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Formation of olivine veins by dehydration during viscously deforming serpentinite: a numerical study

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The dehydration of serpentinite during subduction and the associated formation of dehydration veins is an important process for the global water cycle and the dynamics of the subducting plate. Field observations suggest that olivine veins can form by dehydration during viscous shear deformation of serpentinite. However, this hypothesis of olivine vein formation, involving the coupling of rock deformation, dehydration reactions and fluid flow, has not been tested and quantified by hydro-mechanical-chemical (HMC) models. Here, we present a new two-dimensional HMC numerical model to test whether olivine veins can form by dehydration during viscous shearing of serpentinite. The applied numerical algorithm is based on the pseudo-transient finite difference method. We consider the simple reaction antigorite + brucite = forsterite + water. Volumetric deformation is viscoelastic and shear deformation is viscous with a shear viscosity that is an exponential function of porosity. In the initial model configuration, total and fluid pressures are homogeneous and in the antigorite stability field. Small, initial perturbations in porosity, and hence in viscosity, cause pressure perturbations during far-field simple shearing. During shearing, the fluid pressure can locally decrease and reach the thermodynamic pressure required for the dehydration reaction, so that dehydration is triggered locally. The simulations show that dehydration veins form during progressive shearing and grow in a direction parallel to the maximum principal stress. During the dehydration the porosity can increase locally from 2% (initial value) to more than 50% inside the dehydration vein. The numerical model allows quantifying the mechanisms and variables that control the evolution of porosity and fluid pressure. We show that the porosity evolution is controlled by three mechanisms: (1) volumetric deformation of the porous solid, (2) temporal variation of the solid density and (3) mass transfer during the dehydration reaction. We quantify the evolution of the fluid pressure that is controlled by five variables and processes: (1) the total pressure of the porous rock, (2) elastic effects of the total volumetric deformation, (3) the temporal variation of porosity, (4) the temporal variation of solid density and (5) mass transfer during the dehydration reaction. This model supports the observation-based hypothesis of the formation of olivine veins due to dehydration during viscous shearing of serpentinite. More generally, our HMC model provides quantitative insights into the evolution of porosity, and hence dynamic permeability, fluid pressure and mass transfer during dehydration reactions in deforming rock.