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Surface topography as key constraint on thermo-rheological structure of cratons

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The question why Archean cratons (i.e. the oldest continental plates such as Canada and Australia) survived for billions of years while the rest of the lithosphere has been reworked for several times is both enigmatic and fundamental for plate tectonics. Craton longetivity has been so far explained by their buoyancy and analysed by testing gravitational stability of hardly detectable cratonic mantle “keels” as a function of a hypothesized plate thickness and thermo-rheological structure. Catastrophic destruction of some cratons suggests that buoyancy is not the only factor of their stability, and previous studies show that their mechanical strength is as important as buoyancy. The upper bounds on their strength are provided by flexural studies demonstrating that Te values (equivalent elastic thickness) in cratons are highest in the world and limited to $\sim$ 150 km. Yet, the lower bounds are still matter of debate, as well as the question how the mechanical strength is partitioned between crust and mantle, and which set of rheological parameters represents this behaviour. We show that primary observed cratonic features - flat topography and “frozen” heterogeneous crustal structure – represent the missing constraints for understanding of craton longevity. The cratonic crust is characterized by huge isostatically misbalanced density heterogeneities, suggesting that the lithosphere has to be strong enough to keep them frozen through the time without producing major gravitational instabilities and topographic undulations. Hence, to constrain thermo-rheological properties of cratons one should first investigate the stability of their topography and internal structure. Our thermo-mechanical numerical experiments accounting for free surface boundary condition notably demonstrate that craton stability cannot be warranted by crustal strength, and that strong dry olivine mantle rheology and cold thick lithosphere (1330°C at $\sim$300 km depth) are needed for craton survival, allowing for discarding weaker, “wetter” or hotter alternatives. Hence, without pretending to explain the whole enigma of cratonic survival, nor to reproduce the evolution of any particular craton, we find fairly robust lower-bound limits on their thermo-rheological structure.