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Scaling of Mixing Rate in Mantle Convection Models: Influence of Plate Tectonics, Melting and Crustal Production

Paul Tackley
Department of Earth Sciences, ETH Zurich, Zurich, Switzerland (ptackley@ethz.ch)

It is generally thought that the early Earth's mantle was hotter than today, which using conventional convective scalings should have led to vigorous convection and mixing. Geochemical observations, however, suggest that mixing was not as rapid as would be expected, leading to the suggestion that early Earth had stagnant lid convection [Debaille et al., 2003]. Additionally, the mantle's thermal evolution is difficult to explain using conventional scalings because early heat loss would have been too rapid, which has led to the hypothesis that plate tectonics convection does not follow the conventional convective scalings [Korenaga, 2003]. One physical process that could be important in this context is partial melting leading to crustal production, which has been shown to have the major effects of buffering mantle temperature and carrying a significant fraction of the heat from hot mantle [Nakagawa & Tackley, 2012], making plate tectonics easier [Lourenco et al., 2016], and causing compositional differentiation of the mantle that can buffer core heat loss [Nakagawa & Tackley, 2010]. Here, the influence of this process on mantle mixing is examined, using secular thermo-chemical models that simulate Earth's evolution over 4.5 billion years. Mixing is quantified both in terms of how rapidly stretching occurs, and in terms of dispersion: how rapidly initially close heterogeneities are dispersed horizontally and vertically through the mantle. It is found that convection with plate tectonics, melting and crustal production does not follow the conventional Nu-Ra and velocity-Ra scalings derived from boundary-layer theory, and thus mixing in the early Earth is much less rapid than earlier thought. Reasons for this will be analysed in this presentation.