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The Middle Valley Sulfide Deposits, Northern Juan de Fuca Ridge: Radiogenic Isotope Systematics

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Abstract

The Bent Hill and the Ore Drilling Program massive sulfide deposits in Middle Valley, the sediment-filled rift valley at the northern Juan de Fuca Ridge, are among the largest and richest sulfide deposits on the modern sea floor. Drilling during Ocean Drilling Program Leg 169 allowed a complete hydrothermal system to be sampled for the first time. Representative samples from this leg were analyzed for radiogenic isotopes (Sr, Nd, and Pb), with the objectives of determining the sources of metals in the deposits and the nature of fluid circulation and evolution of the hydrothermal systems. Samples were chosen both from the sulfide deposits and host units, the latter including sediments, basaltic flows, and sills. Sr, Nd, and Pb isotope compositions of the basalts and sills below the Bent Hill massive sulfide deposit confirm that both were highly altered by hydrothermal solutions. The data also show that the sills are cogenetic petrologically with the underlying basaltic basement.

Pb isotope compositions of the massive sulfides in both sulfide deposits vary within narrow ranges (i.e., $^{206}Pb/^{204}Pb$ ranges of 18.83–18.89 and 18.77–18.89 for Bent Hill and Ore Drilling Program, respectively), which could reflect remobilization, replacement, and recrystallization of sulfides during formation of the sulfide mounds, but also mixing and homogenization during hydrothermal circulation of fluids below the sea floor. Data for the massive sulfides form elongate clusters between the basalts and the sediment clusters in Pb isotope diagrams. The most simple explanation for these patterns involves the mixing of Pb from a basaltic source ($^{206}Pb/^{204}Pb$ range of 18.64–18.74) with Pb from isotopically heterogeneous sediments comprising a hemipelagic component with relatively higher $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values, and a clastic component (turbidite) with relatively higher $^{206}Pb/^{204}Pb$ values. A third potential source is represented by hydrothermal sulfides present in both the sediments and basalts that have relatively unradiogenic Pb isotope ratios ($^{206}Pb/^{204}Pb$ range of 17.83–18.36), implying an old crustal source, possibly older than 1.5 Ga.

The overlapping Pb isotope compositions of the massive sulfides in the two deposits suggest that the same sources were involved and in similar proportions to form the deposits. Ore Drilling Program massive sulfide is extremely enriched in Zn compared to Bent Hill massive sulfide. If the metal sources are the same for the two deposits, other parameters must have produced the differences between them, such as different fluid chemistry, temperature, or factors at the depositional site. Pb isotope data for sulfides of the Bent Hill massive sulfide feeder zone and the stratiform Deep Copper zone ($^{206}Pb/^{204}Pb$ range of 18.59–18.82) are both much less radiogenic than the massive sulfides and overlap with the field for the underlying basalts. The Pb isotope ratios, a high Cu/Zn ratio, and intense alteration of the basalts strongly suggest that the basalts were the main source for the metals in the Deep Copper zone and related feeder zones, rather than a higher sediment influence in the overlying massive sulfides. This conclusion is also supported by positive correlations between the Pb isotope value and Zn/Cu ratio contents of Pb and Mo.

A silicified zone immediately above the Deep Copper zone may have played a major role in the formation of the deposits by serving as an efficient seal, preventing the deep-seated fluids to escape to the sea floor, as observed even today. When the seal formed, the fluids were forced to circulate in the lower part of the sedimentary sequence and in

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the basalts. The seal would have insulated this hydrothermal system, leading to higher temperatures in the fluids and subsequently to more efficient leaching of metals. This model offers an explanation for differences in the Pb isotope compositions of the massive sulfides and the underlying Deep Copper zone and feeder zones.