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Predicting isotopic signatures resulting from melting in global mantle models

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Many outstanding problems in Earth science relate to the geodynamical explanation of geochemical observations. Nowadays, extensive geochemical databases of surface observations exist, but satisfying explanations of underlying processes are lacking. Longstanding problems such as; the possible existence and sustainability of chemically distinct reservoirs in the Earth's mantle; the possible need of layered convection through much of Earth's history to explain chemical observations; and the heat flow paradox remain unsolved. One way to address these problems is through numerical modeling of mantle convection while tracking chemical information throughout the convective mantle. In the past decade, both numerical mantle convection codes and computer power have grown sufficiently to begin to grasp much of the full problem of the complex interlocking physics, chemistry and thermodynamics of the convecting mantle, lithosphere, continents and atmosphere.

We implemented a new way to track both bulk composition and concentration of trace elements in the well-developed mantle convection code TERRA. Our approach is to track bulk composition and trace element abundance via particles. One value on each particle represents bulk composition; it can be interpreted as the basalt component. The system is set up to track both radioactive isotopes (in the U, Th, K system) and noble gases (He, Ar). In our model, chemical separation on bulk composition and trace elements happens at self-consistent, evolving melting zones. Melting is defined via a composition dependent solidus, such that the amount of melt generated depends on pressure, temperature and bulk composition of each particle. A novel aspect is that we do not move particles that undergo melting; instead we transfer the chemical information carried by the particle to other particles. Molten material is instantaneously transported to the surface, thereby increasing the basalt component carried by the particles close to the surface, and decreasing the basalt component in the residue. For molten material that arrives at the surface, a fraction of its content of isotopes is moved into separate continent and atmosphere reservoirs.

Results will be presented in which we test and show the success and limitations of our implementation. We choose to use a simplified setup with calculations of incompressible mantle convection in spherical geometry. In these we will avoid complexities such as phase changes and elastic/plastic deformation and focus on different density and viscosity profiles. For these calculations we will show: 1: The evolution of bulk composition over time, showing the build up of oceanic crust (via melting induced chemical separation in bulk composition); i.e. a basalt-rich layer at the surface overlying a thin layer of depleted material (Harzburgite), and the transportation of these chemical heterogeneities through the deep mantle. 2: The amount of melt generated over time. 3: The evolution of the concentrations and abundances of different isotopes of the elements: U, Th, K, Pb, He and Ar, throughout the mantle as well as the atmosphere and continent reservoir. 4: Numerical details about the implementation.