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Early Earth tectonics and the generation of continental TTG crust in global mantle convection models

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The majority of continental crust formed during the hotter Archean was composed of Tonalite-Trondhjemite-Granodiorite (TTG) rocks. In contrast to the present-day loci of crust formation around subduction zones and intra-plate tectonic settings, TTGs are formed when hydrated basalt melts at garnet-amphibolite, granulite or eclogite facies conditions. Generating continental crust requires a two step differentiation process. Basaltic magma is extracted from the pyrolytic mantle, is hydrated, and then partially melts to form continental crust. Here, we use the mantle convection code StagYY (Tackley, PEPI 2008) with 2D spherical annulus geometry and show the self-consistent generation of TTG rocks under certain P, T conditions (Moyen, Lithos 2011) by parametrising the melt production and melt extraction processes. We systematically vary the ratio of intrusive (plutonic) and eruptive (volcanic) magmatism, initial core temperature, and internal friction coefficient to study the growth of TTG and the geodynamic regime of early Earth. As the amount of TTG that can be extracted from the basalt (or basalt-to-TTG production efficiency) is not known, we also test two different values in our simulations, thereby limiting TTG mass to 10% or 50% of basalt mass. For simulations with lower basalt-to-TTG production efficiency, volume of TTG crust produced is in agreement with net crustal growth models (Armstrong, AJES 1981; Dhuime et al., Sediment. Geol. 2017) but overall crustal (basaltic and TTG) composition stays more mafic than expected from geochemical data (Tang et al., Science 2016). With higher production efficiency, abundant TTG crust is produced, with a production rate far exceeding typical net crustal growth models but the felsic to mafic crustal ratio follows the expected trend. A general observation in all our simulations is the lateral spreading of the plumes at the surface, which forces parts of the lithosphere to be buried in the mantle. We see TTG production happening at the tip of these deformation fronts. The resolution of our simulations allows us to see lower crustal delamination and dripping, and recycling of continental crust. These modelling results indicate that (i) early Earth exhibited "plutonic squishy lid" or vertical-tectonics geodynamic regime, (ii) present-day slab-driven subduction was not necessary for the production of early continental crust, and (iii) Archean Earth was dominated by intrusive magmatism as opposed to "heat-pipe" eruptive magmatism.