Geophysical Research Abstracts
Vol. 20, EGU2018-5039, 2018
EGU General Assembly 2018

Dehydration embrittlement and compaction instabilities in subduction zones

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During prograde metamorphism in subduction zones, hydrous phases such as serpentines progressively dehydrate, forming free fluid phases at depth. Such dehydration reactions are systematically associated with a net decrease in solid volume (the reactions forming solid products denser than reactants), and with a variable change in fluid volume, the sign of which being controlled by the pressure and temperature conditions at which the reaction occurs. From initially nonporous metamorphic rocks (such as antigorite serpentinite), dehydration reactions therefore produce, at least transiently, a porous rock saturated with fluids, the rheology of which is markedly different from the original rock (e.g. Rutter et al., 2009). One key specific impact of dehydration reactions is their potential to trigger unstable faulting and earthquakes, a phenomenon generally termed “dehydration embrittlement”. This phenomenon corresponds to the transition from ductile to brittle deformation due to a dehydration-induced increase in pore fluid pressure. It is often thought that dehydration- embrittlement is one of the main causes of intermediate-depth earthquakes in subduction zones (Brantut and Sulem 2012).

We formulate a model for coupled deformation and dehydration of antigorite, based on a porosity-dependent yield criterion and including shear enhanced compaction. It is shown that dehydration can lead to unstable pore pressure rise and deformation when the net volume change of the reaction is negative, i.e. at intermediate-depth in subduction zones, due to a positive feedback between pore fluid pressure, compaction and dehydration rate (Brantut et al. 2017). The instability criterion is derived in terms of the dependence of the yield criterion on porosity (Stefanou & Sulem, 2014). It is obtained that the instability is associated with strain localisation, over characteristic length scales controlled by the hydraulic diffusivity, the elasto- plastic parameters of the rock, and the reaction rate. Typical lower bounds for the localisation length are of the order of 10 to 100 m for antigorite dehydration and deformation at 3 GPa. The fluid pressure and deformation instability is expected to induce stress build-up in the surrounding rocks forming the subducted slab, which provides a mechanism for the nucleation and propagation of intermediate-depth earthquakes.

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