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Mixed-mode strain localization generated by hydration reaction at crustal conditions

Francois Renard (1,2), Xiaojiao Zheng (1), Benoit Cordonnier (1,3), Jessica McBeck (1), Bjørn Jamtveit (1), and Wenlu Zhu (4)

(1) The Njord Centre, Physics of Geological Processes, Department of Geosciences, University of Oslo, box 1048, Blindern, 0316 Oslo, Norway (francois.renard@geo.uio.no), (2) Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France, (3) ESRF – The European Synchrotron, CS40220, Grenoble 38043, France, (4) Department of Geology, University of Maryland, College Park, MD 20742, USA

Hydration reactions influence rock density and rheology and have important consequences for geodynamic (serpentinization, eclogitization) and geoengineering processes (expansive cement used to seal boreholes). Volume increases produced in hydration reactions may generate sufficient tensile and shear stress to fracture both the rock undergoing the reaction and the surrounding host rock. We performed in situ dynamic X-ray synchrotron microtomography experiments to investigate reaction-induced fracturing. We used a novel deformation apparatus, the Hades rig, which allows imaging rocks samples at in situ conditions during fluid-rock interactions. We performed three experiments on hydration of periclase at 180 or 190 degrees C, under a confinement of 10 or 80 MPa, a pore fluid pressure of 5 MPa or 75 MPa, and with or without differential stress, respectively. The sample assembly consists of a periclase cylinder inserted into a central hole within a serpentinite cylinder. The reaction from periclase to brucite results in a large volume increase (110%), pushing the periclase/brucite against the serpentinite and ultimately breaking it. Using time-resolved three-dimensional imaging, we quantify the spatial and temporal distribution of the reaction-induced fractures. We perform digital volume correlation (DVC) analysis to obtain the incremental strain tensors throughout the hydration and fracturing process. We assess the distribution of normal tangential stress within the serpentinite using the boundary element method code Fric2D. The numerical model shows that failure initiates on the inside wall for a hydration pressure of 30 MPa, as in the experiments. The DVC results show mixed-mode strain localization. The von Mises strain, indicative of shear, increases by a larger percentage than the contractive or dilative strain components as the reaction-induced fractures grow. The magnitude distribution of von Mises strain follows a power law relationship, indicative of stress interactions during fracturing. This experimental finding sheds insights on the mechanisms of microseismicity measured in areas undergoing active serpentinization and the mechanisms of borehole sealing when using expansive cement.