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Experimental dehydration and deformation of serpentinite under controlled pore pressure

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The strength and ductility (deformability) of rocks in nature is believed to be strongly influenced by metamorphic reactions, especially when fluids are evolved and volume changes occur. Serpentinites are well-suited to the study of deformation/metamorphism relations because the rock is initially strong yet can undergo substantial changes in mechanical properties in association with its dehydration reaction. It is also an important reaction in its own right because it is believed to play a key role in seismogenesis in subduction zones and in oceanic transform faults.

We deformed intact cylinders of lizardite serpentinite under drained conditions, preventing the buildup of high pore fluid pressures, so that we could specifically study the influence on deformability of microstructural changes such as of grain size and porosity. In all experiments, pore volumometry was used, that enabled tracking of volume changes during the dehydration phase and during deformation, except when the duration of the deformation was comparable to the duration of the dehydration reaction. The dehydration of lizardite occurs in the laboratory over the temperature range 500 to 580 ˚C, over a period from a few days to a few hours.

Samples were deformed at different temperatures, (a) before reaction onset, (b) during the course of the reaction, and (c) after the reaction has gone to completion, over a range of strain rates, in order to study its effect on strength and ductility. Complete reaction generates about 20% of new porosity if carried out at effective pressures low enough that pore collapse does not occur. Thus the deformation of the resulting porous rock is expected to behave in accordance with the concept of critical state soil mechanics, even at high temperatures. Here, the yield surface on a plot of deviatoric stress versus effective mean pressure shows a positive slope at low pressures, when dilatancy and faulting control failure. At higher pressures the yield surface displays a negative slope, characteristic of shear-enhanced compaction, until the condition is reached where failure by pore collapse can occur under hydrostatic pressure alone. The boundary line between dilatant and compactive failure is the critical state, at which deformation occurs at constant volume. The yield surface shows an elliptical form, which shrinks in size with decreasing strain rate and/or with increasing porosity.

We found critical state-type behaviour in the serpentinite used in this study but, unexpectedly, the size of the yield surface also depended on the effective pressure at which the dehydration reaction was carried out. Thus at high pressures a linked framework microstructure of olivine grains was produced, leading to a higher yield strength. At low dehydration pressures, new olivine grains were more isolated, leading to relative weakness. Stress/strain behaviour was characterized by strain hardening ductile flow, as pore collapse progressively occurred, until steady state flow at the critical state condition was attained.

With decreasing strain rate the strength of the serpentinite decreased rapidly with a linear viscous characteristic. Microstructurally, the new olivine grains were composed of aggregates of ultrafine grained (100 nm) olivine, which we infer flowed by diffusion-accommodated grain boundary sliding, in the same way as we found in an earlier study of sliding along fault surfaces in dehydrating serpentinite. The observed rapidity with which serpentinite can relax deviatoric stress suggests that in subduction zones dehydrating serpentinite cannot support the stresses necessary to permit seismogenic failure, but instead, overpressured water released from dehydrating serpentinite permeates adjacent, non-dehydrating rocks such as gabbro. Coupled with stress transfer from the serpentinite, this is likely to favour seismicity in the gabbro.

Serpentinite may act as a useful proxy for the mechanical behaviour of other (crustal) rock types taking part in dehydration reactions, but it must be remembered that the microstructural evolution we see in rapid laboratory experiments (rapid nucleation and growth to produce fine grained reaction products) may not correspond to coarser grained aggregates produced during slower reaction with smaller thermal oversteps in nature. Unfortunately, during prograde reactions in nature, thermal equilibration and grain growth tend to outstrip deformation events, wiping out microstructural evidence of deformation/metamorphism realationships.