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Mafic rocks at the brittle-viscous transition – interplay between fracturing, reaction and viscous deformation

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Deformation experiments have been performed on crushed Maryland Dibase ($\sim$ 55% Plg(An60-70), 42% Px, 3% accessories, 0.2 w.t.-% H_2O added) in a Griggs-type deformation apparatus in order to explore the brittle-viscous transition and the interplay between deformation and mineral reactions. Shear experiments at constant displacement rate of 1e-8 m/s (resulting shear strain rate $\sim$ 1e-5 /s) are conducted at T=600 to 800°C and confining pressures of Pc = 1.0 and 1.5 GPa.

Below 700°C, the microstructure is dominated by brittle deformation processes. At 700°C, the steady state strength approaches the Goetze criterion. The microstructure shows less evidence of brittle deformation and the onset of mineral reactions and diffusive mass transport are observed. Samples deformed at 800°C sustain significantly lower stresses than the Goetze criterion and reaction products are far more abundant. For both, 700°C and 800°C experiments, the main reaction products are Amph, Plg(An45-50) and zoisite (Zo, at Pc=1.5).

Deformation localizes in all experiments. At 700°C, displacement takes place either along shear fractures or in shear bands formed by fine grained Plg and fibrous Amph. Reaction products such as Amph and Plg occur almost restricted along such zones of localized deformation. Strain energy introduced by early fracturing seems to be an important factor enhancing reaction kinetics.
At 800°C, strain localizes into broader shear bands formed by a mixture of Plg + Amph (+ Zo). Phases in shear bands are extremely fine grained with equivalent diameters between 0.1 – 0.4 μm for Plg. Px grains rarely show signs of deformation and mostly form porphyroclasts overgrown by Amph. Fracturing is largely absent.
The spatial distribution of Amph within the shear bands indicates material transport and precipitation of Amph between Plg-Plg boundaries. Thermodynamic modeling suggests that phases such as Grt + Cpx should grow abundantly but grow only in minor amounts (< 1 vol.-%). Amph and Plg have the highest nucleation rates. The reaction rate seems to limited by the nucleation rate of phases.
Minor partial melting ($\sim$ 1 vol.-%) occurs in the 800°C experiments. Localization of deformation occurs predominantly along favourable oriented grain- and phase-boundaries. At sites of incipient deformation cavities are observed, which are often filled by the melt phase.

While in the 700°C experiments brittle processes kinematically contribute to deformation, fracturing is largely absent at 800°C. Diffusive mass transfer dominates. The absence of thermodynamically stable phases such as Grt and Cpx is explained by low nucleation rates. On the other hand, Amph and Plg are able to react sufficiently fast to keep up with the high experimental strain rates and the relatively low experimental T. The very small grain size within shear bands in the 700°C and 800°C experiments favours grain size sensitive deformation mechanisms. Due to the presence of water (and relatively high supported stresses), dissolution-precipitation creep is interpreted to be the dominant strain accommodating mechanism. Thus, viscous deformation takes place at comparatively low experimental temperatures, hence providing a realistic phase assemblage and likely deformation mechanism in a strong lower crust.