Understanding stability of cratons using numerical modelling

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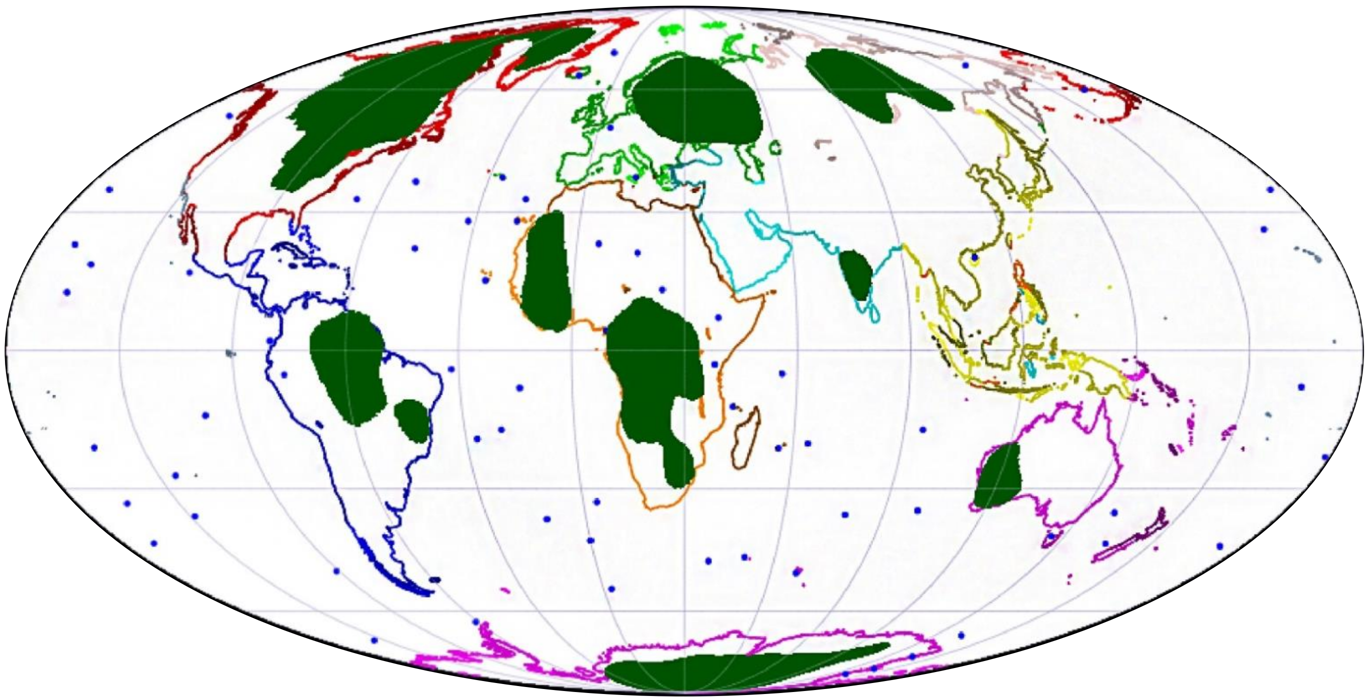
Introduction

Stable continental parts

Fast seismic velocity



Thick lithosphere

Nataf and Ricards, 1996

Low heat flow

On Stability of cratons

Why do we bother?

Every other non-cratonic lithosphere gets recycled into mantle

Lithosphere Recycling processes:

1. Subduction
2. Gravitational delamination
3. Mantle shearing

Aim of my work

Investigate the reasons of cratonic stability:

- They are only neutrally buoyant? (Jordan 1975, 1978)
- Only low density material can not withstand convective erosions (Lendardic et al. 2003)
- Need for a strong material to withstand mantle convection forces (high viscosity)

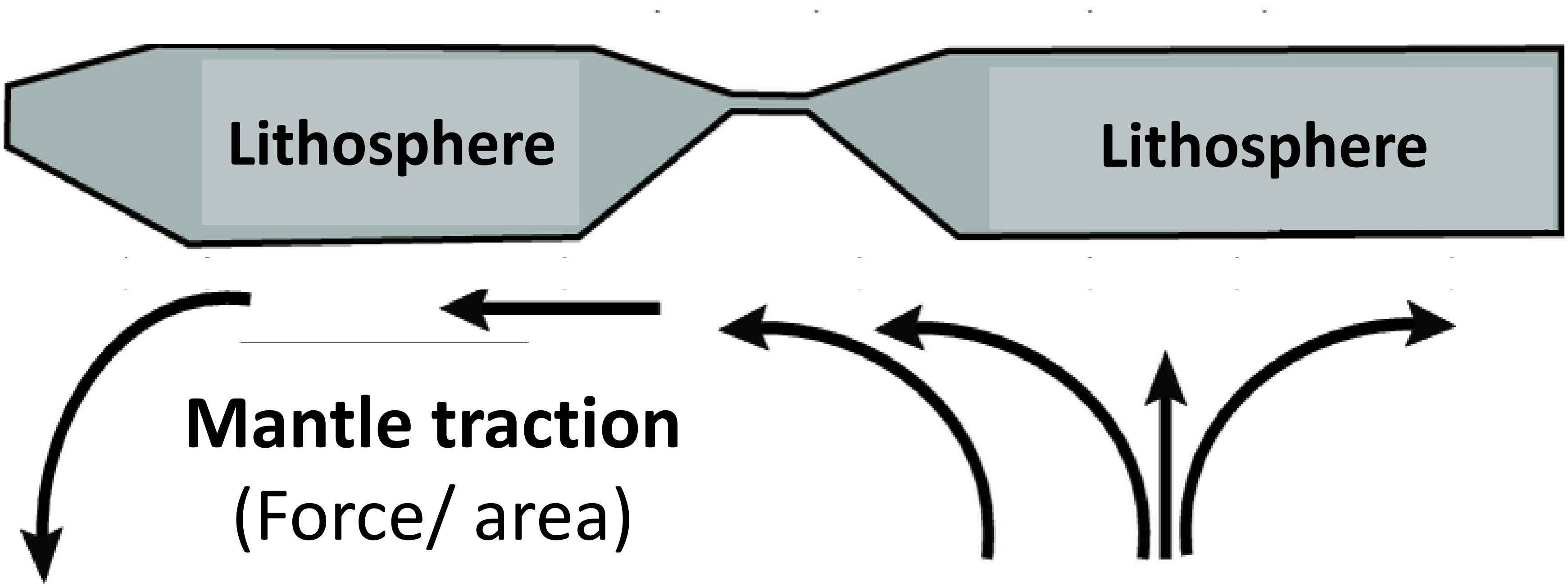
Can we have an estimate for craton viscosity?

Does asthenosphere play an important role in cratons' stability

Chapter 1: Traction and strain rates at the base of the lithosphere: Insight into cratonic stability

Motivation of problem

How mantle shearing deforms the base of the lithosphere ?



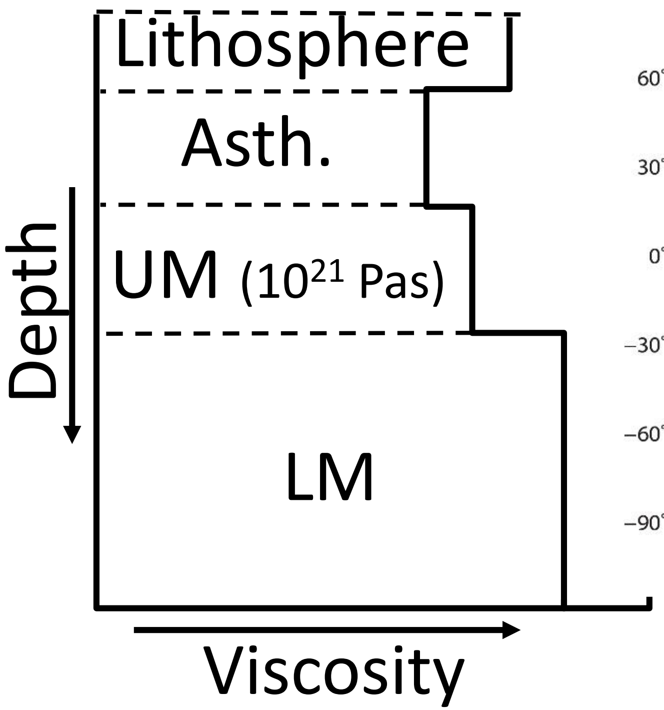
Do the thickness and strength (viscosity) of lithosphere play any role in this deformation?

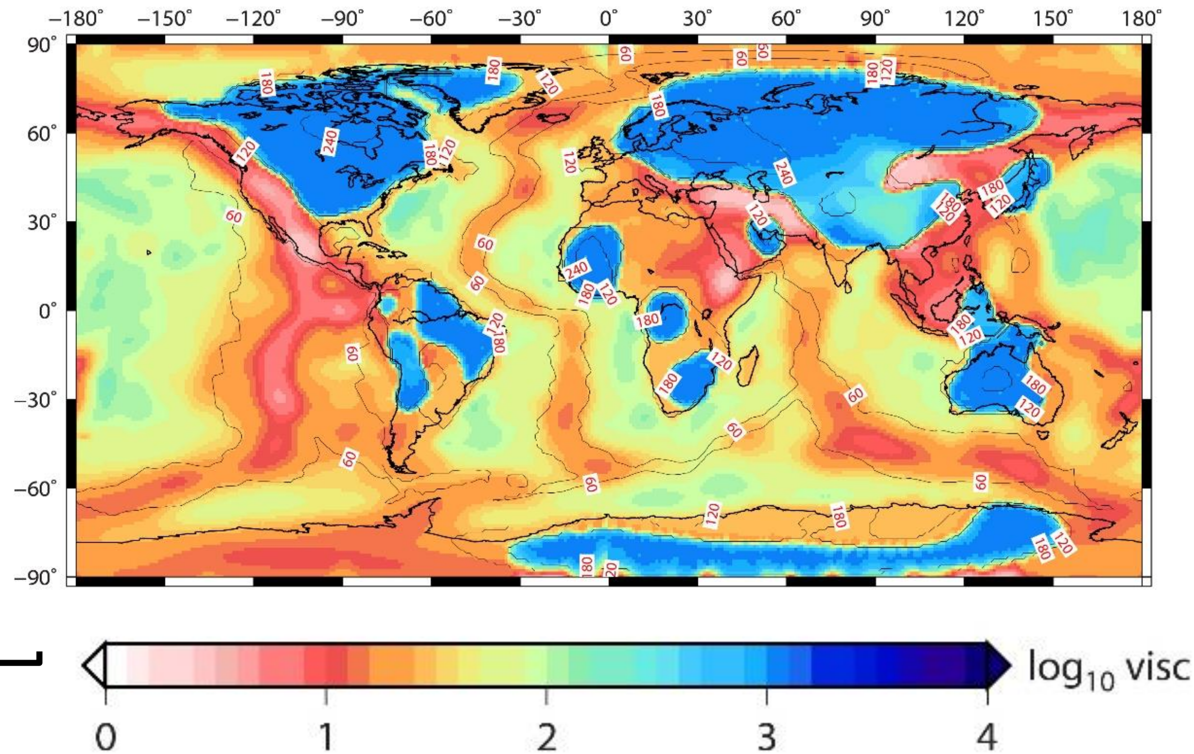
Mantle flow modelling

Convection equation solver: CitcomS (Zhong et al. 2000)

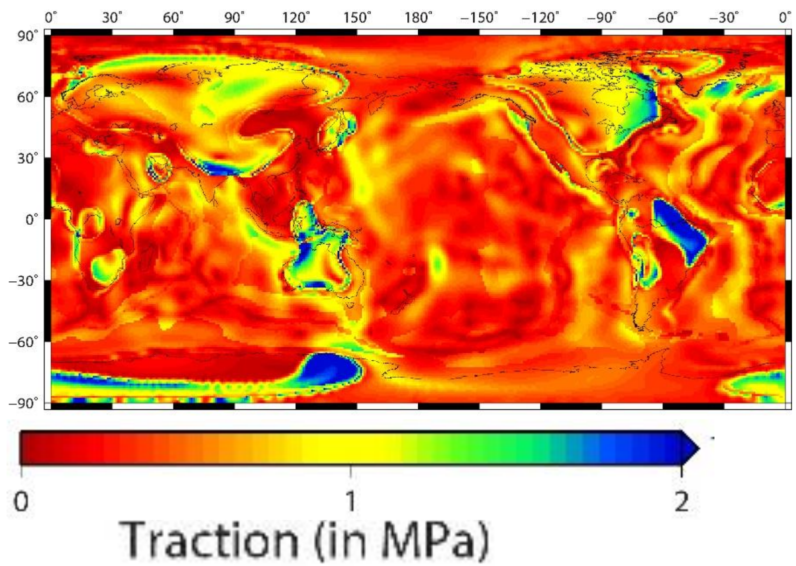
Convection is driven by density anomalies derived from Seismic velocity anomaly, SMEAN2 (Becker and Boschi, 2002)

Viscosity

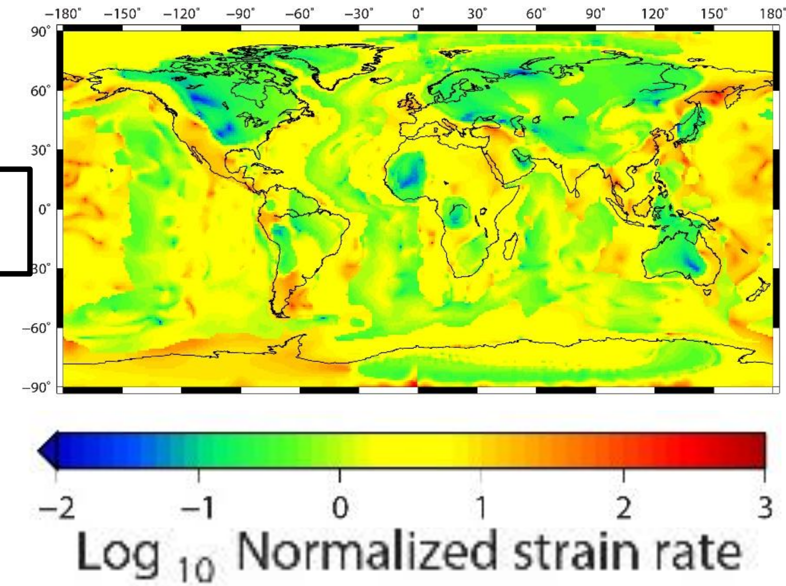


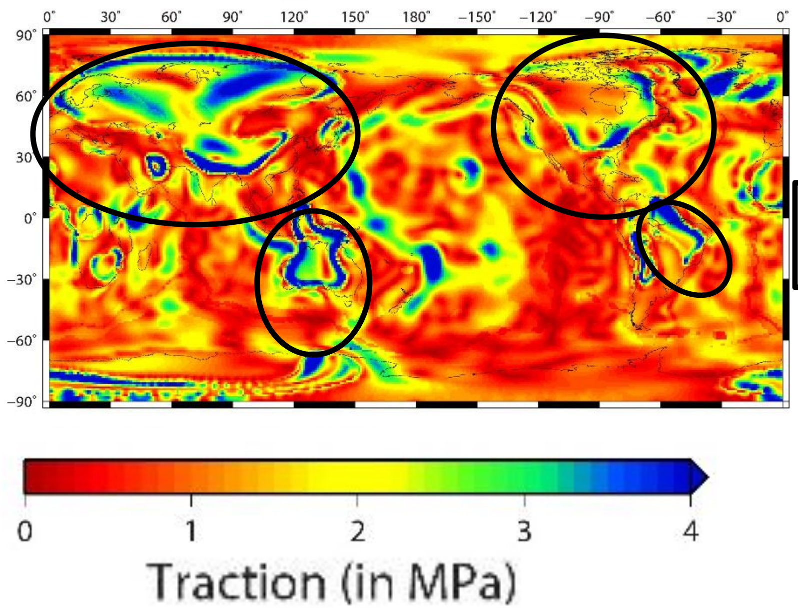


Shearing at the base of the lithosphere

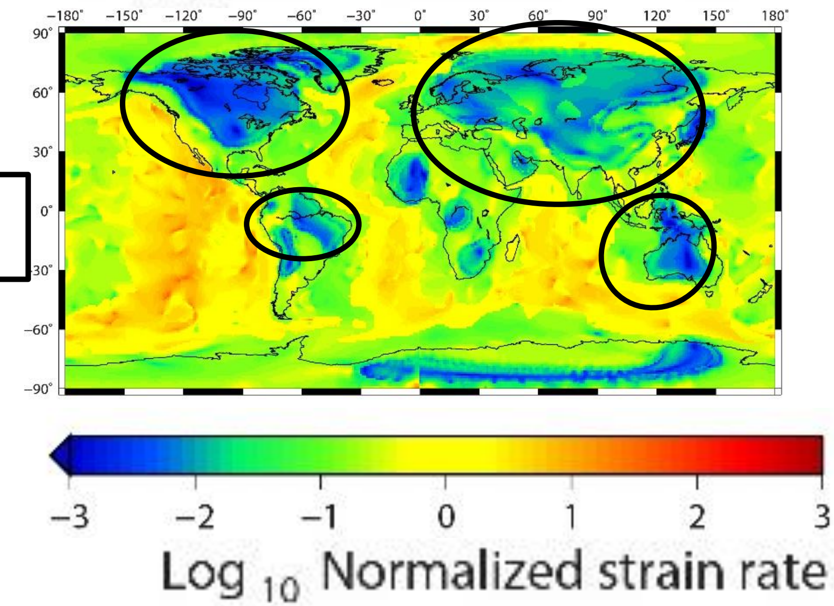


0.01, 100

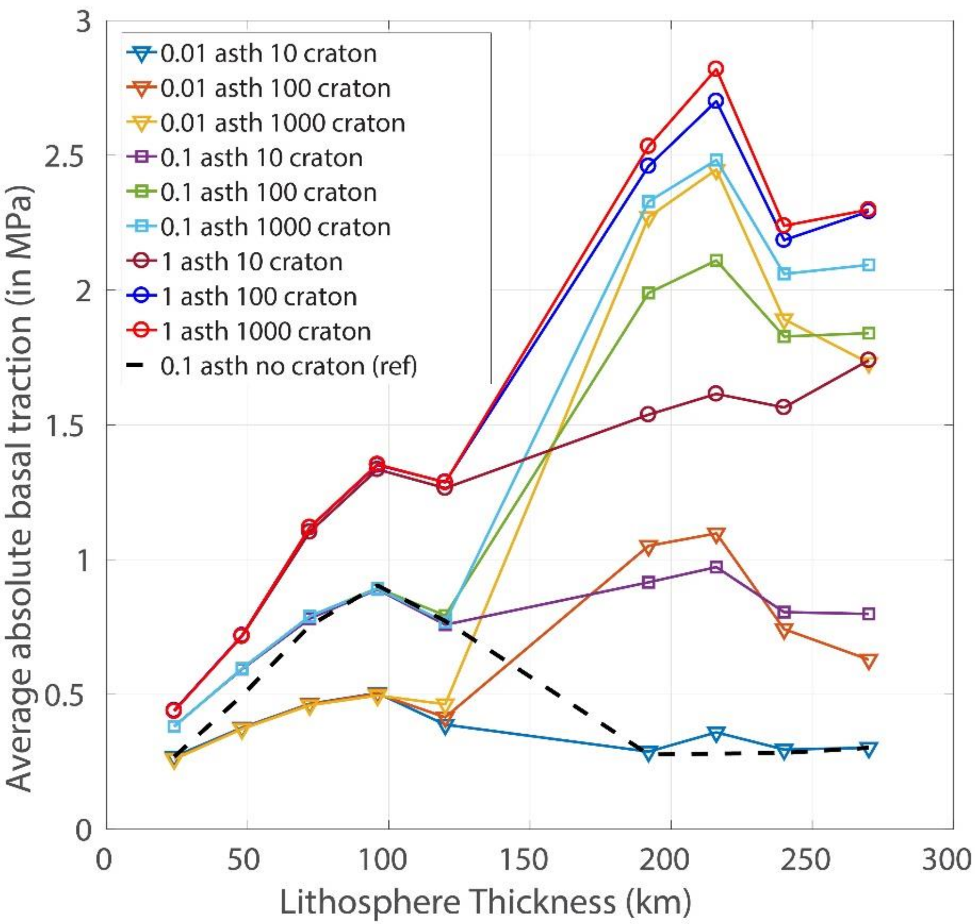


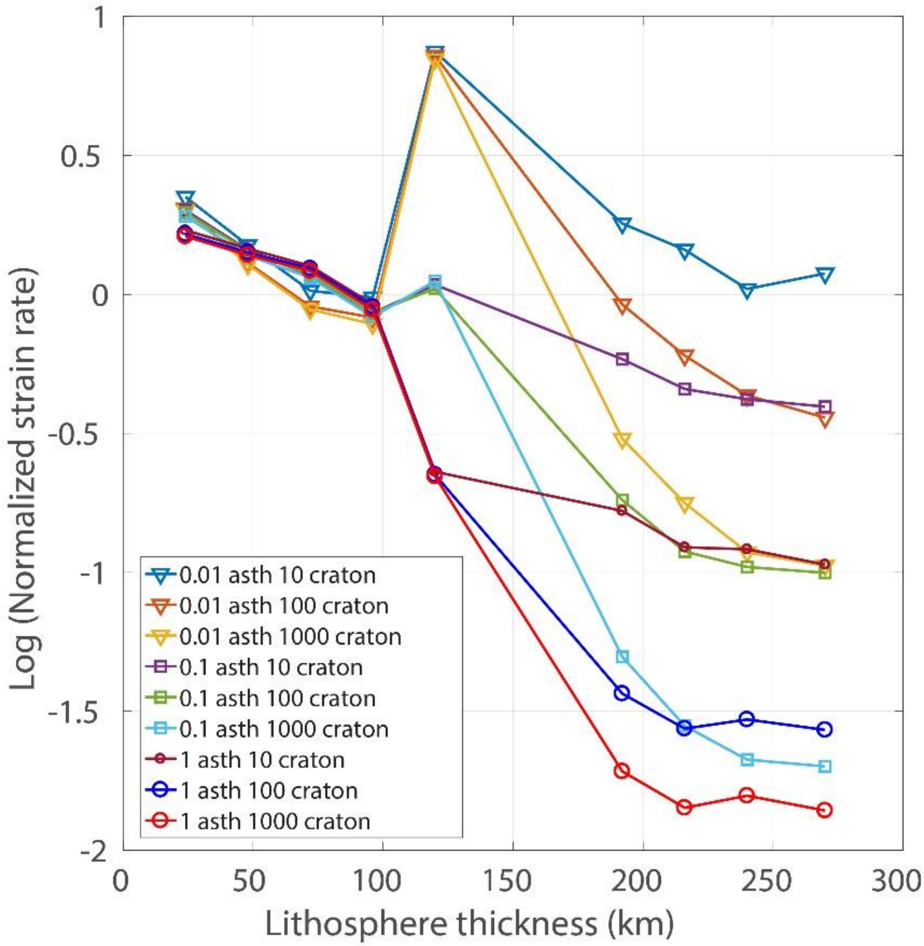


1, 100



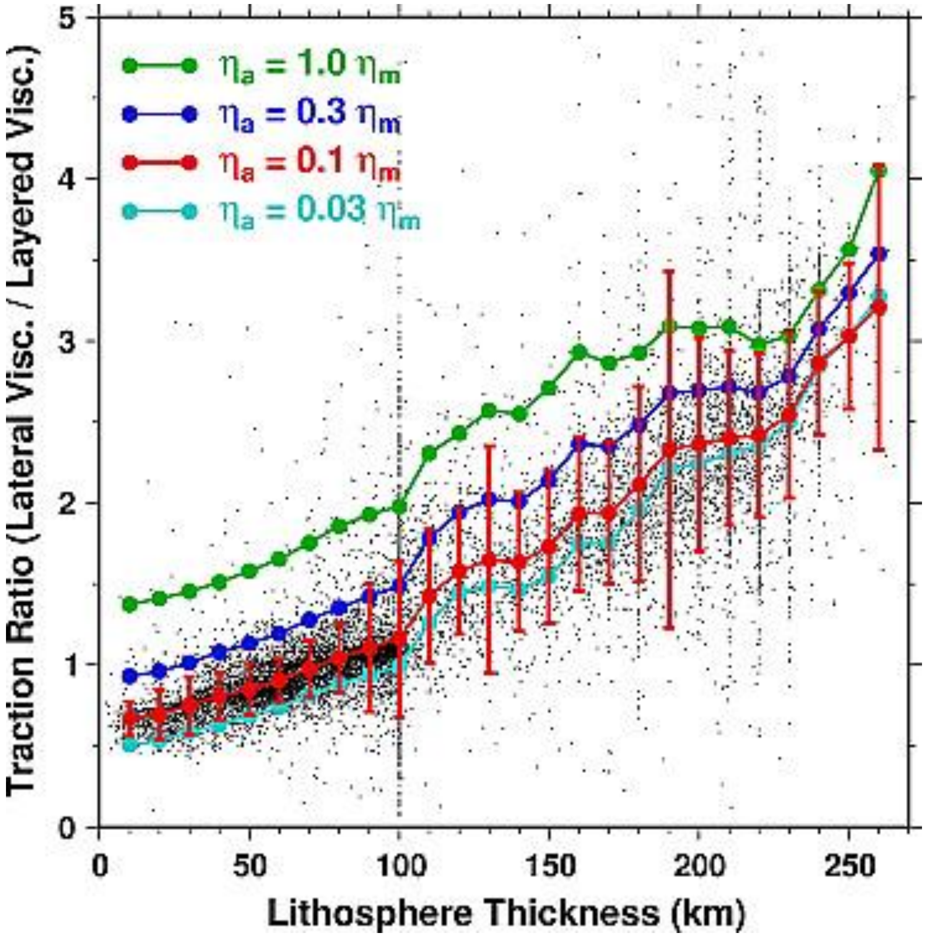
Shearing at the base of the lithosphere



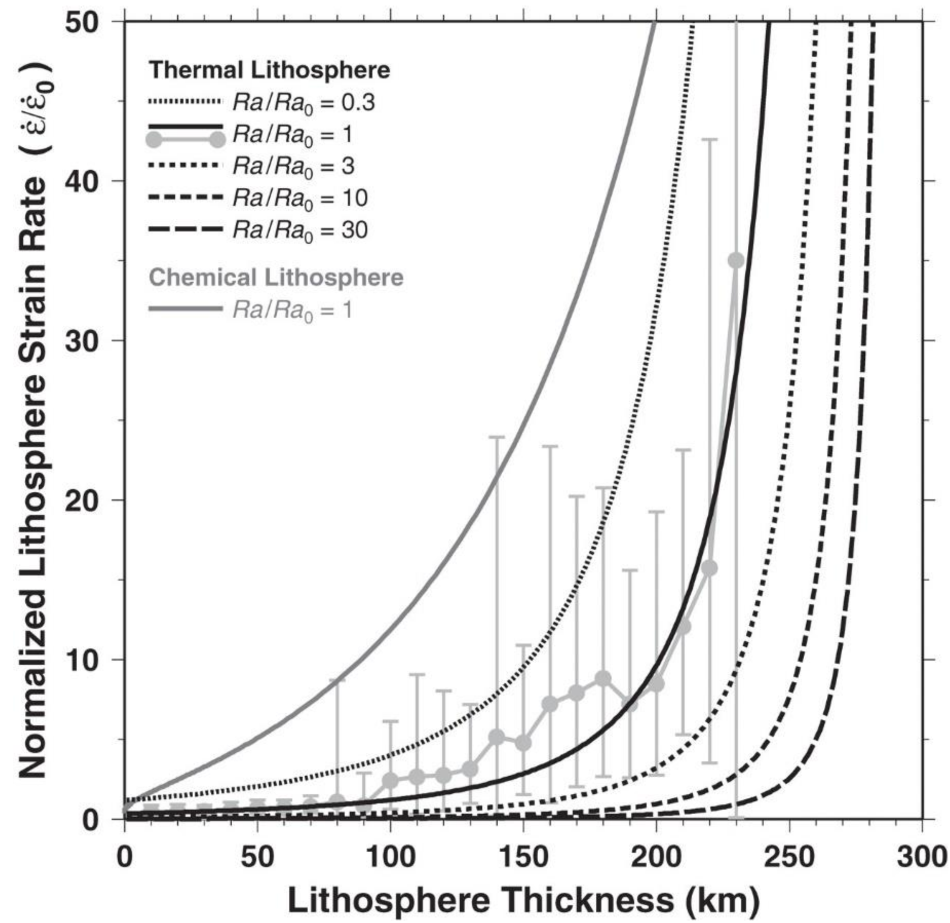


Traction increases with increasing lithosphere thickness and strain rates reduce.

Effect of free slip boundary condition



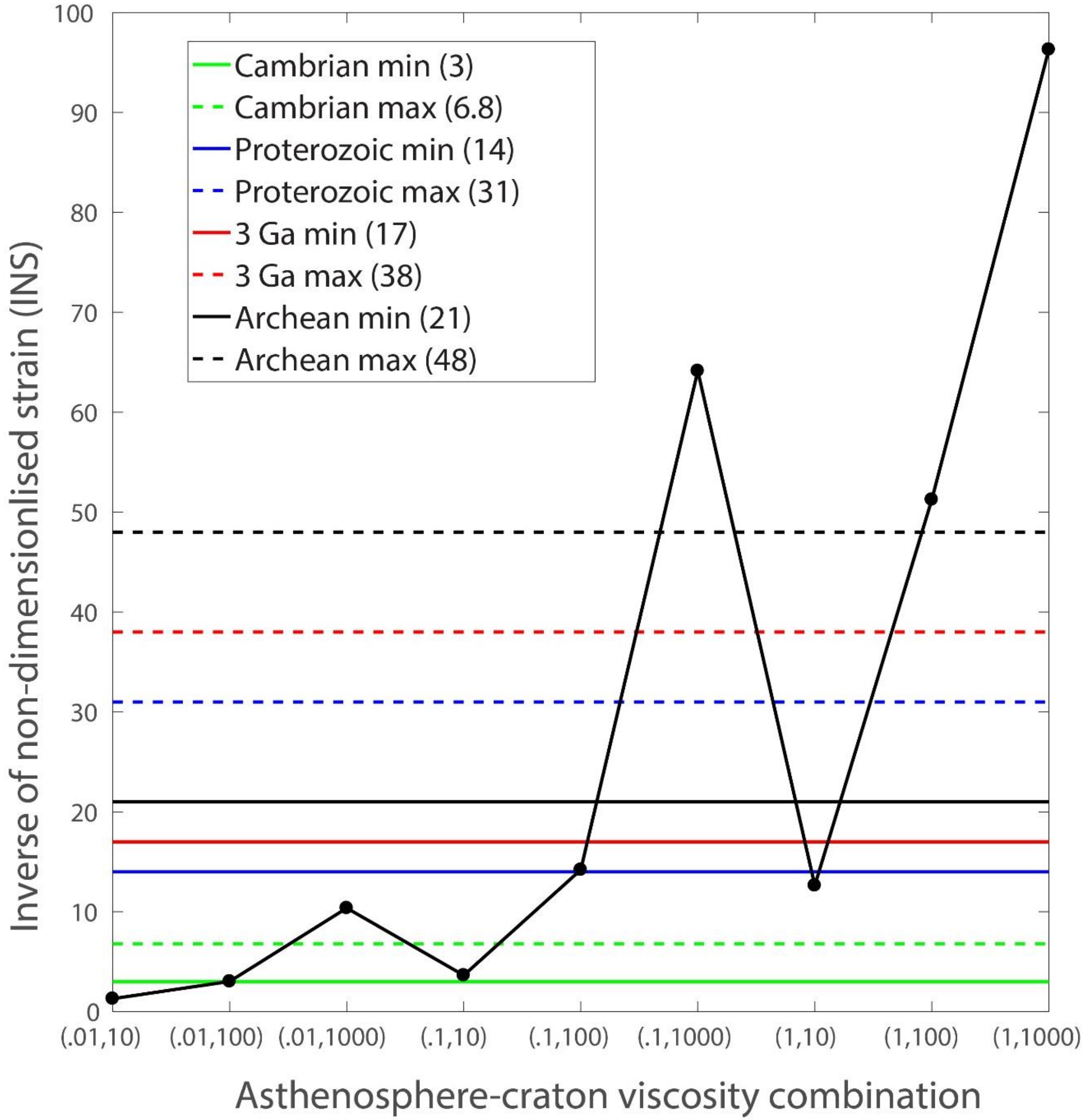
Conrad and Lithgow-Bertelloni (2006)



Cooper and Conrad (2009)

Studies using rigid boundary condition showed increment of traction and strain rates with increasing lithosphere thickness

Viscosity estimate for a stable craton



Stable combination: Asthenosphere viscosity not less than 10^{20} Pas, cratons at least 100 times more viscous than ambient layer.

Chapter 2: Forward convection modelling to understand cratonic stability since early Phanerozoic

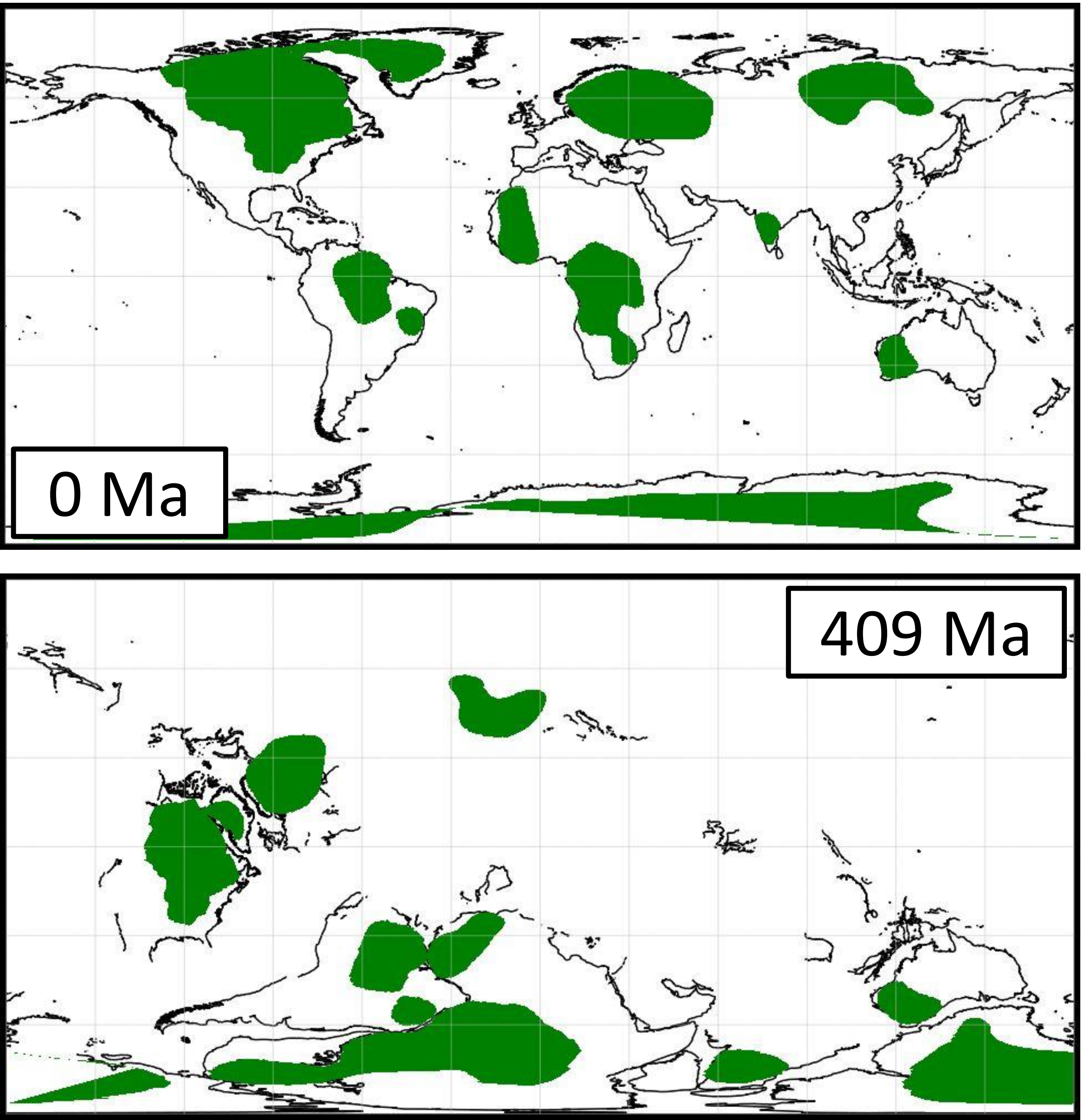
Motivation of problem

Can strain rates from instantaneous model predict the long term stability of cratons?

Do the viscosity combinations for stabilizing cratons estimated from instantaneous model remain same in time-dependent forward model?

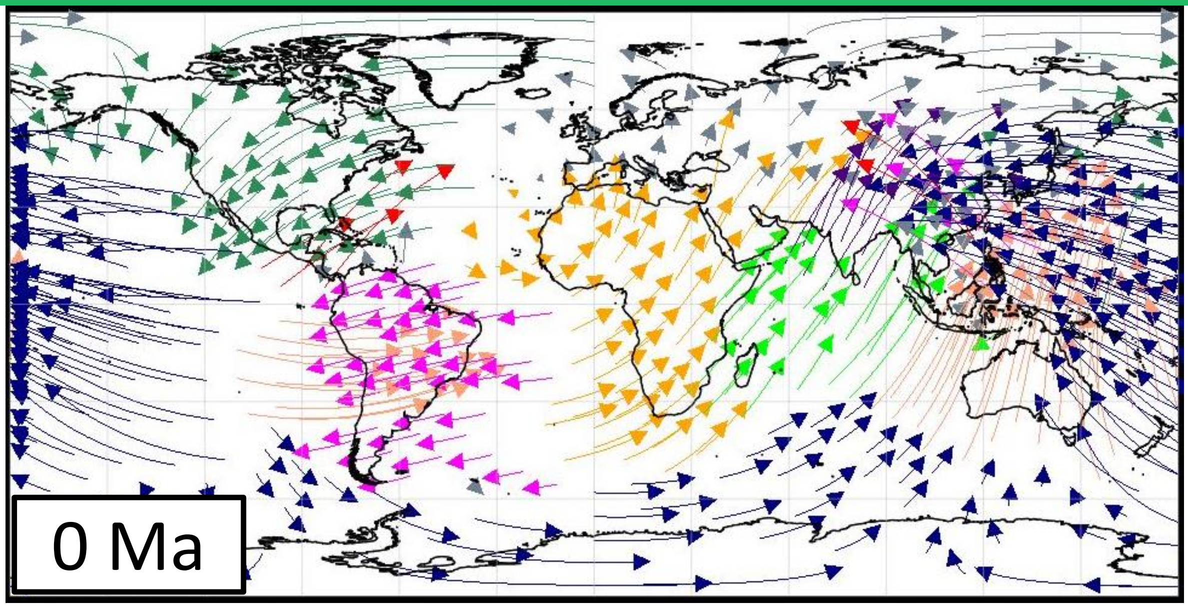
Does the asthenosphere viscosity really playing a role in stability of cratons?

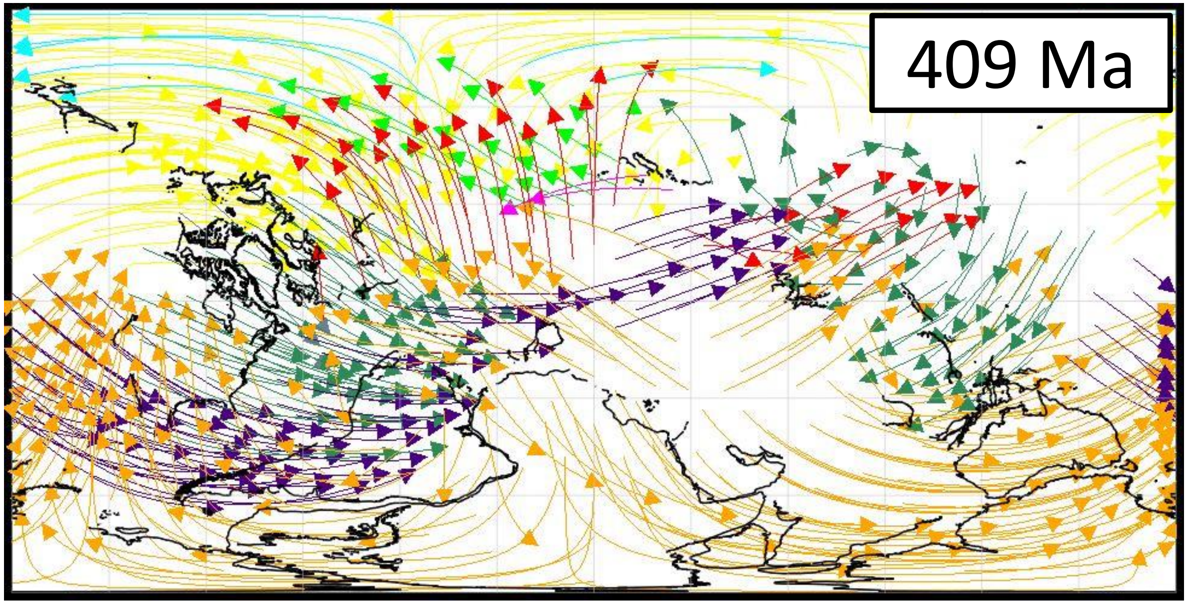
Developing forward models



Reconstructed cratons' location using Gplates
(Matthews et al. 2016)

Developing forward models





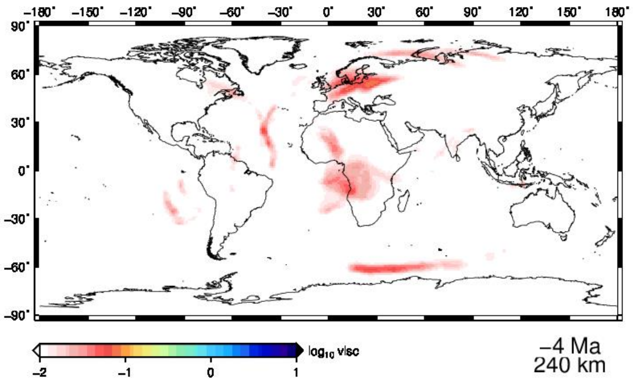
Velocities back in time using Gplates (Matthews et al. 2016)

Why velocity?

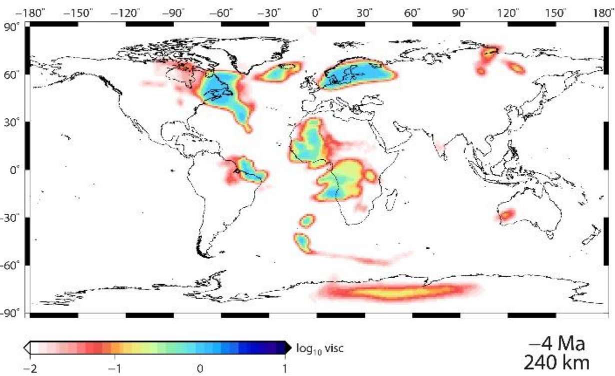
Density data are not well-constrained in deep time.

Velocities become driver of mantle convection in this case

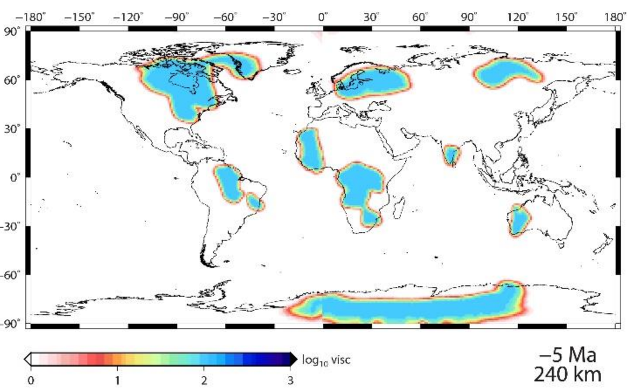
Deformation underneath cratons



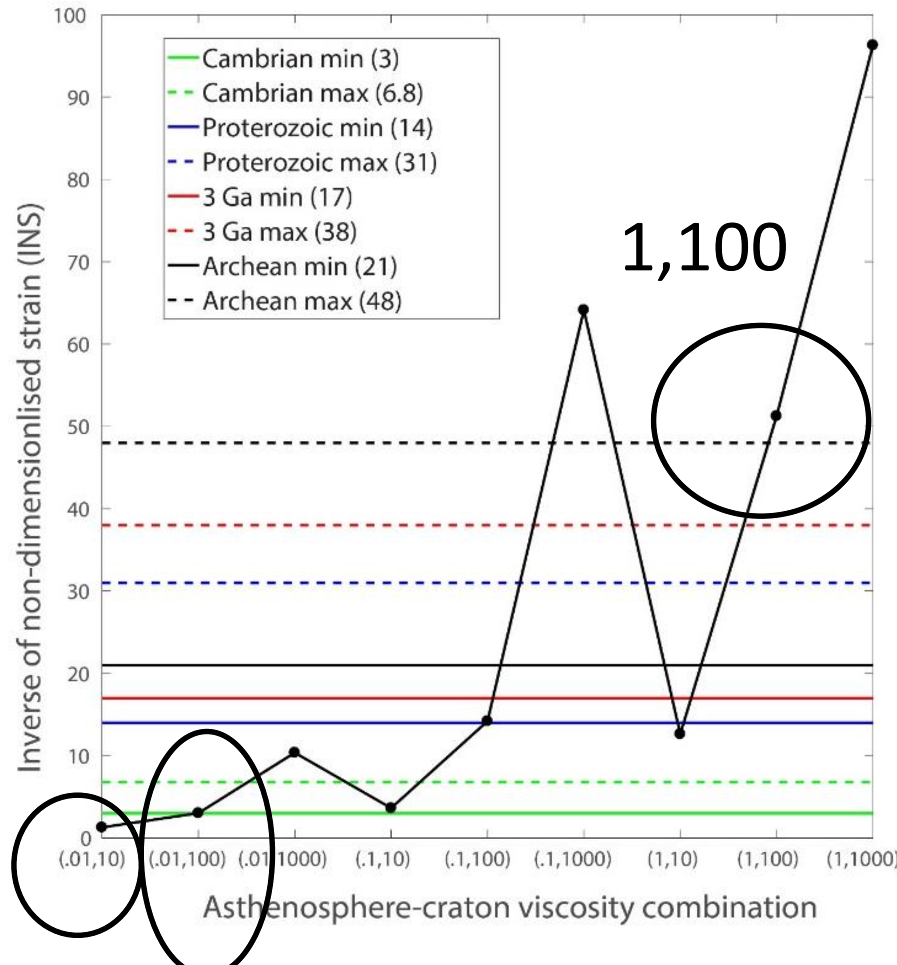
Does not survive till 410 Ma



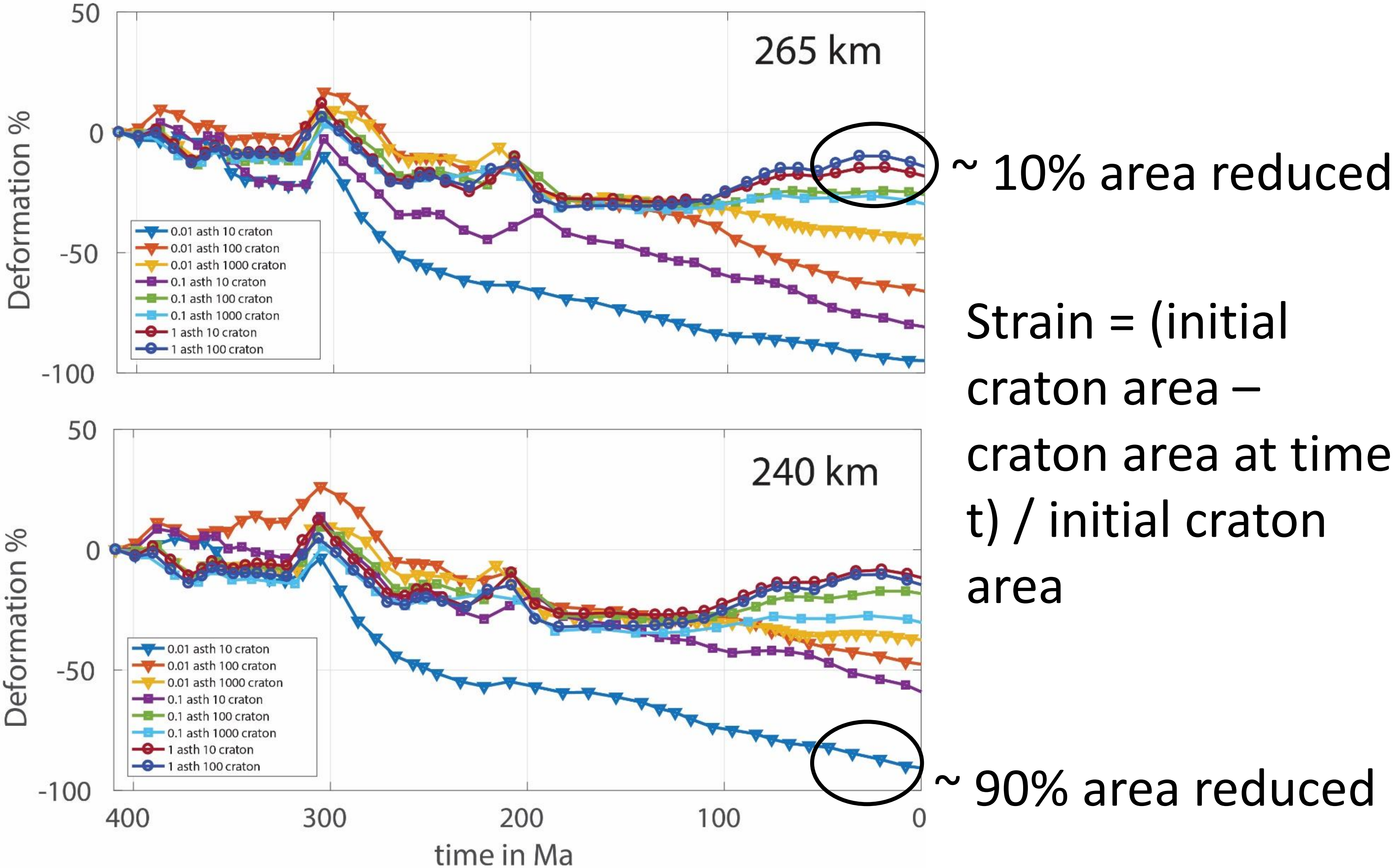
Marginally survives till 410 Ma



Barely deforms in 410 Ma



Deformation underneath cratons



Strain = (initial craton area – craton area at time t) / initial craton area

Conclusions

1. Slow deformation underneath the cratons is a potential reason for their long term stability.
2. Such slow deformation is due to their high viscosity value and thickness.
3. Asthenosphere viscosity plays an important role for cratonic stability.
4. To become a stable craton since Archean, asthenosphere viscosity should not be less than 10^{20} Pas and the cratons should be 100-1000 times viscous than the surroundings.

A thousand splendid problems hiding under the cratons

1. What is the thickness of the cratons?
2. Do mobile belts help cratons in their survival?
3. What if cratons follow non-Newtonian viscosity?
4. How did they form at the first place?
5. Do all the cratons have mid-lithospheric discontinuity?
6. How did the MLDs form only under the cratons?
7. Does MLD play a role in craton destruction?
8. Did lid breaking event produce thick cratons?
9. How do they interact with mantle plumes?
10. What happens if a craton comes near subduction zone?
11. What is the thickness of Indian Cratons?

Chapter 3 and 4

A Project proposed

Publications related to PhD work

In peer reviewed journal:

1. J Paul, A Ghosh, and CP Conrad, Traction and strain rate at the base of the lithosphere: An insight into cratonic stability, Geophysical Journal International, In Review.

Conferences:

3. A Ghosh, J Paul, CP Conrad, The Relation Between Tractions and Strain Rate at the Base of the Lithosphere: Key to Understanding Cratonic Stability, American Geophysical Union, Fall Meeting, 2018.

2. J Paul, A Ghosh, Stability of cratons since early Phanerozoic, American Geophysical Union, Fall Meeting, 2018.

1. J Paul, A Ghosh, Variation of traction and strain rate with lithospheric thickness: An insight into understanding cratonic stability. EGU General Assembly, 2018, Vienna.

Time line	Project	Thesis	Status
2015-2017	**Deformation under North American craton**	May be included	Completed
2017 Oct – 2018 July	**Traction and strain rates at the base of the lithosphere: Insight into cratonic stability**	Chapter 1	Completed; 2 Conference abstracts; 1 journal (in review)
2018 April- 2018 Dec	**Forward convection modelling to understand cratonic stability since early Proterozoic**	Chapter 2	Almost completed; 1 Conference abstract; Ms in prep
2018 Aug – 2019 Dec	**Effect of mobile belts on cratonic stability**	Chapter 3	Presently working
2018 Aug- 2019 Mar	**Effect of non-Newtonian viscosity on cratonic stability**	Chapter 4	Presently working
Sometime in between	**Effect of mid-lithospheric discontinuity on cratonic stability**	Chapter 5	Not started yet
2019 Dec – 2020 June	**Compilation**		**Thesis submission**