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Fractional Crystallisation of Archaean Trondhjemite Magma at 12-7 Kbar: Constraints on Rheology of Archaean Continental Crust

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Tonalite-Trondhjemite-Granodiorite (TTGs) group of rocks, that mostly constitute the Archaean continental crusts, evolved through a time period of ∼3.8 Ga-2.7 Ga with major episodes of juvenile magma generations at ∼3.6 Ga and ∼2.7 Ga. Geochemical signatures, especially HREE depletions of most TTGs conform to formation of this type of magma by partial melting of amphibolites or eclogites at 15-20 kbar pressure. While TTGs (mostly sodic in compositions) dominates the Eoarchaean (∼3.8-3.6 Ga) to Mesoarchaean (∼3.2-3.0 Ga) domains, granitic rocks (with significantly high potassium contents) became more dominant in the Neoarchaean period. The most commonly accepted model proposed for the formation of the potassic granite in the Neoarchaean time is by partial melting of TTGs along subduction zones. However Archaean granite intrusive into the gabbro-ultramafic complex from Scourie, NW Scotland has been interpreted to have formed by fractional crystallization of hornblende and plagioclase from co-existing trondhjemitic gneiss.

In this study we have studied fractional crystallization paths from a Mesoarchaean trondhjemite from the central Bundelkhand craton, India using MELTS algorithm. Fractional crystallization modeling has been performed at pressure ranges of 20 kbar to 7 kbar. Calculations have shown crystallization of garnet-clinopyroxene bearing assemblages with progressive cooling of the magma at 20 kbar. At pressure ranges 19-16 kbar, solid phases fractionating from the magma are mostly clinopyroxene with minor orthopyroxene. Plagioclase crystals appear at pressures $\leq$ 15 kbar. Plagioclase crystals are mostly albitic in composition (XAb ∼0.70-0.75).

At each pressure, with progressive cooling and fractionation of solid phases, crystal-melt ratio becomes significantly higher, magma becomes more depleted in $Al2O_3$, MgO, with significant increase in K2O/Na2O ratio and water content. With progressive cooling and fractionation, overall composition of the magma changes from trondhjemitic to granitic, with increase in viscosity from 4.5 poise to 5.5 poise.

The study thus reveals that fractional crystallization of trondhemitic magmas at different depths can form more potassic granitic magma with higher viscosity. As Hf isotope signatures from most Archaean TTGs reveal longer crustal residence, it is likely that granitic magmas that became more common in the Neoarchaean period, could also possibly been derived by fractional crystallization from trondhjemitic magmas in Mesoarchaean time.

Granitic magmas hence generated have much higher viscosity compared to the parent trondhjemitic magma. Low viscosity of trondhjemitic magmas and low crystal-melt ratios in the initial stages of crystallization (as derived in this study), may be the cause of formation of large bodies of TTGs in Early Archaean period. Close to Neoarchaean period more granitic magmas are observed. In this study it has been observed that crystallization of these magmas lead to high crystal-melt ratios and the magmas have higher viscosity. Such change in composition from Early to Neoarchaean time must have made Archaean crusts stronger and hence more prone to deformation. This observation hence support occurrence of Phanerozoic style signatures from poly-deformed terrains of Neoarchaean time.