

Reaction control of the chemical and isotopic compositions of hydrothermal fluids at a sedimented ridge (Middle Valley, ODP Leg 139)

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Introduction

Recent drilling of the Ocean Drilling Program (ODP) during Leg 139 at Middle Valley, an axial rift valley of the northern Juan de Fuca Ridge, provided an important opportunity to characterize sub-seafloor hydrothermal processes at a sediment-covered spreading centre (Davis, Mottl, Fisher, *et al.*, 1992). In this study, we have determined the mineralogical and chemical composition of representative bulk samples and hydrothermal precipitates and have analyzed the stable isotope compositions of pore waters and authigenic phases in the altered sedimentary sequences recovered at three sites: 856 (a former hydrothermal area), 857 (a 'hydrothermal reservoir'), and 858 (an active hydrothermal discharge zone). The mineralogical, chemical and stable isotope signatures provide a record of high temperature, convective hydrothermal circulation associated with the deposition of massive sulphides and allow the evaluation of reactions occurring along the fluid pathways.

Results

Stable isotope ratios of authigenic carbonates at Sites 857 and 858 trace the inflow of cooler, oxidizing sea water and its heating and reduction with circulation and fluid-rock interaction at depth. The active hydrothermal system at Site 858 represents one arm of a convective hydrothermal circulation cell and provides an analogue for former hydrothermal systems, such as at Site 856. Vertical thermal gradients, calculated on the basis of oxygen isotope ratios of authigenic carbonates and silicates, range from 2.2°C/m in distal regions (Holes 858A & 858C) to up to 10°C/m at the central vent areas (Holes 858B & 858D) (Früh-Green *et al.*, 1994).

Bulk sediment and pore water geochemistries at Middle Valley are controlled by the progress of

mineral reactions in response to variations in temperature gradients and fluid flux rates. Bulk sediment chemistries at Hole 858A are comparable to distal holes at the former discharge area at Site 856 and reflect a dominance of detrital components over authigenic phases. Changes in Ca and Mg concentrations of the hydrothermal fluids below 100 mbsf in Hole 858A (Davis, Mottl, Fisher, *et al.*, 1992) suggest an upward flux of Ca released during albitization of plagioclase and decrease in Mg due to chloritization in the underlying sediments and basement rocks.

The immediate vent area, Hole 858B, is characterized by a distinct mineralogical zonation defined by a progressive decrease in detrital components and an increase in pure hydrothermal phases (Fig. 1). Neofomed and detrital phyllosilicates are clearly distinguished on the basis of morphology and mineral chemistry through SEM and TEM analysis (Buatier *et al.*, 1994). The detrital or hydrothermal origin of clay fractions is confirmed by stable isotope data, with $\delta^{18}\text{O}$ and δD ranging from 14‰ and -98‰ in the detrital phyllosilicates to less than 8‰ and approximately -40‰, respectively, in the hydrothermal phyllosilicates. The bulk sediment chemistries reflect the mineralogical layering and precipitation of hydrothermal phases. Comparison of sediment and the pore fluid compositions indicates that Si and Mg concentrations are directly controlled by the precipitation of Mg-rich phyllosilicates (corrensite, chlorite and swelling chlorite). Ca, Fe, Sr, Zn and Cu contents correspond to layers rich in hydrothermal sulphates and Fe-sulphides.

The oxygen and hydrogen isotope ratios of pore waters squeezed from sediments at Sites 857 and 858 indicate an altered isotopic composition of the circulating fluid, characterized by an enrichment in both ^{18}O and deuterium relative to seawater. This enrichment is most pronounced at Hole 858D near the vent area, where $\delta^{18}\text{O}$ values

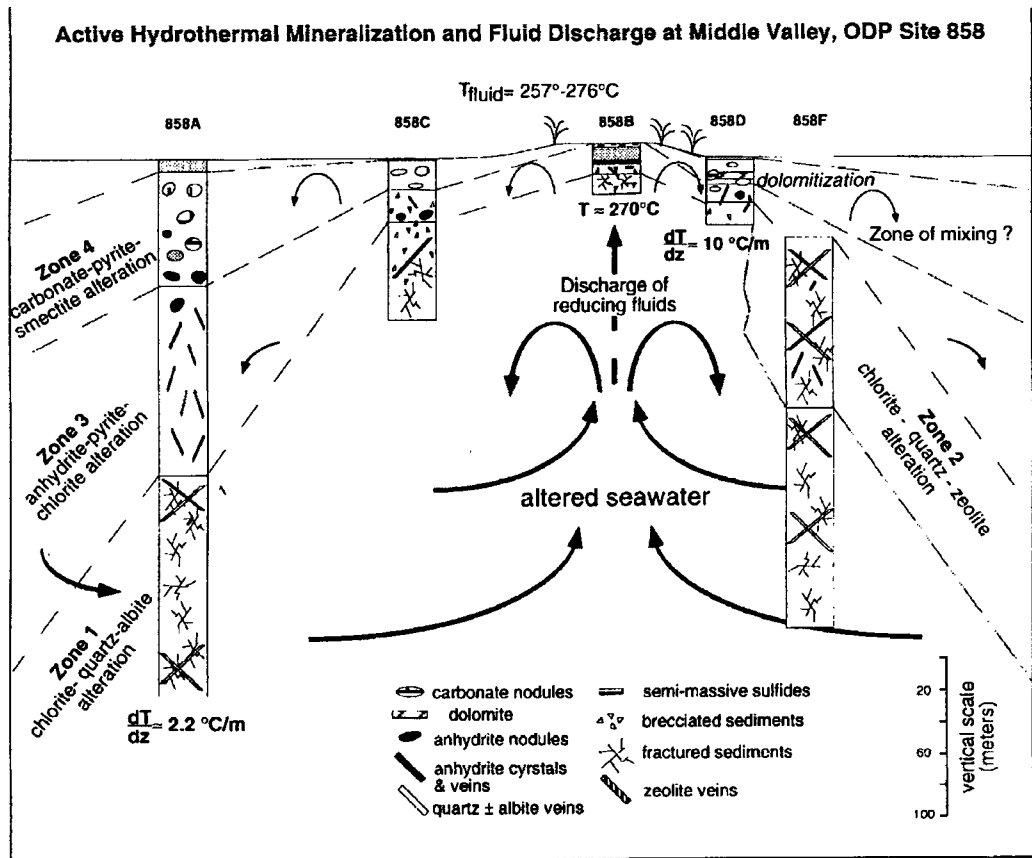


FIG. 1. Schematic diagram of Site 858 (modified after Davis, E.E., Mottl, M., Fisher, A., *et al.*, 1992) showing lithologic variations, mineralogic hydrothermal alteration zones of the sedimentary cover and the convective hydrothermal circulation inferred from geochemical and stable isotope data.

of the pore fluids range from -0.6‰ to 2.9‰ , with δD ranging from -1‰ to 7‰ . Variations in oxygen and hydrogen isotope ratios with depth indicate lateral flow of hydrothermal fluids at depths as shallow as 5 metres below the surface (mbsf) and zones of seawater recharge at approximately 20 mbsf in the immediate vent region.

This study demonstrates that large-scale convective hydrothermal circulation through the sedimentary sequence drives smaller-scale fluid advection with shallow subsurface mixing of heated seawater with ascending hotter hydrothermal fluids at the vent area. The isotopic compositions of pore waters and hydrothermal phases, together with mineralogies and pore water

chemical data, indicate that the rates of mineral reaction in the sediments must be high relative to fluid flux rates.

References

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