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Influence of Plate Tectonics, Melting and Crustal Production on the Scaling of Mixing Rate, Velocity and Heat flux

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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., EPSL 2013). 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, GRL 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 and Tackley, EPSL 2012), making plate tectonics easier (Lourenco et al., EPSL 2016), and causing compositional differentiation of the mantle that can buffer core heat loss (Nakagawa and Tackley, GCubed 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 in terms of how rapidly stretching occurs, in terms of dispersion (how rapidly initially-close heterogeneities are dispersed horizontally and vertically through the mantle) and in terms of processing rate (re-melting). 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, and also compared to geochemically-inferred mixing rates.