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Hydrothermal Alteration of Basalts beneath the Bent Hill Massive Sulfide Deposit, Middle Valley, Juan de Fuca Ridge

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Abstract

Burial of midocean ridges by clastic sediments, particularly at continental margins, profoundly affects the geometry and chemistry of hydrothermal circulation and mineralization in the upper crust. Middle Valley, the sediment-covered northern extension of the bare-rock Endeavour segment of the Juan de Fuca Ridge, is host to the base metal-rich (Cu-Zn) Bent Hill massive sulfide deposit. At a water depth of 2,400 m, the ~9 Mt Bent Hill deposit is a steep-sided body ~200 m across and ~100-m-thick. Ocean Drilling Program (ODP) hole 856H penetrates through the massive sulfide and underlying feeder zone extending to a total depth of 500 m below sea floor through the base of the strongly recrystallized (quartz + chlorite) sediment pile and into the uppermost volcanic basement. The basaltic rocks beneath the Bent Hill deposit include narrow sills intruded into indurated sediments, a volcanic flow erupted on top of sediments, and pillow lavas below the lowermost sediments recovered.

Similar styles of alteration are present in both the sills and flows, and alteration is dominated by the effects of large-scale hydrothermal upflow rather than hydrothermal activity associated with individual eruptions or intrusions. The basalts are slightly to completely altered to greenschist facies secondary minerals, principally quartz, chlorite, and titanite, with subsidiary epidote, Cu-Fe sulfides, and rare actinolite. There are steep mineralogical, chemical, and isotopic alteration gradients from the highly altered basalt-sediment interfaces down to the less altered flow interiors, suggesting the channeling of hydrothermal fluids along the basalt-sediment boundaries. Alteration is reflected in intense metasomatic changes in the basalts. Assuming immobile TiO_2, the most intensely altered basalts have undergone about 20 percent mass loss during recrystallization to chlorite-quartz rocks, with depletions in silica, alumina, and alkali, alkali earth, and base metals. Chloritized pillow margins with strongly light rare earth element-enriched chondrite-normalized patterns ($[La/Sm]_N$ = 1.5; cf. fresh basalts, ~0.7), that mimic profiles for midocean ridge hydrothermal fluids, require fluid-rock exchange with large quantities of hydrothermal fluid (W/R ~27,000). Oxygen isotope compositions of chlorite-quartz rocks ($\delta^{18}O$ = 1.8–2.4‰) suggest that alteration occurred between ~320° and 370°C.

Strontium isotope compositions of the altered basalts and the chlorite-quartz rocks are not homogeneous and range from $^{87}Sr/^{86}Sr$ ratio = 0.7037 to 0.7046. There is a strong mode in $^{87}Sr/^{86}Sr$ ratio at ~0.7038, suggesting that much of the alteration occurred by isotopic exchange with a hydrothermal fluid of that composition. This ratio is significantly lower than that measured for 265 °C fluids venting from the nearby ODP mound ($^{87}Sr/^{86}Sr$ = 0.7044). The occurrence of epidote and isocubanite in the chloritized glassy pillow margins suggests that these rocks may retain a record of the high-temperature (>350°C) hydrothermal fluid responsible for the formation of the overlying Bent Hill massive sulfide deposit. The strontium isotope composition of the chloritized glassy pillow margins, and hence the mineralizing fluid, is slightly more radiogenic ($^{87}Sr/^{86}Sr$ = 0.7046). This composition could result from the addition of ~15 percent of a pelagic or sedimentary component to the $^{87}Sr/^{86}Sr$ ratio = 0.7038 fluid responsible for most of the Sr isotope exchange with the upper basement.

The sediments beneath the Bent Hill deposit are also strongly recrystallized to quartz and chlorite. Although their strontium isotope compositions are much lower than those in pelagic or terrigenous sediments in the region ($^{87}Sr/^{86}Sr$ = 0.709–0.720), the range of compositions ($^{87}Sr/^{86}Sr$ = 0.7046–0.7060) has little overlap with that of the altered basalts and chlorite-quartz rocks from the sills and uppermost basement. This lack of overlap suggests that the sediments either retain some of their original sedimentary strontium or that there is a range of fluid compositions in the sediment pile beneath the Bent Hill deposit. Sediments from the margins of Middle Valley, far from zones of active black smoker venting (ODP site 855), have $^{87}Sr/^{86}Sr$ ratios with a significant hydrothermal component (0.7059–0.7086). These ratios indicate that the subsurface hydrology of Middle Valley is dominated by evolved fluids rather than seawater, and that recharge into this system is not through boundary faults or through the sedimentary blanket as suggested by previous models. Rather, exposed basement rocks that form the flanks of Middle Valley are the most likely zones of regional seawater recharge to the deep high-temperature hydrothermal systems.

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