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Application of FE software Elmer to the modeling of crustal-scale processes

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We extended Elmer (the open source finite element software for multiphysical problems, http://www.csc.fi/english/pages/elmer) by user-written procedures for the two-dimensional modeling of crustal-scale processes. The standard version of Elmer is an appropriate tool for modeling of thermomechanical convection with non-linear viscous rheology. In geophysics, it might be suitable for some type of mantle convection modeling. Unlike the mantle, the crust is very heterogeneous. It consists of materials with distinct rheological properties that are subject to highly varied conditions: low pressure and temperature near the surface of the Earth and relatively high pressure and temperature at a depth of several tens of kilometers. Moreover, the deformation in the upper crust is mostly brittle and the strain is concentrated into narrow shear zones and thrusts. In order to simulate the brittle behavior of the crust, we implemented pressure-dependent visco-plastic rheology. The material heterogeneity and chemical convection is implemented in terms of active markers. Another special feature of the crust, the moving free surface, is already included in Elmer by means of a moving computational grid. Erosion can easily be added in this scheme.

We tested the properties of our formulation of plastic flow on several numerical experiments simulating the deformation of material under compressional and extensional stresses. In the first step, we examined angles of shear zones that form in a plastically deforming material for different material parameters and grid resolutions. A more complex setting of “sandbox-type” experiments containing heterogeneous material, strain-softening and boundary friction was considered as a next testing case.

To illustrate the abilities of the extended Elmer software in crustal deformation studies, we present two models of geological processes: diapirism of the lower crust and a channel flow forced by indentation. Both these processes are assumed to take place during the late stage of the Variscan orogeny in the area of the Bohemian Massif and they are well documented in the geological record. Extensive geological data are thus available and they can be compared with the results of our numerical simulations. Firstly, we model the indentation of a stiff block into a thick and hot crustal root and the consequent flow of the orogenic crust. For the development of the flow, the free surface deformation and erosion are essential. The importance of plastic deformation varies with the thermal structure of the domain. Secondly, we show an influence of thermal, density and viscosity structure of the crust on the time evolution and the final geometry of diapirs. The importance of the strain-rate dependence of viscosity, which is neglected in some numerical models, is discussed.