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A comparison of numerical formulations for the Stokes equations with strongly variable viscosity

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Numerical modeling of geodynamic problems typically requires the solution of the Stokes equations for creeping, highly viscous flows. Since material properties such as effective viscosity of rocks can vary many orders of magnitudes over small spatial scales, the Stokes solver needs to be robust even in the case of highly variable viscosity. Currently, a number of different techniques (e.g. finite element, finite difference and spectral methods) are in use by different authors. Benchmark studies indicate that the accuracy of the velocity solution is satisfying for most methods. The accuracy of deviatoric stresses and pressure, however, is typically less than that of velocity. In the case of highly variable viscosity, some methods even result in oscillating pressures. This problem becomes particularly important in coupled problems, where the pressures feeds back to the solution. Examples of such coupled problems are mechanically-driven fluid-flow, or melt migration through deforming viscous media. The purpose of this study is therefore to evaluate the accuracy of the pressure solution for a number of numerical techniques. Thereby, we make use of a recently developed 2D analytical solution for the stress distribution inside and around a viscous inclusion in matrix of different viscosity subjected to pure-shear or simple-shear boundary conditions. Results will be presented for a streamfunction finite difference approach, a staggered grid velocity-pressure finite difference method and a velocity-pressure finite element technique with either linear or quadratic shape functions for velocity.