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Fluid migration in ductile shear zones

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Fluid migration in metamorphic environments depends on a dynamically evolving permeable pore space, which was rarely characterised in detail. The data-base behind our understanding of the 4-dimensional transport properties of metamorphic rocks is therefore fragmentary at best, which leaves conceptual models poorly supported.

Generally, it seems established that deformation is a major driver of permeability generation during regional metamorphism, and evidence for metamorphic fluids being channelled in large scale shear zones has been found in all depth segments of the continental crust. When strain localizes in ductile shear zones, the microfabric is modified until a steady state mylonite is formed that supports large deformations. A dynamic porosity that evolves during mylonitisation controls the distinct transport pathways along which fluid interacts with the rock. This dynamic porosity is controlled by a limited number of mechanisms, which are intrinsically linked to the metamorphic evolution of the rock during its deformational overprint.

Many mid- and lower-crustal mylonites comprise polyphase mixtures of micron-sized grains that show evidence for deformation by dissolution/precipitation-assisted viscous grain boundary sliding. The establishment of these mineral mixtures is a critical process, where monomineralic layers are dispersed and grain growth is inhibited by the heterogeneous nucleation of secondary mineral phases at triple junctions.

Here we show evidence from three different mid- and lower-crustal shear zones indicating that heterogeneous nucleation occurs in creep cavities. Micro- and nanotomographic observations show that creep cavities provide the dominant form of porosity in these ultramylonites. They control a “granular fluid pump” that directs fluid migration and hence mass transport. The granular fluid pump operates on the grain scale driven by viscous grain boundary sliding, and requires only small amounts of fluid. The spatial arrangement of creep cavities suggests that the synkinematic permeability is highly anisotropic and responds to mechanical boundary conditions.

In summary, we present observations indicating that the evolution of porosity in ductile shear zones is directly coupled to the tectonometamorphic processes controlling strain localisation and rock deformation on the grain scale. The location and spatiotemporal extent of these processes determine fluid transport pathways and hence sites of fluid-rock interaction in steady state shear zones.