Understanding deformation of cratons in presence of mid-lithospheric discontinuity

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Introduction

What is MLD?

Goal of our study

Methodology

Mantle viscosity and MLD

Description of all models (Table)

Conclusion:

Weak MLDs can decrease the stress inside the cratons, but enhance strain-rates which can **potentially promote delamination from the middle of the cratons**.

The presence of a weak MLD **changes the global stress magnitudes**, even though they are local features.

Presence of a weak layer may change the **anisotropy direction** underneath cratons.

Results and Discussions

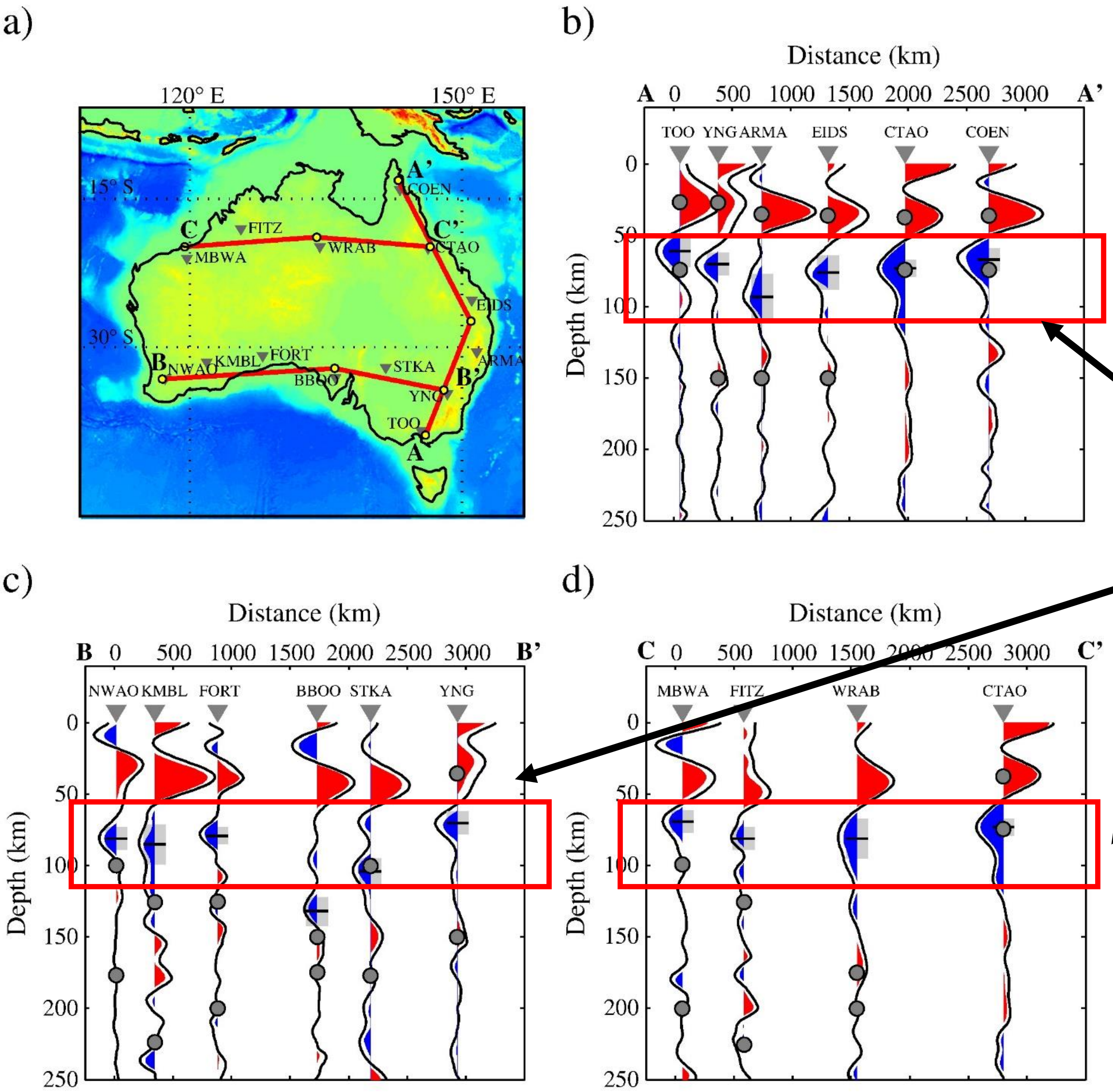
Stress and strain-rates in presence or absence of MLDs

Effect on anisotropy due to weak MLD

Click on boxes to go to the respective slides

What is MLD?

Back to main



Mid-Lithospheric discontinuity (MLD) is a seismic low-velocity zone occurring at around 80-160 km depth under the thick cratonic lithosphere.

MLD at 3 different cross-sections under the Australian Craton

Controversy:
Are they weak? If so, how do they affect cratons' stability?

(Ford et al., 2010)

Goals of the present work

Back to main

Geochemical data suggests that some cratons (eg. eastern part of the North-China Craton) has been destroyed. Many studies suggest such destruction is due to presence of a weak MLD under the cratons. A 3-D geodynamic model to study the effect of MLD is yet to be developed.

Our Goal

1. Developing 3-D full spherical earth-like mantle convection models to investigate the effect of MLDs in cratons' survival

2. To test whether MLDs are really weak.

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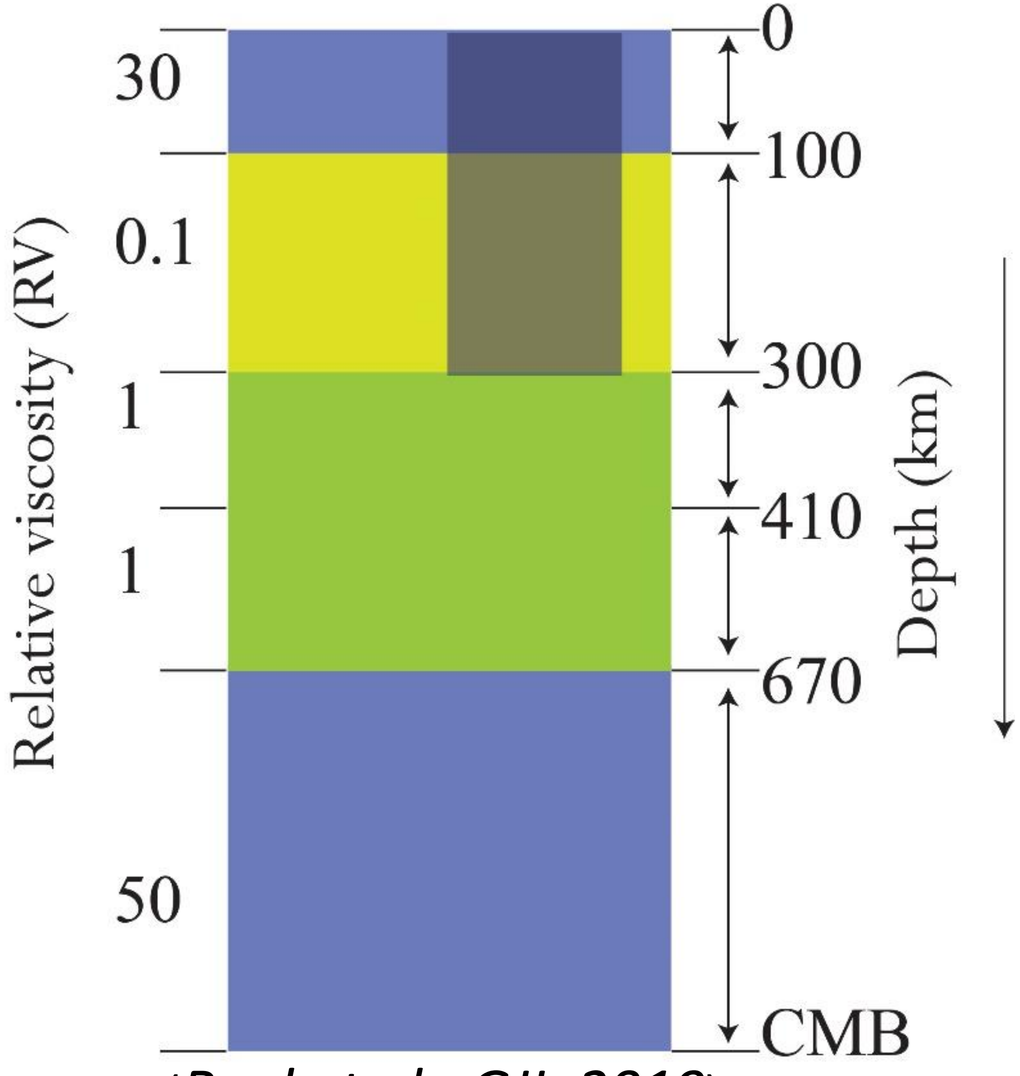
Methodology

Back to main

1. Our models are developed by a **FE code CitcomS** that can solve convection equations (Zhong et al., 2000).
2. **Instantaneous mantle flow** driven by density anomalies derived from **SEMAN2 tomography** (modified form Becker and Boschi 2002)with **free-slip boundary condition at the surface and at the CMB**.
3. High velocity anomalies are removed till 300 km depth to impose **neutrally buoyant cratons.**
4. Both **radial** and **lateral** viscosity variations (LVV) are imposed (Fig in next page). LVV is arising from temperature dependent viscosity following an Arrhenius type equation, $\eta = \eta_0 \exp[E(T_0 - T)]$, where η_0 is the radial viscosity. T_0 and T are non-dimensional reference and actual temperatures.
5. **Highly viscous cratons** are imposed till 300 km depth

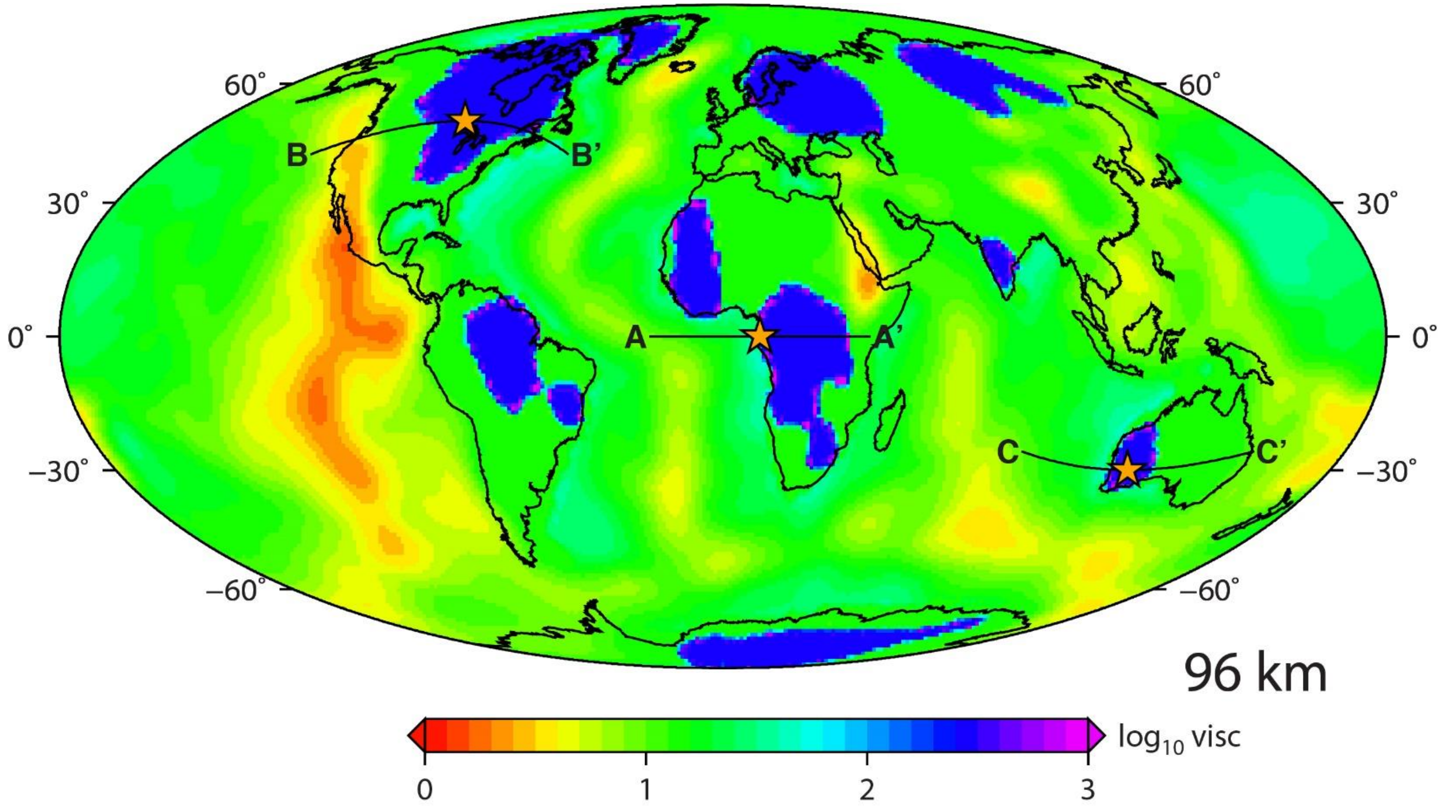
Viscosity variations in models

Radial viscosity structure of mantle



(*Paul et al., GJI, 2019*)

Lateral viscosity structure of mantle

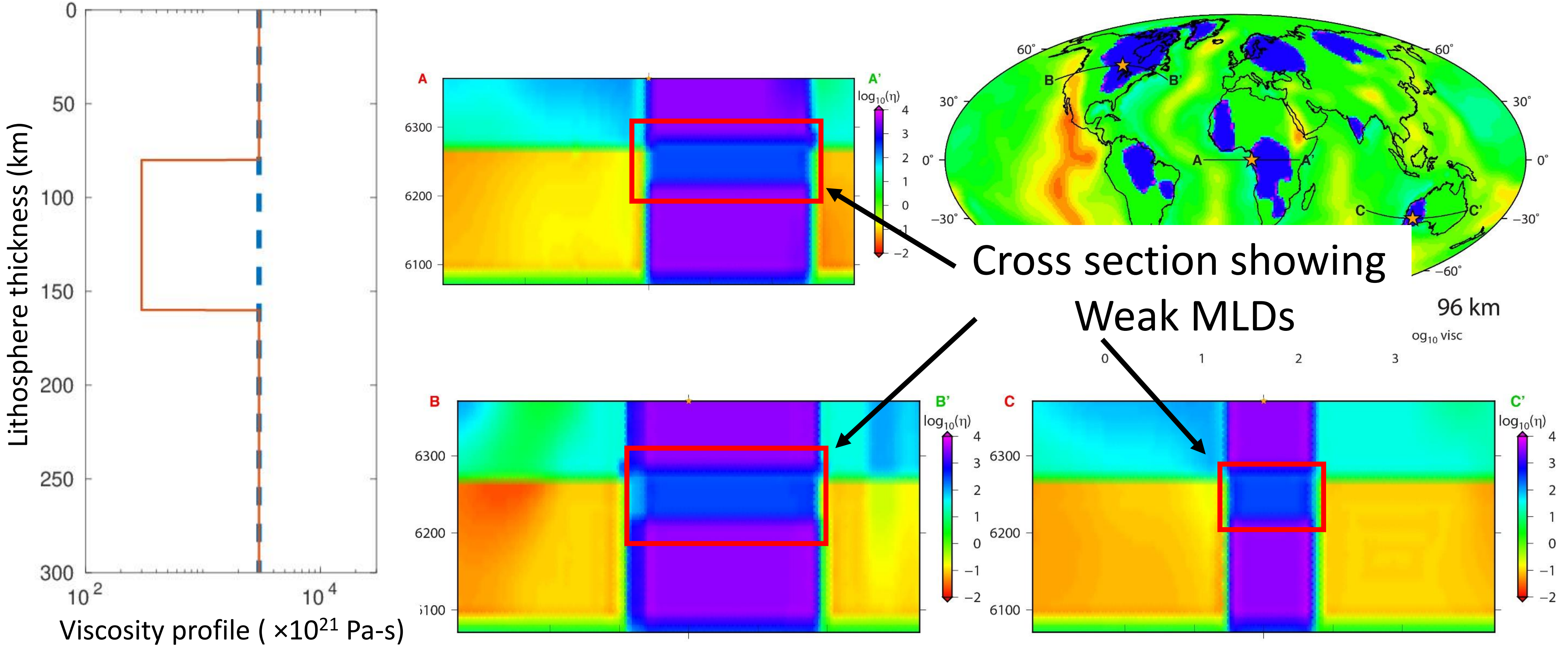


Craton locations are taken from 3SMAC model (Nataf and Ricard, 1996)

Incorporating MLDs inside cratons

Back to main

Two types of cratons are incorporated in the models: 1. **Uniformly viscous** (Blue line) 2. **Cratons with MLD** in between 80-160 km Depth (red line).



All model descriptions

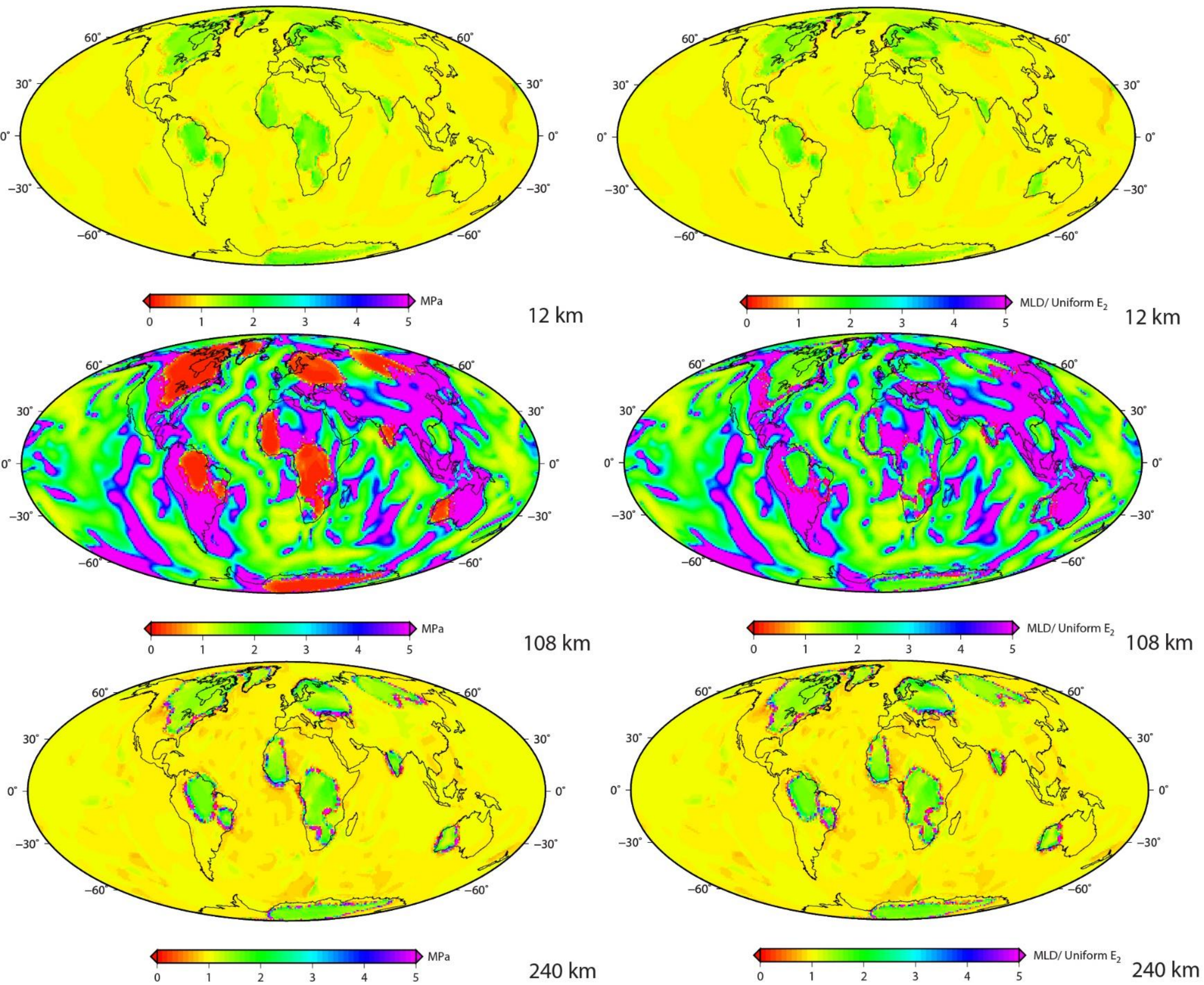
Back to main

Sl. No	Normalised asthenosphere viscosity	Actual asthenosphere viscosity	Craton viscosity multiple w.r.t. lithosphere*	MLD depth	MLD viscosity w.r.t craton
1-3	0.01	10^{19} Pa-s	10,100,100	80-160	0.1
4-6	0.1	10^{20} Pa-s	10,100,100	80-160	0.1
7-9	1	10^{21} Pa-s	10,100,100	80-160	0.1
10-12	0.01	10^{19} Pa-s	10,100,100	80-160	0.01
13-15	0.1	10^{20} Pa-s	10,100,100	80-160	0.01
16-18	1	10^{21} Pa-s	10,100,100	80-160	0.01
19-21	0.01	10^{19} Pa-s	10,100,100	80-120	0.1
22-24	0.1	10^{20} Pa-s	10,100,100	80-120	0.1
25-27	1	10^{21} Pa-s	10,100,100	80-120	0.1

*Lithosphere viscosity is always 30×10^{21}Pa-s

Go to stress results

2[nd] invariant of stress (J_2) and strain-rates (E_2)



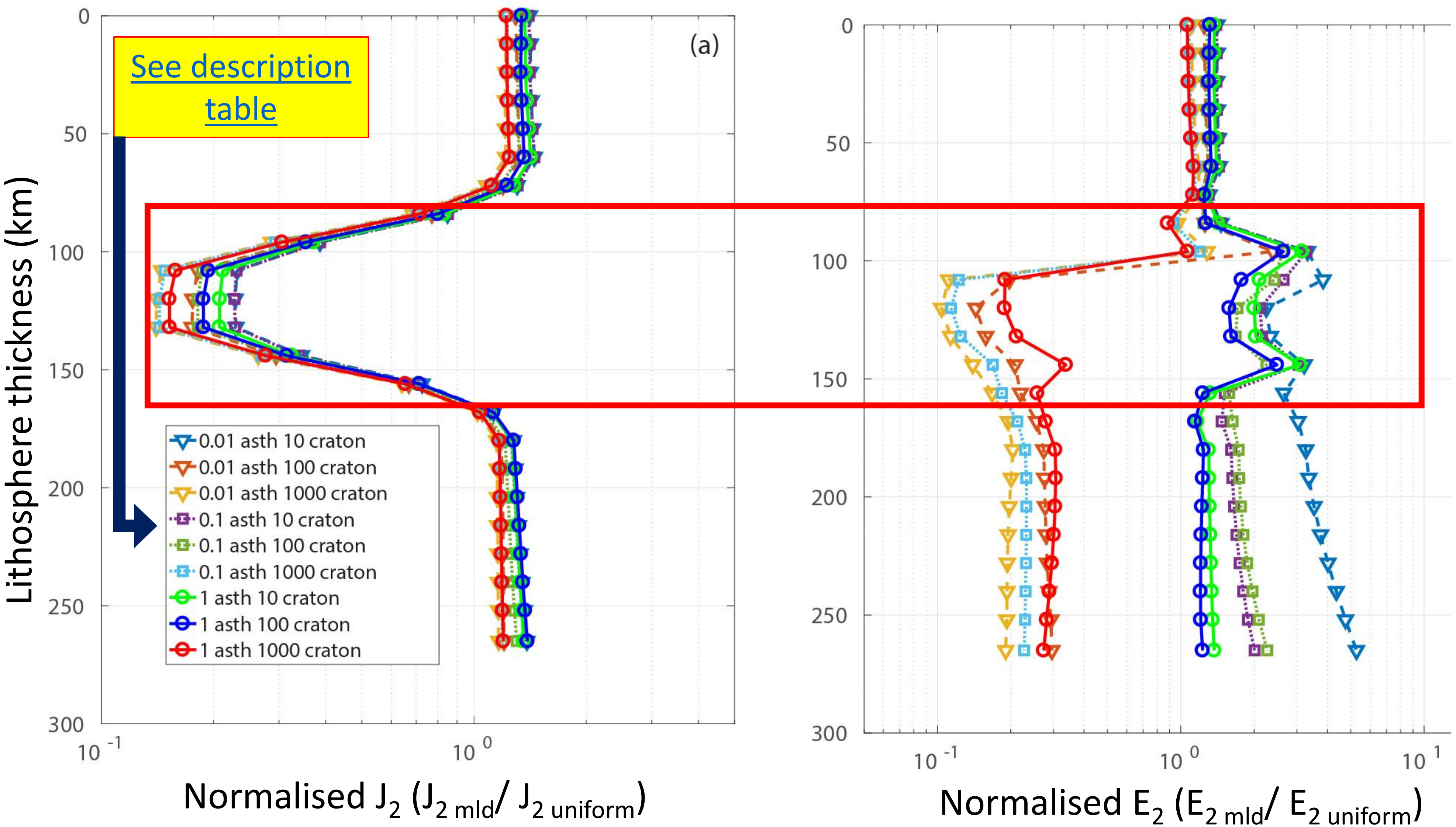
Example case:
100 times viscous craton,
Asthenosphere 10^{20} Pa-s
MLD is 10 times weaker
than the craton

Left : $J_{2\ mld} / J_{2\ uniform}$
Right : $E_{2\ mld} / E_{2\ uniform}$

J_2 and E_2 magnitudes behave differently within MLD layer
and change globally, even if MLDs are locally placed.

Variation of 2nd invariants under cratons

10 times weaker MLD, J_2 drops, E_2 increases in the weak zone



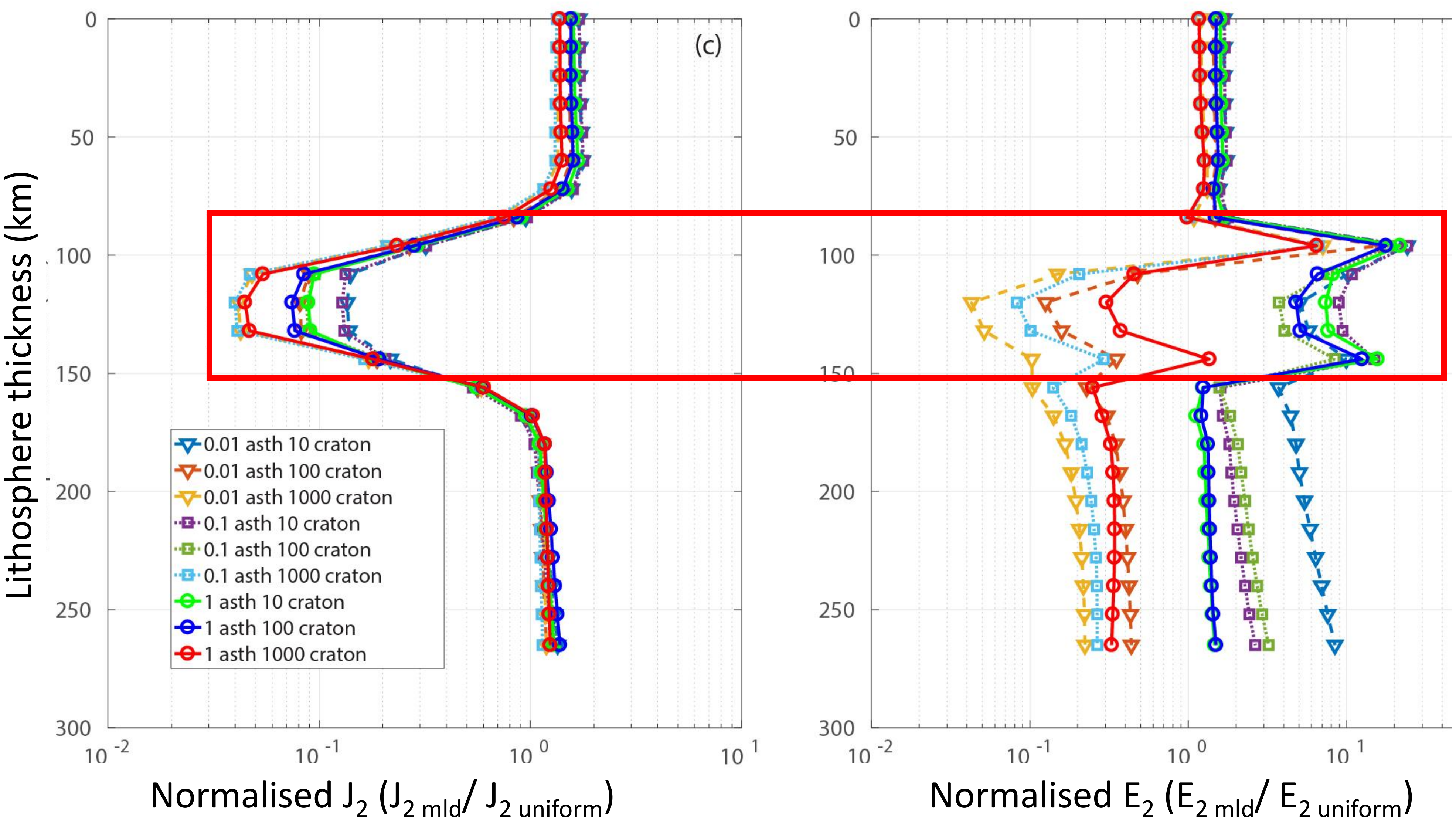
Due to enhanced strain-rate chances of **craton delamination along the weak MLD** increase.

Such delamination has been observed under a few cratons, e.g. North-China Craton

Variation of 2[nd] invariants under cratons

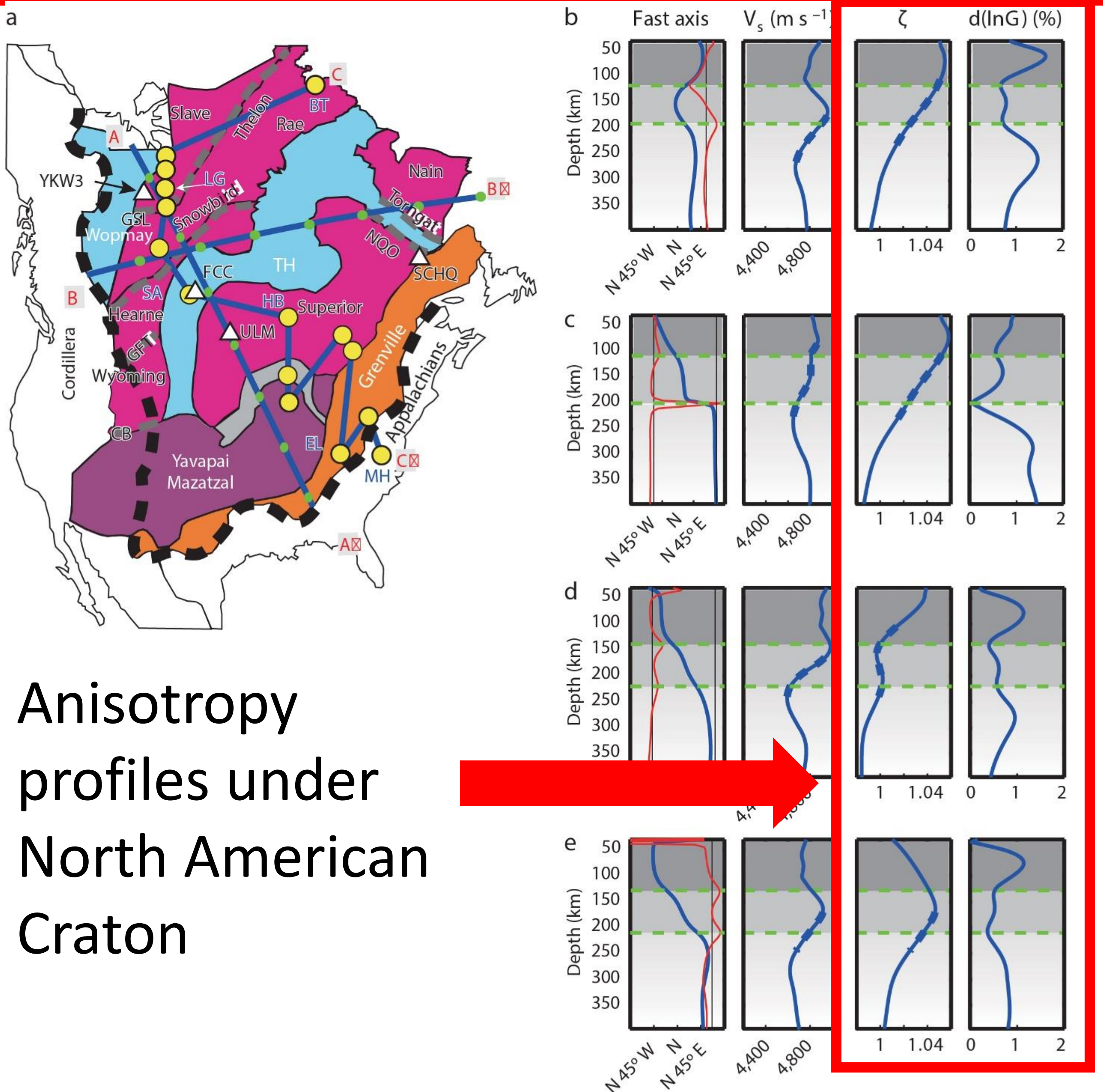
Back to main

100 times weaker MLD, more drop in J_2 and more increase in E_2



Decreasing the strength of MLD another 10 times (i.e., 100 times weaker) leads to around **two times faster deformation** that can lead to craton delamination in shorter time-scale.

Effect of MLD on anisotropy



Anisotropy profiles under North American Craton

Radial anisotropy (ζ) and azimuthal anisotropy (G) under the North American Craton changes in the mid-lithospheric depth range.

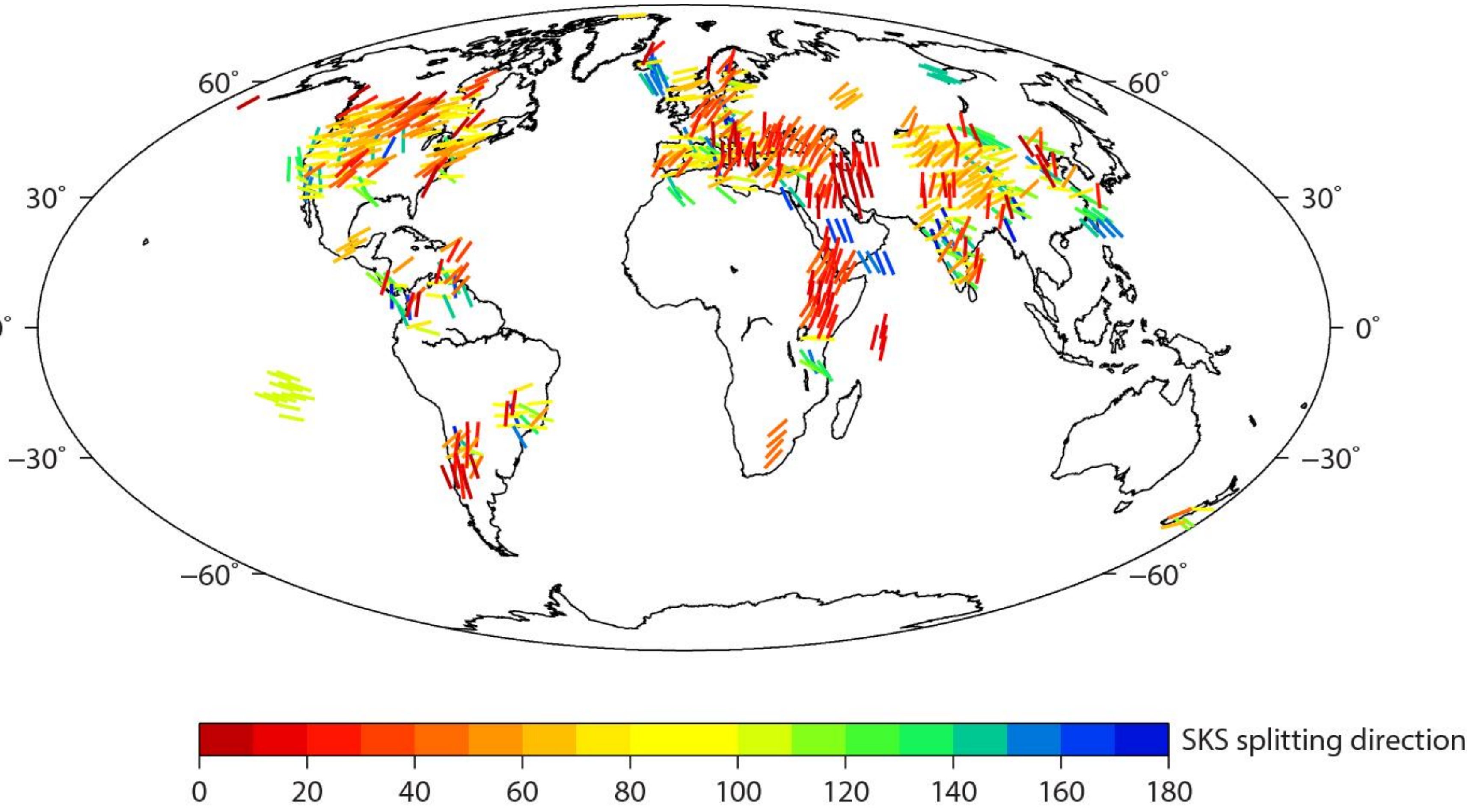
Looking at anisotropy could be an important tool to understand rheology of the MLDs.

Do weak MLDs in our models influence anisotropy under the cratons?

(Yuan and Romanowicz, 2010, Nature)

Predicted and observed anisotropy

Prediction of anisotropy: Anisotropy from global mantle flow is predicted from **calcpi** code (*Conrad et al., 2007*) which follows the approach of *Kaminski & Ribe (2002)*



Observed anisotropy: SKS splitting provide the observed anisotropy direction

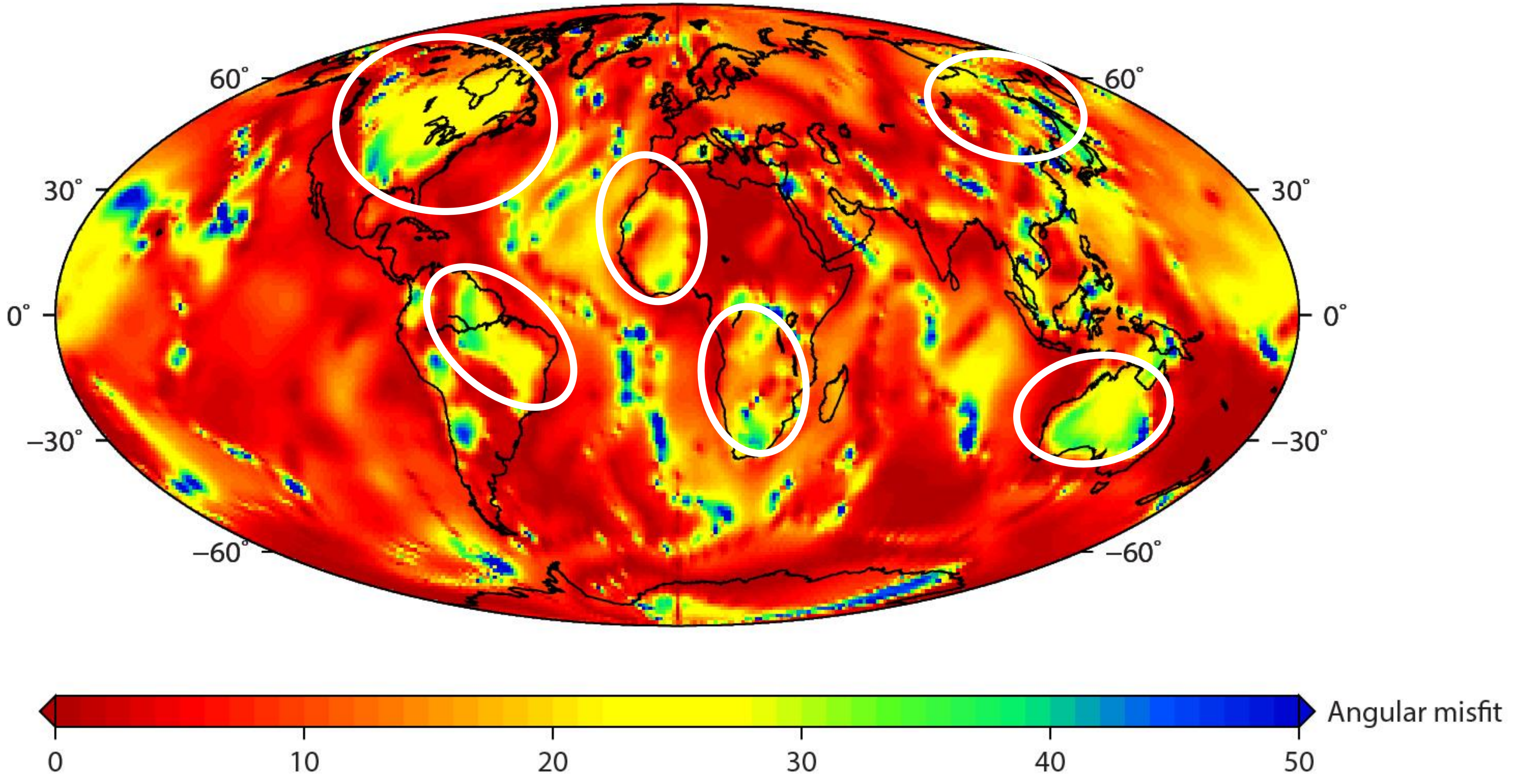
Individual SKS splitting database, Becker et al. 2012, Updated August, 2017

Effect of MLD on anisotropy

Back to main

Aim:

- To calculate the misfit between observed anisotropy and predicted anisotropy from our flow models.
- How does the misfit change due to presence of MLDs?
- **Can we quantify the rheology of MLDs?**



Preliminary results show that there is a high angular misfit (>20°) of anisotropy directions between uniformly viscous cratons and cratons with weak MLD. So, **<u>presence of weak layer may change the anisotropy direction.</u>**

Conclusion

Back to main

- Weak MLDs can decrease the stress inside the cratons, but enhance strain-rates which can potentially promote delamination from the middle of the cratons.
- The presence of weak MLDs change the global stress magnitudes, even though they are local features.
- Presence of a weak layer may change the anisotropy direction underneath cratons.