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Generation of Archean TTGs by slab melting during sluggish, drip-like subduction

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The tectonic processes responsible for the formation of early Earth felsic crust (predominantly composed of tonalite-trondhjemite-granodiorite, or TTGs) inform the global regime of mantle convection that operated at this time. Many models have been proposed to explain the formation of Archean TTGs, including melting of downgoing crust in hot subduction zone settings, or melting of crust that is buried by lava flows and founders into the mantle. Formation in a subduction zone setting would imply at least some form of mobile-lid tectonics on the early Earth, while TTG formation via crustal burial and foundering does not require subduction or plate tectonics, and can thus occur in a stagnant-lid regime.

Regardless of tectonic setting, TTGs can only form if hydrated basaltic protocrust melts before it experiences metamorphic dehydration. Previous work has argued that this constraint may preclude a subduction origin to TTGs. Regional scale numerical models have found that slabs sink quickly and steeply through the mantle at Archean mantle temperatures, such that they dehydrate before melting. However, these models do not consider evolution of grainsize in the mantle interior and in plate boundaries. Using numerical models of mantle convection with grain damage, a mechanism for generating mobile-lid convection via grain size reduction, I show that a sluggish, drip-like style of subduction emerges at early Earth conditions. This subduction style is a result of plate boundaries becoming effectively stronger with increasing mantle temperature, and leads to significant slab heating at shallow depths.

To test whether TTGs can form from this style of sluggish subduction, I use scaling laws developed from numerical models combined with a simple model of the evolution of the vertical temperature profile through a slab. Results show that the slower sinking speed of slabs caused by grain size evolution in plate boundaries allows for crustal melting for a much wider range of mantle temperatures and subducting plate thicknesses than if the effects of grain size evolution were ignored. Overriding plate thickness is also important, with thin overriding plates favored for TTG formation. These results have important implications for the settings where subduction could generate Archean TTGs, and for potential episodicity in TTG formation resulting from both short- and long-term episodicity in subduction.