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Longevity and rheology of cratons: key constraints from surface topography

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Archean cratons are stable remnants of Earth's early continental lithosphere. Their structure, composition and survival over geological time spans make them ones of the most unique and enigmatic features of the Earth's surface. It has become evident from both geophysical and petrological studies that cratons exhibit deep lithospheric roots, which remained stable ever since their formation in the early Archean.

The question of how some of the cratons survived destruction over timescales of billions of years remains a subject of vigorous debate. In order to understand what controls the long-term stability of the cratons, we investigated the impact of the thermo-rheological structure of the lithosphere on the evolution of both surface topography and cratonic roots using fully coupled thermo-mechanical numerical models (600*3000 km, free upper surface topography, layered lithospheric structure).

Our model has a particular focus on the Canadian Shield, where considerable structural and thermal data are available from both geological and geophysical studies. In particular, we compare the implications of the "Cratonic" "Jelly-Sandwich" rheology (JS; strong dry olivine mantle, strong crust, cold geotherm with Moho temperature of 400°C, thermal lithosphere thickness of 250 km) with those of the "Crème Brûlée" rheology (CB; strong crust, weak wet olivine mantle, Moho temperature of 600°C, thermal lithosphere thickness of 150 km) (Figure 1). Our experiments show that, in the case of a laterally homogeneous lithosphere and in the absence of tectonic shortening or extension (blocked borders), both JS and CB rheologies may account for the stability of the shield and its surface topography. In this case continental lithosphere remains stable over large time spans, even for the weakest wet olivine mantle (but for "cold" thermal gradients). Nevertheless, for a laterally heterogeneous crust, as is the case for the Canadian Shield and most cratons, dry olivine mantle JS rheology provides a far more stable lithosphere, with surface undulations < 1000m over 0.3 Gy time spans, compared to the unlikely $\sim$8000m surface undulations produced by CB rheology (Figure 2). In addition, the CB lithosphere gets quickly unstable when minor tectonic compression is applied, generating unrealistic short-wavelength surface undulations. These results demonstrate the need to consider buried loads and tectonic forces whenever constraining long-term rheological properties of the lithosphere, and suggest that the "Jelly-Sandwich" rheology so far better accounts for natural observations.

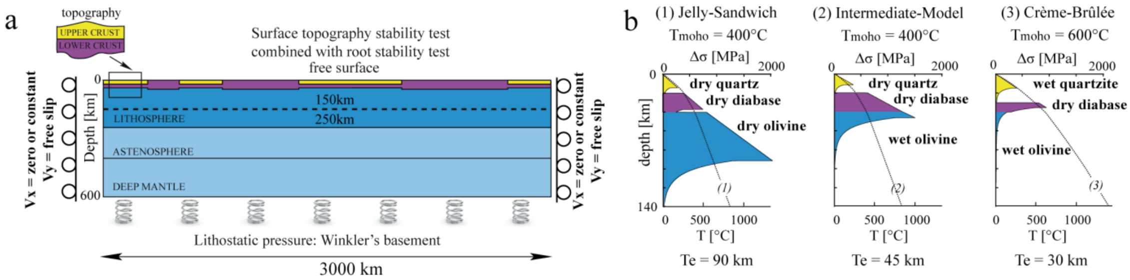

Figure 1: (a) Design of the numerical model for stability analysis of lithosphere with a positively buoyant depleted mantle. (b) Three tested visco-elasto-plastic yield strength rheological profiles: two end-member assumptions (strongest and weakest) and one intermediate case, respectively: "Jelly-Sandwich", JS, "Crème-Brûlée" profile, CB, and Intermediate profile, IM.

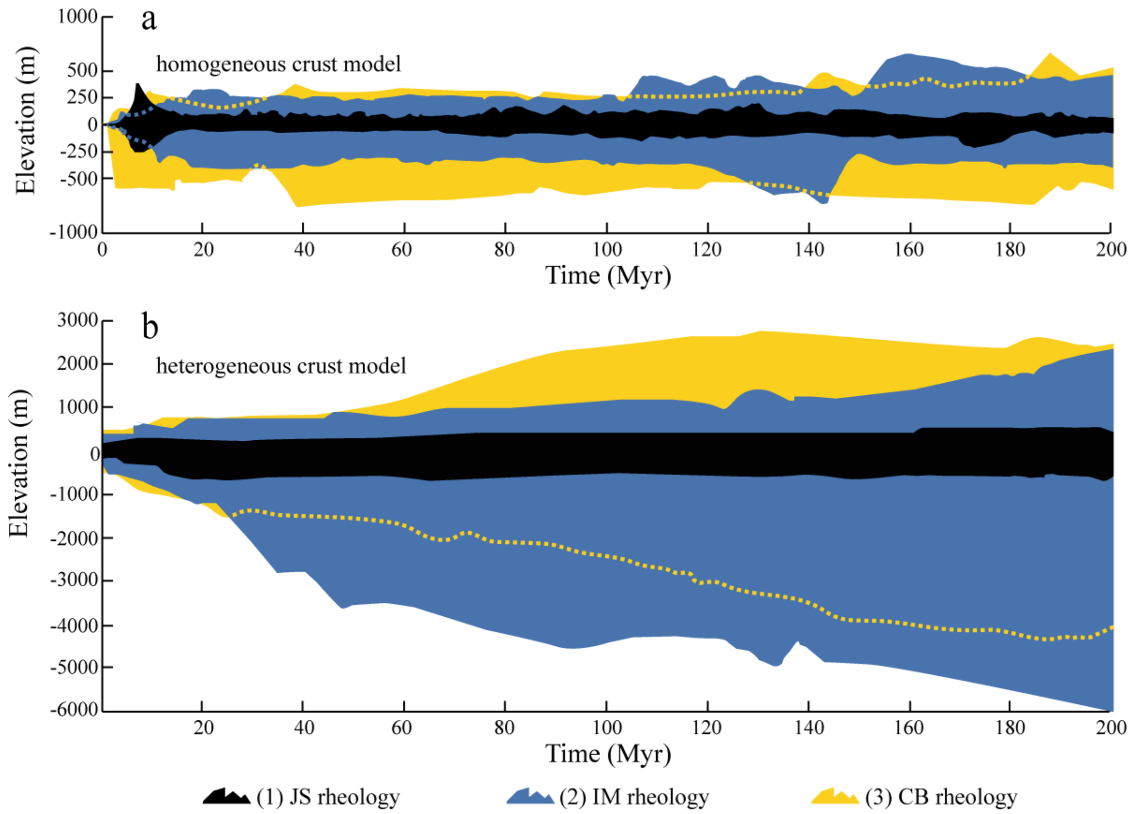

Figure 2: Predicted maximum amplitude of surface topography as a function of time in the case of homogeneous crustal model (a) and heterogeneous crustal model (b) for the three rheological assumptions.