The role of weak seeds in numerical modelling of continental extensional systems

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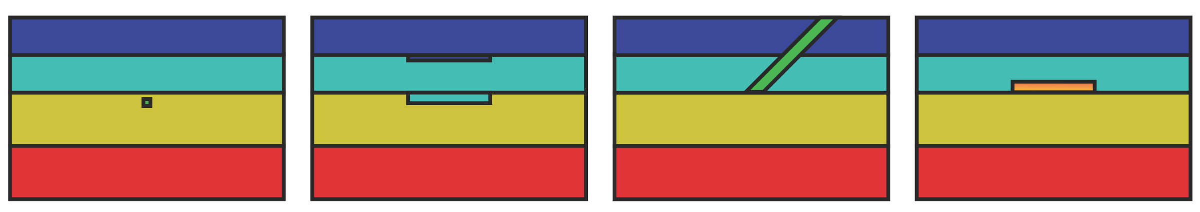
Introduction

Numerical models investigating the dynamics of the lithosphere and upper mantle typically include a perturbation (mechanical, thermal, etc.) in order to localize and initiate deformation. In models of continental extension, perturbations in the form of small, mechanically weak regions ('seeds') are often used to quickly localize deformation and minimize initial thinning of the entire lithosphere. The aim of this poster is to investigate the role of weak seeds in the initial and later stages of continental extension by answering the following questions:

- What is the effect of the geometry of the weak seed?
- What is the effect of the nature of the weak seed?

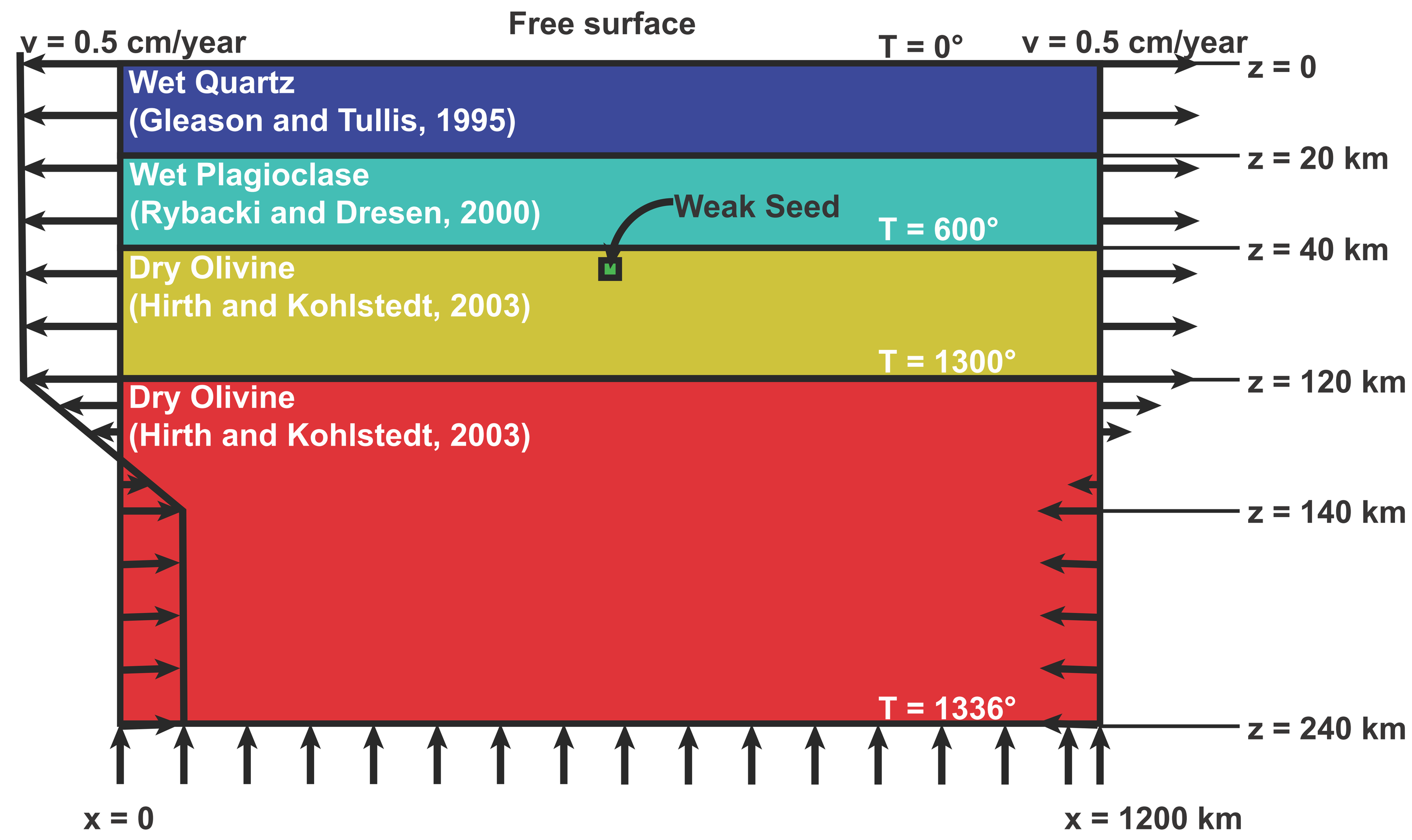
Ultimately, the question we would like to answer is:

Does it matter how we start our models?



Square weak seed | Thick crust | Fault | Temperature anomaly

Model setup

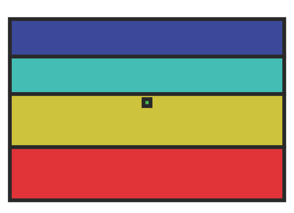


We use the thermal-mechanical ALE (Arbitrary-Lagrangian-Eulerian) codes SULEC and ELEFANT for our visco-plastic experiments. Two codes with identical numerical setups are used to test wether observed effects are influenced by small differences in numerical formulation. The numerical setup (left) uses velocity boundary conditions to drive extension.

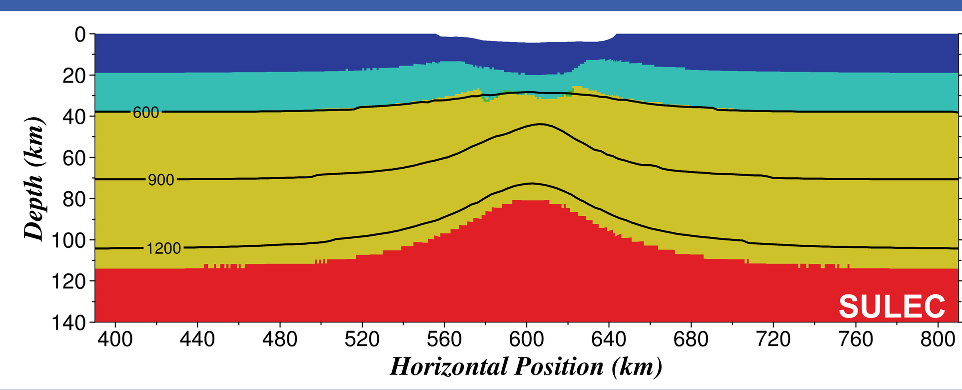
All models on this poster are shown at a model time of 10 Myr (2000 time steps).

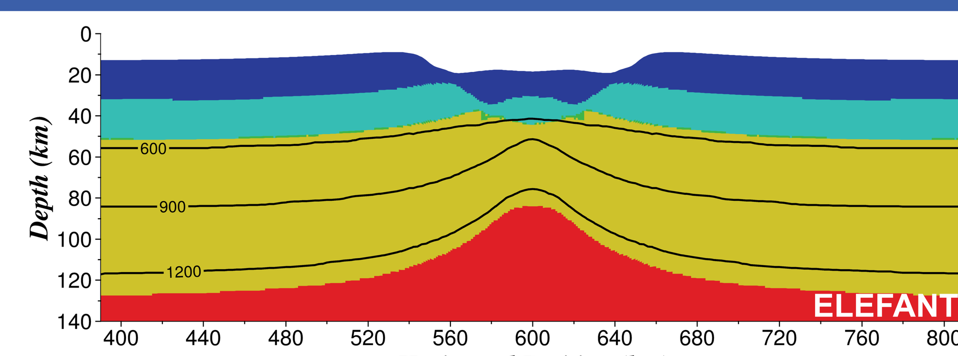
Results

Reference model



6x6 km frictionally weak

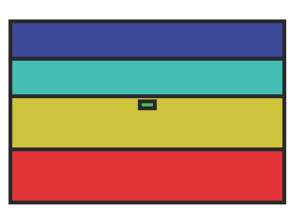




A comparison of SULEC and ELEFANT reference models (time = 10 Myr) shows similar stages of deformation, but somewhat distinct fault architectures.

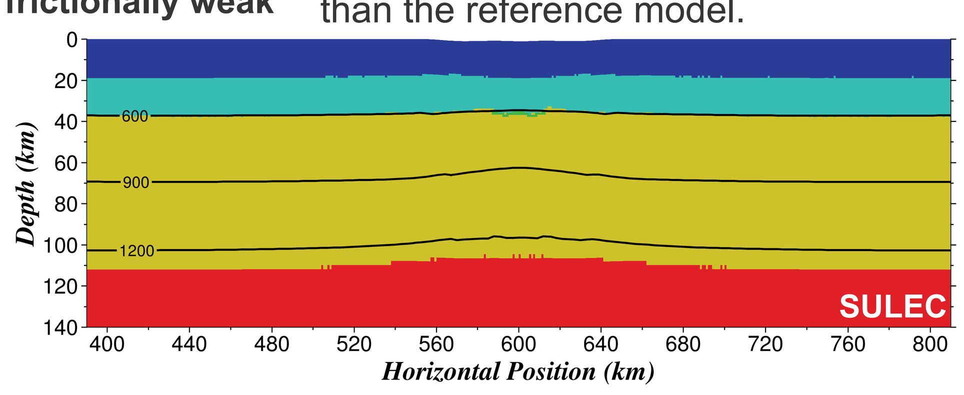
Each plot shows the material field (see model setup) and temperature contours in °C.

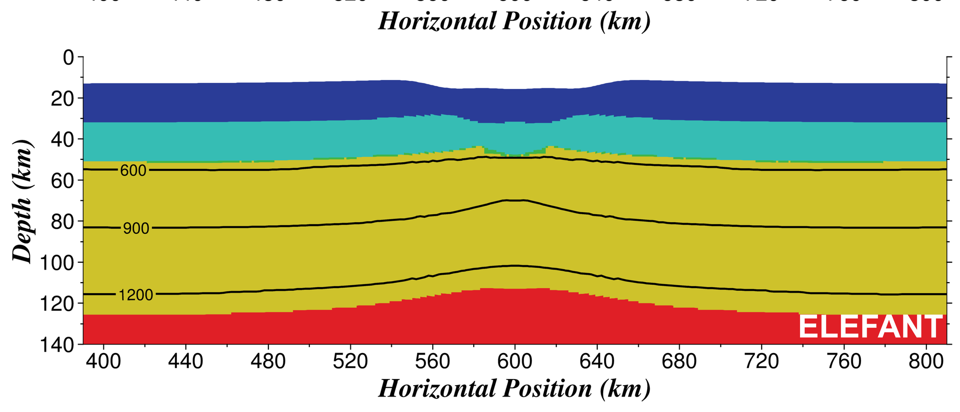
Seeding through mechanical inhomogeneity

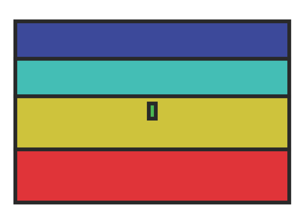


12x3 km frictionally weak

Changing the weak seed to a horizontal 12x3 km shape results in slower localization of deformation. The models show less asthenospheric upwelling, shear zone development and surface topography at 10 Myr model evolution than the reference model.

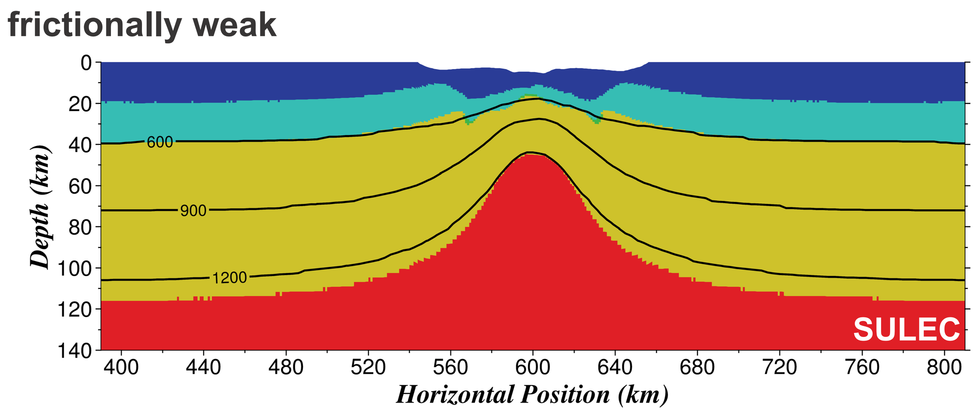


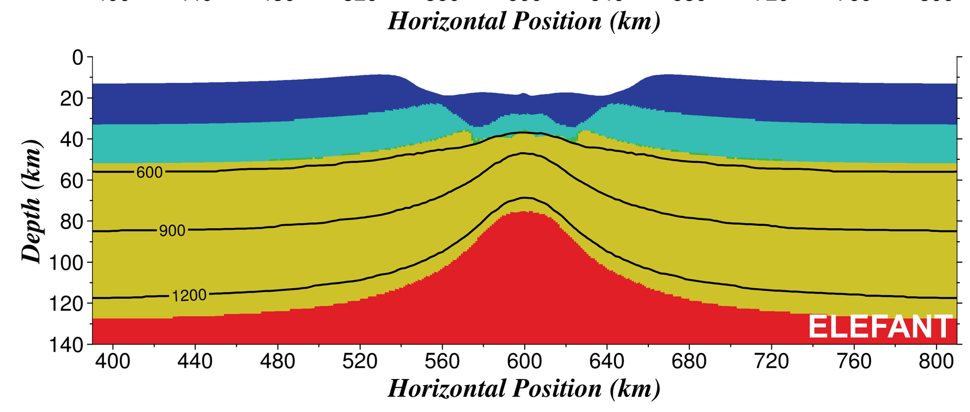


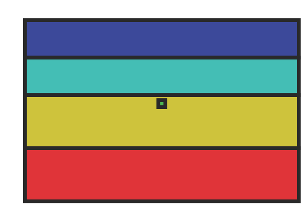


3x12 km frictionally weak

Changing the weak seed to 3x12 km results in faster deformation localization and asthenospheric upwelling in SULEC, but comparatively little change in ELEFANT.

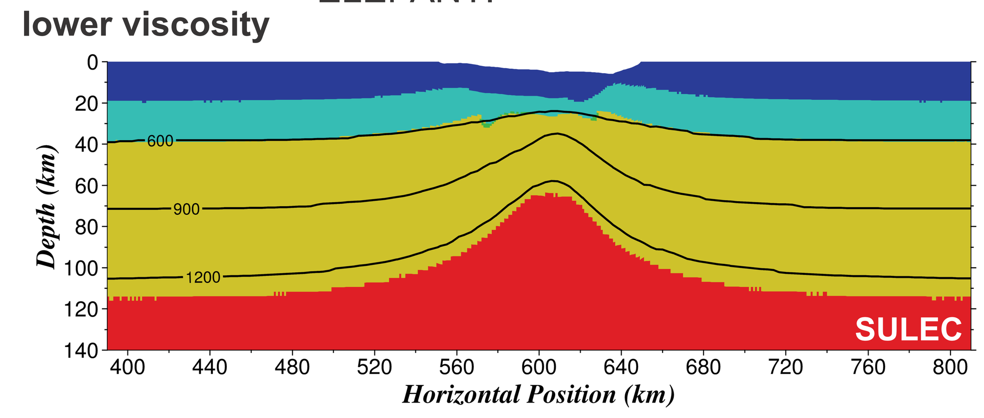


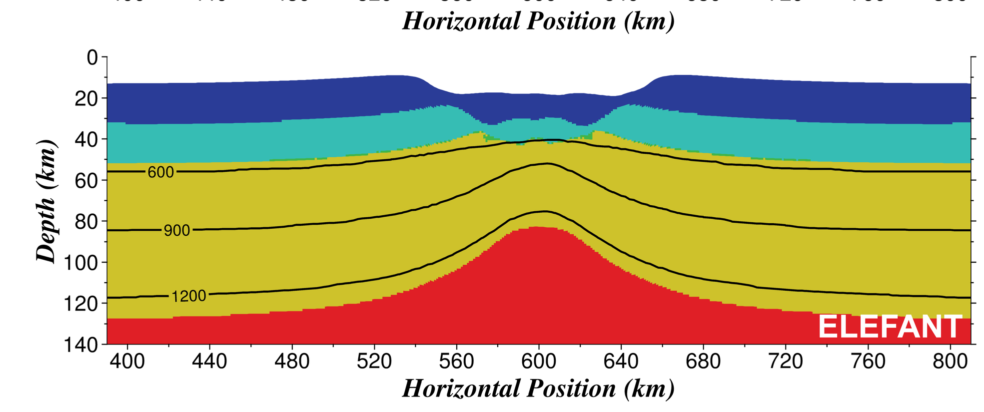


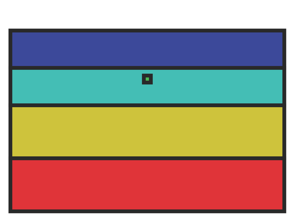


6x6 km lower viscosity

Reducing the viscosity (by a factor of 100) of the 6x6 km weak seed and removing the initial brittle weakness produces slight changes in localization rate in SULEC, but again comparatively little change in ELEFANT.

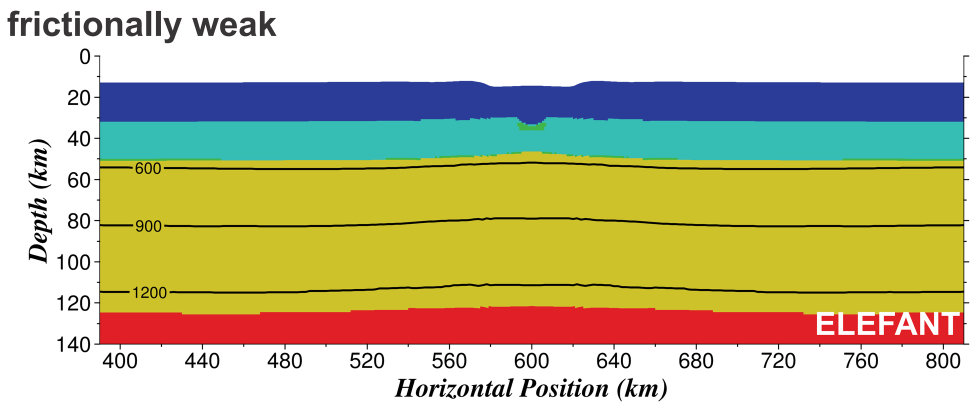


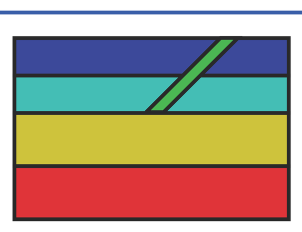




6x6 km, lower crust frictionally weak

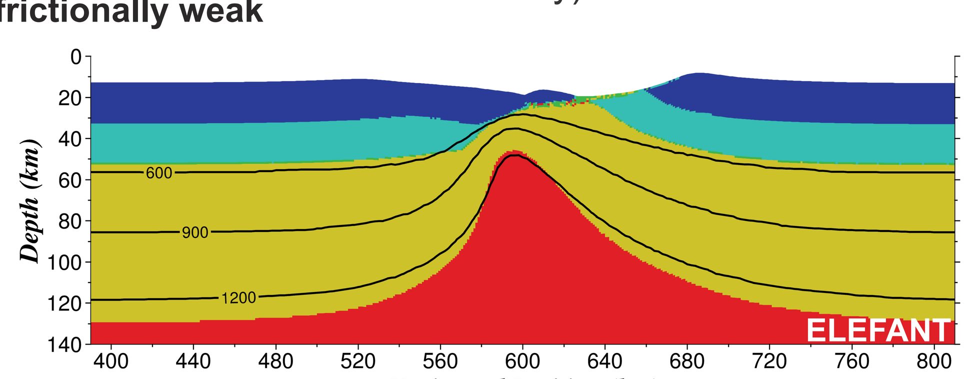
Moving the weak seed from the upper mantle to the lower crust results in less accumulated deformation and localization in both ELEFANT and SULEC (not shown here).



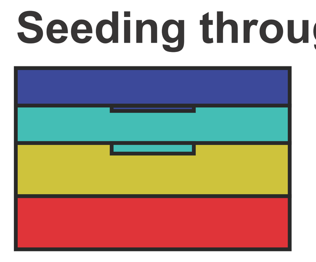


fault: 45°, 2 km wide frictionally weak

Replacing the 6x6 km weak seed with a dipping (45°) 2 km thick crustal seed produces highly asymmetric deformation with significant surface topography and asthenospheric upwelling (results for ELEFANT only).

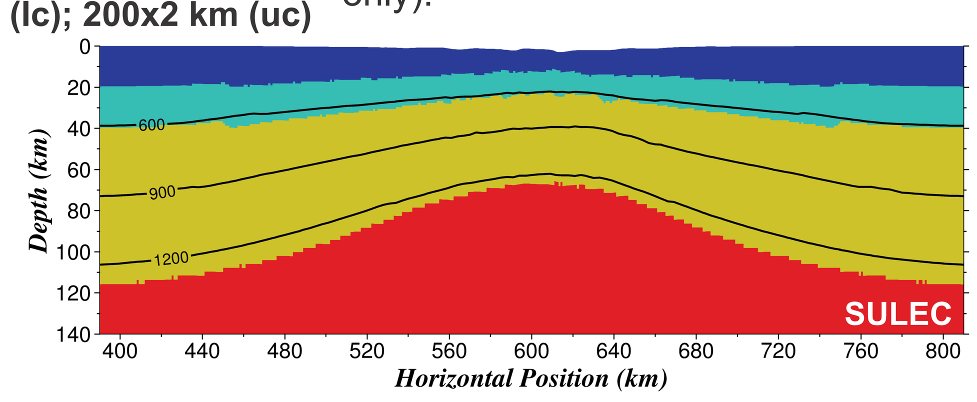


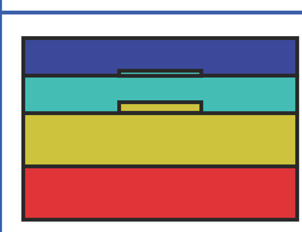
Seeding through geometric discontinuities



thick crust: 200x4 km (lc); 200x2 km (uc)

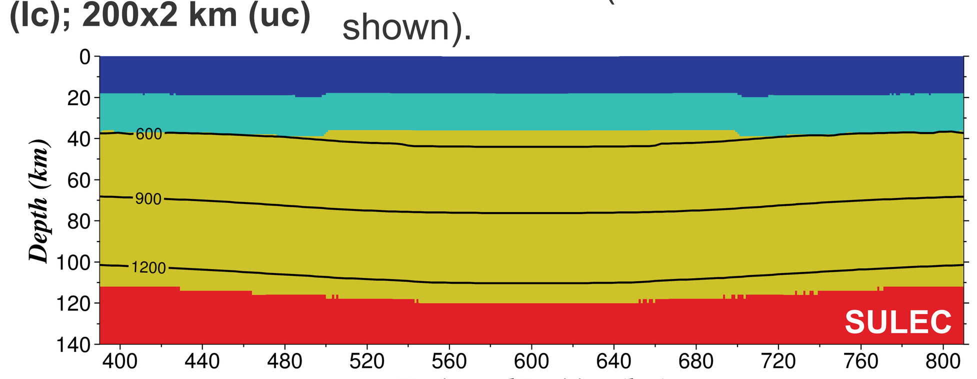
Replacing the mechanical inhomogeneity (6x6 km seed) with thickened crust over a 200 km wide zone results in a broad zone of lithospheric thinning with minimal shear localization (results for SULEC only).



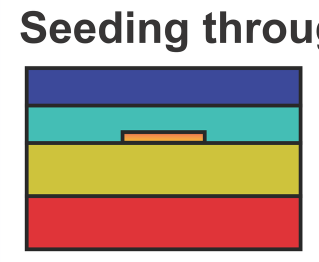


thin crust: 200x4 km (lc); 200x2 km (uc)

Replacing the mechanical inhomogeneity (6x6 km seed) with thinned crust over a 200 km wide zone, produces no apparent shear zone localization, with asthenospheric upwelling restricted to the model sides (ELEFANT results not shown).

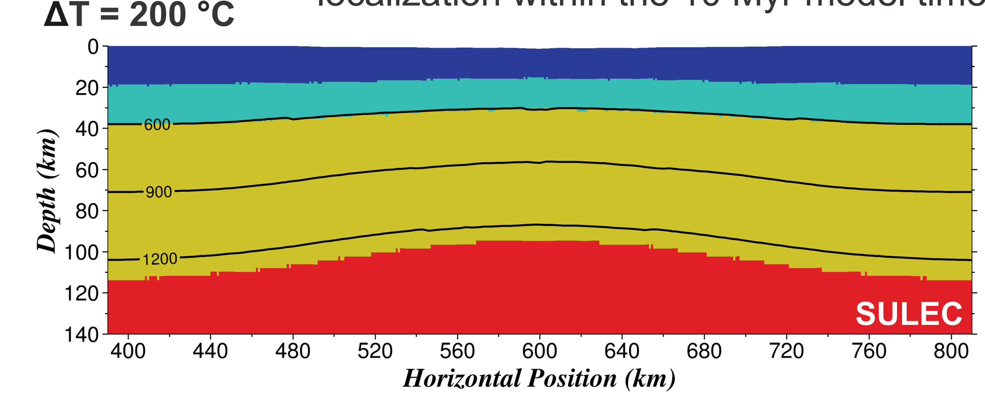


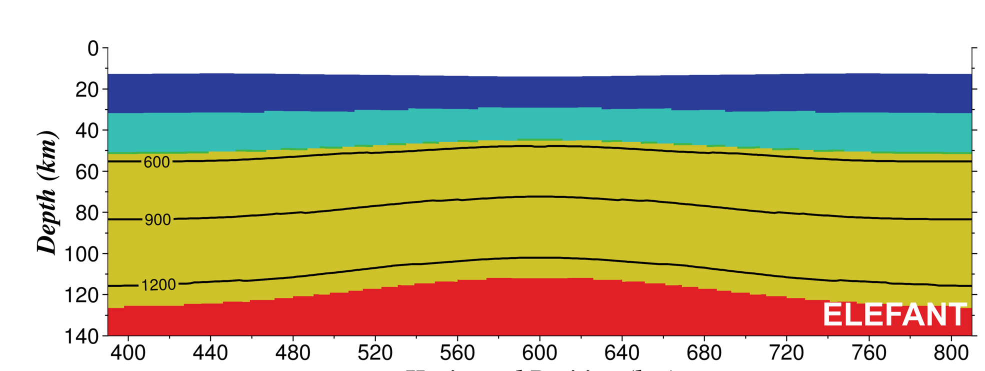
Seeding through thermal effects



200x4 km
ΔT = 200 °C

Replacing the mechanical inhomogeneity (6x6 km seed) with a 200 km wide thermal anomaly (increase of 200 °C in lower crust) produces slow rates of lithospheric thinning and almost no apparent shear zone localization within the 10 Myr model time.





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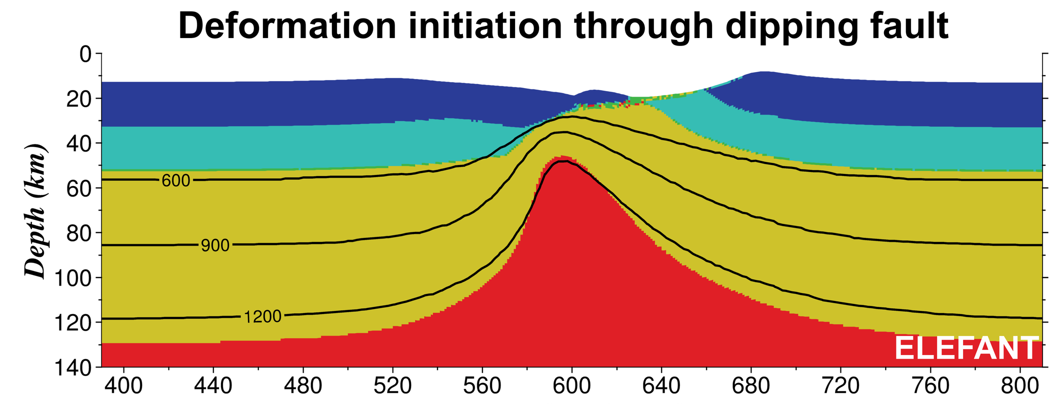
Conclusion

Does it matter how we start our models?
Yes!

Initiating models with different types of seeds can lead to large variations in the style of deformation and the timing of deformation initiation and development.

Deformation initiation through dipping fault



Deformation initiation through thermal perturbation