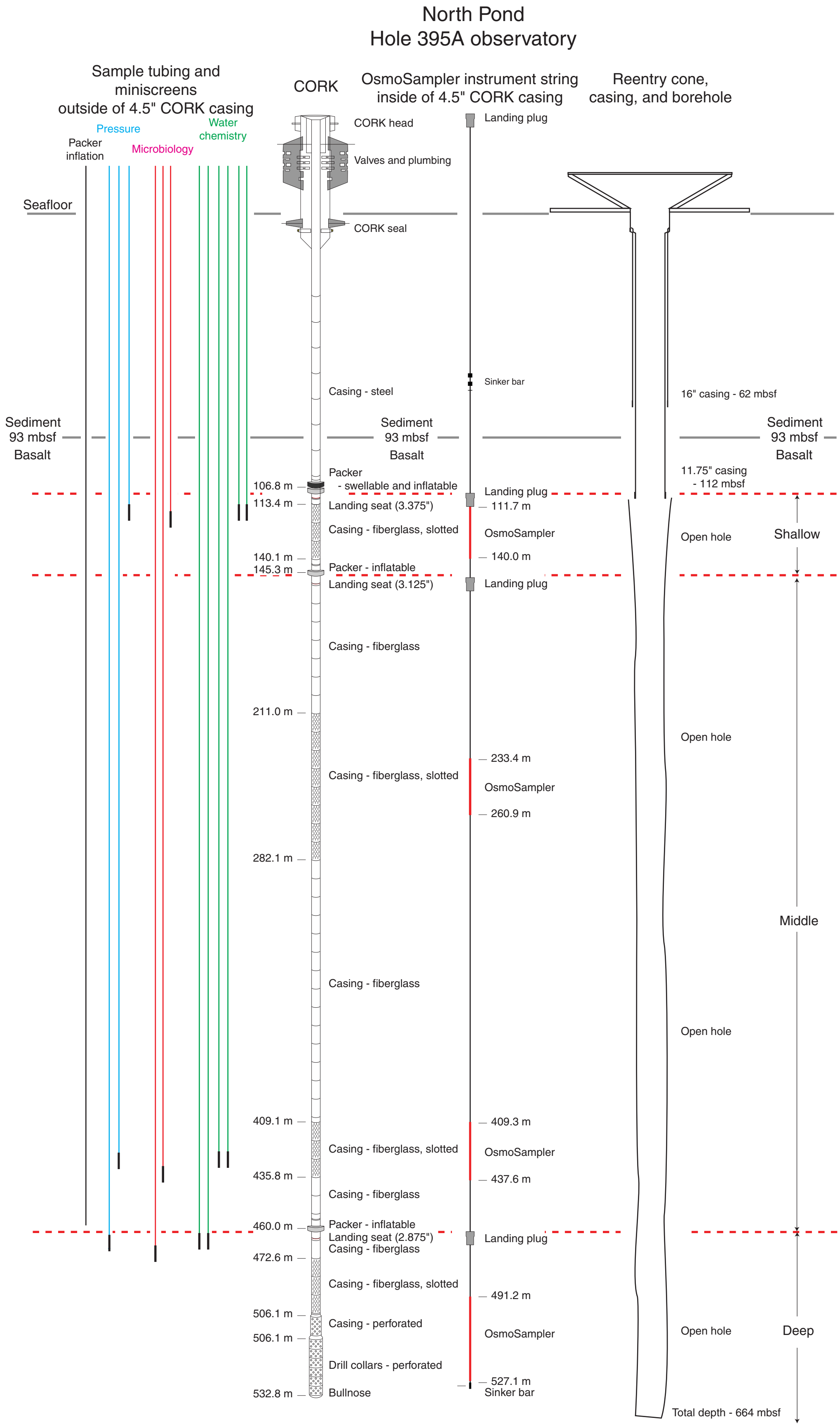

Figure F5. Summary of Hole U1382A logging results. Blue lines = log unit divisions, black lines = limits of pipe and casing. Measurements include borehole diameter (C1, C2 = Formation MicroScanner [FMS] Pass 1; CALI = adapted microbiology combination I [AMC I] uplog), gamma ray (TGR FMS p2, TGR FMS p1 = total gamma ray from FMS-HNGS Pass 1, Pass 2; TGR FMS DL = total gamma ray from FMS-HNGS downlog; TGR EDTC DL = total gamma ray from AMC I downlog), density (bulk density = from AMC I uplog, bulk density HR = high-resolution data from AMC I uplog, MAD = moisture and density testing on discrete samples), resistivity (RLA5 UL, RLA5 DL = deepest resistivity from AMC I uplog, downlog; RLA4 UL and RLA4 DL = deep resistivity from AMC I uplog, downlog), and temperature (Temp UL, Temp DL = temperature from LEH-MT sensor on AMC I uplog, downlog). A summary of core recovery and lithologic units is provided at the far left. (Figure shown on next page.)

Figure F5 (continued). (Caption shown on previous page.)

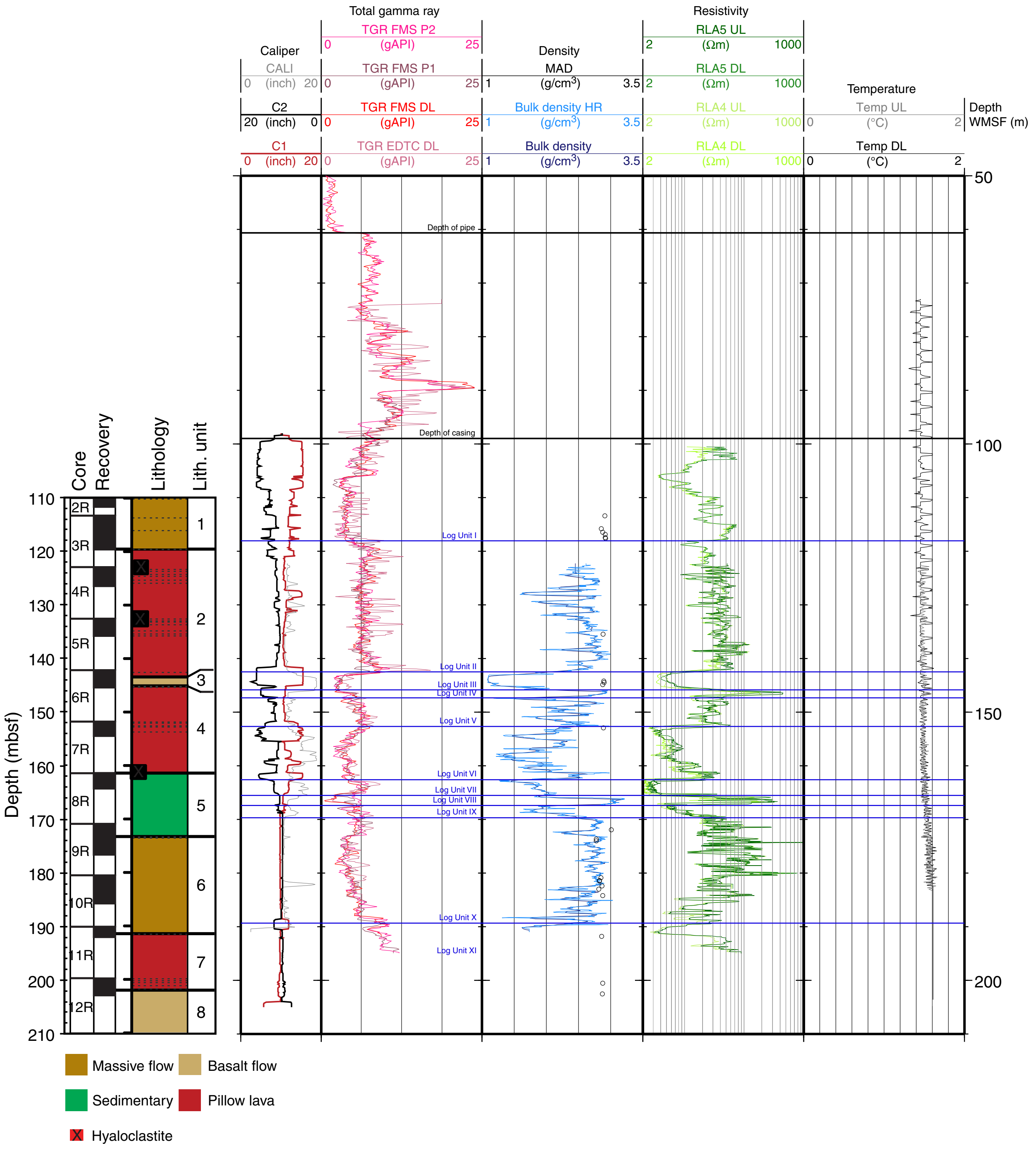

Figure F6. Configuration of the primary parts of the subseafloor borehole observatory (CORK) installed in Hole U1382A.

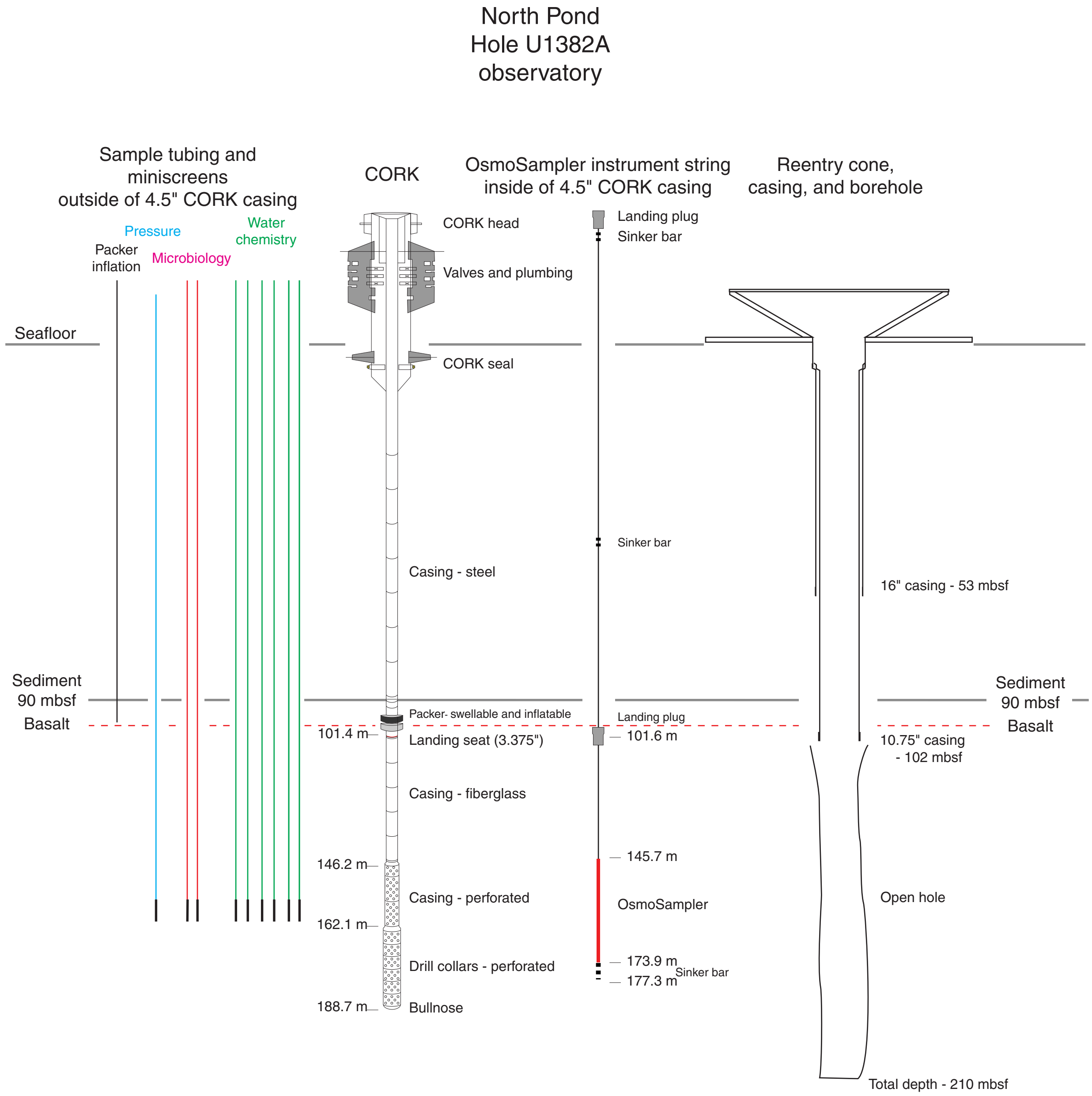

Figure F7. Schematic of the reentry cone and casing installed in Hole U1383B. CSG = casing, TD = total depth.

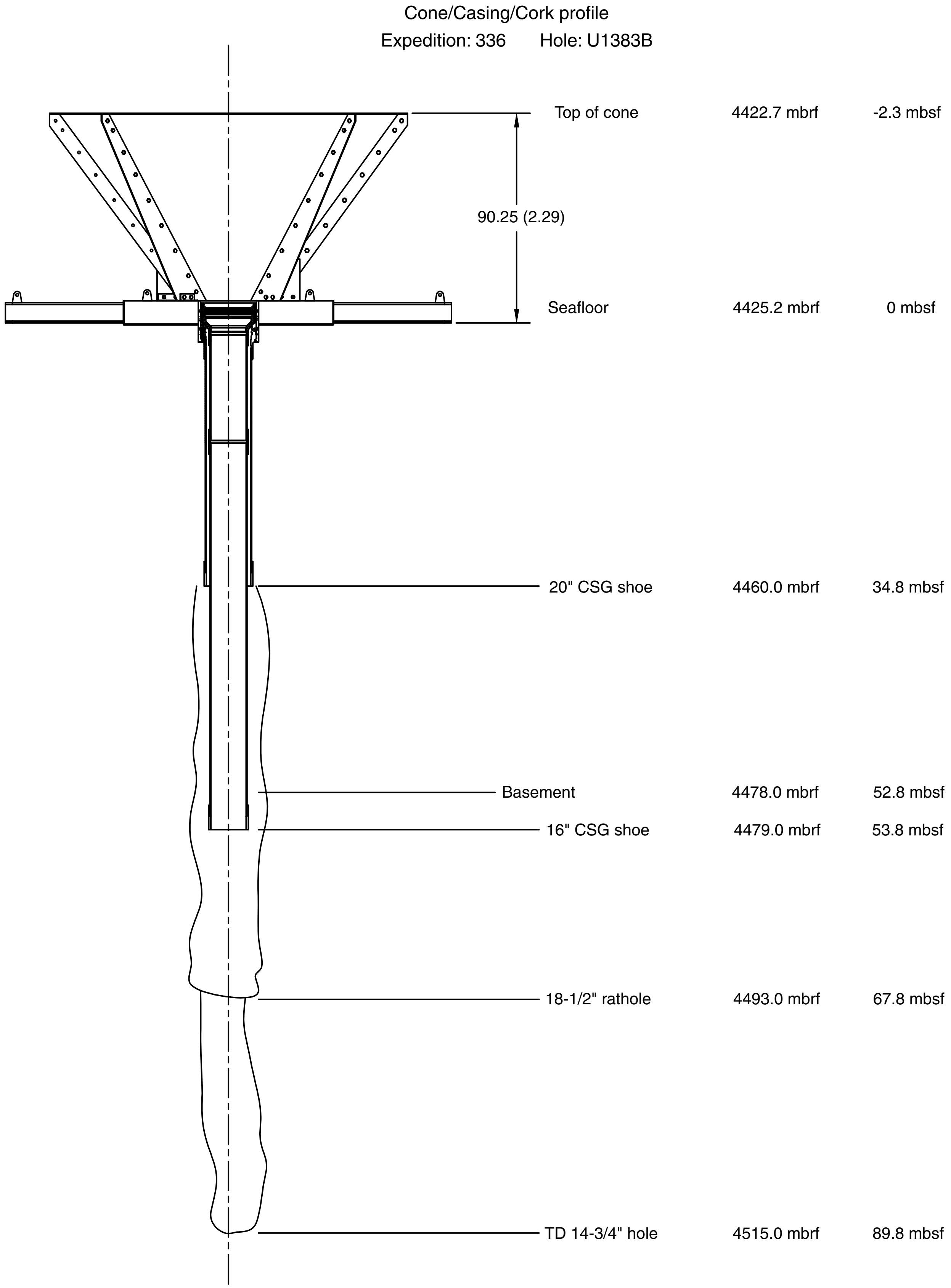

Figure F8. Summary of Hole U1383C logging results. Blue lines = log unit divisions, black lines = limits of pipe and casing. Measurements include borehole diameter (FMS C1, C2 = Formation MicroScanner [FMS] Pass 1; CALI = adapted microbiology combination II [AMC II] Uplog 1), gamma ray (TGR AMCII UL2 = total gamma ray from AMC II Uplog 2; TGR FMS P1, P2 = total gamma ray from FMS-sonic Pass 1, Pass 2; TGR AMCII D1 = total gamma ray from AMC II Downlog 1), density (bulk density = from AMC II Uplogs 1 and 2; MAD = moisture and density testing on discrete core samples), apparent resistivity (calculated resistivity FMS P2, FMS P1 = calculated resistivity from FMS pad average from Pass 1, Pass 2), compressional velocity (V_P core = from discrete core cube samples; V_P P1, P2 = from FMS-sonic Pass 1, Pass 2). A summary of core recovery and lithologic units is provided at the far left, and on the far right is electrical stratigraphy based on FMS electrical images. (Figure shown on next page.)

Figure F8 (continued). (Caption shown on previous page.)

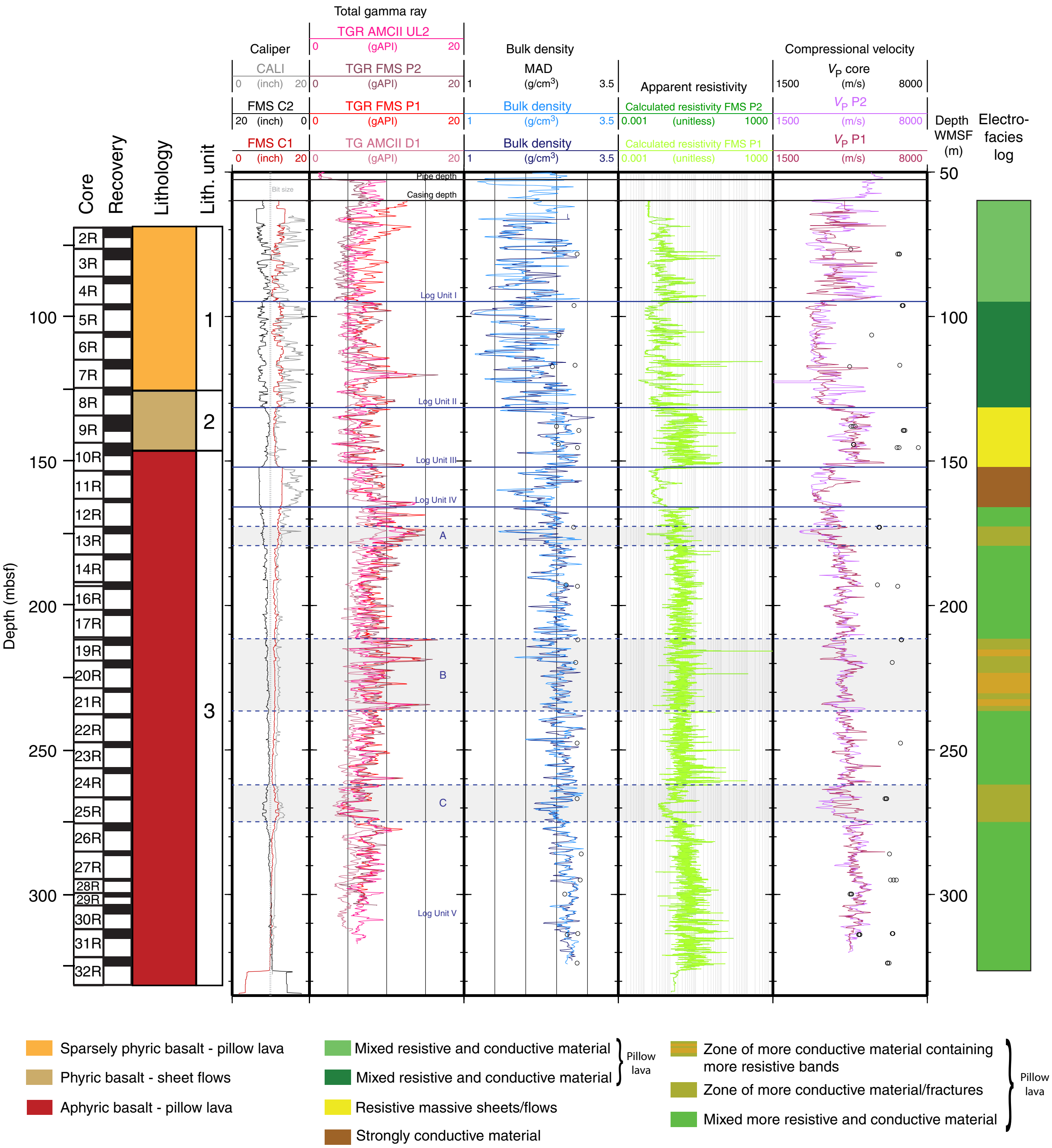

Figure F9. Configuration of the primary parts of the subseafloor borehole observatory (CORK) installed in Hole U1383C.

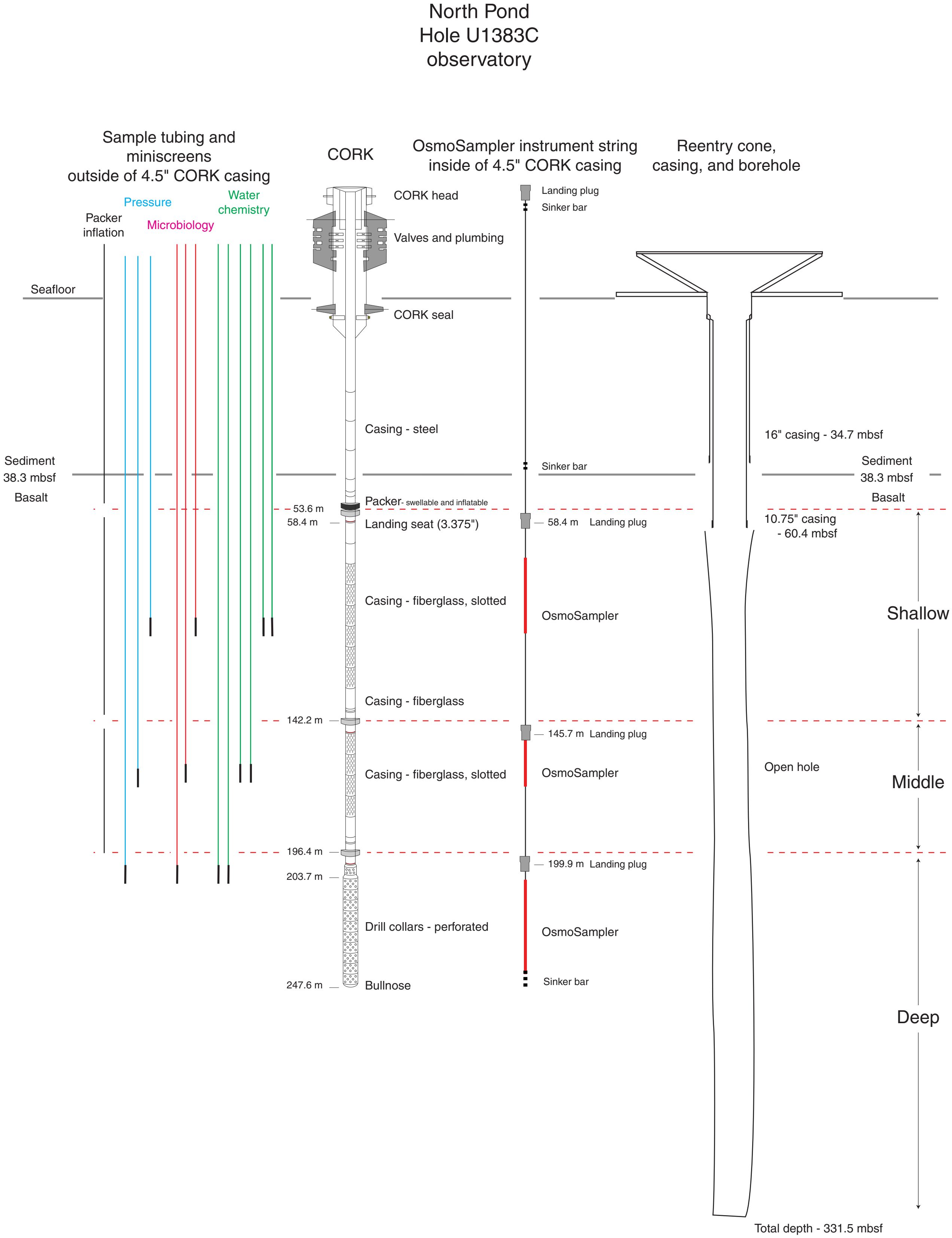

Figure F10. Summary of basement section cored, Hole U1383C.

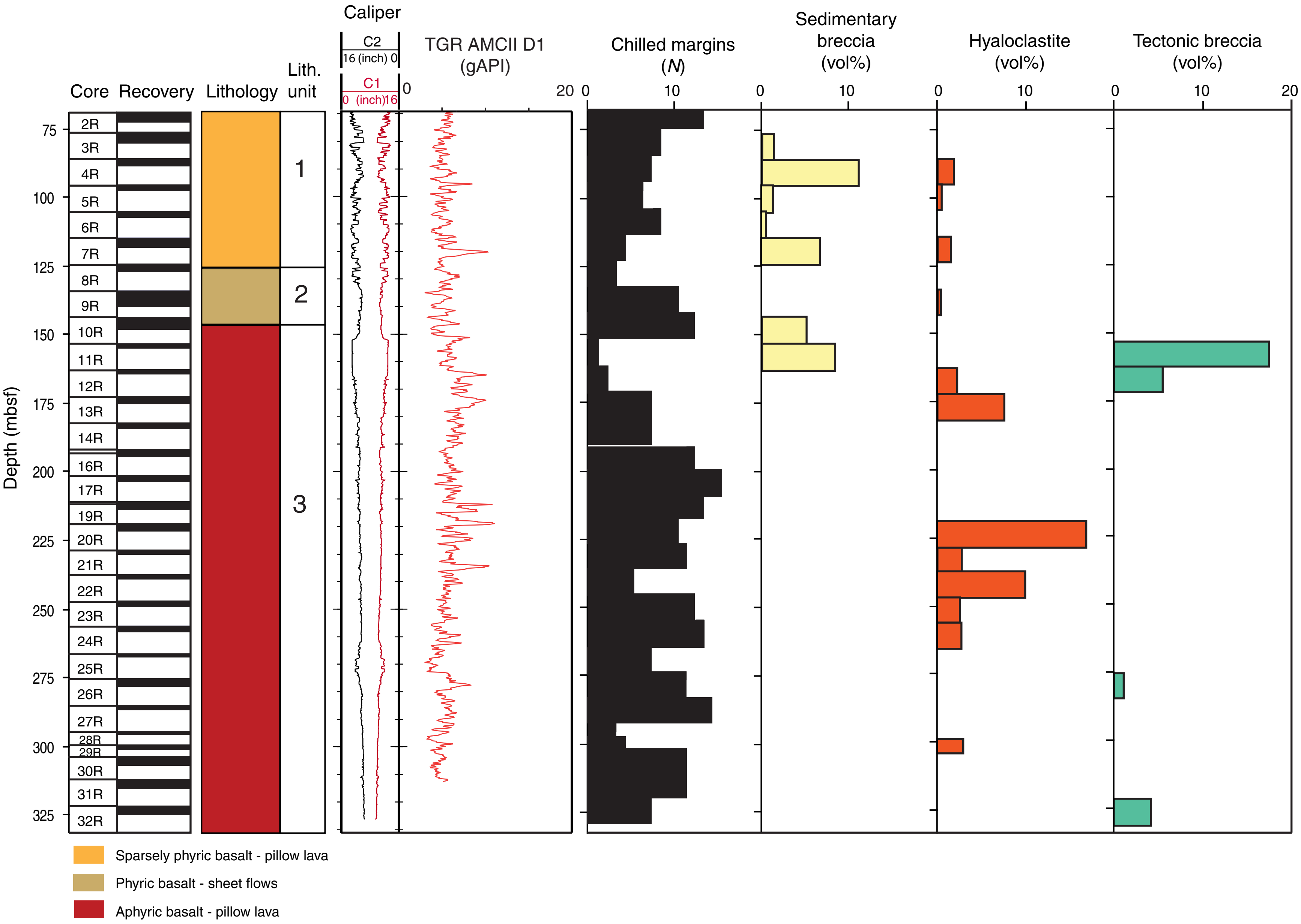

Figure F11. Summary of alteration and basement section cored, Hole U1383C.

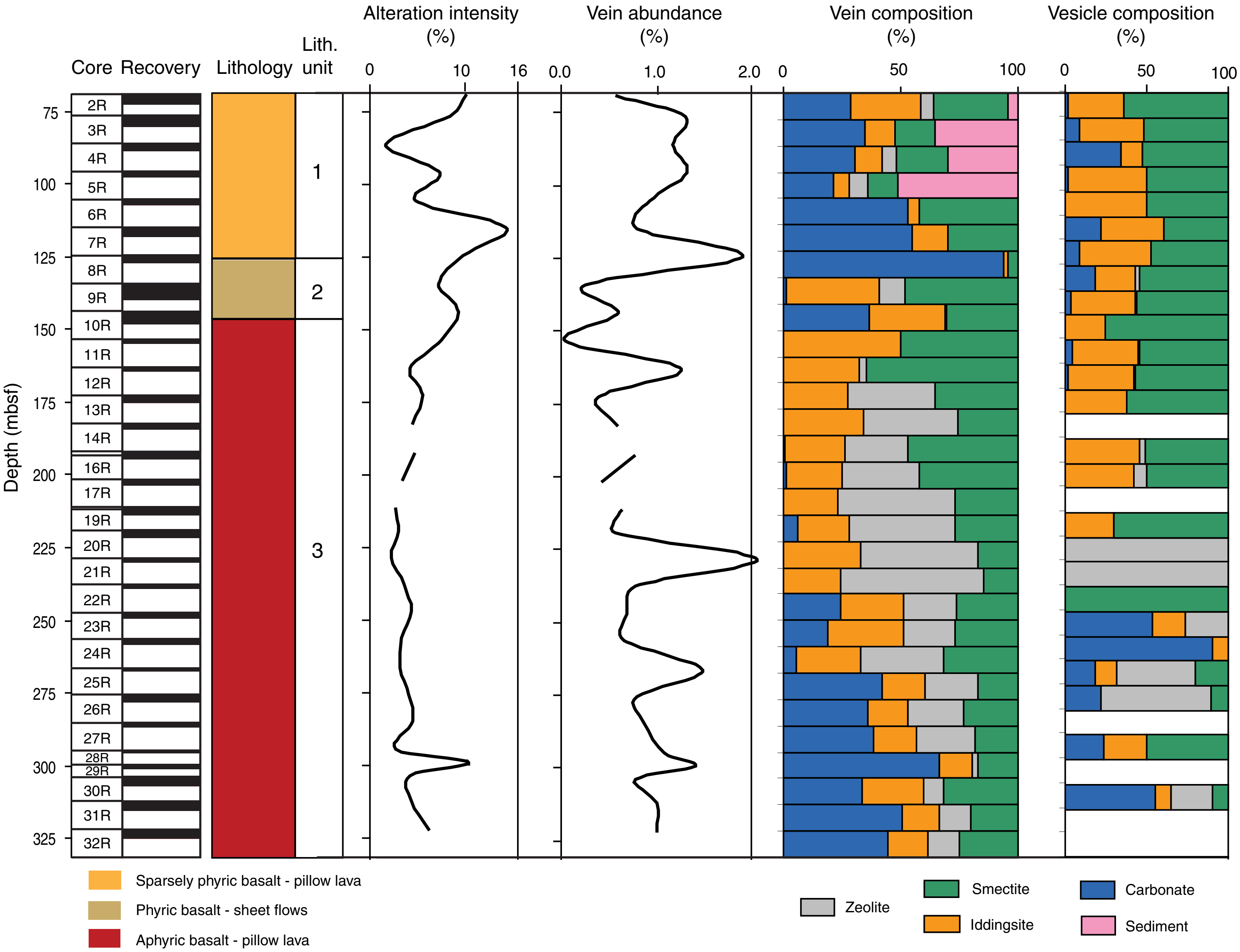

Figure F12. Summary of basement section cored, Hole U1382A. TGR FMS dl = total gamma ray from FMS-HNGS downlog.

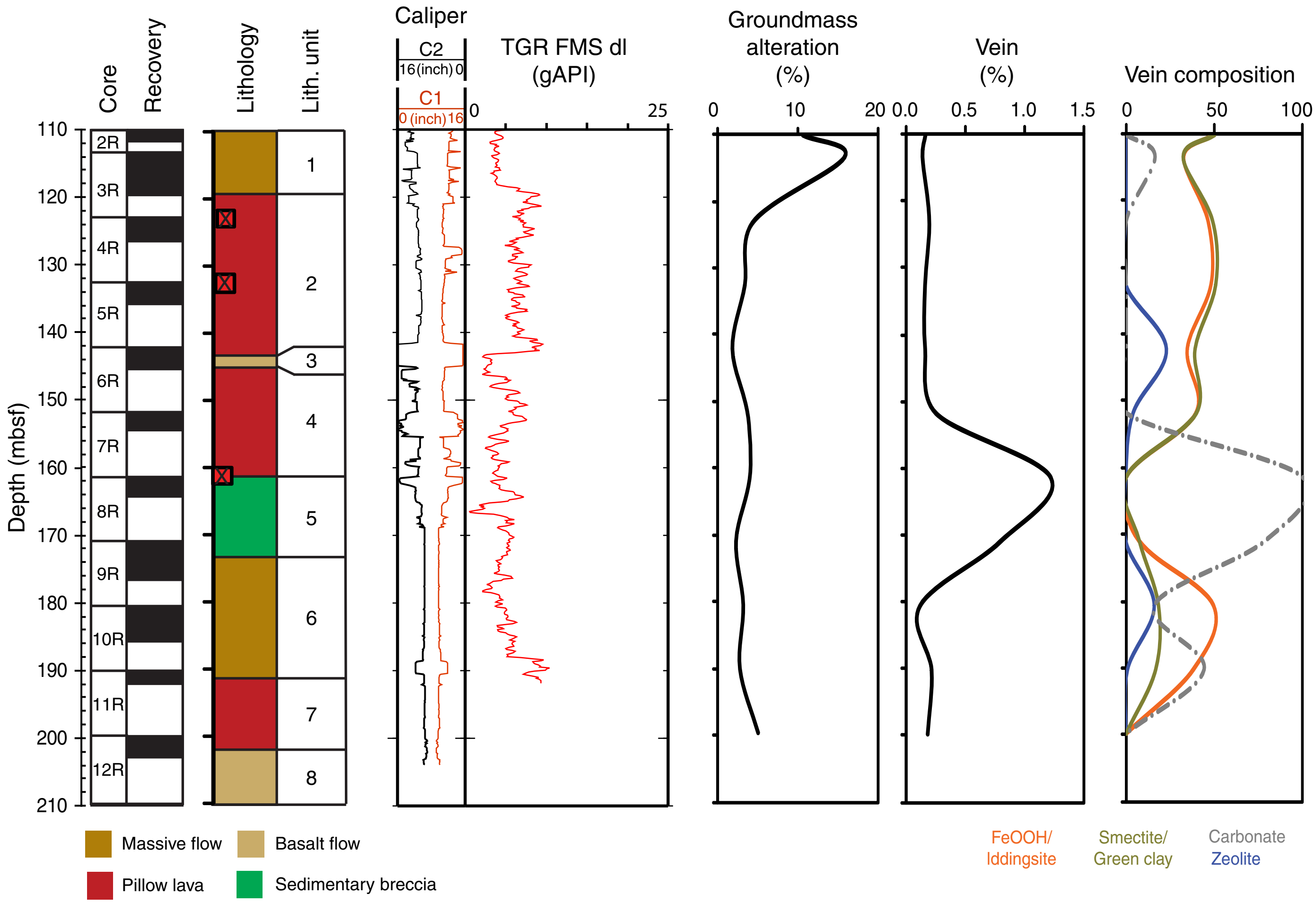

Figure F13. Comparison of page views (top) and visits (bottom) to the *JOIDES Resolution* website (joidesresolution.org/) during three different time periods.