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Grain-scale interplay of deformation mechanisms and fluid flow and the implication for large-scale shear zones

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Besides deformation, fluid flow also is often localized along large-scale shear zones. Based on several cross-sections parallel to the transport directions of the Helvetic nappes, we investigated the changes of microfabrics and associated deformation mechanisms in thrust-related carbonate tectonites as a function of increasing temperature. Particular focus was paid on the interplay between deformation and fluid flow, since fluids were present in these systems during prograde, peak and retrograde metamorphic conditions.

Our results indicate that the type and intensity of veining, as indicator for fluid flow, are directly related to the active deformation mechanisms in the viscous matrix, which are controlled by the deformation conditions and mineralogical composition of the matrix (mono- vs. polymineralic). The key parameter with this respect is the recrystallized grain size, because a decreasing grain size yields a larger grain boundary volume and consequently an enhanced permeability. Small recrystallized grain sizes (1-20 µm) are (i) either formed at intermediate temperature conditions (220-330°C) in the case of monomineralic calcite mylonites or, in the case of elevated temperatures (T>330°C), (ii) occur in polymineralic calcite mylonites. In the latter case, second-phase minerals keep the calcite grain size as small as in case of intermediate-temperature rocks due to grain boundary pinning of calcite. In terms of deformation mechanisms, weak CPOs, small and equiaxed grains with straight grain boundaries or interfaces point to viscous granular flow (diffusion creep) as dominant deformation mechanism under these premises. In contrast, dislocation creep dominated deformation can be inferred for the coarser-grained monomineralic mylonites at the elevated temperatures as is evident by strong CPOs, elongated, oblique grains, sutured grain boundaries and the occurrence of subgrains. Interestingly, the abundance of calcite veins is highest in the aforementioned granular flow dominated tectonites, suggesting a close link between the location of fluid flow and the mechanisms responsible for matrix deformation. Particularly the granular flow associated formation of new grain boundary porosity by a combination of rotation of calcite grains and grain boundary sliding yield local under pressure resulting in a pumping of fluid into the shear zone. With ongoing deformation, pore fluid pressures will build up due to compression of the newly formed pores inducing brittle deformation by hydrofracturing. In this cyclical manner, porosity and permeability will change continuously on the grain-scale as function of ongoing deformation.

Il light of implications for the large-scale shear zones, changes in these microphysical processes, dependent on local temperature gradients, will result in different capacities of fluid pumping along the shear zone as manifest by concentrated occurrence of calcite veins at intermediate temperature intervals (220-320°C). It might therefore be no coincidence that in the corresponding depth interval (10-15km) seismicity in recently active shear zones is elevated.