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Tectonic and magmatic controls on serpentinization at slow spreading mid-ocean ridges

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Serpentinization of mantle-derived peridotites at mid-ocean ridges occurs in slow spreading rate contexts, next to large-offset axial normal faults (detachment faults) that bring these mantle-derived rocks into the upper lithosphere. In this context, serpentinization contributes to the formation of a 2 to 5 km-thick geophysically-defined crustal layer. Based on an overview of mostly published geological, petrological and geophysical constraints, we address the tectonic and magmatic controls on mid-ocean ridge serpentinization, and on its spatial distribution.

Microstructural, mineralogical and oxygen isotope studies indicate that mid-ocean ridge serpentinization involves an initial stage of formation of a serpentine mesh texture under low fluid-rock ratio conditions, followed by several stages of higher fluid-rock ratio veining and recrystallization of the initial serpentine, all occurring for the most part at relatively high temperatures (200-350°C), within the range that is most kinetically favorable for olivine serpentinization. Microcracks that are used as pathways for hydrothermal fluids at the mesh texture formation stage are tightly-spaced (< a few hundred microns) and kinetic constraints indicate that this stage probably occurs within a few years of hydrothermal fluids gaining access to the peridotite. This leads to a conceptual model of mesh texture formation in the axial ultramafic basement in and next to axial detachment fault zones, at temperatures in the 200-350°C range, and in association with weak hydrothermal circulation. Seismicity constraints suggest that this may occur at depths of as much as 15km below seafloor at very slow spreading ridges. Yet, gravity and seismic velocity constraints are not consistent with large volumes of serpentinized mantle at such depths, suggesting that this type of serpentinization is restricted to the fault's damage zone. Lower temperature serpentinization also probably occurs (at slower rates) at shallower, crustal depths, in tectonically damaged domains farther away from the fault, although we lack the samples to check this. Finally, episodes of extensive serpentinization involving black-smoker type fluids occur locally in domains of the tectonically damaged ultramafic basement that channel vigorous hydrothermal cells cooling magmatic intrusions. These three modes of serpentinization are expected to combine in detachment-dominated ridge regions to create an upper lithosphere layer made of partially serpentinized peridotites and isolated gabbroic bodies, with crustal-type seismic velocities and densities.