# Growing and strengthening cratonic mantle

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Cratonic mantle preserves radiogenic isotopic signatures dating back to the time of craton formation, and is thus thought to have been isolated from the convecting mantle for billions of years. This longevity seems to require that cratonic mantle is intrinsically strong. While their cold temperatures make cratonic roots strong, temperature alone is insufficient to maintain strength as cratonic roots should heat up with time. The strength of cratonic roots is thus thought to be due to the depletion of trace hydrogen in olivine due to high degrees of melt extraction. However, xenolith studies show that cratonic mantle in many cases may have been re-hydrated by metasomatic processes, which should paradoxically make cratonic mantle weak. Here, we first show that the igneous protoliths of cratonic mantle formed at high temperature and low pressure, but were then subjected to thickening and cooling during a major orogenic event. At high temperatures, Al solubility in pyroxenes is high such that igneous pyroxenes should have higher Al contents. Upon cooling and pressure increase, Al is exsolved out in the form of subsolidus garnet. Modern analogs of this process are seen in sub-arc environments, where garnet exsolution from pyroxene results in the development of Al diffusion depletion halos in pyroxenes adjacent to garnet. We show that pyroxenes in cratonic mantle peridotites have uniformly low Al and REE contents, indicating exsolution of garnet. However, we see no evidence for zonation in Al. For any plausible cooling history, diffusion modeling predicts that zonation should exist for the lengthscales characterizing the pyroxenes (mm). We show that the only way mineral grains can be completely homogenized in Al is if characteristic grain sizes were initially much smaller, on the order of hundreds of microns or less. This suggests that garnet exsolution occurred when grain sizes were very small, perhaps due to mylonitization associated with deformation during orogenic thickening. Subsequent annealing led to grain growth, resulting in unzoned coarse grains. As strength scales with grain size in the diffusion creep regime, we suggest that such annealing led to strengthening of the lithosphere, eventually transitioning the lithosphere into a dislocation creep regime. Such a model may reconcile how cratonic roots can remain strong even if they have been rehydrated by metasomatism. Metasomatism itself may have accelerated grain growth, leading to rapid strengthening.