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Mechanisms and Controls on Listvenite Formation: Implications for Carbon Sequestration in Subduction Zones

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The transformation of variably hydrated peridotites into carbonate-quartz (listvenite) and carbonate-talc (soapstone) rocks through COH-fluid-driven carbonation is a process of large-scale carbon sequestration that has the potential to substantially modulate deep carbon fluxes. Effective CO_2 storage occurs within the forearc mantle via the carbonation of partially hydrated peridotites, as evidenced by (1) naturally occurring, nearly fully carbonated peridotites, (2) high-pressure experiments replicating fluid-rock interactions in subduction zones, and (3) thermodynamic fluid infiltration-fractionation models.

We explore the factors and feedback mechanisms that influence natural listvenite formation, assess the key prerequisites for this process, and examine its broader implications for the deep carbon cycle[1]. To achieve this, we integrate thermodynamic fluid infiltration-fractionation models - designed to simulate stepwise carbonation under idealized conditions - with experimental data and natural observations. We quantify variations in volume, mass, solute transport (e.g., Mg and Si mobility), redox conditions, and pH throughout the reaction's progression, considering the influence of protolith composition, fluid chemistry, temperature, and pressure.

Our modeling and analysis of typical CO_2 concentrations in metamorphic and hydrothermal fluids indicate that listvenite formation necessitates sustained sufficient fluid CO_2 concentrations and high fluid flux. CO_2-fluids might be sourced, for instance, by devolatilization of C–bearing silicate rocks along subduction zones and has the potential to cause extensive carbonation in overlying, partially hydrated peridotites during focused fluid ascent. High fluid fluxes, in turn, depend on the continuous renewal of permeability, despite reactive volume expansion. Reaction driven cracking may open new fluid pathways. Listvenites are commonly exposed along tectonic boundaries between crustal and ultramafic rocks in ophiolites, which mark major orogenic sutures. Thus, external stress fields may impose brittle failure and opening of new reaction pathways. Although critical for fluid-rock interactions and carbonation, the structure and evolution of micro- to nanoscale porosity in variously carbonated serpentinite during deformation is not well understood. Preliminary experimental findings indicate that under stress ductile deformation becomes essential once carbonation initiates.

[1] Menzel,M.D., Sieber,M.J., Godard,M. Earth-Science Review, 225(104828), 2024, 10.1016/j.earscirev.2024.104828