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Behaviour of a rimmed elliptical inclusion in 2D slow incompressible viscous flow

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The shape preferred orientation of natural populations of inclusions (or "porphyroclasts") is often inconsistent with predictions from established analytical theory for inclusions with coherent boundaries (e.g., Pennacchioni et al. 2001). A totally incoherent or slipping interface can explain observed stable back-rotated (or antithetic) orientations but not the observed cut-off axial ratio, below which inclusions still rotate. However, this behaviour is reproduced by a rimmed inclusion with a rim viscosity that is not infinitely weak but still weaker than the matrix (e.g., Schmid and Podladchikov 2005; Johnson et al. 2009). In this study, finite-element numerical modelling (FEM) is employed to investigate this system in 2D over a very wide parameter space, from a viscosity ratio (relative to the matrix) of the inclusion from 10^6 to 1, the rim from 10^{-6} to 1, the axial ratio from 1.00025 to 20, and the rim thickness from 5% to 20%. Theoretical consideration of a concentric elliptical inclusion and ellipse reduces the number of scalar values to be determined to fully characterize the system to two: one for the rate of stretch of the inclusion and one for the rate of rotation. From these two values, the rotation and stretching rate can be calculated for any orientation and 2D background flow field. For effectively rigid particles, the cut-off axial ratio between rotation and stabilization is determined by the remaining two parameters, namely the rim viscosity and the thickness, with low rim viscosity or thick rims promoting stabilization. The shape fabric of a population of particles in a high strain shear zone, presented as a typical R_f/ϕ plot, can be forward modelled using an initial value Ordinary Differential Equation (ODE) approach. Because the rim does not remain elliptical to high strain, this method cannot accurately model the behaviour of individual inclusions. However, a statistical approach, allowing variation in rim viscosity, which is also a proxy for variation in rim thickness, reproduces the characteristics of the shape preferred orientation of natural clast populations remarkably well. Deformable inclusions with a very weak rim show very similar behaviour to rigid inclusions. As inclusion viscosity is decreased and rim viscosity is increased toward that of the matrix, there is an increasing tendency for inclusions to elongate, which promotes back-rotation and development of (quasi-) stable orientations, rather than the continued rotation of low axial ratio inclusions. Power-law rheology increases the effective viscosity ratios between inclusion, rim and matrix: the slowly deforming strong inclusion is stronger and generally nearly rigid, whereas high strain rate in (parts of) the rim lowers the effective viscosity, tending to stabilize the inclusion. Because of the range of controlling parameters involved, any attempt at "vorticity analysis" based on clast shape preferred orientation or on the "stable" orientation of individual clasts is not really practical. Measurement of apparently stable back-rotated angles or estimation of the cut-off axial ratio below which inclusions continuously rotate does not allow a unique determination of the vorticity of flow.

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