Leg 139

Drilling Quenches Hot Rocks of the Northern Juan de Fuca Ridge

September 1991 COLLEGE STATION, TX -- Leg 139 of the Ocean Drilling Program ended in Victoria, British Columbia on September 11 after two months of drilling in Middle Valley, a sediment-filled rift of the Juan de Fuca Ridge. Leg 139 was the first of several legs planned that will drill into young oceanic crust along axes of seafloor spreading, to study active processes of crustal formation, hydrothermal circulation, and ore deposition. These legs will be technically challenging, because of the highly fractured nature of young igneous rock, and because of the high formation temperatures and corrosive fluids that are bound to be encountered. Planned operations include extensive coring, downhole measurements, and the emplacement of long-term observatories; despite potential difficulties, Leg 139 realized a remarkably high degree of technical and scientific success.

Middle Valley was chosen as one of these drilling targets because it is an active spreading center with a well-developed hydrothermal system. The valley includes sites of active venting, at temperatures up to 286 °C, and polymetallic mineral sulfide deposits. Although somewhat unusual, Middle Valley and other sediment-covered spreading centers provide excellent targets for studying seafloor hydrothermal circulation. Continuous, relatively impermeable sediment cover acts as both a thermal blanket and a hydraulic seal, limiting recharge and discharge, and causing the basaltic crust beneath it to heat up at shallow levels. Where fluid does discharge, large mineral deposits can be produced. In addition, the thick sediment cover in these settings permits drillholes to be established with relative ease.

Drilling in Middle Valley was designed to investigate four distinct parts of an active submarine hydrothermal system. One site was devoted to each: a recharge zone, a large polymetallic massive sulfide deposit, a hydrothermal "reservoir", and an active discharge zone. All sites are located in the eastern part of the valley, over crust estimated to range from 250 to 400 ky old.

The recharge zone is situated along the westward-dipping normal fault that defines the eastern edge of the valley, where heat flow is relatively low, about 0.4 W/m2. Four holes were drilled into the hanging-wall block of the fault. All four intersected basaltic basement, two in the foot-wall block and two in the hanging-wall block, at depths ranging from 45 to 108 m below the seafloor. These holes define the overall dip on the fault as about 45°, and indicate that basement probably outcrops along the base of the fault scarp. In each hole, the composition of sediment pore water changes with depth as a result of reaction with the sediment, but then returns to the composition of bottom seawater as igneous basement is approached. This observation suggests that seawater is being drawn down into basement at a significant rate along the rift-bounding fault.

The massive sulfide deposit chosen to be drilled during Leg 139 is situated next to a small circular hill of uplifted sediment that is underlain by a bright seismic reflector. Such hills are common in sedimented rifts and are often associated with sulfide mineralization. Several hundred m to the south of the deposit and the hill is a small vent field, where clear water discharges at 265 °C from a small mound of sulfide rubble. Six holes were drilled into the massive sulfide deposit, and two into the nearby hill. The holes drilled into the deposit revealed that it is at least 60 m wide at the seafloor and more than 95 m thick, thicker than we were able to penetrate with the drill. Although core recovery averaged only 28% of the 159 m of massive sulfide penetrated by the two deepest holes, electrical resistivity, natural gamma-ray, and geochemical logs confirmed that the deposit is virtually pure massive sulfide, with no sedimentary or igneous rock interlayers. The sulfide apparently formed by precipitation at the seafloor rather than by infiltration and replacement of detrital sediment, and it formed rapidly and without significant interruption. The massive sulfide recovered is dense and consists mainly of pyrite and pyrrhotite, with subordinate chalcopyrite and sphalerite. Stratigraphic relationships strongly suggest that this large deposit formed well before the uplift of the nearby hill, which probably occurred during the Holocene. Drilling into the hill showed that it is constructed of sediment uplifted by a small intra-sedimentary intrusion of a primitive, picritic magma. This magma probably ascended directly from the mantle, without residing in a shallow-level magma chamber, and hence could not have provided sufficient energy to drive the hydrothermal system that formed the massive sulfide deposit. The genetic relationship between the sulfide deposit and the nearby hill is unclear.

The hydrothermal reservoir and discharge sites are located closer to the axis of the valley, about 6 km west of the fault scarp along which the recharge site is located. Both sites are situated within a heat flow anomaly that is 15 km long, parallel to the spreading axis, and 1 km wide. Heat flow within this anomaly exceeds 0.8 W/m2 and is greater than 20 W/m2 in isolated locations. At the reservoir site, about 500 m of turbidites overly a sequence of interbedded turbidites and diabasic sills which continue at least to 936 m below the seafloor at the bottom of the deepest hole. While we failed to reach pure igneous "basement", we did reach a hydrothermal "reservoir" as defined by the alteration of the rock and the extremely high permeability measured within the sill complex. The combination of high permeability and the large differential pressure between the cold-hole and warm-formation hydrostats stimulated downhole flow at a rate of over 10,000 1/min.

Fluid flow at this location is not restricted to basement; significant lateral fluid flow is indicated chemically within the sediment section. Within one interval centered at 300 m below the seafloor, the chemistry of pore waters indicates considerable flow between the reservoir site and the discharge zone nearly 2 km away. Metasomatic sodium enrichment in the solid fraction of the sediment is observed in the same interval, indicating that the flux has been relatively long-lived.

The discharge zone is delineated by an area of high backscatter in side scan sonar images. This area is about 800 m long parallel to the spreading axis and 400 m wide, and contains numerous active vents. Six holes were drilled within and near this vent field, at distances ranging from 5 to 150 m away from active high-temperature vents. The discharge zone appears to be localized above a small basement high that was intersected while drilling the two deepest holes at this site at 258 m beneath the seafloor; we penetrated 175 m of this basement and recovered only hydrothermally altered basalt flows. These holes reveal that hot water is flowing laterally within the upper few meters to tens of meters of sediment. Temperature measurements in two holes outside the vent field indicate that heat flow is dominated by conduction rather than advection only 70 m distant from active high-temperature vents. Within the discharge zone temperatures climb conductively to over 200 °C at only 20 m below the seafloor, where a carbonate-cemented cap was encountered. Below this cap temperatures appear to be nearly isothermal with depth.

The deepest hole at this site penetrated 175 m into the buried basement edifice, and yielded hydrothermally altered extrusive basalts. As at Site 857, high permeability and downhole flow were observed, confirming that a hydrothermal "reservoir" had again been reached. Hydrologic seals were installed in the deep reentry holes at both the reservoir and discharge sites to stop the flow of water into basement. The seals are instrumented to monitor formation temperatures and pressures for up to two years as the disturbance due to drilling diminishes. A brief visit to these long term observatories in late September 1991 by submersible allowed preliminary data to be collected and demonstrated that the instruments are functioning properly.

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