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Efficient computational formulation of elastoviscoplasticity for 3D modeling of strain localization in lithosphere

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The most complicated phenomenon exhibited by the Earth materials is the formation of shear bands and macroscopic discontinuities (fracture). Conventional modeling of this process by means of strain softening may cause ill-posedness of mathematical description of the problem, thus leading to physically unacceptable results. More adequate description is provided by the non-local and gradient-enhanced damage models or even by switching to the analysis of contact interaction along localized internal interfaces. In this work, however, we confine our interest to the conventional models of creep and plasticity without strain softening and demonstrate that even this simplified approach can still be useful for the three-dimensional modeling of strain localization in the lithosphere. Specifically, we employ extended non-associative Drucker-Prager elastoplastic model along with arbitrary combination of diffusion, dislocation and Peierls creep mechanisms.

Numerical modeling of mechanical processes in geodynamics is indeed an inherent part of computational mechanics in the sense that many difficulties are shared with the other areas of application, of which engineering is the most productive. Many powerful techniques, that form a qualitative level of computational formulation, were initially designed for engineering applications. We are striving to adopt this extensive experience for the purposes of computational geodynamics as far as possible in our work. Namely, we utilize Hughes-Winget incrementally objective implicit time integration algorithm which allows an arbitrary combination of rheological mechanisms (elastic, viscous and plastic) within a single finite element model. For this approach to make sense, elastic strains must remain vanishingly small - behavior closely followed by the Earth materials. However the magnitude of plastic and viscous strains is not

restricted. An approximate linearization of discrete equilibrium equation is employed in order to use time step which is limited only by the characteristics of the mechanical process that we simulate and can be orders of magnitude larger than Maxwell time. Details of material tangent operator derivation are discussed in addition, along with stable element formulation and robust solver for linear equation system. We present a set of benchmarks and simplified models in order to validate our approach.