Formation and Transformation of Clay Minerals in the Hydrothermal Deposits of Middle Valley, Juan de Fuca Ridge, ODP Leg 169

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Abstract

Mineralogical, chemical, and isotopic characteristics of clays from Ocean Drilling Program (ODP) sites 1035, 856, 1036, and 858, drilled in Middle Valley at the northern end of the Juan de Fuca Ridge during Legs 139 and 169, were studied using X-ray powder diffraction, differential thermal analysis, infrared spectroscopy, scanning electron microscopy, transmission electron microscopy, X-ray fluorescence, and inductively coupled plasma-mass spectrometry. Oxygen isotope measurements on authigenic clay minerals provide a record of mineral formation temperatures. Holes 1036A and 858B are located in the present-day hydrothermally active Area of Active Venting and reflect several stages of hydrothermal alteration. Smectite and some mixed-layer chlorite-smectite clays are the dominant phyllosilicates in the upper part of holes 1036A and 858B. Nearly pure chlorite-smectite mixed-layer clays and corrensite mainly occur more than 20 meters below the seafloor. Formation temperatures of these nearly pure chlorite-smectite mixed-layer clays and corrensite were calculated as 250° to 268°C. In the deepest unit, chlorite is the dominant phyllosilicate coexisting with authigenic quartz. The high-temperature alteration stages resulted in gains (50-85%) of Mg and Zn, an almost complete loss of K, Ca, Cu, Rb, Sr, and Ba (= 90%), and depletion (20-40%) in Si, Fe, Na, and Zr.

Alteration effects in hemipelagic and turbiditic sediments from hole 856H, drilled near the summit of the Bent Hill massive sulfide deposit, are similiar to those of sediments in hole 1035H, which was drilled 350 m south of hole 856H near the southernmost peak of the Ocean Drilling Program mound. At both holes, the clay fraction of the sedimentary sequence between 140 and 470 m below seafloor is composed of varying amounts of authigenic quartz and chlorite indicating high-temperature alteration. The chlorite formation temperatures calculated from oxygen isotope data lie at 290° to 320°C in hole 1035H and 250° to 264°C in hole 856H. Mineralogical data from hole 1035D, drilled 75 m east of hole 856H, and hole 1035A, drilled 77 m west of hole 856H, indicate lower temperatures of hydrothermal alteration in the upper 50 m of their sedimentary sequences. These sequences are partly altered to chlorite-smectite mixed-layer clays coexisting with several detrital minerals and with a dolomite formation temperature of 74°C. Oxygen

isotope evidence indicates authigenic chlorite in the deeper sedimentary section of hole 1035A that formed at relatively low temperatures (180°C), whereas chlorites from hole 1035D formed at higher temperatures (277°-292°C). Chemical changes in the strongly altered clay fractions of hole 856H and 1035D include gains (60-75%) of Fe, Mg, Zn, and Cu, a nearly complete loss (= 95%) of K, Na, Ca, Rb, Sr, and Ba, and a strong depletion (30-70%) in Si, Ti, and Zr. All of the chondrite-normalized rare earth element patterns of chlorite are characterized by negative Eu anomalies and varying levels of light rare earth enrichment.

The chloritization observed at the Area of Active Venting is similar to the Mg-rich chlorite and to chloritic minerals observed at sediment-covered spreading centers in Escanaba trough on Gorda Ridge and in Guaymas basin on the East Pacific Rise. This observation suggests intense Mg metasomatism in a mixing zone where hydrothermal fluids interact with seawater and sediment at temperatures above 200°C.

The similarity of the Fe-rich chlorites from the Bent Hill massive sulfide deposit to Fe-rich chlorites from several ancient massive sulfide deposits indicates that they probably reflect hydrothermal fluid-rock interaction at high temperatures below the zone of seawater mixing.