Understanding stability of cratons using numerical modeling

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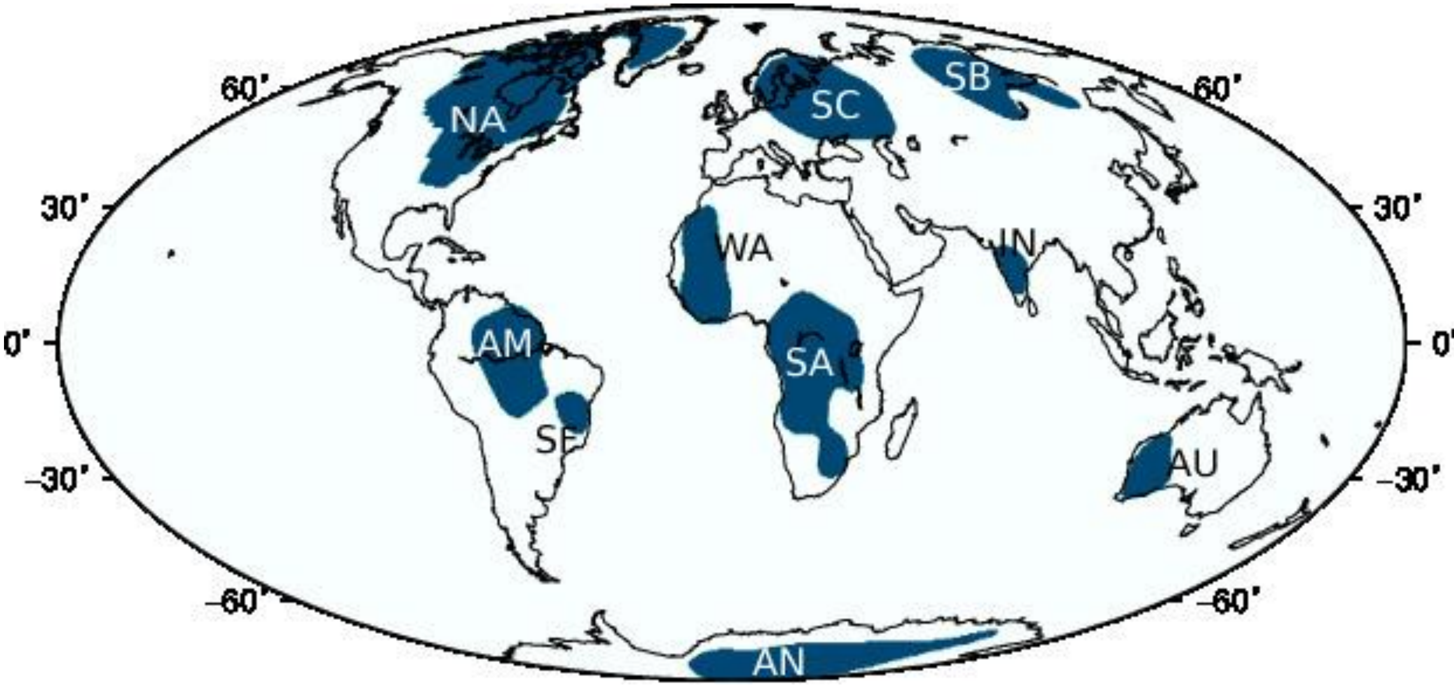
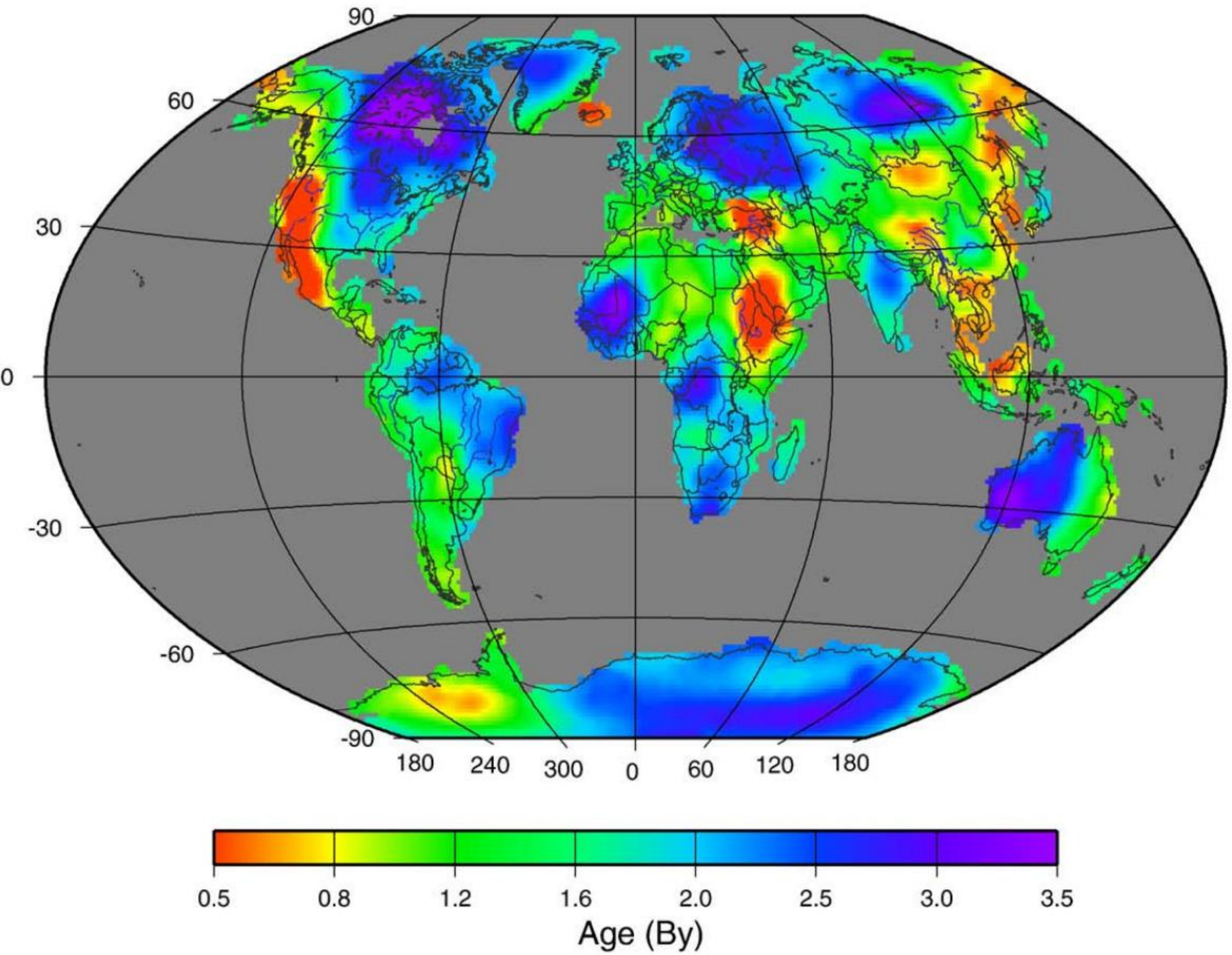
Chapter 1: Introducing the problem

Geophysical definition of cratons



- Landmass older than Cambrian (~ 540 Ma)
- No significant deformation after Cambrian
- High seismic velocity anomalies
- Thick lithosphere
- Low heat flow

Origin of problem



(Poupinet and Shiparo, 2008, Lithos)

Oldest oceanic lithosphere ~200 Ma

- Non-cratonic continental lithosphere is not as old as cratons
- How did cratons survive for such a long time?

Reasons for craton destruction

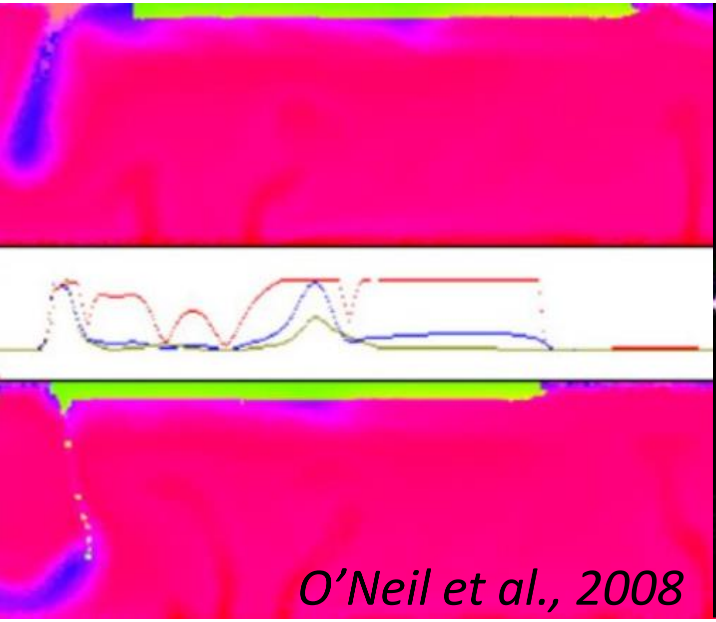
Mechanisms to destroy lithosphere:

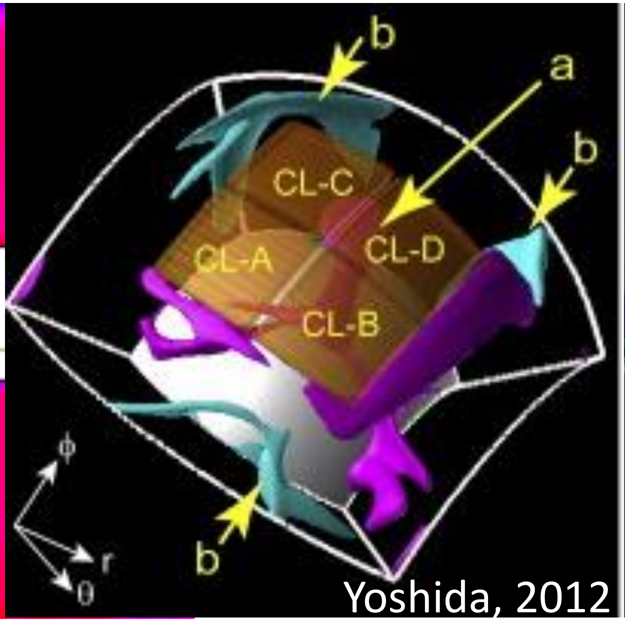
- Subduction
- Gravitational delamination
- Mantle shearing

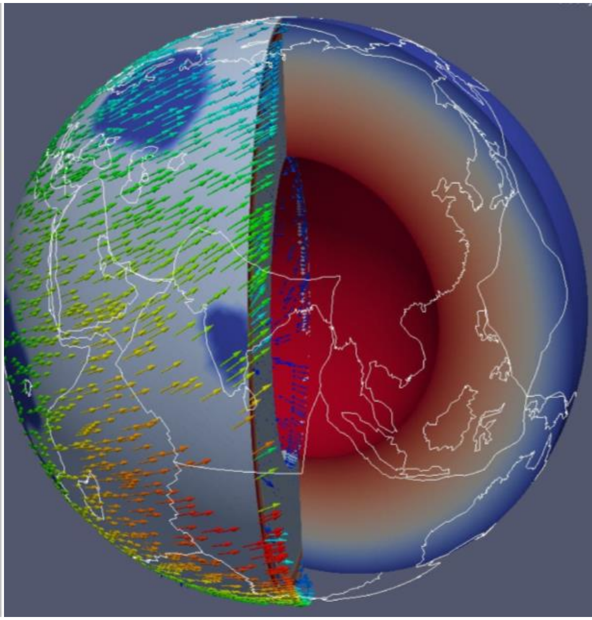
What happens to cratonic lithosphere?

- Do not subduct as they are not dense enough (Jordan 1975)
- Density can protect from gravitational delamination (Jordan 1975, 1978)
- Can cratons resist mantle shearing?

Aim of the present work





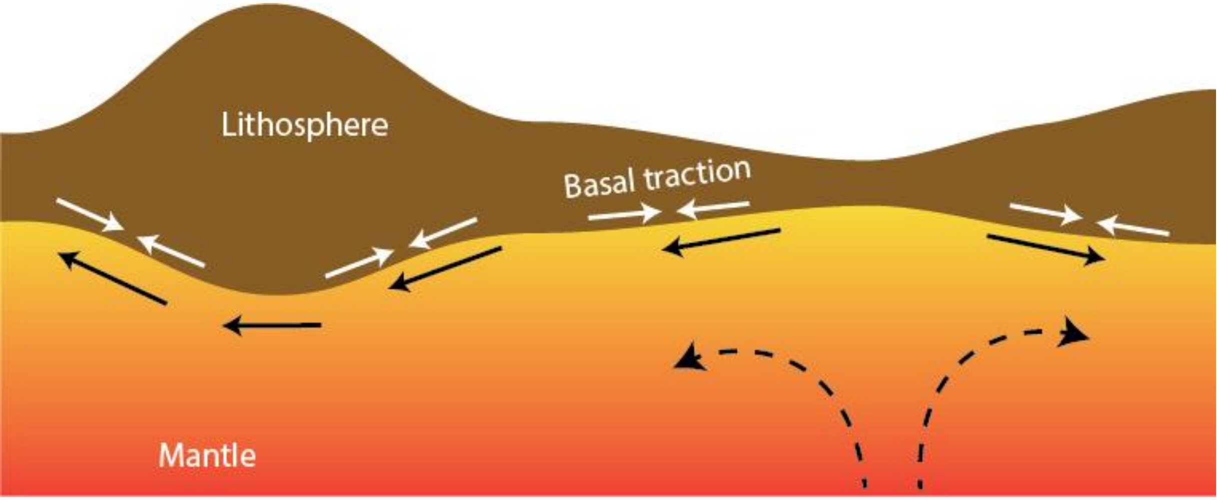


- Developing 3-D realistic earth-like mantle convection models to understand cratonic evolution.
- Estimate viscosity of cratons
- Does asthenosphere play a role in cratons’ survival?
- How mid-lithospheric discontinuity affects survival of craton?

Chapter 2: Traction and Strain-rates at the base of the lithosphere: Insight into cratonic stability

Published in Geophysical Journal International, 2019

Approaching the problem



Mantle traction:
Shear stress acting at the base of the lithosphere

- How does mantle traction deform lithosphere?
- Does it vary with lithospheric thickness and viscosity?

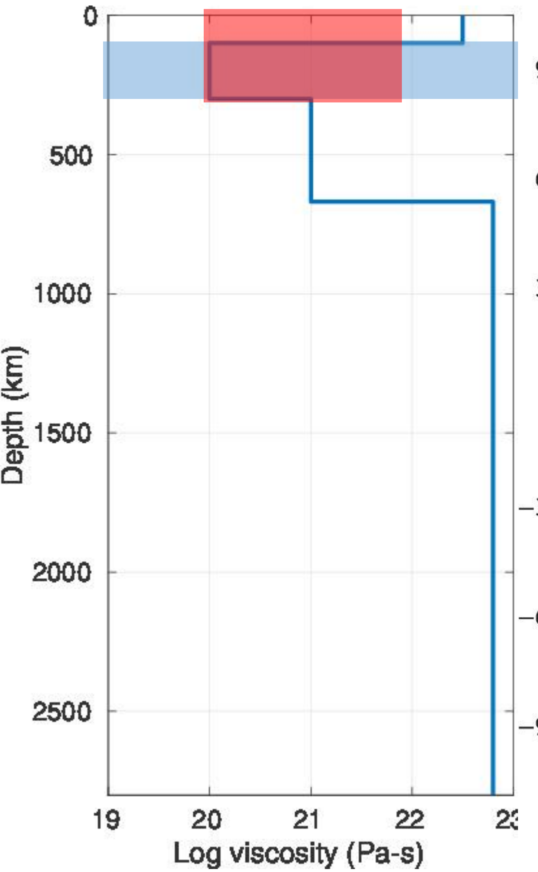
Convection model

Convection code: CitcomS (Zhong et al. 2000)

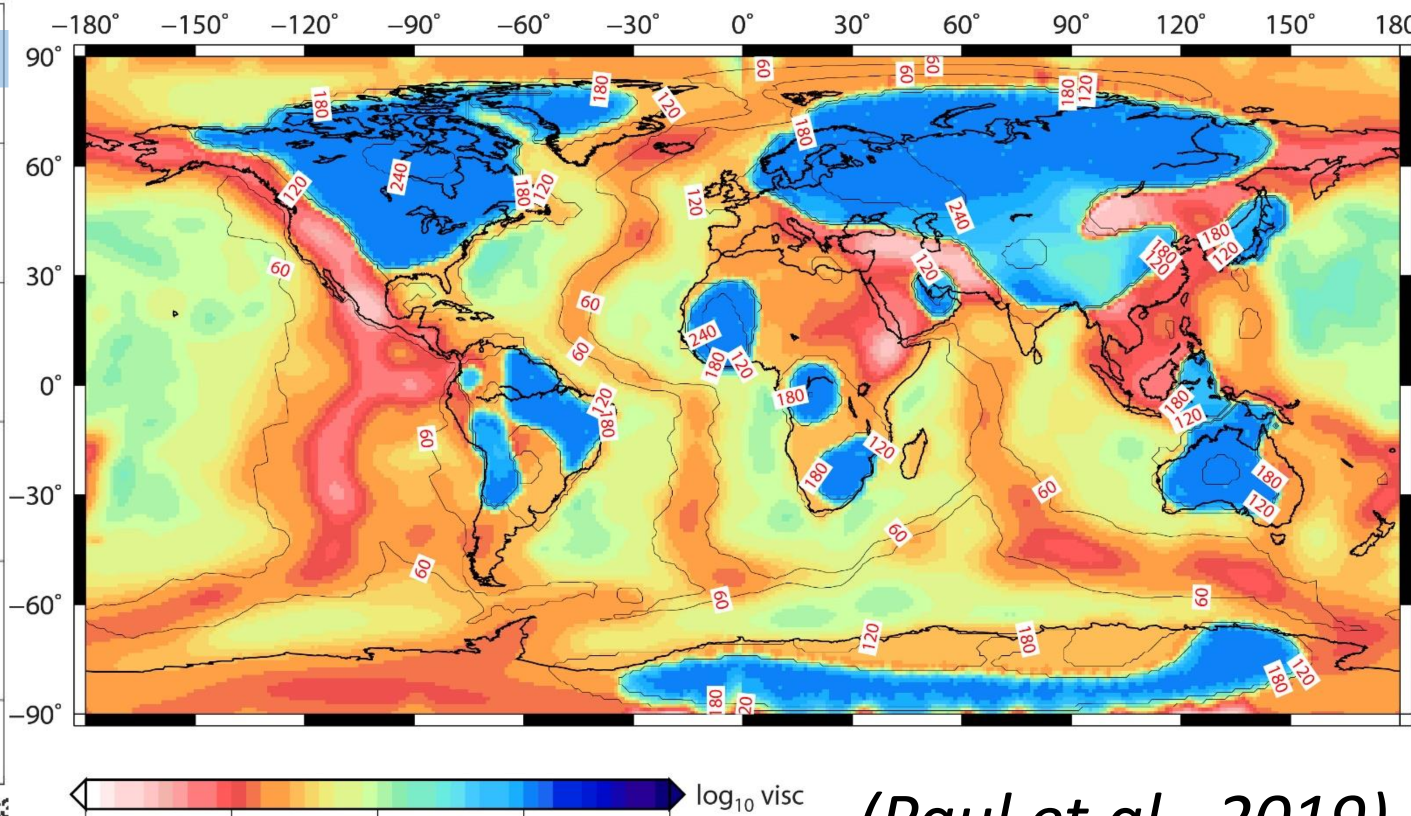
Convection driven by density anomalies derived from seismic tomography

Estimating viscosity of cratons

Radial viscosity



Lateral viscosity variation



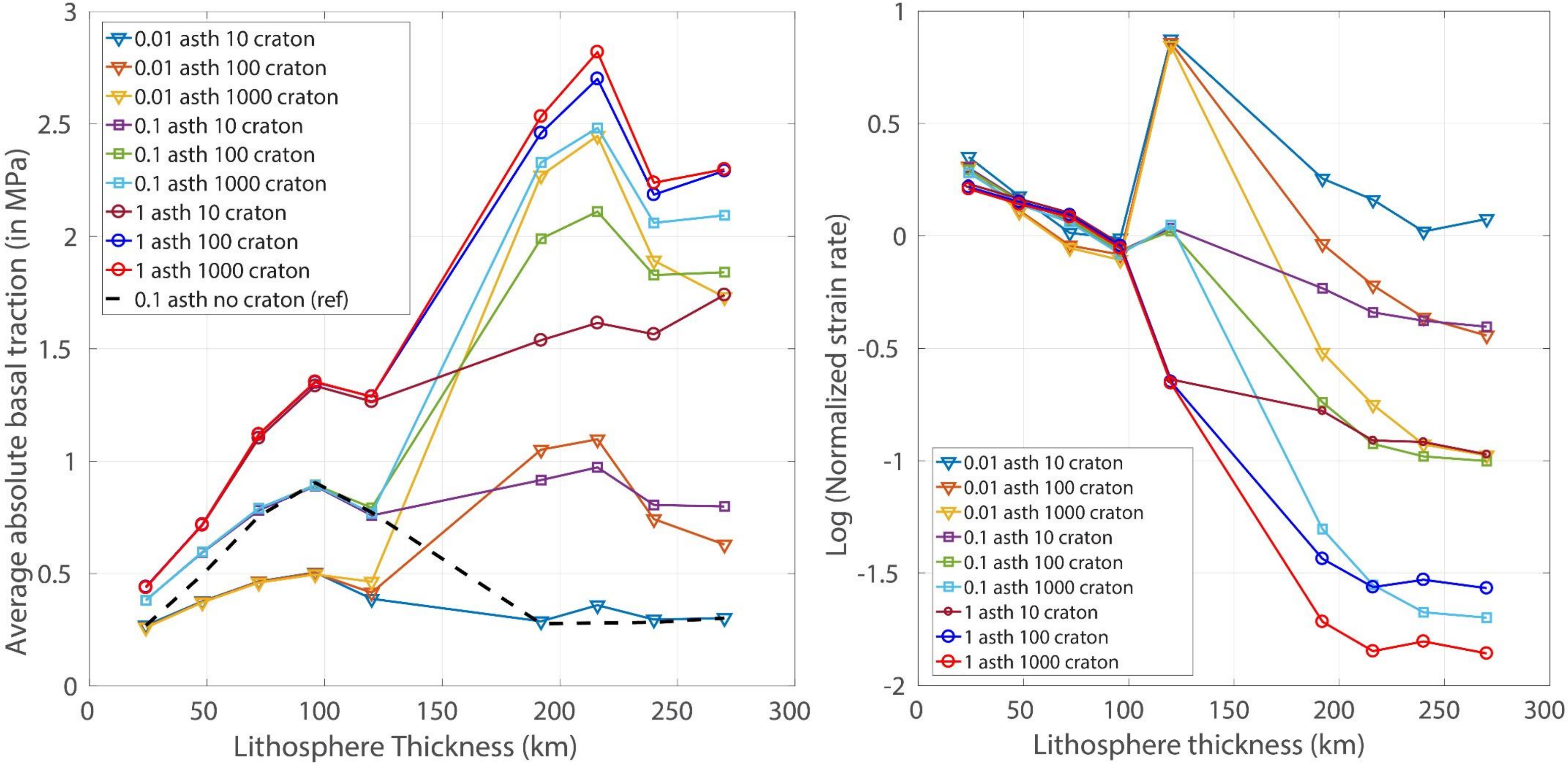
(Paul et al., 2019)

Viscosity of asthenosphere: 10^{19} (0.01) to 10^{21} (1)Pa-s

cratons: 10 to 1000 times viscous than surroundings

Deformation at the base of lithosphere

Traction increases with lithosphere thickness and viscosity of craton and asthenosphere *(Paul et al., 2019)*



Deformation follows the opposite trend

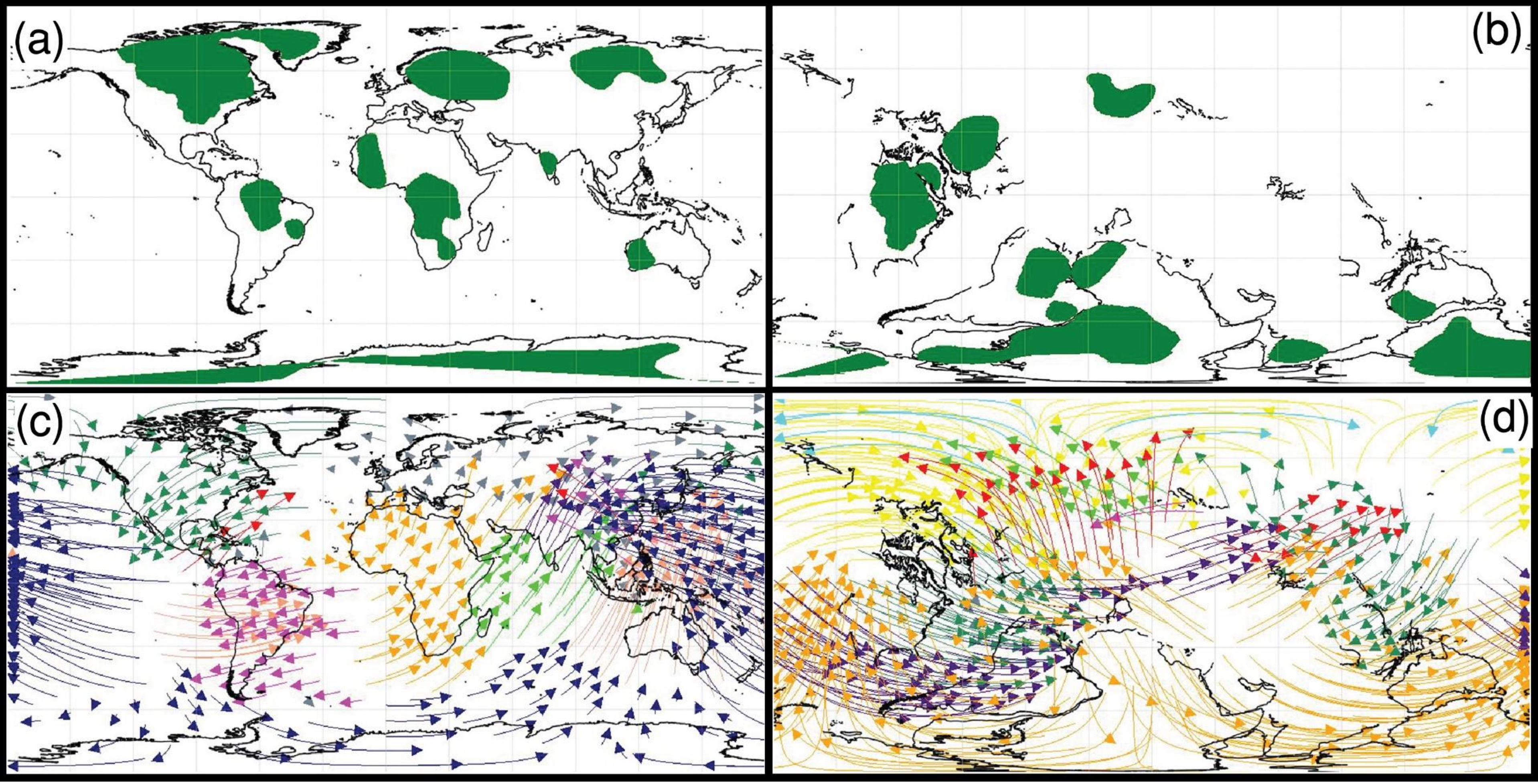
Conclusions

1. Thick and highly viscous cratons can resist deformation in spite being under highest traction
2. Asthenosphere plays an important role in the survival of cratons
3. For long-term survival of cratons, they need to be at least 100 times viscous than the surroundings and asthenosphere viscosity should not be less than 10^{20} Pa-s

Chapter 3: Evolution of cratons through the ages: A time-dependent study

Published in Earth and Planetary Science Letters, 2019

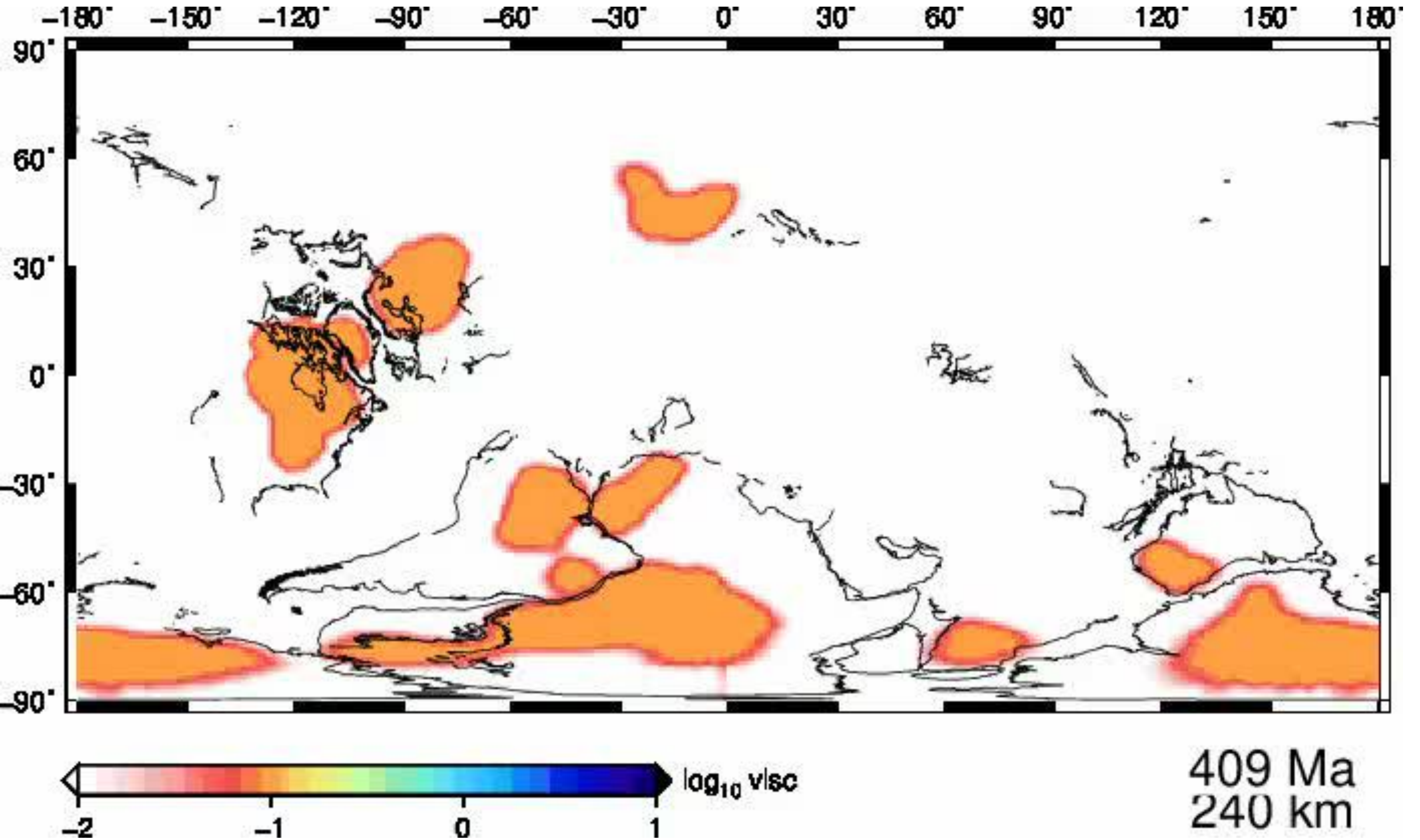
Approaching the problem



(Paul and Ghosh, 2020, EPSL)

Plate velocity driven mantle convection from 409 Ma to present day using Gplates (Gurnis et al., 2013)

Evolution of cratons



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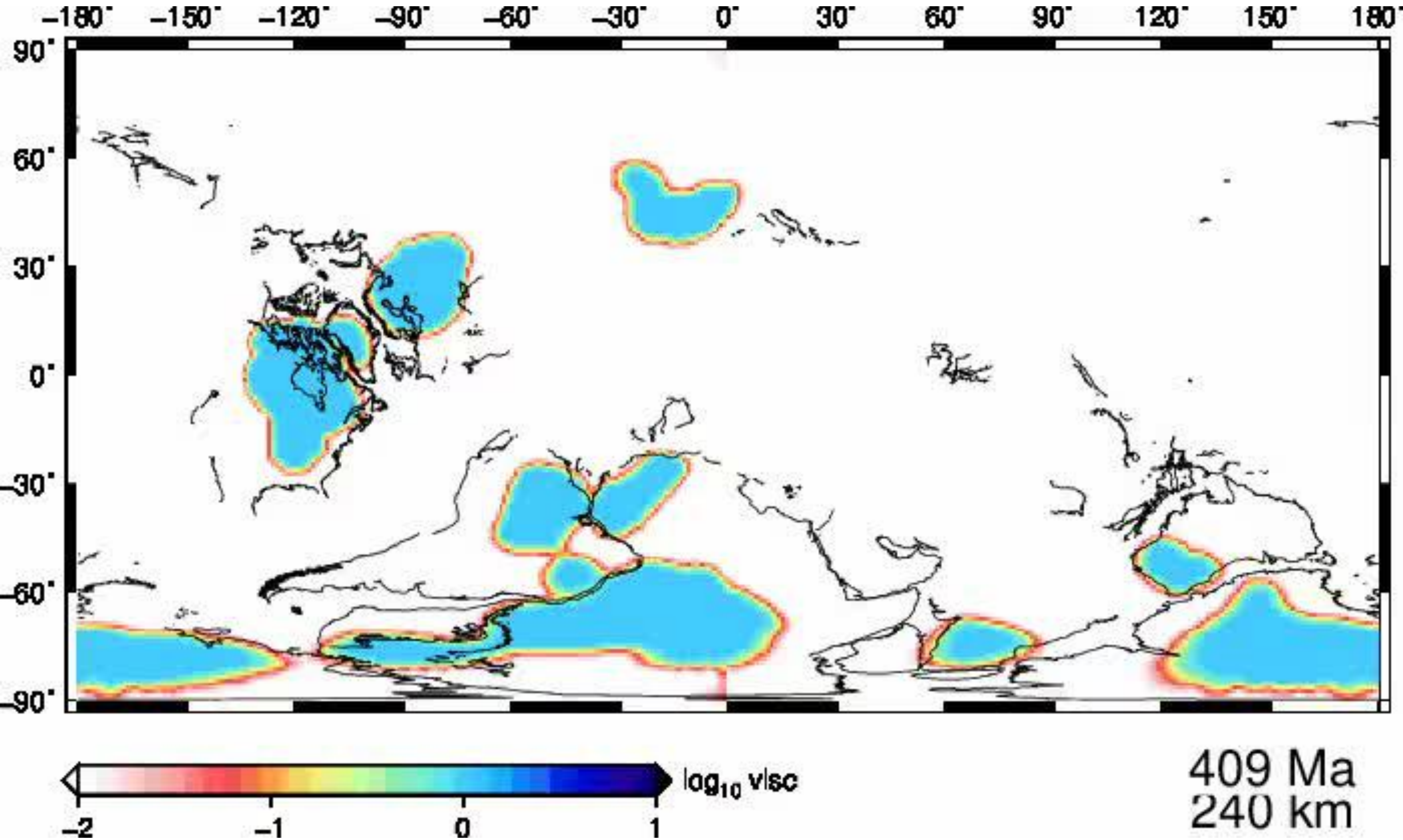
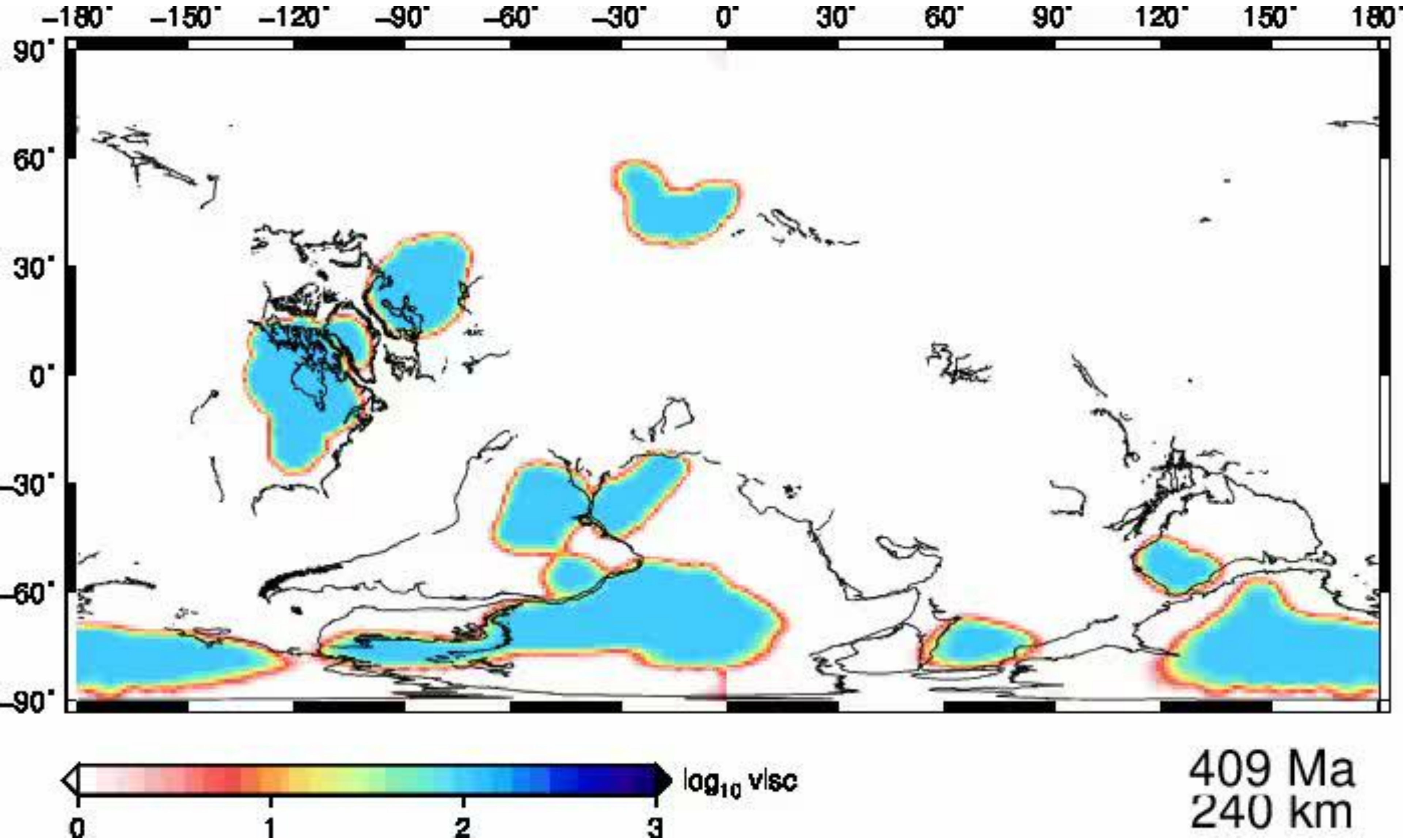
Evolution of cratons



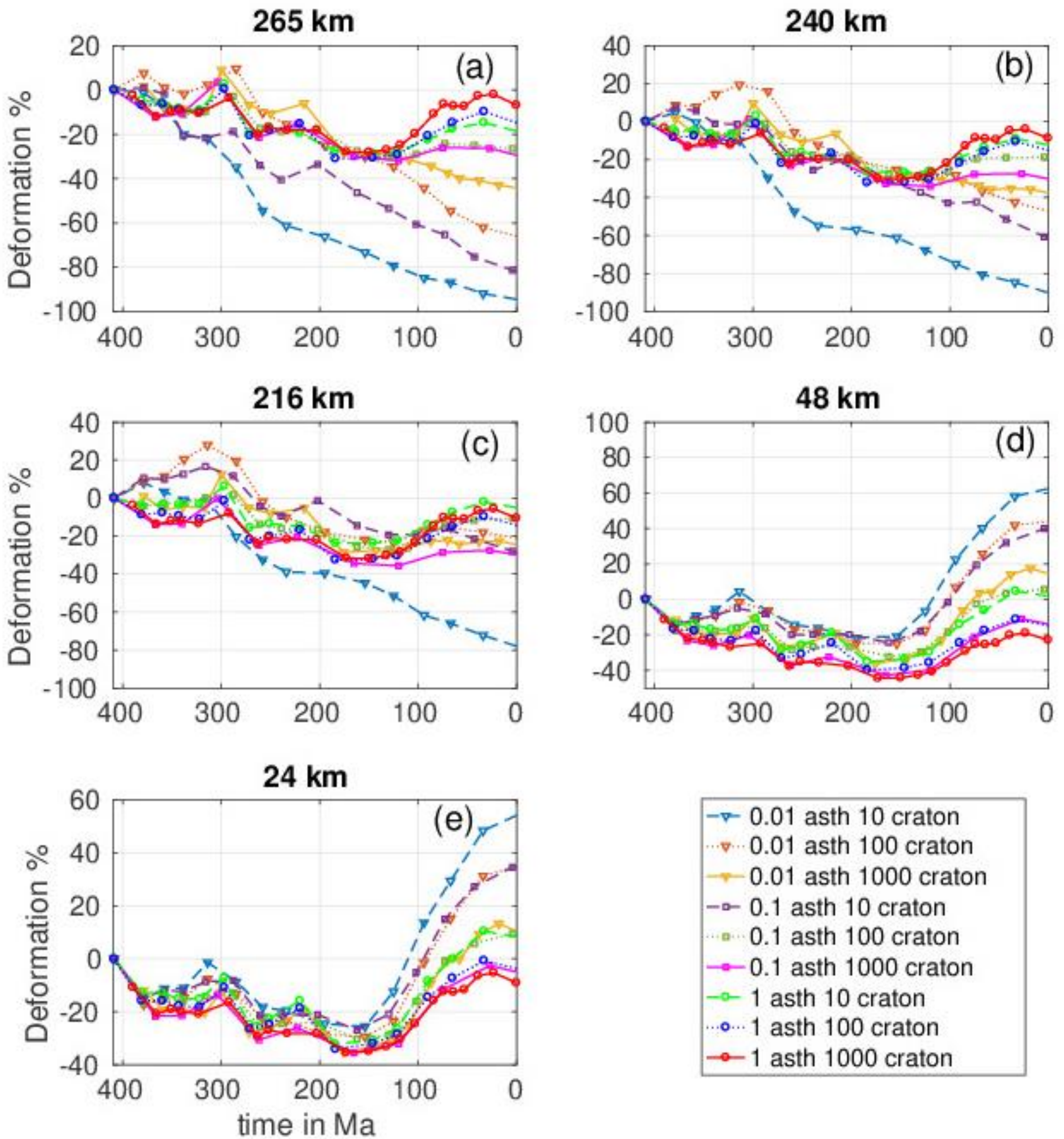
(Paul and Ghosh, 2020, EPSL)

Evolution of cratons



(Paul and Ghosh, 2020, EPSL)

Quantifying deformation



$$\frac{A_{409} - A_t}{A_{409}} \times 100$$

(Paul and Ghosh, 2020, EPSL)

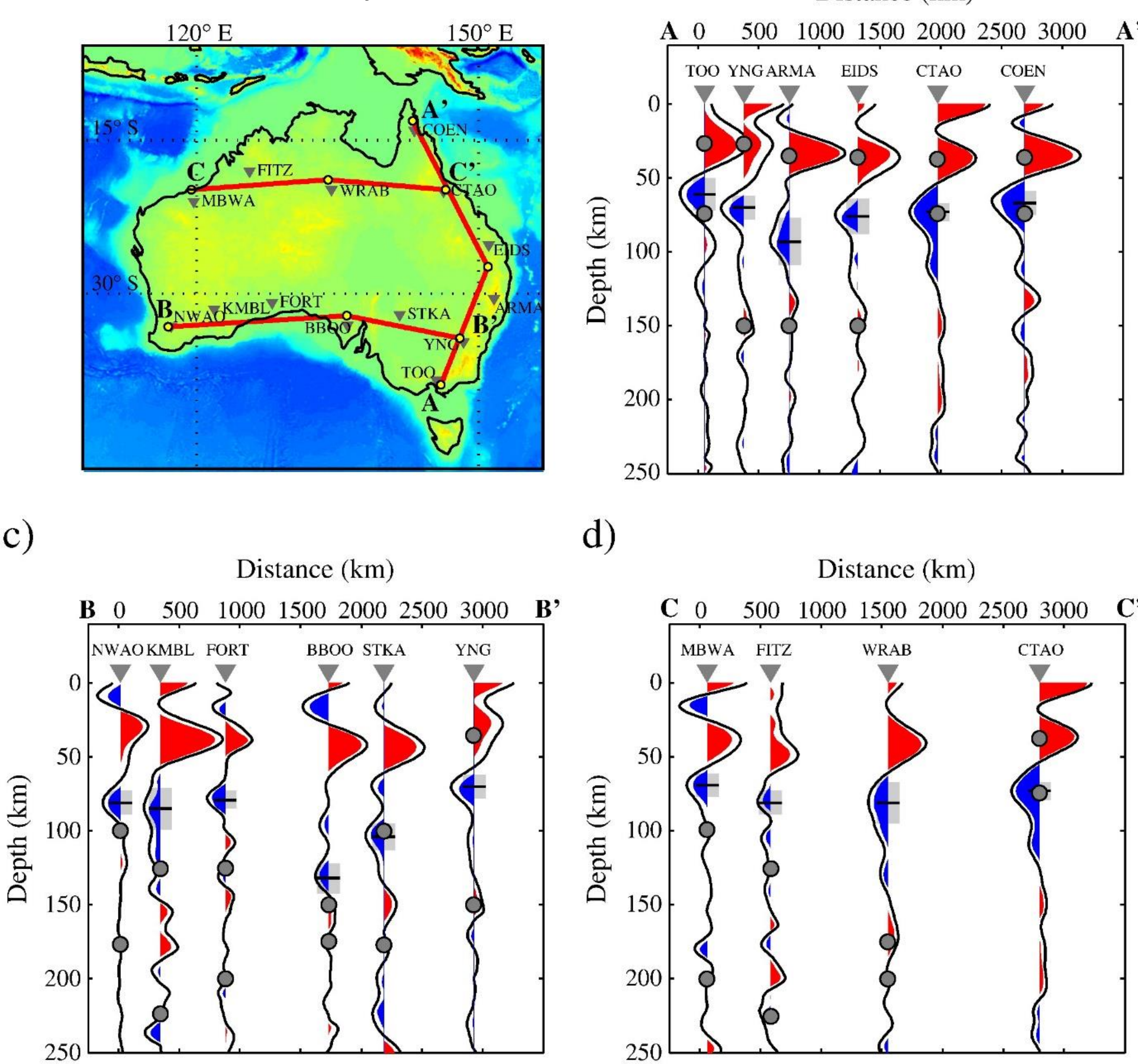
Conclusions

1. The viscosity of craton is the primary factor for their long-term survival
2. Asthenosphere plays important role in cratons' survival
3. Craton need to be 100 times more viscous and asthenosphere viscosity should not be less than 10^{20} Pa-s.

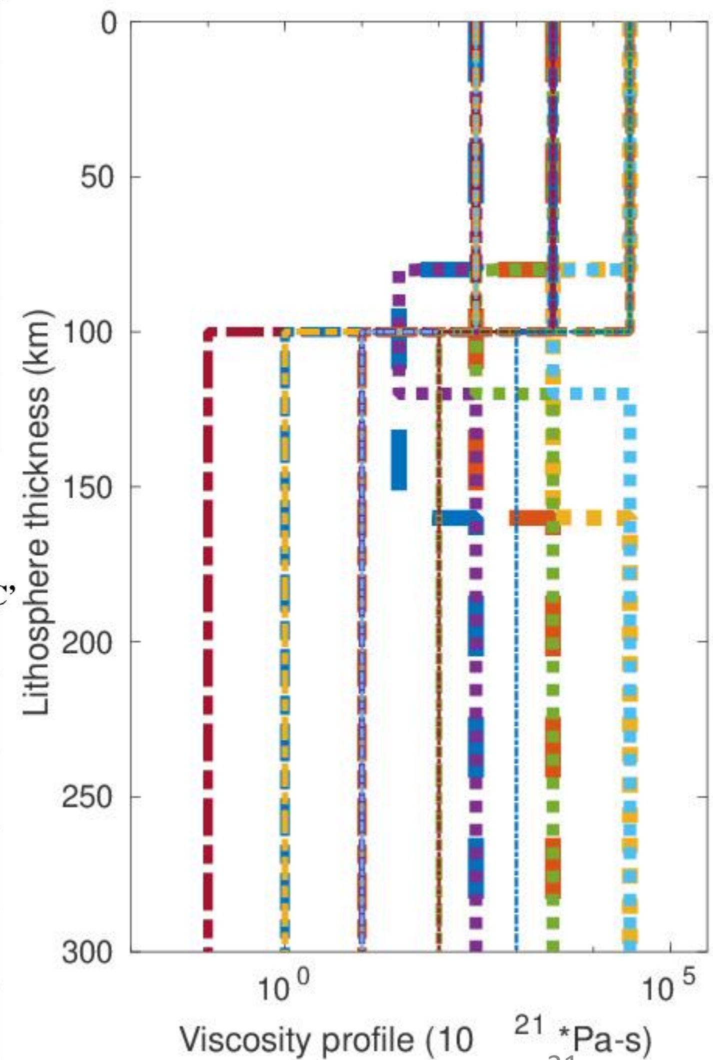
Chapter 4: Effect of mid-lithospheric discontinuity in the survival of cratons

Approaching the problem

Ford et al., 2010

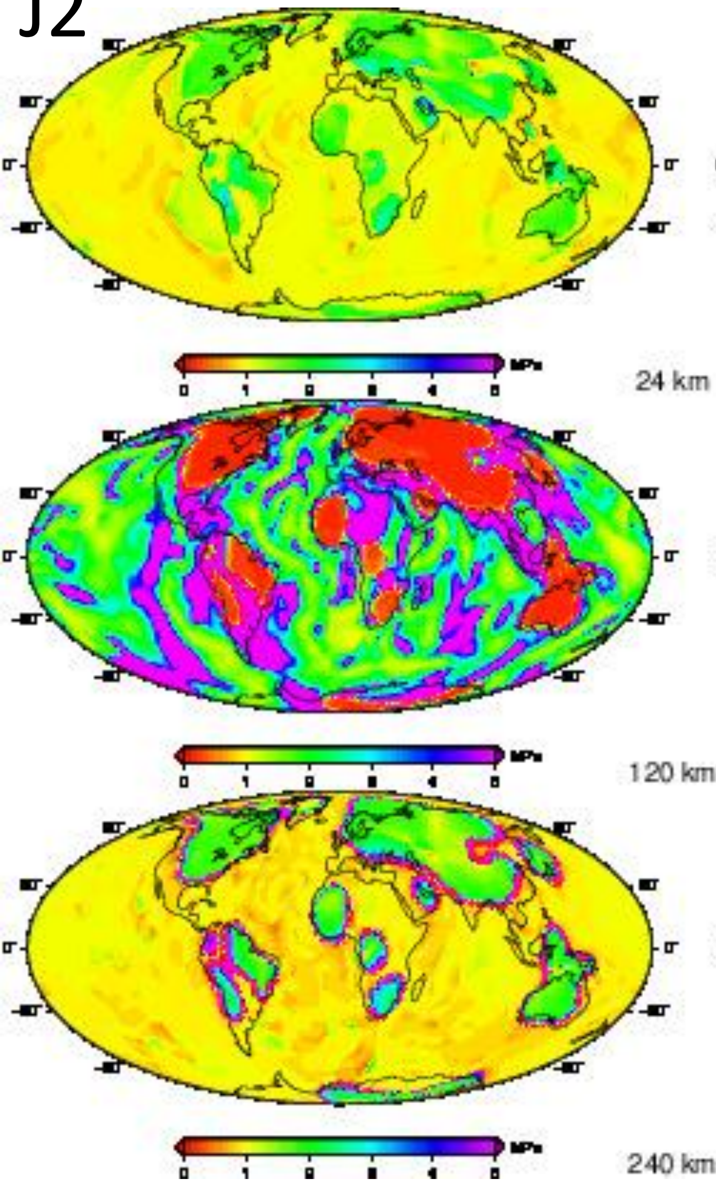


Viscosity profile

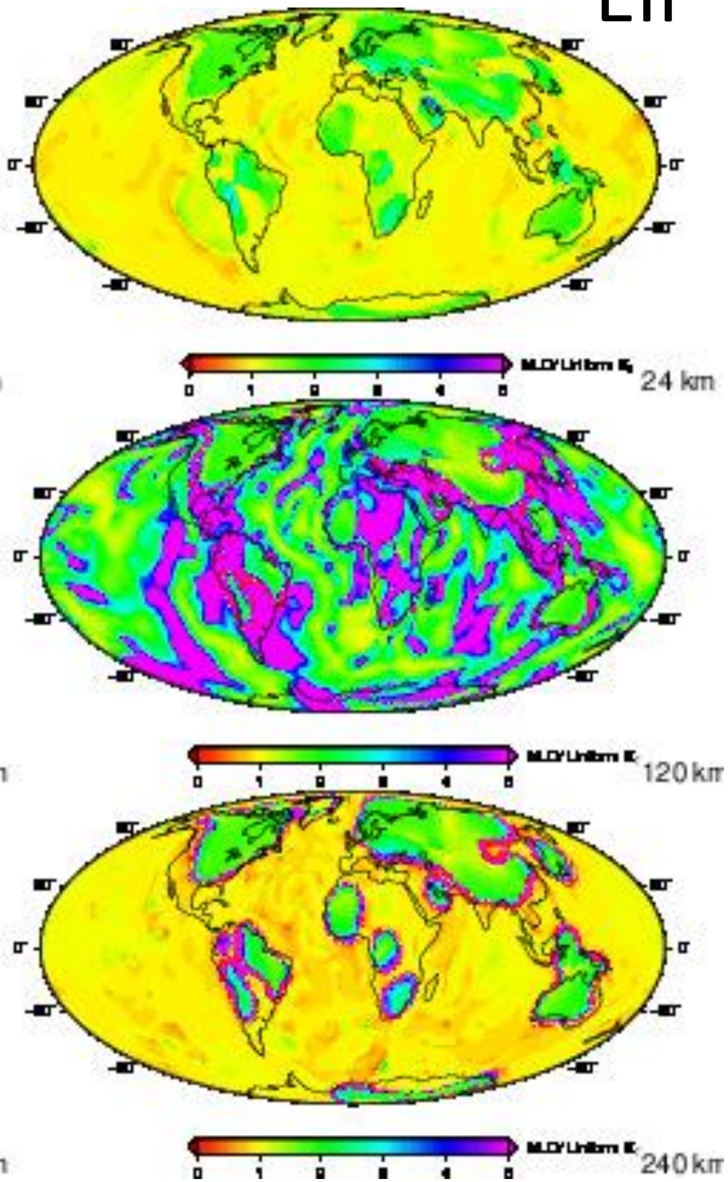


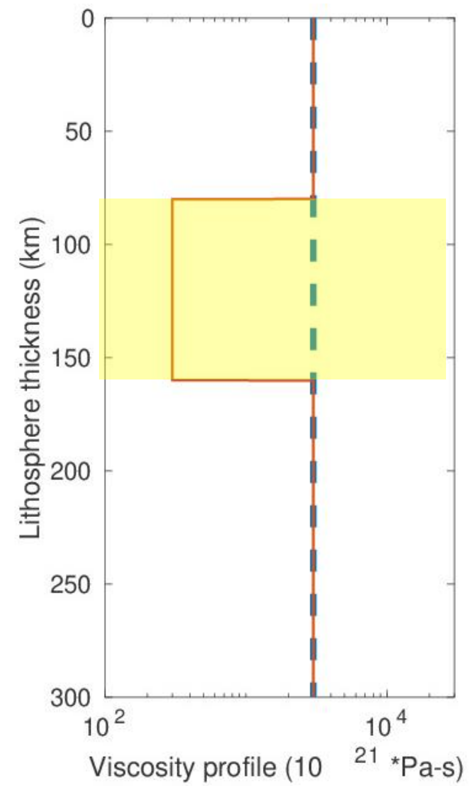
Second invariant of stress and strain-rates

J2

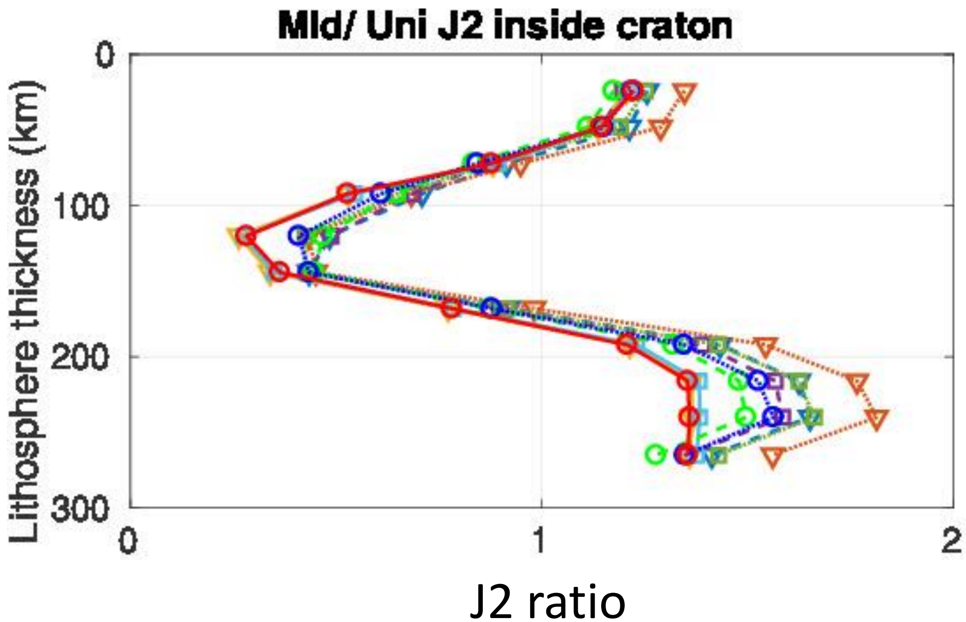


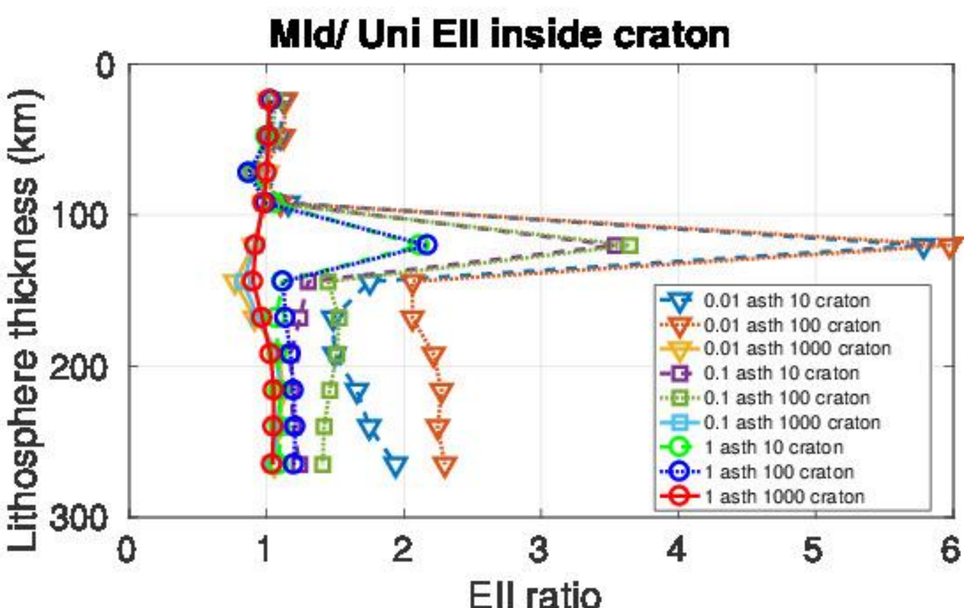
EII

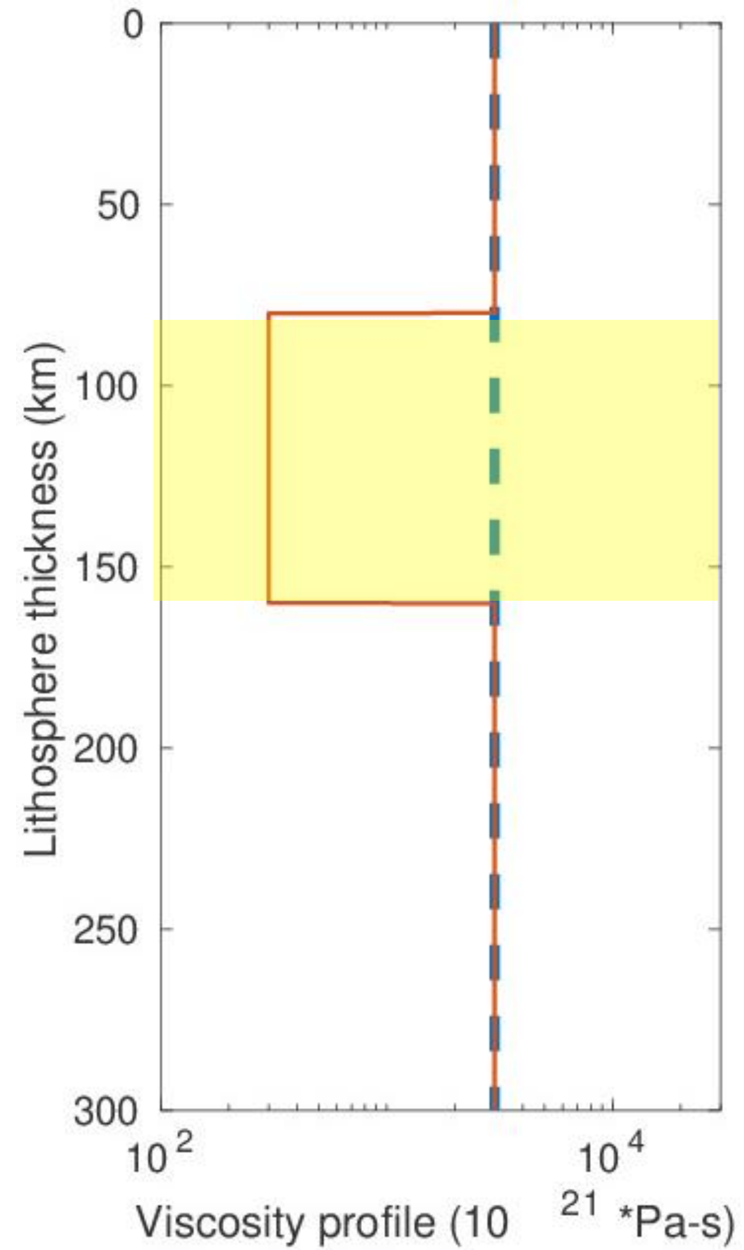




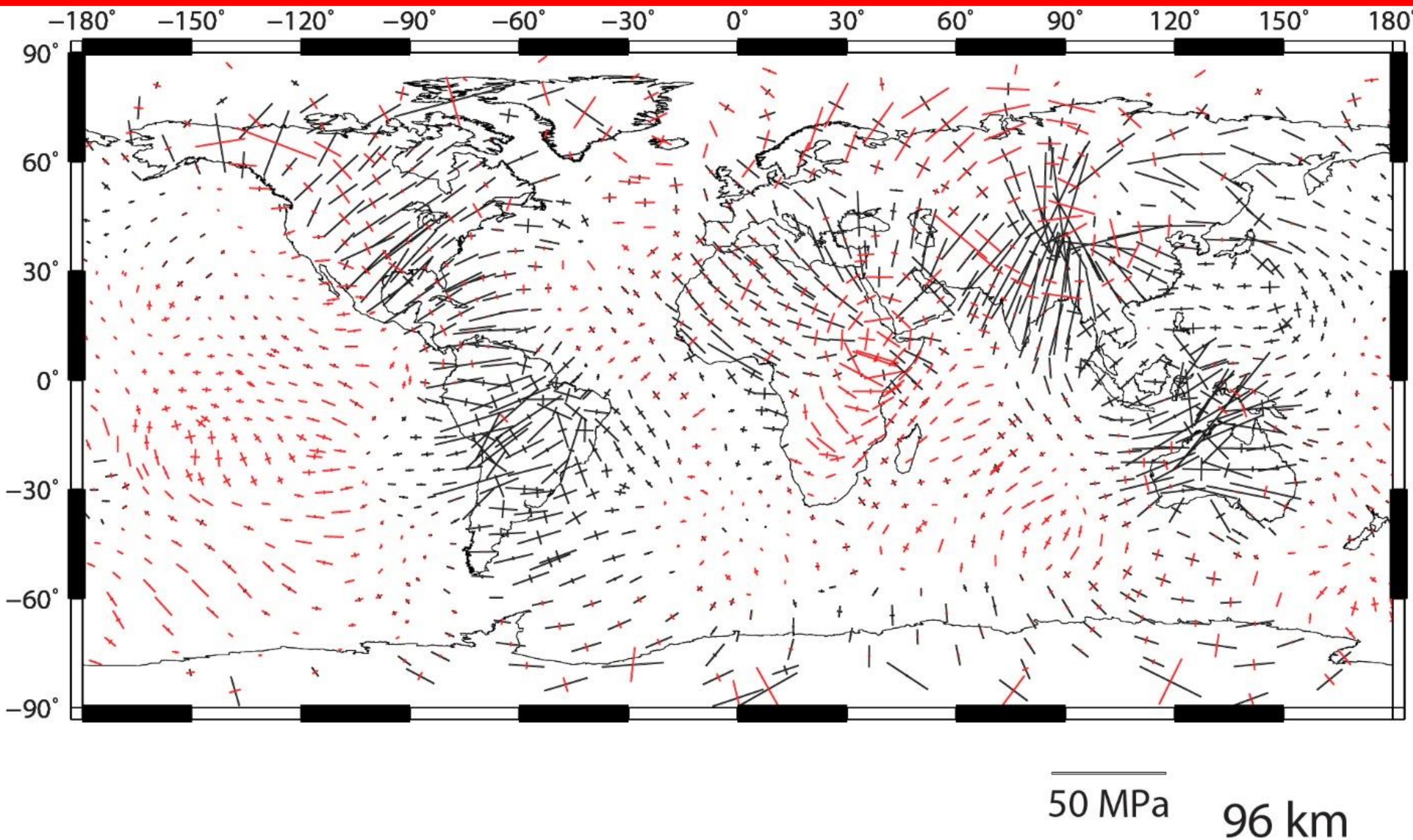
Deformation in presence of MLD







Global stress pattern in presence of MLD



Red lines: Maximum compressive stress

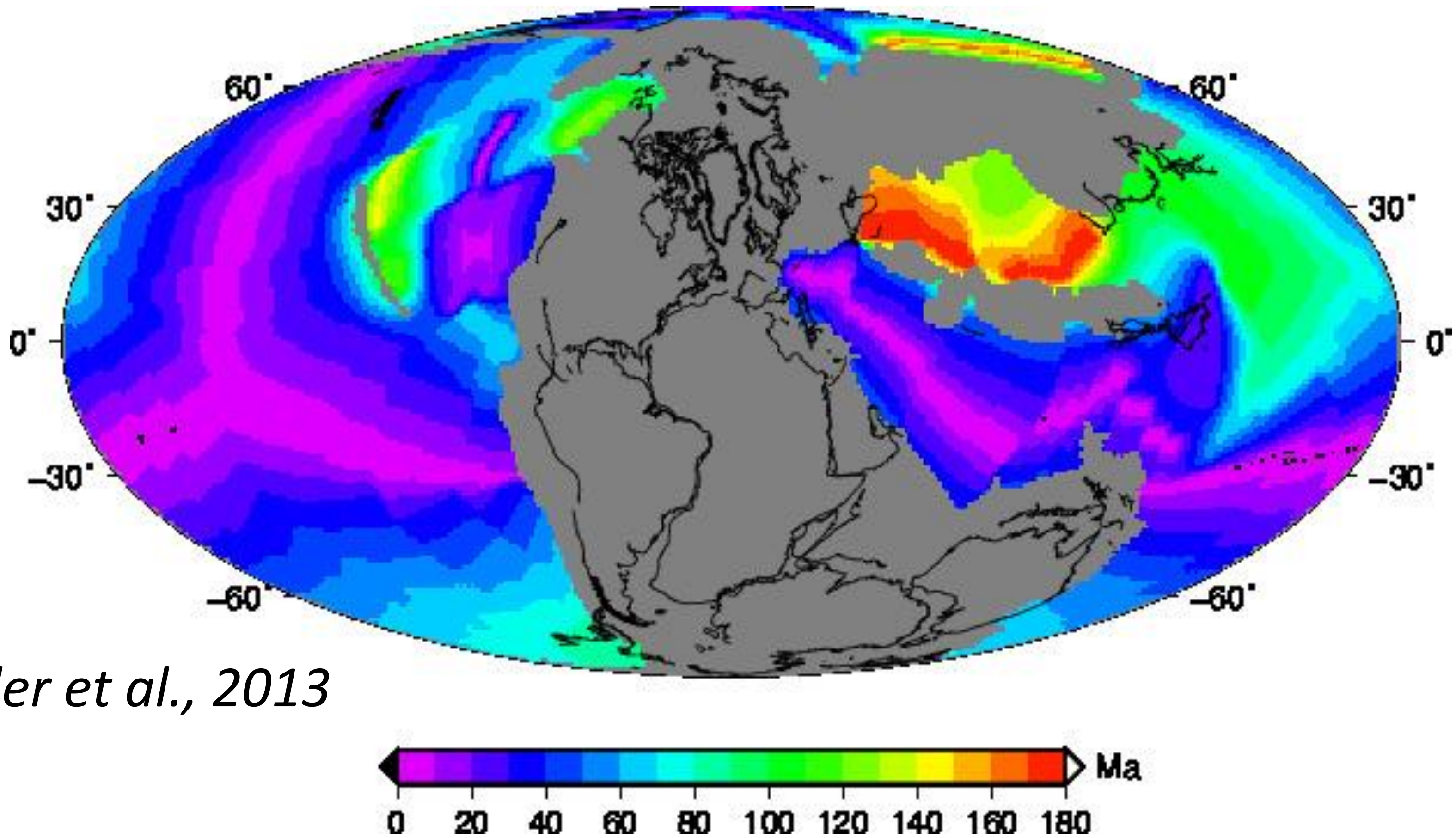
Black lines: Maximum extensional stress

Conclusions

1. In presence of MLD, stress drops but strain-rate increases
2. Weak MLD can accelerate delamination from the middle of the cratons, but does not influence deformation significantly at the base of cratons

Chapter 5: Evolution of cratons through ages using reconstructed density anomalies

Approaching the problem



Muller et al., 2013

$$\frac{T - T_0}{T_1 - \ T_0} = \mathrm{erf}\left(\frac{y}{2\sqrt{kt}}\right)$$

Project	Time	Status
Traction and Strain-rates at the base of the lithosphere: Insight into cratonic stability	2017-2018	Published in Geophysical Journal International, 2019
Evolution of cratons through the ages: A time-dependent study	2018-2019	Published in Earth and Planetary Science Letters
Effect of mid-lithospheric discontinuity in survival of cratons	2019-2020	Mid-way
Evolution of cratons through ages using reconstructed density anomalies	2019-2020	Just started

Publications from PhD projects

In peer reviewed journals

2. J. Paul, A. Ghosh, 2019, Evolution of cratons through the ages: A time-dependent study, Earth and Planetary Science, in Press.
1. J. Paul, A. Ghosh, C.P. Conrad, 2019. Traction and strain-rate at the base of the lithosphere: An insight into cratonic survival. *Geophysical Journal International.*

Conference Presentations

6. **J. Paul**, A. Ghosh, 2019, Evolution of cratons in time-dependent mantle convection models. AGU Fall Meeting, San Francisco
5. A. Ghosh, **J. Paul**, 2019, Effect of Weak Mid-lithospheric Discontinuities on the Survival of Cratons . AGU Fall Meeting, San Francisco
4. J. Paul, **A. Ghosh** , 2019, Evolution and survival potential of cratons: A numerical study. IUGG General Assembly, Montreal.
3. **J. Paul** , A. Ghosh, 2018, Stability of cratons since early Phanerozoic. AGU Fall Meeting, Washington DC.
2. A. Ghosh, **J. Paul** , C.P. Conrad, 2018, The Relation Between Tractions and Strain Rate at the Base of the Lithosphere: Key to Understanding Cratonic Stability. AGU Fall Meeting, Washington DC.
1. **J. Paul** , A. Ghosh, 2018, Variation of traction and strain rate with lithospheric thickness: An insight into understanding cratonic stability. EGU General Assembly, Vienna.