Mobile Continental Mantle Lithosphere and the Formation of Rifted Margins

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- In collaboration with :
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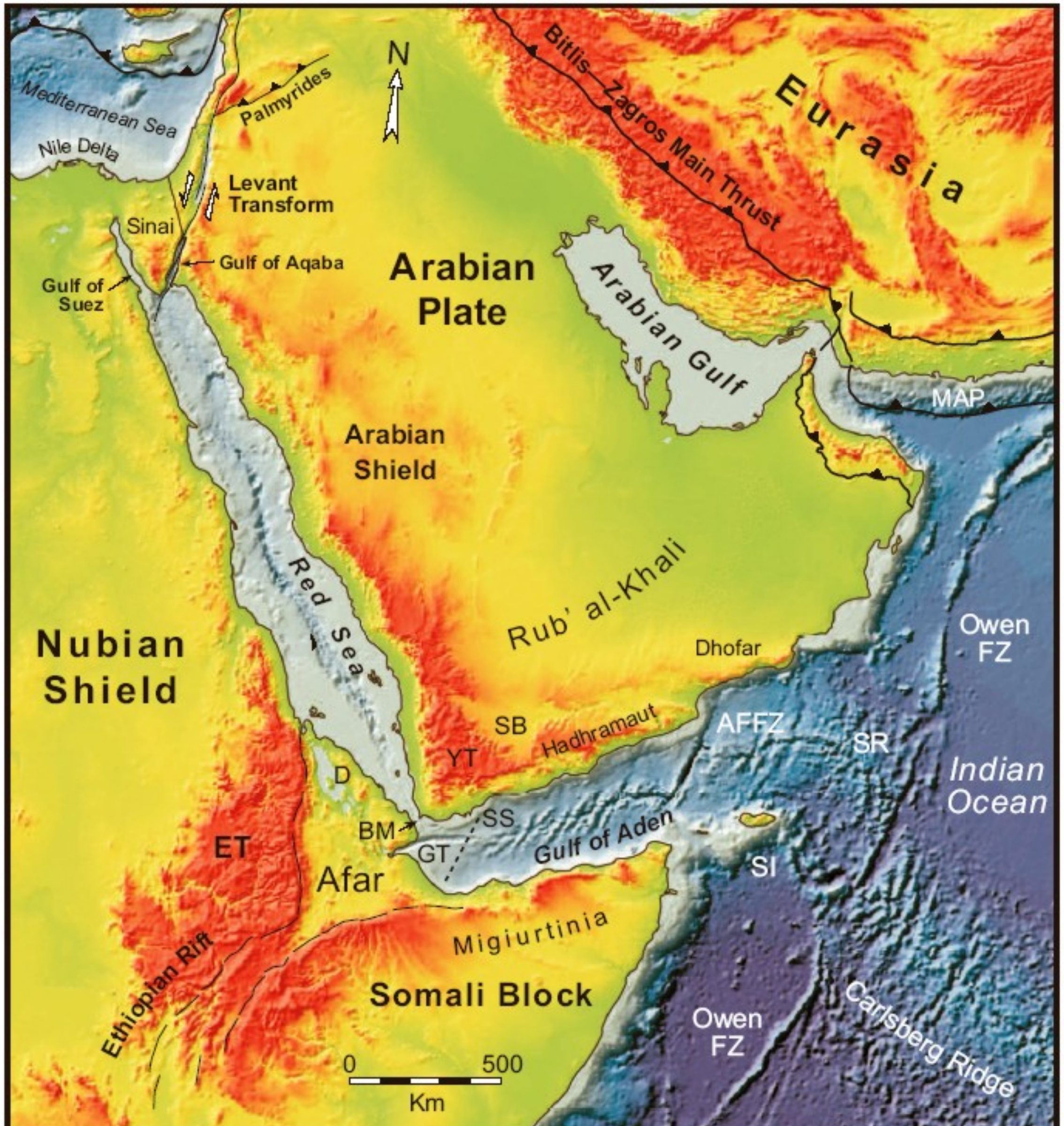
Overview

- **Contrasting styles of non-Volcanic rifted margin formation**
- Type I: Narrow non volcanic rifted margins
- Type II: Wide rifted margins
- Effect of lower lithosphere counterflow

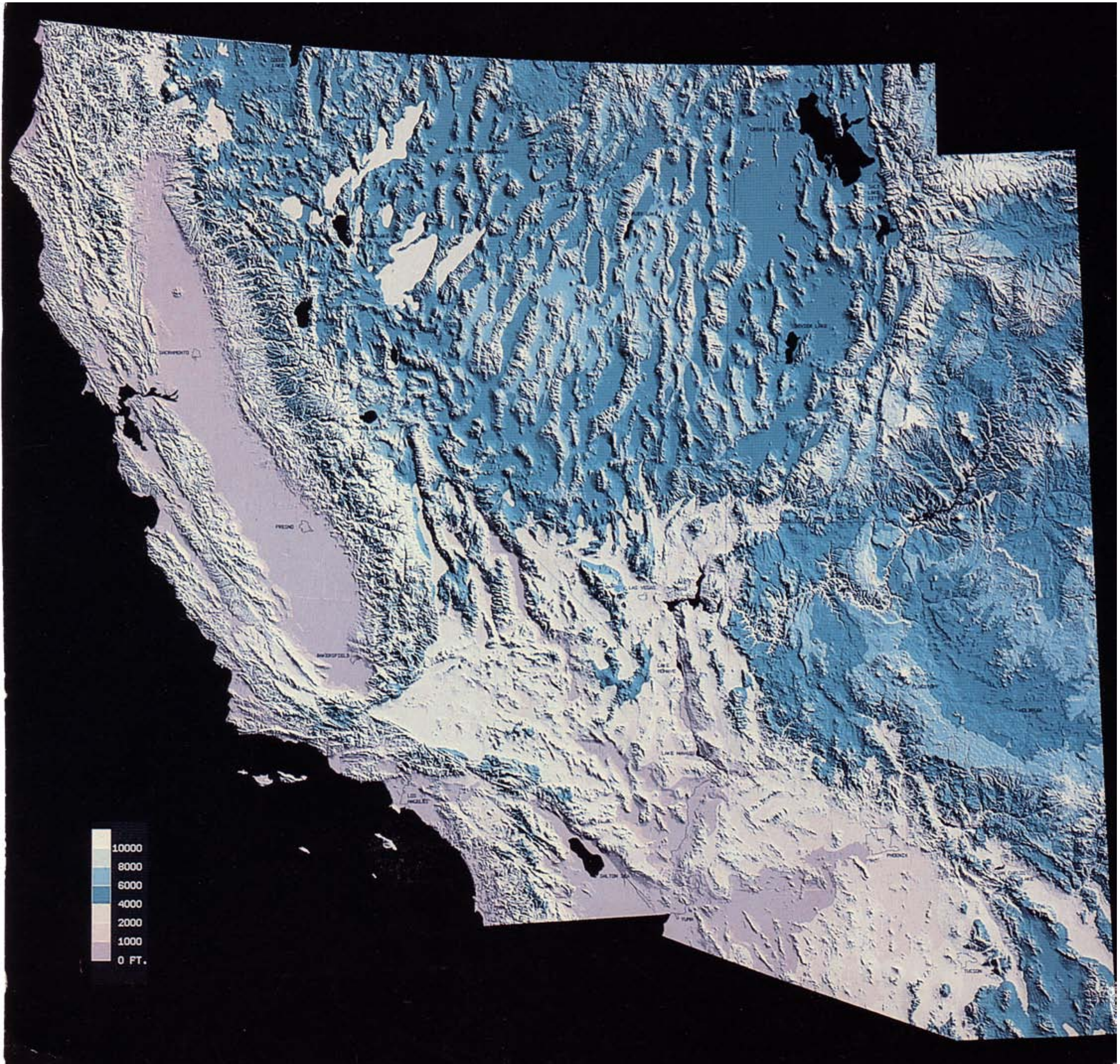
Narrow (A) Symmetric Rifting



Red Sea / Gulf of Suez

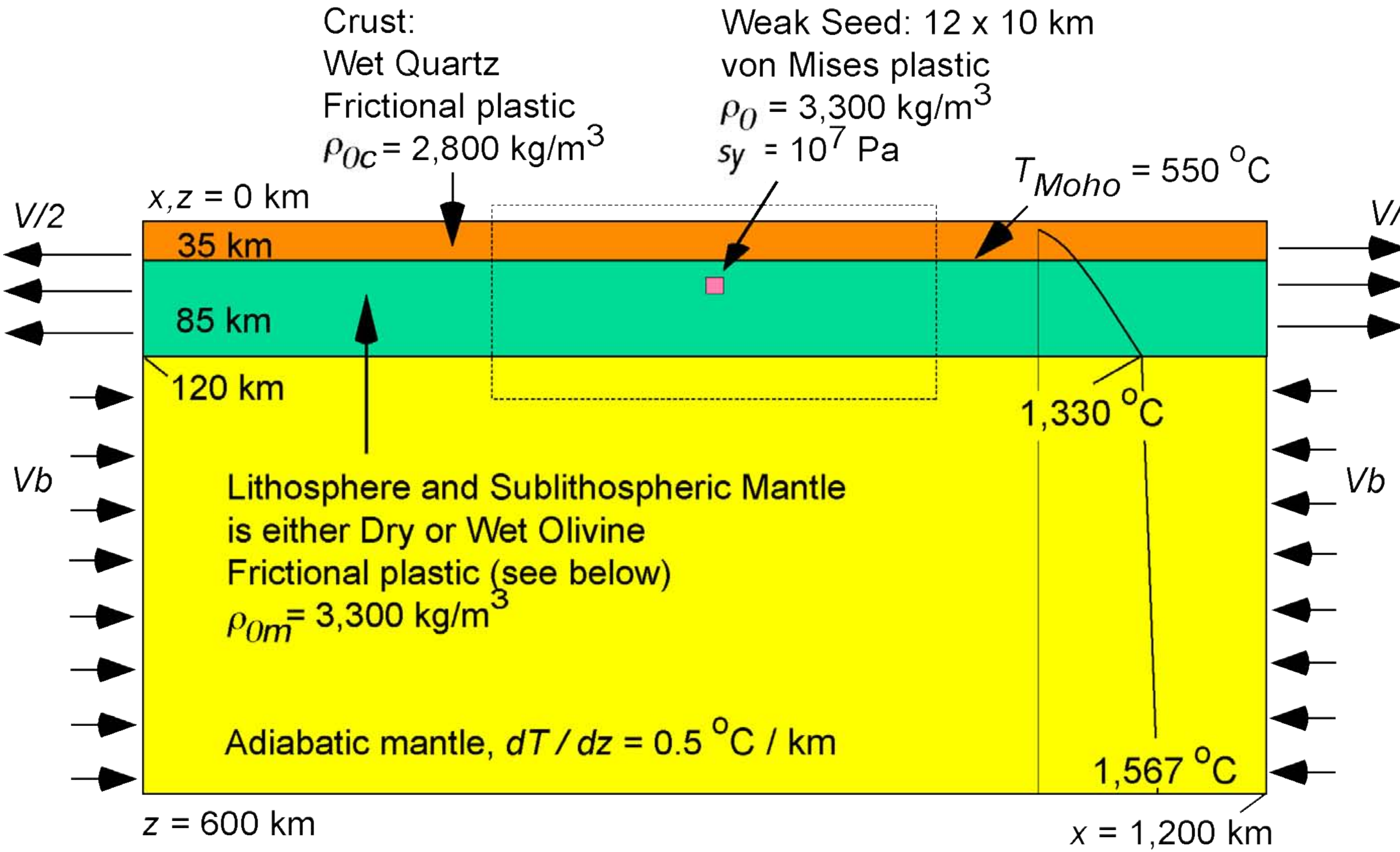
Extension is localized in a Narrow rift system with a width ~ 100 - 150 km

Symmetric or Asymmetric?

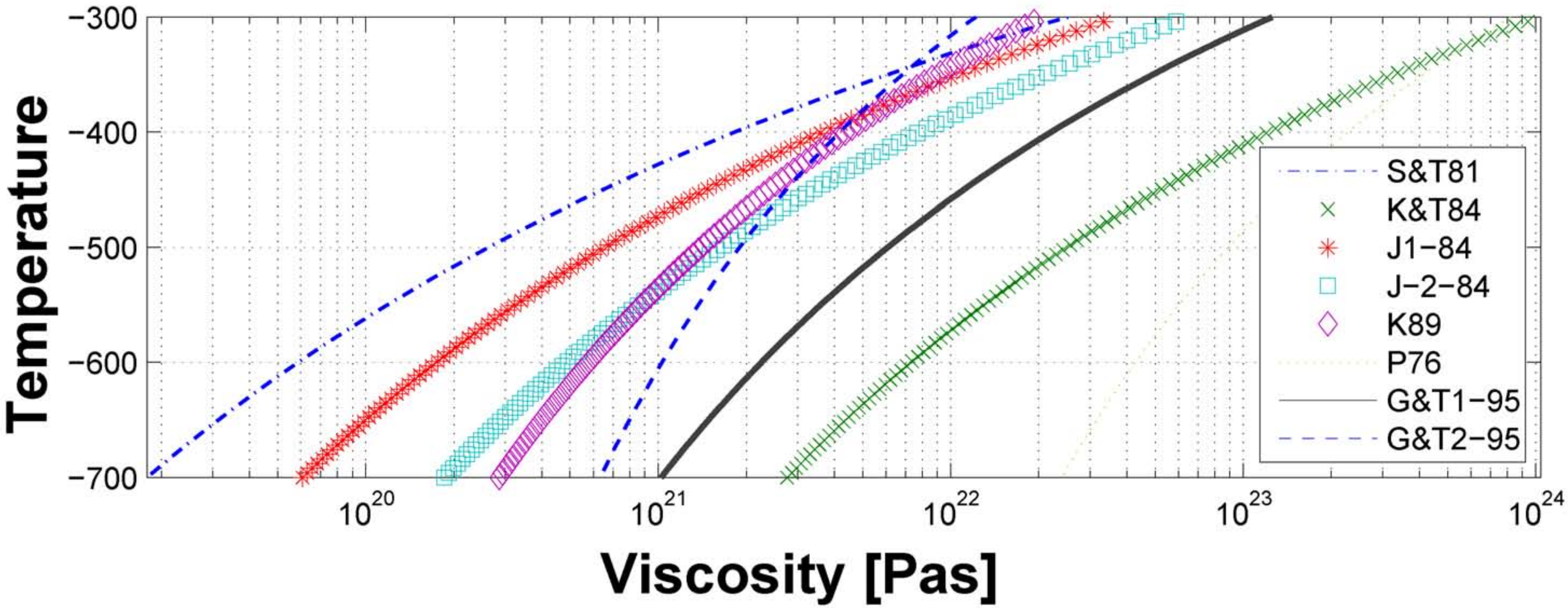


- Basin and Range
- wide rift (800 km)
- Multiple horst and
- grabens
- Distributed
- Extension

Thermo-Mechanical Model Setup

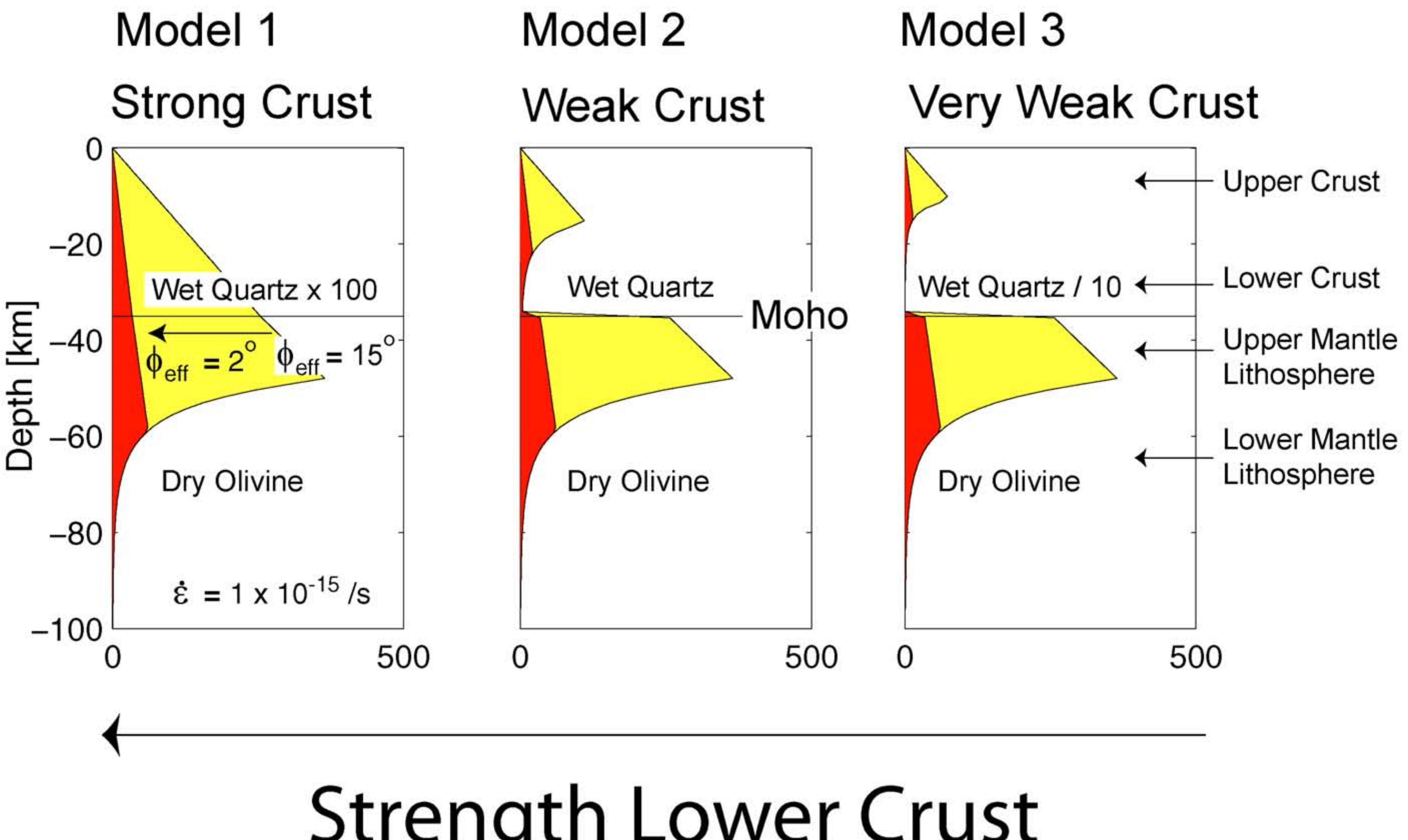


Variability Effective Viscosity Wet Quartz



•Huismans and Beaumont, Nature 2011

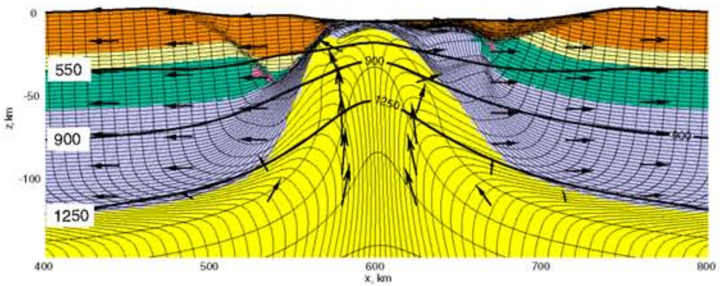
Model Crust Strength Variation



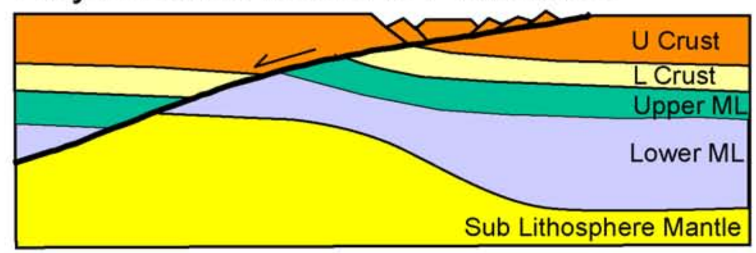
Huismans and Beaumont, 2005

Sensitivity of Rift Mode to Strength Lower Crust

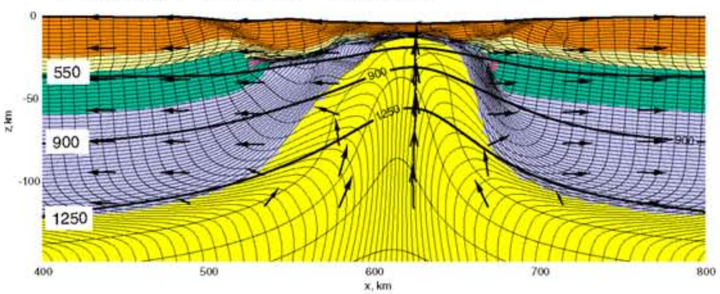
Strong Lower Crust



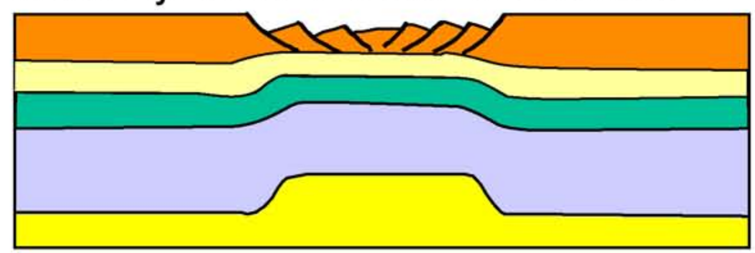
Asymmetric Mode of Extension



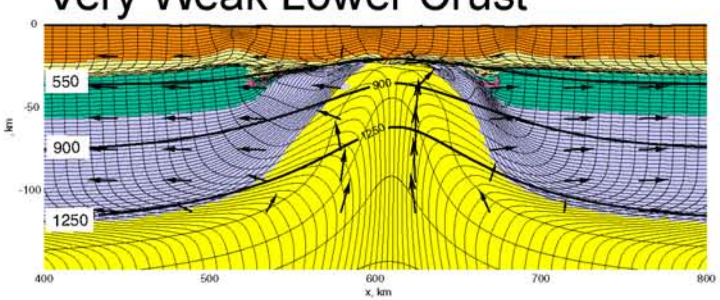
Weak Lower Crust



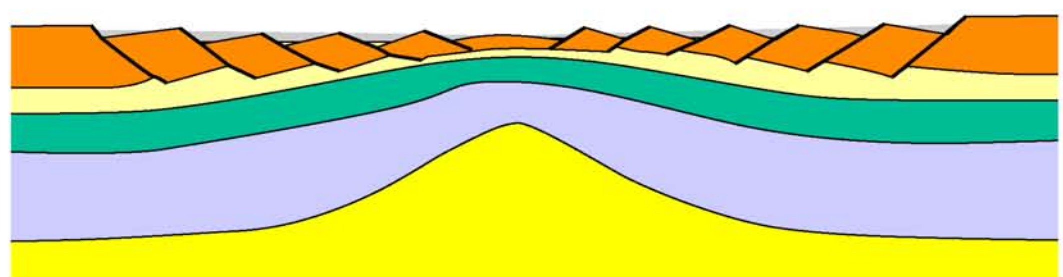
More Symmetric Mode of Extension



Very Weak Lower Crust

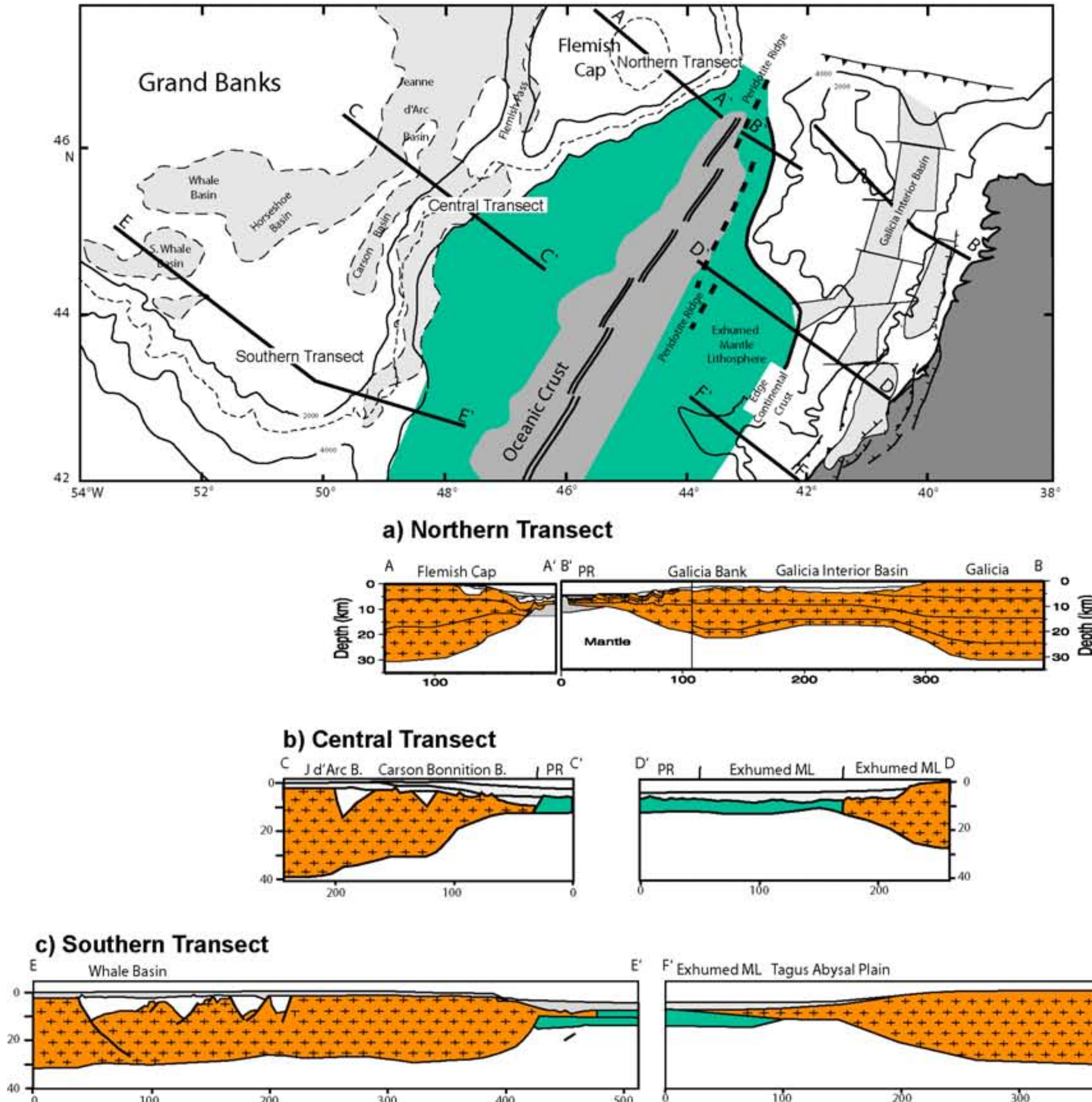


Wide Crustal Rifting / Narrow Mantle Lithosphere Rifting



Huismans and Beaumont, 2001, 2002, 2005, 2008

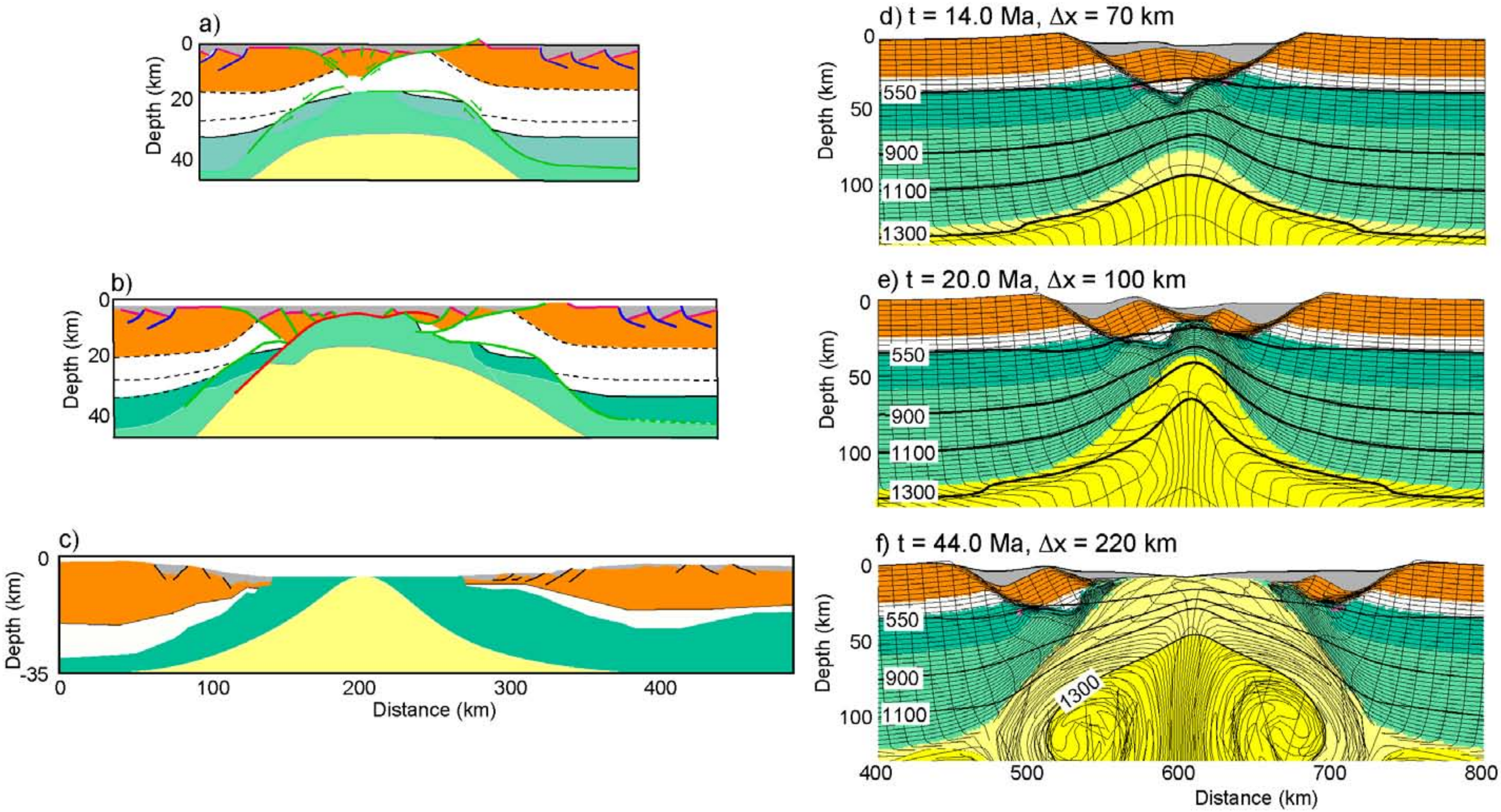
Cold Non Volcanic Margins
Iberia - Newfoundland



- Magma starved rifting
- Exhumation of Mantle Lithosphere to seafloor
- Final rift stage very narrow with very narrow crustal necks <100km
- Mantle lithosphere exhumation decreases with increasing crustal neck width
- Progressive deeper levels of ML in distal positions

Huismans and Beaumont, 2004, 2007

Iberia-NFL Type I narrow margins with strong crust



Huismans and Beaumont, Nature 2011

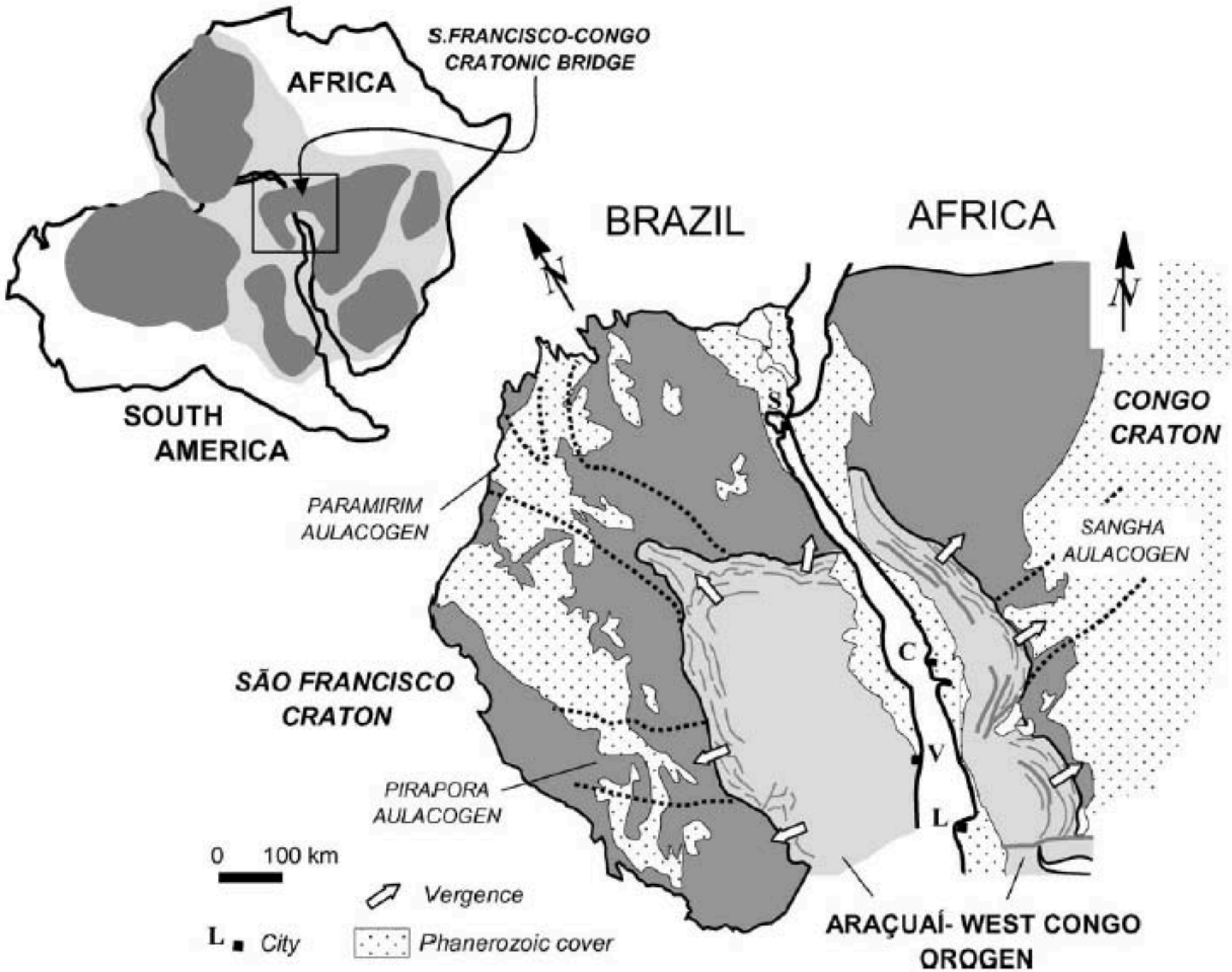
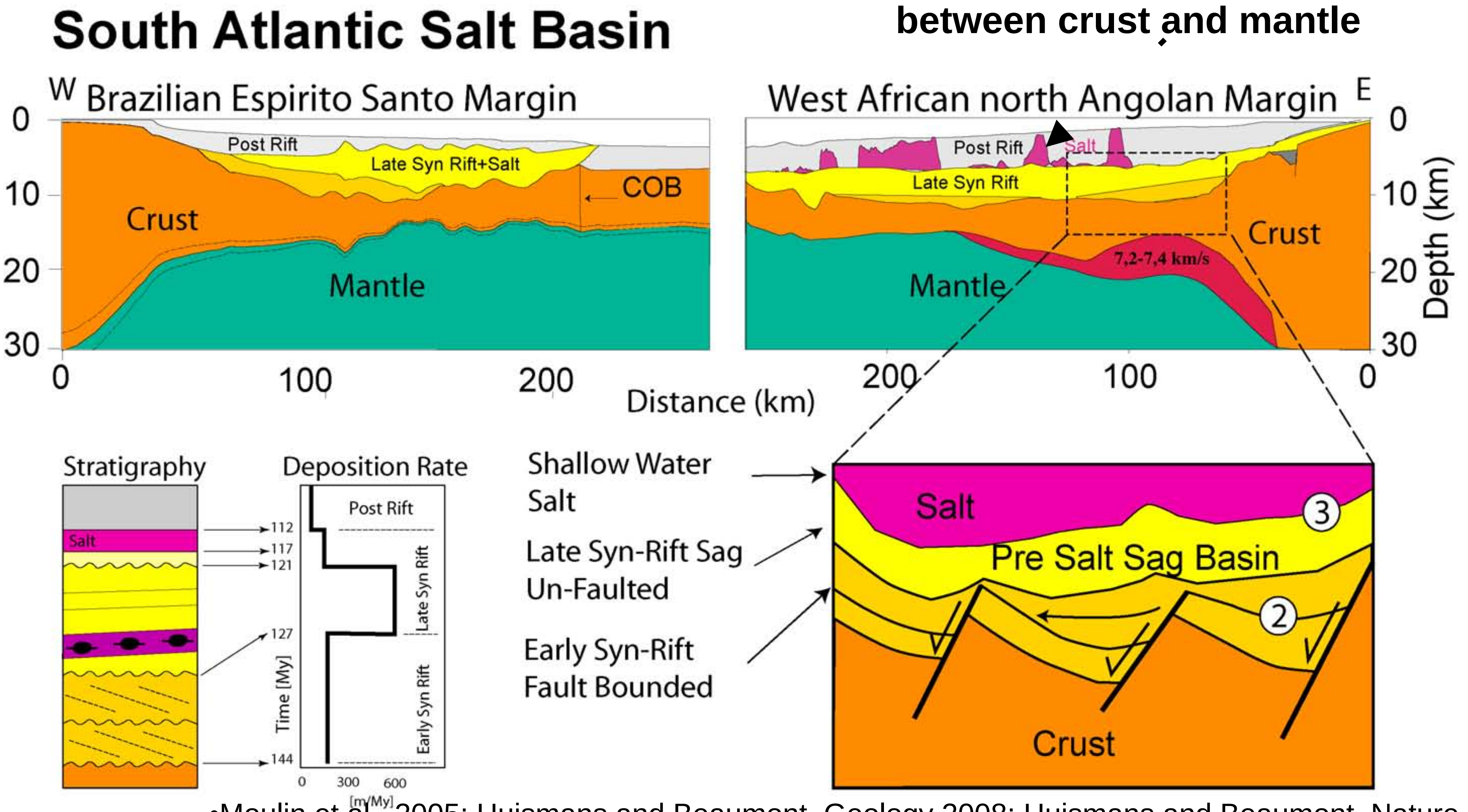


Fig. 1. The Araçuaí-West Congo orogen and the adjacent São Francisco-Congo craton in the context of West Gondwana. South America-Africa fit after De Wit et al. (1988). V = Vitória, S = Salvador; L = Luanda; C = Cabinda.

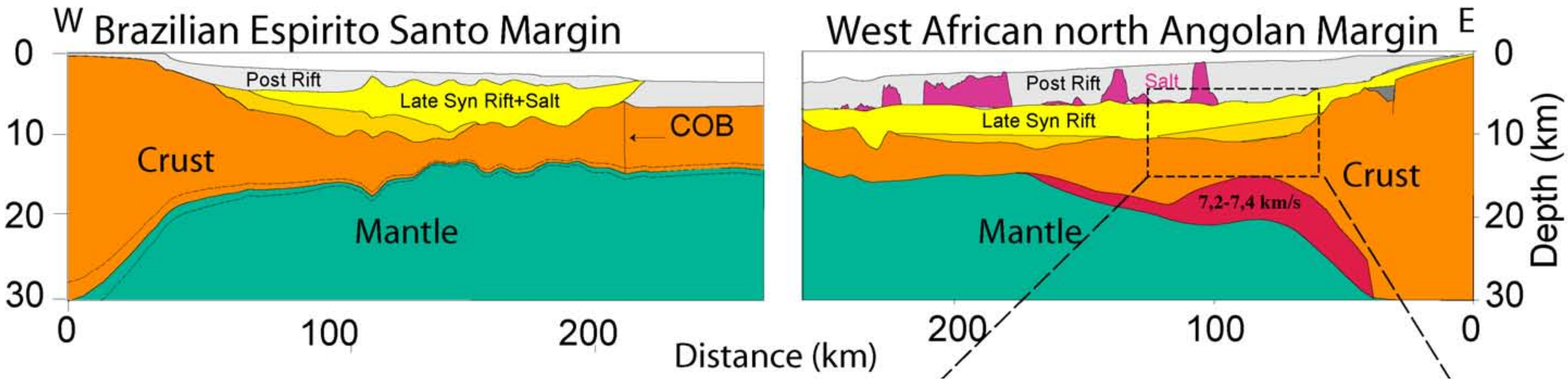
Wide Hot Rifted Margins with Anomalous Vertical Motions, Depth Dependent Stretching (and Magmatism ?)

Late shallow water salt on thin crust indicates depth dependent thinning between crust and mantle



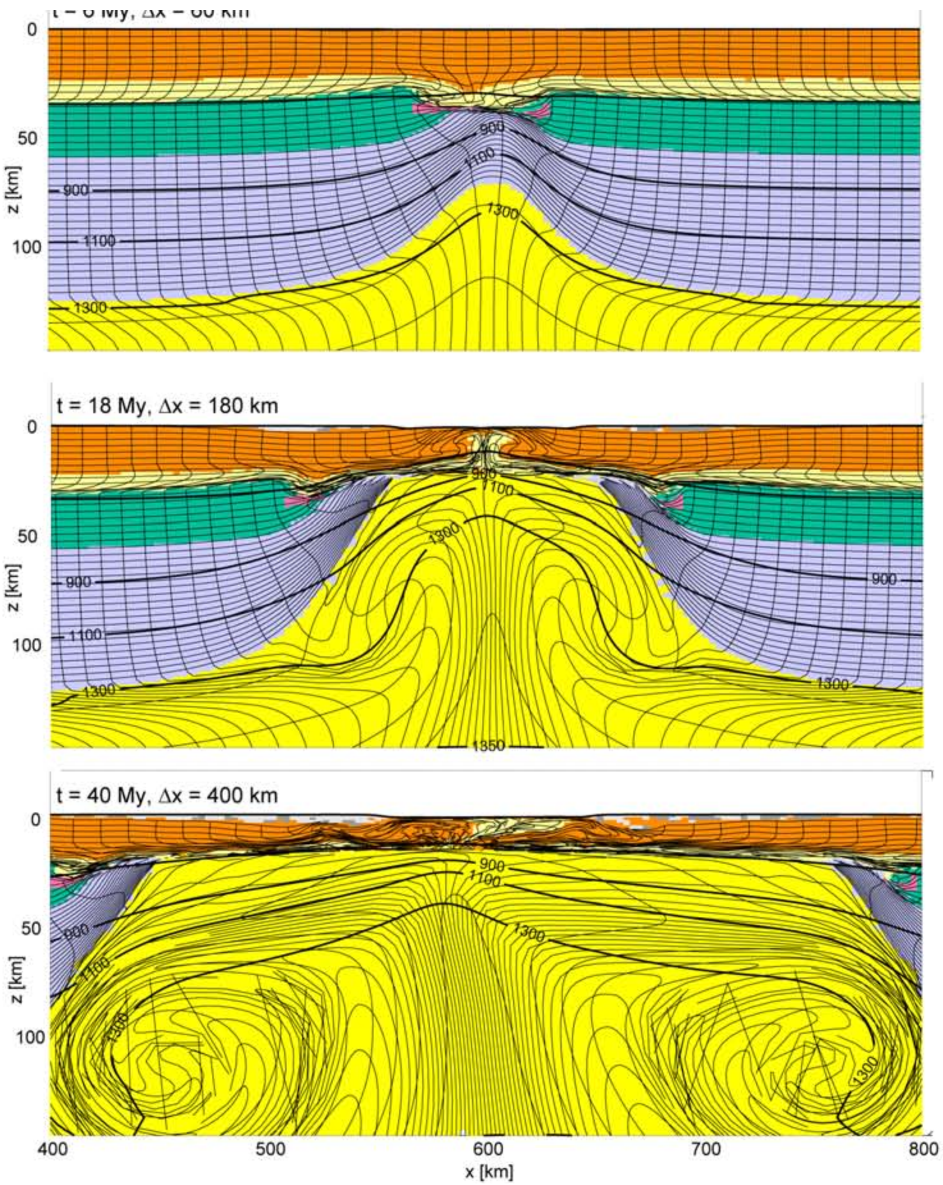
•Moulin et al., 2005; Huismans and Beaumont, Geology 2008; Huismans and Beaumont, Nature

South Atlantic



- Need to explain:
  - Wide distributed thinning of the crust
  - Lack of apparent upper crustal thinning (undeformed sag, flat basement)
  - Shallow lacustrine,marine sediments and salt in sag basin on highly thinned crust
  - Nature of transitional domain

Type II : Very Weak Lower Crust



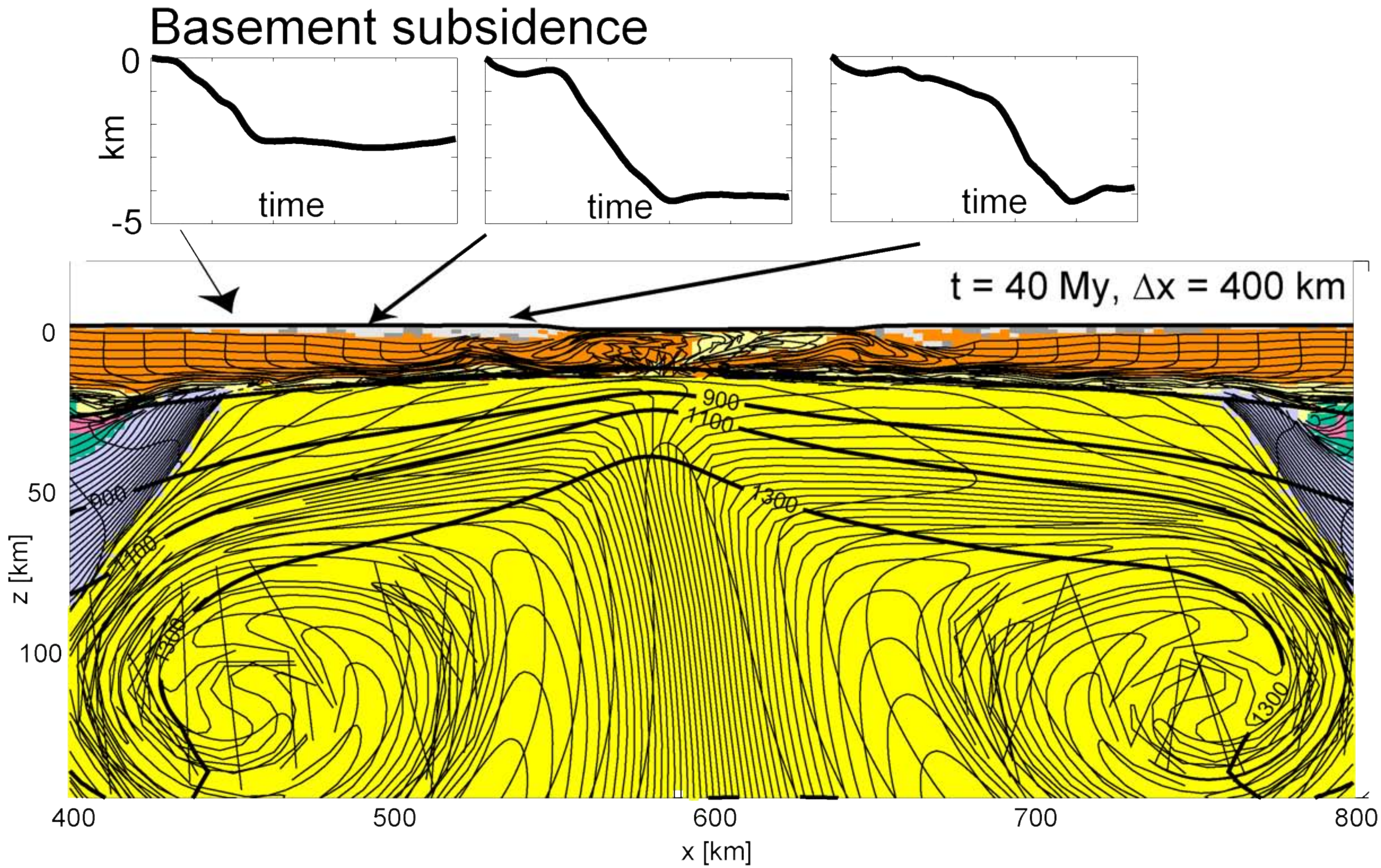
- Narrow rifting of mantle lithosphere
- Distributed extension in crust
- Lower crustal flow to thinning area

- Narrow rifting of mantle lithosphere
- Lower crustal flow to thinning area
- Regional ‘sag’ subsidence

- Very wide upper crustal sections
- Lower crustal flow to distal margin
- Regional ‘sag’ subsidence
- Little deformed upper crustal section

Huismans and Beaumont, Nature 2011

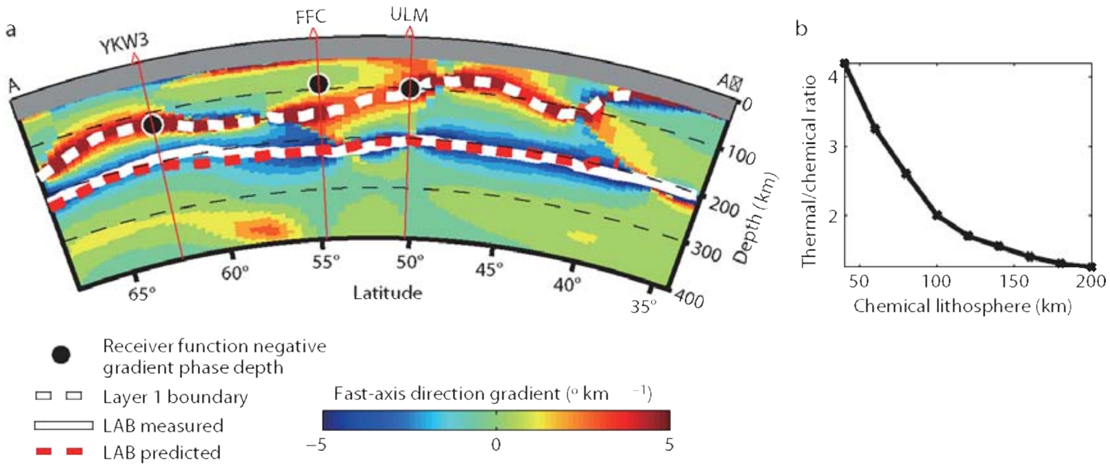
Type II : Very Weak Lower Crust

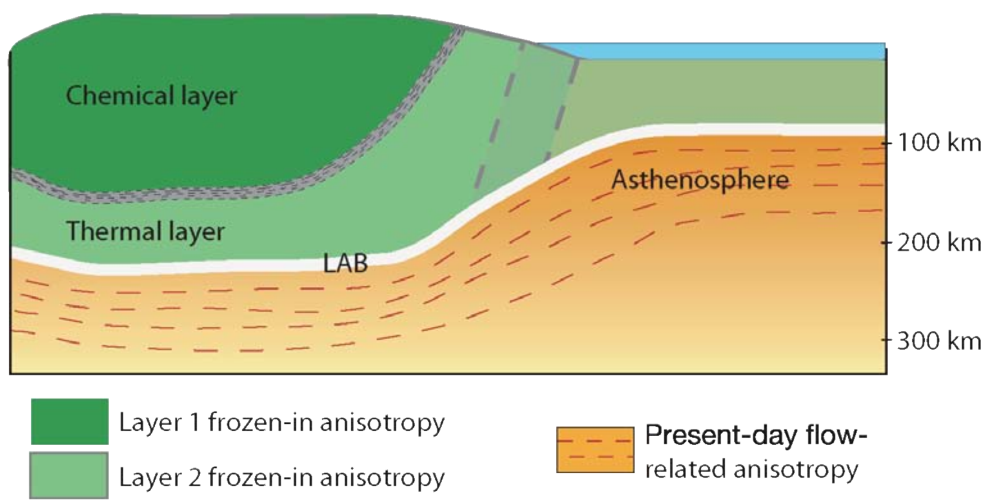


- Lower crustal flow to distal margin
- Diachronous ‘sag’ subsidence

•Huismans and Beaumont, Nature 2011

Mantle Lithospheric Structure and Composition





Yuan and Romanovich, Nature 20

Continental material in the shallow oceanic mantle—How does it get there?

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ABSTRACT

Unusual compositions of some oceanic basalts have been attributed to their sources containing continental lithosphere detached during the breakup of Gondwana. However, the processes of how such continental lithospheric material is detached and transported into the ocean basin have not been constrained. Here we identify Walvis Ridge, where it has been argued that Deep Sea Drilling Project (DSDP) Site 525A contains continental material, as a unique location to constrain these processes. Absolute plate motion (relative to the Tristan mantle plume) and relative plate motion (between Africa and South America) of the African plate are oblique to one another, such that tectonic detachment versus hotspot-related thermal erosion should sample spatially separated continental units of different age. We present isotopic compositions of xenoliths representing the neo-Proterozoic lithosphere at the inferred site for tectonic detachment during continental breakup and show that this process does not explain the Walvis Ridge DSDP Site 525A mantle source. Rather, thermal erosion of ancient cratonic mantle by the Tristan mantle plume is indicated. A convective return flow is required to transport the eroded subcontinental lithospheric mantle to the site of plume activity some ~50 m.y. later and provides constraints on the direction and velocity of mantle flow in the upper mantle.

Cunha, Inaccessible, and Gough islands form a tight cluster in isotope space (Fig. 2, open circles, diamonds, and squares) that overlaps with Walvis Ridge DSDP Sites 527 and 528 basalt compositions (open triangles). In contrast, samples from Walvis Ridge DSDP Site 525A (Fig. 2, black circles in black field) do not overlap with any other oceanic basalt compositions from the Tristan plume track. Instead, DSDP Site 525A basalts are indistinguishable from Urubici-Khumib–type flood basalts (Fig. 2, black diamonds and triangles in gray field) (Milner and le Roex, 1996; Peate et al., 1999), which have a restricted spatial extent (Fig. 1; region highlighted in gray within the northern Etendeka flood basalt province shows their occurrence on the African side) and are thought to reflect the composition of

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The Role of Continental Crust and Lithospheric Mantle in the Genesis of Cameroon Volcanic Line Lavas: Constraints from Isotopic Variations in Lavas and Megacrysts from the Biu and Jos Plateaux

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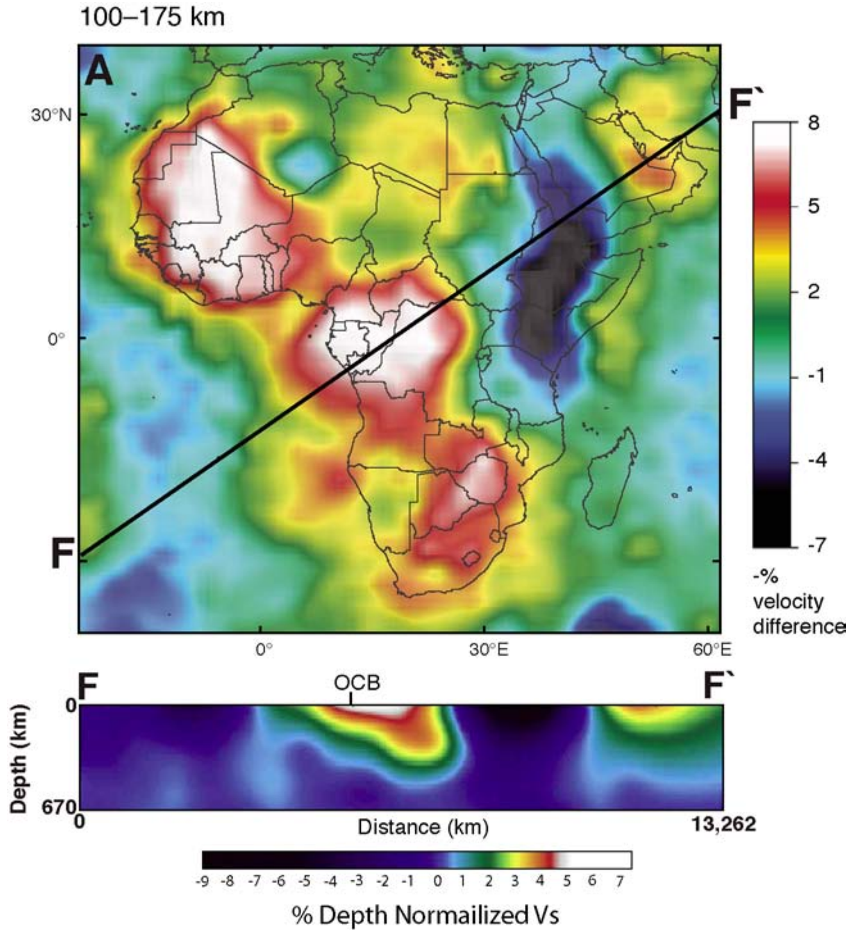
S-wave tomography



- High velocity – low density depleted lower lithospheric root extending out under margin and ocean basin
- Implications for lack of magmatism and anomalous vertical motions

•Begg et al, Geosphere 2009

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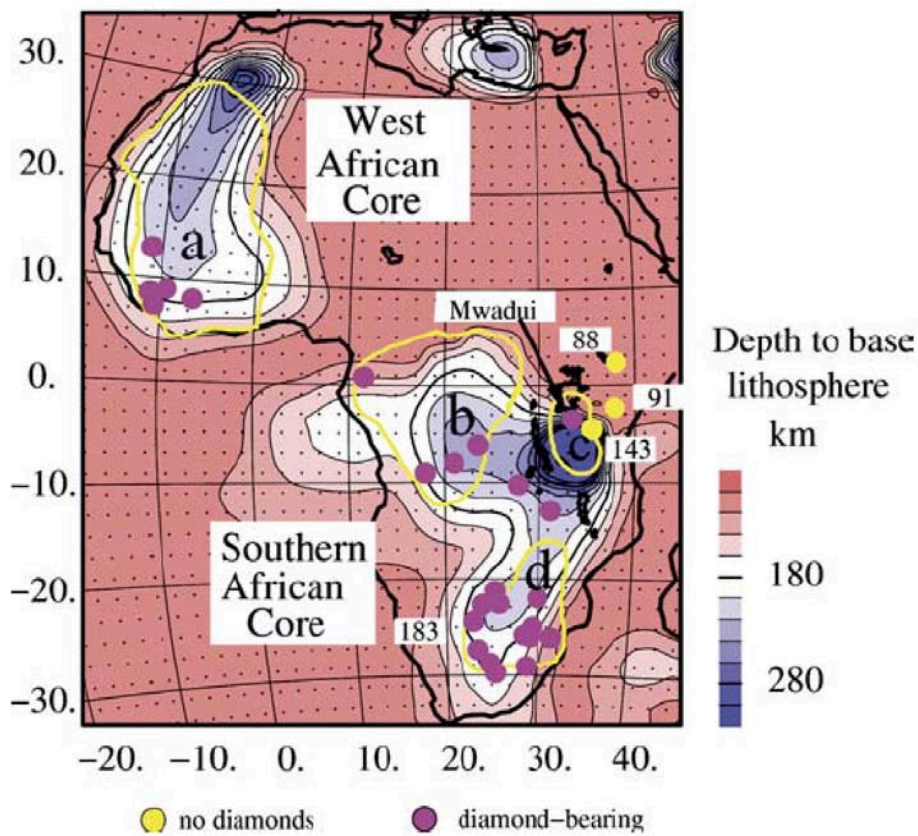
The influence of lithospheric thickness variations on continental evolution

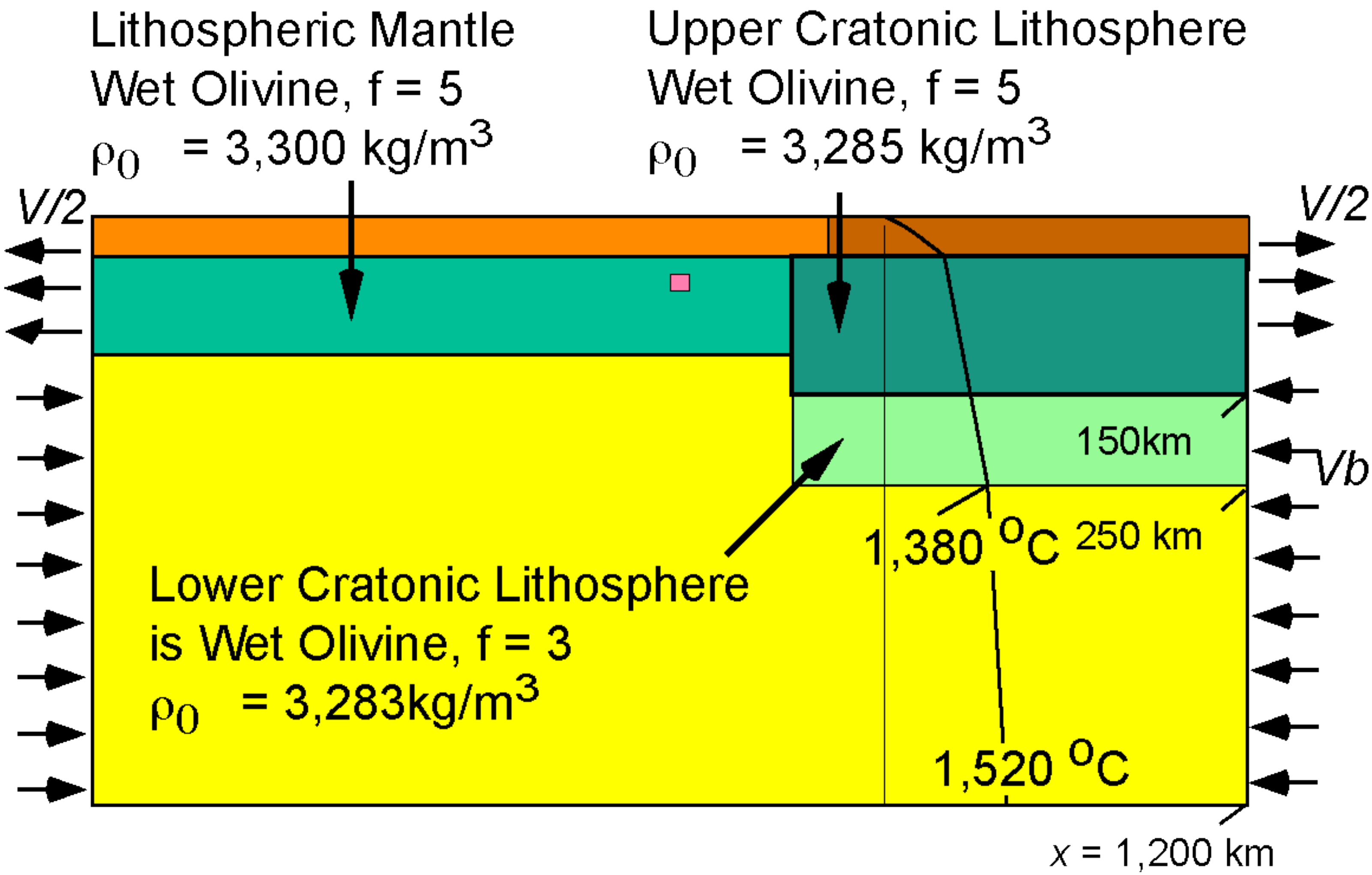
Dan McKenzie*, Keith Priestley

Institute of Theoretical Geophysics, Bullard Labs of the Department of Earth Sciences, Cambridge University, UK

Received 21 November 2006; accepted 22 May 2007
Available online 6 June 2007

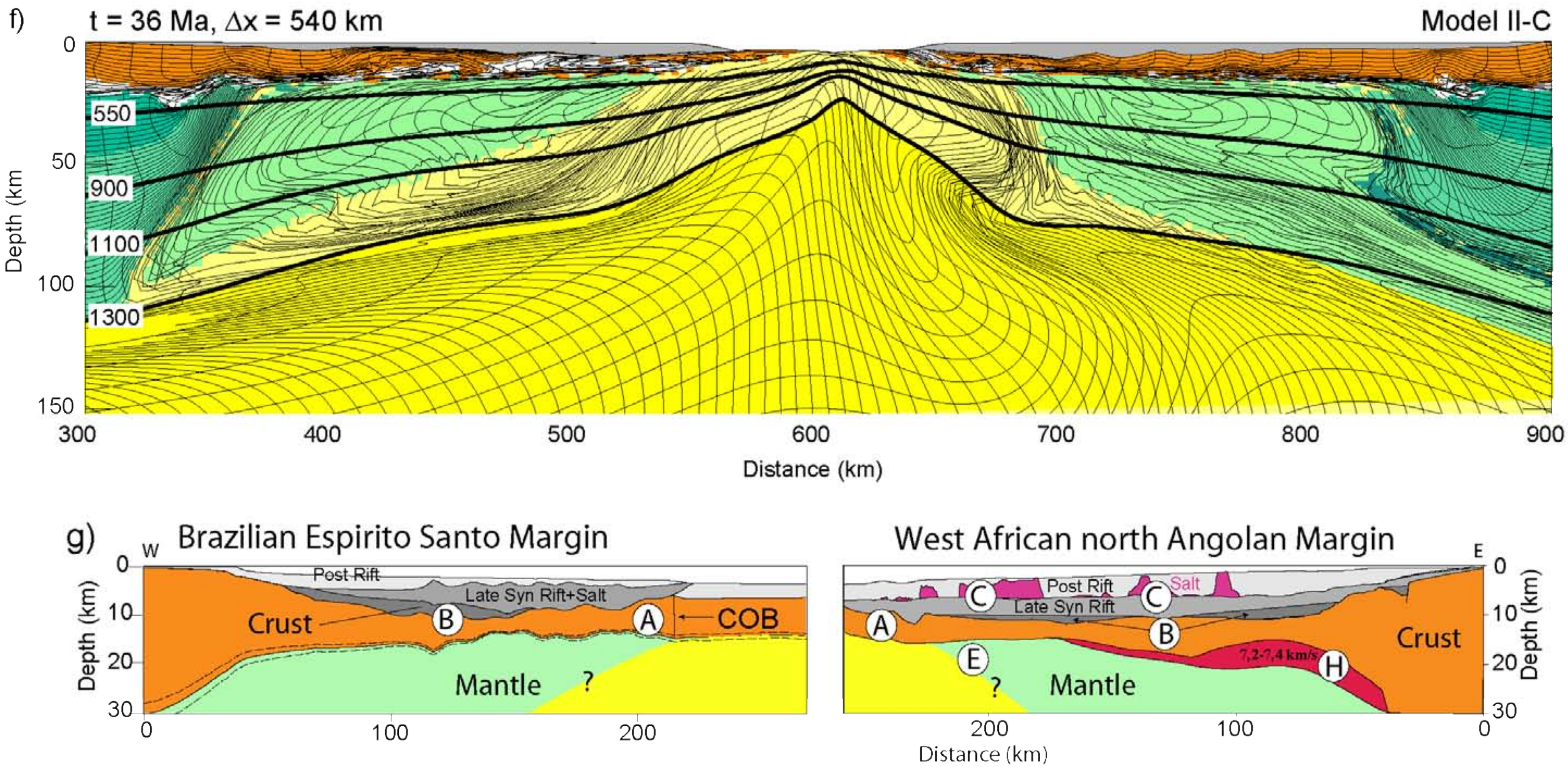


Effect Mobile Lower Lithosphere



•Huismans and Beaumont, Nature 2011

Type II-C
Depleted Lower Lithosphere Counter Flow



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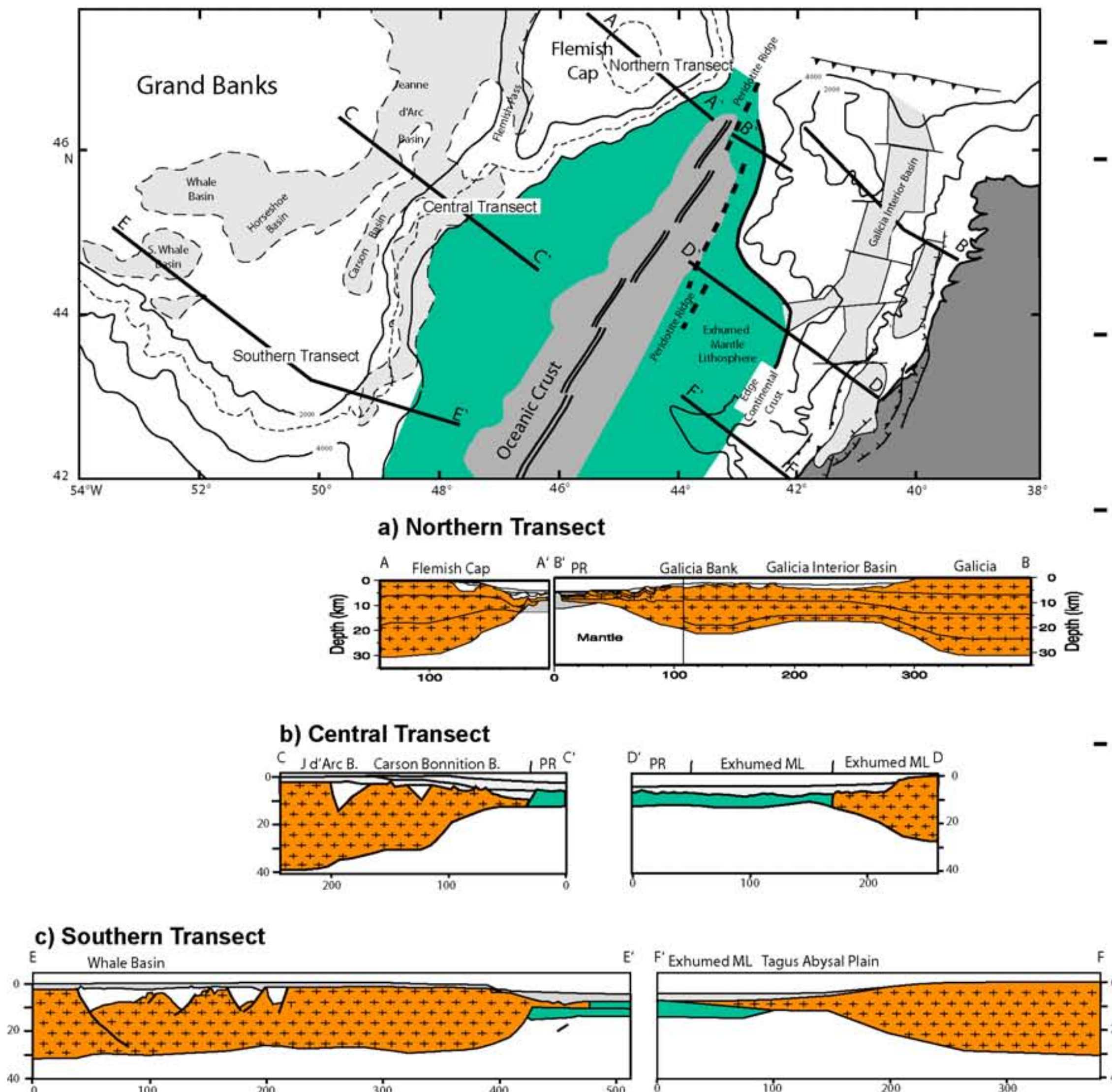

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Huismans and Beaumont, 2004, 2007

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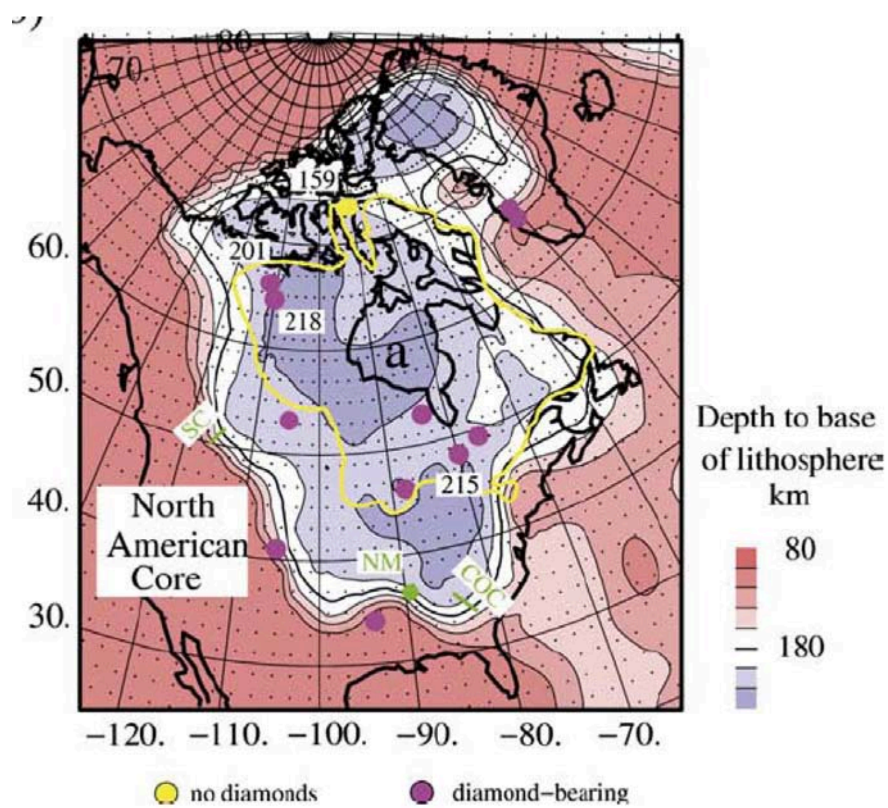

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Thermal and compositional structure of the subcontinental lithospheric mantle: Derivation from shear wave seismic tomography

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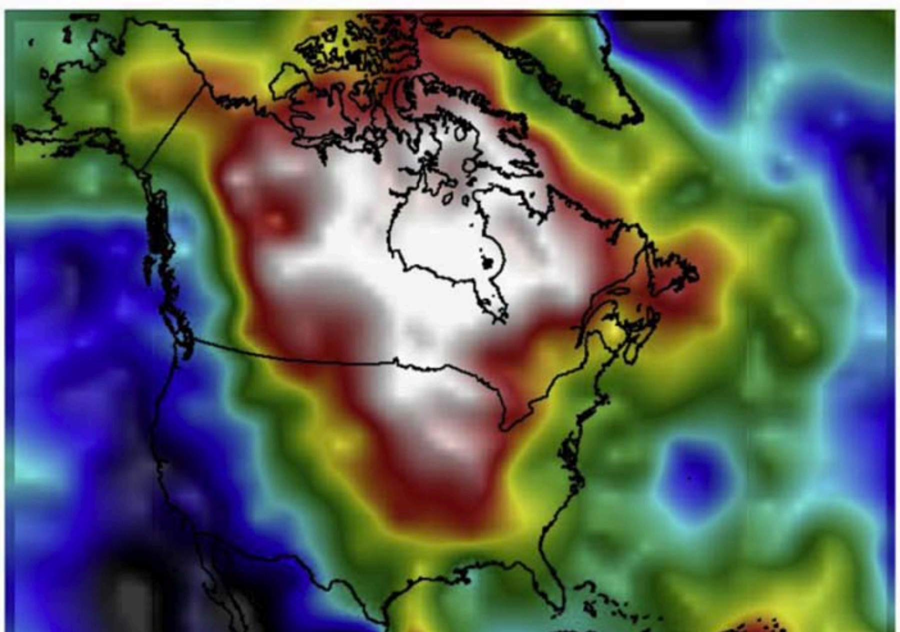
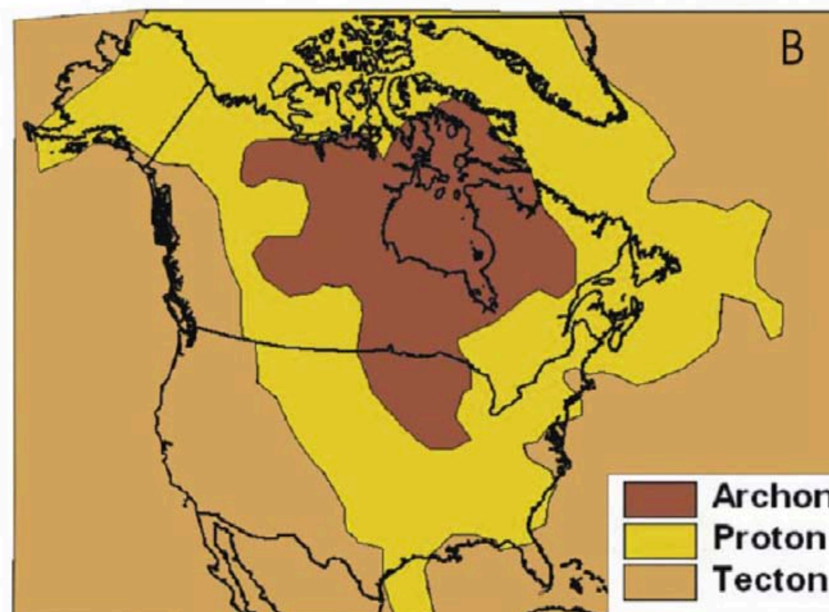
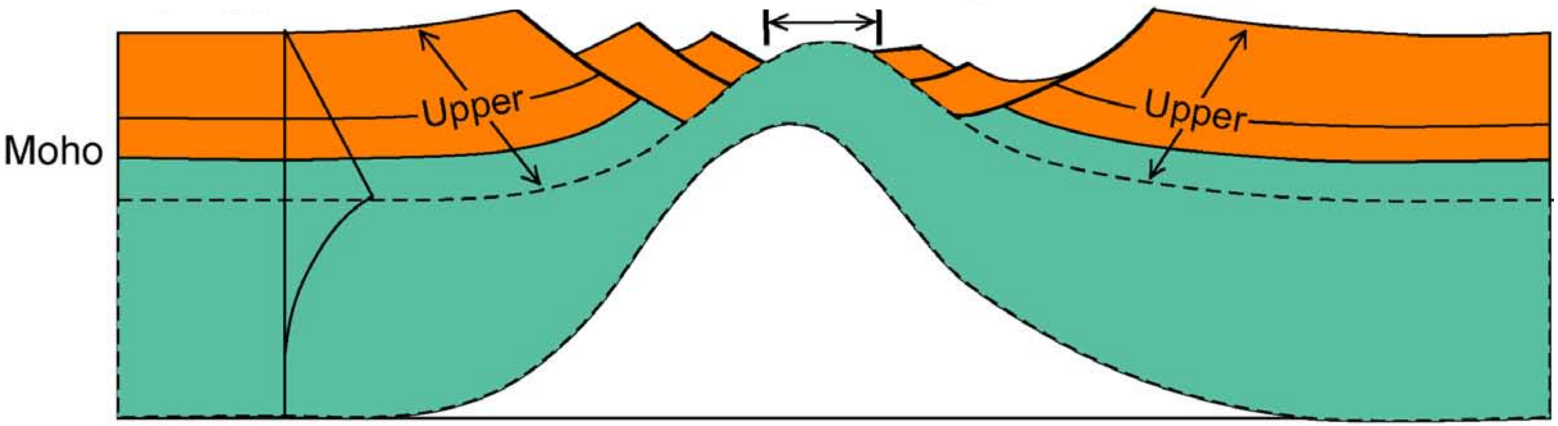




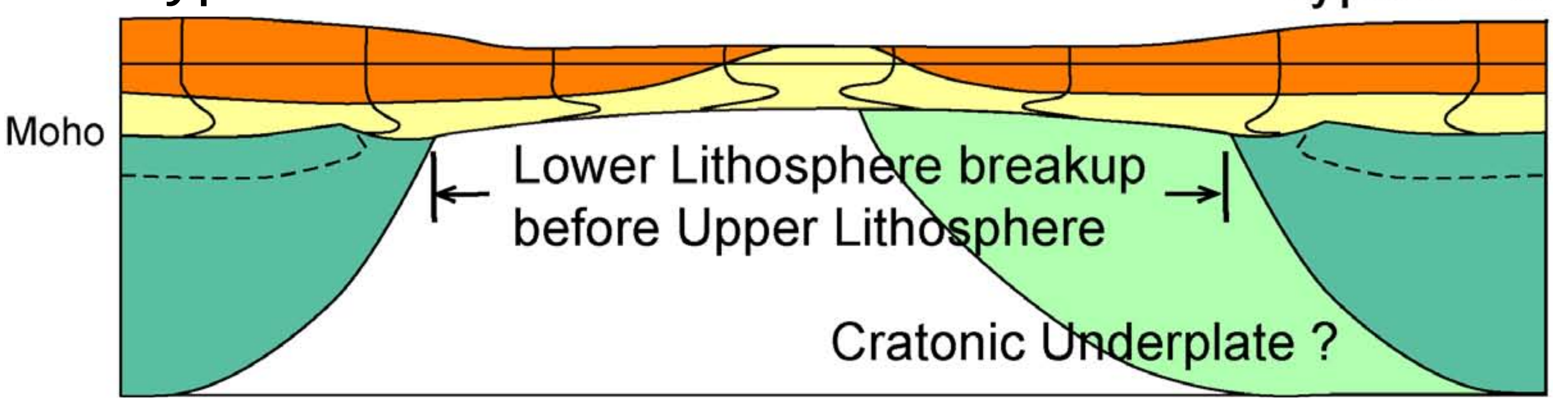
Type I & II Contrasting Styles

Type I: Strong Crust



Type II-A: Weak Crust

Type II - C



Huismans and Beaumont, Nature 2011

Non Volcanic Rifted Margins

Favored by stronger crust:

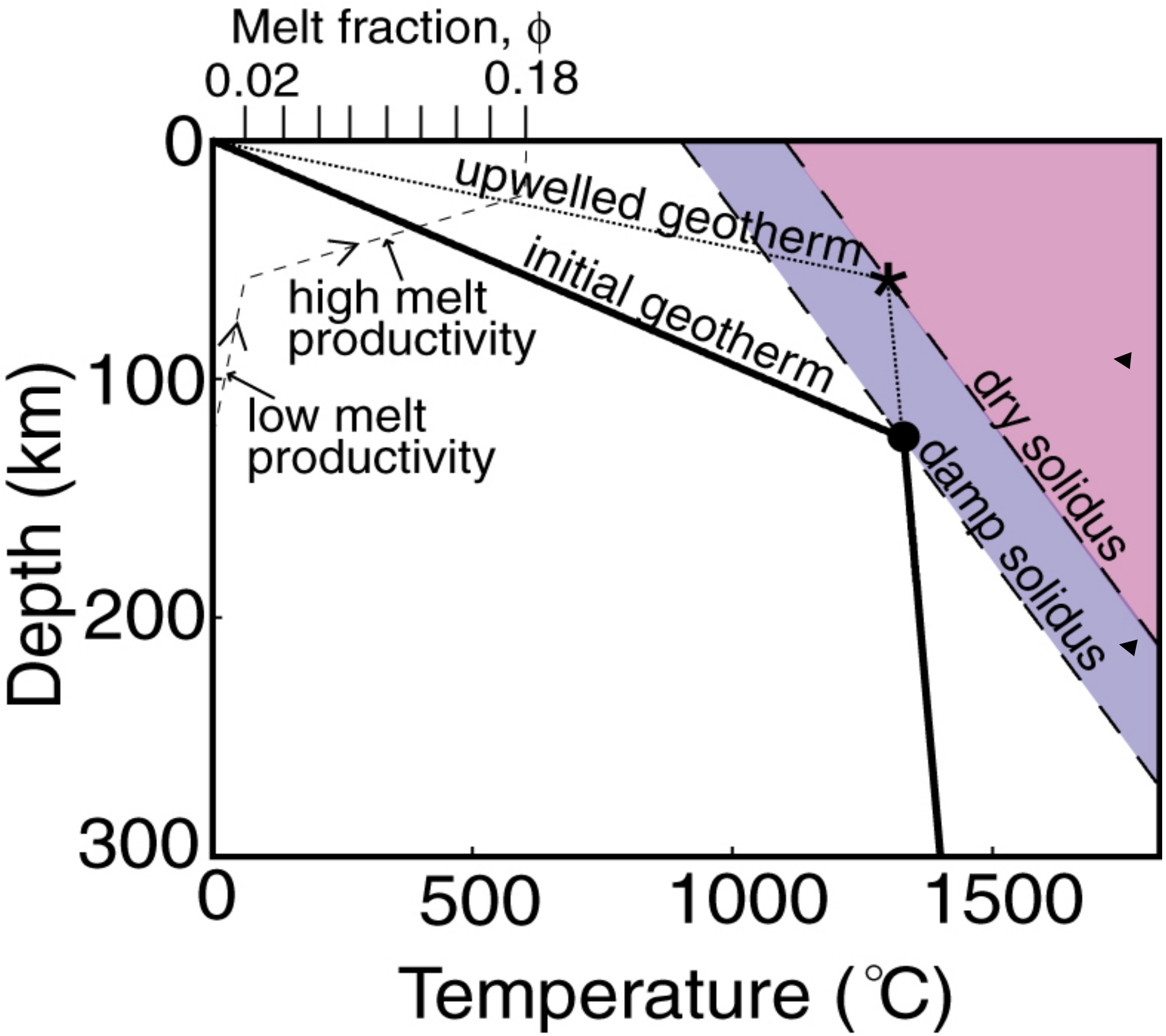
- Type I margins:
  - Crust breaks first, mantle lithosphere necks later
  - Exhume moderate amount (max 50 km) mantle lithosphere

Favored by weak crust

- Type II-A margins:
  - Mantle lithosphere necks first, crust breaks later
  - No mantle lithosphere exhumation, possible non-magmatic asthenosphere

- Type II-C margins:
  - Depleted (cratonic) lower mantle lithosphere flows into necking area
  - Low density owing to depletion promotes shallow water depth
  - Depleted nature inhibits magmatism

Model setup: computing melt production



- *Dry Melting:*
- *Higher melt*
- *productivity*

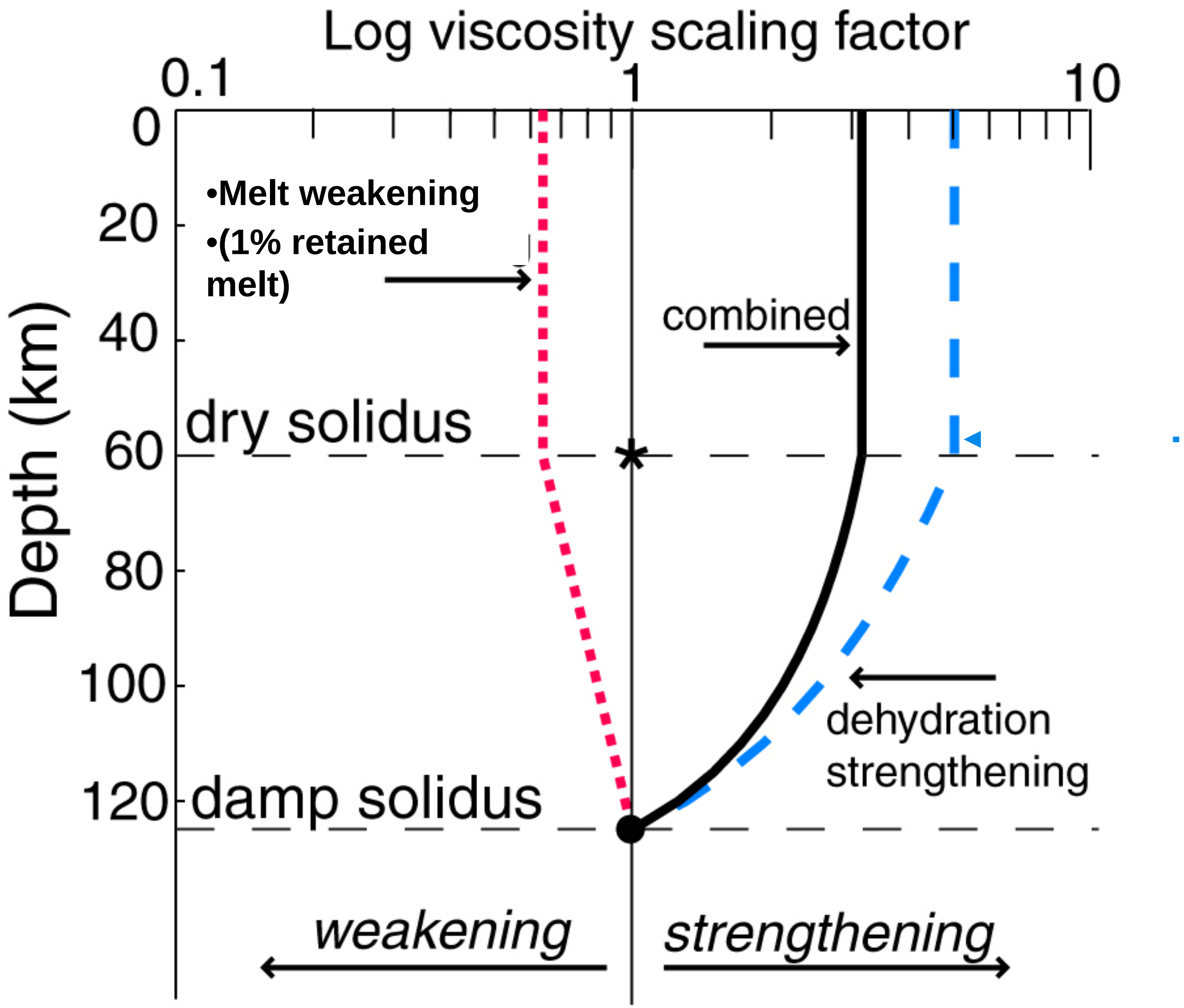
- *Damp Melting:*
- *Low melt*
- *productivity*

- *Melting relations derived from Scott (1992)*

Simon et al., 2009

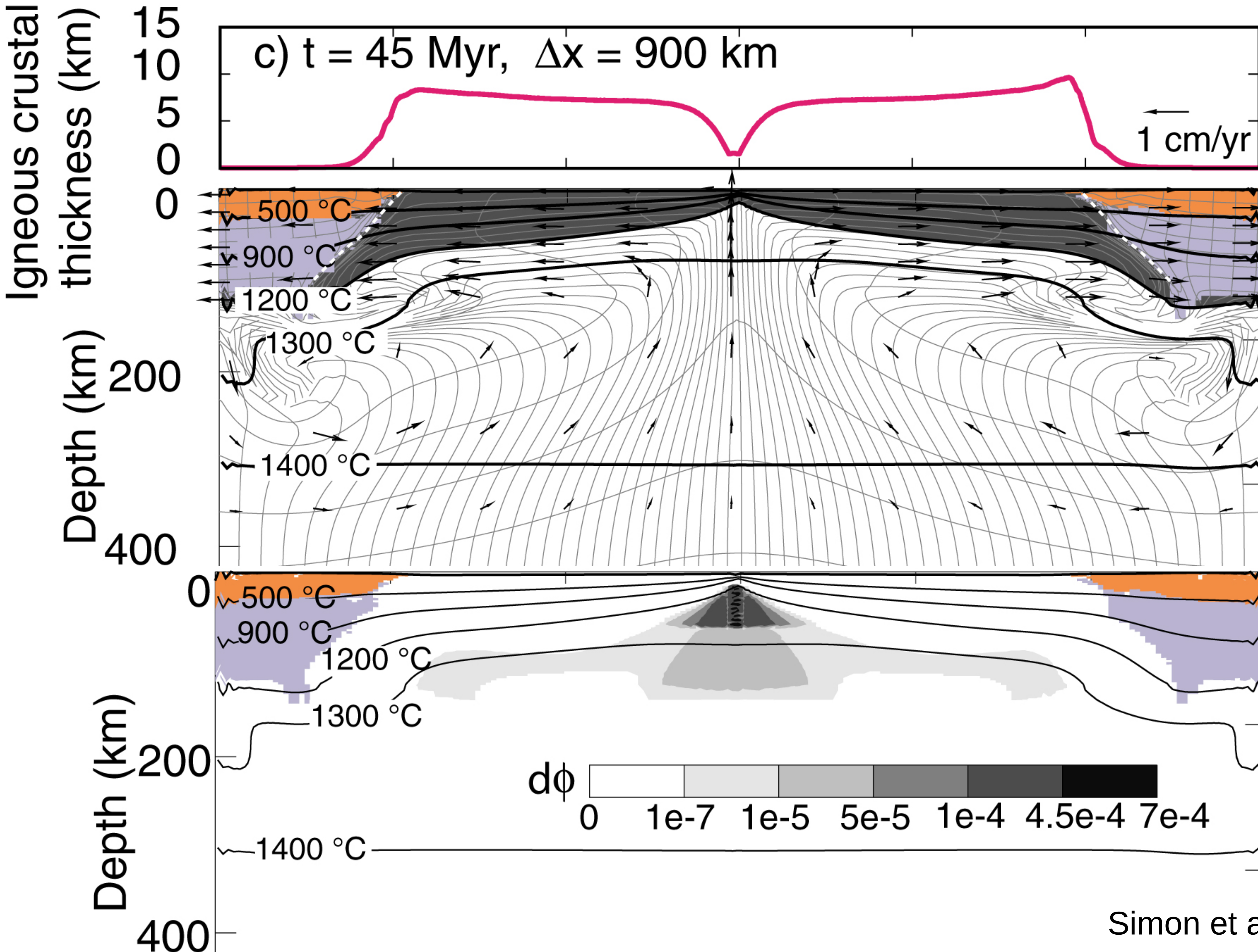
Melt weaking & dehydration strengthening

- *Melt feedback changes on viscosity → scaling factors*



Simon et al., 2009

Model 1: stable passive upwelling, 45 Myr



Simon et al., 2009