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Buoyancy-driven ascent of (U)HP bodies: strain localisation and resulting finite strain

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Buoyancy-driven ascent is frequently suggested to explain a number of observed geological phenomena. For example, 1) the exhumation of (ultra)-high pressure ((U)HP) crustal rock units within orogens, and 2) the ascent of magmatic plutons through the lower and upper crust. However, these hypotheses are often disputed in favour of ascent via tectonically forced processes with minor buoyancy impact; e.g. large-scale extension or forced extrusion for (U)HP bodies, and ascent through dykes for the formation of magmatic plutons. The buoyancy-driven ascent causes characteristic strain localization around the buoyant object and sometimes within the object. One possibility to better constrain the mechanism of ascent for (U)HP units and plutons is to compare numerically calculated finite strain distribution in and around buoyantly-rising bodies with field observations of finite strain.

We present two-dimensional numerical simulations of buoyantly rising elliptical viscous inclusions with a viscous matrix for both linear and power-law viscous flow laws. This density perturbation and associated buoyant rise induce heterogeneous strain localization in and around the rising inclusion for a range of inclusion viscosities, without using prescribed strain softening mechanisms. Therefore, we quantify the impact of: 1) effective viscosity ratio between inclusion and surrounding matrix ($\Delta\eta$), 2) type of flow law used, and 3) numerical resolution on finite strain. For $\Delta\eta < 10$, significant internal deformation occurs within inclusions. For $\Delta\eta > 100$ inclusions rise essentially without internal deformation. Compared to linear viscous flow, power-law viscous flow doesn't change the overall finite strain pattern but generates higher spatial strain gradients. We also quantify the characteristic shear zone thickness around the rising inclusion. The highest values of deviatoric stresses correspond to the buoyancy stress and occur inside and towards the matrix-inclusion boundary for stronger inclusions. Increasing numerical resolution doesn't change the finite strain magnitude and distribution, but allows resolving thin 'tails' of highly localized strain at the rear of the inclusion. Equally, for rheologically strong inclusions, areas of low strain ('strain shadows') are locally observed in the surrounding matrix. Comparison of simulated strain patterns with field-observed strain distributions may help to assess the mechanisms and characteristics of buoyantly exhuming (U)HP units. Thus, we compare our numerical results with structural observations of the high-pressure Monte Rose nappe in the western Alps. The presented mechanism of strain localization due to buoyant flow in heterogeneous viscous fluids should be considered when interpreting natural shear zones as a result of material softening.