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Metasomatism and the Weakening of Cratons: A Mechanism to Rift Cratons

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The preservation of cratons is a demonstration of their strength and resistance to deformation. However, several cratons are rifting now (e.g. Tanzania and North China Craton) or have rifted in the past (e.g. North Atlantic Craton). To explain this paradox, we suggest that widespread metasomatism of the originally cold depleted dehydrated craton mantle lithosphere root can act as a potential weakening mechanism. This process, particularly melt metasomatism, increases root density through a melt-peridotite reaction, and reduces root viscosity by increasing the temperature and rehydrating the cratonic mantle lithosphere. Using 2D numerical models, we model silicate-melt metasomatism and rehydration of cold cratonic mantle lithosphere that is positioned beside standard Phanerozoic lithosphere. The models are designed to investigate when a craton is sufficiently weakened to undergo rifting and is no longer protected by the initially weaker adjacent standard Phanerozoic lithosphere. Melt is added to specified layers in the cratonic mantle lithosphere at a uniform volumetric rate determined by the duration of metasomatism (3 Myr, 10 Myr or 30 Myr), until a total of $\sim$30% by volume of melt has been added. During melt addition heat and mass are properly conserved and the density and volume increase by the respective amounts required by the reaction with the peridotite. No extensional boundary conditions are applied to the models during the metasomatism process.

As expected, significant refertilization leads to removal and thinning of progressively more gravitationally unstable cratonic mantle lithosphere. We show that the duration of metasomatism dictates the final temperature in the cratonic upper mantle lithosphere. Consequently, when extensional boundary conditions are applied in our rifting tests in most cases the Phanerozoic lithosphere rifts. The craton rifts only in the models with the hottest cratonic upper mantle lithosphere. Our results indicate rifting of cratons depends on the timing of extension, with respect to metasomatism. The key effect is the associated increase in temperature which must have time to reach peak values in the initially cold and strongest, uppermost mantle lithosphere. However, it remains true that the model cratons mostly remain strong and only rift when subjected to intensive metasomatism. This may explain why so many cratons have survived and only a few have rifted.

An additional effect is that the craton surface subsides isostatically to balance the increasing density of craton mantle lithosphere where it is moderately metasomatized. We suggest that this is the mechanism that forms intracratonic basins. If correct, subsidence and subsequent uplift of intracratonic basins, and cratonic rifting constitute evidence of progressive metasomatism of cratonic mantle lithosphere.