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3D Spherical models of coupled mantle thermo-chemical evolution, plate tectonics, magmatism and core evolution incorporating self-consistently calculated mineralogy

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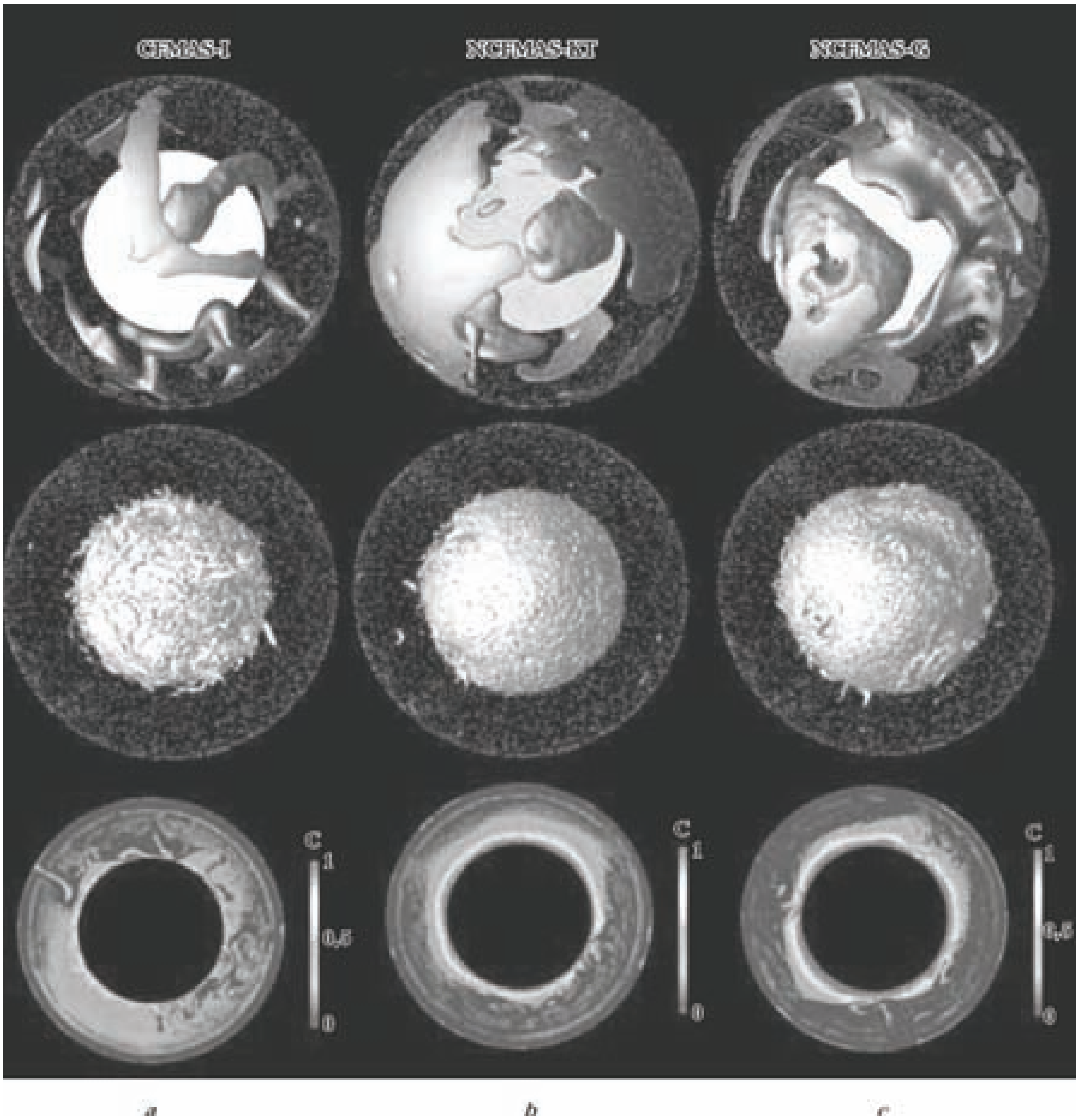
High pressure and temperature experiments and calculations of the properties of mantle minerals show that many different mineral phases exist as a function of pressure, temperature and composition (e. g., [Irifune, Ringwood, 1987]), and that these have a first-order influence on properties such as density, which has a large effect on the dynamics, and elastic moduli, which influence seismic velocity. Numerical models of thermo-chemical mantle convection have typically used a simple approximation to treat these complex variations in material properties, such as the extended Boussinesq approximation. Some numerical models have attempted to implement multiple, composition-dependent phases into thermo-chemical mantle convection (e. g., [Tackley, Xie, 2004]) and to calculate seismic anomalies from mantle convection simulations based on polynominal fitting for temperature, composition and mineral phase [Nakagawa, Tackley, 2006]. However, their linearised treatments are still approximations and may not adequately represent properties including effect of composition on phase transitions. In order to get closer to a realistic mineralogy, we calculate composition-dependent mineral assemblages and their physical properties using the code PERPLEX, which minimizes free energy for a given combination of oxides as a function of temperature and pressure [Connolly, 2005], and use this in a numerical model of thermo-chemical mantle convection in a three-dimensional spherical



Simulation results using three different compositions for basalt and harzburgite, showing (red isosurfaces) hot upwellings (blue isosurfaces) cold downwellings, (green isosurfaces) subducted crust, (bottom row) slices of compositoin. For full details see [Nakagawa et al., 2010].

shell, to calculate three-dimensionally-varying physical proporties. In this presentation we compare the results obtained with this new, self-consistently-calculated treatment, with results using the old, approximate treatment, focusing particularly on thermo-chemical-phase structures and seismic anomalies in the CMB region and the transition zone [Nakagawa et al., 2009; 2010]. The numerical models treat the evolution of a planet over billions of years, including self-consistent plate tectonics arising from plastic yielding, melting-induced differentiation, and a parameterised model of core evolution based on heat extracted by mantle convection. Results indicate while the behaviour is broadly similar between the self-consistent treatment and the parameterised treatment, details of the behaviour depend quite sensitively on exact compositions, particularly in the contents of Al and Na [Nakagawa et al., 2010]. This approach is also being used to study Mars, Venus, Mercury and super-Earths (Figure).

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Induced small-scale convection in the asthenosphere in continent-continent collision zones

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We investigated interaction of the lithosphere and the asthenosphere in continent-continent collision zone using a rheologically stratified model of the Earth outer shell including sedimentary layer, the lithosphere, the asthenosphere and uppermost part of the mantle. [Mikhailov et al., 1996]. The lithosphere — asthenosphere boundary is a rheological one and determined by position of specified isotherm. Equation for the top of the model includes detailed description of sedimentation and erosion. The model is asymptotically matched to the model of mantle convection what solves the problem of boundary conditions at its lower boundary. The model permits modelling of active extension and compression by mantle-induced or intraplate forces as well as relaxation of mechanical and thermal disequilibrium arose at active tectonic stages.

Active tectonic deformations of the Earth's outer shell by external mantle-induced or intraplate forces disturb thermal and mechanical equilibrium within this shell. Our model demonstrates that these disturbances lead to formation of small-scale convection within low-viscosity asthenosphere. This convection plays important role in restoration of thermal and mechanical equilibrium in the Earth outer shell and it style depends also on the surface (sedimentation and erosion) processes. Small-scale convection lasts over a long period of time after cessation of external tectonic forces, causing deformations in overlying lithosphere. In a continent-continent collision environment the small scale convection amplifies uplift of orogenic belts and causes subsidence at their periphery. We consider the small scale convection to be the main driving mechanisms of foredeep basins formation [Mikhailov et al., 1999; Timoshkina et al., 2010].

To illustrate this model we perform results of detailed modelling of the Great Caucasus orogen formation. To assign correctly initial conditions to the beginning of compressional stage, we considered preceding stages including: 1) extension of continental lithosphere in the early Jurassic; 2) subsequent post-extensional subsidence; 3) compressional (collisional) stage, when the system orogen — foredeeps forms. Parameters of the lithosphere and the asthenosphere and parameters of exten-