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Aluminum speeds up the hydrothermal alteration of olivine

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The reactivity of ultramafic rocks toward hydrothermal fluids controls chemical fluxes at the interface between the internal and external reservoirs of silicate planets. On Earth, hydration of ultramafic rocks is ubiquitous and operates from deep subduction zones to shallow lithospheric environments where it considerably affects the physical and chemical properties of rocks and can interact with the biosphere. This process also has key emerging societal implications, such as the production of hydrogen as a source of carbon-free energy. To date, the chemical model systems used to reproduce olivine hydrothermal alteration lead to the formation of serpentine with sluggish reaction rates. Although aluminum is common in geological environments and in hydrothermal systems in particular, its role in serpentinization or olivine dissolution has not been investigated under hydrothermal conditions. Nevertheless, abundant Al supply is expected in fluids released from dehydration of metapelites in subduction zones as well as during the hydrothermal alteration of gabbros at mid-ocean ridges. Aluminum was also abundant in primitive environments of both the Earth and Mars, stored in either Al-rich minerals like plagioclase or Al-enriched ultramafic lavas.

We have investigated the role of Al on the hydrothermal alteration of olivine in a series of experiments performed in a low-pressure diamond anvil cell while following the reaction progress in situ by optical imaging and Raman spectroscopy. Experiments were run for 4.5 to 7.5 days with two olivine grains reacted in saline water (0.5 molal NaCl) at 200°C and 300°C, and P=200 MPa. After two days, olivine crystals were fully transformed to an aluminous serpentine, also enriched in iron. The presence of Al in the hydrothermal fluid increases the rate of olivine serpentinization by more than one order of magnitude by enhancing olivine solubility and serpentine precipitation. The mechanism responsible for this increased solubility has to be further investigated but this result motivates a re-evaluation of the natural rates of olivine serpentinization and of olivine hydrolysis in general in a wide range of settings where olivines or peridotites are intimately associated with Al-providers. Such a fast reaction rate may affect the contribution of reaction-enhanced processes at the micrometer-scale, such as reaction-driven cracking, already proposed for enhancing serpentinization or carbonation of olivine. The effect of Al on lower crust and upper mantle metasomatism is expected to be even stronger at higher pressure in subduction zones where those reactions control the rheology and physical properties of the subducting plate and mantle wedge.