Diffuse Cretaceous-Cenozoic rifting in the Southern Ross Sea: the influence of inheritance and kinematics

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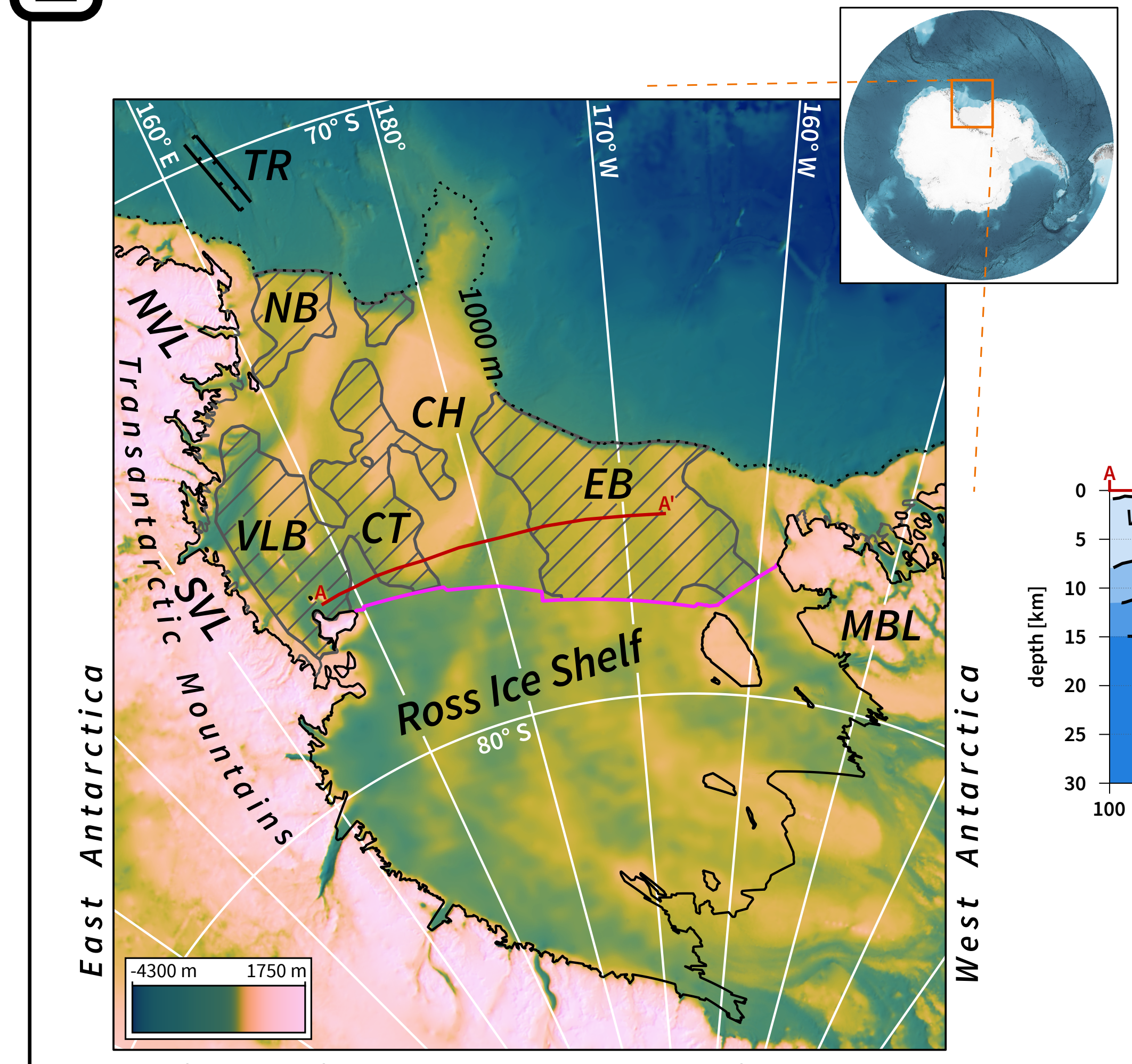
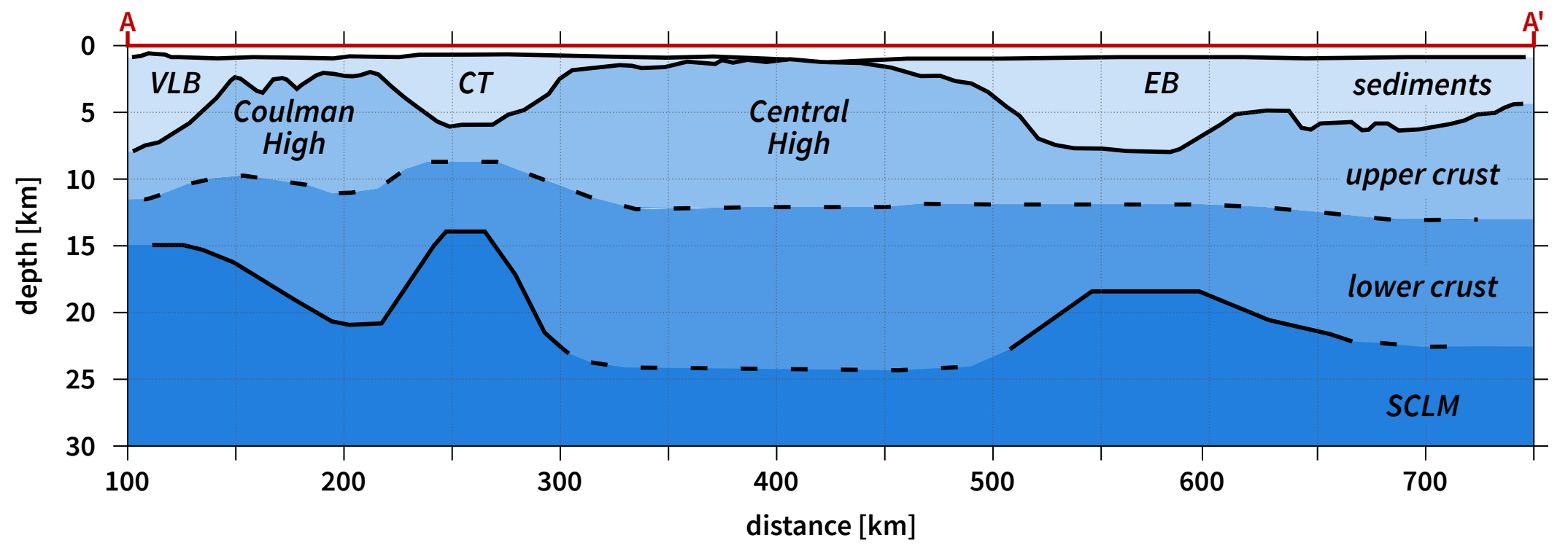
1 Introduction & motivation



Map of the main features in the West Antarctica Rift System and the surrounding provinces. **VLB:** Victoria Land Basin, **CT:** Central Trough, **CH:** Central High, **EB:** Eastern Basin, **NB:** Northern Basin, **TR:** Terror Rift, **NVL:** North Victoria Land, **SVL:** South Victoria Land, **MBL:** Marie Byrd Land. Red line: seismic profiles BGR-02 and ACRUP2. Purple line: grounding line of the Ross Ice Shelf. Dotted black line: 1000 m isobath. Hatched areas: sedimentary basins redrawn from Decesari et al. (2007) and Davey and Brancolini (2013). Bed bathymetry from IBSCO v2 (Dorschel et al., 2022).

The Cretaceous - middle Neogene extension in the **West Antarctica Rift System (WARS)** bears evidence of the **concurrent formation of multiple basins** normal to the rift axis. In its southernmost portion, on the Ross Shelf, three main basins can be identifed: the Victoria Land Basin, the Central Trough, and the Eastern Basin - for a present-day length of almost 1000 km.

The different basins, bounded by structural highs, exhibit significant variations in the thickness and thinning of the underlying crust and lithosphere. This multiple-basin pattern suggests that, at least for some part of **the rifting, the deformation occurred in a diffuse pattern**, instead of being localized in a small portion of the rift system. The reconstructed kinematics suggests 2 separate rifting phases.



Section sketch along the ACRUP2 profile, redrawn from Trey et al. (1999)

We aimed at two peculiar features observed in the southern portion of the rift system:

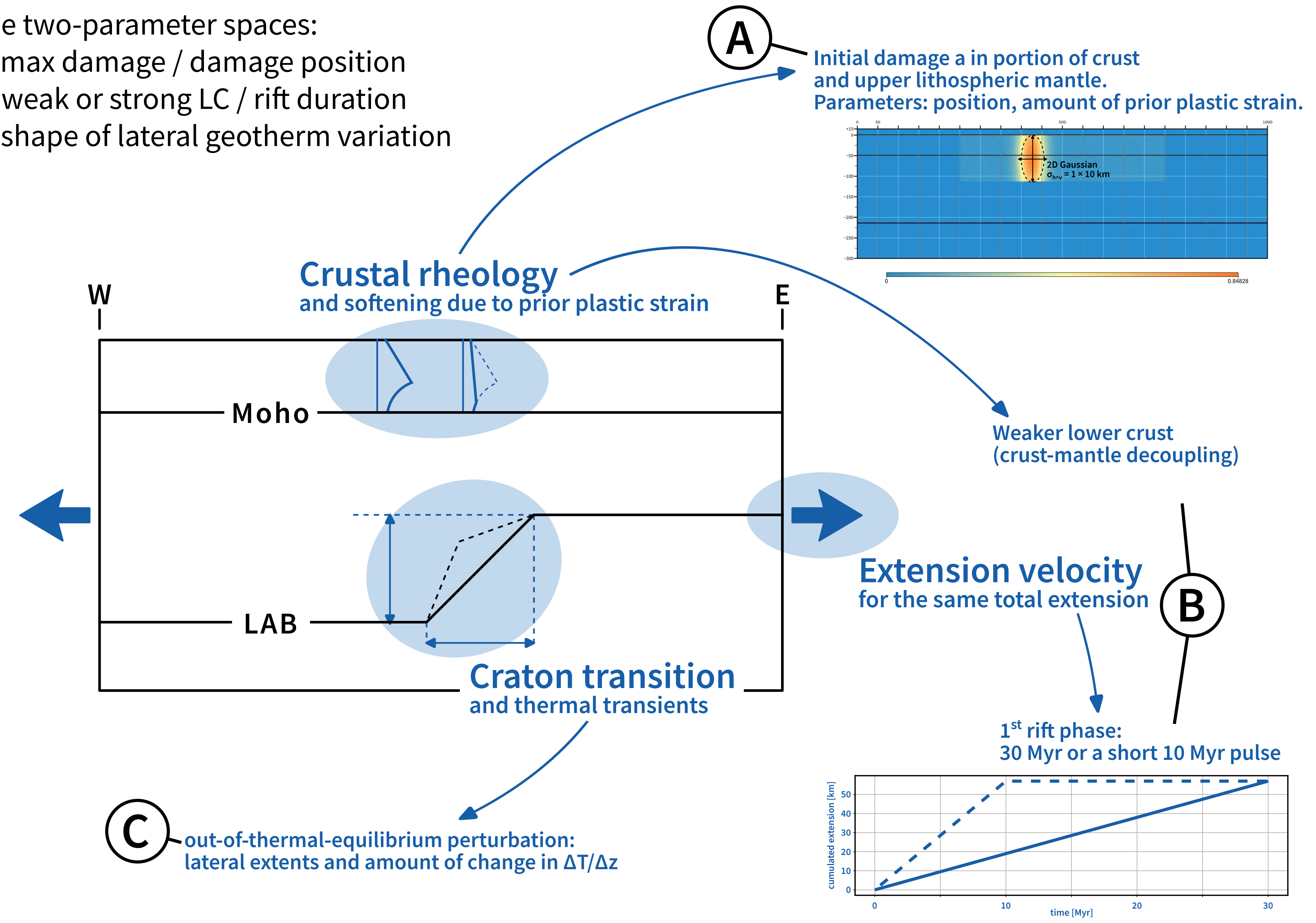
- the transition, in time, **from diffuse to focused deformation**
- the migration of the deformation focus **from east to west**, towards the cratonic domains of East Antarctica

This pattern seems unlikely in a simple model of a lateral transition to an off-craton domain. To test what is required to trigger this behaviour, we set up a parametric study in a simplified 2D analogue of the southern Ross Sea at around 110 Ma. We aim at assessing the sensitivity of rift evolution to inherited structures, improving the knowledge on the initial conditions and the parameter choices involved in basin modelling (e.g. in paleo-bathymetric reconstructions, see Colleoni et al. 2021).

2 Parametric study scheme

What shaped the basins in the Ross Sea?
What is the sensitivity to the initial conditions?

Three two-parameter spaces:
- **A)** max damage / damage position
- **B)** weak or strong LC / rift duration
- **C)** shape of lateral geotherm variation



A Initial damage a in portion of crust and upper lithospheric mantle. Parameters: position, amount of prior plastic strain.

Crustal rheology and softening due to prior plastic strain

Weaker lower crust (crust-mantle decoupling)

Extension velocity for the same total extension **B**

1st rift phase: 30 Myr or a short 10 Myr pulse

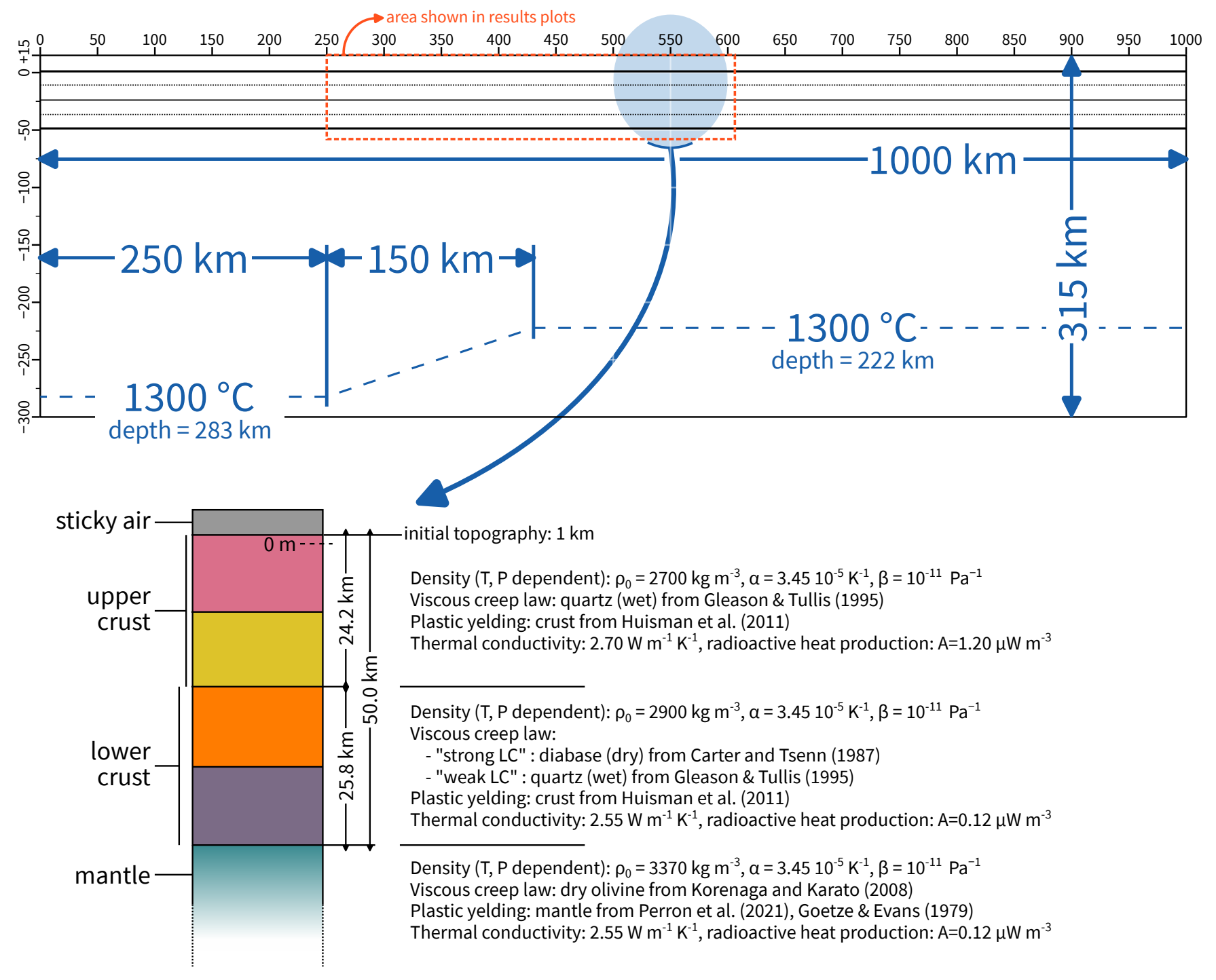
Craton transition and thermal transients

C out-of-thermal-equilibrium perturbation: lateral extents and amount of change in ΔT/Δz

3 Model setup

We employ a 2D thermo-mechanical synthetic model of the lithosphere and upper asthenosphere, relying on the open source **Underworld 2** code (particle-in-cell finite element approach, see Mansour et al., 2020).

We use a non-deforming orthogonal Cartesian mesh of 534 × 168 (H × V) Q1 elements. The solver of the advection diffusion equation is the Semi-Lagrangian Crank-Nicholson (SLCN) algorithm. The free topographical surface is modelled using the sticky air approach: $\eta(air) = 10^{19}$ Pa s.



initial topography: 1 km

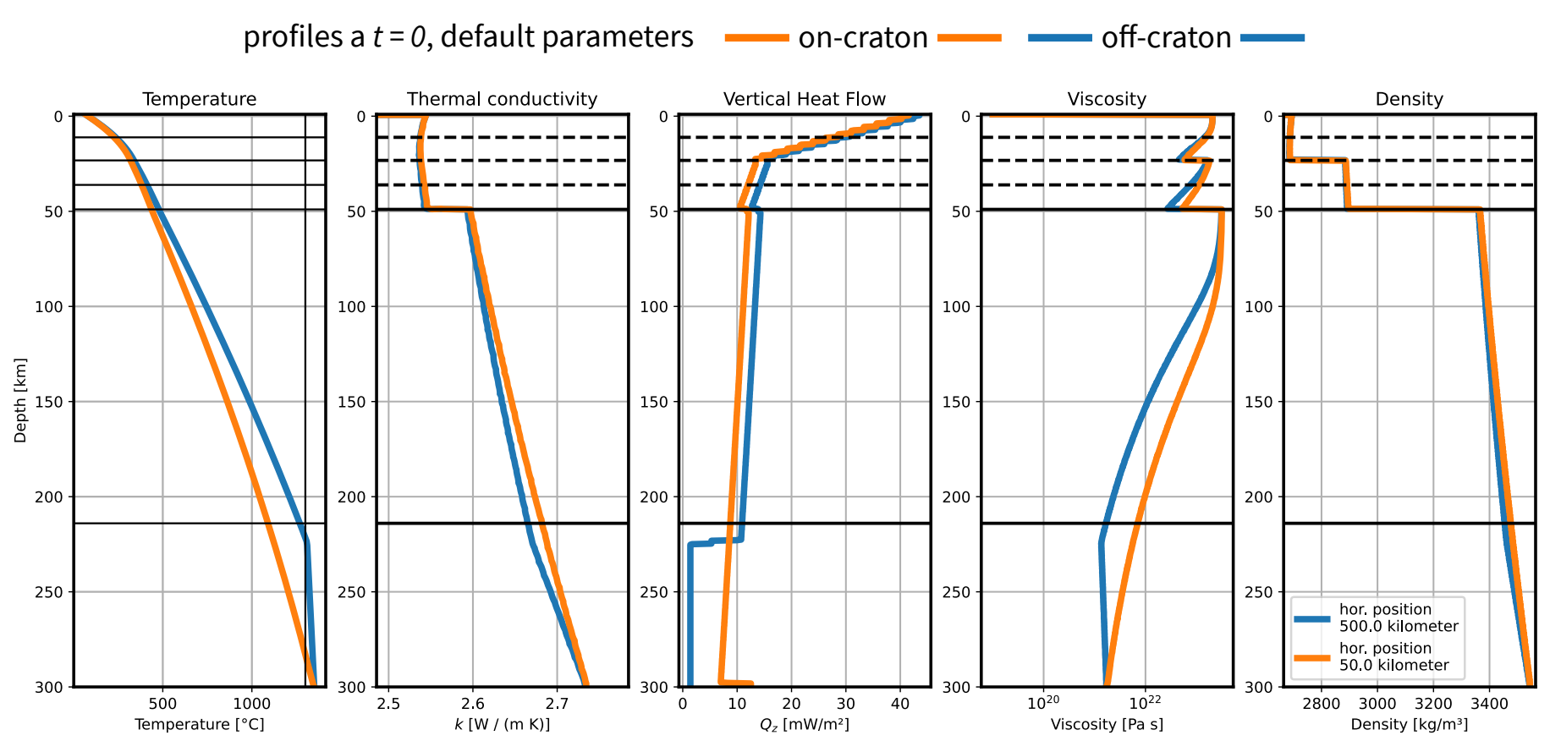
Density (T, P dependent): ρ_0 = 2700 kg m^{-3}, α = 3.45 10^{-5} K^{-1}, β = 10^{-11} Pa^{-1}
Viscous creep law: quartz (wet) from Gleason & Tullis (1995)
Plastic yelding: crust from Huisman et al. (2011)
Thermal conductivity: 2.70 W m^{-1} K^{-1}, radioactive heat production: A=1.20 μW m^{-3}

Density (T, P dependent): ρ_0 = 2900 kg m^{-3}, α = 3.45 10^{-5} K^{-1}, β = 10^{-11} Pa^{-1}
Viscous creep law:
- "strong LC" : diabase (dry) from Carter and Tsenn (1987)
- "weak LC" : quartz (wet) from Gleason & Tullis (1995)

Plastic yelding: crust from Huisman et al. (2011)
Thermal conductivity: 2.55 W m^{-1} K^{-1}, radioactive heat production: A=0.12 μW m^{-3}

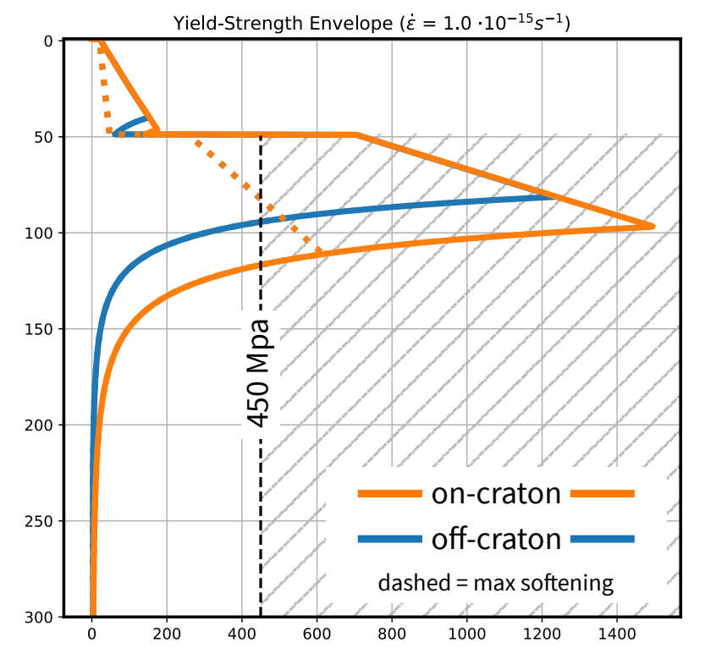
Density (T, P dependent): ρ_0 = 3370 kg m^{-3}, α = 3.45 10^{-5} K^{-1}, β = 10^{-11} Pa^{-1}
Viscous creep law: dry olivine from Korenaga and Karato (2008)
Plastic yelding: mantle from Perron et al. (2021), Goetze & Evans (1979)
Thermal conductivity: 2.55 W m^{-1} K^{-1}, radioactive heat production: A=0.12 μW m^{-3}

Water and sediment infill are set at a threshold of 0 and -1 km, respectively → we approximate sedimentation as always matching the subsidence rate.
The **initial temperature** field is modelled with a steady-state solution, using a basal heat flow of Q(-300 km) = 9 mW m^{-2}. A thermal transient, in terms of a temperature gradient perturbation, is then superimposed. Temperature in the mantle is limited by the adiabatic temperature gradient (0.532 K km^{-1} with a potential temperature of 1300 °C).

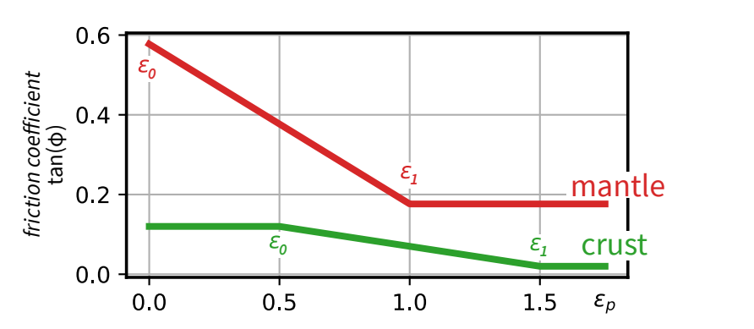


Visco-plastic rheology:

$$\left.\begin{aligned} \eta_{eff}^{vcreep} &= \frac{1}{2} A^{\frac{-1}{n}} \dot{\epsilon}^{\frac{1-n}{n}} d^{\frac{m}{n}} \exp\left(\frac{E+PV}{nRT}\right) \\ \eta_{eff}^{pl} &= \frac{\sigma_y}{2\dot{\epsilon}} \quad \text{with the yield value criterion: } \sigma_y = \min(C\cos\phi + \sin\phi P, \sigma_p) \end{aligned}\right\} \eta_{eff}^{vp} = \min(\eta_{eff}^{vcreep}, \eta_{eff}^{pl})$$



We use a **stress limiter** at σ_p **= 450 MPa** to approximate Peierls creep in the mantle.
Softening due to cumulated plastic strain is modelled with a linear degradation of the friction angle ϕ:



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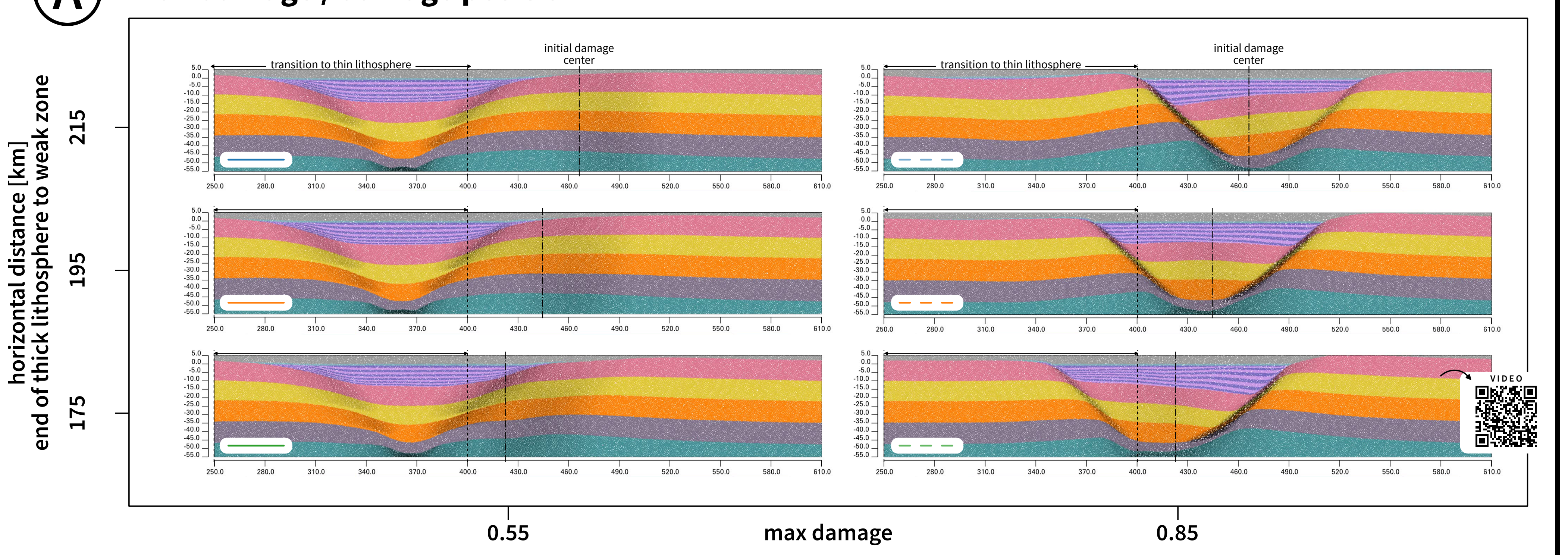
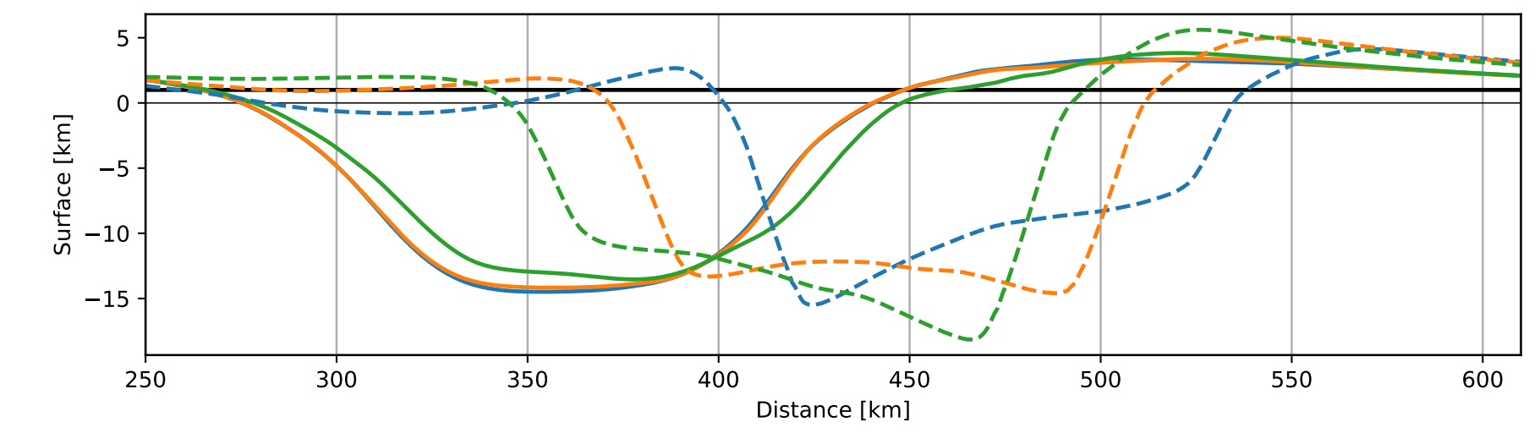
4 Results & discussion

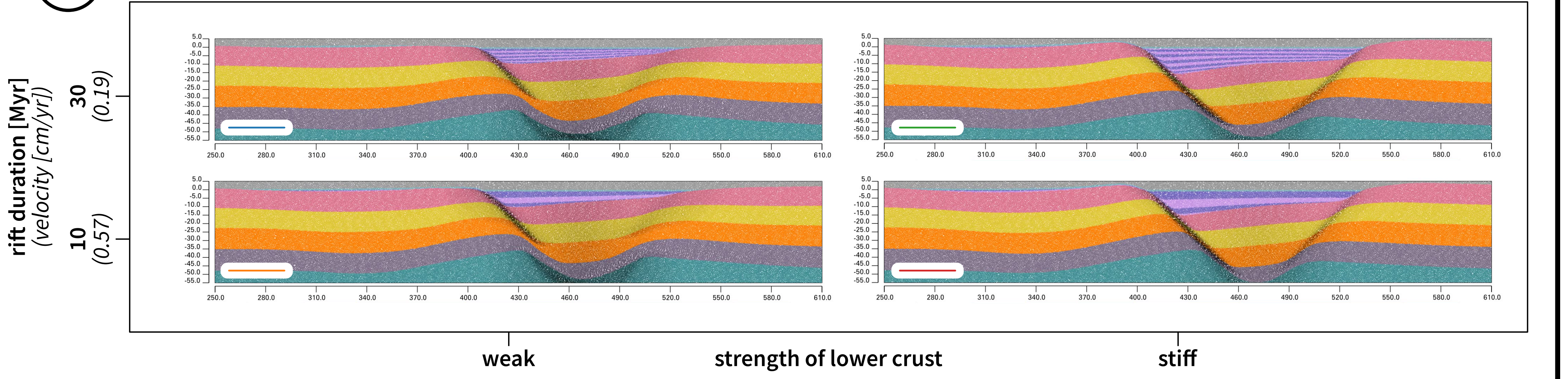
A max damage / damage position

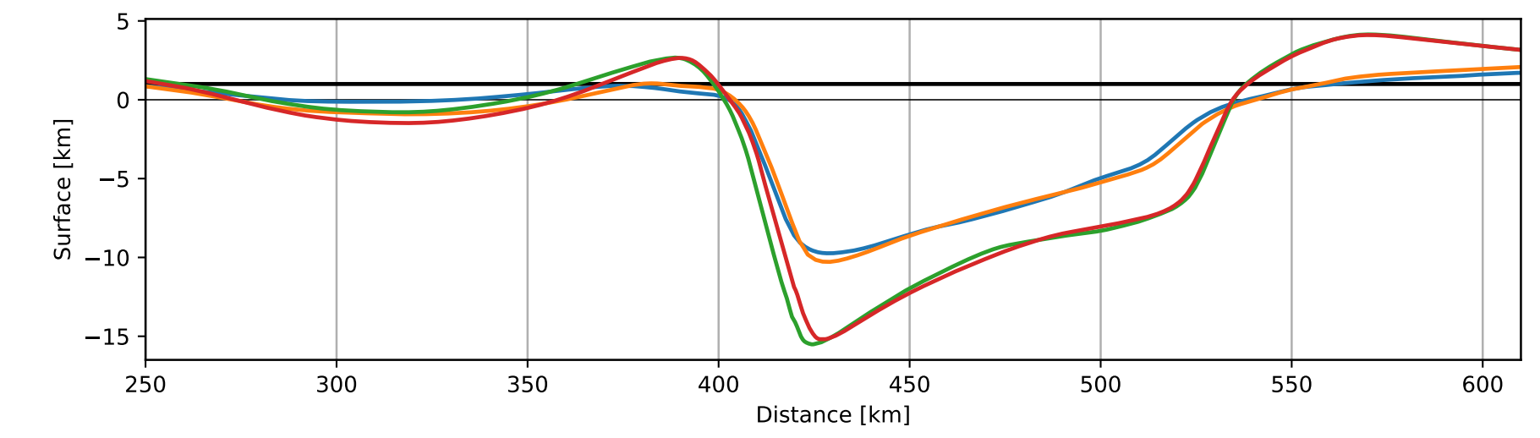


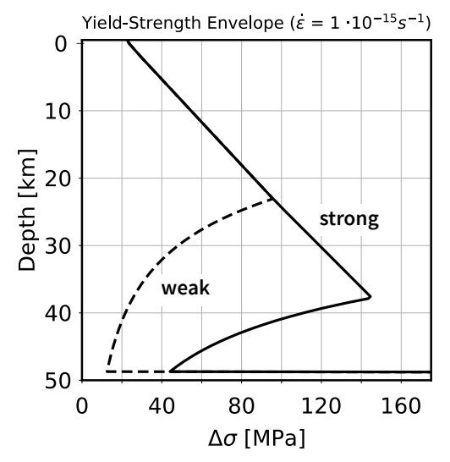


- imposing enough damage in the off-craton portion results in a **strong damage-controlled basin position**
- however, there is still significant influence of the western domains: **basin asymmetry (and its evolution in time)**
- with a close weak zone, **subsidence starts asymmetrical, then the west part matches the subsidence rate** (see bottom-right model)
- **below a damage threshold, the style is purely controlled by the position of lithosphere thickness transition**

B weak or strong lower crust / rift duration

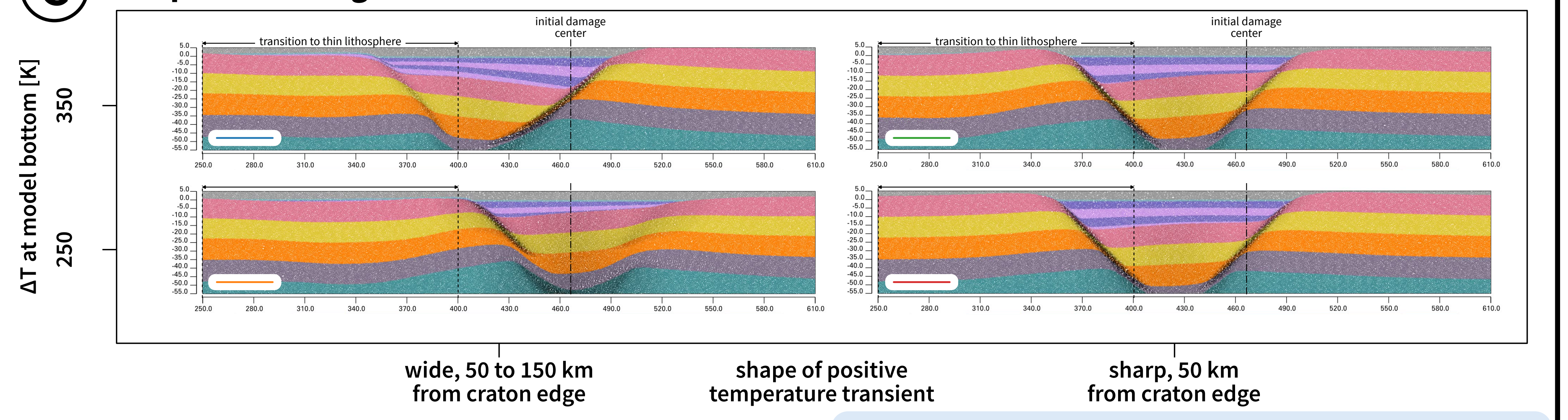


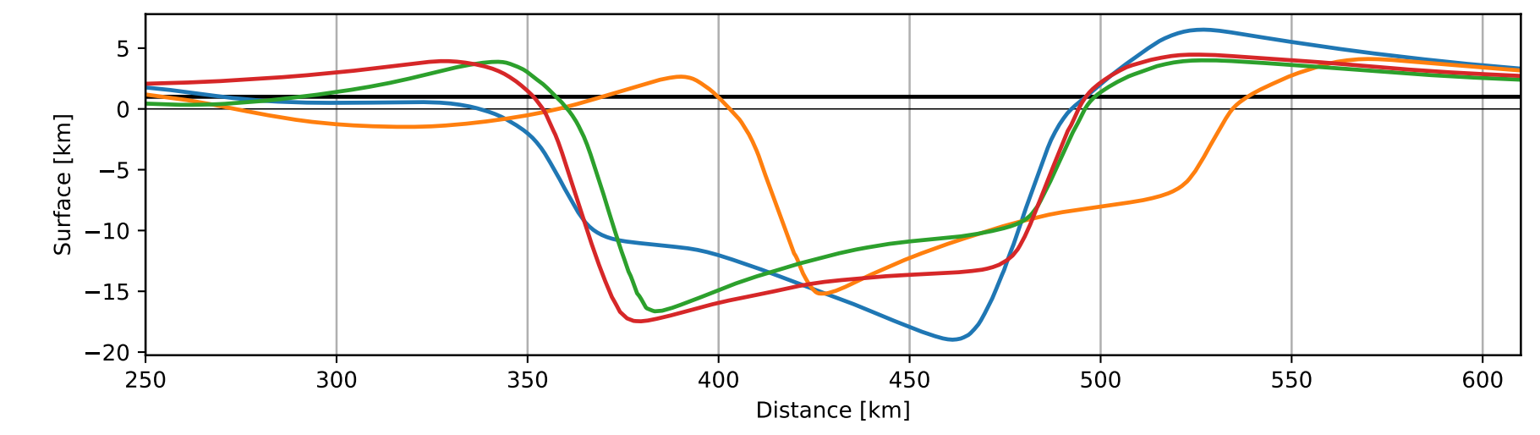




- the **influence of velocity seems negligible** (same extension in 1/3 of time)
- it should be noted that we are **allowing for a large sedimentation rate**, a different outcome is likely if infill is not always matched to subsidence
- **weak lower crust:** surface expression of (almost) decoupling crust and mantle: **less steep basin sides and no uplift of rift flanks**

C shape of lateral geotherm variation





- a sharp transition (small lateral extents) results in **almost no sensitivity to a larger temperature transient**
- with a wide transition: **asymmetry is reversed** when the steeper transient temperature gradient is imposed, more **west-ward increase of subsidence and thinning in the latter stages**
- what are the **analogues** of a warmer lithosphere at a craton boundary?

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