Integrated Ocean Drilling Program
Expedition 327 Preliminary Report

Juan de Fuca Ridge-Flank Hydrogeology

The hydrogeologic architecture of basaltic oceanic crust: compartmentalization, anisotropy, microbiology, and crustal-scale properties on the eastern flank of Juan de Fuca Ridge, eastern Pacific Ocean

5 July–5 September 2010

Expedition 327 Scientists

Published by
Integrated Ocean Drilling Program Management International, Inc.,
for the Integrated Ocean Drilling Program

Publisher's notes

Material in this publication may be copied without restraint for library, abstract service, educational, or personal research purposes; however, this source should be appropriately acknowledged. Core samples and the wider set of data from the science program covered in this report are under moratorium and accessible only to Science Party members until 5 September 2011.

Citation:

Expedition 327 Scientists, 2010. Juan de Fuca Ridge-flank hydrogeology: the hydrogeologic architecture of basaltic oceanic crust: compartmentalization, anisotropy, microbiology, and crustal-scale properties on the eastern flank of Juan de Fuca Ridge, eastern Pacific Ocean. *IODP Prel. Rept.,* 327. doi:10.2204/iodp.pr.327.2010

Distribution:
Electronic copies of this series may be obtained from the Integrated Ocean Drilling Program (IODP) Scientific Publications homepage on the World Wide Web at **www.iodp.org/scientific-publications/.**

This publication was prepared by the Integrated Ocean Drilling Program U.S. Implementing Organization (IODP-USIO): Consortium for Ocean Leadership, Lamont Doherty Earth Observatory of Columbia University, and Texas A&M University, as an account of work performed under the international Integrated Ocean Drilling Program, which is managed by IODP Management International (IODP-MI), Inc. Funding for the program is provided by the following agencies:

National Science Foundation (NSF), United States

Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan

European Consortium for Ocean Research Drilling (ECORD)

Ministry of Science and Technology (MOST), People's Republic of China

Korea Institute of Geoscience and Mineral Resources (KIGAM)

Australian Research Council (ARC) and New Zealand Institute for Geological and Nuclear Sciences (GNS), Australian/New Zealand Consortium

Ministry of Earth Sciences (MoES), India

October 2010

Expedition 327 participants

Expedition 327 scientists

Andrew Fisher
Co-Chief Scientist
Earth and Planetary Sciences Department
University of California, Santa Cruz
1156 High Street
Santa Cruz CA 95064
USA
afisher@ucsc.edu

Takeshi Tsuji
Co-Chief Scientist
Graduate School of Engineering
Kyoto University
C1-1-110 Kyotodaigaku-Katsura
Nishikyo-ku, Kyoto 615-8540
Japan
tsuji@earth.kumst.kyoto-u.ac.jp

Katerina Petronotis
Expedition Project Manager/Staff Scientist
Integrated Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA
petronotis@iodp.tamu.edu

Stefan Mrozewski
Logging Staff Scientist
Borehole Research Group
Lamont-Doherty Earth Observatory
PO Box 1000, Route 9W
Palisades NY 10964
USA
stefan@ldeo.columbia.edu

Keir Becker
CORK Specialist/Hydrologist
Division of Marine Geology and Geophysics
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami FL 33149-1098
USA
kbecker@rsmas.miami.edu

James P. Cowen
Microbiologist/Organic Geochemist
Department of Oceanography/SOEST
University of Hawaii at Manoa
Marine Sciences Building
Honolulu HI 96822
USA
jcowen@soest.hawaii.edu

Michelle Harris
Petrologist
National Oceanography Centre
University of Southampton
European Way
Southampton SO14 3GR
United Kingdom
michelle.harris@noc.soton.ac.uk

Samuel M. Hulme
Inorganic Geochemist/CORK Specialist
Hawaii Institute of Geophysics and Planetology
University of Hawaii at Manoa
1680 East-West Road
Postal Building, Room 504
Honolulu HI 96822
USA
hulme@higp.hawaii.edu

Katherine Inderbitzen
Physical Properties Specialist
Division of Marine Geology and Geophysics
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
University of Miami
Miami FL 33149-1098
USA
kinderbitzen@rsmas.miami.edu

Fuwu Ji
Inorganic Geochemist
School of Ocean and Earth Science
Tongji University
1239 Siping Road
Shanghai 200092
P.R. China
jifuwu@tongji.edu.cn

Reona Masui
Geophysicist/Physical Properties Specialist
Graduate School of Engineering
Kyoto University
C1-1-118 Kyotodaigaku-Katsura
Nishikyo-ku, Kyoto 615-8540
Japan
r_masui@earth.kumst.kyoto-u.ac.jp

Hiroki Miyamoto
Logging Scientist/Structural Geologist
Graduate School of Engineering
Kyoto University
C1-1-118 Kyotodaigaku-Katsura
Nishikyo-ku, Kyoto 615-8540
Japan
h_miyamoto@earth.kumst.kyoto-u.ac.jp

Sylvain Morvan
CORK Engineer
Laboratoire de Géologie
École Normale Supérieure
24 Rue Lhomond
75231 Paris
France
morvan@geologie.ens.fr

Beth Orcutt
Microbiologist/Organic Geochemist
Center for Geomicrobiology
Århus Universitet
Ny Munkegade 114-116, Building 1540
8000 Århus
Denmark
beth.orcutt@biology.au.dk

Jennifer Rutter
Inorganic Geochemist/Petrologist
National Oceanography Centre
University of Southampton
European Way
Southampton SO14 3GR
United Kingdom
jer1g09@soton.ac.uk

Amanda G. Turner
Microbiologist/CORK Specialist
Center for Earth Sciences
University of Southern California
3651 Trousdale Parkway
Los Angeles CA 90089-0740
USA
agturner@usc.edu

C. Geoffrey Wheat
Inorganic Geochemist/CORK Specialist
Global Undersea Research Unit
University of Alaska Fairbanks
PO Box 475
Moss Landing CA 95039
USA
wheat@mbari.org

Dustin M. Winslow
Physical Properties Specialist/Hydrologist
Earth and Planetary Sciences Department
University of California, Santa Cruz
1156 High Street
Santa Cruz CA 95064
USA
dwinslow@ucsc.edu

Education and outreach

Leslie Peart
Staff Educator
Consortium for Ocean Leadership
1201 New York Ave NW, Fourth Floor
Washington DC 20005
USA
lpeart@oceanleadership.org

Nora Dinah Bowman
Outreach Officer
Dinah Bowman Studio and Gallery
312 5th Street
Portland TX 78374
USA
dinah@dinahbowman.com

Jean Marie Gautier
Outreach Officer
College Jean Vilar
St. Sever Calvados
14500 Calvados
France
Ronbleud@hotmail.com

Jacqueline Kane
Outreach Officer
St. Ursula Academy
4025 Indian Road
Toledo OH 43606
USA
jkane@toledosua.org

Stephanie Keske
Outreach Officer
Department of Visualization
Texas A&M University
College Station TX 77840
USA
skeske@gmail.com

Bejonty Richardson
Outreach Officer/HBCU Fellow
Science, Engineering, and Technology Department
Virginia State University
1 Hayden Drive
Petersburg VA 23806
USA
chaostheory18@comcast.net

Brigitte Thiberge
Outreach Officer
Lycée Alain Chartier
30 Rue Froide
14400 Ryes
France
brigitte.thiberge@libertysurf.fr

Operational and technical staff

Robert Aduddell
Engineer

Chris Bennight
Chemistry Laboratory

Timothy Blaisdell
Applications Developer

Lisa Brandt
Chemistry Laboratory

Timothy Bronk
Assistant Laboratory Officer

Trevor Cobine
Paleomagnetism Laboratory

James Cordray
Marine Computer Specialist

William Crawford
Imaging Specialist

Lisa Crowder
Assistant Laboratory Officer

Dean Ferrell
Engineering Electronics Technician

Paul Foster
Supervisor of Applications Development

Tim Fulton
Publications Specialist

Clayton Furman
Logging Engineer, Schlumberger

Randy Gjesvold
Marine Instrumentation Specialist

Thomas Gorgas
Physical Properties Laboratory

Kevin Grigar
Engineer

Kristin Hillis
Underway Geophysics Laboratory

Dwight Hornbacher
Applications Developer

Jennifer Hutchinson
Marine Computer Specialist

Sarah-Jane Jackett
Core Laboratory

Eric Jackson
X-Ray/Microbiology Laboratory

J. Cecil Jones
Cementer, BJ Services Company

Mike Meiring
Engineering Electronics Technician

Stephen Midgley
Operations Superintendent

Lara Miles
Curatorial Specialist

William Mills
Laboratory Officer

Michael Storms
Operations Superintendent

Garrick Van Rensburg
Marine Instrumentation Specialist

Abstract

Integrated Ocean Drilling Program (IODP) Expedition 327 and related experiments focus on understanding fluid–rock interactions in young, upper ocean crust on the eastern flank of the Juan de Fuca Ridge, delineating the magnitude and distribution of hydrologic properties; the extent to which crustal compartments are connected or isolated (laterally and with depth); the rates and spatial extent of ridge-flank fluid circulation; and links between ridge-flank circulation, crustal alteration, and geomicrobial processes. Expedition 327 built on the achievements of IODP Expedition 301 and subsequent submersible and remotely operated vehicle (ROV) expeditions. Both drilling expeditions installed subseafloor borehole observatories ("CORKs") in basement holes to allow borehole conditions to recover to a more natural state after the dissipation of disturbances caused by drilling, casing, and other operations; provide a long-term monitoring and sampling presence for determining fluid pressure, temperature, composition, and microbiology; and facilitate the completion of active experiments to resolve crustal hydrogeologic conditions and processes.

During Expedition 327, two basement holes were cored and drilled at Site U1362. Hole U1362A was cored and drilled to 528 meters below seafloor (mbsf) (292 meters subbasement [msb]), subjected to geophysical logging and hydrologic testing, and instrumented with a multilevel CORK observatory. Hole U1362B was drilled to 359 mbsf (117 msb), subjected to a 24 h pumping and tracer injection experiment, and instrumented with a single-level CORK observatory. Both CORK observatories include monitoring of pressure and temperature and downhole fluid and microbiology sampling. Wellhead samplers will be added and a long-term cross-hole test will be initiated during a postdrilling ROV expedition scheduled for Summer 2011. In addition, part of an instrument string deployed in Hole U1301B during Expedition 301 was recovered, and a replacement string of thermal sensors was installed. Finally, a program of shallow sediment coring was completed adjacent to Grizzly Bare outcrop, a suspected site of regional hydrothermal recharge. Thermal measurements and analyses of pore fluid and microbiological samples from a series of holes aligned radially from the outcrop edge will elucidate rates of fluid transport and evolution during the initial stages of ridge-flank hydrothermal circulation.

Introduction and background

Scientific background

Fluid flow within the volcanic oceanic crust influences the thermal and chemical state and evolution of oceanic lithosphere and lithospheric fluids; the establishment and maintenance of subseafloor microbial ecosystems; the diagenetic, seismic, and magmatic activity along plate-boundary faults; the creation of ore and hydrate deposits both on and below the seafloor; and the exchange of fluids and solutes across continental margins (e.g., Alt, 1995; Huber et al., 2006; Parsons and Sclater, 1977; Peacock and Wang, 1999). The global hydrothermal fluid mass flux through the upper oceanic crust rivals the global riverine fluid flux to the ocean and effectively passes the volume of the oceans through the crust once every 10^5–10^6 y (Elderfield and Schultz, 1996; Johnson and Pruis, 2003; Mottl, 2003). Most of this flow occurs at relatively low temperatures, far from volcanically active seafloor-spreading centers where new ocean floor is created. This "ridge-flank" circulation can be influenced by off-axis volcanic or tectonic activity but is driven mainly by the transport of lithospheric heat from below the crust. Although the average maximum age at which measurable heat is lost advectively from oceanic lithosphere is 65 Ma (Parsons and Sclater, 1977), many sites remain hydrologically active for tens of millions of years beyond this age, with circulation largely confined to basement rocks that redistribute heat below thick sediments (Fisher and Von Herzen, 2005; Von Herzen, 2004).

Despite the importance of fluid–rock interactions in the crust, little is known about the magnitude and distribution of critical hydrologic properties; the extent to which crustal compartments are well connected or isolated (laterally and with depth); the rates and spatial extent of ridge-flank fluid circulation; or the links between ridge-flank circulation, crustal alteration, and geomicrobial processes. Integrated Ocean Drilling Program (IODP) Expedition 327 is part of a long-term experimental program that began nearly two decades ago and has included multiple survey, drilling, submersible, and remotely operated vehicle (ROV) expeditions; observatory and laboratory testing, sampling, and monitoring; and modeling of coupled fluid-thermal-chemical-microbial processes. Expedition 327 builds on the technical and scientific achievements and lessons learned during Ocean Drilling Program (ODP) Leg 168 (Davis, Fisher, Firth, et al., 1997), which focused on hydrothermal processes within uppermost basement rocks and sediments along an age transect (Fig. **F1**), and IODP Expedition 301 (Fisher, Urabe, Klaus, and the Expedition 301 Scientists, 2005), which penetrated deeper into the crust at the eastern end of the Leg 168 transect (Fig. **F2**).

During both expeditions, subseafloor borehole observatories ("CORKs") were installed in basement holes to allow borehole conditions to recover to a more natural state after the dissipation of disturbances caused by drilling, casing, and other operations; to provide a long-term monitoring and sampling presence for determining fluid pressure, temperature, composition, and microbiology; and to facilitate the completion of active experiments to resolve crustal hydrogeologic conditions and processes (Fisher et al., 2005). During subsequent ROV and submersible expeditions, data were downloaded from the Leg 168 and Expedition 301 CORKs, and batteries, data loggers, and sampling systems at the seafloor and downhole were replaced.

The primary goals of Expedition 327 were to (1) drill two new basement holes, core and wireline log one of these holes across a depth range of 100–360 meters subbasement (msb), conduct a 24 h pumping and tracer injection test, and install a multilevel CORK in each of the new holes; (2) recover an existing CORK installed in a shallow basement hole during Leg 168, deepen the hole by ~40 m, and install a new multilevel CORK with instrumentation; and (3) recover and replace an instrument string deployed in one of the Expedition 301 CORKs.

Geological setting and earlier work

Many studies have summarized geology, geophysics, and basement-fluid chemistry and hydrogeology within young seafloor on the eastern flank of the Endeavour segment of the Juan de Fuca Ridge (e.g., Davis et al., 1992; Elderfield et al., 1999; Fisher et al., 2003; Hutnak et al., 2006; Mottl et al., 1998; Stein and Fisher, 2003; Wheat and Mottl, 1994; Wheat et al., 2000, 2003, 2004). Topographic relief associated with the Juan de Fuca Ridge axis and abyssal hill bathymetry on the ridge flank has helped trap turbidites flowing west from the continental margin (Fig. **F1**), which has resulted in the burial of young oceanic basement rocks under thick sediments. Sediment cover is regionally thicker and more continuous to the east, but there are seamounts and smaller basement outcrops up to 100 km east of the spreading center, north and south of the Expedition 327 work area. Regional basement relief is dominated by linear ridges and troughs (Fig. **F3**) oriented subparallel to the spreading center and produced mainly by faulting, variations in magmatic supply at the ridge, and off-axis volcanism. Low-permeability sediment limits advective heat loss across most of the ridge flank, resulting in strong thermal, chemical, and alteration gradients in basement.

During Leg 168, a transect of eight sites was drilled across 0.9–3.6 Ma seafloor; sediment, rock, and fluid samples were collected; thermal, geochemical, and hydrogeologic conditions in basement were determined; and a series of CORKs was installed in the upper crust (Davis, Fisher, Firth, et al., 1997). Two of the Leg 168 observatories were placed in 3.5–3.6 Ma seafloor in Holes 1026B and 1027C, near the eastern end of the drilling transect (Figs. F2, F3). Expedition 301 returned to this area and drilled deeper into basement; sampled additional sediment, basalt, and microbiological materials; replaced the borehole observatory in Hole 1026B; and established two additional CORK observatories at Site U1301 for use in long-term, three-dimensional hydrogeologic experiments (Fisher, Urabe, Klaus, and the Expedition 301 Scientists, 2005).

Before Leg 168 there was a largely two-dimensional view of the dominant fluid circulation pathways across the eastern flank of the Juan de Fuca Ridge, with recharge occurring across areas of basement exposure close to the ridge (near the western end of the Leg 168 transect) and flowing toward the east. Some results from Leg 168 are consistent with this view, including seafloor heat flow and basement temperatures that increase and basement fluids that are warmer and more altered with progression from west to east along the drilling transect (Davis et al., 1999; Elderfield et al., 1999; Stein and Fisher, 2003). However, Leg 168 results and subsequent surveys revealed inconsistencies with this simple model of large-scale hydrogeologic flow. Although basement fluids are warmer and older along the western end of the drilling transect with increasing distance from the ridge (from Sites 1023 to 1025), fluids are younger with respect to ^{14}C at the next nearest site to the east (Site 1031) and even younger farther to the east (Site 1026), despite being warmer and more altered (Elderfield et al., 1999; Walker et al., 2007). In addition, reexamination of existing bathymetric data and collection of new data near Sites 1023 to 1025 show that basement outcrops to the north and south could allow hydrothermal fluids to recharge and discharge, with flow occurring largely perpendicular to the Leg 168 transect (Hutnak et al., 2006). It is also difficult to understand how basement fluids flowing from west to east at the western end of the Leg 168 transect might exit the crust where sediment cover is thick and continuous and there are no known outcrops (Davis et al., 1999; Hutnak et al., 2006).

Regional site surveys in preparation for Expedition 301 focused on and near basement outcrops that could be fluid entry and exit points to and from the crust (Fisher et al., 2003; Hutnak et al., 2006; Zühlsdorff et al., 2005). Thermal data suggest a significant component of south–north (ridge parallel, along strike) fluid flow in basement at the eastern end of the Leg 168 transect, an interpretation consistent with geochemical studies (Walker et al., 2007; Wheat et al., 2000). Bathymetric, sediment thickness, and heat flow data near the western end of the transect are also consistent with a significant component of north–south fluid flow in basement (Hutnak et al., 2006). Numerical models were created to simulate single-outcrop and outcrop-to-outcrop hydrothermal circulation between Grizzly Bare and Baby Bare outcrops (separated by 52 km in the along-strike direction) and to estimate the nature of basement properties that would allow these inferred patterns and rates of fluid circulation (Fig. F4). These studies show that outcrop-to-outcrop hydrothermal circulation can be sustained when basement permeability is $\geq 10^{-12}$ m^2. At lower permeabilities, too much energy is lost during lateral fluid transport for circulation to continue without forcing, given the limited driving pressure difference at the base of recharging and discharging fluid columns (Hutnak et al., 2006). In addition, fluid temperatures in upper basement are highly sensitive to modeled permeability. When basement permeability is too high (10^{-10} to 10^{-9} m^2), as interpreted from analyses of formation responses to tidal and tectonic perturbations, fluid circulation is so rapid that basement is chilled to temperatures below those seen regionally (modeled values of 20°–50°C). A good match is achieved to observed upper basement temperatures of 60°–65°C when lateral basement permeability is 10^{-11} m^2 (Fig. F4).

Drill string packer experiments in upper basement during Expedition 301 indicate a layered crustal structure with permeabilities of 10^{-12} to 10^{-11} m^2 (Becker and Fisher, 2008). Additional hydrogeologic analyses completed using the formation pressure response to the long-term flow of cold bottom seawater into basement at Site U1301 in the 13 months after drilling, as observed at Site 1027 (2.4 km away) (Fisher et al., 2008), suggest large-scale permeability at the low end of or below values indicated by packer testing (Fig. F5). Results from borehole testing during and after Expedition 301 are broadly consistent with the global ensemble of measurements, but cross-hole tests indicate lower crustal permeability than do single-hole tests (Fig. F6). This result was unexpected because the former method is generally thought to test a much larger crustal volume than does the latter. The results from both sets of measurements and the difference between these permeability estimates and others based on modeling and analyses of formation responses to tidal and tectonic perturbations may be reconciled by azimuthal anisotropy in basement hydrogeologic properties. Azimuthal permeability anisotropy is also consistent with preferential flow in the north–south direction at both ends of the Leg 168 transect, inferred mainly from thermal and chemical observations, and with the highly faulted nature of the upper crust in the Expedition 327 field area (Fig. F3). Experiments conducted during and planned for after Expedition 327 will provide a direct test of permeability anisotropy using a network of sealed borehole observatories.

Seismic studies/Site survey data

Two site surveys were completed in 2000 in support of Expeditions 301 and 327. The Image-Flux survey was completed with the R/V *Sonne* and included nearly 500 lines of seismic data and extensive hydrosweep coverage (Zühlsdorff et al., 2005; Zühlsdorff and Spiess, 2006). The RetroFlux expedition was completed on the R/V *Thomas G. Thompson* with a focus on coring and heat flow and limited acquisition of hydrosweep data (Fisher et al., 2003; Hutnak et al., 2006). Finally, a 2002 expedition of the R/V *Maurice Ewing* collected multichannel seismic (MCS) data mainly across the Juan de Fuca Ridge, with one line positioned to cross Leg 168 and Expedition 301/327 drill sites and additional secondary sites (Carbotte et al., 2008; Nedimovic et al., 2008). Collectively, these data provided clear drilling targets for Expedition 327 operations (Fig. **F3**).

Conversions from two-way traveltime between the seafloor and top of basement to sediment thickness were developed by Davis et al. (1999) using drilling results from Leg 168 (Davis, Fisher, Firth, et al., 1997). Shipboard *P*-wave velocity measurements made on recovered sediments were combined to generate an equation for time–depth conversion. This conversion was shifted linearly to force a fit through basement depths determined during drilling, with a resulting sediment velocity range of 1500–1700 m/s. For Expedition 327, the greatest uncertainty in estimating depths for drilling goals from seismic data lay in picking targets where the upper basement surface is sloped and irregular. Experience from Leg 168 and Expedition 301 suggested that these picks have uncertainties of ±5–10 m, which is consistent with our experience during this expedition.

Scientific objectives

The primary scientific objectives for Expedition 327 comprised work at Sites U1362 (proposed Sites SR-2A and SR-2B; Fisher et al., 2010), 1027, and U1301. Secondary scientific objectives were achieved at Site U1363 (proposed Sites GRB-1A, GRB-2A, and GRB-3A), adjacent to Grizzly Bare outcrop.

Site U1362

We intended to drill and case Hole U1362A (proposed Site SR-2A), the deepest of the two new holes drilled during Expedition 327, through the sedimentary section and the uppermost 100 m of basement, with coring planned only for ~100–260 m into basement. The final hole depth was to be determined by hole conditions and available time. The operations plan included wireline logging with a single string (to assess lithologic layering and properties and locate suitable locations for setting packers), testing for permeability using a drill string packer, and instrumenting the borehole with a multilevel CORK.

We planned to drill and case Hole U1362B (proposed Site SR-2B) through sediment and the upper ~30 m of basement, followed by ~50 m of basement drilling with no coring or logging. A 24 h pumping and tracer injection experiment was scheduled to be completed before the borehole was instrumented with a CORK to monitor a single basement interval. Both of the Site U1362 CORK designs included instruments to monitor formation fluid pressure and temperature, sample fluids (using downhole and wellhead OsmoSamplers), and provide growth substrate for microbes inhabiting the basement aquifer.

Site U1301

The primary scientific objectives at Site U1301 were to recover the CORK instrument string deployed in Hole U1301B during Expedition 301 and deploy a new instrument string that included some combination of thermal sensors, fluid samplers, and microbial growth substrates. The extent of new instrumentation deployed in Hole U1301B would depend on the amount of instrumentation recovered and the amount of space available in the 4½ inch CORK casing. Researchers were unable to recover the instrument string deployed in Hole U1301B in Summer 2009 from the R/V *Atlantis*, despite pulling with a surface winch at >5000 lb. Apparently, the instrument package was being held in the open hole below the CORK, probably because the borehole collapsed after the instrument string was originally deployed. We were hopeful that some instruments would be recovered from Hole U1301B because the coring line on the *JOIDES Resolution* can be pulled with greater force than could the Plasma line used on the portable winch on the *Atlantis*. We also planned to complete a depth check of open casing in Hole U1301B (unless we were fortunate enough to recover the entire instrument string) and collect thermal data inside the CORK to evaluate the thermal state of the borehole surrounding the CORK installation following Expedition 321T cementing operations.

Site 1027

The primary scientific objectives at Site 1027 were to recover the existing CORK in Hole 1027C, core and deepen the hole by ~40–50 m, run hydrologic tests of the open hole, and deploy a new multilevel CORK for monitoring, sampling, and associated experiments. The CORK in Hole 1027C was installed during Leg 168 and originally contained a data logger, pressure sensors, thermistors at multiple depths, and a fluid sampler. These instruments were retrieved in 1999, and the pressure logging system was replaced. The CORK in Hole 1027C was supposed to be replaced during Expedition 301, but problems setting the CORK in Hole U1301B and a lack of time and materials prevented completion of any Hole 1027C operations during that expedition. Hole 1027C was fully sealed and continued to record formation pressure before, during, and after Expedition 301 (Fisher et al., 2008).

Site U1363

Site U1363 (proposed Sites GRB-1A, GRB-2A, and GRB-3A) was drilled adjacent to the northeastern edge of Grizzly Bare outcrop to test the hypothesis that this outcrop is a site of regional hydrothermal recharge. A short transect of holes extending radially away from Grizzly Bare outcrop was expected to show an initial warming and a loss of oxygen and nitrate in basement fluids. Little change was expected for many of the major ions, even with elevated basement temperatures, because of the slow rate of reaction and the short residence time of formation fluids. The microbial population was expected to initially be predominantly that found in bottom seawater. Farther from Grizzly Bare, as dissolved oxygen and nitrate are depleted, we anticipated a decrease in sulfate as a result of diffusive loss to the overlying sediment during rapid lateral flow in basement. Observable changes were expected in additional minor elements and in the microbial communities seen in sediments immediately above basement.

Education, outreach, and communication objectives

An international team of six education, outreach, and communication (EOC) personnel sailed during Expedition 327, with leadership provided by the education director from the United States Implementing Organization (USIO) and assistance from shore-based personnel. Earlier full-length scientific ocean drilling expeditions included a single onboard education officer who focused on a relatively small set of EOC objectives, whereas shorter expeditions or transits have included 12–18 teachers, faculty, and museum professionals who participated in shipboard activities while limited, if any, science operations were performed. The primary goals of the Expedition 327 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 Earth and life science topics, (3) create and distribute multimedia materials (written, photographic, video, and audio) related to expedition objectives and accomplishments, and (4) help Expedition 327 scientific personnel learn to communicate the excitement of their research and other activities to an audience of nonscientists. EOC personnel were also trained in shipboard scientific and technical tasks involving core analysis and collection of downhole data, which was helpful with core processing in the laboratories. The diverse EOC team comprised a high school physics teacher, a computer animation graduate student, an undergraduate engineering student representing Historically Black Colleges and Universities, and an artist (all from the United States) and two high school Earth and life science teachers from France selected by the European Consortium for Ocean Research Drilling (ECORD).

Site summaries

Site U1362

Hole U1362A was drilled and cored to 528 meters below seafloor (mbsf; 292 msb; Fig. **F7**), subjected to geophysical logging and hydrologic testing, and instrumented with a multilevel CORK observatory (Tables **T1, T2, T3**). Hole U1362B was drilled to 359 mbsf (117 msb; Fig. **F8**), subjected to a 24 h pumping and tracer injection experiment, and instrumented with a single-level CORK observatory.

Basement in Hole U1362A was cored from 346.0 to 496.0 mbsf (110–260 msb) with 44.4 m of core recovered. The recovered core consisted of (1) aphyric to moderately phyric pillow basalts, (2) aphyric to sparsely phyric sheet flows, and (3) sparsely to highly phyric basalt flows (Fig. **F9**). The above lithologies were divided into eight units based on changes in lava morphology, rock texture, and phenocryst occurrence. Pillow lava units (Units 1, 3, and 5) were subdivided according to changes in phenocryst abundance and mineralogy. Sheet flow units (Units 4, 6, and 8) were subdivided based on the presence of chilled margins and variations in phenocryst mineralogy. No breccia units were recovered (only two centimeter-sized breccia pieces were recovered in total).

Pillow basalt is the most abundant flow morphology of Hole U1362A, with Units 1, 3, and 5 accounting for 78.85 m of the stratigraphy. Pillow basalt was primarily identified by the occurrence of curved glassy chilled margins with perpendicular radial cooling cracks. The basalt is sparsely to highly phyric with olivine, clinopyroxene, and plagioclase phenocrysts having spherulitic, hyalophitic, intersertal, and glomeroporphyritic textures. Pillow basalts range from sparsely to moderately vesicular, with a range of secondary minerals filling the vesicles. Alteration in the pillows is variable and ranges from slight to highly altered.

Sheet flows are the second most common lava morphology in Hole U1362A, and these were classified on the basis of continuous sections of the same lithology that increase in grain size downward through the unit. Curated core recovery in these units averaged 43% and was as high as 119% in Core 327-U1362A-17R. Two near-continuous sheet flows were recovered in Cores 17R and 18R and were divided into two subunits on the basis of a change in phenocryst mineralogy. The primary mineralogy of the sheet flows is very similar to that of the pillow basalts, comprising a range of aphyric to moderately phyric basalt with olivine, clinopyroxene, and plagioclase phenocrysts. Grain size within the sheet flows ranges from cryptocrystalline to fine grained, and textures vary from intersertal to intergranular. The sheet flows are nonvesicular to highly vesicular, with some flows exhibiting a similar abundance throughout and others having high variability within the flow. Alteration within the sheet flows varies from slight to complete. Fracture and vein intensity within the sheets flows is lower than in the pillow basalts and resulted in improved core recovery and larger individual pieces.

The third lithologic type of basalt flow was classified based on the absence of definitive morphological features associated with either pillow lavas or sheet flows, allowing only a general "basalt flow" interpretation to be made. These units are aphyric to moderately phyric crypto- to microcrystalline basalt with the same primary mineralogy as all basalts from Hole U1362A. They are generally sparsely vesicular with secondary minerals filling vesicles, and textures vary from hyalophitic to variolitic. Alteration is moderate to high and is present as groundmass replacement (mesostasis and phenocrysts), vesicle fill, vein formation, and halos.

Two individual pieces of breccia were recovered, a hyaloclastite sample in Core 327-U1362A-13R and a hydrothermal breccia vein in Core 327-U1362A-9R. The hyaloclastite is characterized by moderately to highly altered angular clasts in a saponite and altered glass matrix. The hydrothermal breccia vein is formed of subangular clasts with moderate alteration similar to the host rock and exhibits evidence of clast rotation and separation with a matrix of highly altered, ground basalt.

Geochemical analyses of basalt samples indicate that they are all normal depleted mid-ocean-ridge basalt (N-MORB), and based on cross-plots of TiO_2 vs. Zr they are inferred to all have the same magmatic source. Hydrothermal alteration of the basement was observed in all basalts from Hole U1362A, varying from slight to completely altered, with the majority moderately altered. Alteration of the rocks manifests in four ways: (1) replacement of phenocrysts, (2) replacement of groundmass (mostly mesostasis), (3) filling of veins and adjacent alteration halos, and (4) lining and filling of vesicles. In thin section, alteration was observed to range from 8% to 91%. Away from vesicles and veins, background alteration is generally moderate to high in pillow lavas and predominantly moderate in sheet and basalt flows and is dominated by saponitic background alteration. Olivine is present only as completely replaced pseudomorphs.

The secondary mineralogy is dominated by clay minerals that are present in all four types of alteration. Saponite is the most abundant of the clay minerals and is present as black, dark green, greenish brown, and pale blue colors and in thin section is characterized by a pale brown color and mottled or fibrous form. Celadonite is also present in all four styles of alteration but is less abundant than saponite. In thin section, celadonite is bright green, and within some vesicles the color varies in intensity, reflecting a mix of saponite and celadonite. Iron oxyhydroxide is the second most abundant secondary phase, occurring both alone as iron oxyhydroxides and mixed with saponite and other clay phases to form iddingsite. Iron oxyhydroxides are identifiable by a bright orange to red color and often stain other phases present. Zeolite phillipsite was identified by X-ray diffraction (XRD) analysis of mixed veins and altered chilled margins in addition to montmorillonite (smectite group) and sepiolite (clay) from veins. Carbonate is present as vesicle fill, in veins, and within chilled margins and predominantly occurs mixed with clays and occasionally sulfides. Anhydrite is rarely present in veins from Subunit 6B.

A total of 1230 veins were logged, with an average frequency of 27 veins per meter of recovered core. Vein width ranges from <0.1 to 4 mm, and vein morphology is variable. Saponite is the most abundant vein fill and is present in 76% of the veins, with unidentified clay minerals filling 50% of veins. The next most abundant vein fill is iron oxyhydroxides, which fill 32% of veins. Carbonate and pyrite are present in 10% of veins but are only occasionally the dominant components. Celadonite occurs in

2% of veins and is a larger component of the background alteration. Rare anhydrite veins are present within Subunit 6B. Alteration halos flank 15% of hydrothermal veins and are otherwise found flanking rock edges or apparently unassociated from structural features. Halos range from single-color black, green, or orange halos to complex multihalos with mixed colors.

The dips of 519 veins and fractures were measured, and three types of fractures were distinguished: (1) veins flanked by alteration halos (haloed veins), (2) veins not flanked by alteration halos but filled with secondary minerals (nonhaloed veins), and (3) joints sometimes flanked by alteration halos but not filled with minerals. Nonhaloed veins were the most frequently observed structures. Nonhaloed veins were identified mainly in the massive lavas and in some pillow-lava pieces. No faults or shear veins with any evidence of displacement were found.

Whole-round basalt core sections were run through the Whole-Round Multisensor Logger (WRMSL) and Natural Gamma Radiation Logger (NGRL) prior to splitting. Gamma ray attenuation (GRA) density data vary widely as a result of unfilled core liners in sections with poor recovery. Despite this, peak bulk density values are consistent at ~2.5 g/cm^3 for much of the core recovered. For the more cohesive, massive sections recovered in deeper cores, GRA results are slightly >2.5 g/cm^3. Magnetic susceptibility measurements also vary widely, ranging from 0 to 3300 × 10^{-6} SI. Total counts from the NGRL are generally low (1–5 counts/s). For all measurements, the highest values were found in massive sections, with other lithologies, namely pillow lavas and sheet flows, generally yielding much lower values.

Thermal conductivity was tested in three samples from the uppermost section of pillow basalts, yielding values of 1.63, 1.67, and 1.72 W/(m·K) at depths of 349, 354, and 355 mbsf, respectively. These values compare well with data collected at similar depths at nearby Hole U1301B (1.70 ± 0.09 W/[m·K]). Problems with the thermal conductivity half-space system prevented additional measurements.

P-wave velocities were measured on 71 discrete samples. *P*-wave velocity values determined by manual picking of the first arrival range from a minimum of 4.3 km/s to a maximum of 6.0 km/s, with an average of ~5.4 km/s. The average value is greater than values obtained from Hole U1301B. The lowest velocity was measured on a heavily altered sample (327-U1362A-14R-1, 11–13 cm). A test of nearby unaltered material yielded much higher velocity, which demonstrates the influence of rock alteration on

P-wave velocity. We found no statistically significant overall velocity trend with depth or overall velocity anisotropy depending on sample direction.

Moisture and density properties were determined on 71 discrete samples from Hole U1362A. Bulk density values range from 2.58 to 2.89 g/cm^3, with an average of ~2.74 g/cm^3 (Fig. **F9**). Grain density values range from 2.66 to 3.16 g/cm^3, with a mean of ~2.88 g/cm^3. Porosity values range from 2.8% to 14.2%, with a mean of 7.9%. The highest value of porosity was obtained from a highly altered sample that also had the lowest velocity. Overall, *P*-wave velocity and porosity are inversely correlated.

Twenty-five whole-round samples (4–20 cm long) were collected for microbiological analysis. Samples were preserved for shore-based deoxyribonucleic acid (DNA) analysis, shore-based fluorescent in situ hybridization (FISH) and cell counting analysis, and shipboard fluorescent microsphere analysis. One sample was also collected for shore-based analysis of particulate organic carbon and nitrogen as well as carbon and nitrogen isotopic compositions. Hard rock samples span a range of lithologic units, alteration states, and presence of chilled margins, and most contain at least one vein per fracture. Additionally, a few recovered plastic bags that held fluorescent microspheres were collected as a contamination check for DNA analysis. Colonization experiments were assembled for Hole U1362A and U1362B CORK instrument strings. Fluid samples were collected for shore-based microbiological analysis during the 24 h tracer injection experiment in Hole U1362B.

Remanent magnetization measurements were made on 79 discrete pieces and on portions of 23 core sections. Samples were demagnetized at 5 or 10 mT steps from 0 to 50 mT using the cryogenic magnetometer's inline alternating-field (AF) coils. Most samples display simple magnetization behavior. Principal component analyses were performed on select samples. The majority of samples have positive inclinations, indicating that magnetization was acquired during a normal-polarity period, consistent with crust age at this location. Some samples have steep, positive inclinations that might be influenced by a drilling overprint. A few samples have reverse magnetizations, which are most likely the result of alteration. Inclinations are scattered around 460–470 mbsf in Unit 6. The average inclination for Hole U1362A basalts is 72°, slightly higher than the expected geocentric axial dipole direction.

A single wireline logging string was deployed in Hole U1362A to identify suitable intervals for packer placement and to determine physical and hydrological properties. The logging string consisted of a qualitative spontaneous potential electrode and sensors for measuring natural spectral gamma ray, bulk density, borehole fluid temperature, tool orientation, tool motion, ultrasonic borehole images, and hole diameter. Two passes were run over the entire open hole section, and a third pass was run over two intervals of particular interest. Seven logging units were identified on the basis of petrophysical log response and borehole conditions.

Both the mechanical and ultrasonic calipers revealed a borehole that was highly enlarged over most of the open hole section (Fig. **F9**). Notable near-gauge sections were identified at 417 and 447 mbsf. Good conditions were expected in these sections based on rotary core barrel (RCB) recovery and by the apparent coring and drilling rates of penetration. Low recovery and higher rates of penetration correlate well with an enlarged borehole. Where the ultrasonic caliper values appear meaningful, they indicate a nearly circular borehole through the near-gauge intervals.

The ultrasonic borehole images are marred by rotational and heave-induced tool motion. In addition, the ultrasonic tool's sonde head is undersized for these borehole diameters, and, where Hole U1362A is enlarged, no meaningful images can be expected. Certain fractures and other features were observed in the 447 mbsf near-gauge section, particularly during the third imaging pass made at the highest vertical resolution.

The density readings were impaired by poor borehole conditions in many intervals. Where hole condition was good, logged density compares favorably with density measurements on discrete core samples (Fig. **F9**).

Gamma ray measurements in the basaltic crust are driven by potassium content and were repeatable over the three passes. Where increases in gamma ray values correspond with enlarged borehole intervals, such as the one at 470 mbsf, they may represent zones of greater alteration and may be indicative of focused hydrothermal fluid flow. A pronounced gamma ray deflection was observed at and above the 10¾ inch casing shoe, likely a measure of trace uranium and thorium in the cement.

Borehole fluid temperature data were acquired while running into the hole and during the three upward logging passes. The borehole temperature gradient increases steeply at the top of the 447 mbsf near-gauge interval, and a 0.5°C temperature anomaly was observed 8 m below the casing shoe.

Packer experiments were completed in Hole U1362A to assess the permeability of the formation. The sealed-hole pressure baseline was recorded for 1 h, and two 1 h long injections tests were conducted, each followed by 1 h to allow the pressure to recover to baseline conditions. Preliminary data analysis indicates a bulk permeability consistent with that in nearby Hole U1301B (Becker and Fisher, 2008).

A 24 h pumping and tracer injection experiment was conducted prior to the CORK deployment in Hole U1362B. Fast-sampling reverse osmosis pumps and pressure gauges were run in a specially designed stinger sub just below the casing shoe in the open hole. After waiting 1 h to allow the hole to equilibrate, seawater was pumped into the formation at a rate of 20 strokes per minute (~7 L/s) (Fig. **F10**). At 2 and 20 h into the experiment, freshwater was pumped into the formation for 1 h instead of seawater. The tracers injected included SF_6 gas (for ~22 h), CsCl and $ErCl_3$ salts (at 3 h) and CsCl and $HoCl_3$ salts (at 19 h), fluorescent microspheres (at 20 h), and stained bacteria (at 21 h) extracted from sea-surface water. Pumping ceased during the last hour of the experiment so the hole could equilibrate again.

The CORKs deployed during Expedition 327 are based on the CORK-II design prepared for Expedition 301. The Hole U1362A CORK monitors two basement intervals: a shallow interval extending from the base of the 10¾ inch casing to the top of the deepest set of swellable packers (307.5–417.5 mbsf) and a deeper interval extending from the base of the deepest inflatable packer to the bottom of the hole (429.2–528.0 mbsf) (Fig. **F11**). Pressure in both intervals is monitored through ¼ inch stainless steel tubing connected to miniscreens installed just below the inflatable packers at the top of the isolated intervals. Three ½ inch stainless steel fluid sampling lines terminated at two depths (two below packers in the upper interval and one below packers in the lower interval). A single ½ inch polytetrafluoroethylene (PTFE) microbiology sampling line ends in a titanium miniscreen that rests on perforated and coated 5½ inch casing, 7 m below the base of the deepest inflatable packer, just above the perforated collars. The downhole instrument string includes 6 OsmoSamplers and microbial growth incubators positioned within the coated perforated 5½ inch casing and collars, 11 autonomous temperature probes, and a 200 lb sinker bar.

The Hole U1362B CORK monitors a single basement interval that extends from a single set of swellable and inflatable packers positioned just inside the base of the 10¾ inch casing to the bottom of the hole (272–359 mbsf) (Fig. **F11**). Pressure in this interval is monitored via a ¼ inch stainless steel tube connected to a miniscreen installed just below the inflatable packers. The intakes of the three ½ inch stainless steel fluid sampling lines are located on perforated and coated 5½ inch casing, about 3 m below the packers, providing sampling redundancy. A single ½ inch PTFE microbiology sampling line ends in a titanium miniscreen that rests on perforated and coated 5½ inch casing, 7 m below the base of the deepest inflatable packer, just above the perforated collars. The downhole instrument string comprises six separate OsmoSamplers and microbial growth incubators; eight autonomous temperature probes, including two installed in OsmoSamplers suspended inside the perforated and coated drill collars at depth in the hole; and a 200 lb sinker bar.

Both CORKs include a large-diameter ball valve in the wellhead that can be opened to allow fluids to bypass the top plug through a "lateral" pipe that extends from the main CORK tubing above the seafloor seal ("L-CORK" design). Researchers will initiate a long-term flow experiment in Summer 2011 by deploying a flow meter and opening the ball valve on one of the Site U1362 CORKs using the submersible *Jason*. Flow will continue for at least 1 y, allowing testing of a much larger volume of crust than has been tested previously during scientific ocean drilling experiments.

Site U1301

We recovered an incomplete portion of the instrument string deployed during Expedition 301, comprising five autonomous temperature loggers and part of the Spectra cable (Tables **T1, T2, T3;** see **"Operations"**). The rest of the instrumentation was left in the CORK and/or hole. Of the five autonomous temperature loggers recovered from Hole U1301B, one was able to communicate and download data during Expedition 327. All of the tools were deployed well beyond their intended 4–5 year battery life. The four nonoperational tools will be returned to the manufacturer for servicing and data download (data are stored in nonvolatile memory). The tool that did provide data showed that temperatures at depth began to rise beginning in Summer 2009, soon after cementing during Expedition 321T. In addition, the temperature log collected in the upper 364 m of the open CORK casing shows that the thermal gradient in Hole U1301B has nearly returned to a predrilling state. Collectively, these data suggest that the remedial cementing conducted in Summer 2009 during Expedition 321T was successful in sealing the hole. A short instrument string with three temperature loggers was deployed in Hole U1301B and will be useful in assessing the continued thermal rebound of the hole.

Site 1027

No scientific results were obtained at Site 1027 as a result of the failed attempt to recover the CORK installed during Leg 168 (see **"Operations"**).

Site U1363

Five holes were cored at Site U1363, adjacent to the edge of Grizzly Bare outcrop (Tables T1, T2, T3; Fig. F12). Sediments are composed of turbidites interspersed with hemipelagic clay, consistent with core recovery during Leg 168 and Expedition 301 (Davis, Fisher, Firth et al., 1997; Fisher, Urabe, Klaus, and the Expedition 301 Scientists, 2005). Four lithologic units were distinguished (Fig. F12).

Unit 1 is composed of hemipelagic mud (clayey silt to silty clay), thin-bedded turbidites (sand-silt-clay), and thick-bedded medium sand turbidites. Unit 2 is composed of beds of silt and sandy silt intercalated with hemipelagic mud deposits (silty clay to clayey silt). Unit 3 is composed of hemipelagic carbonate-rich claystone rich in foraminifers and nannofossils. Unit 4 is represented by a few small pieces of basalt recovered from the sediment/basement interface in Holes U1363B and U1363D. The basalt is cryptocrystalline and plagioclase phyric, with glomeroporphyritic texture visible in hand specimens. Phenocrysts are large (up to 8 mm) and are anhedral to euhedral in shape. The basalt is sparsely vesicular with highly variable vesicle size and shape. Secondary minerals are present as background groundmass replacement and alteration halos as well as filling vesicles and lining hydrothermal veins.

All cores were run through the WRMSL, yielding magnetic susceptibility values from $<500 \times 10^{-6}$ SI in clay sections to $\sim1400 \times 10^{-6}$ SI in sandy turbidites. Point magnetic susceptibility data collected with the Section Half Multisensor Logger (SHMSL) are similar, with split-core values tending to be slightly lower than whole-round values, except in the case of turbidite sequences, where SHMSL values are consistently higher. GRA density averages ~1.8 g/cm^3, depending on lithology, with some compaction evident with depth in clay data. *P*-wave velocities measured on the WRMSL range from ~1.46 to ~1.87 km/s, excluding the erroneously low values derived from insufficient sediment filling within core liners.

Discrete measurements, including moisture and density (MAD), *P*-wave velocity, and thermal conductivity, were measured on most cores from Holes U1363B, U1363C, U1363D, and U1363F. Insufficient time was available to measure samples from Hole U1363G. Thermal conductivity at Site U1363 averages 1.31 ± 0.19 W/(m·K), whereas MAD bulk densities average 1.72 g/cm^3, both showing bimodal distributions corresponding to clay and sand lithologies. MAD porosities range from 39% to 76%, with an average value of ~60%. *P*-wave velocities average 1.52 km/s, with considerable variability across lithologies. The velocities derived from discrete measurements agree with those measured on the whole-round sections with the WRMSL. Velocities also show weak anisotropy between vertical and horizontal directions. *P*-wave velocity increases ~50 m/s within the uppermost 50 mbsf. On the other hand, grain density is remarkably consistent regardless of depth or lithology.

Pore water samples were recovered from five holes, providing systematic trends to gauge the composition of the underlying basaltic formation fluid at these locations. Pore waters were extracted in a nitrogen atmosphere, and some analyses (alkalinity and ion chromatography) were conducted immediately to guide future drilling operations. We collected 57 pore water samples: 15 from Hole U1363G, 14 from Hole U1363F, 14 from Hole U1363B, and 14 from (adjacent) Holes U1363C/U1363D, with basement depths of 25, 33, 54, and 223 mbsf, respectively. In the upper portion of the sediment, biogenic processes release dissolved Mn and Fe near the sediment/water interface and consume sulfate with a sulfate minimum of 22 mM at 20 mbsf. There is a corresponding increase in alkalinity, phosphate, and ammonium and an initial decrease in Ca resulting from carbonate formation given the high alkalinity values. Similar trends for sulfate, Mn, and Fe exist near the sediment/basement interface. However, phosphate and ammonium are more influenced by diffusion and reaction within the upper basaltic basement. The cations Ca, Mg, and K show gradients near the sediment/basement interface, indicative of a formation fluid that is slightly altered relative to seawater. Minor and trace elements in seawater also show gradients in the basal sediment section, with greater alteration at greater distance from the outcrop.

Alkalinity shows a progression with increasing distance from the outcrop, from higher to lower values at the sediment/basement interface, and a progression of increasing values in the mid-sediment column. pH is consistently near 7.3 from the seafloor to the sediment/basement interface. In Hole U1363G, alkalinity increases from 3.5 meq/L at 1.5 mbsf to 4.6 at 10 mbsf and then decreases to 2.9 meq/L at 25 mbsf at the basement. Hole U1363F has a similar profile, with alkalinity increasing from 6.7 meq/L at 4.5 mbsf to 10.5 meq/L at 12 mbsf and then decreasing to 1.8 meq/L at the sediment/basement interface at 33 mbsf. The highest alkalinity measured was 13.9 meq/L at 16.5 mbsf in Hole U1363B, decreasing to 2.1 meq/L at the sediment/basement interface. Only the lowermost 50 m of Holes U1363C/U1363D was sampled, so an alkalinity maximum in shallower sediments was not sampled. The lowest alkalinity measured was 1.3 meq/L at 233 mbsf at the Hole U1363D sediment/basement interface. These findings are consistent with a progressively altered basement fluid with increasing distance from the Grizzly Bare outcrop.

Microbiologists collected whole-round core and pore water samples from sediments and basement pieces recovered at Site U1363. Eleven sediment intervals were targeted for microbiology sampling in Hole U1363B. Most samples were taken from hemipelagic clay layers, although some sandy turbidite layers were also sampled. The deepest sediment sample was taken from a carbonate-rich layer near the sediment/basement interface. Thirteen sediment intervals and one basement basalt interval were sampled from Holes U1363C and U1363D. Again, sediment samples were mostly from clay-rich layers, although some samples contained sand. The basement sample from Core 327-U1363D-6X was a relatively unfractured basalt with spots of light green and orange alteration crusts. Nineteen sediment and basement samples were taken from Hole U1363F. Most samples contained either clays or sandy layers, with the exception of samples from Section 327-U1363F-4H-2 and deeper, which also contained manganese crust, basalt fragments, and lighter tan-colored sediment resembling the foraminifer-rich carbonate sediments from Hole U1363B. Sixteen samples were collected from Hole U1363G. All samples were clay rich, and no hard rock samples were recovered.

At each sampling location, whole-round core samples were collected for shore-based DNA analysis, shore-based characterization of halogenated organic matter, and shore-based incubation experiments to examine dehalogenation reaction activities. Syringe samples were also collected for headspace gas analysis and microsphere contamination checks from the interior and exterior of the cores. Headspace samples were analyzed on board for safety purposes, and only a few samples contained quantifiable levels of methane or higher hydrocarbon gases. Microsphere samples will be returned to the shore-based laboratory for postcruise analysis because of time limitations at the end of the cruise. These samples will also be used for shore-based cell counting analysis and FISH analysis. A subset of samples was collected for analyses of dissolved organic carbon (DOC)/dissolved nitrogen (DN), particulate organic carbon (POC)/particulate nitrogen (PN), amino acids, low molecular weight organic acids, and lipid biomarkers.

Remanent magnetization measurements were made on two-thirds of core sections from Hole U1363B. Samples were demagnetized at 10 mT steps from 0 to 40 mT using the cryogenic magnetometer's inline AF coils. Although the majority of samples have positive inclinations, there is a large scatter of positive and negative inclinations. This is probably the result of core deformation during drilling and the alternating sequences of hemipelagic mud and turbidite deposits.

Temperature measurements were collected with the third-generation advanced piston corer temperature tool (APCT-3) and the Sediment Temperature (SET) tool in Holes U1363B–U1363E. Good measurements were obtained with both tools, and these data will be analyzed postexpedition to assess seafloor heat flow and thermal conditions in basement.

Education, outreach, and communication summary

EOC, scientific, and technical personnel participated in an initial seminar on constructivist and inquiry-based education methods, and EOC personnel followed up with several weeks of exercises to investigate Earth science concepts to gain a foundation in the regional geology and the scientific objectives of the expedition. Projects outlined in general terms during precruise webinars were clarified, and strategies were developed for completing them.

Progress reports and meetings were conducted every two weeks to facilitate and modify plans, as needed, and to assess achievements. Independence and constructivist learning were emphasized, allowing individuals to work on projects that were beneficial to their future goals and to the ocean drilling community and that relied on each person's set of skills to carry out. Projects ranged from Earth science classroom activities to computer learning interactives, demonstrations on robotics, computer animation, and science-related fine arts. More than 70 individual activities were completed and are ready for testing with teachers and students.

The shipboard EOC team advanced the scientific goals of the expedition and of IODP by communicating the importance 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 blogs, up-to-the-minute social media, and live video interactions with schools and museums. More than 90 blog posts in English and French were added to **joidesresolution.org/** (USIO Web site oriented toward a nonscientific audience) by eight authors. Ohio teacher Jackie Kane's blogs were notable for the close one-on-one dialogue she maintained with students and her rapid and thorough responses to comments (Fig. **F13A**). Kane's page ranked second only to the home page, with 1257 views during August, or 7.5% of the total 16,660 page views. Overall, **joidesresolution.org/** visitorship and use increased 40% in July compared to the previous two months, with August bringing 2435 new visitors to the site (Fig. **F13D**).

The Adopt-A-Microbe from the Deep Biosphere Web site (spearheaded by Expedition 327 microbiologist Beth Orcutt), attracted and engaged numerous visitors, introducing them to the nature of dark biosphere research (**sites.google.com/site/adoptamicrobe/**). This site is notable for its rich variety of formats and activities, and it attracted numerous visitors, many of whom participated in weekly hands-on activities and submitted their results to the site. As one of the first IODP education and outreach activities focused on communicating the exciting discoveries being made about microbial life in the deep biosphere, the Adopt-A-Microbe model will be replicated and incorporated into future expedition education and outreach activities. This Web site was linked to **joidesresolution.org/,** as was scientist Amanda Turner's blog for eighth grade special education students in Phoenix, Arizona. Turner's blog resulted in a set of engaging math and science-related interviews with scientists and other shipboard personnel, emphasizing the importance of mathematics and science in careers. These interviews will be added to the **joidesresolution.org/** career interactive later this year, along with adaptive activities for special needs students. The team also focused on outreach through the *JOIDES Resolution* and Deuxprofsembarques Joides Facebook pages, the *JOIDES Resolution* Twitter page, and three YouTube channels.

EOC team members conducted 15 live video events for approximately 500 participants at museums, summer camp groups, and schools in the United States (California, Florida, New Jersey, Ohio, Pennsylvania, Tennessee, Texas, and Washington, D.C.), France, and New Caledonia. Further information will be collected through user surveys, but anecdotal and qualitative information, as well as increased social media and Web site activity immediately following these video events, suggest generally positive response to the fast-paced virtual tours of shipboard laboratories and interviews with scientific, technical, and engineering staff. Noteworthy broadcasts included women on the ship talking with high school girls at a career-focused summer camp, shipboard educators talking directly to their students, and an all new safety-oriented ship and laboratory tour intended to introduce New Jersey eighth graders to the use of personal protective equipment, fire drills, and accident reporting. Other novel outreach contributions during Expedition 327 include a live-action video introducing CORK technology and experimental goals crafted by scientific personnel and forwarded in advance of videoconferences, an animated presentation of drilling and CORK technology to be used for public and scientific outreach, audio podcasts featured on the Centers for Ocean Sciences Education Excellence (COSEE)-sponsored

OceanGazing podcast site, and two video conferences conducted with the research vessels D/V *Chikyu* and R/V *Thompson*.

Preliminary assessment of expedition achievements

Site U1362

Drilling and coring objectives were fully achieved at Site U1362; however, there were challenges, and hole conditioning occupied much more time than anticipated. Core recovery in basement (~30%) is consistent with recovery from the same area during Expedition 301 and with recovery in the uppermost few hundred meters of young crust drilled during other expeditions. The lithostratigraphy developed for Hole U1362A is somewhat different from that developed for Hole U1301B, located only 800 m to the south (Fig. **F9**). Compared to Hole U1301B, core from Hole U1362A contains considerably greater fractions of sheet flows and basalt flows (called “massive basalt” and “basalt lava,” respectively, for Hole U1301B) and evidence for more extensive and higher temperature hydrothermal alteration. Hole U1362A also contains less hyaloclastite breccia; however, only five coherent pieces of this rock type were recovered from Hole U1301B, and it seems likely that much more of this fragile rock type was present but not recovered from the formation in both locations.

A comparison of caliper logs and apparent penetration rates from Holes U1362A, U1362B, and U1301B suggests that there is some along-strike, lateral continuity in major basement units (Fig. **F14**). The uppermost 100 m of basement in all holes at Sites U1301 and U1362 was drilled without coring using a 14¾ inch drill bit, and the lower parts of Holes U1362A and U1362B were drilled with a 9⅞ inch drill bit rather than a coring bit, so quantitative comparison of penetration rates in individual holes can be difficult. Tides also influence both apparent penetration rates and recovery of individual cores in basement (Fig. **F15**). It may take 2–6 h to cut a 9.5 m basement core, and sea level in the Expedition 327 work area can change by 1–3 m during this time. If the ship experiences a rising tide while drilling, some of the apparent penetration is a result of lowering the pipe as needed to keep weight on the bit. The opposite occurs when coring during a falling tide, making penetration appear to be less than it really is (as occurred with Core 327-U1362A-17R, which had an apparent recovery >100%; Fig. **F15B**). Over the length of an expedition, tidal influences generally average out, but penetration rates while coring or drilling are calculated using relatively short time intervals (minutes to hours), so tidal information is certainly mixed in with the penetration rate calculations made from rig instrumentation data. Despite these caveats, the generally positive correlation between penetration rate and hole diameter suggests that the former is a useful indicator of lithologic character. For example, the uppermost 100 m in all basement holes was drilled relatively quickly at Sites U1301 and U1362, consistent with the rubbly and oversized character of the resulting boreholes and difficulties encountered when deploying 10¾ inch casing (Fig. **F14**).

Packer testing in Hole U1362A was partly successful, and tests were completed at the most important setting location in open hole (the same depth at which CORK packers were set). Unfortunately, the packer element was damaged either during this initial inflation and/or prior to the start of testing when the drill string was lowered into the hole to check for fill and bridges that could impede CORK deployment. Packer data will require postcruise processing, but preliminary examination of the data suggests that the lower ~90 m of Hole U1362A is about as permeable as the lower ~100 m of Hole U1301B.

A 24 h pumping and tracer injection experiment was completed in Hole U1362B (Fig. **F10**), and these data also indicate generally high permeability in the formation surrounding the borehole. The pressure record will require considerable processing to account for tides and changes in fluid density associated with switching from freshwater to saltwater and with the injection of additional salts as part of the tracer experiment. Rig floor and stinger fluid samples were collected during tracer injection, and shore-based analysis will be required to develop a detailed history of injectate chemistry and particle density during the test. Pressure data and chemical samples will be collected from CORKs in this area in Summer 2011, which will provide the first information from scientific ocean drilling on hole-to-hole solute and particle velocities.

Two new CORK observatories were successfully installed at Site U1362 (Fig. **F11**), but no scientific information will be recovered from these systems until ROV servicing in Summer 2011. Experience during Expedition 327 confirms the benefit of having sufficient weight on the bottom of long CORK casing strings (three drill collars, ~10,000 lb) to assist with "pulling" the bottom of the CORK casing into the holes. Despite difficult hole conditions, we had no problem setting either CORK in the hole during the final stages of deployment.

However, deploying these CORKs required considerably more time than was originally allocated for several reasons. First, we spent much more time drilling, reaming, and cleaning Holes U1362A and U1362B than planned, as was required to ensure that the CORKs could be deployed once they were made up and lowered from the ship into the hole. Additionally, when the swellable packers were uncrated (just prior to deployment), we discovered that the elements were too large to be run in the open hole. Almost a day was required during the construction of the Hole U1362A CORK to reduce the diameter of the packer elements. More time was lost when the instrument string deployed below in the Hole U1362A CORK was found to be too long (most likely because of cable stretch twice that calculated based on manufacturer specifications). Because we did not have the RS tool needed to unlatch the top plug from the CORK wellhead after it was deployed, the CORK itself had to be returned to the ship to recover, shorten, and redeploy the instrument string and lower the CORK back to the seafloor. We had additional difficulty deploying the instrument string and top plug in the Hole U1362B CORK, which might have been avoided if the top plug had been fit-tested in the CORK prior to deployment. Part of the difficulty with string deployment originated with the hammer-shear release system (the same system used during Expedition 301, when it also was problematic), which should be replaced with an electronic release for future CORK expeditions. We also had problems deploying the ROV landing platform on the Hole U1362A CORK because the protective bolt installed above the packer inflation line was too long, creating an upset for the platform delivery system. Finally, we had repeated problems with the subsea camera system, which failed during several deployments and had to be recovered for repairs.

Site U1301

We were pleased to recover five of the autonomous temperature loggers deployed in Hole U1301B during Expedition 301 and to learn that thermal conditions in Hole U1301B are recovering toward natural conditions. This indicates that the cementing effort during Expedition 321T was successful in sealing the borehole after five years of cold bottom water flowing down the casing and into basement. However, the same cementing effort apparently fouled two of the three pressure lines or gauges that monitor conditions at depth below this CORK (as determined from data downloads during Summer 2010 CORK servicing). In addition, more instruments were left in Hole U1301B than were recovered, including additional temperature loggers, OsmoSamplers, and two microbiological growth experiments. Some of these instruments might have been recovered had a weak link been used above the sinker bar at depth on the original instrument cable, although we do not know precisely where the cable was fouled at depth, and all of the OsmoSamplers and microbial experiments were deployed in unstable open hole. Lessons learned from this experience, particularly the 2009 instrument recovery attempt from the *Atlantis*, guided planning for Expedition 327, including the placement of all downhole instruments inside coated and perforated casing.

Site 1027

The inability to complete any of our planned research activities in Hole 1027C was the greatest disappointment of Expedition 327. Initially, we attempted to use the wrong CORK recovery tool. Because we did not have the right CORK recovery tool with us at sea, considerable additional time was spent fabricating a tool and making a second recovery attempt. This attempt was also unsuccessful, and we abandoned the CORK recovery effort and focused on the remaining high-priority objectives of Expedition 327.

An ROV servicing expedition to this area is scheduled for Summer 2011, and researchers will prepare to recover the existing data logger and retrofit the Hole 1027C CORK with a new coupler and pressure logger and gauges before beginning the 1–2 year long free-flow cross-hole experiment. However, we missed the opportunity to deepen Hole 1027C, emplace a multilevel observatory, and instrument this system with fluid and microbiological sampling experiments.

Site U1363

Primary coring, sampling, and measurement objectives were achieved during the final days of Expedition 327 at Site U1363. Five holes were cored in four locations at this site. Additional holes were drilled as needed to determine basement depths and space out cores to optimize recovery of material near the sediment/basement interface. Successful temperature measurements were made in all holes. Both coring and temperature measurements were challenging because of the unstable nature of unconsolidated sandy turbidites. Preliminary analyses of temperature data and geochemical data from sedimentary pore fluids suggest that we successfully captured variations in fluid evolution associated with recharge through Grizzly Bare outcrop and subsequent regional flow to the north.

Education and outreach

Sailing multiple educators as a team provided a unique opportunity to create innovative science communication products with a critical mass of dedicated individuals. Preliminary data show an increase of 370 *JOIDES Resolution* Facebook fans (highest single-expedition increase) and >590 monthly active fans, plus an additional 120 fans interacting with the French page. Facebook usage peaks can be correlated with photograph and video posts, important research activities, and live video events for schools and museums. Further analysis of the Web sites and postexpedition user surveys will be completed postcruise to provide additional quantifiable metrics of impact from Expedition 327 EOC activities.

EOC team members were asked to reflect on their experiences in written form twice during the expedition, followed by a video narrative and written evaluation during the final weeks. Team members were asked to include a scientist or ship staff member in the video to discuss their mutual learning. The videos will be viewed and analyzed first by USIO outreach personnel, who will consult and share findings with the EOC team leader.

The synthesis of new learning will also be assessed by the quality and depth of the blogs (which equate with journaling) and team member projects. We will compare and contrast this new model for collaborative shipboard teaching, learning, and outreach with School of Rock and the onboard education officer program. Finally, a follow-up survey using phone interviews will be conducted in October and November 2010 to assess scientist participation, perceptions, and learning through the collaborative EOC/science partnership.

Two abstracts focusing on Expedition 327 EOC activities were submitted during the cruise for the Fall 2010 meeting of the American Geophysical Union, and two peer-reviewed publications delineating both the extent and nature of EOC preparation, shipboard activities, and metrics of success are planned.

Operations

Transit from Victoria, British Columbia, to Site U1362

Expedition 327 began on 5 July 2010, following the *JOIDES Resolution*'s maintenance in Victoria, British Columbia (Canada). The last line was released at 1212 h local ship time (Universal Time Coordinated [UTC] – 7 h) on 9 July, and the vessel began the 196 nmi journey to Site U1362.

Site U1362

We arrived at Site U1362 at 0815 h on July 10 and deployed a positioning beacon at 0922 h. The vessel was positioned 15 m west of Hole U1362B, the bottom-hole assembly (BHA) was assembled, and the drill string was run to bottom. Seafloor was tagged at 2672 meters below rig floor (mbrf) at 2200 h. A jet-in test was initiated at 2230 h and completed by 1100 h on July 11. The drill string was pulled clear of the seafloor, and the vessel moved ~300 m in dynamic positioning (DP) mode to a position 15 m west of Hole U1362A. The seafloor was again tagged at 2672 mbrf, and a second jet-in test was initiated at 1250 h.

Hole U1362A Stage 1

The first stage of operations in Hole U1362A consisted of deploying a reentry cone with a 20 inch conductor casing attached, drilling a hole a few meters into basement, and then cementing a string of 16 inch casing to isolate the sediment column above basement (Tables **T1, T2, T3;** Fig. **F7**). Based on the results of the jet-in test, a 53 m string of 20 inch casing was made up and latched into a reentry cone. The reentry cone was deployed through the moonpool at 1700 h on 12 July, and Hole U1362A was spudded at 2345 h. The cone reached the seafloor at 1100 h on 13 July. A drilling BHA was assembled using an 18½ inch tricone drill bit and an underreamer with its cutters set to a maximum diameter of 21.5 inches. The drill string was lowered to the seafloor, and the reentry cone was reentered at 0245 h. After drilling for 17 h at an average rate of penetration (ROP) of 18 m/h, the hole was terminated at 2913 mbrf (241 mbsf). The hole was cleaned with repeated mud sweeps, and the drill string was pulled out of the hole at 0920 h on 15 July. The depth of the basement contact was inferred to be at 2908 mbrf (236 mbsf). Frequent referral to the tide tables for this time period contributed to keeping the drilling depths consistent, because throughout our time on site the tidal fluctuation resulted in a 3 m change in the sea level reference datum used by the driller (Fig. **F15**). The rig floor was prepared for running casing, and by 1415 h on 15 July ~230 m of 16 inch casing was assembled, with each joint being welded together. Once the casing running tool was attached, the casing was lowered to the seafloor and Hole U1362A was reentered for a second time. The casing hanger was landed at 2315 h with the casing shoe at 230 mbsf, ~6 m above the basement contact. The bottom of the hole was cemented with 42 bbl of cement preblended with Cello Flake and a 1.6% by volume calcium chloride accelerator. The drill string cleared the rig floor at 0930 h on 16 July, ending the initial stage of operations in Hole U1362A.

Hole U1362B Stage 1

The first stage of operations in Hole U1362B was similar to that in Hole U1362A (Tables T1, T2, T3; Fig. F8). An identical 53 m string of 20 inch casing was made up and latched into another reentry cone. Hole U1362B was spudded at 2135 h on 16 July. The cone reached the seafloor at 1005 h on 17 July. The drilling BHA was assembled as before, the drill string was lowered to the seafloor, and the reentry cone was reentered at 0056 h on 18 July. Drilling commenced at 0230 h and continued until 1700 h at an ROP of 25 m/h. The hole was terminated at 2922 mbrf (250 mbsf), with the basement contact inferred at 242 mbsf. The hole was cleaned with repeated mud sweeps, and the drill string trip back to the surface was initiated at 2245 h on 18 July. The bit cleared the rotary table at 0600 h 19 July, and the rig floor was prepared for running casing. By 1100 h that morning, 18 joints of 16 inch casing (242 m in length) were made up and attached to the casing hanger. Hole U1362B was reentered at 1500 h, and the casing was washed down to 242.0 mbsf. The bottom of the hole was cemented at 1900 h on July 19 with 40 bbl of cement preblended with Cello Flake and a 1.6% by volume calcium chloride accelerator, with the goal of having 30 m of cement inside the casing and between the casing and the borehole wall. The drill string cleared the rig floor at 0330 h on 20 July, ending the initial stage of operations in Hole U1362B.

Hole U1362A Stage 2

The second stage of operations in Hole U1362A consisted of drilling a 14¾ inch hole to 346 mbsf for the 10¾ inch casing string with the goal of casing the upper portion of basement. The 14¾ inch drilling BHA was assembled, and Hole U1362A was reentered for the third time at 1525 h on 20 July. The top of the cement plug was tagged at 2874 mbrf (202 mbsf), which is within 2 m of the theoretical calculated depth of ~200 mbsf. This is a good indication that the cement job successfully cemented the lower 30 m of the hole. After drilling out the cement, basement drilling proceeded without incident to 298 mbsf by 1545 h on 21 July, followed by a 1.25 h period when the drill string was stuck. After the string was freed, several hours were spent washing and reaming the hole, and by 2315 h the hole was relatively stable. Drilling continued until the desired total depth of 3018 mbrf (346 mbsf). After conditioning the hole further, by 0100 h on 24 July the hole was deemed acceptable for running casing. The assembly of the 10¾ inch casing string began at 0930 h. Twenty-four joints of 10¾ inch casing were made up, followed by a TAM Freecap swellable packer joint. The packer was deployed for the first time by IODP and was designed to provide an additional seal to the cement job and the casing hanger seal ring. The swellable packer was designed to absorb water and expand, sealing off the space between the 10¾ and 16 inch casing strings. The drill string trip began at 1500 h on 24 July. Hole U1362A was reentered for the fourth time at 1900 h. The casing was washed to 2991 mbrf (319 mbsf) before it became tightly stuck around midnight. After working the pipe for 4.5 h, it was eventually freed at 0430 h on 25 July. Multiple attempts to advance the casing past 2983 mbrf (311 mbsf) failed, and at 1000 h the decision was made to shorten the casing string. The drill string was tripped back to the surface by 1530 h. The swellable packer was inspected and determined to be undamaged and to gauge, so the 10¾ inch casing hanger and packer were laid out together as a unit. Two joints of casing were removed, reducing the length of the casing string by 27.5 m and resulting in an overall string length of 308.5 m. The swellable packer assembly was made up once again to the remaining casing string. Hole U1362A was reentered for the fifth time at 2310 h on 25 July. A few problems were encountered in advancing the casing string past the sediment/basement interface, but after this point the installation went smoothly and the casing hanger landed at 0530 h. The bottom of the hole was cemented with 40 bbl of cement preblended with Cello Flake and a 1.6% by volume calcium chloride accelerator designed to fill the bottom ~60 m of the hole. The volume pumped was double the required amount to allow for potential significant loss of cement into the highly fractured formation. At 0730 h on 26 July the drill string was tripped back to the surface, and the ship was offset back to Hole U1362B.

Hole U1362B Stage 2

The second stage of operations in Hole U1362B consisted of drilling a 14¾ inch diameter hole to 282 mbsf for the 10¾ inch casing string, with the goal of casing the upper portion of basement. The BHA was assembled for drilling out the cement inside the 16 inch casing and deepening the hole. The drill string was tripped to the bottom and Hole U1362B was reentered for the third time at 2030 h 26 July. The bit tagged the top of the cement plug at 213 mbsf. By 0100 h the following morning the cement was drilled out, and by 0600 h the hole had been cleaned out to the original depth of 250 mbsf. Drilling of the 14¾ inch diameter hole was completed at 1645 h on 27 July to 282 mbsf. This left a 10 m rat hole below the projected 10¾ inch casing shoe depth of 272 mbsf. A significant amount of time was spent on hole conditioning, including multiple wiper trips and mud sweeps. By 2130 h on 27 July the hole was considered to be in acceptable condition, and the drill string was recovered back to the surface. The bit cleared the rotary table at 0215 h on 28 July, and preparations began on the 10¾ inch casing string. The BHA included a 10¾ inch casing hanger with a TAM Free-cap 10¾ inch × 14¾ inch expandable packer designed to seal the annulus between the 10¾ and 16 inch casings. The string was terminated with a conventional Texas-pattern casing shoe and contained enough casing to place the casing shoe at 272 mbsf. Note that all casing collars were welded with four 2 inch long tack welds to ensure that none of the joints backed off during subsequent drilling. A caliper measurement of the swellable packer confirmed a 14¾ inch outer diameter, and the assembly was ready for deployment by 0830 h on 28 July. The hole was reentered at 1150 h. The casing was deployed without incident, and at 1330 h the hanger was landed and latch-in was verified with 15,000 lb of overpull. As before, the bottom of the hole was cemented with 40 bbl of cement preblended with Cello Flake and a 1.6% by volume calcium chloride accelerator. Because of an earlier-than-expected pressure spike, we suspected that the cement either hardened too quickly while still inside the casing or that the formation was sealed with cement, preventing any further flow out into the formation. To verify the location of the top of the cement plug, we decided to reenter Hole U1362B with the tricone drilling assembly before offsetting the ship back to Hole U1362A. The drilling assembly was tripped to the seafloor, and Hole U1362B was reentered for the fourth time at 0320 h. The bit tagged cement at 173 mbsf, suggesting that ~32 bbl (98 m) of cement was inside the casing and 8 bbl (27 m) had exited the casing shoe. The hope was that this cement had gone up the annulus ~27 m or nearly back to the 16 inch casing shoe at the sediment/basement interface. Because of the significant amount of cement inside the casing, we decided to drill out the cement before it hardened any further. This was a good decision because another 13.25 h was required to drill out 89 m of fresh cement at an average ROP of 6.7 m/h. Drilling was halted 10 m above the casing shoe because the science party did not want to open up Hole U1362B to seawater circulation this early in the expedition. The drilling assembly was pulled clear of the seafloor at 1905 h on 29 July, ending the second stage of operations in Hole U1362B.

Hole U1362A Stage 3

Hole U1362A was reentered for the sixth time at 0050 h on 30 July. The drill bit was lowered to 282 mbsf before contacting cement, which is within 2 m of the calculated displacement depth, placing the cement exactly where desired. Drilling of the cement plug started at 0230 h on 30 July, and at 0730 h the bit broke through the last of the cement at 309 mbsf, or ~1 m below the 10¾ inch casing shoe. Cleaning up the rat hole below the casing shoe to 346 mbsf proved to be more difficult than expected. Once again, a significant amount of time was required for hole cleaning and conditioning. This included multiple wiper trips, mud sweeps, and aggressive reaming of several trouble spots. The hole was believed to be in good enough condition for coring by 0200 h on 31 July, after 18.5 h of struggling through the same 38 m section. The drilling BHA cleared the rig floor by 0900 h, and preparations began for rotary core barrel (RCB) coring. An RCB roller cone bit with a C-7 cutting structure was made up to a standard bit sub. Three additional drill collars were picked up, allowing a 5-stand BHA to be assembled. The total length of drill collars in the BHA was 158.7 m, which allowed the BHA to extend ~21 m inside the 10¾ inch casing when the bit was at total depth. Thus, only slick pipe was in the borehole, with the only upset located right at the bit. This technique was successfully used in the past during Expedition 301 to minimize the potential for a stuck drill string.

Hole U1362A was reentered for the seventh time at 1715 h on 31 July, and the first RCB core barrel was deployed at 2215 h. The preliminary drilling needed to install the casing was designated as a drilled interval, dictating that the first RCB core be identified as Core 2R (Table **T3**). This core advanced 6.6 m to 352.6 mbsf according to drill pipe measurements and was on deck at 0535 h on 1 August. Recovery was 1.99 m, for an official recovery percentage of 30.2%. Because of tidal influences, the actual advance was closer to 5.5 m, which yields an unofficial recovery percentage of 36.2%. Cores 3R, 4R, and 5R were advanced to 362.2, 364.7, and 370.2 mbsf, respectively. Continuous challenges were encountered throughout the coring process. Effective hole cleaning was a constant problem, necessitating successively larger and more frequent high-viscosity mud sweeps and higher pump strokes while cutting the core. Penetration rates were variable, ranging from ~1 m/h in the more massive altered rock to >4 m/h in the more friable material. Recovery was variable as well, with an average of 27.1%.

Coring continued, with the formation alternating between massive and highly fractured zones and rapid penetration rates associated with high drill string torque and circulation pressures. These conditions almost always led to the pipe getting stuck and losing rotation and circulation. The highest vulnerability seemed to be when drill pipe connections were made after a cored interval was completed. Ultimately, what seemed to work best was using more frequent and larger mud sweeps (35–50 bbl each) and spotting heavy mud pills in the pipe just prior to making a connection. Coring continued at an average pace of ~23 m per day, which included many hours of lost time getting unstuck and making impromptu wiper trips to get coring parameters back to normal.

Cores 327-U1362A-6R through 14R advanced to 3120.6 mbrf (448.6 mbsf). The drill string was recovered for a bit change and to extend the length of the BHA. We believe that the only reason coring was maintained in this hole is because only slick pipe (i.e., 8¼ inch drill collars) extended into the open hole below the 10¾ inch casing shoe. Having the collars in the hole with no external upsets allowed the pipe to be pulled back up the hole when required to reestablish rotation and circulation. As a result, when the drill string was tripped to the surface to change the core bit to a new C-7 RCB bit, an additional nine drill collars were added to the drill string. Severe damage was noted on the upward pointed shoulder of the used bit as a result of the backreaming required by the multiple incidents of stuck pipe. The BHA was heavily sandblasted and polished on all joints that extended below the reentry cone.

The pipe was tripped to bottom once again, and in <15 min Hole U1362A was reentered for the eighth time at 2335 h on 5 August. After the top drive was picked up, the bit was washed/reamed to within 1 m of total depth without any major issues. At that point, however, the drill string became stuck and an additional 6 h was required to work the drill string free and condition the hole before coring could resume. RCB coring continued with Core 327-U1362A-15R at 448.6 mbsf and continued through Core 21R to a total depth of 3168 mbrf (496.0 mbsf). Core 21R was on deck at 1255 h on 8 August. Cores 15R through 18R were cut at very low ROPs of 1–2 m/h or less in a much more massive and less fractured formation. Recovery through this interval was excellent, averaging >75%. Cores 19R through 21R, however, were recovered from highly fractured material with ROPs in the 4–5 m/h range, and recovery dropped to 24.3%. The last core (21R) was cut with elevated drill string torque indicative of potential hole problems to come. The use of significantly larger mud sweeps (65–150 bbl each) seemed to contribute to more effective hole cleaning and fewer stuck pipe incidents.

The coring cycle was followed by three wiper trips to the 10¾ inch casing shoe and back to total depth. Hole conditions improved with each cycle but not to an acceptable level for wireline logging, packer testing, and ultimately the CORK deployment. The first wiper trip required 7 h of washing/reaming and had 54 m of fill to remove from the bottom of the hole. The second wiper trip required 4.5 h of washing/reaming and had 46 m of bottom fill. The third wiper trip required only 3.5 h of washing/reaming and had 28 m of fill. Further wiper trips were abandoned in favor of deepening the hole by drilling, and at 0700 h on 9 August the pipe trip began back to the surface.

The RCB assembly was switched to a 9⅞ inch tricone drilling assembly. The tricone bit is equipped with bigger cutters and bearings that are better suited to rough drilling conditions and is also capable of handling the higher flow rates necessary for effective hole cleaning. The pipe round-trip began at 0700 h on 9 August, and at 1935 h Hole U1362A was reentered for the ninth time. The bit was run to 476 mbsf without rotation or circulation. The hole was washed and reamed through 20 m of soft fill to total depth and a 50 bbl high-viscosity mud sweep was circulated. Another 17 h was required to deepen the hole by 32 m to a final total depth of 528 mbsf. Two 75 bbl high-viscosity mud sweeps were pumped, and at 1800 h on 10 August a series of three wiper trips was initiated to clean up and condition the hole. This required 11 h to complete, including the requisite mud sweeps. After the third wiper trip, the pipe was lowered without rotation or circulation to 515 mbsf. After some resistance at that depth, the pipe broke through the plug easily, and the hole was clean to total depth. At 0500 h on 11 August, the pipe was tripped back to the casing shoe and 3.5 h was spent on stand-by, waiting for the hole to equilibrate and to allow any remaining cuttings to fall to the bottom. During that time, general rig maintenance was conducted as well as a pressure test of the rig circulation system in preparation for the packer flow test. At 0930 h on 11 August the drill string was lowered into the hole without rotation or circulation, reaching 512 mbsf. A 75 bbl high-viscosity mud sweep was circulated, and the drill string was recovered back to the surface.

Hole U1362A wireline logging and packer pumping test

The wireline logging/packer BHA was assembled, the drill string was tripped to the seafloor once again, and at 0211 h on 12 August Hole U1362A was reentered for the tenth time. The pipe was spaced out to 264 mbsf (still inside 10¾ inch casing) and preparations began for wireline logging. At 0545 h on 12 August, a single suite of logging tools was run in the hole, reaching 507 mbsf without any resistance. Two full passes were made from 507 mbsf to the casing shoe at 308 mbsf. A third partial pass was made from 508 to 373 mbsf across the area of interest for setting the lower packer. Wireline logging was completed and the tools were rigged down by 1615 h on 12 August.

The drill string was then lowered to 519 mbsf without rotation or circulation for another depth check. The end of the pipe was raised to 436 mbsf, positioning the TAM packer assembly at the desired depth of 424.5 mbsf. After some difficulty setting the packer in open hole (attributed to the >2 m of vessel heave), the first flow test was completed by 0430 h on 13 August. The drill string was raised up into the 10¾ inch casing for the second and final flow test. This test was canceled when the packer failed to lock in pressure after repeated attempts. It was possible to pressure up the packer, but the pressure could not be locked in the element to set the packer. At 1000 h on 13 August, the drill string was tripped to the surface and the end of the pipe cleared the rotary table at 1800 h. Upon recovery, inspection of the packer showed evidence of extensive damage, and water was seen leaking from a bad gouge near the lower end, explaining why the packer failed to hold pressure.

Hole U1362A CORK wellhead and casing deployment

Assembly of the CORK began at 1845 h on 13 August. The CORK running tool was made up to a 2 m drill collar joint and laid out on the rig floor for later use. The bullnose was then made up with three perforated and coated 8¼ inch drill collars. A single joint of perforated and coated 5½ inch casing, along with the required crossover subs, was then made up and lowered into the moonpool area. The coated collars and casing joint were wiped clean with isopropyl alcohol and held off the steel penetrator in the moonpool floor. A microbiology miniscreen was installed on the lower end of the 5½ inch casing joint, and its umbilical was attached. A chemistry miniscreen was attached in the upper third of the 5½ inch casing joint along with its umbilical. The first inflatable packer was installed at 2130 h, followed by a landing collar and the first swellable packer assembly. A pressure miniscreen was installed on the 4½ inch casing mandrel below the inflatable packer along with the umbilical connection.

When the first swellable packer sub was picked up on the rig floor, it was determined that the swellable element was >9¾ inches in places, considerably larger than the 8½ inch diameter that was expected and too large to be run in an irregular open hole drilled with a 9⅞ inch drill bit. The swellable packer subs to be used at depth below the CORK wellheads comprised two separate packer elements, each with 30 inch sealing length, built around the same 4½ inch casing used for most of the rest of the CORK casing. The two swellable elements were intended to be deployed in pairs. Each element was split longitudinally, with molded channels on the inside to accommodate the umbilical lines. The halves are bolted together over the umbilicals and the design is such that the packer will swell into and seal against the casing or borehole wall over time. This process is supposed to take several weeks to complete once the element is submerged in seawater. Because there were concerns about getting a 9¾ inch plus diameter into the open hole, we decided that the packer elements should be machined down to 8½ inches. Although time consuming (almost 24 h for both swellable packer elements), this was considered better than running the packers with too large a diameter or omitting them entirely.

The first pair of swellable packer elements was ready for installation at 1100 h on 14 August, allowing work to proceed in the moonpool with umbilical connections and miniscreen installations. Installation of the second swellable packer pair began at 1830 h that evening. By 2200 h, eight additional joints of 4½ inch casing were run, and additional chemistry and pressure miniscreens were installed below the inflate-able packer. The second set of swellable packers was installed. This packer set did not have to be reduced in diameter because it was to be run inside 10¾ inch casing rather than open hole. Another 22 joints of 4½ inch casing were run by 0845 h on 15 August. At that point, the CORK head was picked up, the CORK running tool was made up to the CORK head, and the head was made up to the top 4½ inch casing joint, all within 30 min. The final umbilical terminations were made, including all strapping and securing. Only a few casing centralizers were installed on the CORK stinger to minimize the potential for getting stuck in the open hole during deployment. A single 5½ inch centralizer was used to protect the lowermost chemistry miniscreen. A 4½ inch centralizer was used next to the lowermost pressure screen, above the first swellable packer and below the second inflatable packer. This was followed by a pair of 4½ inch centralizers installed on all of the 4½ inch casing joints that would remain inside the 10¾ inch casing. The packer inflation hose was installed between the running tool and the CORK head, the valves were opened, and after picking up a single stand of drill collars, the CORK was lowered into the water. The CORK was pulled back up after 5 min to close the valves and secure the valve handles with rubber bands. One final operation was to test fit the vibration-isolated television (VIT)/subsea television (TV) frame over the CORK head. The pipe trip to the seafloor with the CORK assembly was initiated at 1300 h on 15 August.

Hole U1362A CORK instrument string deployment

At 1630 h on 15 August, the drill string was positioned just above the seafloor and preparations began for deployment of the instrument string. A 200 lb sinker bar was assembled below six OsmoSampler sections. With the OsmoSamplers suspended in the pipe, the deployment of the Spectra rope and temperature loggers began. The deployment proceeded faster than in the past because the string had lifting eyes prespliced into the Spectra rope at 25 m increments. It is estimated that this new technique saved hours of rig time in the deployment of the 464 m instrument string. The instrument string was slowly lowered to the bottom at 1815 h, and by 1945 h the string had landed and latch-in had been verified with 400 lb of overpull. Within minutes, the weakened shear pin was sheared off and the wireline was recovered. By 2230 h the drill string was spaced out for reentry and the VIT/subsea TV arrived at the end of the pipe. The attempted reentry was suspended at this point when it became apparent that the instrument string was protruding beyond the end of the CORK bullnose. The wireline sinker bar and at least the first OsmoSampler section were visible beyond the CORK stinger. It was considered unwise to attempt reentry and deployment in the open hole because this would most likely result in damage to the instrument string and possibly loss of the hole. Unfortunately, we did not have the small RS fishing tool needed to unlatch the top plug from the CORK, so we had no way to recover the instrument string without retrieving the CORK wellhead. We decided to bring the wellhead back to the surface, and at 0200 h on 16 August the CORK was hung off in the moonpool. The instrument string was released using the bolts built into the top of the wellhead, designed as a secondary release mechanism during submersible or ROV operations, should the RS fishing tool fail to release the plug. The top plug was lifted, part of the Spectra cable was pulled from the hole, shortened and spliced, and reinserted into the CORK. The top plug was latched into place while the wellhead was at the surface, rather than waiting until it was at the seafloor. At 0600 h the drill string was once again tripped to the seafloor. The trip took longer than usual because the pipe had to be filled from a water hose after assembling each stand. The water was needed to prevent a differential pressure from building up and overloading the latch system on the instrument string. Hole U1362A was reentered for the eleventh time at 1150 h. The CORK was landed without incident, and the inflatable packer assemblies were inflated with 1500 psi pressure over a period of 30 min. The VIT/subsea TV was recovered, and at 1600 h preparations began for deploying the CORK platform.

The platform halves were maneuvered onto the moonpool doors and bolted together. Another 2 h was spent assembling the platform deployment vehicle with the VIT sleeve and rigging the various required slings. At 1800 h the platform began its trip to the seafloor, but at 2007 h the subsea TV camera went black. After some initial troubleshooting by the Overseas Drilling Limited (ODL) electronics technician, the VIT/subsea TV with the suspended CORK platform was recovered back to the ship. A faulty connector was replaced, and the VIT was once again run to bottom. Upon initial landing at 0230 h on 17 August, the platform reached the CORK running tool but failed to release. After it was worked up and down for ~1 h, the platform eventually released. The VIT was recovered back to the ship, and the deployment tool was removed along with all platform deployment slings. This was done so they would not become entangled with the CORK installation. The VIT/subsea TV was deployed back to bottom, confirming that the platform had not released correctly and was hanging at an angle from the CORK running tool. The VIT sleeve was set down on the platform multiple times before the platform was jarred off and fell into position on the rim of the reentry cone. The running tool was released from the CORK head at 0600 h on 17 August, successfully completing the installation of the Hole U1362A CORK. The drill string was tripped back to the surface, and the recovery tool cleared the rig floor at 1045 h, ending operations in Hole U1362A. Close inspection of the platform deployment tool indicated that one of its arms was bent from impact with the bolt screwed into the CORK running tool to protect the packer inflation hose fitting. As a result, only two of the three arms released initially, causing the platform to hang on the third arm and resulting in the cocked position of the platform on the CORK head. A shorter bolt that would not interfere with the platform deployment was installed for the next set of CORK deployment operations.

Hole U1362B Stage 3

The drill string was recovered following operations in Hole 1027C (see **"Hole 1027C"** below). The BHA was changed to a drilling BHA, and a new 9⅞ inch tricone drill bit was deployed. Hole U1362B was reentered for the sixth time at 0423 h on 21 August. The bit was advanced to bottom, taking weight at 172 mbsf. The top drive was picked up and the hole was washed/reamed to 262 mbsf, where the top of the major concentration of cement was contacted. The cement was drilled out, and the hole was cleaned to the bottom of the 14¾ inch hole at 282 mbsf. The hole was deepened another 57 m to 339 mbsf, 3 m short of the original target depth of 342 mbsf. A 50 bbl sweep of high-viscosity mud was circulated, and two successive wiper trips were conducted from the 10¾ inch casing shoe to total depth. During the last wiper trip, the driller noted some resistance at 310 mbsf, but this was easily passed and 6 m of hard fill was noted on bottom. Another 50 bbl mud sweep was circulated, and at 1630 h on 22 August the drill string trip back to the surface began. The seafloor was cleared at 1745 h, and assembly of the injection test BHA began at 2200 h on 22 August.

Hole U1362B 24 h pumping test and tracer injection experiment

The assembly of the pumping/injection test BHA began at 2200 h on 22 August. This BHA included a specially made injection sub that had axial circulation slots in the sides and functioned as a carrier for the osmotic samplers, which would be used to sample the injectate downhole, and downhole pressure gauges. The BHA length resulted in the bottom of the injection pipe being 13.4 m below the 10¾ inch casing shoe into open hole. The drill string was tripped to the seafloor, and at 0330 h on 23 August a preinjection exercise was conducted to ensure that all parties involved (drill crew, gas injection crew, cementer, and rig floor sampling crew) understood their respective roles and that all equipment was set up properly. Hole U1362B was reentered for the seventh time at 0715 h. The drill string was run in the hole and began taking weight ~3 m before landing the Dril-Quip (DQ) tool in the 10¾ inch casing hanger. The pipe was eventually worked down, and the DQ tool was landed. After waiting 1 h for the hole to equilibrate and establish a baseline starting point, the rig pumps were engaged at a circulation rate of 20 strokes per minute. When pump pressure rose quickly, it became apparent that the system was clogged. The drill string was tripped back to the surface, clearing the rig floor at 1700 h.

Upon recovery, the end of the stinger was found to be packed with drill cuttings, ground up cement, and drilling mud. Not only did this inhibit injection, it was an indication that the hole was likely packed-off and would have to be opened up before a viable injection test could be conducted. The same bit and drilling BHA used previously was reassembled and deployed to the seafloor. Hole U1362B was reentered for the eighth time at 0125 h on 24 August. The drilling assembly was run to bottom without rotation or circulation, taking weight at 308 mbsf. No sign of what was plugging the hole was detected. The hole was repeatedly washed, reamed, and swept with high-viscosity mud. Once the hole was thought to be in acceptable condition, the drill string was pulled back into the 10¾ inch casing string. At 1015 h on 25 August, a 1 h waiting period commenced to allow the hole to stabilize. This period was followed by another round of wiper trips and hole conditioning because there continued to be spots in the hole that could not be passed without using circulation and/or rotation. The most troublesome spots seemed to be at 353 and 359 mbsf. Ultimately, these were cleared and the drilling assembly was recovered back to the surface.

The injection BHA was reassembled at 2100 h on 25 August. This time, the space-out was changed to position the lower end of the injection stinger only 3.76 m beyond the 10¾ inch casing shoe. The assembly was redeployed to the seafloor, and prior to reentry a series of pressure readings were taken at slow circulation rates to provide baseline pressures. Hole U1362B was reentered for the ninth time at 0642 h on 26 August. This time, the injection assembly landed without incident. Once again, a 1 h waiting period began to provide a baseline for the start of the 24 h injection test. At 0900 h, the injection test started at 20 strokes per minute on the rig circulating pumps, using seawater as the injected medium. The VIT/subsea TV camera was lowered initially to provide assurance that there was no fluid leaking from the hole. The 24 h injection test was successfully completed by 0900 h on 27 August, followed by a 1 h waiting period to allow the hole to equilibrate. The injection BHA was recovered back to the ship, and the osmotic samplers and downhole pressure data loggers were removed from the injection sub carrier.

Hole U1362B CORK wellhead and casing deployment

Because having enough open hole was critical to the successful deployment of the CORK, a final depth check was conducted using a drilling BHA. At 2130 h on 27 August, Hole U1362B was reentered for the tenth time. The drill string was lowered to 261 mbsf (inside the 10¾ inch casing), and the top drive was picked up in case it became necessary to wash or ream to bottom. The bit was lowered without rotation or circulation to 348 mbsf (just 11 m above the total depth of the hole at 359 mbsf), which was below the CORK stinger space-out depth of 312 mbsf. The drilling assembly was then recovered back to the surface.

At 0530 h on 28 August, preparations began for assembling and deploying the CORK in Hole U1362B. The running tool was made up to a 2 m drill collar pup joint and laid out on the rig floor for later use. The bullnose was made up with three 8¼ inch perforated and coated drill collars and a single joint of perforated and coated 5½ inch casing, along with the required crossover subs. The coated collars and casing joint were wiped clean with isopropyl alcohol and held off the steel penetrator in the moonpool floor. A microbiology miniscreen was installed on the lower end of the 5½ inch casing joint, and the umbilical was attached. Three chemistry miniscreens were attached to the upper part of the 5½ inch casing joint, along with their respective umbilical lines. This was followed by an inflatable packer, a landing collar (for a future internal instrument string having a bottom plug), and a swellable packer set. The single pressure miniscreen was installed on the 4½ inch casing mandrel below the inflatable packer and connected to the final umbilical. Nineteen joints of 4½ inch casing were made up, and the umbilical lines were strapped and secured to the casing using bands. The CORK running tool was made up to the CORK head, the head was made up to the top 4½ inch casing joint, and the umbilicals were terminated. Only a few casing centralizers were installed on the CORK stinger to minimize the potential for hanging up in open hole during deployment. A single 5½ inch centralizer was used to protect the chemistry miniscreens. A single 4½ inch centralizer was installed near the base of the 4½ inch packer mandrel. Two 4½ inch casing centralizers were installed on each 4½ inch casing joint that would remain inside the 10¾ inch casing string. The packer inflation hose was installed between the running tool and the CORK head, the valves were opened, and, after picking up a single transition stand of drill collars, the CORK was lowered into the water. The CORK was then pulled back to close the valves and secure the valve handles with rubber bands. The CORK assembly trip to the seafloor started at 2315 h on 28 August.

Hole U1362B CORK instrument string deployment

At 0200 h on 29 August, the drill string was positioned just above the seafloor and preparations began for deploying the instrument string. A ~200 lb sinker bar (wet weight) was assembled with the osmotic sampler sections, temperature data loggers, Spectra rope, and the landing sub. This process, including the trip to the seafloor, required ~4 h. The wireline trip was made at a very slow speed (15–20 m/min). A Spectra stretch test using the traveling block on the rig (completed prior to string deployment) indicated that scientists needed to allow for ~2% stretch, rather than the 1% indicated by the manufacturer, so the cable was terminated accordingly. To avoid the problem experienced in Hole U1362A where the instrument string extended past the end of the CORK stinger, the last 20 m of deployment was made very slowly while monitoring the end of the CORK with the VIT camera. This would allow the winch operator to stop quickly should anyone see the string protrude beyond the end of the CORK stinger. In that case, the instrument string could have been recovered before latching in, thus avoiding a drill pipe trip with the CORK. This time, the space-out on the Spectra rope was fine, and the instrument string landed without extending past the bullnose on the CORK stinger. The perceived latch-in was verified with several hundred pounds of overpull, and the GS overshot, equipped with a weakened shear pin, was jarred off after four attempts. The sinker bar string was recovered back to the surface and at 0648 h Hole U1362B was reentered for the eleventh time. During subsequent rig operations to space out the drill pipe to land the CORK, water was noted to be periodically flowing from the drill pipe onto the rig floor in association with the ship's heave. This suggested that the landing sub might have been unseated. The drill string was pulled clear of the reentry cone, and the sinker bars were deployed once again to engage the pulling neck on the instrument string to verify latching. Again, after applying several hundred pounds of overpull, it appeared that the string was properly latched. However, during the jar-off attempt, the wireline gained the weight of the instrument string. Either the string was latched and the jarring caused the latching mechanism to fail or the string was never fully latched in originally. The instrument string was recovered back to the surface and inspected. Nothing was noted that would indicate a problem with the latch or the Spectra rope. The landing/latch assembly was changed out in case of a tolerance problem or an issue with the latch assembly that was not readily apparent. At 1030 h the string was redeployed. This time, however, it was difficult to achieve any overpull, suggesting that the latch in the plug might not be engaging with the wellhead. The GS overshot was jarred off once again, and the sinker bars were recovered.

Subsequent discussions regarding the water pumping action focused on whether there was enough clearance in the latch-down mechanism to allow the plug to lift off the seat as a result of heave-induced pipe surge, allowing water to flow past the small-diameter O-ring seal. In fact, latching the top plug is not required to seal the CORK; the latch is intended mainly as a means to check that the plug is landed, but sealing is provided by an O-ring on a tapered seal surface, held down by the weight of the instrument string. At 1330 h, Hole U1362B was reentered for the twelfth time. The CORK assembly was run in the hole without incident, and at 1515 h the CORK head landed in the 10¾ inch casing hanger at the correct drill string depth measurement. Visual observation confirmed that the CORK head was in the correct position, and the VIT/subsea TV was recovered back to the surface. The inflatable packers on the CORK string were inflated with 1000 psi for 30 min. The VIT platform deployment tool and CORK platform were assembled in the moonpool area, and at 1800 h the platform was deployed through the moonpool. The CORK platform was successfully released at 1930 h, the VIT was recovered, and the deployment slings and tool were rigged down. The VIT was redeployed at 2200 h, and visual confirmation was received that the platform was resting properly on the reentry cone. At 2217 h on 29 August, the running tool was released, completing the Hole U1362B CORK installation.

The VIT was run back to the seafloor with a grappling hook to recover a beacon that had not surfaced. The beacon was grabbed at 0146 h and was on deck by 0255 h. We discovered that the beacon had not released properly because it had a tangled tether, which kept the weight attached. The drill string was pulled up by 0815 h, and the rig was secured for transit by 1300 h. At 1315 h, the thrusters were raised and the ship was under way to Grizzly Bare Site U1363.

Site U1301

Following the deployment of the Hole U1362A CORK, the ship was offset in DP mode to Hole U1301B, 800 m south–southwest (Fisher, Urabe, Klaus, and the Expedition 301 Scientists, 2005). A BHA that included a CORK recovery tool was made up and tripped to the seafloor by 1615 h on 17 August. At 1730 h, the recovery tool engaged the Hole U1301B CORK head, but before the J-slot tool could be engaged, the recovery tool heaved off. This required a second engagement attempt, and by 1815 h the tool was back on the CORK head. Engagement of the J-slot tool was ineffectual, so 10,000 lb of weight was applied to the top of the CORK, allowing us to proceed with string-recovery operations. We later determined that the CORK running tool used for operations was incompatible with the wellhead, which had J-slot lugs that were too large.

The sinker bars were lowered, and after multiple attempts the GS overshot engaged the instrument string top plug. Tension was applied to the instrument string, which was found to be stuck in place, as it was during the *Atlantis* recovery effort in Summer 2009. After the sandline was worked with various amounts of overpull, the cable stretched or the instrument string began creeping slowly upward. At 0920 h on 17 August, the Spectra cable parted. The CORK recovery tool was disengaged, and a portion of the instrument string was recovered back to the surface. Upon recovery, a splice in the Spectra rope was found to have failed directly above the middle plug of the installed instrument string. Five temperature data loggers and 377 m of Spectra rope were recovered. After laying out the recovered portion of the instrument string the CORK head was reengaged at 2225 h.

Another sandline run was made to deploy a temperature logger to obtain a temperature profile of the upper part of the CORK casing and to determine the depth of casing available for subsequent instrument deployment. This allowed proper configuration of the replacement instrument string. The logging tool was stopped for 5 min at 5 m increments in the upper 50 m of the CORK and subsequently at 25 m intervals. The bottom of the open CORK casing was tagged at 3037 mbrf (370 mbsf). The recovery tool was disengaged once again at 0130 h on 18 August. Make up of the replacement instrument string, including rigging of the Schlumberger electric logging line, began at 0145 h. The prototype Electronic “RS” (ERS; “RS” is an oilfield designation for a particular geometry of fishing tool) tool system, under development by Stress Engineering for use with the developmental SCIMPI CORK system, was used for this deployment because the Hole U1301B CORK system was not configured with an instrument string latch-down system. Historically, there have been a lot of problems jarring off the instrument string without dislodging the top plug, which has tended to get pulled out of the wellhead during deployment. Therefore, we hoped that the prototype ERS system would provide a more reliable mechanism for releasing the top plug. The replacement instrument string, which included three thermistor probes and extended to ~50 mbsf, was ready for deployment at 0330 h, and the CORK running tool was engaged once again at 0435 h. The instrument string was successfully landed and released using the ERS without incident, and the Schlumberger logging line was recovered and rigged down. At 0530 h on 18 August, the CORK recovery tool was disengaged, ending operations in Hole U1301B.

Hole 1027C

Following operations in Hole U1301B, the ship was offset in DP mode to Hole 1027C. At 1000 h on 18 August, a CORK recovery tool was slipped onto the CORK head, and, by 1015 h, engagement of the J-slots with the CORK lugs was verified. Another 3.5 h was spent unsuccessfully attempting to recover the CORK, pulling with up to 140,000 lb. Ultimately, we realized that another set of lugs farther down on the CORK head (below the CORK platform) had to be engaged to release this type of CORK, but this required a release tool that was not brought to sea. The recovery tool deployed was not long enough to reach these latches. The drill string was recovered to the surface while we discussed various options.

After some discussion, we decided that the crew could fabricate the required recovery tool using the existing tool as a starting point. This fabrication took 36 h to complete. A test-fitting jig was built to emulate the CORK head that was to be recovered, a section of 20 inch casing was used to extend the length of the tool so it could reach deep enough to engage the lower set of CORK latches, the lower section of the tool was enlarged to the correct inside diameter, and the small reverse cone used to improve the recovery tool's ability to slip over the CORK head was cut down to a 32 inch diameter. Everything had to be welded back together, doubler plates were added for extra strength, and then the tool was fit over the test jig for the final time.

The drill string was tripped to the seafloor, and at 1200 h on 20 August the new recovery tool was slipped over the CORK head. The tool was lowered down through the 48 inch hole in the center of the CORK platform, and by 1245 h the lower latches on the CORK head were engaged with the "modified" recovery tool J-slots. The next 3.5 h was spent trying to pull the CORK, but the latching mechanism would not release. Attempts alternated between allowing the recovery tool to hammer down on the

CORK head with 10,000 lb and exerting an overpull of up to 100,000 lb, again without success. It is unclear why the CORK could not be released from the hole.

At 1615 h, the recovery tool was disengaged from the CORK head, and the drill string was recovered back to the surface. The subsea TV was recovered, and at 2130 h on 20 August the recovery tool cleared the rotary table, ending operations in Hole 1027C.

Transit to Site U1363

After completion of the CORK deployment in Hole U1362B, the drill string was tripped back to the ship, and five stands of control length drill collars were laid down. The rig was secured by 1300 h on 30 August, and the 31 nmi transit to Grizzly Bare outcrop took 3 h at an average speed of 10.0 kt. Upon arrival, the thrusters and hydrophones were lowered, and the ship was moved in DP mode to a location midway between the anticipated Grizzly Bare holes so that a positioning beacon could be deployed.

Hole U1363A

At 1730 h on 30 August, the ship was offset to Hole U1363A. A two-stand advanced piston corer (APC)/extended core barrel (XCB) BHA was made up and tripped to the seafloor, and an XCB center bit was deployed. The seafloor was tagged at 2250 h on 30 August at 2689 mbrf. Drilling without coring continued for 2.5 h to the basement contact at 58 mbsf. The XCB center bit was recovered, and the drill string was pulled out of the seafloor. The sole purpose of drilling Hole U1363A was to determine the depth of basement to avoid possible impact with an APC core barrel or temperature shoe at the next hole.

Hole U1363B

The ship was offset 10 m on a bearing of 135°, and Hole U1363B was spudded at 0530 h on 31 August at 2690 mbrf. APC Cores 327-U1363B-1H through 6H advanced to 42.5 mbsf by 1300 h, at which point the APC was not able to penetrate the sandy turbidite formation. APCT-3 temperature measurements were taken with Cores 327-U1363B-3H through 6H. Cores 327-U1363B-7X and 8X advanced to 55.0 mbsf by 1610 h. The first SET temperature measurement was taken at ~56 mbsf, and coring continued with Core 327-U1363B-9X, which advanced through the sediment/basement interface to 57 mbsf. Core 327-U1363B-10X advanced to 61 mbsf and was on deck by 2100 h. The drill string was pulled clear of the seafloor at 2140 h on 31 August.

Hole U1363C

The ship was offset in DP mode to Hole U1363C, the deepest along the transect at Grizzly Bare. Hole U1363C was spudded at 2255 h on 31 August at 2689 m. Hole U1363C was drilled without recovering cores to 170 mbsf. An SET temperature measurement was taken at ~171 mbsf, followed by Cores 327-U1363C-2X and 3X to 183.2 mbsf. A second SET temperature measurement was taken at ~184 mbsf, followed by Cores 327-U1363C-4X and 5X to 202.4 mbsf. A third SET temperature measurement was taken at ~204 mbsf. At 1445 h on 1 September, the SET tool became stuck inside the outer core barrel because of the sandy formation, and the drill string had to be recovered back to the ship. The SET tool was retrieved at 0100 h on 2 September, and the ship was offset 10 m on a bearing of 135°.

Hole U1363D

Hole U1363D was spudded at 0745 h on 2 September at 2689 mbrf. Drilling without coring continued using an XCB bit to 198 mbsf. Cores 327-U1363D-2X through 5X advanced to 231 mbsf by 0035 h on 3 September, and the drill string was pulled out of the seafloor at 0700 h, ending Hole U1363D.

Hole U1363E

Hole U1363E was spudded at 0840 h on 3 September and was drilled without coring to establish the depth to basement. The sediment/basement interface was confirmed at 36 mbsf at 1000 h. The drill string was pulled out of the seafloor at 1125 h, ending Hole U1363E.

Hole U1363F

Hole U1363F was spudded at 1200 h on 3 September, and Cores 327-U1363F-1H through 4H advanced to 35 mbsf by 1600 h. APCT-3 temperature measurements were taken with Cores 327-U1363F-3H and 4H. The drill string was pulled out of the seafloor at 1735 h, ending Hole U1363F.

Hole U1363G

The ship was offset, and basement contact was again established at 17 mbsf by washing down. Hole U1363G was spudded at 2000 h on 3 September, and Cores 327-U1363G-1H through 3H advanced to 24.9 mbsf by 2250 h. The true advance is closer to 17 mbsf because the last core recovered mostly flow-in material. An APCT-3 temperature measurement was taken with Core 327-U1363G-2H.

Transit to Victoria, British Columbia (Canada)

The rig floor was secured for transit, the thrusters were raised, and the ship was under way at 1015 h on 4 September. The first line was cast ashore at 0836 h on 5 September.

References

Alt, J.C., 1995. Subseafloor processes in mid-ocean ridge hydrothermal systems. *In* Humphris, S.E., Zierenberg, R., Mullineaux, L., and Thomson, R. (Eds.), *Seafloor Hydrothermal Systems: Physical, Chemical, Biological and Geological Interactions within Hydrothermal Systems.* Geophys. Monogr., 91:85–114.

Becker, K., and Fisher, A.T., 2008. Borehole packer tests at multiple depths resolve distinct hydrologic intervals in 3.5-Ma upper oceanic crust on the eastern flank of Juan de Fuca Ridge. *J. Geophys. Res., [Solid Earth],* 113(B7):B07105. **doi:10.1029/2007JB005446**

Carbotte, S.M., Nedimovic, Canales, J.P., Kent, G.M., Harding, A.J., and Marjanovic, M., 2008. Variable crustal structure along the Juan de Fuca Ridge: influence of on-axis hot spots and absolute plate motions. *Geochem., Geophys., Geosyst.,* 9:Q08001. **doi:10.1029/2007GC001922**

Davis, E.E., Chapman, D.S., Mottl, M.J., Bentkowski, W.J., Dadey, K., Forster, C., Harris, R., Nagihara, S., Rohr, K., Wheat, G., and Whiticar, M., 1992. FlankFlux: an experiment to study the nature of hydrothermal circulation in young oceanic crust. *Can. J. Earth Sci.,* 29(5):925–952.

Davis, E.E., Chapman, D.S., Wang, K., Villinger, H., Fisher, A.T., Robinson, S.W., Grigel, J., Pribnow, D., Stein, J., and Becker, K., 1999. Regional heat flow variations across the sedimented Juan de Fuca Ridge eastern flank: constraints on lithospheric cooling and lateral hydrothermal heat transport. *J. Geophys. Res., [Solid Earth],* 104(B8):17675–17688. **doi:10.1029/1999JB900124**

Davis, E.E., Fisher, A.T., Firth, J.V., et al., 1997. *Proc. ODP, Init. Repts.,* 168: College Station, TX (Ocean Drilling Program). **doi:10.2973/odp.proc.ir.168.1997**

Elderfield, H., and Schultz, A., 1996. Mid-ocean ridge hydrothermal fluxes and the chemical composition of the ocean. *Annu. Rev. Earth Planet. Sci.,* 24(1):191–224. **doi:10.1146/annurev.earth.24.1.191**

Elderfield, H., Wheat, C.G., Mottl, M.J., Monnin, C., and Spiro, B., 1999. Fluid and geochemical transport through oceanic crust: a transect across the eastern flank of the Juan de Fuca Ridge. *Earth Planet. Sci. Lett.,* 172(1–2):151–165. **doi:10.1016/S0012-821X(99)00191-0**

Fisher, A.T., Davis, E.E., and Becker, K., 2008. Borehole-to-borehole hydrologic response across 2.4 km in the upper oceanic crust: implications for crustal-scale properties. *J. Geophys. Res.*, 113(B7):B07106. **doi:10.1029/2007JB005447**

Fisher, A.T., Davis, E.E., Hutnak, M., Spiess, V., Zühlsdorff, L., Cherkaoui, A., Christiansen, L., Edwards, K., Macdonald, R., Villinger, H., Mottl, M.J., Wheat, C.G., and Becker, K., 2003. Hydrothermal recharge and discharge across 50 km guided by seamounts on a young ridge flank. *Nature (London, U. K.),* 421(6923):618–621. **doi:10.1038/nature01352**

Fisher, A.T., Tsuji, T., and Gamage, K., 2010. Juan de Fuca Ridge-Flank Hydrogeology: the hydrogeologic architecture of basaltic oceanic crust: compartmentalization, anisotropy, microbiology, and crustal-scale properties on the eastern flank of Juan de Fuca Ridge, eastern Pacific Ocean. *IODP Sci. Prosp.,* 327. **doi:10.2204/iodp.sp.327.2010**

Fisher, A.T., Urabe, T., Klaus, A., and the Expedition 301 Scientists, 2005. *Proc. IODP,* 301: College Station, TX (Integrated Ocean Drilling Program Management International, Inc.). **doi:10.2204/iodp.proc.301.2005**

Fisher, A.T., and Von Herzen, R.P., 2005. Models of hydrothermal circulation within 106 Ma seafloor: constraints on the vigor of fluid circulation and crustal properties, below the Madeira Abyssal Plain. *Geochem., Geophys., Geosyst.,* 6(11):Q11001. **doi:10.1029/2005GC001013**

Fisher, A.T., Wheat, C.G., Becker, K., Davis, E.E., Jannasch, H., Schroeder, D., Dixon, R., Pettigrew, T.L., Meldrum, R., McDonald, R., Nielsen, M., Fisk, M., Cowen, J., Bach, W., and Edwards, K., 2005. Scientific and technical design and deployment of long-term, subseafloor observatories for hydrogeologic and related experiments, IODP Expedition 301, eastern flank of Juan de Fuca Ridge. *In* Fisher, A.T., Urabe, T., Klaus, A., and the Expedition 301 Scientists, *Proc. IODP,* 301: College Station, TX (Integrated Ocean Drilling Program Management International, Inc.). **doi:10.2204/iodp.proc.301.103.2005**

Huber, J.A., Johnson, H.P., Butterfield, D.A., and Baross, J.A., 2006. Microbial life in ridge flank crustal fluids. *Environ. Microbiol.*, 88(1):88–99. **doi:10.1111/j.1462-2920.2005.00872.x**

Hutnak, M., Fisher, A.T., Zühlsdorff, L., Spiess, V., Stauffer, P.H., and Gable, C.W., 2006. Hydrothermal recharge and discharge guided by basement outcrops on 0.7–3.6 Ma seafloor east of the Juan de Fuca Ridge: observations and numerical models. *Geochem., Geophys., Geosyst.,* 7(7):Q07O02. **doi:10.1029/2006GC001242**

Johnson, H.P., and Pruis, M.J., 2003. Fluxes of fluid and heat from the oceanic crustal reservoir. *Earth Planet. Sci. Lett.*, 216(4):565–574. **doi:10.1016/S0012-821X(03)00545-4**

Mottl, M.J., 2003. Partitioning of energy and mass fluxes between mid-ocean ridge axes and flanks at high and low temperature. *In* Halbach, P.E., Tunnicliffe, V., and Hein, J.R. (Eds.), *Energy and Mass Transfer in Marine Hydrothermal Systems:* Berlin (Dahlem Univ. Press), 271–286.

Mottl, M.J., Wheat, G., Baker, E., Becker, N., Davis, E., Feely, R., Grehan, A., Kadko, D., Lilley, M., Massoth, G., Moyer, C., and Sansone, F., 1998. Warm springs discovered on 3.5 Ma oceanic crust, eastern flank of the Juan de Fuca Ridge. *Geology,* 26(1):51–54. **doi:10.1130/0091-7613(1998)026<0051:WSDOMO>2.3.CO;2**

Nedimovic, M.R., Carbotte, S.M., Diebold, J.B., Harding, A.J., Canales, J.P., and Kent, G.M., 2008. Upper crustal evolution across the Juan de Fuca Ridge flanks. *Geochem., Geophys., Geosyst.,* 9(9):Q09006. **doi:10.1029/2008GC002085**

Parsons, B., and Sclater, J.G., 1977. An analysis of the variation of ocean floor bathymetry and heat flow with age. *J. Geophys. Res., [Solid Earth],* 82:803–827. **doi:10.1029/JB082i005p00803**

Peacock, S.M., and Wang, K., 1999. Seismic consequences of warm versus cool subduction metamorphism: examples from southwest and northeast Japan. *Science,* 286(5441):937–939. **doi:10.1126/science.286.5441.937**

Rosenberger, A., Davis, E.E., and Villinger, H., 2000. Data report: hydrocell-95 and -96 single-channel seismic data on the eastern Juan de Fuca Ridge Flank. *In* Fisher, A., Davis, E.E., and Escutia, C. (Eds.), *Proc. ODP, Sci. Results,* 168: College Station, TX (Ocean Drilling Program), 9–19. **doi:10.2973/odp.proc.sr.168.021.2000**

Ryan, W.B.F., Carbotte, S.M., Coplan, J.O., O'Hara, S., Melkonian, A., Arko, R., Weissel, R.A., Ferrini, V., Goodwillie, A., Nitsche, F., Bonczkowski, J., and Zemsky, R., 2009. Global multi-resolution topography synthesis. *Geochem., Geophys., Geosyst.,* 10(3):Q03014. **doi:10.1029/2008GC002332**

Stein, J.S., and Fisher, A.T., 2003. Observations and models of lateral hydrothermal circulation on a young ridge flank: numerical evaluation of thermal and chemical constraints. *Geochem., Geophys., Geosyst.,* 4(3):1026. **doi:10.1029/2002GC000415**

Von Herzen, R.P., 2004. Geothermal evidence for continuing hydrothermal circulation in older (>60 Ma) ocean crust. *In* Davis, E.E., and Elderfield, H. (Eds.) *Hydrogeology of the Oceanic Lithosphere:* Cambridge (Cambridge Univ. Press), 414–450.

Walker, B.D., McCarthy, M.D., Fisher, A.T., and Guilderson, T.P., 2007. Dissolved inorganic carbon isotopic composition of low-temperature axial and ridge-flank hydrothermal fluids of the Juan de Fuca Ridge. *Mar. Chem.*, 108(1–2):123–136. **doi:10.1016/j.marchem.2007.11.002**

Wheat, C.G., Elderfield, H., Mottl, M.J., and Monnin, C., 2000. Chemical composition of basement fluids within an oceanic ridge flank: implications for along-strike and across-strike hydrothermal circulation. *J. Geophys. Res., [Solid Earth],* 105(B6):13437–13447. **doi:10.1029/2000JB900070**

Wheat, C.G., Jannasch, H.W., Kastner, M., Plant, J.N., and DeCarlo, E.H., 2003. Seawater transport and reaction in upper oceanic basaltic basement: chemical data from continuous monitoring of sealed boreholes in a ridge flank environment. *Earth Planet. Sci. Lett.,* 216(4):549–564. **doi:10.1016/S0012-821X(03)00549-1**

Wheat, C.G., and Mottl, M.J., 1994. Hydrothermal circulation, Juan de Fuca Ridge eastern flank: factors controlling basement water composition. *J. Geophys. Res., [Solid Earth],* 99(B2):3067–3080. **doi:10.1029/93JB01612**

Wheat, C. G., Mottl, M.J., Fisher, A.T., Kadko, D., Davis, E.E., and Baker, E., 2004. Heat flow through a basaltic outcrop on a sedimented young ridge flank. *Geochem., Geophys., Geosyst.,* 5(12):Q12006. **doi:10.1029/2004GC000700**

Zühlsdorff, L., Hutnak, M., Fisher, A.T., Spiess, V., Davis, E.E., Nedimovic, M., Carbotte, S., Villinger, H., and Becker, K., 2005. Site surveys related to IODP Expedition 301: ImageFlux (SO149) and RetroFlux (TN116) expeditions and earlier studies. *In* Fisher, A.T., Urabe, T., Klaus, A., and the Expedition 301 Scientists, *Proc. IODP,* 301: College Station, TX (Integrated Ocean Drilling Program Management International, Inc.). **doi:10.2204/iodp.proc.301.102.2005**

Zühlsdorff, L., and Spiess, V., 2006. Sedimentation patterns, folding, and fluid upflow above a buried basement ridge: results from 2-D and 3-D seismic surveys at the eastern Juan de Fuca Ridge flank. *J. Geophys. Res., [Solid Earth],* 111(B8):B08103. **doi:10.1029/2004JB003227**

Table T1. Expedition 327 operations summary. (See table notes.)

Operational task	Start Date (2010)	Start Local ship time (h)	End Date (2010)	End Local ship time (h)	Task time h	Task time Days
Depart Victoria, British Columbia, and transit 196 nmi to Site U1362	9 Jul	1215	10 Jul	0815	20.00	0.8
Site U1362 (SR-2)						
Jet-in test at Hole U1362B	10 Jul	0815	11 Jul	1130	27.25	1.1
Jet-in test at Hole U1362A	11 Jul	1130	12 Jul	0815	20.75	0.9
Hole U1362A (SR-2A) Stage 1						
Install reentry cone and 20 inch casing to 53 mbsf	12 Jul	0815	13 Jul	1800		
Make up BHA with underreamer cutters set to 21-1/2 inches diameter; run in hole	13 Jul	1800	14 Jul	0345		
Drill 21-1/2 inch hole for 16 inch casing to 235.7 mbsf (18-1/2 inch hole to 242)*	13 Jul	1800	15 Jul	0915		
Install 16 inch casing to 230 mbsf	15 Jul	0915	15 Jul	2315		
Cement 16 inch casing shoe and annulus	15 Jul	2315	16 Jul	0345		
Pull out of hole	16 Jul	0345	16 Jul	0930	97.25	4.1
Hole U1362B (SR-2B) Stage 1						
Install reentry cone and 20 inch casing to 53 mbsf	16 Jul	0930	17 Jul	1630		
Make up BHA with underreamer cutters set to 21-1/2 inches diameter; run in hole	17 Jul	1630	18 Jul	0145		
Drill 21-1/2 inch hole for 16 inch casing to 243.7 mbsf (18-1/2 inch hole to 250)*	18 Jul	0145	19 Jul	0630		
Install 16 inch casing to 242 mbsf	19 Jul	0630	19 Jul	1900		
Cement 16 inch casing shoe and annulus	19 Jul	1900	19 Jul	2015		
Pull out of hole	19 Jul	2015	20 Jul	0330	90.00	3.8
Hole U1362A (SR-2A) Stage 2						
Make up 14-3/4 inch drilling assembly; run in hole	20 Jul	0330	20 Jul	1645		
Drill out cement	20 Jul	1645	20 Jul	2400		
Drill 14-3/4 inch hole for 10-3/4 inch casing to 346 mbsf	20 Jul	2400	24 Jul	0340		
Install 10-3/4 inch casing to 308.5 mbsf	24 Jul	0340	26 Jul	0530		
Cement 10-3/4 inch casing	26 Jul	0530	26 Jul	0730		
Pull out of hole	26 Jul	0730	26 Jul	1245	153.25	6.4
Hole U1362B (SR-2B) Stage 2						
Make up 14-3/4 inch drilling assembly; run in hole	26 Jul	1245	26 Jul	2145		
Drill out cement	26 Jul	2145	27 Jul	0100		
Drill 14-3/4 inch hole for 10-3/4 inch casing to 282 mbsf	27 Jul	0100	28 Jul	0215		
Install 10-3/4 inch casing to 272 mbsf	28 Jul	0215	28 Jul	1330		
Cement 10-3/4 inch casing	28 Jul	1330	28 Jul	1515		
Pull out of hole	28 Jul	1515	28 Jul	2030		
Make up 9-7/8 inch drilling assembly; run in hole	28 Jul	2030	29 Jul	0500		
Drill out cement to 10 m above casing shoe	29 Jul	0500	29 Jul	1815		
Pull out of seafloor	29 Jul	1815	29 Jul	1900	78.25	3.3
Hole U1362A (SR-2A) Stage 3						
Run in hole with 9-7/8 inch drilling assembly	29 Jul	1900	30 Jul	0230		
Drill out cement	30 Jul	0230	30 Jul	0730		
Condition hole	30 Jul	0730	31 Jul	0900		
Make up 9-7/8 inch RCB assembly; run in hole	31 Jul	0900	31 Jul	2215		
RCB coring from 346 to 496 mbsf	31 Jul	2215	9 Aug	1400		
Make up 9-7/8 inch drilling assembly; run in hole	9 Aug	1400	9 Aug	2400		
Drill 9-7/8 inch hole to 528 mbsf; stand by and conduct open hole depth check	9 Aug	2400	11 Aug	1845		
Make up wireline logging/packer BHA; run in hole	11 Aug	1845	12 Aug	0330		
Rig up Schlumberger line and make up logging tool string	12 Aug	0330	12 Aug	0545		
Wireline logging with three passes	12 Aug	0545	12 Aug	1645		
Conduct open hole depth check	12 Aug	1645	12 Aug	1900		
Conduct packer flow test	12 Aug	1900	13 Aug	1800		
Make up CORK assembly with 4-1/2 inch casing, packers, miniscreens, umbilicals	13 Aug	1800	15 Aug	1630		
Deploy OsmoSamplers, sinker bar, Spectra rope with thermistors	15 Aug	1630	16 Aug	0600		
Install CORK (to 470 mbsf) and pressure up packers	16 Aug	0600	16 Aug	1600		
Deploy ROV platform and release CORK head	16 Aug	1600	17 Aug	0600		
Pull out of hole	17 Aug	0600	17 Aug	1045	447.75	18.7
Hole U1301B						
Run in hole with CORK recovery tool	17 Aug	1045	17 Aug	1615		
Engage CORK head and recover partial instrument string	17 Aug	1615	17 Aug	1945		
Run in hole for depth check and temperature profile	17 Aug	1945	18 Aug	0145		
Deploy replacement instrument string	18 Aug	0145	18 Aug	0530	18.75	0.8
Hole 1027C						
First (failed) attempt to recover CORK	18 Aug	0530	18 Aug	1830		
Fabricate modified CORK recovery tool	18 Aug	1830	20 Aug	0600		
Second (failed) attempt to recover CORK	20 Aug	0600	20 Aug	1600		
Pull out of hole	20 Aug	1600	20 Aug	2130	64.00	2.7

Table T1 (continued).

Operational task	Start		End		Task time	
	Date (2010)	Local ship time (h)	Date (2010)	Local ship time (h)	h	Days
Hole U1362B (SR-2B) Stage 3						
Make up 9-7/8 inch drilling assembly; run in hole	20 Aug	2130	21 Aug	0730		
Drill out cement	21 Aug	0730	21 Aug	1030		
Drill 9-7/8 inch hole to 339 mbsf	21 Aug	1030	22 Aug	2200		
Make up tracer injection BHA with instrument package; run in hole	22 Aug	2200	23 Aug	0900		
First attempt at 24 h flow test and tracer injection experiment	23 Aug	0900	23 Aug	1700		
Make up 9-7/8 inch drilling assembly; run in hole	23 Aug	1700	24 Aug	1315		
Deepen 9-7/8 inch hole to 359 mbsf	24 Aug	1315	25 Aug	2100		
Make up tracer injection BHA with instrument package; run in hole	25 Aug	2100	26 Aug	0800		
Conduct 24 h flow test and tracer injection experiment	26 Aug	0800	27 Aug	1000		
Pull out of hole; recover instrument package	27 Aug	1000	27 Aug	1615		
Make up 9-7/8 inch drilling assembly; run in hole; conduct depth check	27 Aug	1615	27 Aug	2400		
Pull out of hole	27 Aug	2400	28 Aug	0530		
Make up CORK assembly with 4-1/2 inch casing, packers, miniscreens, umbilicals	28 Aug	0530	29 Aug	0200		
Deploy OsmoSamplers, sinker bar, Spectra rope with thermistors	29 Aug	0200	29 Aug	1315		
Install CORK (to 311 mbsf) and pressure up packers	29 Aug	1315	29 Aug	1545		
Deploy ROV platform and release CORK head	29 Aug	1545	29 Aug	2230		
Recover positioning beacon from seafloor	29 Aug	2230	30 Aug	0300		
Pull out of hole; secure rig for transit	30 Aug	0300	30 Aug	1300	231.50	9.6
Transit to Grizzly Bare site	30 Aug	1300	30 Aug	1615	3.25	0.1
Site U1363 (GRB-1A to GRB-3A)						
Make up APC/XCB drilling assembly; run in hole	30 Aug	1615	30 Aug	2130		
Hole U1363A: drilling without coring to 58 mbsf	30 Aug	2130	31 Aug	0330	11.25	0.5
Hole U1363B: APC/XCB coring to 61 mbsf; 4 APCT-3 and 1 SET deployments	31 Aug	0330	31 Aug	2145	18.25	0.8
Hole U1363C: drilling to 150 mbsf; XCB coring to 203 mbsf; 3 SET deployments	31 Aug	2145	2 Sep	0100	27.25	1.1
Hole U1363D: drilling to 198 mbsf; XCB coring to 231.8 mbsf	2 Sep	0100	3 Sep	0700	30.00	1.3
Hole U1363E: drilling without coring to 37 mbsf	3 Sep	0700	3 Sep	1130	4.50	0.2
Hole U1363F: APC coring to 35 mbsf; 2 APCT-3 deployments	3 Sep	1130	3 Sep	1730	6.00	0.3
Hole U1363G: APC coring to 24.9 mbsf; 1 APCT-3 deployment	3 Sep	1730	4 Sep	1015	16.75	0.7
Transit to Victoria, British Columbia	4 Sep	1015	5 Sep	0845	22.50	0.9
				Totals:	1388.50	57.9

Notes: * = for both 21-1/2 inch holes, an 18-1/2 hole was cut 6.3 m deeper by a tricone bit. Local ship time = UTC – 7. BHA = bottom-hole assembly. ROV = remotely operated vehicle, CORK = subseafloor borehole observatory. RCB = rotary core barrel, APC = advanced piston corer, XCB = extended core barrel. APCT-3 = third-generation advanced piston corer temperature tool, SET = Sediment Temperature tool. Site U1362 total time was 47.8 days.

Table T2. Hole locations during Expedition 327. (See table note.)

Hole	Latitude	Longitude	Seismic line	CDP
U1362A	47°45.6628′N	127°45.6720′W	GeoB00-482	439
U1362B	47°45.4997′N	127°45.7312′W	GeoB00-476	316
U1363A	47°17.3555′N	128°2.1107′W	GeoB00-170	2836
U1363B	47°17.3518′N	128°2.1060′W	GeoB00-170	2836
U1363C	47°17.5759′N	128°1.7641′W	GeoB00-170	2776
U1363D	47°17.5724′N	128°1.7599′W	GeoB00-170	2776
U1363E	47°17.3310′N	128°2.1447′W	GeoB00-170	2841
U1363F	47°17.3261′N	128°2.1374′W	GeoB00-170	2841
U1363G	47°17.3118′N	128°2.1698′W	GeoB00-170	2846
U1301B	47°45.228′N	127°45.827′W	GeoB00-466	556
1027C	47°45.387′N	127°43.867′W	GeoB00-203	741

Note: CDP = common depth point.

Table T3. Expedition 327 hole summary. (**See table notes.**)

Hole	Latitude	Longitude	Water depth (mbsl)	Cores (*N*)	Interval cored (m)	Core recovered (m)	Recovery (%)	Drilled interval (m)	Total penetration (m)	Time on hole (h)	Time on site (days)
U1362A	47°45.6628′N	127°45.6720′W	2661	20	150.0	44.4	30	378.0	528.0	719	30.0
U1362B	47°45.4997′N	127°45.7312′W	2661	NA	NA	NA	NA	359.0	359.0	427	17.8
		Site U1362 totals:		20	150.0	44.4	30	737.0	887.0	1146	47.8
U1363A	47°17.3555′N	128°2.1107′W	2678	NA	NA	NA	NA	58.0	58.0	11.25	0.5
U1363B	47°17.3518′N	128°2.1060′W	2679	10	61.0	49.7	82	0	61.0	18.25	0.8
U1363C	47°17.5759′N	128°1.7641′W	2678	4	32.4	7.0	22	170.0	202.4	27.25	1.1
U1363D	47°17.5724′N	128°1.7599′W	2678	4	33.8	15.0	44	198.0	231.8	30.00	1.3
U1363E	47°17.3310′N	128°2.1447′W	2678	NA	NA	NA	NA	37.0	37.0	4.50	0.2
U1363F	47°17.3261′N	128°2.1374′W	2678	4	35.0	31.2	89	0	35.0	6.00	0.3
U1363G	47°17.3118′N	128°2.1698′W	2677	3	24.9	22.9	92	0	24.9	16.75	0.7
		Site U1363 totals:		25	187.1	125.8	67	463	650.1	114	4.8
U1301B	47°45.228′N	127°45.827′W	2671	NA	NA	NA	NA	NA	NA	18.75	0.8
1027C	47°45.387′N	127°43.867′W	2667	NA	NA	NA	NA	NA	NA	64.0	2.7
		Expedition 327 totals:		45	337.1	170.2	50	1200.0	1537.1	1342.75	55.9

Notes: *N* = number. NA = not applicable.

Figure F1. Index map for IODP Expedition 327 and small inset showing work area. Site U1362 is located at the eastern end of the ODP Leg 168 drilling transect (Davis, Fisher, Firth et al., 1997), whereas Site U1363 is located adjacent to a large basement outcrop ~52 km to the south–southwest, a hypothesized location of ridge-flank hydrothermal recharge (Wheat et al., 2000; Fisher et al., 2003; Hutnak et al., 2006). Location of Fig. F2 is indicated by yellow box. Map generated using GeoMapApp (www.geomapapp.org/) and the global multiresolution topography synthesis (Ryan et al., 2009).

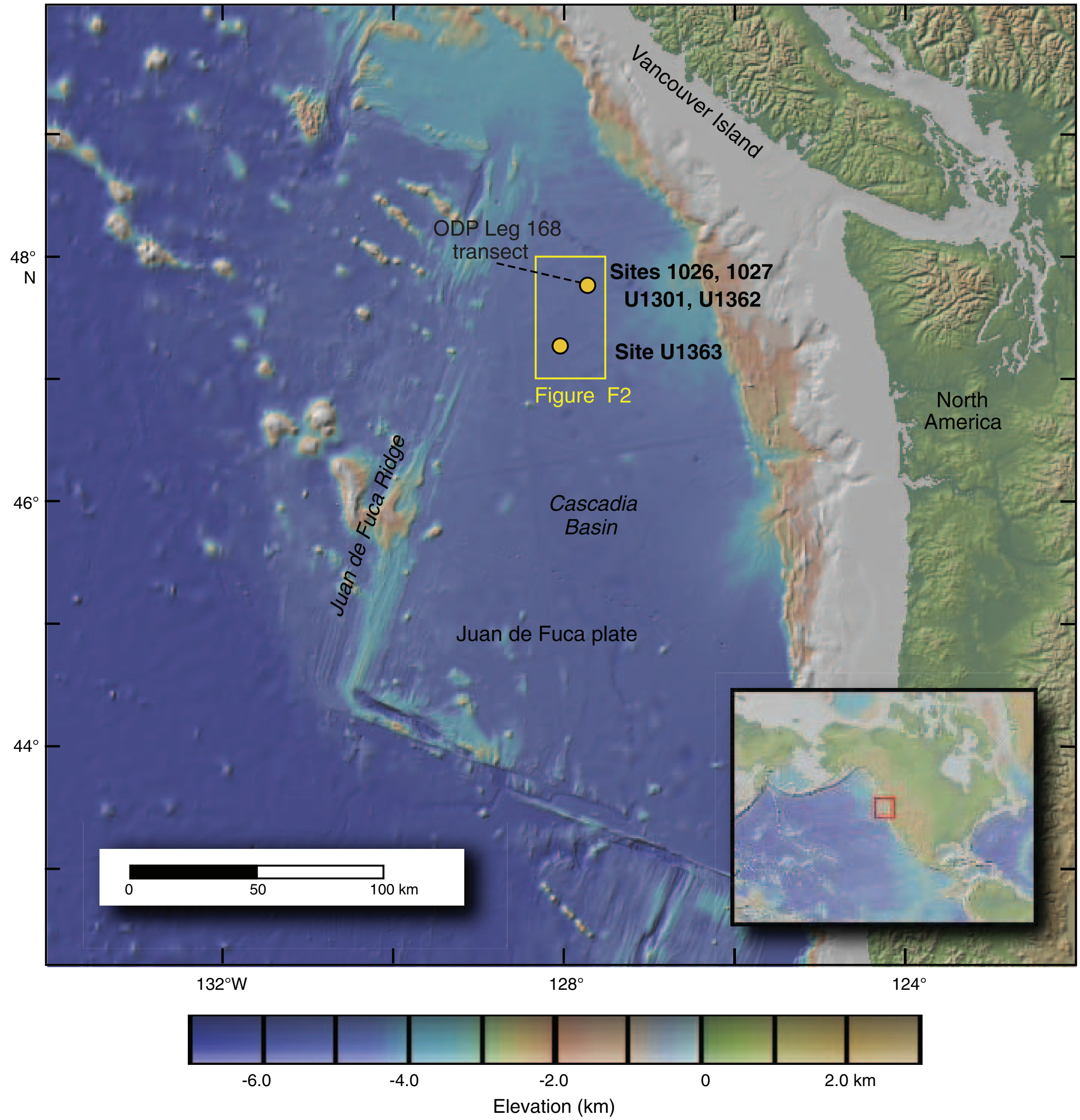

Figure F2. Regional bathymetric map showing locations of Expedition 327 drill sites and basement outcrops (modified from Zühlsdorff et al., 2005). Thermal and chemical data suggest that hydrothermal fluids recharge at Grizzly Bare outcrop and flow to the north–northwest (white arrow).

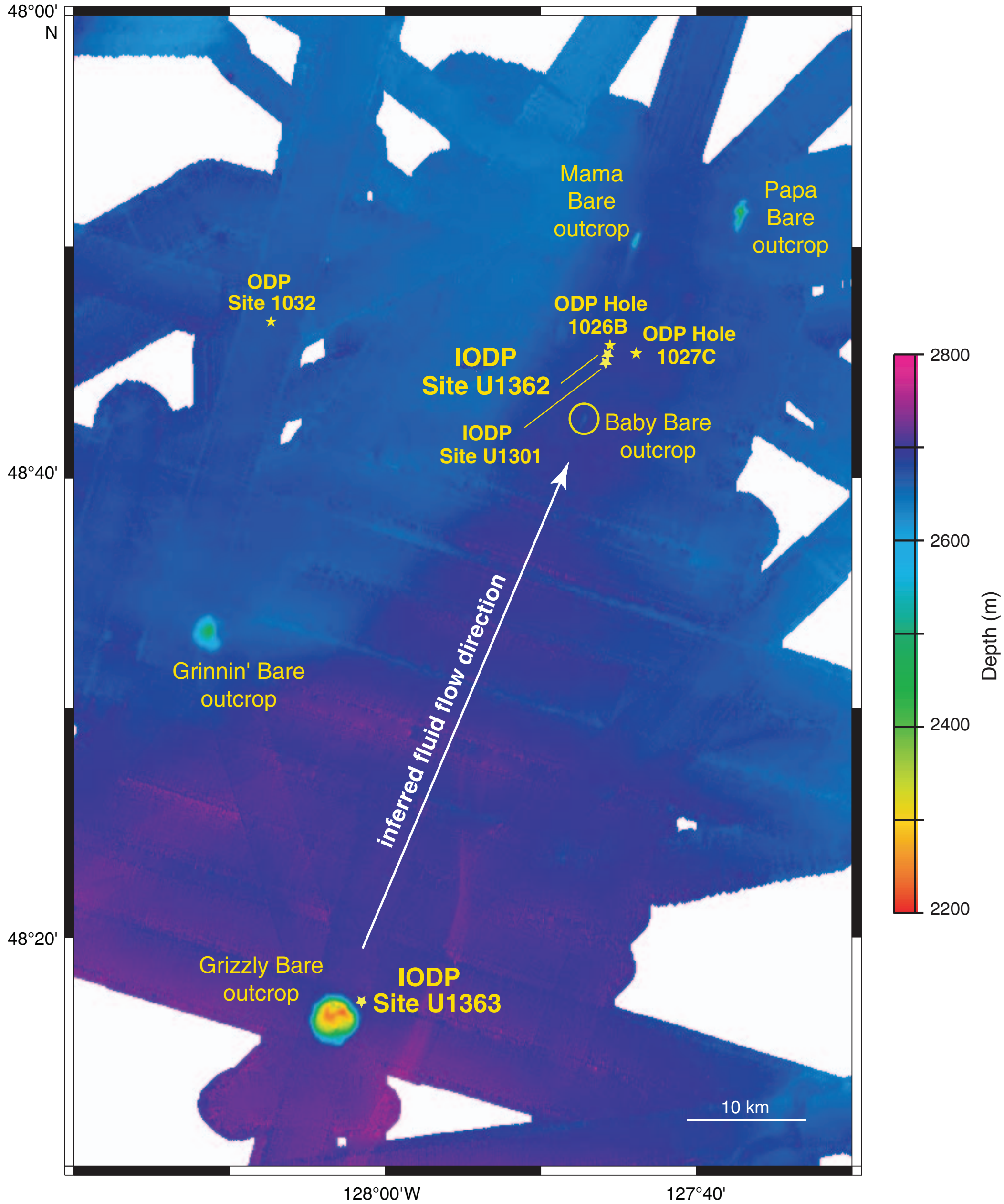

Figure F3. Three-dimensional perspective views of basement relief around Expedition 327 drill sites. Bathymetry based on digitization of seismic lines across work areas (data from Rosenberger et al., 2000; Zühlsdorff et al., 2005; Hutnak et al., 2006). Relief is shown as two-way traveltime, with no conversion to sediment thickness or depth. **A.** Basement relief around Sites 1026, 1027, U1301, and U1362, contoured to maintain continuity along-strike ~N20E to highlight steeply dipping normal faults to west of drill sites. **B.** Basement relief around Site U1363, adjacent to Grizzly Bare outcrop.

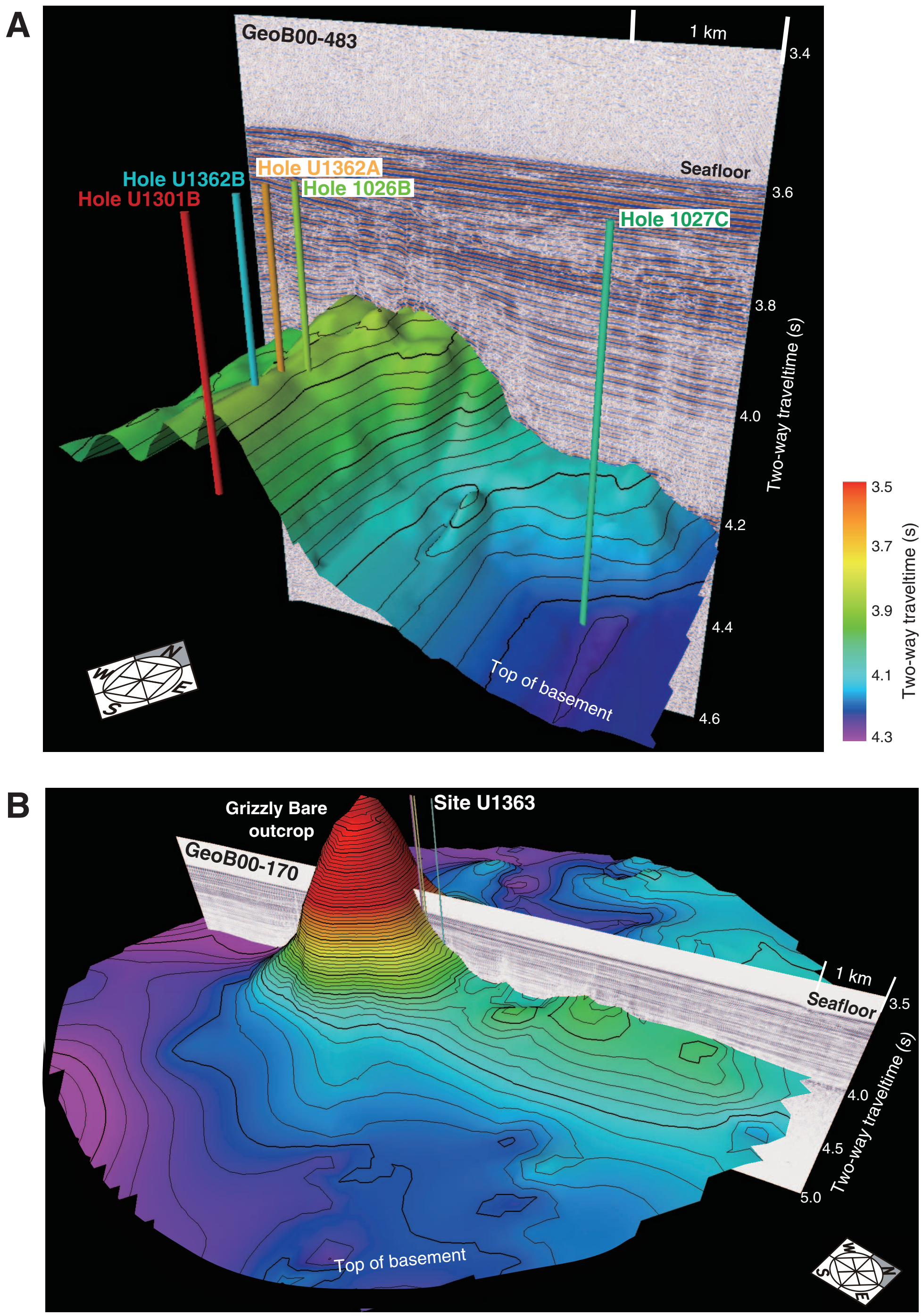

Figure F4. Seafloor heat flow data and numerical modeling results of single-outcrop and outcrop-to-outcrop hydrothermal circulation (modified from Hutank et al., 2006). **A.** Heat flow measured within 7 km of Baby Bare outcrop, projected along a single profile. **B.** Fluid flow vectors through upper basement and across seafloor, simulating single-outcrop circulation. Radial fluid flow results in heat flow pattern shown in A (dashed lines). **C.** Vertical temperature profiles from two-dimensional simulations of self-sustaining fluid and heat flow from Grizzly Bare to Baby Bare outcrops. Low temperatures are maintained in the recharge conduit (through Grizzly Bare; blue lines and symbols), whereas various temperatures are maintained through the discharge conduit (through Baby Bare; red lines and symbols), with the upflow temperature being dependent on the permeability of upper basement. When permeability is too high, basement is cooled by rapidly flowing fluids. When permeability is too low, basement becomes warmer. A match to the observed regional upper basement temperature of 60°–65°C is achieved with a basement permeability on the order of 10^{-11} m².

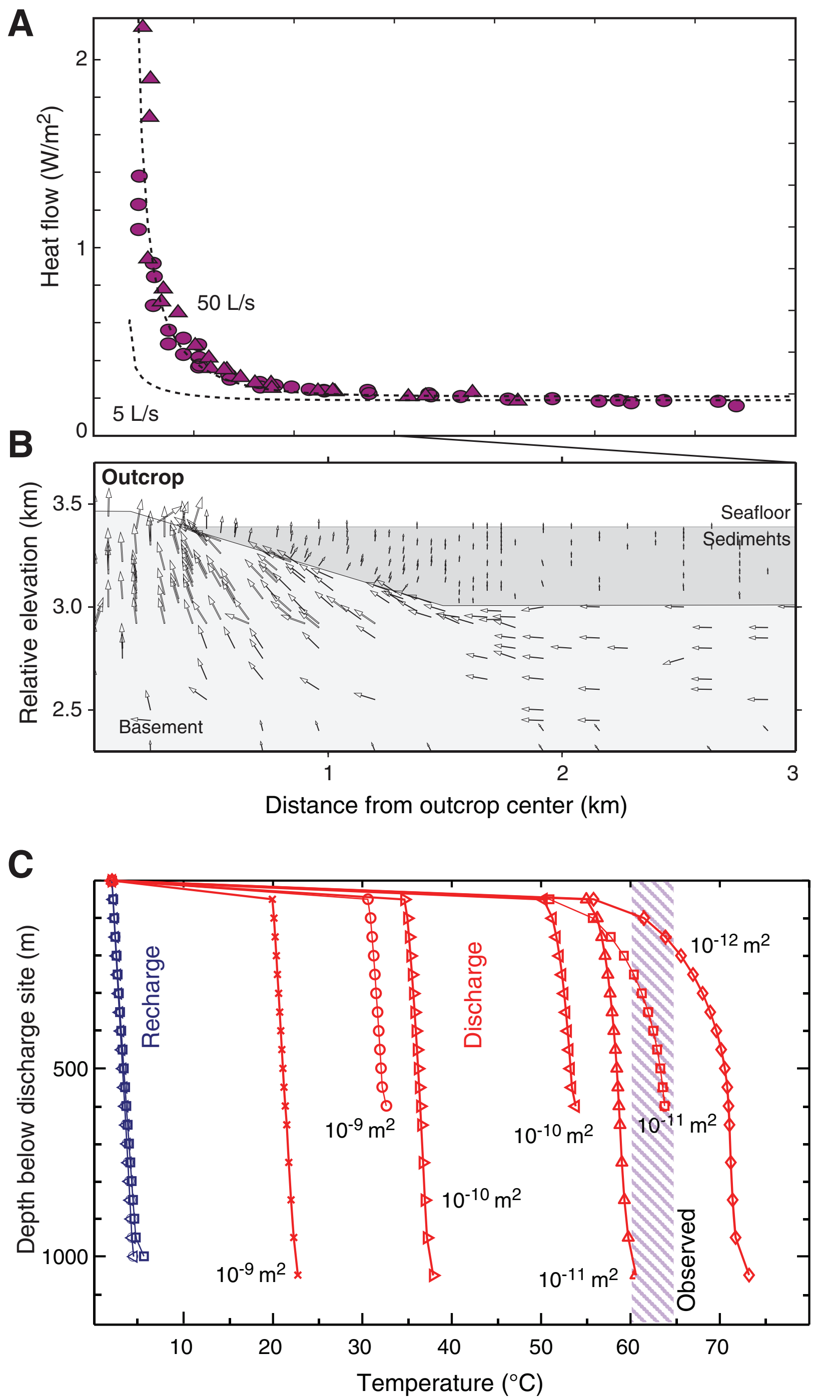

Figure F5. A. Cross-hole response in Hole 1027C CORK to long-term flow into Hole U1301B, 2.4 km away (Fisher et al., 2008). Pressure record from Hole 1027C (blue line), corrected for tidal loading and other instantaneous responses, indicates basement permeability shown, a range lower than that indicated by packer tests or larger scale methods. **B.** Geometry of cross-hole pressure response. Hole 1027C is oriented along a trend oblique to the structural strike of basement. The direction of greatest permeability is hypothesized to be along structural strike, N20E (blue dashed arrow), whereas cross-hole response direction is N70E (red dashed arrow), an azimuthal angle of 50°. **C.** Calculated effective permeability as a function of testing angle in an anisotropic medium. The full cross-hole experiment, with monitoring wells at different angles and depths, will test for permeability anisotropy.

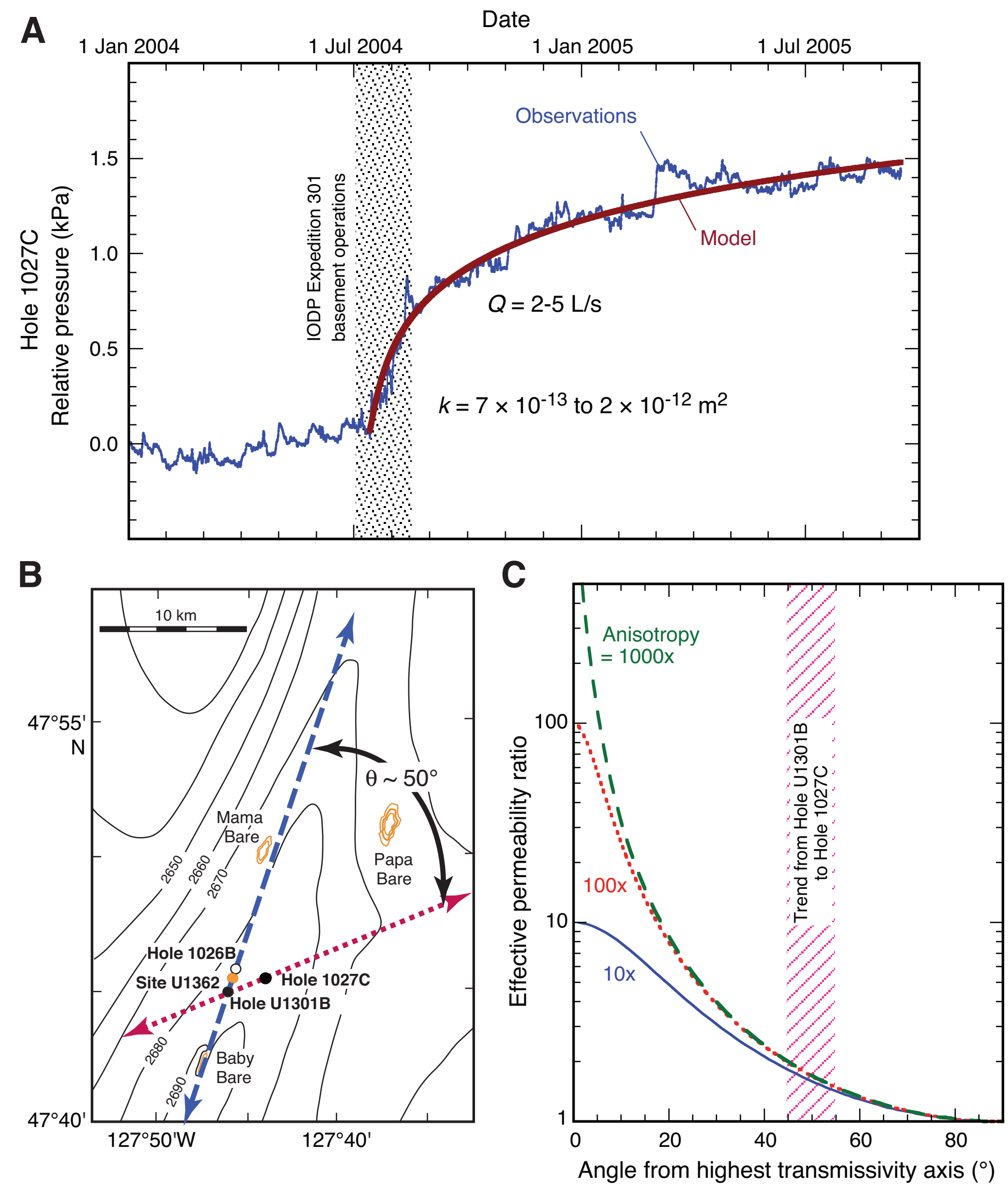

Figure F6. Composite of the global data set of borehole permeability estimates from packer testing and other select methods. Data from Hole U1301B are broadly consistent with the global data set, but single-hole packer results suggest higher permeability than does the cross-hole response. This is surprising because testing of large rock volumes tends to result in higher permeability estimates. Also shown is the range of values generally determined on the basis of idealized crustal response to tidal loading and seismic events and using numerical models of coupled fluid and heat flow.

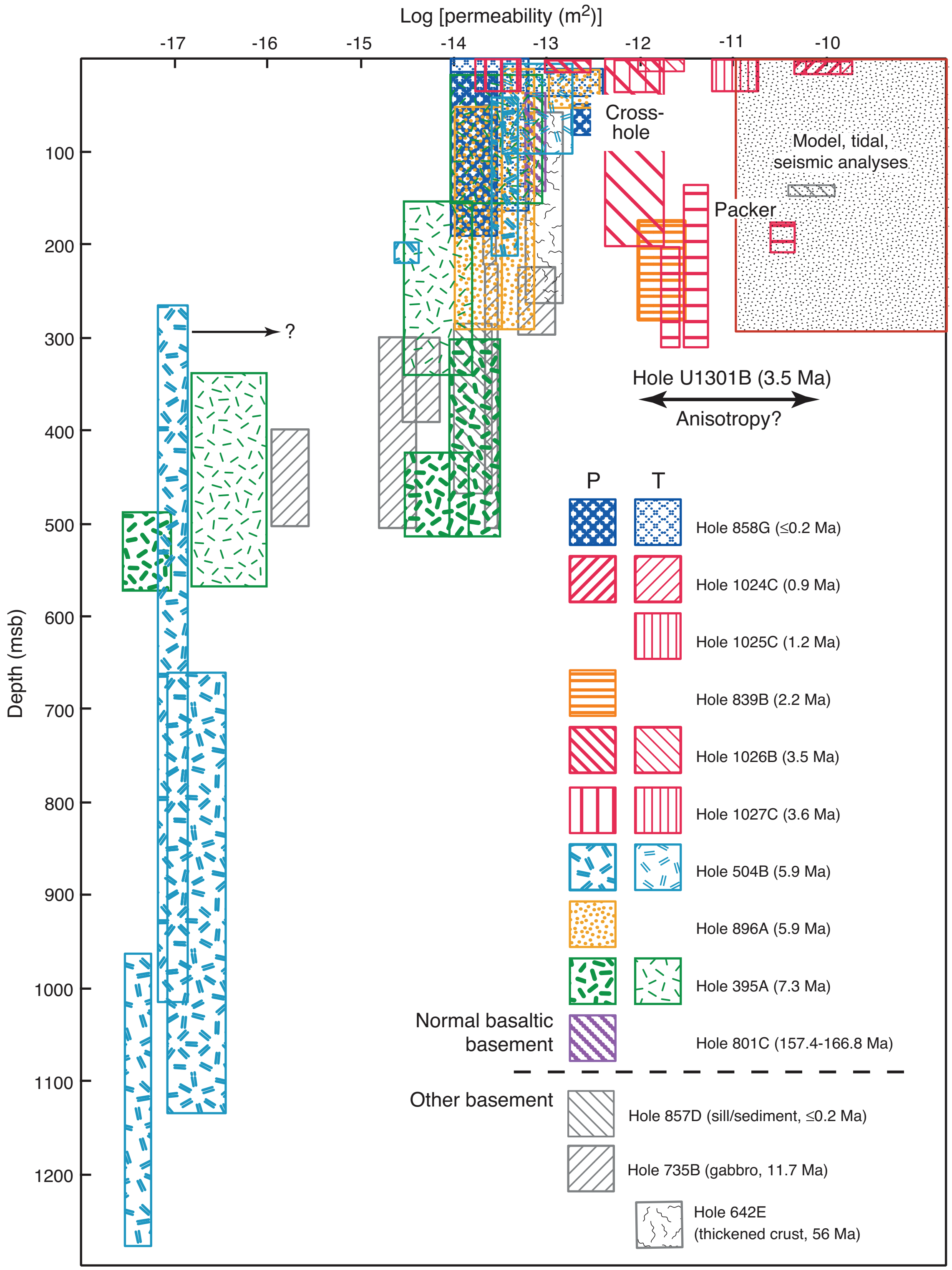

Figure F7. Schematic of Hole U1362A seafloor installation.

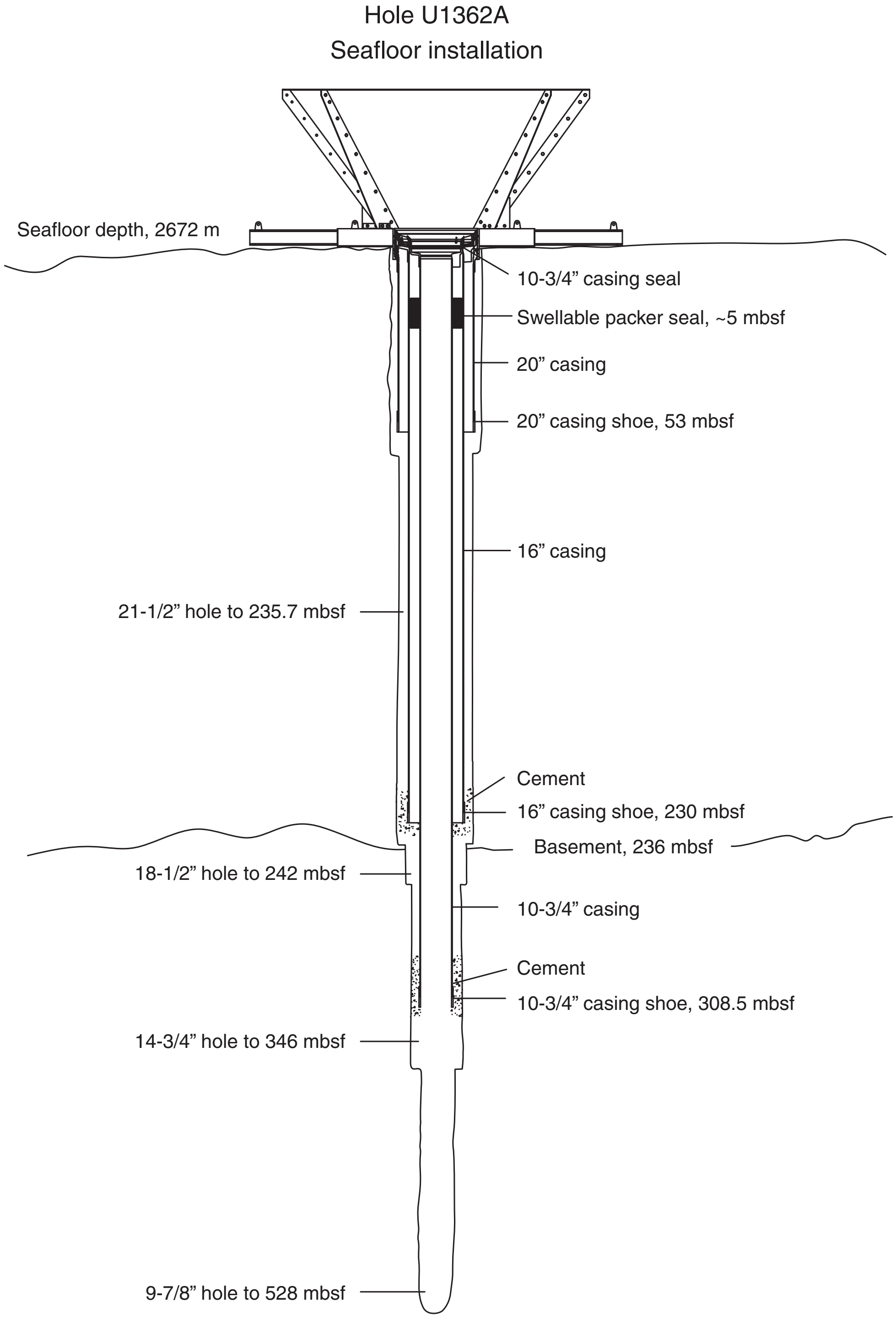

Figure F8. Schematic of Hole U1362B seafloor installation.

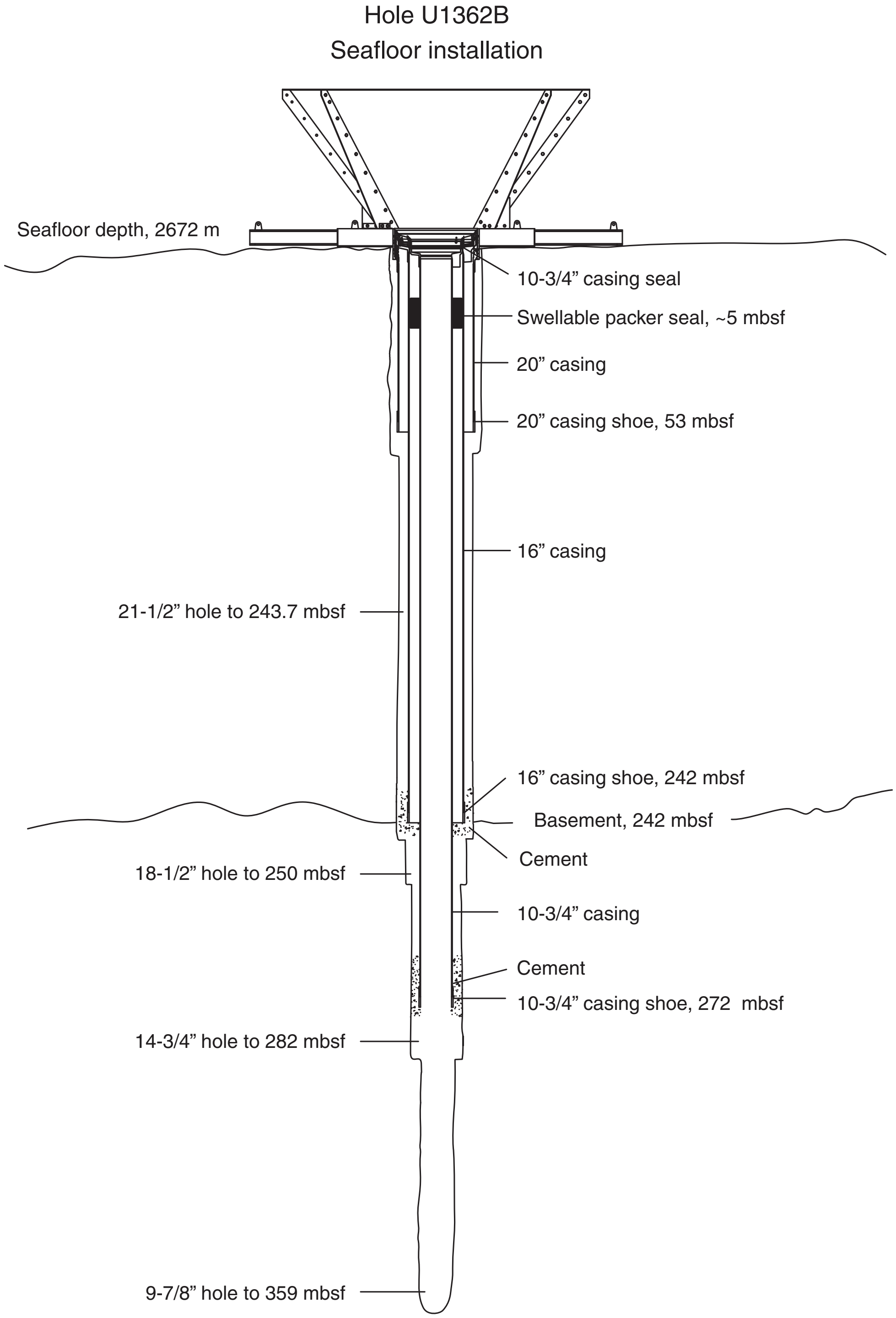

Figure F9. Composite diagram showing basement recovery, lithology, hole diameter, and bulk density of logging and discrete measurements from Holes U1362A and U1301B (Expedition 301). Primary lithologies were described using different terminology during Expeditions 301 and 327, but they are equivalent, as indicated by color and pattern. Hole diameter was determined by mechanical caliper on lithodensity log. The upper part of Hole U1362A (above the lithologic column) was drilled with a 14¾ inch tricone bit, whereas other hole sections shown were drilled with 9⅞ inch bits.

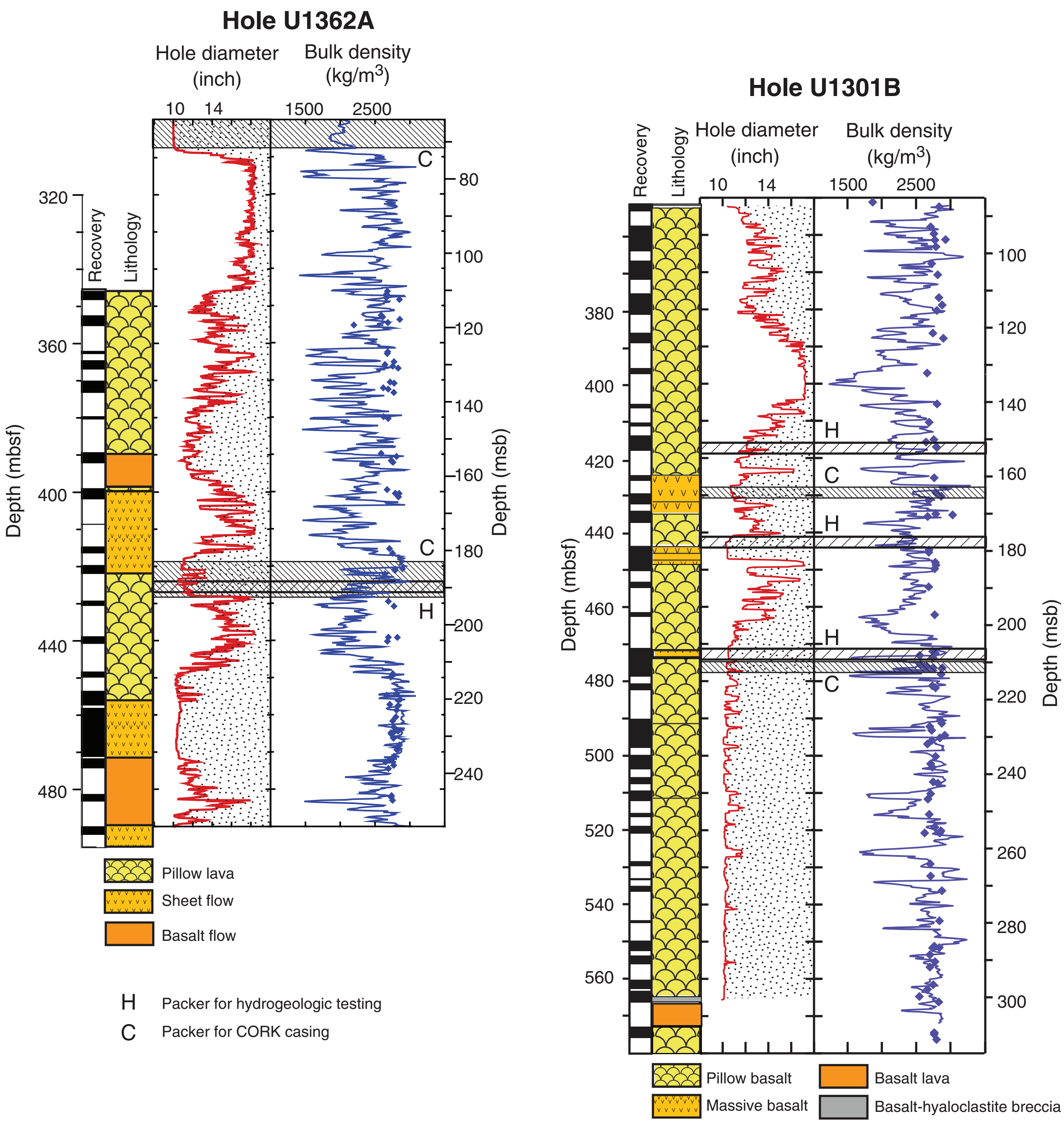

Figure F10. Plots showing schematic variations in pumping rates and tracer concentrations during 24 h pumping experiment. Actual values will be calculated postcruise using detailed records of pumping rates, gas and fluid pressure, and injectate chemistry. **A.** Flow rate. The mud pump was run at a constant rate of 20 strokes per minute (~7 L/s). The cement pump added injectate four times during the experiment, briefly increasing total injection rate into the formation. **B.** Injectate salinity and SF_6 concentration. SF_6 was added to the injectate using a regulator and valve manifold connected to the standpipe upstream of the mud pump. A differential pressure of ~80 psi was used to inject the gas at a constant concentration, except when flow from the cement pump was added, briefly reducing the SF_6 concentration (but having no influence on the mass rate of SF_6 injection). Seawater was the primary injectate, except for two 1 h periods when freshwater was injected and two other times when Cs, Er, and Ho salts were added, temporarily increasing injectate salinity. **C.** Approximate concentrations of Cs, Er, and Ho salts and relative concentrations of fluorescent microspheres and bacteria.

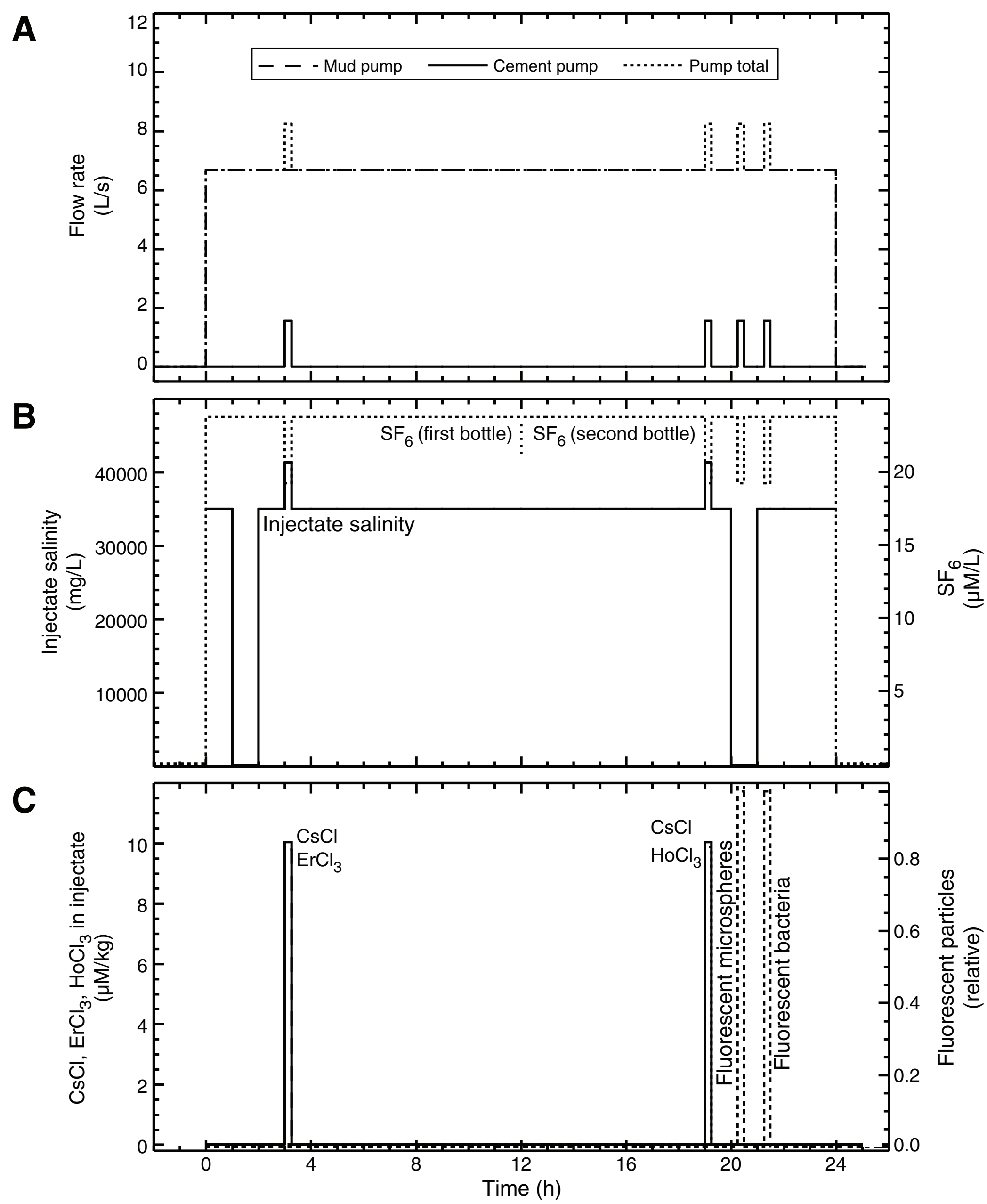

Figure F11. Schematic diagrams showing CORK completions in Holes U1362A and U1362B. Figures are exaggerated horizontally but drawn vertically to scale and hung on a common datum at the sediment/basement interface. Each CORK comprises four concentric casing strings, a casing seal and swellable casing packer near the seafloor, and one or two sets of inflatable and swellable packers at depth. Both CORKs use the new "L-CORK" design, with a lateral casing section extending from the inner 4½ inch CORK casing to a free-flow ball valve at the wellhead. The CORKs both have perforated and coated 5½ inch casing and drill collars, into which numerous OsmoSamplers and microbiological growth experiments were placed. Pressure loggers and gauges were installed in the wellhead and connected to monitored intervals at depth with ¼ inch tubing and miniscreens. Fluid and microbiological sampling will be accomplished from the wellhead using dedicated lines and miniscreens at depth.

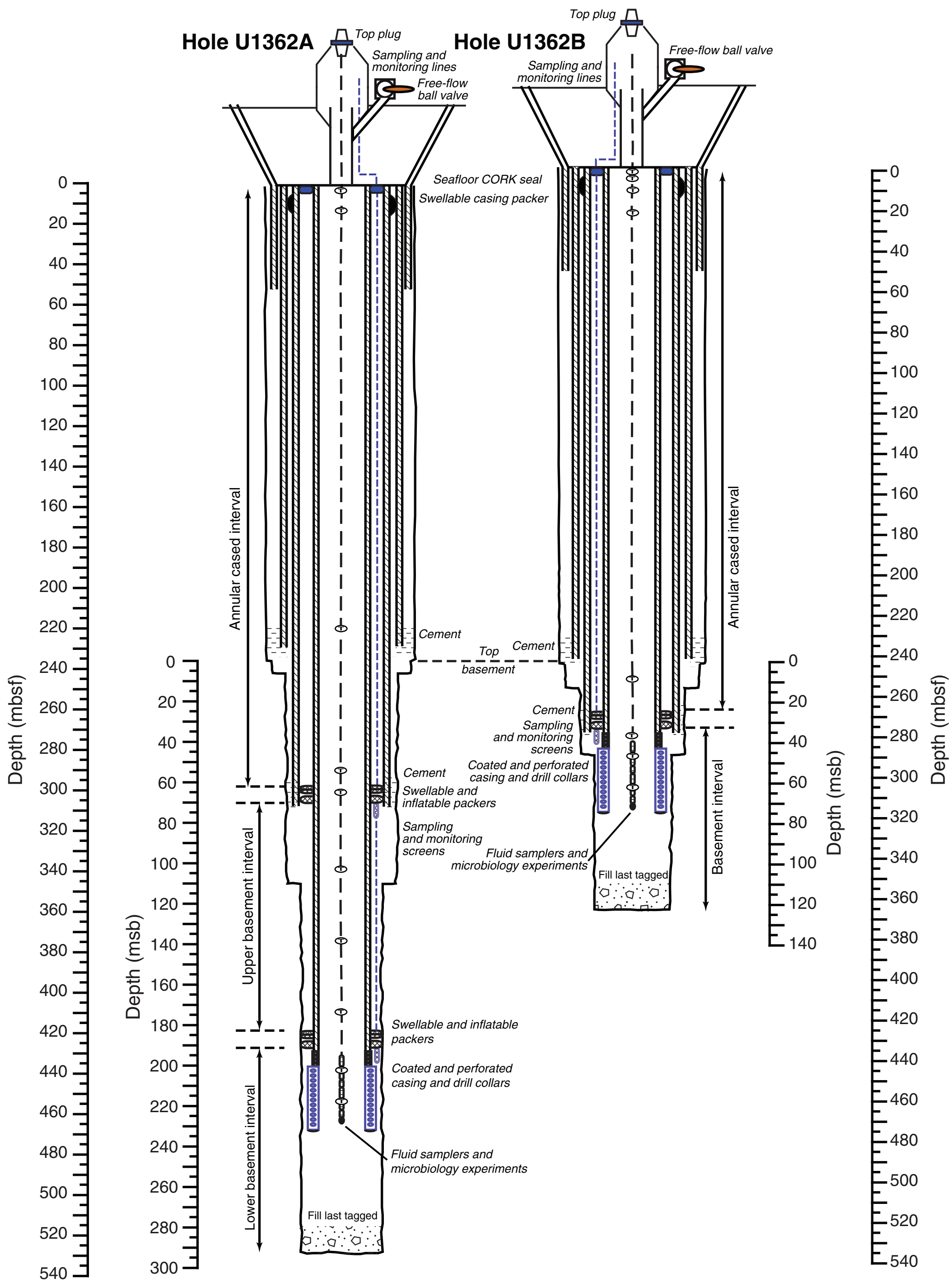

Figure F12. Sediment recovery and lithostratigraphy, Site U1363. A bathymetric map with Site U1363 hole locations is also shown.

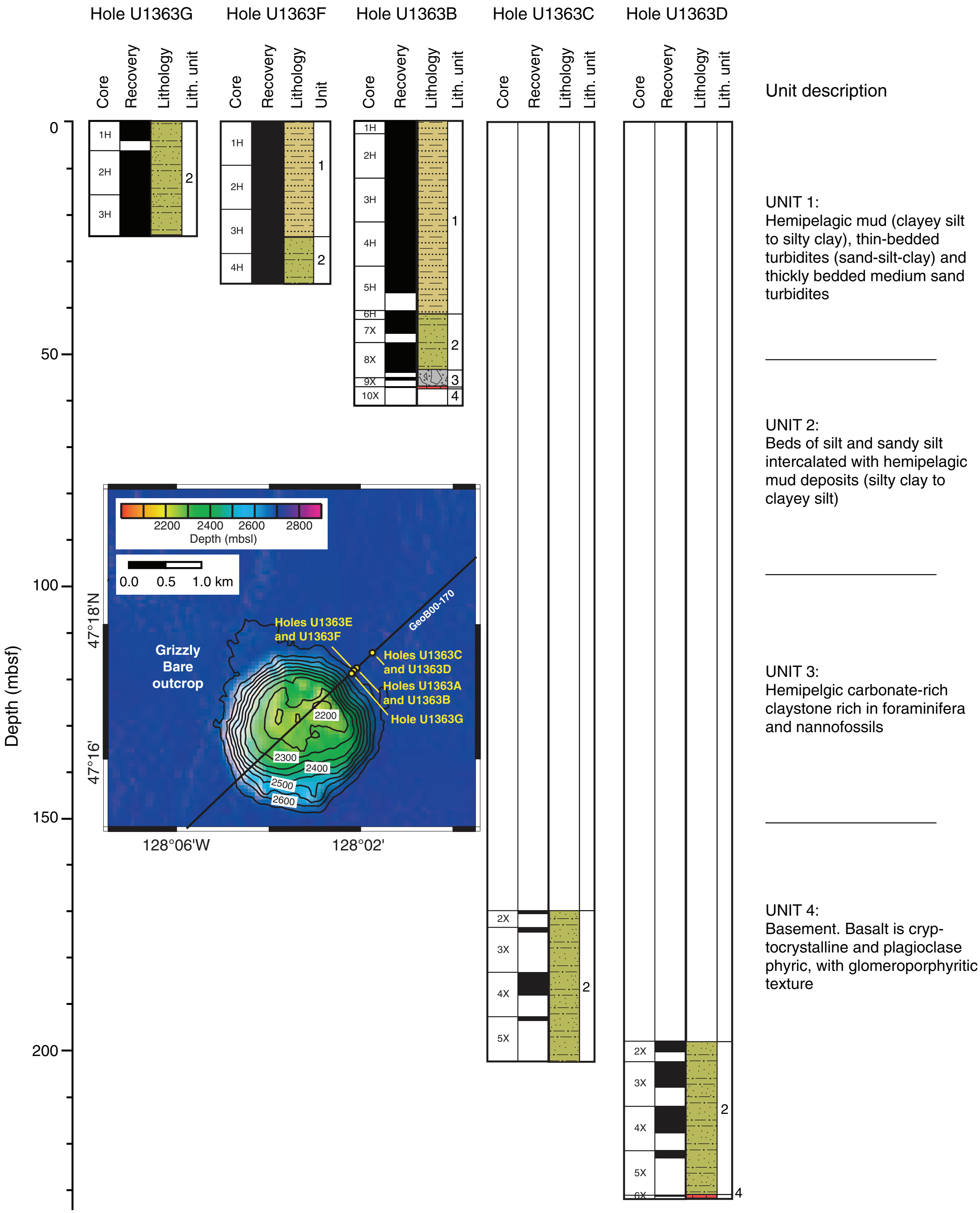

Figure F13. Selected education, outreach, and communication (EOC) projects during Expedition 327. **A.** Screenshot of a staff-maintained blog. **B.** Screenshot of the Adopt-A-Microbe Web site, which includes educational materials, activities, stories, art work, and other information. **C.** Screenshot of Ocean Gazing podcast Web site. **D.** Metrics showing site visits on a daily basis for www.joidesresolution.org/. Traffic at this site increased by 40% during Expedition 327.

Figure F14. Comparison of borehole caliper width and penetration rates for Holes U1362A, U1362B, and U1301B. Some continuity of distinct basement layers is apparent between the holes, which are separated by 300–500 m in an along-strike direction (Fig. **F3**).

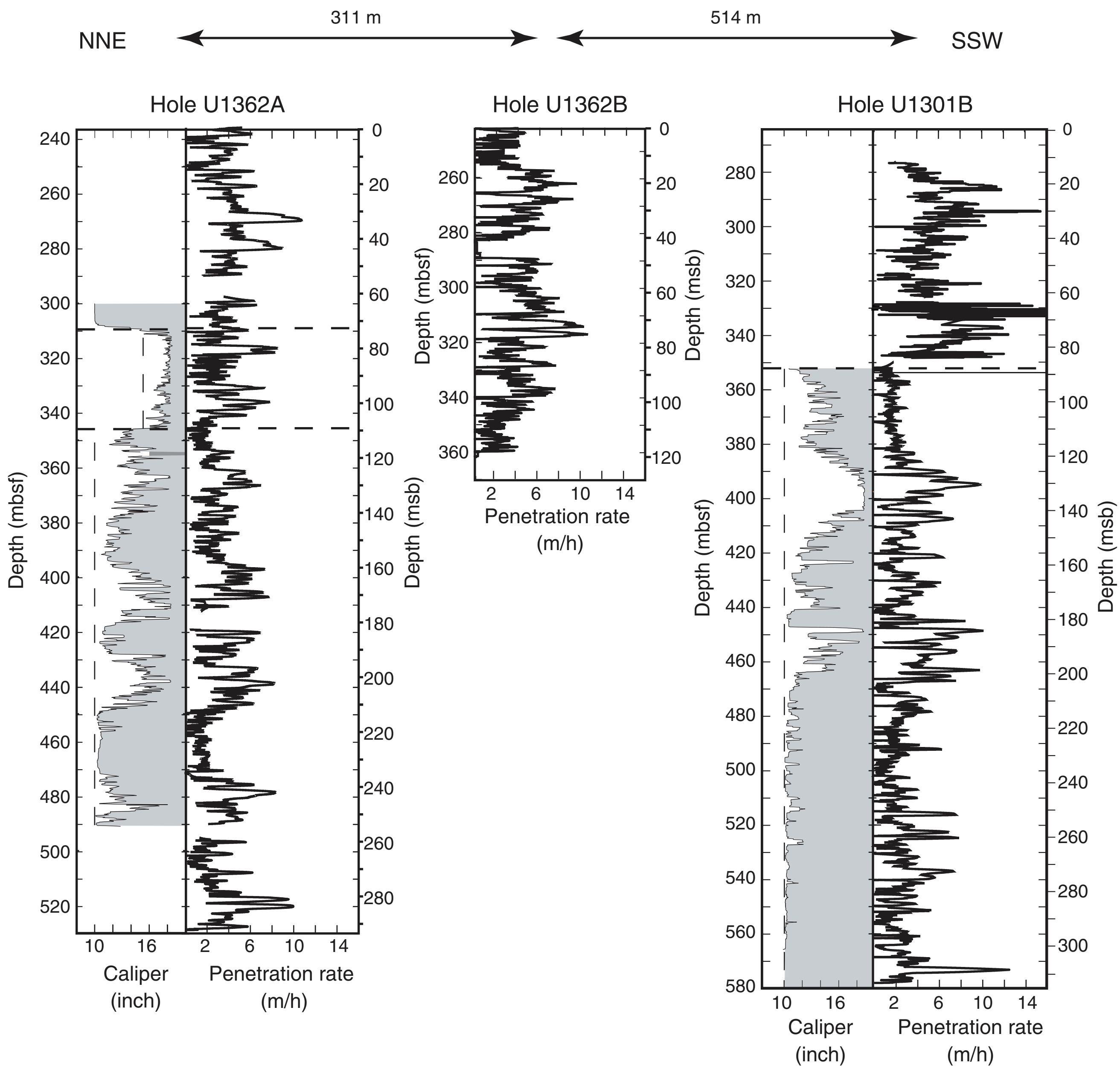

Figure F15. Calculated tides at the Expedition 327 drill sites. **A.** Tides for duration of expedition. **B.** Tides for a two-day period, including period when >100% of a hard rock core was recovered. When the ship moved downward during a falling tide, penetration sometimes exceeded the relative motion of the bit with respect to the rig floor.