Time dependent 3-D numerical modeling of cratonic evolution

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Origin of problem (a)

More than **65-70% of continental crust** was formed around **3 Ga** and **only 5%** of them are preserved today as **cratons (Blue areas in Fig.2)**. **How did these cratons survive for billions of years?**

Only **compositional density can not provide** long-term stability of cratons; they need to be **mechanically strong or highly viscous.**

Estimate of craton viscosity remains elusive.

Earlier findings from instantaneous models (b)

Paul et al. (2019) developed instantaneous mantle convection models driven by density anomalies obtained from tomography. Additionally, they used free slip boundary condition at the surface and core-mantle boundary.

Their results showed that with **increasing lithospheric thickness** intensity of **deformation decreases** (Fig. 1). This could potentially stabilize cartons (thickness > 180 km). Moreover, they also found **asthenosphere viscosity** plays an important role in cratons' survival.

Goals of present study: 1. Do we observe similar **deformation pattern** In time-dependent models?

2. Does asthenosphere viscosity play a significant role in craton survival?

3. What is the **minimum requirement of viscosity** for cratons and asthenosphere?

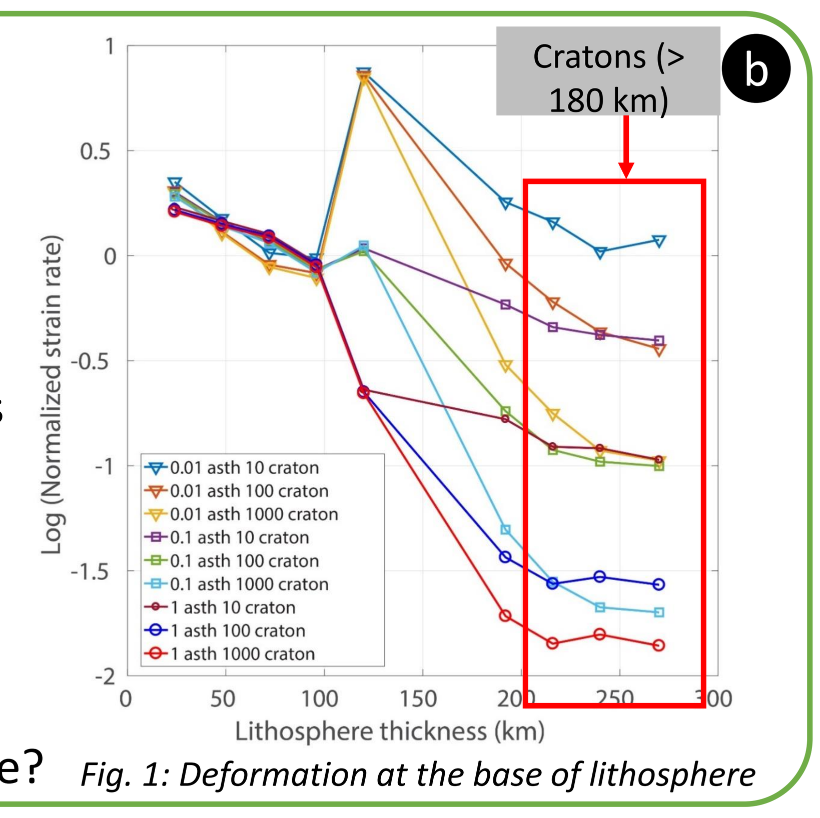


Fig. 1: Deformation at the base of lithosphere

Present approach using time-dependent models (c)

We **reconstruct** cratons' locations till 409 Ma using finite rotation of Euler poles using Gplates (Fig. 2). CitcomS is used to develop time-dependent mantle convection **models from 409 Ma to present day** using velocity (obtained from GPlates) as surface boundary condition at every 1 Myr. Few results of cratonic evolution are shown below (Figs. 4, 5).

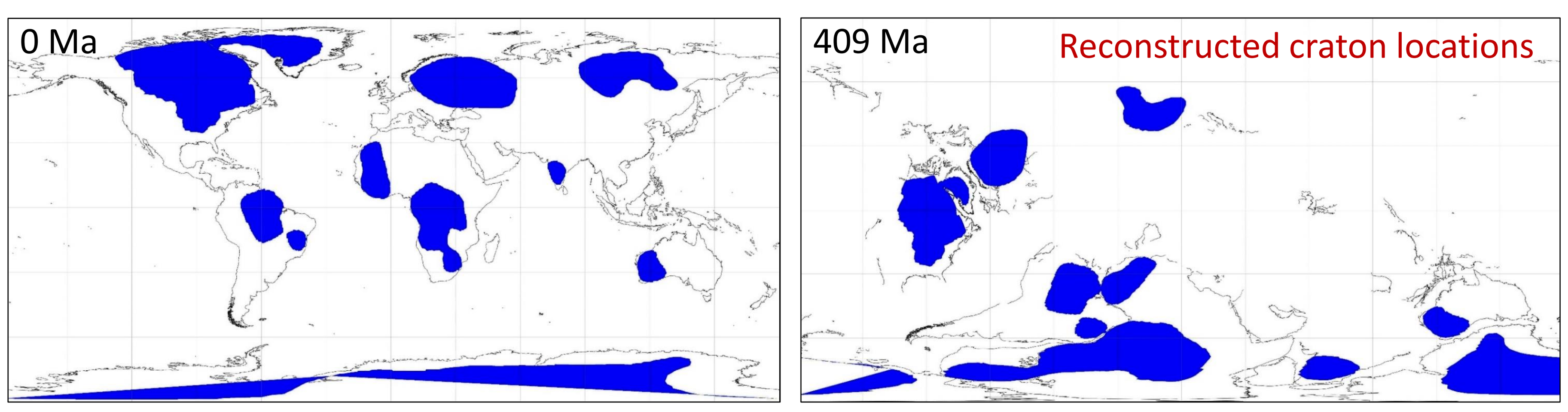
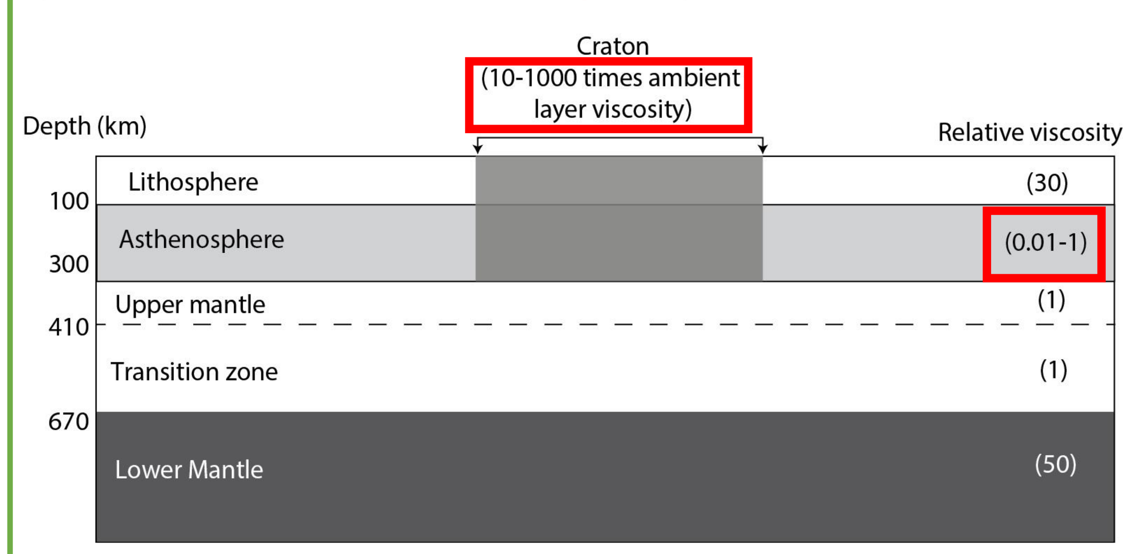


Fig. 2: Present day locations and reconstructed location of cratons

Viscosity of mantle models (d)

Both **radial and lateral viscosity variation** is incorporated in convection models (Fig. 3) and 9 models of different viscosity combination are produced. **Craton viscosity** vary from **10-1000** times the surroundings;



asthenosphere viscosity ranges between **10^{19} – 10^{21} Pa-s.**

Relative viscosity is multiplied with reference viscosity of upper mantle

Fig. 3: viscosity structure of mantle model

Cratonic evolution with time in different models (e)

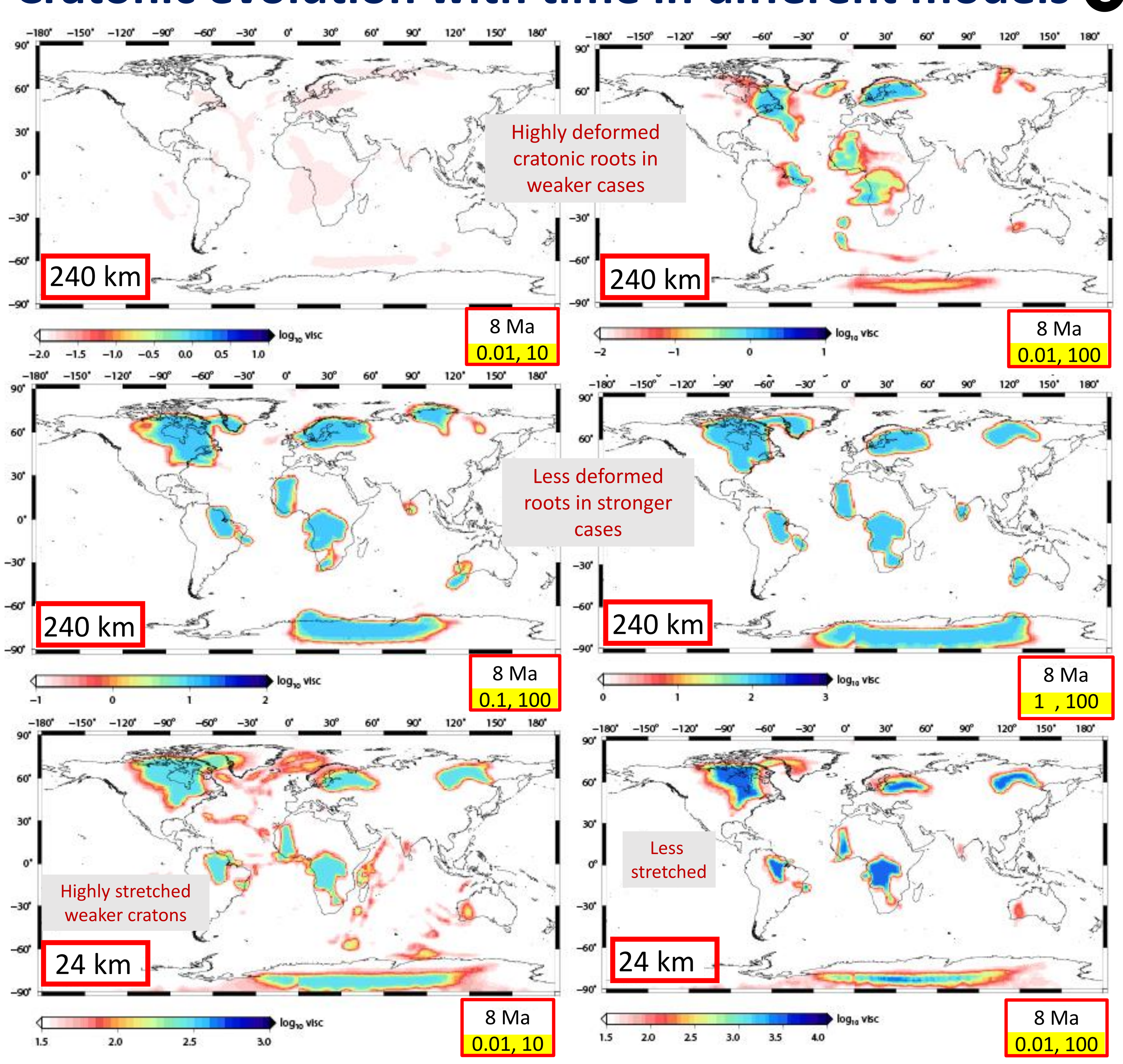


Fig 4 : Viscosity maps of final stage of cratonic evolution (Paul and Ghosh, in review, EPSL)

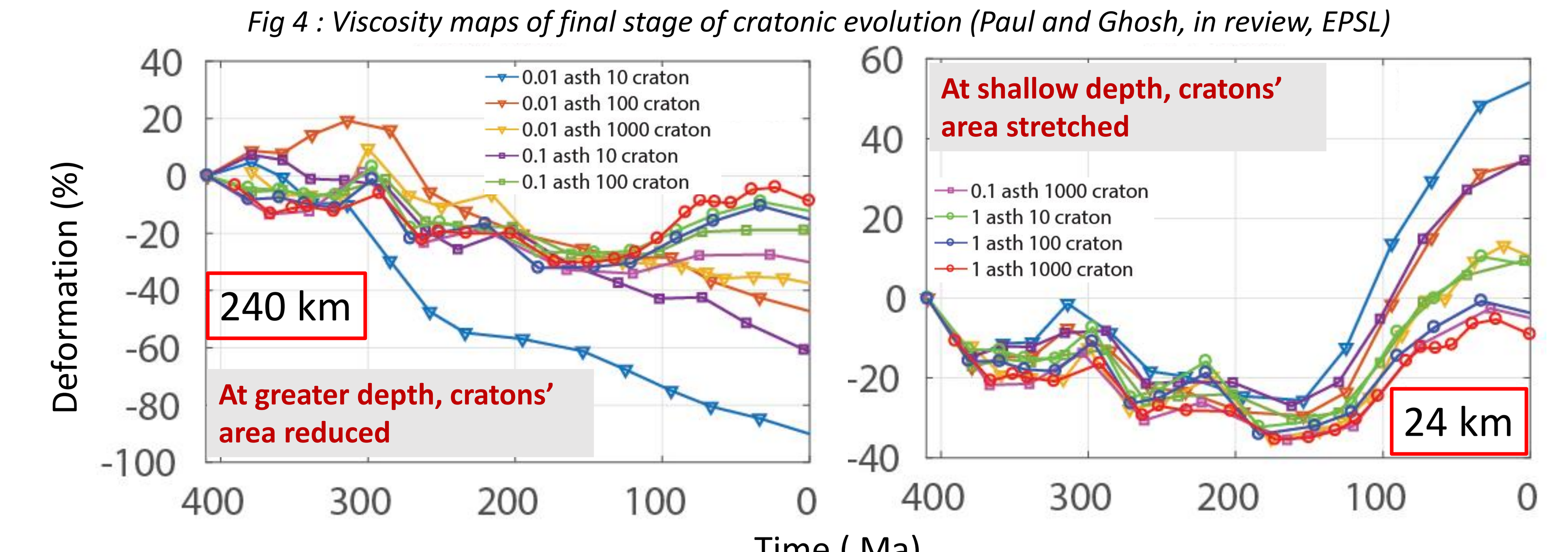


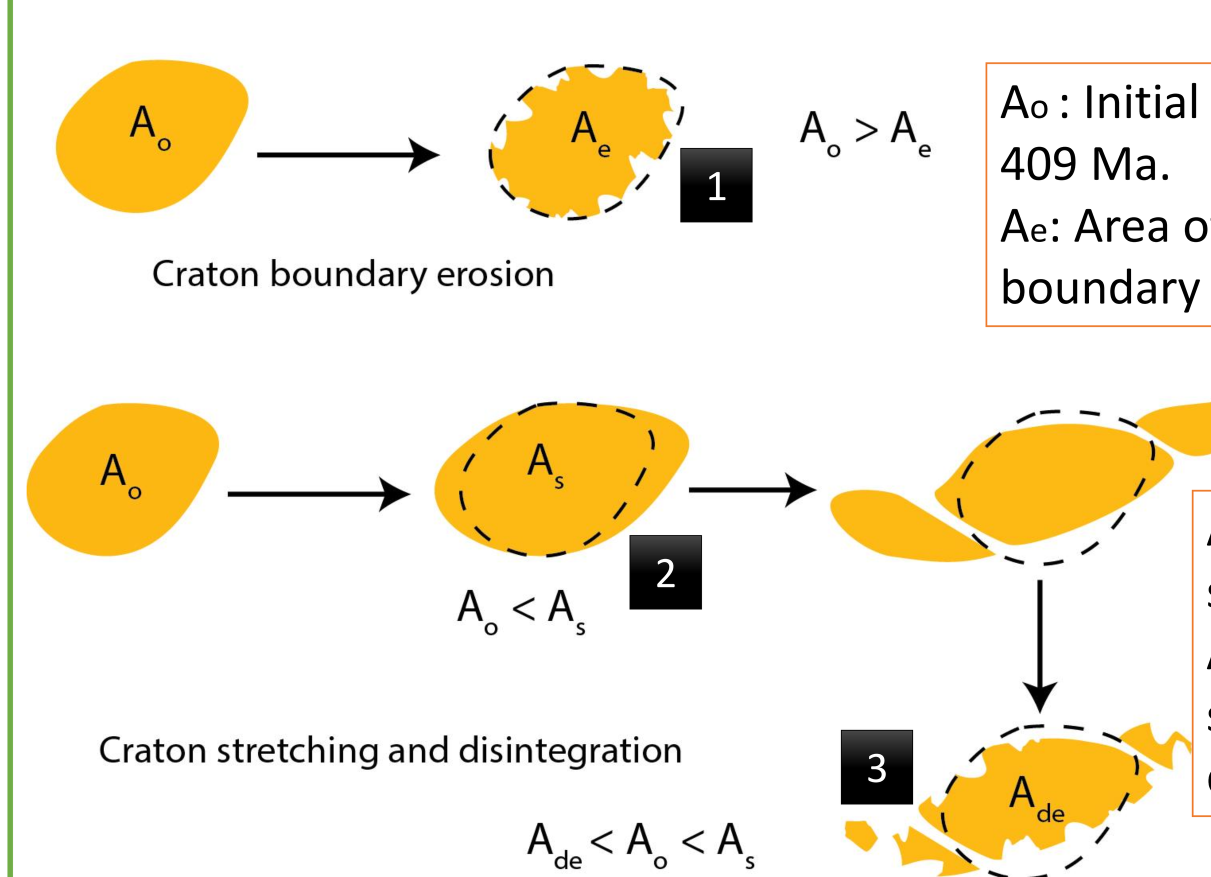
Fig 5: Deformation of cratons with time (Paul and Ghosh, in review, EPSL)

$$\text{Deformation (D)} = 100 \times \left(1 - \frac{\text{Area of craton at 409 Ma } (A_o)}{\text{Area of craton at time t } (A_t)}\right)$$

D > 0, extension of cratons area; D < 0, reduction of cratonic area

Numbers within yellow highlighted boxes indicate asthenosphere and craton viscosity, respectively.

Mechanism of deformation (f)

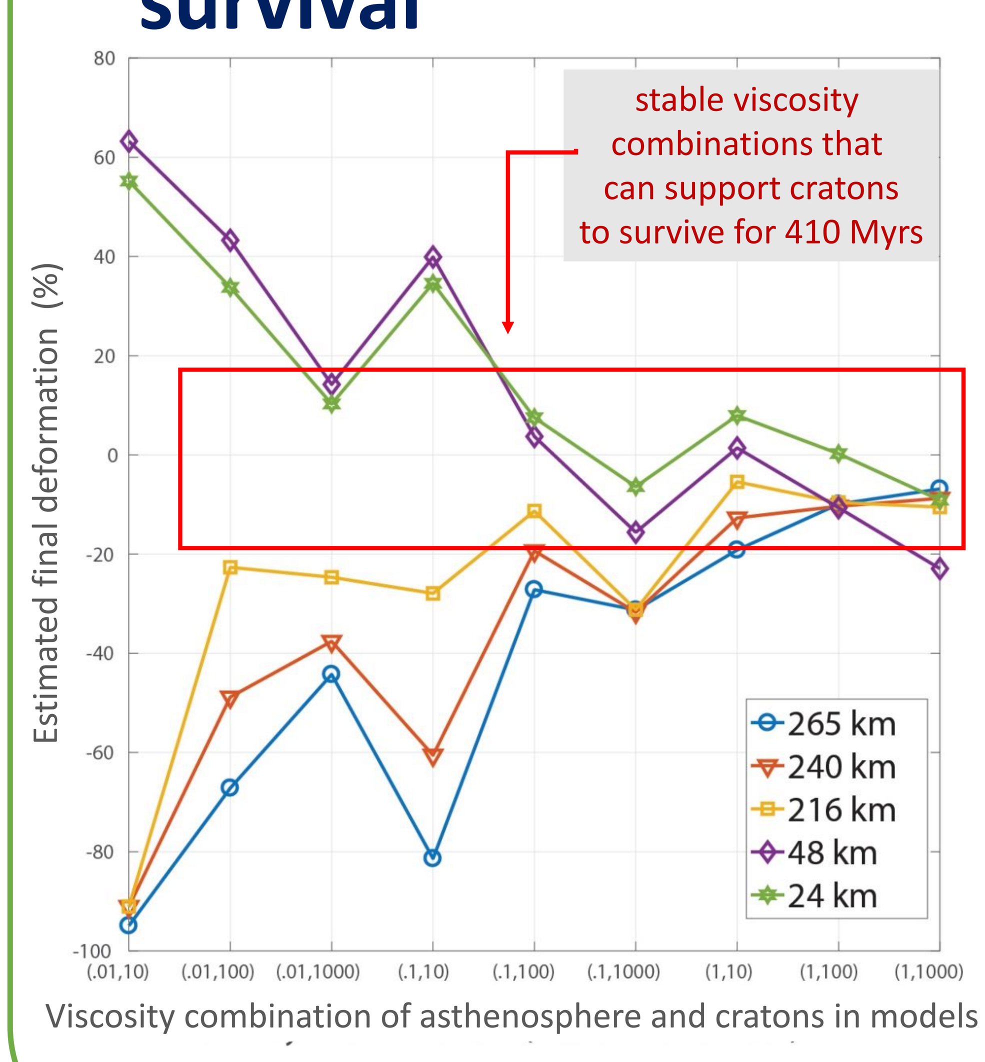


A_o : Initial area of craton at 409 Ma.
A_e: Area of craton after boundary erosion

A_s : Area after stretching
A_{de}: Area after stretching and disintegration

Fig 6. Schematic diagram of craton deformation (Paul and Ghosh, in review, EPSL)

Viscosity combination for cratons' survival (g)



Deformation of cratons at the present day estimated from all models at different depths.

10 times viscous cratons surrounded by 10^{19} Pa-s asthenosphere have undergone ~90% reduction of roots and ~70% stretching near surface within 410 Myrs. This combination of viscosity can not support long term survival of cratons.

With increasing viscosity deformation decreases and cratons can potentially survive for billions of years.

Fig 7. Final deformation of cratons at different depths (Paul and Ghosh, in review, EPSL)

Conclusions (h)

1. Survival of cratons is dependent on the **viscosity of cratons** and as well as that of the **surrounding asthenosphere**.
2. Minimum requirement of viscosity: **asthenosphere** viscosity **10^{20} Pa-s**, **cratons 100 times** more viscous than surrounding.
3. Cratons having the above viscosity structure are at least able to survive till 410 myrs.

Reference: 1. J. Paul, A. Ghosh, C. P. Conrad. Traction and strain-rate at the base of the lithosphere: An insight into cratonic survival, *Geophysical Journal International,* 2019.

2. J. Paul and A. Ghosh,. : Evolution of cratons through ages: A time-dependent study, *Earth and Planetary Science Letters, In review.*

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