August 20, 2004

IODP EXPEDITION 301: JUAN DE FUCA HYDROGEOLOGY SITE SUMMARY: SITE 1301

Work at Site 1301 comprised operations in and around four holes. Hole 1301A included penetration of 262 m of sediment and the upper 108 m of basement, installation of casing, short-term hydrogeologic testing, and emplacement of a single-level CORK-II borehole observatory. Hole 1301B penetrated through 265 of sediment and 318 m of basement. This hole was RCB cored over the lower 232 m of basement, logged, subjected to hydrogeologic testing within multiple depth intervals, and fitted with a multi-level CORK-II borehole observatory. Hole 1301C was discontinuously APC-cored to 265 mbsf, and in-situ temperatures were determined to evaluate the thermal state of uppermost basement. Hole 1301D was APC spot-cored to recover sediment from an interval that had not been cored in Hole 1301C.

Sediments

The lithostratigraphy of sediments at Site 1301 was found to be virtually the same as that cored at Site 1026 during ODP Leg 168, 1-2 km to the north along the same buried basement ridge, comprising fine- to coarse-grained turbidites, debris flows, and hemipelagic clay. Resampling much of the same sedimentary interval during Expedition 301 was justified because APC coring had not previously penetrated below 100 mbsf in this area, and we wished to collect high-quality samples for microbiological and geochemical analyses, especially in the interval close to the sediment-basement interface and the underlying crustal aquifer. Time constraints prevented continuous coring of the complete sedimentary section, but intervals that were cored generally yielded excellent recovery and high-quality samples. Exceptions to this rule included intervals where coarse sand or gravel prevented complete penetration of the APC barrel.

Silt-rich and clay-rich APC cores from Hole 1301C and 1301D are of exceptionally high quality, even from depths below 250 mbsf. Cores recovered from sandy and gravely intervals are generally of poorer quality and often include intervals within which there was complete resuspension and settling of clastic particles. Because of discontinuous coring, irregular recovery, and extensive whole-round sampling, we were unable to determine well-constrained lithologic boundaries for the primary stratigraphic units in Hole 1301C. Unit I is an upward-fining turbidite sequence, with gravel interbeds, and Unit II is a hemipelagic clay sequence. The true boundary between Units I and II occurs somewhere within the non-cored interval between 197 and 236 mbsf, but its approximate location may be inferred from its equivalent depth in Hole 1026C (216 mbsf).

There are differences between the lithologies recovered at Site 1301 and those documented at Site 1026. The coarsest layers recovered at Site 1026 comprised mainly muddy sand and mud clasts, whereas coarse sediments from Hole 1301C included clasts serpentinite, green amphibolite, quartzite, felsic volcanics, calcareous sandstone and shallow water shell fragments. One explanation for the difference is that the two sites sampled different parts of the turbidite distributary channel network, but it seems just as likely that coarse intervals were simple not recovered during XCB and RCB coring on Leg 168. The other significant difference was the greater thickness of the hemipelagic clay unit, which is at least 27 m thick in Hole 1301C, but was only 13 m thick at Site 1026. This may result from subtle differences in basement relief and depositional regime, which influence whether hemipelagic clay or fine-grained turbidites dominate deposition over basement highs.

Pore water chemical-depth profiles from Site 1301 are similar to those from ODP Site 1026. As observed at numerous DSDP and ODP holes drilled to basaltic basement, there are two biogeochemical zones identified on the basis of steep geochemical gradients at the seawater-sediment and sediment-basement interfaces. The gradients are particularly well-defined in the dissolved sulfate, manganese and iron profiles. The downhole pattern of sulfate concentrations indicates active sulfate reduction at depths ~50 mbsf and ~125 mbsf, and diffusive sources from bottom seawater and the basaltic formation fluid, respectively. Concentrations of dissolved barium are high in between these depths. Alkalinity, chlorinity and ammonium profiles are also nearly identical at Sites 1301 and 1026, and have end-member compositions that approach those of spring fluids from Baby Bare outcrop 6 km away.

However, there are several significant differences in the profiles from these two sites for the minor elements, most notably for dissolved iron. Data from IODP Site 1301 have a maximum iron concentration of 133 µmol/kg, compared to 14.8 µmol/kg at ODP Site 1026. This highlights the importance of squeezing the sediment within a nitrogen atmosphere. Other differences between chemical profiles IODP Site 1301 and ODP Site 1026 exist for Mn, B, Sr and Li. For these elements the upper portion of the profiles are identical but differences occur within the basal sediments. These differences are likely caused by differences in composition and not sampling artifacts as was the case for iron, because each of these elements is highly reactive within the sediment section. The carbon content of the pore water increases in the first 40 m of sediment, reaching a maximum at 47 mbsf. From 179 mbsf to the bottom of the hole, dissolved carbon concentrations are very low.

The depth profile of methane varies inversely with sulfate and indicates the presence of two sulfate-methane interfaces. Methane concentrations are low in the upper part of the sediment but increase sharply in the depth interval between 60 and 70 mbsf and reach a maximum near 100 mbsf. Higher molecular weight hydrocarbon gases were not detected in samples from Site 1301. The highest methane concentrations occur within the interval where sulfate is nearly depleted. This relationship indicates that the methane results from microbiological production. The disappearance of almost all of the methane at the depths of sulfate depletion indicates that most of this methane is likely consumed by anaerobic methane oxidation. Consequently, methane concentrations remain low in zones without active methanogenesis.

The solid phase of recovered sediments has relatively low organic carbon, nitrogen, and hydrogen contents. Organic carbon contents are highest close to the sediment/water interface (0.9 wt%) but decrease rapidly and fluctuate around 0.3 wt% throughout the sediment column. Total nitrogen averages around 0.04 wt% and has a depth trend similar to organic carbon. Calculated atomic C/N ratios generally indicate organic matter of marine origin, but there are discrete sediment layers within a significant source of terrestrial organic matter is apparent. We also find distinct layers with highly elevated carbonate contents below the postulated lower zone of anaerobic methane oxidation. Observed carbonate peaks coincide with elevated carbonate levels found at Site 1026 below the lower zone of anaerobic methane oxidation and at the sediment/basement interface.

Microbiological samples were collected from all sediment cores. Perfluorocarbontracer (PFT) was pumped during all coring operations to help in evaluating core contamination. PFT concentrations were evaluated across the cut faces of the cores, and results of these tests indicate that contamination was generally minimal, usually indicating a ratio of introduced to native cells of 10^{-9} or fewer. We found no relationship between drilling fluid contamination and core depth or lithology (clay versus sand).

Total cell counts decreased slightly with depth, from near-surface concentrations of 7.5×10^{8} to concentrations of 1.8×10^{7} cells cm^{-3} at 248 mbsf. Overall, the profile of microbial cell densities follows a similar trend to that defined for other ODP sites. Tiny coccoid-shaped cells dominated throughout the sediment column. Numbers of rod-shaped cells fluctuated strongly. Aggregates of up to 30 microbial cells were detected in four horizons between 63 and 90 mbsf. Interestingly, an increase in cell numbers was observed near the sediment-basement interface. This increase in biomass may be supported by upward flux of electron acceptors from hydrothermal fluids in the underlying bedrock. Sulfate may be an important oxydizer in the deepest part of the sediment column, illustrating how water in the basaltic crust might support microbial growth in overlying sediments.

Approximately 1000 enrichment cultures of indigenous microorganisms were inoculated on board using three methods. Samples were cultured in various forms using different media and incubation temperatures ranging from 5 to 85 °C. None of the anaerobically incubated enrichments showed growth during Expedition 301. The incubation time was probably too short for most of the microorganisms to grow, and studies will be continued on shore.

Physical properties from Hole 1301C data are highly bimodal, with clay- and sand-rich sediments showing distinctive trends for most measurements. Magnetic susceptibility data show trends that are typical for turbidites, with higher values in the coarse sandy layers, and lower values in clay-rich layers. In contrast, natural gamma radiation levels were not particularly helpful in distinguishing primary lithology. Bulk density of the clay layers increases systematically from 1.4 g/cm^3 at the seafloor to ~2 g/cm^3 at 100 mbsf, and correlates with a ~30% decrease in porosity over the same depth interval. The porosity of sand layers remains relatively constant at ~40% to a depth of 115 mbsf. No core was recovered from two large continuous sections below 100 mbsf, prohibiting analysis of trends at greater depth. Bulk density values from clay lithologies recovered in the 30 m above basement vary slightly about a mean of 1.9 g/cm^3. The bulk density of sand layers is relatively consistent at 2.0 ± 0.1 g/cm^3. Grain density is remarkably consistent at 2.8 ± 0.1 g/cm^3 regardless of depth or lithology. The higher than expected grain density could be attributable to pyrite, which has a grain density of ~5 g/cm^3.

Thermal conductivity was strongly controlled by lithology, with values for clay being significantly less than values for sand, averaging 1.12 ± 0.12 and 1.53 ± 0.19 W/m-K, respectively. A systematic increase of thermal conductivity is apparent in the upper 100 mbsf within clay-rich layers. A matrix thermal conductivity of ~2.5 W/m-K was indicated for clay-rich layers, a value ~1 W/m-K less than estimated at Hole 1026A. P-wave velocity values range from ~1480 to 1780 m/s over the 265-m cored interval, with an increase of ~10% occurring within the uppermost 50 mbsf. We found no evidence for velocity anisotropy. Indrained shear strength was also found to increase with depth through the sediment section.

Two attempts to determine in-situ temperatures in Hole 1301C were made with the APC tool, and three with the DVTP. One of each kind of measurement was unsuccessful, but the remaining data were sufficient to determine both the temperature of uppermost basement and heat flow through the sediments. The upper basement temperature is ~62°C, approximately the same as measured at nearby Sites 1026 and 1027, and heat flow through the sediments is 280 mW/m^2 and entirely conductive.

Basement

The geology of the uppermost 85 m of basement is poorly known at Site 1301 because no coring was attempted from the sediment-basement interface to this depth. The decision to drill and case off uppermost basement at Site 1301 was made during planning for Expedition 301 on the basis of general and local experience. RCB core recovery was only 5% within the upper 40 m of Hole 1026B [Shipboard Scientific Party, 1997], and that hole required installation of a liner at depth to keep basement "open" for testing and monitoring.

Records of drilling penetration rates within the upper 100 m of basement at Site 1301 provide limited lithostratigraphic insight. Penetration rates less than 3-4 m/hr generally corresponded to relatively massive rock and stable hole conditions, whereas penetration rates greater than 8-10 m/hr were usually accompanied by hole instability. Although there is not a one-to-one correspondence between penetration rates at equivalent basement depths in the two holes, there are gross similarities. For example, the interval from 55-65 m into basement drilled relatively slowly in both holes, whereas the interval from 65-80 m into basement drilled much more quickly. We initially attempted to place casing across this fast-drilling interval in Hole 1301A, but failed to land the original casing string. We had to shorten this string and cased off only the uppermost 15 m of basement in this hole. We subsequently cased most of this fast-drilling interval in Hole 1301B.

Basement was cored in Hole 1301B from 351 to 583 mbsf (86 to 317.6 m sub-basement [msb]). The 69.1 m of recovered core, comprising recovery of 30%, consisted of (1) basalt-hyaloclastite breccia, (2) aphyric to highly phyric pillow basalt and (3) massive basalt. Eight units were defined on the basis of changes in lava morphology, rock texture and grain size. Pillow lava units (Units 1, 3, 5, 7 and 8) were subdivided based on changes in phenocryst mineralogy and abundances. Massive lava units (Units 2, 4 and 6) were subdivided into individual cooling units, based on the presence of chilled margins.

Pillow basalt was the most abundant rock type recovered from Hole 1301B. Pillow lavas were identified by the presence of curved chilled margins, oblique to the vertical axis of the core, with perpendicular radial cooling cracks. Pillow fragments have dominantly hypocrystalline textures with a glassy to microcrystalline groundmass. They are sparsely to highly plagioclase, clinopyroxene ± olivine phyric. Observed basalt textures vary from glassy to hyalo-ophitic (typically with sheaf-spherultic or plumose textures) to glomeroporphyritic, seriate and intersertal. The pillows are sparsely vesicular, containing 1-5% round gas vesicles, and are slightly to moderately altered. Alteration styles include interstitial groundmass replacement, vesicle fill, vein formation (with associated alteration halos) and the complete replacement of olivine phenocrysts. An almost complete section through a single pillow was recovered in one 45-cm-long interval of essentially continuous core.

Several pieces of basalt-hyaloclastite breccia were recovered and defined as subunits. These thin breccias (< 1 m of recovered core) are composed of clasts of basalt that are similar to the underlying basalts, some with glassy margins. Given the low recovery of these intervals, and the dedicated use of most of the recovered rock for microbiological analysis, it is not possible to determine the relationship between the hyaloclastite portions and underlying lavas, specifically whether or not they are part of the same cooling unit.

Massive basalts consist of continuous sections of up to 4.5 m of similar lithology, which increases in grain size towards the center of the flows. Some massive flows have upper and/or lower planar glassy chilled margins. High recovery, up to 100% in one case, allows individual lava flows or cooling units to be distinguished. Mineralogically the massive lavas are very similar to the sparsely phyric pillow basalts, containing plagioclase, olivine and clinopyroxene as phenocryst as well as groundmass phases. The massive basalts are sparsely to highly vesicular, with an average of 1-5% round gas vesicles, up to 3 mm in diameter. The vesicles are generally concentrated in the upper portions of the flows, but one unit has a distinct 20-cm-wide vesicular band in its center, which is 15% vesicles. The massive flows are slightly to moderately altered and exhibit similar alteration styles to the pillow basalts; vesicle fill, vein formation (and the development of associated alteration halos) and the complete replacement of olivine phenocrysts. However, the massive basalts contain fewer fractures and veins than the pillow basalts, allowing better core recovery and the retrieval of individual pieces up to 94 cm long.

Geochemical analysis of basalt samples indicates that they are normal depleted mid-ocean ridge basalt (MORB). The consistency of cross plots such as TiO_2 versus Zr suggests that all the basalt recovered from Hole 1301B came from the same magmatic source. All of the basement rocks recovered from Hole 1301B have undergone alteration. Most pieces are slightly to moderately altered, with secondary minerals (1) lining or filling vesicles and cavities, (2) filling fractures and veins, (3) replacing phenocrysts, and (4) replacing interstitial mesostasis and glass. Thin section observations indicate that the degree of alteration varies from ~ 5 to 25%, excluding the hyaloclastite breccia which is ~ 60% altered. The freshest rocks are the interior, dark gray cores of most pieces, which have a saponitic background alteration. Fresh olivine occurs only as microphenocrysts in some glass margins, and elsewhere is completely replaced. Clay minerals are the most abundant secondary minerals, and are the principal constituent of all four styles of alteration (vesicle fill, vein fill, phenocrysts replacement, background mesostasis alteration). Saponite is the most abundant of the clay minerals, identified in every thin section. It occurs as cryptocrystalline granular or fibrous aggregates and varies in color from black to dark greenish brown to pale blue in hand specimen and tan brown to olive green in thin section. Saponite lines or fills vesicles, is the most common olivine phenocryst replacement, occurs in mono- and poly- minerallic veins, replaces mesostasis and glassy margins and forms the matrix of the hyaloclastite breccia.

Celadonite, bright blue-green in hand specimen and bright green in thin section, also fills vesicles and veins and replaces olivine phenocrysts and mesostasis. However, celadonite is typically restricted to the alteration halos, frequently occurring as intergrowths with saponite and/or iron oxyhydroxide. Iddingsite, a mixture of clay minerals and iron oxyhydroxide, is the second most abundant alteration product identified in Hole 1301B cores, producing a characteristic red-orange or reddish brown color in both hand specimen and thin section. It fills veins and vesicles, stains primary minerals, and is intergrown with the clays that replace olivine. Calcium carbonate was observed in only six cores, filling vesicles and veins, and as a minor component of the basalt-hyaloclastite breccia matrix. Secondary pyrite was observed lining vesicles, as fine grains within saponite vesicle linings, with saponite ± calcium carbonate in veins, and as disseminate fronts bounding some alteration halo. Zeolites (analcime and phillipsite) were tentatively identified in several basalt samples in veins as well as the matrix of the hyaloclastite breccia.

A total of 2301 veins were identified in the core recovered from Hole 1301B, with an average frequency of 31 veins/m of recovered core. Saponite is the most abundant vein-filling mineral, present in 98% of the veins. Iron oxyhydroxide was documented in 1010 veins, whereas celadonite was identified in only 93 veins, typically occurring with iron oxyhydroxide ± saponite. Pyrite was observed in 59 veins, and is typically associated with saponite. Calcium carbonate was observed in 38 veins, with saponite ± pyrite. Clay bearing veins are ubiquitous in the rocks recovered from Hole 1301B and vary in width from 10μm to 6 mm, averaging 0.2 mm. The maximum width of the simple dark green saponite veins is 2 mm. These predominantly narrow veins are prolific in pillow fragments, with saponite filling many of the radial cooling cracks along pillow margins. Iron oxy-hydroxide and celadonite bearing clay veins vary in width from 10μm to 6 mm, and average 0.2 mm. They are most common in the pillow lavas, but the most spectacular iron oxy-hydroxide bearing vein occurs in a massive lava flow and is 6 mm wide with a 10–25 mm wide alteration halo. Goethite and minor celadonite were identified within this vein by X-ray diffraction.

The dips of 647 veins and fractures were measured in the recovered cores from Hole 1301B. Four types of fractures were distinguished in the cores; (1) veins flanked by alteration halos, (2) veins not flanked by alteration halos, (3) calcite filled shear-veins with slicken fibers (micro-faults with contemporaneous displacement and secondary mineral growth) and (4) microveins (< 0.05 mm wide), identified in thin sections. Haloed veins were the most frequently observed structures, typically 3–10 mm wide and predominantly black to dark green, depending on the secondary clay alteration assemblage present. Non-haloed veins were identified in the massive lavas and some pillow lava pieces. Calcite filled shear-veins or faults were identified in three of the recovered pieces. These steeply-dipping structures have calcite slickenfibers or overlapping fibers. The fibers define a steeply plunging lineation with asymmetrical calcite crystals indicating dip-slip motion. This extensional style of deformation may relate to regional normal faulting. Interestingly, a compilation of dip angles shows that rocks recovered from Hole 1301B have dominantly high-angle fracture dips, despite the expected bias towards sampling of low-angle features by coring a vertical hole.

Paleomagnetic measurements of basement rocks from Hole 1301B were made on 158 discrete samples. Characteristic remanent magnetization directions from the samples thought to be most reliable are highly scattered when plotted versus depth in the hole. The mean inclination within the upper 100 m of the cored interval is 50-60°, somewhat shallower than that expected based on the current (and past) latitude of the site, and data from the lowest 150 m of the hole show a more complex pattern. There is more variability in apparent inclinations, and some intervals include dominantly negative inclinations. Given the known basement age, it seems unlikely that these rocks cooled from magma during a period of dominantly-reversed magnetic polarity. There could have been short periods of magnetic reversal within dominantly positive magnetic polarity, but the samples yielding negative inclinations are often closely associated with other samples that yielded positive inclination.

Two other explanations are self-reversal or remagnetization. Reversed magnetization could occur if alteration and magnetic mineral replacement occurs during a period of time with an opposite magnetic polarity. This seems the most likely explanation for negative inclinations in some Hole 1301B samples because geologic observations indicate pervasive hydrothermal alteration, and because shipboard paleomagnetic studies point to multiple magnetization components as well as the occurrence of pyrrhotite in some samples. Pyrrhotite is a mineral that is a common byproduct of the dissolution of magnetic minerals, such as magnetite, and the conversion of the iron into iron sulfide minerals. If this interpretation is correct, then the negative inclinations may correspond to zones where greater alteration has occurred.

Of 69.1 m of hard rock core recovered in Hole 1301B, 9% was taken as whole round samples on the catwalk and dedicated to microbiological analyses. Shipboard scientists attempted to make total cell counts in samples fixed in ethanol and containing small pieces of basalt and basalt that had been crushed to powder. However, the material showed a high amount of cell-like structures (small crystals and needles) with strong fluorescent signals. Even after testing a variety of dilutions that had been filtered and stained, it was impossible to distinguish cells from other particulate matter.

PFT analyses were completed to evaluate potential for microbiological contamination and the efficacy of cleaning and heating techniques for removing PFT. PFT removal by flame-heating and washing was highly effective for sample exteriors, and little or no PFT was detected in solid rock interiors.

We inoculated approximately 300 rock and rock-powder samples in test tubes in 12 different growth media at five different temperatures (20ºC-85ºC). After two weeks of incubation, we observed cell growth in less than 10% of total cultures. We obtained cells that could grow at near in-situ temperature, potentially suggesting successful enrichment of indigenous microbes from the warm, shallow basalt aquifer. Microscopic observations of DAPI-stained cells revealed coccoid-shaped cells attached to iron sulfide particles. These particles were part of the growth medium. Curiously, in these enrichments no cells were found in association with basalt particles. Considering the chemical composition of the growth medium, these microorganisms probably grow with the provided substrates as carbon sources, and ferrous iron as an electron donor. In other enrichments at room temperature, we found anaerobic mesophilic microbes, likely to be fermenters and/or heterotrophic sulfate-reducers. There are three conceivable explanations for the retrieval of mesophilic strains: microbes might be derived from sediment above basement, contaminants imported by drilling fluid, or relicts transferred to the basaltic oceanic crust by hydrothermal circulation. Further physiological and phylogenetic characterizations of retrieved microbes will be performed as part of shorebased studies.

Parts of whole-round basalt cores were run through the MST prior to splitting. Magnetic susceptibility ranged from 0 to ~4000 $\times 10^{-6}$ SI, with the highest values corresponding to massive lava flows. Other lithologies (pillow lava and hyaloclastite) generally yielded much lower values.

Sixty-eight basalt samples were tested for thermal conductivity, yielding values of 1.17–1.84 W/m•K, with an average of 1.70 ±0.10 W/m•K over the depth range of 351.2–576.3 mbsf. There is no statistically-significant change in thermal conductivity with depth. Values >1.75 W/m•K consistently came from large massive samples (> 6 cm in length), recovered in either massive flows or pillow basalts. The lowest values of 1.17 and 1.37 W/m•K correspond to the two hyaloclastite samples, suggesting that recovery and sampling biases towards unfractured basalt skew the data toward higher values, and likely provide an upper bound on the effective thermal conductivity of uppermost basement in this region.

P-wave velocities were measured on 106 discrete samples, yielding values of 3.9 to 5.8 km/s, with an average of 5.1 ± 0.3 km/s. This average value is greater than that estimated at a regional scale based on seismic reflection data, but is consistent with shipboard values from Leg 168. This value is also slightly greater than the 5.0 km/s interval velocity determined for 110-160 msb determined by the VSP experiment. The lowest velocity was measured on a highly-vesicular sample recovered from within a massive flow unit. Additional samples recovered from the same lithological unit include velocities as great as ~5500 m/s, demonstrating the extent of small-scale heterogeneity. There is no statistically-significant overall velocity trend with depth, although P-wave velocity may be reduced locally by alteration and fracturing.

Index properties were determined on 83 discrete samples from Hole 1301B. Bulk density values were 1.86–3.03 g/cm^3, with an average of 2.75 ± 0.13 g/cm^3. Grain density exhibited a range of 2.23–3.11 g/cm^3, with an mean of 2.86 ± 0.09 g/cm^3. The lowest values of both grain and bulk density were made in a highly brecciated hyaloclastite sample, whereas the highest densities come from the boundary between massive and pillow basalt. Porosity values span the range of 1.9–30.3%, with a mean of 5.8 ± 3.5%. Grain density variability decreases with decreasing porosity, as seen in previous studies of upper basement rocks. Similarly, seismic velocity and porosity are inversely correlated, and velocity displays a weak positive correlation with grain density.

Four wireline logging strings were run in Hole 1301B to characterize formation properties at a scale intermediate between hand samples and regional seismic data. The triple-combo string (natural gamma ray, lithodensity, porosity, spontaneous potential) penetrated essentially to TD, yielding excellent data over most of the open hole (350-580 mbsf, 100-320 msb). Unfortunately, subsequent logging strings (formation microscanner, sonic, borehole televiewer, vertical seismic profile) could not penetrate across an obstruction at 410 mbsf (150 msb), limiting data collection to the uppermost part of the cored intereval. Data were also collected through casing, but data from this interval are highly attenuated.

Much of the upper 100 m of open hole is washed out, with the caliper logs open to full scale near 400 mbsf (Figure 9). The lower 120 m of the hole is almost entirely in gauge, being only slightly larger in diameter than the 9-7/8" coring bit. Formation bulk density varies from 1.5 to nearly 3.0 g/cm^3, but the lowest apparent values were measured in washed out zones and should be used cautiously. In the deeper part of Hole 1301B, variations in bulk density are consistent with observations from numerous other basement holes, and with physical properties measurements. There are thin (meter-scale) intervals of lower density separated by thicker (~10-m scale) intervals of higher density, interpreted to comprise more fractured and massive rock, respectively. Near-hole formation resistivity generally increases with depth in the hole, particularly below the upper 100 m. The spontaneous potential log shows several regions where the curve deflects to the higher values, but it is difficult to interpret these signals hydrogeologically because the logs were collected so soon after drilling, while the formation is still thermally disturbed. Collectively, logging data from the triple combo tool string help to define two main regions in basement. The uppermost 100 m of open hole are enlarged, have highly-variable bulk density, and very low electrical resistivity. The lower 120 m of open hole has a diameter close to that of the coring bit, less variable bulk density, and higher electrical resistivity. The boundary between these two zones, at ~460 mbsf (210 msb) is an important one for subsequent packer testing and CORK monitoring, as described later (Figure 9).

P-wave velocities determined with the sonic log in the upper 80 m of open basement are generally in the range of 4-6 km/s, and are broadly consistent with physical properties measurements. A vertical seismic profile run over a depth range of ~360-420 mbsf (100-160 msb) indicates an interval velocity in upper basement of 5.0 km/s.

Unfortunately, no data is available at present from the borehole imaging tools (formation microscanner, borehole televiewer). There are apparently problems with the new wireline heave compensator and/or the acceleration module used with the tools; hopefully, post-cruise processing will allow useful images to be generated.

Drill string packer experiments were conducted in Holes 1301A and 1301B to assess hydrogeologic properties near the boreholes. We originally intended to run the packer in “straddle mode” in Hole 1301B, to assess permeabilities within one or more narrow zones, but because of difficulties encountered in passing a gap in the 10-3/4” casing, we elected to run the packer only in single-element mode.

Inflation of the packer within the open-hole section of Hole 1301A was precluded by poor hole conditions and the large diameter of the hole, which was drilled with a 14-3/4” bit. The packer was positioned at 267 mbsf, 10 m above the casing shoe. A depth check before testing found an obstruction at 34 msb, compared to total drilled depth of 107.5 msb. We assume that the obstruction was incomplete and that the hydraulically tested interval comprises the 92.6 m section between casing and total drilled depth. After packer inflation, we recorded sealed-hole pressure, then ran a series of five constant-rate injection tests at 15-100 strokes/min (spm). Following each period of injection, the pressure recovery was monitored for a period of the same duration as the respective pumping time.

Pressure records recovered from downhole gauges after these tests will require considerable processing in order to determine formation properties because of the confounding influence of pressure changes induced through density differences between cold ocean water and warm formation fluids, and of formation recovery from the disturbance due to drilling. However, a crude estimate of apparent formation permeability suggests a value on the order of 10^{-11} to 10^{-10} m^2, considerably greater than determine by packer or flow testing within the upper part of basement in Hole 1026B.

A longer series of packer tests were conducted in Hole 1301B, with the packer set at three depths in open hole. The three packer seats were at 472 mbsf (207 msb), 442 mbsf (177 msb), and 417 mbsf (152 msb). These test depths allow us to assess bulk hydrogeologic properties within the lower formation around Hole 1301B, and (by difference) conditions within the upper part of the hole. Packer inflation in open hole also allowed us to test potential CORK packer seats. After setting the packer at each seat, we conducted 2-3 injection tests at pumping rates of 11-30 spm. As with data from Hole 1301A, considerable effort will be required to separate the influence of pressure differences associated with formation recovery from drilling and pumping of cold ocean water during the tests themselves. Nevertheless, a crude estimate of near-borehole formation permeability suggests values on the order of 10^{-11} m^2, possibly with lower values in the deeper part of the hole.

A CORK system was installed in Hole 1301A to monitored a single depth interval including as much as 92 m of open hole. The large diameter of the borehole (14-3/4”) precluded setting a CORK packer in open hole, so the packer was set near the bottom of the 10-3/4” casing. Slotted 4-1/2” casing was extended below the packer element to protect the Osmosamplers and temperature loggers.

The CORK in Hole 1301A used an umbilical comprising a single 1/2” packer inflation line, six 1/4” pressure-monitoring and sampling lines, and one 1/8” sampling line. The 1/4” and 1/8” lines were run through the packer and ended in small wire-wrapped screens. Four of the screens attached to 1/4” lines were attached to the 4-1/2” casing just below the packer element, and the remaining screens and lines were terminated roughly in the middle of the 4-1/2” slotted casing. As with the Hole 1026B CORK, the pass-through across the 10-3/4” casing seal that was not plumbed to a formation sampling or monitoring line was connected to a three-way valve and manifold for future installation of pressure-monitoring instrumentation at the well head. This plumbing will allow monitoring of fluid pressure below the casing seal and above the packer element, to evaluate system integrity. An Osmosampler was attached to one of the fluid-sampling manifolds at the well head for short-term collection of fluids during the initial few weeks of CORK equilibration.

The Hole 1301A instrument string includes four Osmosampler packages. The uppermost Osmosampler contains a copper coil for gas sampling. The next Osmosampler contains microbiological incubation substrate. The third Osmosampler has Teflon tubing for fluid sampling and rare-earth tracer injection. The final Osmosampler includes a module for acid injection into the sampling line, to prevent precipitation of metal compounds. There is a single, self-contained temperature logger in each of the Osmosamplers (3.7 m apart), and two additional temperature instruments were installed 2.5 m and 7.5 m above the bottom plug. Thus temperature monitoring in Hole 1301A extends across approximately 24.2 m of upper basement.

The CORK borehole observatory installed in Hole 1301B includes monitoring of three intervals. We initially attempted to set a CORK system in Hole 1301B with three casing packers, all set in open hole, but this system was seriously damaged during deployment and we had to modify its design. The final Hole 1301B CORK system included two casing packers set in open hole. The lowermost packer element isolates the deepest ~120 m of the hole, whereas this and the shallowest packer isolate a 42-m-thick interval above. A third monitored interval includes uppermost basement and the 10-3/4” casing string below the cone, but includes only pressure and temperature monitoring. It should be possible to assess the quality of the hydrogeologic seal at the seafloor using the pressure monitoring line and valve into this interval.

The Hole 1301B CORK system used an umbilical containing nine separate lines: a single 1/2” packer inflation line, four 1/4” pressure-monitoring and sampling lines, and four 1/8” sampling lines. There was a separate 1/2” Tefzel (Teflon variant) microbiological sampling line run to the deepest monitored zone. Four small intake screens were deployed below each of the packer elements. The bottom of the CORK installation included 35 m of drill collars and cross-overs below the lower packer, comprising ~10,000 lbs of metal. This configuration was selected to provide enough weight to pull the long CORK casing string into the hole. Sampling and monitoring valves at the well head were left open on deployments, and three Osmosamplers were attached to the fluid-sampling manifolds for short-term collection of fluids during the initial few weeks of CORK equilibration. Two of these will be recovered during the first visit to the CORK by ROV, whereas the third will be left installed for the first year of reequilibration. This Osmosampler will be recovered when two new instruments are installed by submersible during Summer 2005.

The downhole sensor and sampling string in Hole 1301B included 14 autonomous temperature loggers, six Osmosamplers packages, and three microbiological incubation packages. Temperature monitoring extends from about 1 m below top of basement to 263 m into basement, with typical sensor spacing of ~20-25 m. All of the downhole Osmosamplers and incubators have their intake lines extending beyond the bottom of the CORK casing system, in open hole. The uppermost Osmosampler contains a copper coil for gas sampling. The next Osmosampler contains microbiological incubation substrate and flow cell. The third Osmosampler has Teflon tubing for fluid sampling and additional incubation substrate. The fourth Osmosampler includes a module for acid injection into the sampling line, to prevent precipitation of metal compounds. The fifth Osmosampler will inject rare-earth element tracers, and the final Osmosampler module is configured for acid addition.

After deployment of the submersible/ROV platform, we “reentered” the cone through a hole in the landing platform and pumped a plug of bentonite followed immediately by cement, in an effort to seal the annulus between 10-3/4” and 16” casing strings. Final operations around Hole 1301B included fishing one remaining piece of CORK casing from the initial deployment that was sticking vertically from the seafloor and might have been a hazard to submersible and ROV operations. We conducted a camera survey of the area around Holes 1301A and 1301B, and found no other items on the seafloor that might pose a hazard for future operations at the site.