Evolution of Earth's early crust – coupling petrological and numerical modelling

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Most data suggest that plate tectonics has operated during the latter half of our planet's history, but the extent to which this tectonic mode operated during the first two billion years of Earth history is fiercely debated. Petrological and thermal models suggest ambient mantle potential temperatures (T_p) in the Archean were > or >> 1500 °C, leading to a higher degree of partial melting and generating thick (up to 45 km) MgO-rich primary (oceanic) crust that was underlain by highly residual mantle. However, the preserved volume of this crust is low, suggesting most was recycled or sequestered at depth in the mantle. Was this thick crust capable of being subducted, or was some other mechanism responsible for it's recycling?

We couple calculated phase equilibria for hydrated and anhydrous crust compositions and their residues with parameterized 2D geodynamic models to investigate the stability and evolution of early Archean lithosphere. Assuming a compositionally homogeneous crust, petrological modelling shows that, with increasing MgO content (and T_p), the density of primary crust increases more dramatically than the density of complementary residual mantle decreases. MgO-rich primary crust produced in a hotter mantle was ultramafic (i.e. lacked plagioclase) and would have become gravitationally unstable at its base. Thermomechanical modelling suggests that, at T_p >1500 °C, the base of this thick crust would have delaminated as drips into the underlying mantle. When internal differentiation of the primary crust is considered, the T_p over which efficient crustal delamination occurs is extended to lower values.

Delaminated crust would have refertilized residual mantle or melted as it sank, and return flow of the mantle would have caused adiabatic melting to form new basaltic crust, further driving delamination by magmatic thickening. Ultimately partial melting of this new basaltic crust, and/or lower-MgO components of internally-differentiated primary crust, would have produced the tonalite–trondhjemite–granodiorite rocks that characterise the Archean continental crust.