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Simulations of MOR hydrothermal systems with seafloor spreading: Retention of anhydrite in oceanic crust and implications for the global sulfur cycle

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Since the earliest studies of mid-ocean ridge (MOR) hydrothermal systems the removal of sulfate from seawater into anhydrite ($CaSO_4$) has produced debate about whether this sulfate removal is permanent and to what degree it influences the global sulfur cycle. The answer depends on anhydrite preservation as oceanic crust moves away from the ridge and encounters cooler circulating fluids that can redissolve anhydrite. Drill cores in oceanic crust contain small amounts of anhydrite, but generalizing the observations is difficult. Sulfate is also reduced to sulfide and stored in pyrite which is likely to be permanent. We are addressing the sulfate preservation problem by using thermo-hydro-chemical (THC) simulations of a steady-state MOR hydrothermal system with a newly-devised procedure for simulating seafloor spreading. Fluid-rock interaction is calibrated against high-T vent fluid compositions and the alteration extent and mineralogy at Site 504B and elsewhere. Simulations show that all deposited anhydrite is in the sheeted dike section and is redistributed as spreading proceeds. A dynamic steady-state anhydrite reservoir is maintained within about 500 meters of the spreading axis, concentrated in zones of low permeability. The global mass of this "stored" anhydrite is ≤ 0.01% of the dissolved sulfur in the modern oceans. Anhydrite permanently "retained" in the crust as it moves far from the ridge represents the removal flux of sulfate from seawater. Our simulations suggest this inorganic removal flux of sulfur could be as high as 0.3 Tmol/y or 10% of the continental weathering flux, with 80% sulfate and 20% sulfide. Longer spreading simulations, still in progress, are needed and there are hints that the sulfate removal flux could be lower. Anhydrite preservation depends on porosity and permeability evolution which can be modeled in different ways. Simulation of spreading is critical to modeling of MOR hydrothermal systems, and is providing insights into the expected sequence of alteration minerals, differences between fracture and matrix alteration, and changes in permeability structure and fluid flow. An interesting finding is that redissolution of anhydrite produces zones of high dissolved sulfate in some cooler near-axis hydrothermal fluids. Hot upwelling fluids at the spreading axis maintain near-zero Mg and sulfate.