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How is the dehydration of antigorite coupled to deformation?

LISA EBERHARD[1], MATTIA LUCA MAZZUCCHELLI[2], STEFAN SCHMALHOLZ[2], HOLGER STÜNITZ[3], PROF. PATRICK CORDIER[4], AHMED ADDAD[4] AND OLIVER PLÜMPER[1]

[1]Utrecht University
[2]University of Lausanne, Géopolis
[3]Université d'Orléans
[4]Univ. Lille

Dehydration of hydrous minerals in subduction zones has important implications on larger scale geochemical and geophysical processes. In particular, antigorite dehydration at approximately 630-650 °C releases substantial amounts of fluid. However, fluid release from subducted serpentinites is not strictly limited to antigorite's thermodynamic stability limit. Antigorite, the high-pressure serpentine phase, has a modulated crystal structure and is thought to gradually transition to smaller unit cells during prograde subduction, accompanied by minor fluid release. Additionally, magnetite can facilitate redox-driven dehydration at slightly lower temperatures (520-550 °C), while brucite and carbonates contribute to low-temperature dehydration (400-500 °C) by forming olivine and clinopyroxene. Moreover, the interaction between deformation and chemical reactions is expected to influence the timing, location, and extent of serpentinite dehydration. However, this coupling remains poorly constrained.

Here, we present hydrostatic and coaxial deformation experiments on natural serpentinites in a modified Griggs apparatus, conducted at 1.5 GPa and 620-670 °C, spanning the thermal stability limit of antigorite. Our experiments reveal limited dehydration, occurring only within localized dehydration bands. Notably, dehydration is restricted to deformed samples, whereas hydrostatically treated samples show no evidence of dehydration. These findings contrast with thermodynamic predictions, suggesting that significant dehydration may be inhibited by slow reaction kinetics.

We found no correlation between dehydration reactions and intrinsic chemical variations, mineralogical heterogeneities, or experimental temperature gradients. A combination of microstructural analyses, nanoscale crystal orientation mapping and 2D numerical simulations indicates that deformation acted as the primary driving potential of dehydration. Strain concentration, induced by applied axial stress, locally increased the mechanical work rate. The coupling between mechanical work rate and reaction kinetics facilitated reaction and caused the formation of localized dehydration bands.

Our experiments underscore the significance of coupled mechanical and chemical processes in subduction zone dynamics and highlight the critical role of mechanical processes in controlling fluid release. Furthermore, they demonstrate that mechanical work rate is a key parameter governing the reaction kinetics of antigorite, providing a mechanistic framework for understanding deformation-induced dehydration.