Leg 169 drills a major sulfide deposit on a sediment-buried spreading center

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ODP Leg 169 was the second ODP leg designed to investigate the genesis and evolution of Fe-Cu-Zn deposits formed at sediment-covered spreading centers, with the ultimate goal of quantifying the transfer of mass and energy during hydrothermal circulation. This Leg built on results from drilling at Middle Valley on the Juan de Fuca Ridge during Leg 139 [*Davis et al.,* 1992] with additional drilling in this area, and also investigated hydrothermal sites at Escanaba Through on the Southern Escanaba Ridge.

The Bent Hill Massive Sulfide (BHMS) in Middle Valley comprises three major mineralized parts (Figure 1). The uppermost zone consists of a 100 m thick conical mound of massive sulfide formed at the seafloor and subsequently buried by sediment. Underlying this is a 100 m thick feeder zone consisting of subvertical crosscutting veins filled with Cu-Fe sulfide and pyrrhotite (Figure 2). The intensity of veining decreases with depth and the style of mineralization changes to predominantly subhorizontal impregnation and replacement of sediment. At the base of the feeder zone there is a 4 m thick strongly silicified horizon underlain by a 13 m thick zone of intense alteration and replacement of the host sandstones by Cu-Fe sulfides and chlorite (Deep Copper Zone). This zone of high grade (up to 16% Cu) stratiform copper mineralization may represent a zone where hydrothermal fluid flowed laterally into a permeable sedimentary horizon during stages of the development of the deposit when the pathways to the seafloor, represented by the feeder zone mineralization, were sealed. This zone is capped and isolated by an impermeable silicification front that may have formed in response to in situ cooling of the hydrothermal fluid. Pore fluid derived from below this horizon is distinct from that sampled above and has the low chlorinity signal typical of the only vent known in the area prior to Leg 169 indicating that the hydrothermal system underlying the Bent Hill area is separated from the hydrothermal system that delivers higher salinity fluids to the Dead Dog vent field, which is located 3 km to the northwest. Hole 1035F penetrated this horizon and was vigorously venting hydrothermal fluid after the drilling.

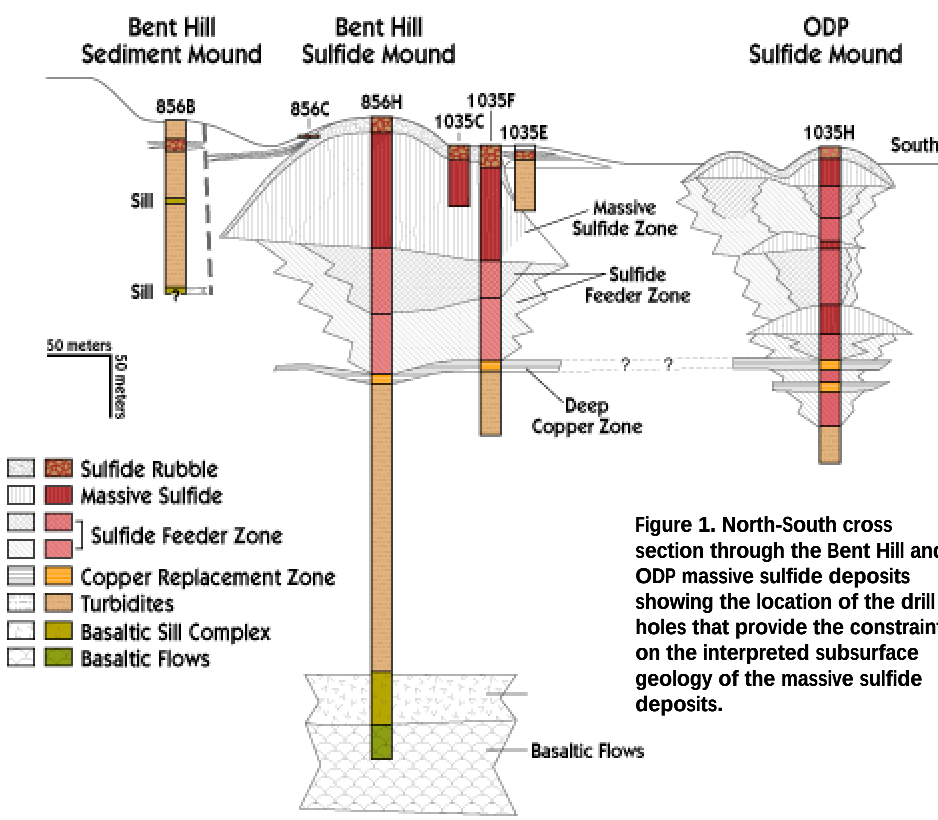

Figure 1. North-South cross section through the Bent Hill and ODP massive sulfide deposits showing the location of the drill holes that provide the constraints on the interpreted subsurface geology of the massive sulfide deposits.

Figure 2. Pyrrhotite-isocubanite-chalcopyrite veins cutting lithified mudstone in the Cu-rich feeder-zone mineralization that immediately underlies the Bent Hill massive sulfide.

The metal zonation observed in ancient massive sulfide deposits is also present in the BHMS. Continued hydrothermal circulation through the massive sulfide after its initial deposition converted much of the primary pyrrhotite to pyrite ± magnetite. In addition, remobilized metals, such as zinc, have been reprecipitated at the top and on the sides of the mound at lower temperatures. Much of the copper transported in the hydrothermal fluid was deposited below the seafloor in the stockwork zone and in the Deep Copper Zone.

A second mound, the Ore Drilling Program (ODP) mound, occurs 350 m south of the BHMS (Figure 1). A single hole was drilled near the top of the mound, 50 meters south of the only known natural active vent. The results were spectacular! Hole 1035H penetrated three stacked zones of massive and semi-massive sulfide along with their feeder zones. Metal grades are much higher than those encountered at BHMS with some samples exceeding 40% Zn and 15% Cu. Most mining geologists will never have the experience of drilling a hole that intersects as much high grade ore as 1038H. However, the true value of this deposit is in the complex record of deposition, recrystallization, and remobilization of metal recorded through the multiple hydrothermal stages that remained focused beneath this mound throughout its history. Although the continuity of mineralization between the ODP mound and BHMS could not be tested, a zone of high-grade stratiform copper mineralization was intersected at approximately the same stratigraphic horizon as the zone under BHMS. Hole 1038H is also now the third known hydrothermal vent in the Bent Hill area. An NSF sponsored "event response" cruise using the R/V *Thompson* and the Canadian ROPOS ROV sampled 272°C hydrothermal fluids from this vent just weeks after its creation [*D.S. Kelley and M.D. Lilley, personal communication*].

Although creating new vents in the Bent Hill area was not a goal of this Leg, conducting active hydrological experiments in the Dead Dog vent field, which is located 4 km to the northwest, was a high priority objective. The existing CORK from Hole 858

G was successfully removed and recovered the first CORK-hosted hydrothermal chimney deposits in the process, and 272°C hydrothermal fluids were sampled from the borehole. The borehole was then reinstrumented with a new temperature string and pressure transducer and a new CORK was installed. The damaged CORK in Hole 857D was recovered and replaced with an 898 m long thermistor string and a new CORK in a technologically difficult operation that was efficiently executed by the ODP engineering group and the SEDCO staff. The recovered CORK data logger contains an important record of the initial recovery of this drill hole from drilling induced disturbance [*E. Davis, personal communication*]. Rapid downflow of cold bottom water in this hole was confirmed, and this may lead to both a pressure pulse that is potentially detectable in Hole 858G, 1.6 km to the north, and to induced seismicity, which may be detected by an array of OBSs deployed prior to drilling by Sparr Webb and colleagues at Scripps Institution of Oceanography. A transect of short holes across the Dead Dog active hydrothermal mound demonstrated that the mound is young and was formed by buildup and collapse of anhydrite chimneys, rather than by subsurface deposition and internal inflation.

A high priority scientific objective was to establish the differences between the mature hydrothermal system developed at Bent Hill in Middle Valley and the young hydrothermal system in Escanaba Trough. These systems differ in more than their state of evolution. Metals in the Middle Valley sulfide deposits seem to be dominantly derived from basaltic rocks, whereas in Escanaba Trough, the composition of the deposits shows extensive contribution of metals from the sediment. Massive sulfide recovered from the Central Hill at Escanaba Through suggests that the thickness of massive sulfide is little different from the amount exposed above the seafloor (5-15m). The absence of a well-developed, veined feeder zone indicates pervasive diffuse venting of hot fluid over a short period of time rather than long-lived, focused high temperature discharge, as was the case at Bent Hill.

A hydrothermal component in the pore fluids from Escanaba Trough indicates that hydrothermal fluid flow was relatively recent. Both low and high salinity fluids are present indicating phase separation, followed by segregation of most of the low salinity fluids in an unconsolidated sand unit in the interval from 70-120 mbsf. Concentrations of alkalis and other elements indicate that the hydrothermal fluids have interacted extensively with sediment, even though most of the recovered sediment is not extensively altered. Organic matter maturation confirms that the sediments have seen at least a brief pulse of high temperature that locally resulted in generation of minor amounts of hydrothermal petroleum.

Documentation of the contrast between the recurrent, highly focused, long-lived hydrothermal activity that formed large massive sulfide deposits at ODP Mound and Bent Hill and the high temperature, pervasive diffuse flow system that resulted in extensive surface mineralization in Escanaba Trough provides important insight into the ore forming process. Discovery of the unexpected high grade copper replacement mineralization (Deep Copper Zone) below the vein controlled feeder zone mineralization may provide new exploration targets for the minerals industry. While this leg was focused on the genesis of metallic mineral deposits, the Leg had considerable success in unraveling the tectonic and sedimentary history of these sediment cover spreading centers. Post cruise research promises to add greatly to our understanding of these systems. The success of Leg 169 is related in large part to the detailed planning and hard work of the group at ODP/TAMU, especially the engineering group, and is yet another example of how the scientific accomplishments of the Ocean Drilling Program are directly relevant to societally important problems such as natural resource availability.

References:
Davis, E.E., M.J. Mottl, A.T. Fisher, et al., *Proc. ODP, Init. Repts.,* 139, 1992.