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Rates of hydration reactions in crustal shear zones and their implications for temporal variations in rheology

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Crustal shear zones are commonly accompanied by retrograde metamorphism of pre-existing higher grade rocks. The retrograde reactions involve hydration, but the localisation of the retrogression suggests that reaction is limited by either the availability of water or the effect of deformation on reaction kinetics. Depending on the rate of retrograde hydration reactions, shear zones may either be uniformly wet for long periods of time during their deformation history, or may be dry for much of the time, experiencing brief periods where free water is present. If the latter scenario is correct, their strength will fluctuate markedly according to the presence or absence of water.

In order to evaluate the likely residence time of water in mid-crustal shear zones, we have carried out experiments to investigate the rate of hydration of a natural granulite under greenschist to amphibolite facies metamorphic conditions (300-500C, 3-5 kbar). Seived and cleaned grains of powdered hornblende granulite were loaded in gold capsules with weighed amounts of water and reacted for periods of between 3 days and 12 weeks. The water consumed by hydration reactions was determined by weighing at the end of the run and combined with estimated surface areas to calculate the rate at which water was lost during the reaction. Results are of the order 10-7 to 10-8 g/s/m2 surface area, and are comparable to previous published data for the rate of hydration of K-feldspar + andalusite. SEM observation of the run charges shows that retrograde minerals including actinolite and sheet silicates were produced. There are no obvious differences in reaction rate between experiments at different P-T conditions.

These reaction rates imply that if water infiltrates along a fracture surface in high grade rocks under mid-crustal conditions, forming a film with a half thickness of 100 microns, it will survive for around 10-100 years only before being consumed by hydration reactions. The film thickness has been estimated based on thicknesses of secondary fluid inclusion planes (normally less than 50 microns) and of mineral growth zones in secondary minerals. These times are short even relative to the repeat rate of earthquakes on major fault systems and suggest that a free water phase is absent from shear zone rocks for most of their history. We propose that shear zones are dry and relatively strong for much of their history but become weakened and deform when water is able to gain access from water-bearing fractures in overlying crust or, possibly, overpressured reservoirs at depth. Each episode of strain in response to water infiltration lasts for times of the order of tens to hundreds of years, and terminates when all the water has been consumed in hydrous minerals, thereby inhibiting further deformation by water-assisted mechanisms. We conclude that strain localisation in shear zones is normally the result of focussed introduction of water from an external source such as a fault at higher levels.