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Sink or swim? The fate of Archean primary crust and the generation of TTG magmas

Tim Johnson (1), Michael Brown (2), and Jill VanTongeren (3)

(1) Earth System Science Research Centre, Institute for Geosciences, University of Mainz, D–55099, Mainz, Germany (tjohnson@uni-mainz.de) , (2) University of Maryland, Department of Geology, Laboratory for Crustal Petrology, College Park, MD 20742, United States, (3) Department of Geology & Geophysics, Yale University, New Haven, CT 06511, United States

Petrological data and thermal models suggest ambient upper-mantle potential temperatures (Tp) in the Archean were > or » 1500 °C, significantly hotter than the present day. Higher ambient Tp would have led to extensive melting of the mantle and the production of a thick (up to 45 km) MgO-rich primary crust that probably formed by over- and intra-accretion of magmas, akin to modern oceanic plateaux. The calculated composition of primary melts and their complementary residues may be used as a proxy for the changing bulk composition of primary crust and lithospheric mantle (LM) with time. Most Archean primary crust was picritic and underlain by a highly residual LM. However, the preserved volume of these picrites is low suggesting that much of the primary crust is missing. Here we model the equilibrium mineral assemblages developed within a wide range of metamorphosed (hydrated) primary crust compositions and their complementary residues, assuming a Moho temperature of 1000 °C. Although the density of the LM decreases slightly with increasing Tp, the increase in the density of the complementary primary crust is much more dramatic. Thick crust built from primary melts with MgO of 21–22 wt% would have become gravitationally unstable at ∼1.5 GPa (∼40–45 km depth), even when fully hydrated, so that any thickening beyond this should have caused the base of the crust to founder. The base of primary crust with MgO > 22 wt%, potentially produced at extreme Tp, would have foundered without the requirement for any thickening. Archean TTG magmas were derived from partial melting of (garnet-) amphibolite, which is only stable in low MgO 'MORB-like' compositions, and cannot have been produced directly from the high MgO primary crust expected in the Archean. Instead, the basaltic protoliths for TTG magmas generated in the early Archean (> 3 Ga) were probably formed from fractional crystallisation of ultramafic primary magmas and/or partial melting of ultramafic primary crust. Three possible tectonic scenarios to generate TTG magmas are suggested as follows. (1) Modest over-thickening of thicker (35–40 km thick) high MgO primary crust could have promoted foundering of the cumulate and/or residue rich lower crust to bring hydrated basaltic protoliths into direct contact with the hot LM and generate TTG magmas that would have risen to shallower levels to stabilize the differentiated crust. (2) Tectonic over-thickening of thinner (25–30 km thick) high MgO primary crust by collision with thicker plateau crust could have driven hydrothermally altered upper crust of the overridden lithosphere into the garnet-amphibolite stability field where it could have melted to produce TTG magmas that would have intruded the overriding plateau crust. (3) In thinner primary crust with lower MgO (« 21 wt%), shallow subduction may have taken hydrothermally altered basaltic upper crust into the garnet-amphibolite stability field where it could have melted to produce TTG magmas that would have intruded the overriding plate.