# IODP Expedition 321T: Cementing Operations at Holes U1301A and U1301B, Eastern Flank of the Juan de Fuca Ridge

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## Introduction

IODP Expedition 301 (Fisher et al., 2005a) was part of a series of expeditions and experiments to quantify hydrogeologic, lithologic, biogeochemical, and microbiological properties, processes, and linkages on the eastern flank of the Juan de Fuca Ridge, North Pacific (Fig. 1). Operations during Expedition 301 included replacement of one existing subseafloor borehole observatory ("CORK", Hole 1026B), drilling two basement holes and installing two new long-term observatories (Holes U1301A and U1301B), coring the upper ~300 m of basement and shallow sediments above basement, and collection of *in situ* hydrogeologic and geophysical data from basement. Subsequent expeditions using a remotely operated vehicle (ROV) and submersible have serviced borehole observatories, collected pressure and temperature data and fluid and microbiological samples, and replaced components as needed to maintain these systems for future use. Another drilling expedition is planned for 2010 (see backcover for schedule) to emplace three more borehole observatories and initiate cross-hole tests, and additional ROV and submersible ex-peditions will conduct long-term experiments and recover subseafloor data and samples.

Borehole observatories installed during IODP Expedition 301 were designed (i) to seal open holes so that thermal, pressure, and chemical conditions could equilibrate following the dissipation of the drilling disturbance; (ii) to facilitate collection of fluid and microbiological samples and temperature and pressure data using autonomous samplers and data logging systems; and (iii) to serve as long-term monitoring points for large-scale crustal testing (Fisher et al., 2005b). Unfortunately, the CORKs installed in Holes U1301A and U1301B were not sealed as intended (Fisher et al., 2005a). Initially, both holes were drawing cold bottom seawater into basement, but as described below, conditions in these holes are dynamic, and flow conditions have changed over time. The primary objective of Expedition 321T was to seal these observatories by pumping cement into the reentry cones surrounding the CORK wellheads, allowing the remaining components of the full experimental program to be completed during subsequent drilling and submersible expeditions.

## Background

Ocean Drilling Program (ODP) Leg 168 completed a drilling transect of eight sites across 0.9–3.6 Ma seafloor east of the Juan de Fuca Ridge. It resulted in collection of sediment, rock, and fluid samples; determination of thermal, geochemical, and hydrogeologic conditions in basement; and installation of a series of CORK observatories in the upper crust (Davis et al., 1997). Two of the Leg 168 observatories were placed in 3.5–3.6 Ma seafloor near the eastern end of the drilling transect, in Holes 1026B and 1027C (Fig. 1). IODP 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 multilevel observatories at Site U1301 for use in long-term, three-dimensional hydrogeologic experiments.

Hole 1026B was drilled to 295 meters below seafloor (mbsf), cased across the sediment/basement interface, and extended to 48 meters sub-basement (msb) during ODP Leg 168 (Davis et al., 1997). The original CORK installed in Hole 1026B included a data logger, pressure sensors, thermistors at multiple depths, and a fluid sampler, all of which (except the fluid sampler) were recovered in 1999. The Hole 1026B CORK was incompletely sealed after being installed in 1996, and because basement fluids are overpressured in this location with respect to ambient hydrostatic conditions (Davis, et al., 1997), this hole discharged fluid for years until it was replaced during IODP Expedition 301. As of the start of Expedition 301, warm (~64°C) altered basement fluid vented freely through the top of the wellhead. The original ODP Leg 168 CORK installed in Hole 1026B was replaced successfully during IODP Expedition 301.

IODP Site U1301 was positioned 1 km south-southwest of ODP Site 1026, where sediment thickness is 260–265 m above a buried basement high (Fig. 1). Hole U1301A was drilled without coring to 370 mbsf (107 msb). The casing was extended into the upper 15 m of basement, but poor hole conditions prevented installation of longer casing, coring, or deeper drilling. A depth check prior to CORK deployment in Hole U1301A revealed that much of the lower part of the hole had filled in with rocks from the rubbly formation around the hole.

Hole U1301B was posi-tion-ed 36 m away. It penetrated to a total depth of 583 mbsf (318 msb). Uppermost basement was drilled without coring, and casing was installed to 85 msb. Basement was cored from 86 msb to 318 msb. The upper 100 meters of the cored interval in Hole U1301B were irregular in diameter, often much larger than the maximum inflation diameter of packers to be used for hydrogeologic testing and CORK observatories. However, the lower 100 meters of the hole were stable and to gauge, allowing collection of high-quality wireline logs and providing several horizons suitable for setting drill string and CORK casing packers.

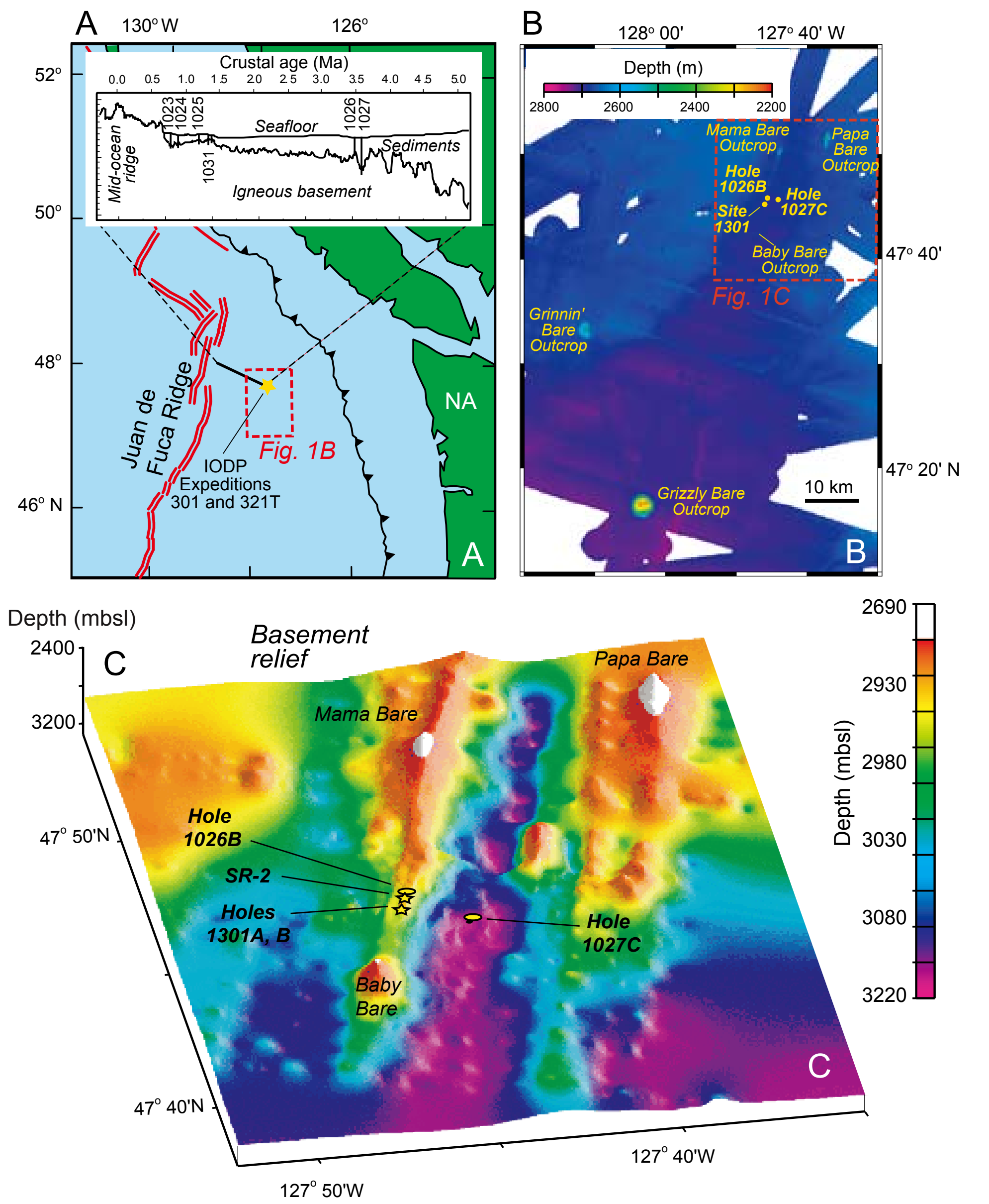


Figure 1. Maps showing the IODP Expedition 301 and 321T field area. [A] Index map showing locations of ODP Leg 168 drilling transect (thick black line), IODP Expedition 301 and 321T work area (gold star), the Juan de Fuca Ridge, and nearby continental areas. Inset profile shows locations of ODP Leg 168 sites. [B] Regional bathymetric map showing locations of ODP Holes 1026B and 1027C and IODP Site U1301. [C] Map of basement relief created from bathymetric and seismic data, showing locations of ODP and IODP drill sites. Areas marked in white are present-day basement outcrops. Figure modified from Zühlsdorff et al., 2005.

Both of the Site U1301 boreholes contained four nested casing strings: a 0.50-m casing (20-inch diameter) in the uppermost sediments, a 0.41-m casing (16-inch diameter) extending just across the sediment/basement interface, a 0.27-m casing (10.75-inch diameter) extending into basement, and a 0.11-m inner CORK casing (4.5-inch diameter) that houses instrument strings and plugs (Fig. 2). The two largest casing strings were sealed by collapse of unconsolidated sediments, and the 0.41-m string was also cemented across the sediment/basement interface. The annulus between 0.41-m and 0.27-m casing strings at Site U1301 was supposed to contain a rubber, mechanical casing seal near the seafloor, but this component was not available for use during Expedition 301 as planned. An attempt was made to seal the 0.27-m casing strings at depth with cement, but rubbly basement prevented the cement from sealing between casing and the borehole wall. Operations were additionally complicated in Hole U1301B by the separation of the unwelded 0.27-m casing string into two sections, which left a gap just above the sediment/basement interface (Fig. 2b). The CORK installed in Hole U1301A included a casing packer (as part of the 0.11-m inner casing) that was set inside the 0.27-m casing. In contrast, the CORK installed in Hole U1301B included two casing packers set in an open hole intended to hydraulically isolate sections of the upper crust (Fig. 2b).

Expedition 301 CORKs and the preexisting CORK in Hole 1027C were visited with an ROV soon after drilling in September 2004, and again by submersible in September 2005. Data recovered during these dives showed that the Hole 1026B observatory was sealed and operating as intended, although the pressure in Hole 1026B was recovering slowly from the thermal perturbation associated with eight years of upflow of warm formation fluid. The CORKs in Holes U1301A and U1301B were incompletely sealed, allowing cold ocean-bottom water to flow into the formation following CORK installation. The flow of this water into the crust at Site U1301 caused a measurable pressure perturbation at Site 1027, 2.4 km away, comprising an unintended (but scientifically useful) cross-hole test (Fisher et al., 2008).

Attempts to seal Hole U1301B using a cement delivery system with the submersible *Alvin* in summers 2006 and 2007 were unsuccessful, as the submersible could not deliver a sufficient quantity of cement to the cone. Shimmering fluid was observed discharging from Hole U1301A during and after summer 2007 dive operations. No such evidence for upflow from the borehole was observed during earlier visits, suggesting that Hole U1301A had "turned around" sometime between 2006 and 2007 servicing operations. In fact, downhole temperature loggers recovered from Hole U1301A in summer 2008 provide a detailed record of this flow reversal. Remarkably, Hole U1301B continued to draw fluid rapidly into basement as of summer 2008, even though it is located just 36 m from Hole U1301A, which was vigorously discharging warm formation fluid to the ocean. Additional research will be needed to understand the pressure and thermal interactions between Holes U1301A and U1301B as well as the implications for local and regional crustal hydrogeology.

The CORK landing platform installed at Hole U1301A included a solid surface that was perforated by eight 25-cm-diameter holes. Screens were welded below these holes prior to deployment so that instrumentation being deployed or manipulated by a submersible or ROV would not fall through the holes. In contrast, the landing platform at Hole U1301B has a series of radial support arms covered by the same screen material as was welded to the bottom of the platform at Hole U1301A. By the time the landing platform was deployed at Hole U1301B during Expedition 301, shipboard personnel realized that later cementing would be necessary, and a slot was cut through the platform screen to facilitate this operation.

## Operations and Results

A special formulation of cement, including "Cello-Flake" lost circulation material (LCM) was loaded onto the *JOIDES Resolution* during a brief port call prior to Expedition 321T. The use of cement with LCM is common in industry drilling and borehole installations, particularly in fractured rock, but this technology had not been used previously in scientific ocean drilling. In addition, a special bottom hole assembly

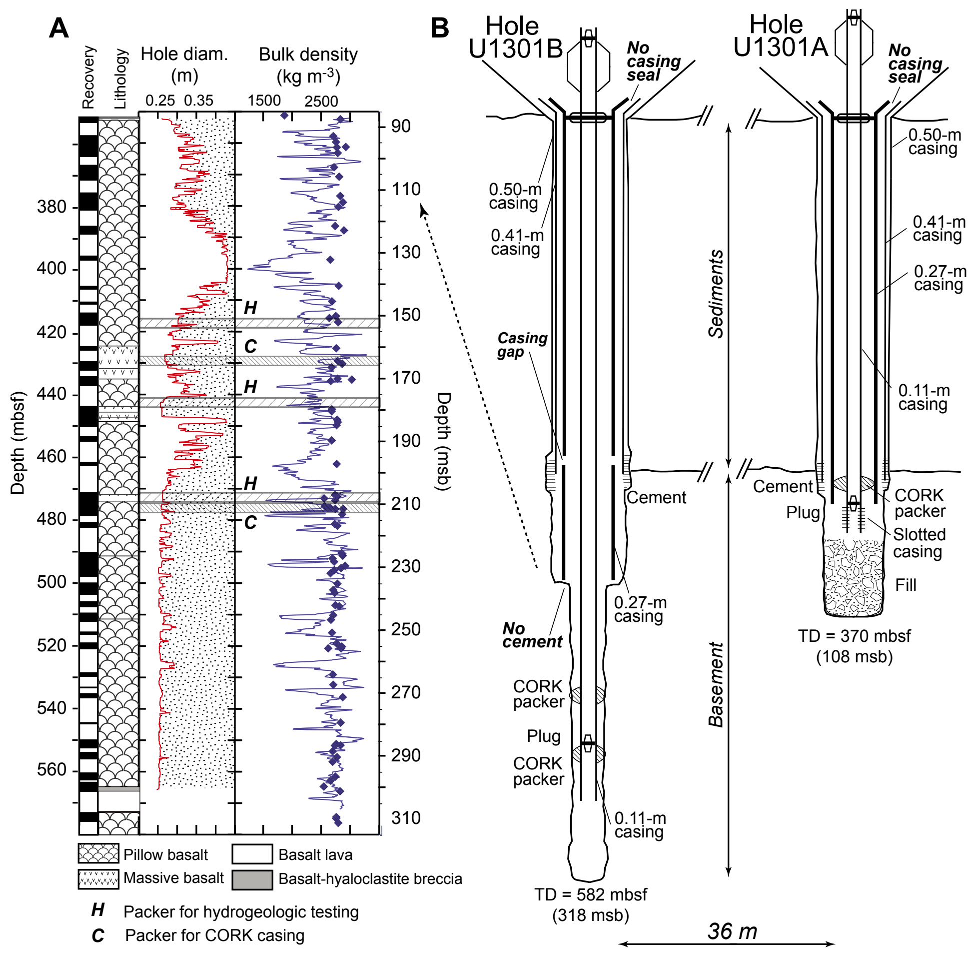


Figure 2. Summary of basement and borehole observatory characteristics in Holes U1301B and U1301A (modified from Fisher et al., 2008). [A] Basement recovery, primary lithology, borehole size, and bulk density from Hole U1301B (Fisher et al., 2005a). Basement cores were collected from ~355 mbsf to 575 mbsf (~100–320 msb), with recovery indicated by black intervals next to depth column. Bulk density log (blue line) and analyses of pieces of rock (diamonds) show evidence for considerable porosity in uppermost basement and a layered basement structure, especially below 470 mbsf (220 msb), with alternating more and less dense intervals. Horizontal bands indicate depths where CORK casing packers and the drill string packer used for hydrogeologic testing were set against the borehole wall. [B] Casing and CORK configurations in Holes U1301B and U1301A. Observatories in both holes lack a critical seal between 0.27-m and 0.41-m casing, which are needed to prevent the flow of cold bottom water into shallow basement or the flow of warm formation fluid out into the ocean. TD = total depth.

(BHA) was designed for Expedition 321T cementing operations, including a cementing "stinger" with a beveled edge that could be used to push through one of eight 25-cm-diameter holes in the landing platform in Hole U1301A.

Cementing operations occurred first at Hole U1301B, where reentry was easier because of the preexisting hole in the landing platform in the cone. Once pipe was run, reentry required 2.25 hrs, after which 60 barrels (bbls) of cement blended with LCM was pumped into the reentry cone. Seafloor operations were observed with the shipboard television camera system, and the cone was visibly filled with cement. The ship was offset to Hole U1301A, where the cement stinger was maneuvered to push through a screened hole in the CORK landing platform. This second reentry was accomplished in 2.75 hrs, after which 114 bbls of cement blended with LCM was pumped into the reentry cone. The ship was offset back to Hole U1301B, the hole was reentered again, and another 70 bbls of cement and LCM was pumped into the cone. Both reentry cones were inspected and found to be filled with cement surrounding the CORK observatory wellheads. Additional cement was observed to have poured over the edges of the cones and into the depressions in the seafloor around the cones. Cementing operations during 321T were completed more quickly, and with greater ease, than anticipated because of a combination of careful planning and preparation, the skill of the shipboard personnel in managing delicate operations, and fortuitous weather and sea conditions.

A scientific group returned to Holes U1301A and U1301B by submersible three weeks after Expedition 321T, downloaded pressure data, and evaluated the success of cementing efforts. As of summer 2009, both holes U1301A and U1301B had "turned around" and returned to overpressured conditions. Hole 1301A continued to leak fluid, as some of the cement pumped into the cone during Expedition 321T drained down into the annular gap between 0.41-m and 0.27-m casings. Additional cementing will be attempted during summer 2010 drilling operations, with a more aggressive use of LCM, to seal hole U1301A more completely. In contrast, Hole U1301B appears to be sealed between 0.41-m and 0.27-m casing, but the fluid overpressure in basement is greater than anticipated, and the top CORK plug was lifted by this pressure. Dive weights were placed on top of the plug during summer 2009 submersible operations, and additional pressure data will be collected from this system during summer 2010 servicing, which will allow a more complete evaluation of the state of this borehole observatory system.

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