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Moderate Aluminum Addition Suppresses H_2 Production during Olivine Serpentinization

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Serpentinization, a water-rock reaction between ultramafic rocks and water, generates molecular hydrogen (H_2) that serves as a primary energy source for chemosynthetic microbial communities in hydrothermal vent fields and sub-seafloor environments. Despite its importance for planetary habitability and the origin of life, the geochemical factors controlling H_2 yields remain poorly constrained [1]. To investigate the role of aluminum (Al) during serpentinization, we conducted hydrothermal experiments at 300 °C and 3.0 kbar by reacting olivine (with and without 6.5 wt.% Al_2O_3) with 0.5 mol/L NaCl solutions. The results show that serpentine and brucite were the dominant secondary minerals. With the addition of 6.5 wt% Al_2O_3, serpentine exhibited a wide range of Al_2O_3 contents (3.3–30.6 wt.%), with Al concentrations positively correlated with FeO content. Transmission electron microscopy and energy-dispersive X-ray spectroscopy elemental mapping confirmed Al incorporation into the crystal structures of serpentine and brucite, with higher Al_2O_3 contents of brucite corresponding to lower FeO levels [2]. Experiments with Al addition yielded 51.2 mmol/kg H_2, accompanied by <9% serpentine after 59 days. In contrast, Al-free systems produced nearly twice the H_2, with 18 wt.% serpentine formed.

This finding contradicts previous studies conducted under Al-saturated conditions (e.g., ~11.5 wt.% Al_2O_3 in Huang et al., 2021 [3]), which reported that Al promotes olivine serpentinization and H_2 generation. Our experiments demonstrate, for the first time, that the effect of Al is concentration-dependent: moderate Al incorporation (6.5 wt.%) suppresses H_2 production by altering iron partitioning between brucite and serpentine, thereby limiting the ferrous iron available for magnetite formation. These results reveal a dual role of Al in serpentinization systems and suggest that Al-bearing phases such as pyroxene in ultramafic rocks may significantly restrict H_2 generation in natural settings, with important implications for assessing energy fluxes that sustain deep subsurface microbial ecosystems.

References:

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