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Including the effects of elastic compressibility and volume changes in geodynamical modeling of crust-lithosphere-mantle deformation

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Materials in Earth's interior are exposed to thermomechanical (e.g. variations in stress/pressure and temperature) and chemical (e.g. phase changes, serpentinization, melting) processes that are associated with volume changes. Most geodynamical codes assume the incompressible Boussinesq approximation, where changes in density due to temperature or phase change effect buoyancy, yet volumetric changes are not allowed, and mass is not locally conserved. Elastic stresses induced by volume changes due to thermal expansion, serpentinization, and melt intrusion should cause 'cold' rocks to brittlely fail at $\sim$1% strain. When failure/yielding is an important rheological feature, we think it plausible that volume-change-linked stresses may have a significant influence on the localization of deformation.

Here we discuss a new Lagrangian formulation for "elasto-compressible -visco-plastic" flow. In this formulation, the continuity equation has been generalised from a Boussinesq incompressible formulation to include recoverable, elastic, volumetric deformations linked to the local state of mean compressive stress. This formulation differs from the 'anelastic approximation' used in compressible viscous flow in that pressure- and temperature- dependent volume changes are treated as elastic deformation for a given pressure, temperature, and composition/phase. This leads to a visco-elasto-plastic formulation that can model the effects of thermal stresses, pressure-dependent volume changes, and local phase changes. We use a modified version of the (Miliman-based) FEM code M2TRI to run a set of numerical experiments for benchmarking purposes. Three benchmarks are being used to assess the accuracy of this formulation: (1) model the effects on density of a compressible mantle under the influence of gravity; (2) model the deflection of a visco-elastic beam under the influence of gravity, and its recovery when gravitational loading is artificially removed; (3) Modelling the stresses induced by heating the interior of a viscoelastic cylinder.