The energetics of evolving convective systems: Internal heating, mixing, and Earth's evolution.

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The Earth's mantle is heated by a combination of internal heating, from the decay of radioactive nuclei, and basal heating associated with core cooling. Convective velocities, energy, and heat loss depends on the combination of these heating modes. Yet, canonical models explicitly assume that endmember heating relationships –either pure basal or pure internal, that are relevant for either radiogenically depleted mantles or for mantle temperatures equal to that of the core, respectively – are valid for mixed heating systems. The key assumption implicit in such models is that a rapid increase in convective velocities, and consequently chemical mixing within the mantle, follows with increasing convective vigor (and surface heat flux) from increasing internal temperatures. This leads to the canonical prediction that younger, or hotter planets will have increased internal and surface velocities in order to balance higher heatflow. It then follows that early/hotter planets mix their interiors efficiently, such that inhomogeneities (e.g., primordial chemical reservoirs) would be difficult to retain, an inference apparently at odds with observations of the Earth.

In this work, we examine the underlying dynamics and energetics of convection using both isoviscous and temperature-dependant viscosity formulations under mixed heating conditions. We find convective velocities are decoupled from internal temperature and surface heat loss over much of the relevant radiogenic range. In pure isoviscous systems velocity decreases asymptotically with increasing internal heating rates, while temperature-dependant viscosity systems show only weak dependency. These results show a significant break with canonical endmember scaling behaviors for mixed heating systems. This suggests that in early planetary systems (with high internal heating rates) velocities may plateau, and that increasing heating (or temperature) will not necessarily result in increasing velocities, or mixing ability despite the increasing surface heat flux and convective vigor. Mixed heating results show that canonical thermal evolution and mixing models for the Earth, and indeed our understanding of Earth's evolution, needs to – and indeed shall – be revisited.