Self-induced craton compression: Potential implications for craton stability

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1. Introduction

Previous numerical modeling studies including thick and viscous cratons showed tractions increase along the periphery of cratons. The reason of such high traction and their role in craton stablization has not be properly explored.

In this study, we develop instanteneous mantle global spherical convection models using a finite element code CitcomS to investigate the reason for having such elevated traction along cratons' periphery and their role in craton stabilization.

2. Hypothesis of self-compression

The diversion of mantle flow by the thick and highly viscous root of a craton can generate strong and inwardly-convergent tractions at the craton's periphery. Inwardly-convergent tractions produce a compressive stress regime within them, supporting cratonic stability against mantle shearing, and therefore could be essential for cratonic longevity.

3. Mantle convection model

Instantaneous global spherical convection models are developed using CitcomS. Cratons are 10x, 100x, 1000x viscous than lithosphere and they are 300 km thick. Models are driven by SMEAN2 tomography densitiy anomly. Resultant traction and stress regime are plotted in fig. 1.

4. Tractions as velocity gradients

Traction vector (τ) from the $\sigma_{r\varphi}$ and $\sigma_{r\theta}$ components of the deviatoric stress tensor that relate to horizontal shear:

$$\bar{\tau} = 2\eta\sqrt{\underbrace{\left(\frac{\partial v_\varphi}{\partial r}+\frac{\partial v_r}{\partial \varphi}\right)^2}_{\sigma_{r\varphi}}+\underbrace{\left(\frac{\partial v_\theta}{\partial r}+\frac{\partial v_r}{\partial \theta}\right)^2}_{\sigma_{r\theta}}}$$

Near craton boundary horizontal velocity (v_φ and v_θ) becomes negligible. Hence, traction can be approximated as horizontal gradient of vertical velocity:

$$\bar{\tau} = 2\eta\sqrt{\left(\cancelto{0}{\frac{\partial v_\varphi}{\partial r}}+\frac{\partial v_r}{\partial \varphi}\right)^2+\left(\cancelto{0}{\frac{\partial v_\theta}{\partial r}}+\frac{\partial v_r}{\partial \theta}\right)^2}$$

6. Conclusions

1. Mantle flow is diverted (typically downward) due to thick and viscous cratonic roots.

2. Large velocity gradients along craton margins amplify tractions along the craton periphery. The downward diversion of mantle flow produces inward-directed tractions that induce a self-compressive stress regime within all cratons.

3. Self-compression could help to keep smaller continental blocks together within larger cratonic units.

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Paul J, Conrad CP, Becker TW, Ghosh A, Convective self-compression of cratons and the stabilization of old lithosphere, Under review, *Geophysical Research Letters.*

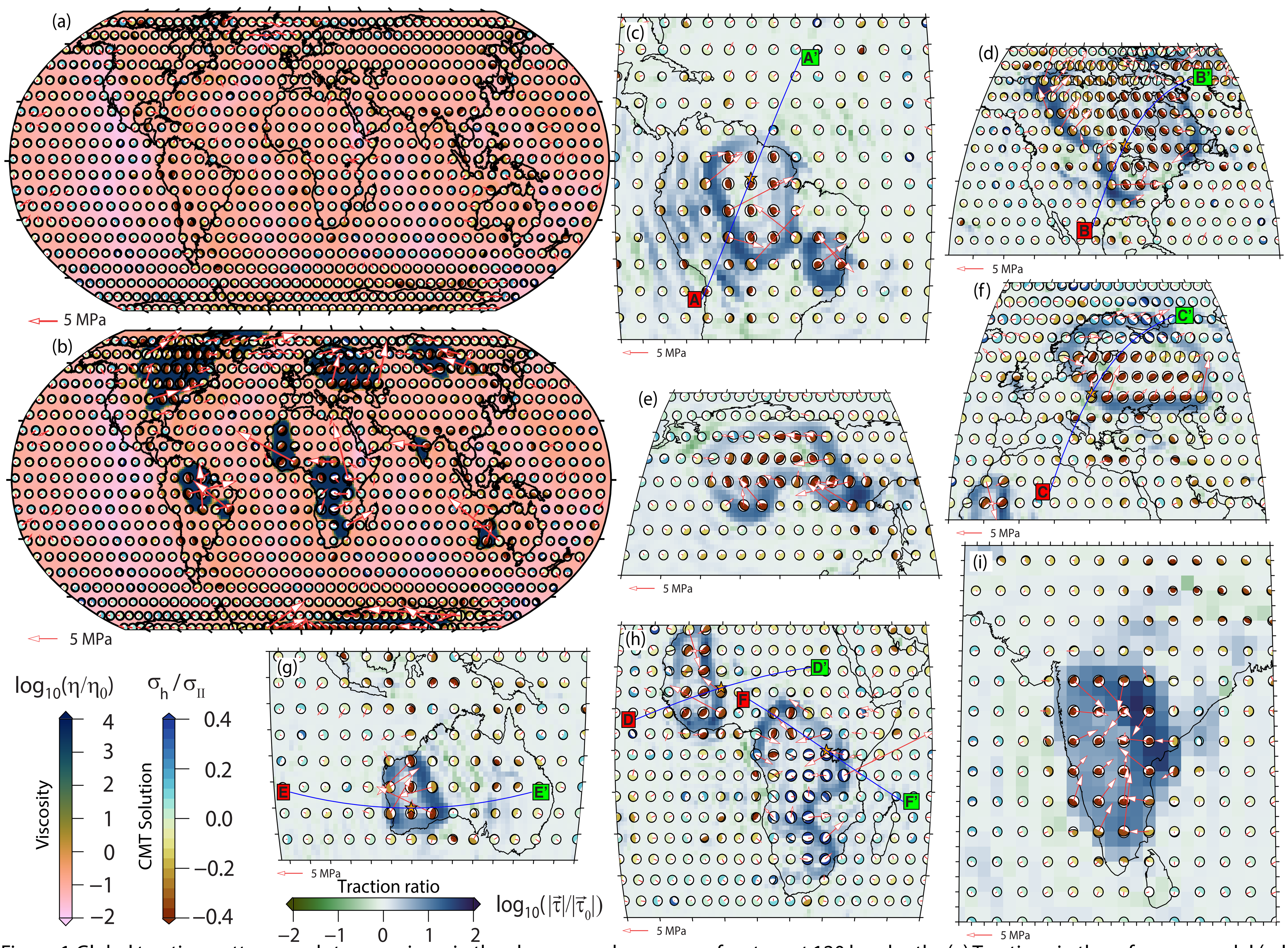

Figure 1.Global traction patterns and stress regimes in the absence and presence of cratonsat 120 km depth. (a) Tractions in the reference model (relative viscosity of asthenosphere is 0.1)without cratons, (b) Tractions in a model with 0.1 relative viscosity of asthenosphere and cratons that are 100×more viscous than the surrounding lithosphere. Background colors in the global plots (a-b) indicate viscosity, and arrows represent the magnitude and direction of absolute trac-tion. CMT symbols are colored as the ratio of mean horizontal stress to the second invariant of deviatoric stress (σ_h/σ_{II}), where negative values represent compressive stress regimes. (c)-(i) Zoomed-in plots near the cratonic regions of South America (c), North America (d), Siberia (e),Scandinavia (f), Australia (g), Africa (h), and India (i). The background colors in (c-i) representthe logarithm of the traction ratio ($\log_{10}(|\bar{\tau}|/|\bar{\tau}_0|)$). Velocity cross-sections along the six transects(AA' - FF') are shown in Fig. 3.

5. Horizontal gradient of vertical velocity and origin of compression

We calculate ratio of horizontal gradient of vertical velocities (RHG) from models with and without cratons. Higher RHG indicates stronger flow diversion. Ring of high RHG is found along craton periphery, indicating flow diversion is the key for the elevated tractions and subsequent compression.

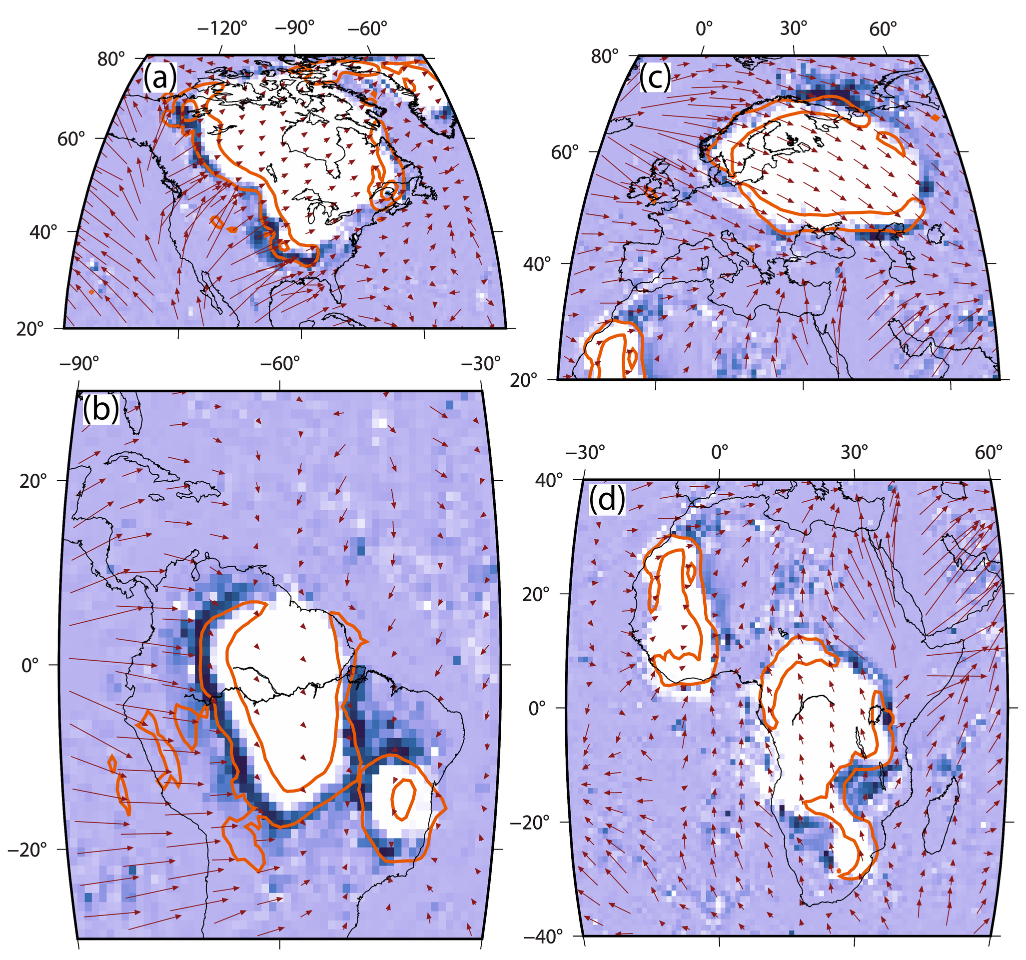

Figure 2. Maps of the ratio of horizontal gradients of vertical velocity (RHG) at120 km depth from model with 0.1 relative viscosity of asthenosphere and 100× viscous cratons than the surrounding lithosphere. Horizontal velocity vectors at 120 km depth are plotted on top of it. Orange lines encircle areas where$|\tau|/|\tau_0|>5$ at 120 km depth.

Figure 3: Comparison of velocity cross-sections up to 600 km with and without cratons along the transects shown in Figs. 1c-i. Each figure is paired where the left figure shows the velocity profile without a stiff craton, and the right figure shows the same with craton. The name ofthe continental mass that contains the craton is given for all corresponding right-side figures. Background colors represent the logarithm of relative viscosity, and the arrows represent velocity vectors along the transect.