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Formation of Amorphous Materials Causes Parallel Brittle-viscous Flow of Crustal Rocks

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Relative motion of tectonic plates is accommodated along lithosphere-scale shear zones. The strength and stability of these shear zones control large scale tectonics and the location of earthquakes. It is widely accepted that rocks undergo a “brittle-to-viscous” transition as depth increases, however the details of how this transition is achieved are a topic of active research.

To study this transition in polymineralic rocks, we sheared bi-mineralic aggregates with varying ratio (30:70, 50:50 & 70:30 vol%) of quartz (Qtz) and potassium feldspar (Kfs) at temperature, T = 750˚C and pressure, Pc = 800 MPa under either constant displacement rate or constant load boundary conditions. Under constant displacement rate, samples reach high shear stress ($\tau \approx$ 0.4 - 1 GPa, depending on mineral ratio) and then weaken. Under constant load, the strain rate shows low sensitivity to stress below shear stresses of 400 MPa, followed by a high stress sensitivity at higher stresses irrespective of mineral ratio (stress exponent, n = 9 - 13, assuming that $strain\ rate \propto stress^{n}$).

Strain is localized along "slip zones" in a C and C’ orientation in all experiments irrespective of mineral ratio. These zones delimit larger cataclastic lenses, which develop a weak foliation. Quartz in the lenses shows pervasive Dauphiné twinning that leads to clear CPO patterns in the {r} and {z} rhomb planes. The {r} maxima (and {z} minima) are sub-parallel to the loading direction and rotate synthetically with increasing finite strain suggesting that they track the local σ_1 direction. The material in the slip zones shows extreme grain size reduction, no porosity and flow features. At peak strength, 1-2 vol% of the sample is composed of slip zones that are straight and short. With increasing strain, the slip zones become anastomosing and branching and occupy up to 9 vol%; this development is concomitant with strain-weakening of the sample. The best developed slip zones are observed in samples with high Kfs contents (70 & 50 vol%). We infer that the material in the slip zones is formed of nanocrystalline to partly amorphous material (PAM) that is predominantly derived from Kfs. By compiling literature data on PAM development, we show that the volume of PAM increases with increasing homologous temperature and work done (stress x strain per unit volume) on the sample in rocks containing feldspars.

Our results suggest that strain localization leads to microstructural transformation of the rocks from a crystalline solid to an amorphous, fluid-like material in the slip zones. This material forms over a broad range of P-T, stress and strain conditions suggesting that it should form readily in nature. The measured rheological response is a combination of viscous flow in the slip zones and cataclastic flow in coarser-grained lenses and can be modeled as a frictional slider coupled in parallel with a viscous dashpot.