BOREHOLE OBSERVATORIES MONITOR ACTIVE HYDROLOGY BENEATH THE SEAFLOOR

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A wide range of fundamental geological problems, such as the exchange of mass and heat between Earth's lithosphere and hydrosphere, the origin of valuable metal ore bodies, and even earthquake activity associated with deep-sea trenches, are linked to a common process — the widespread circulation of fluids beneath the seafloor, through oceanic sediments and underlying crust. Near mid-ocean spreading centers, such circulation is driven by thermal energy released by the formation of oceanic crust from magma, and is therefore termed "hydrothermal circulation." Near subduction zones, subsurface fluid flow is largely driven by compressional forces as plates converge, and the circulating fluids are generally lower in temperature than hydrothermal fluids.

Hydrothermal circulation at the crests and flanks of the mid-ocean ridges results in water-rock chemical exchanges that alter the original compositions of both the igneous oceanic crust and the circulating fluids and modulate the chemistry of the oceans. Hydrothermal vents, both at most ridge crests and at cooler seeps at subduction zones, support unique chemosynthetic biological communities on and beneath the seafloor, completely independent from photosynthesis. Therefore, it has been hypothesized that ancient hydrothermal systems may have been associated with the origins of life on Earth, and recent indications of hydrothermal sites elsewhere in the solar system are generating considerable excitement about the possible existence of primitive extraterrestrial life.

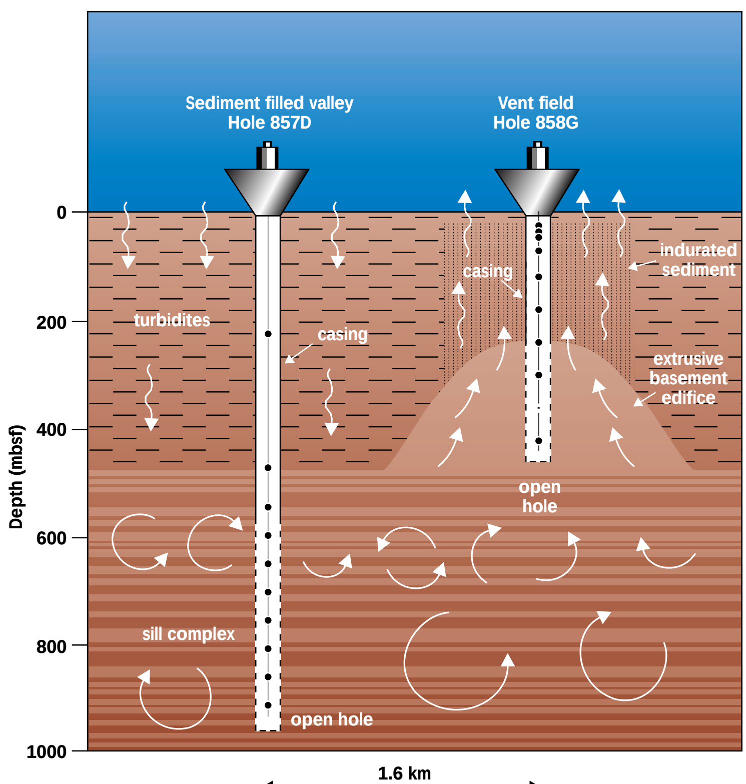

Figure 1: Configuration of the two Middle Valley CORKs, first deployed in 1991, as refurbished in 1996. Lines and dots down the centers of the holes represent thermistor cables and positions.

Present scientific understanding of hydrothermal circulation is largely inferred from the chemistry of fluids exiting the seafloor and from the patterns revealed by heat-flow measurements made just below the seafloor. ODP drilling now provides an innovative means of studying fluid circulation deep beneath the seafloor, by emplacing long-term sensors directly within the formation where circulation occurs. The ODP drilling process uses surface seawater to flush cuttings from the hole, and therefore often disturbs the very hydrothermal system we seek to study. These drilling disturbances make it difficult to conduct meaningful hydrological measurements or to sample pristine, *in situ* fluids from holes that are left open. To overcome this problem, ODP engineers and scientists have developed specialized borehole seals that prevent the flow of water into or out of selected ODP holes after they are drilled, and simultaneously allow emplacement of instruments for long-term use in the sealed holes [*Davis et al.*, 1992; *Davis and Becker,* 1993]. Once these holes are sealed, the hydrological conditions in the rock formation slowly return to the natural state that existed prior to drilling, and the instruments monitor the recovery to true *in situ* conditions as well as any natural hydrologic events that may also occur. Several sites on ridge crests and flanks and in subduction settings have now been instrumented using these so-called "CORK" (Circulation Obviation Retrofit Kit) experiments; ODP installs the instruments, and the data are recovered months to years later from manned or unmanned submersibles.

On the ridge flanks and crests, heat flow surveys dating back to the 1970's clearly demonstrated that hydrothermal systems can extend over large areas — 10's or even 100's of kms. However, we understand little about the subsurface workings of such systems, and this is one of the key objectives of the CORK experiments. A good example is provided by the first two CORKs, which were installed in a sediment-covered spreading center in the Pacific northwest (Figure 1) [*Davis and Becker,* 1994]. One of these CORKs is located in the midst of a hydrothermal-vent field

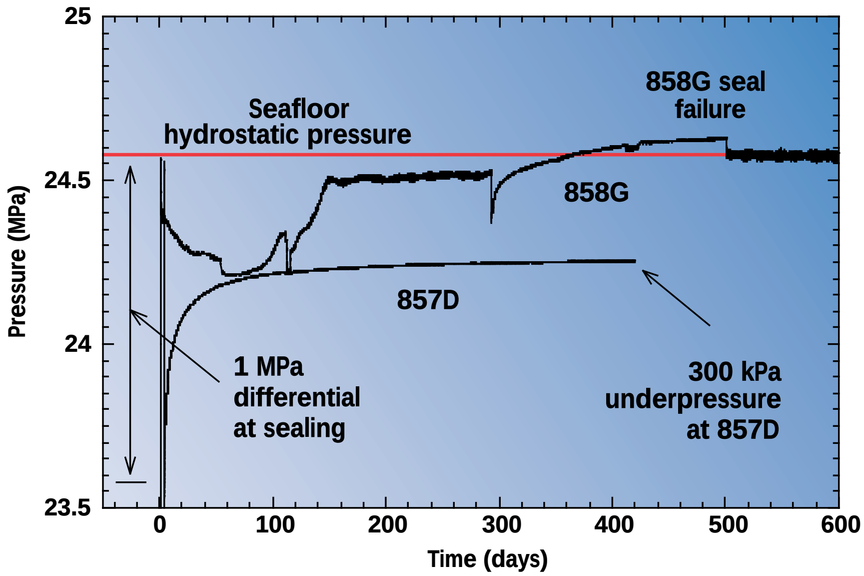

Figure 2: 1991-1993 long-term pressure records from the Middle Valley CORKs.

The most surprising and fundamental result of these observations is the large difference in equilibrium pressures at the two sites. Before the seal failed, the pressure in Hole 858G had become greater than hydrostatic conditions, and was continuing to rise towards a value of about 0.1 MPa above a hydrostatic reference consistent with the local geothermal gradient. This is equivalent to about one bar and represents the excess fluid pressure available to drive water out of the formation at the vent field. In contrast, the long-term record at Hole 857D recovered to about 0.3 MPa below local hydrostatic conditions. This strong "underpressure" indicates that seawater must be slowly percolating down through the sedimentary column to replenish fluids circulating in the subsurface hydrothermal system, possibly linked directly to the vent field near the other hole.

where fluids at temperatures of 260-270°C are expelled. Here, ODP Hole 858G was drilled through hardened sediments into an underlying volcanic edifice, which is thought to act like a permeable "chimney" in focusing the subsurface hydrothermal flow to produce the seafloor vents. Over a kilometer to the south, well away from the vent field, Hole 857D was drilled into highly permeable rocks that may serve as one of the sources of the fluids that vent near Hole 858G.

The data from these two CORKs show surprisingly different trends over time (Figure 2). In both holes, the earliest segments of the borehole pressure records show brief excursions toward extremely low values, caused by the invasion of cold and dense seawater during drilling. In the months that followed, the Hole 857D record shows a smooth recovery towards *in situ* pressures as the formation recovered from the cooling artifact of drilling. In contrast, the time series of pressure data from Hole 858G in the vent field shows several discrete events, including sudden offsets and distinct changes in trends. Some of these may be associated with natural activity in the vent field, while others were probably linked to hydrologic disturbances via a nearby exploratory drill hole that was inadequately backfilled with cement. A thermally induced failure of the CORK seals caused the event about 500 days after CORK deployment. When the seals failed, fluid pressures dropped suddenly to that of the column of seawater at the site ("seafloor hydrostatic pressure") and a full-amplitude tidal signal was observed.

Models using the constraints provided by the CORK data provide one way to quantitatively estimate the extent to which the formation is hydrologically connected. A more direct experiment was conducted when the two drill holes were re-instrumented in 1996 during ODP Leg 169. At that time, a unique cross-hole experiment was carried out to provide an independent estimate of the formation-scale permeability and hydrological connectivity between the holes. (Data from this experiment is scheduled to be recovered in September, 1997, using the remotely operated vehicle, *JASON*.) The high permeability inferred at this site, as well as at other sites instrumented during Leg 168 on the eastern Juan de Fuca ridge flank, suggest that fluids may move through the upper igneous crust at average rates of tens of meters per year, and carry heat and solutes laterally over distances of many tens of kilometers with great efficiency. If this is so, the oceanic crust may be one of the most hydrologically active formations on Earth.

References:

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