I143-020 **Room: 201A** **Time: May 17 14:45-14:57**

A combined parameterized model for the Earth's thermal convection andmaterial fractionation

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The purpose of this study is to combine the following physical and chemical aspects concerning the Earth's evolution, which have been discussed separately so far: the Earth's thermal history deduced from parameterized convection theory and material fractionation of the 2-box geochemical model for the mantle-crust system.

A number of studies have been done on the Earth's thermal history, which suggests that the present-day Earth is under the cooling. Parameterized convection theory has played a significant role among them. The main idea of this theory is that convective heat loss can be expressed by Rayleigh number, Ra. Ra represents the strength of the thermal convection, and can be determined uniquely for a given temperature. The relationship among temperature, Ra, and heat loss can simplify the complex convection system and is useful to discuss the thermal budget.

When we discuss the Earth's thermal history, it is also necessary to consider the heat production terms. Radiogenic decay is one of the most important heat sources. Radioactive elements are fractionated with the material recycling between the mantle and the crusts (both oceanic and continental crusts), which results in a significant variation of the abundances of radioactive elements in the mantle. Existing models for the Earth's thermal history, however, neglect this effect of material fractionation, and assume an uniform exponential decay. Another problem in the existing models is that there are very limited constraints to justify the models, because the model results are expressed only by temperature of the (ancient) mantle, which is difficult to constrain.

The mantle-crust material fractionation is widely argued in isotopic geochemical studies. The idea that the continental crusts were built up by melt extraction from the upper mantle with the island arc volcanism is generally accepted. A number of authors have explored the geochemical models reproduce the present isotopic ratios with numerical methods. They assume plausible partition coefficients and mass fluxes for describing the material fractionation associated with the island arc volcanism. These fluxes are, however, rather ad hoc: e.g., assuming an exponential decay with time.

We try to combine these two models with both physical and chemical aspects. In the thermal history model, the temporal variations in concentrations of radiogenic elements (hence radiogenic heating) in the geochemical reservoirs are incorporated. The mass flux between the upper mantle and the continental crust is given as a function of Ra in the parameterized convection model. This approach gives us a thermal and convective history that is consistent with variations of the isotopic ratios of the mantle and the crusts. The isotopic ratios of the mantle and the crusts are recorded in the rocks, and can be a useful proxy of the thermal and convective state within the Earth. With appropriate parameters, we can reproduce the isotopic data of the present-day rocks, as well as the ancient rocks. Integration of mass fluxes between the reservoirs through time describes the temporal variation of mass of each reservoir, which enables us to calculate growth of the continental crust.