IODP Expedition 327: Juan de Fuca Ridge-Flank Hydrogeology

Site U1363 Summary

5 September 2010

Background

The three basaltic outcrops near the IODP Juan de Fuca drill sites are locations where altered seawater from the basaltic basement vents to the overlying ocean (Wheat et al., 2004). In contrast, Grizzly Bare outcrop is a large basaltic feature 52 km to the south, where heat flow, seismic, and modeling studies indicate that cold seawater enters the crust (Fisher et al., 2003; Hutnak et al., 2006). As at other locations where ridge-flank hydrothermal circulation is guided by basement outcrops, seawater is hypothesized to enter basaltic basement at Grizzly Bare, flow laterally within the crust and become warm, react with basalt, exchange solutes with overlying pore waters in the sediment, and support microbial processes. Thermal and chemical changes are dramatic and clearly defined with temperatures that reach 64°C and a fluid composition that has lost all of its dissolved oxygen, nitrate and magnesium while gaining Ca by the time it reaches Baby Bare. This transition from oxic seawater to a hydrothermal fluid takes tens to hundreds of years in this setting.

Site U1363 (Scientific Prospectus Sites GRB-1A, 2A and 3A; Fisher et al., 2010) was placed adjacent to the northeastern edge of Grizzly Bare outcrop. If Grizzly Bare is a significant hydrothermal recharge site, as hypothesized, fluid and microbiological composition at the base of the sediment column should look much like that near the seafloor, whereas the chemical composition of pore fluids and microbiological communities from the middle of the sediment section will show the influence of diffusion and digenetic reactions as a function of distance from the outcrop, depth, and temperature.

Operations

The *JOIDES Resolution* departed Site U1362 at 1300 hr on 30 August 2010 and the 31 nmi transit to Grizzly Bare outcrop took 3 hr at an average speed of 10.0 kt.

Hole U1363A

Hole U1363A (proposed site GRB-1A) was spudded at 2300 hr on 30 August at a depth of 2689 m. Drilling without coring continued for 2-1/2 hr to the basement contact at 58 m below seafloor (mbsf). The sole purpose of drilling Hole U1363A was to determine the depth of basement to avoid a 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 hr on 31 August at a depth of 2690 m. APC Cores 1H through 6H advanced to 42.5 mbsf by 1300 hr, at which point the APC was not able to penetrate the sandy turbidite formation. APCT3 temperature measurements were taken with Cores 3H through 6H. Cores 7X and 8X advanced to 55.0 mbsf by 1610 hr. The first SET temperature measurement was taken at ~56 mbsf and coring continued with Core 9X, which advanced through the sediment/basement interface to 57 mbsf. Core 10X advanced to 61 mbsf and was on deck by 2100 hr. The drill string was pulled clear of the seafloor at 2140 hr on 31 August.

Hole U1363C

The ship was offset in DP mode to the coordinates for Hole U1363C (GRB-3A), the deepest of the 3-hole transect at Grizzly Bare. Hole U1363C was spudded at 2255 hr on 31 August at a depth of 2689 m. Hole U1363C was drilled without recovering cores to 170 mbsf. A SET temperature measurement

was taken at ~171 mbsf, followed by Cores 2X and 3X to a depth of 183.2 mbsf. A second SET temperature was taken at ~184 mbsf, followed by Cores 4X and 5X to a depth of 202.4 mbsf. A third SET temperature measurement was taken at ~204. At 1445 hr on 1 September, the SET tool became stuck inside the outer core barrel due to the sandy formation and the drill string had to be recovered back to the ship. The SET tool was retrieved at 0145 hr on 2 September and the ship was offset 10 m on a bearing of 135°.

Hole U1363D

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

Hole U1363E

Hole U1363E was spudded at 0840 hr 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 hr. The drill string was pulled out of the seafloor at 1125 hr, ending Hole U1363E.

Hole U1363F

Hole U1363F was spudded at 1200 hr on 3 September. Cores 1H to 4H advanced to 35 mbsf by 1600 hr. APCT3 temperature measurements were taken with Cores 3H and 4H. The drill string was pulled out of the seafloor at 1735 hr, 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 hr on 3 September. Cores 1H to 3H advanced to 24.9 mbsf by 2250 hr. The true advance is closer to 17 mbsf as the last core recovered mostly flow-in material. An APCT3 temperature measurement was taken with Core 2H.

Transit to Victoria, British Columbia, Canada

The rig floor was secured for transit and the ship was underway at 1015 hr on 4 September. The first line ashore was at 0836 hr on 5 September 2010.

Science Results

Lithotratigraphy

Site U1363 sediments are composed of turbidite sequences interspersed with hemipelagic mud. Several lithologic units can be distinguished.

Petrology

Very few, small pieces of basalt were recovered from Site U1363. The basalt is cryptocrystalline and plagioclase phyric, with glomeroporphyritic texture visible in hand specimen. 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, alteration halos, filling vesicles, and lining hydrothermal veins.

Physical Properties

All cores were run through the whole-round multisensor logger (WRMSL), yielding magnetic susceptibility values from $<500 \times 10^{-6}$ SI in clay sections to $\sim1400 \times 10^{-6}$ SI in sandy turbidites. Point susceptibility data run on the section half multisensor logger (SHMSL) are similar, with data tending to be slightly lower than whole round values, except in the case of turbidite sequences where SHMSL

values are consistently higher. Gamma ray attenuation density averages 1.8 to 2.0 g/cm^3, depending on lithology, with some compaction evident with depth in clay data.

Discrete measurements, including moisture and density (MAD), *P*-wave, and thermal conductivity, were measured on most cores from Holes U1363B, U1363C, U1363D, and U1363F, with insufficient time to run cores from Hole U1363G. Thermal conductivity in Hole U1363B averaged 1.30 W/mK, while MAD bulk densities averaged 1.77 g/cm^3, both showing bimodal distributions corresponding to clay and sand lithologies. MAD porosity in Hole U1363B averages 60.6%. *P*-wave velocities in Hole U1363B average 1.52 km/s, with marked differences in both average and variability across lithologies. Velocities also show some anisotropy between vertical and horizontal directions. Insufficient time was available to analyze data gathered in holes other than Hole U1363B.

Geochemistry

Pore water samples were recovered from 5 holes at 4 locations, 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 a total of 57 pore water samples: 15 from Hole U1363G, 14 from Hole U1363F, 14 from Hole U1363B, and 14 from 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 sea water. Minor and trace elements in sea water also show gradients in the basal sediment section, projecting to a formation fluid that is slightly altered relative to sea water and more altered than locations closer to Grizzly Bare outcrop.

Alkalinity shows a progression from higher to lower values at the sediment/basement interface and a progression of increasing mid-sediment column concentrations with increasing depth to the basement for all the sites sampled. Also measured in these samples was pH, with consistent values near 7.3 from the seafloor to the sediment/basement interface. At Hole U1363G, alkalinity increased from 3.5 meq at 1.5 mbsf up to 4.6 at 10 mbsf and then decreased to 2.9 meq at 25 mbsf at the basement. Hole U1363F had a similar profile. At this site, alkalinity rose from 6.7 meq at 4.5 mbsf up to 10.5 meq at 12 mbsf and then decreased to 1.8 meq as the sediment/basement interface of 33 mbsf. The highest alkalinity measured was 13.9 meq at 16.5 mbsf in Hole U1363B, whereas alkalinity was 2.1 meq at the sediment/basement interface. Coring at Holes U1363C/U1363D sampled only the lowermost 50 m, so the alkalinity maximum was missed in the upper sediments. The lowest alkalinity measured was 1.3 meq 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.

Microbiology

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 at 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 were sampled from the combined coring at Holes U1363C and U1363D. Again, sediment samples were mostly from

clay-rich layers, although some samples contained sand. The basement sample from Core U1363D-6X was a relatively unfractured basalt with spots of light green and orange alteration crusts.

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 shipboard for safety purposes and only a few samples had quantifiable levels of methane or higher hydrocarbon gases, which is expected in the high sulfate sediments samples. Microsphere samples will be returned to the shore-based lab for postcruise analysis, due to time limitations at the end of the cruise. Those samples will also be used for shore-based cell counting analysis and fluorescence in situ hybridization analysis. A subset of samples were also collected for analyses of DOC/DN, POC/PN, amino acids, low molecular weight organic acids and lipid biomarkers.

Paleomagnetism
Remanent magnetization measurements were made on ~2/3 of core sections from Hole U1363B. Samples were demagnetized at 10 mT steps from 0 to 40 mT using the cryogenic magnetometer's inline alternating field 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 the drilling process and the alternating sequences of hemipelagic mud and turbidite deposits.

Downhole Measurements
Temperature measurements were collected with the APCT-3 and SET tools at Holes U1363B–U1363E. Several good measurements were obtained with both tools.

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

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

Hutnak, M., A. T. Fisher, L. Zühlsdorff, V. Spiess, P. Stauffer, and C. W. Gable (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, *Geochemistry Geophysics Geosystems (G3)*, *7*, doi:10.1029/2006GC001242.

Wheat, C. G., M. J. Mottl, A. T. Fisher, D. Kadko, E. E. Davis, and E. Baker (2004), Heat and fluid flow through a basaltic outcrop on a ridge flank, *Geochemistry Geophysics Geosystems* (G3), 5(12), doi:10.1029/2004GC000700.