Upscaling laboratory kinetics data: the example of serpentinization

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At slow-spreading ridges, hydrothermal circulation through exhumed mantle rocks leads, through hydration reactions, to the formation of serpentine, $(Mg,Fe)_2Si_2O_5(OH)_4$, magnetite, Fe_3O_4 and brucite, $Fe(OH)_2$. These "serpentinization reactions" are of strong interest not only because they induce major changes in the physical properties of the lithosphere but also because they produce hydrogen when the ferrous iron of the primary minerals (i.e. olivine and pyroxene) is oxidized to form magnetite. Estimating the kinetics of these reactions is thus of primary importance for both geodynamical and economic reasons. It requires to determine the relative importance of all the processes involved in this reaction at scales ranging from the grain to the oceanic lithosphere. Here, hydrothermal experiments were conducted on San Carlos olivine at 50 MPa in the $250 - 350\,°C$ temperature range for run durations up to 514 days. The reaction progress was monitored magnetically and the composition and distribution of the reaction products were analyzed at the end of the experiments. First, serpentinization kinetics were found to be inversely proportional to the geometrical surface area for starting materials composed of olivine powders with sizes ranging from 5 to 150 μm. Olivine dissolution was the rate-limiting step. Reaction progress vs. time curves display sigmoid curves resulting from the progressive increase of the reactive surface area with the formation of etch pits and fractures. Then, aggregates of olivine, sintered at high pressure and high temperature, with two different porosities (1 and 10 %) were used as starting material to estimate the influence of transport processes on the serpentinization kinetics. The measured kinetics were two orders of magnitude slower than the one determined on olivine powders. The surface area accessible to water was limited by water transport through the intergranular region. For grain size relevant to peridotite, water diffusion rate becomes so slow that the aggregate reacts by a "layer by layer" mechanism in which each layer of grain has to fully react in order to expose the next layer to water. In natural peridotites, water transport pathways such as cracks will favor the propagation of water inside the rock and the reaction rate measured on the aggregates set thus a lower time bound of $100 - 1000$ years for the duration of complete serpentinization in the presence of water. This duration is one order of magnitude smaller than the one inferred in the case of natural serpentinization, suggesting that water availability plays a key role in controlling the rate of the reaction. New numerical models taking into account the interplays between reaction, fluid transport and fluid pathways generation are currently developed to better estimate the rate and the extent of mineralogical reaction in natural systems.