Anologue and Numerical models that inform the rifting process

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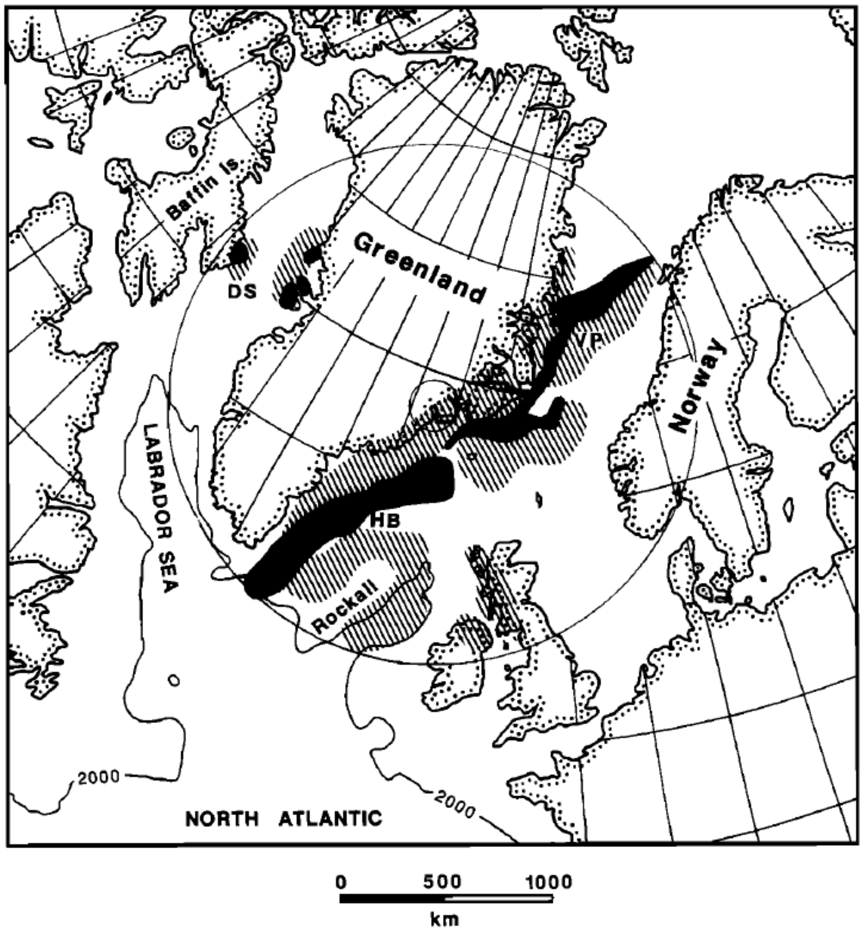
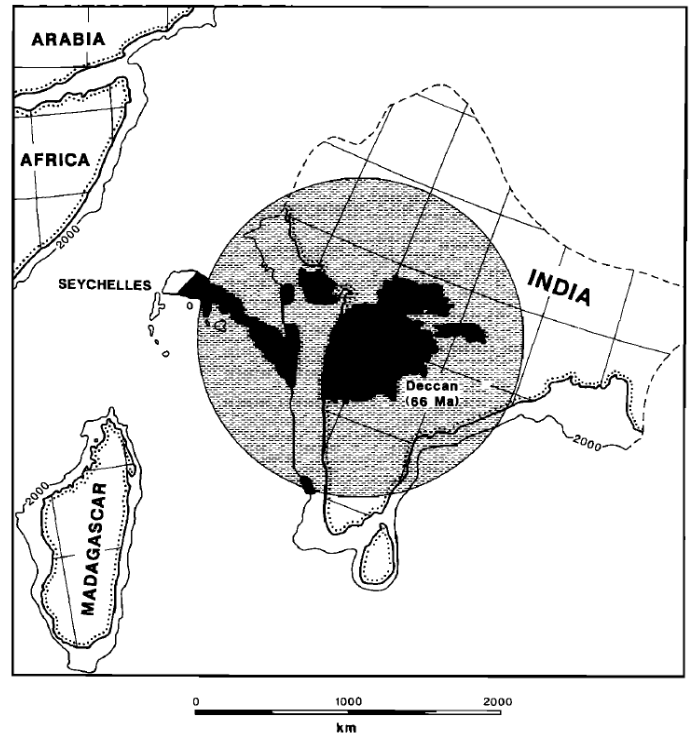
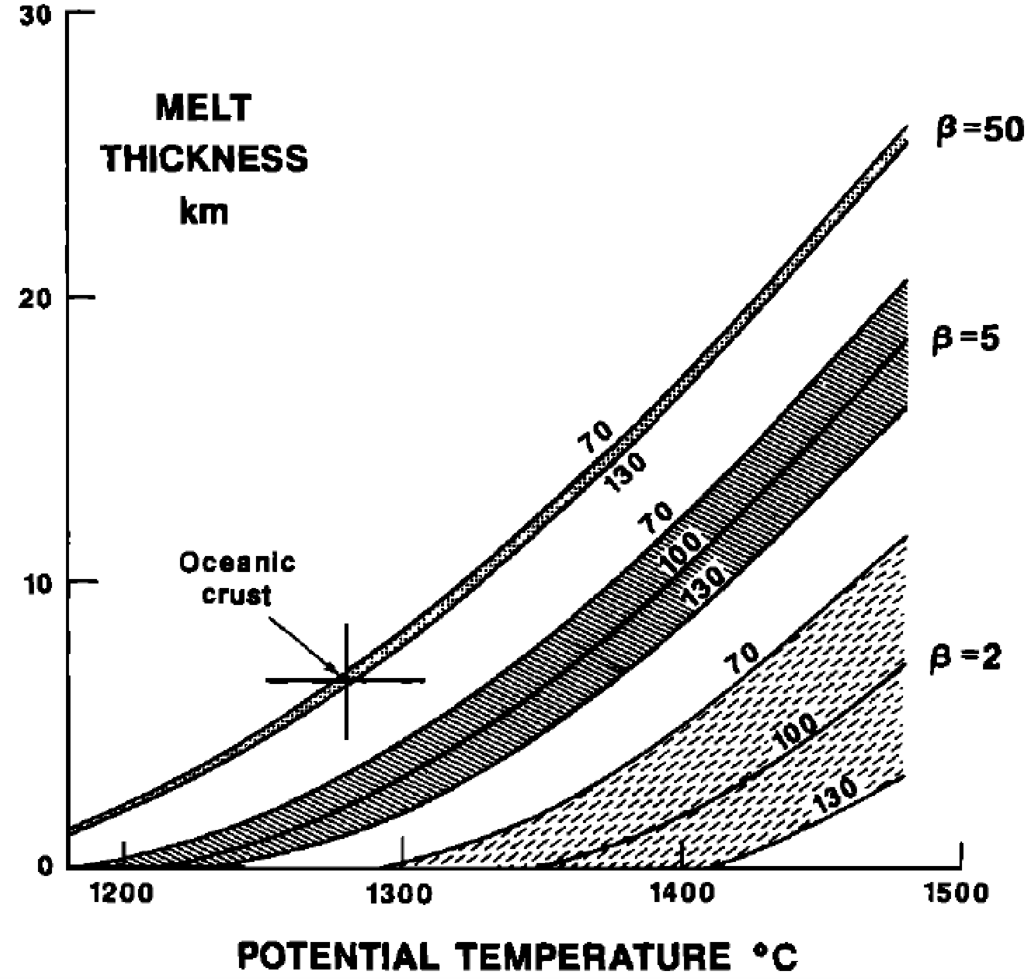
On shore flood basalts and volcanic margins



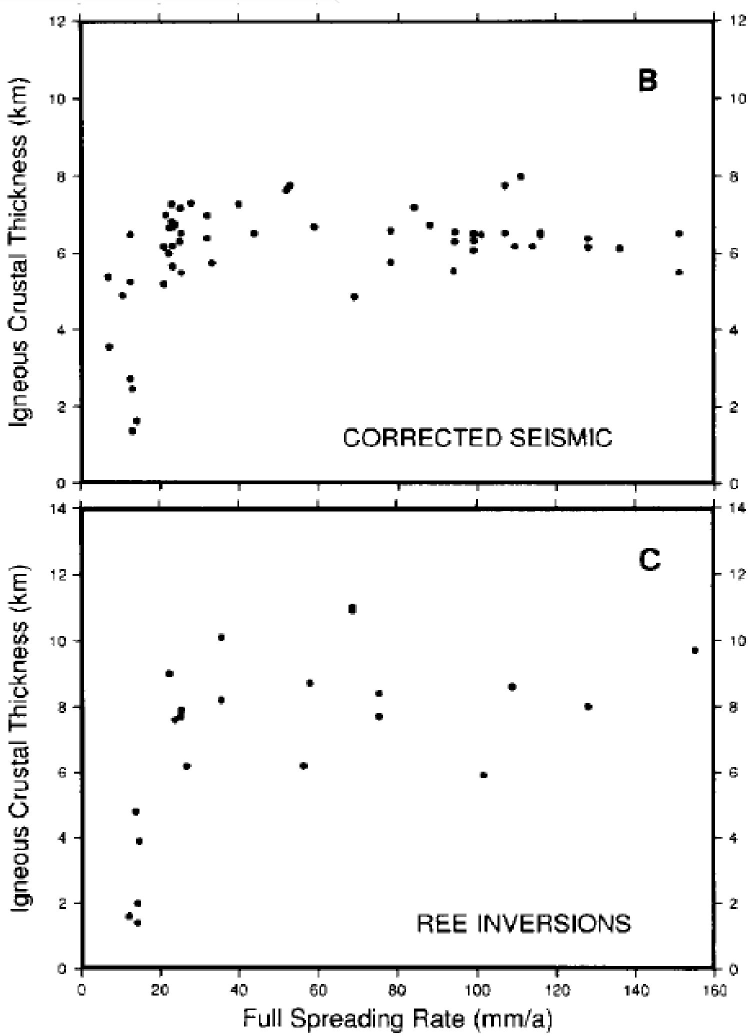


Mantle temperature, lithosphere and melt thickness



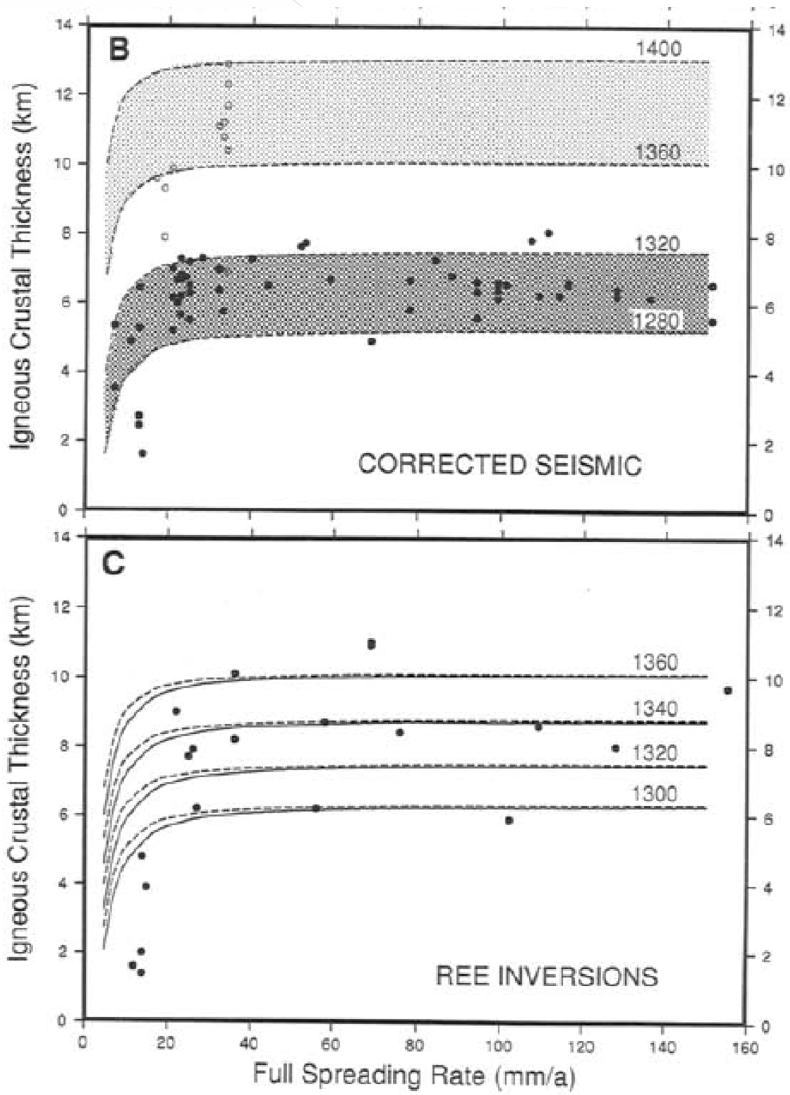
- White & McKenzie, JGR, 1989

How do you make less melt?



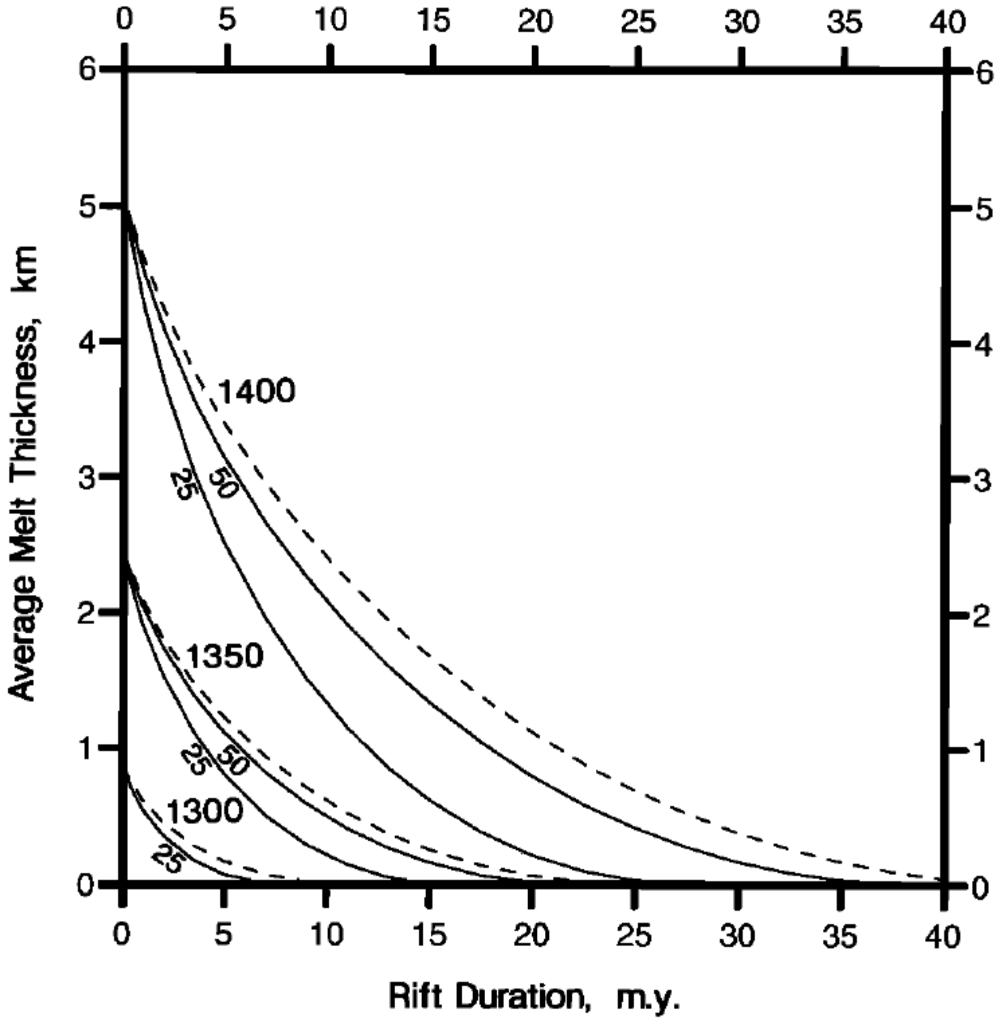
- At low rates of extension (< 20 mm/yr full rate) the crustal thickness can be low (< 5 km).
- Crustal thicknesses at mid-ocean ridges are typically between 5 and 8 km.
- Bown & White, EPSL, 1994.

How do you make less melt?



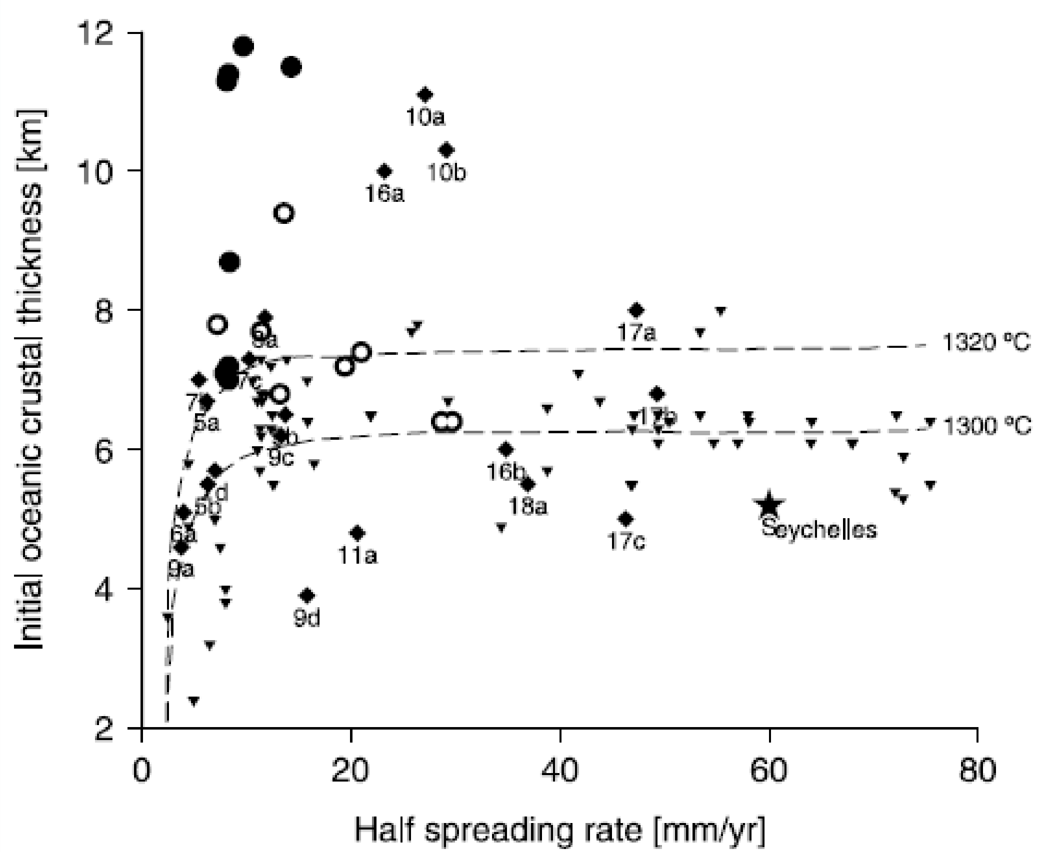
- For mantle of a temperature of 1280 to 1320 °C a corner-flow model can match thickness.
- The North Atlantic margins fit a 100 °C hotter mantle.

How do you make less melt?



- Extend slowly, forming a wide rift with low melt volumes
- Average melt thickness is the volume of melt generated divided by the width.
- Bown & White, JGR, 1995

Update the plot – add a few margins...



Collier *et al.*, JGR, 2009

- Not all slow forming margins lack significant melt.
- Not all thin margins are slow...

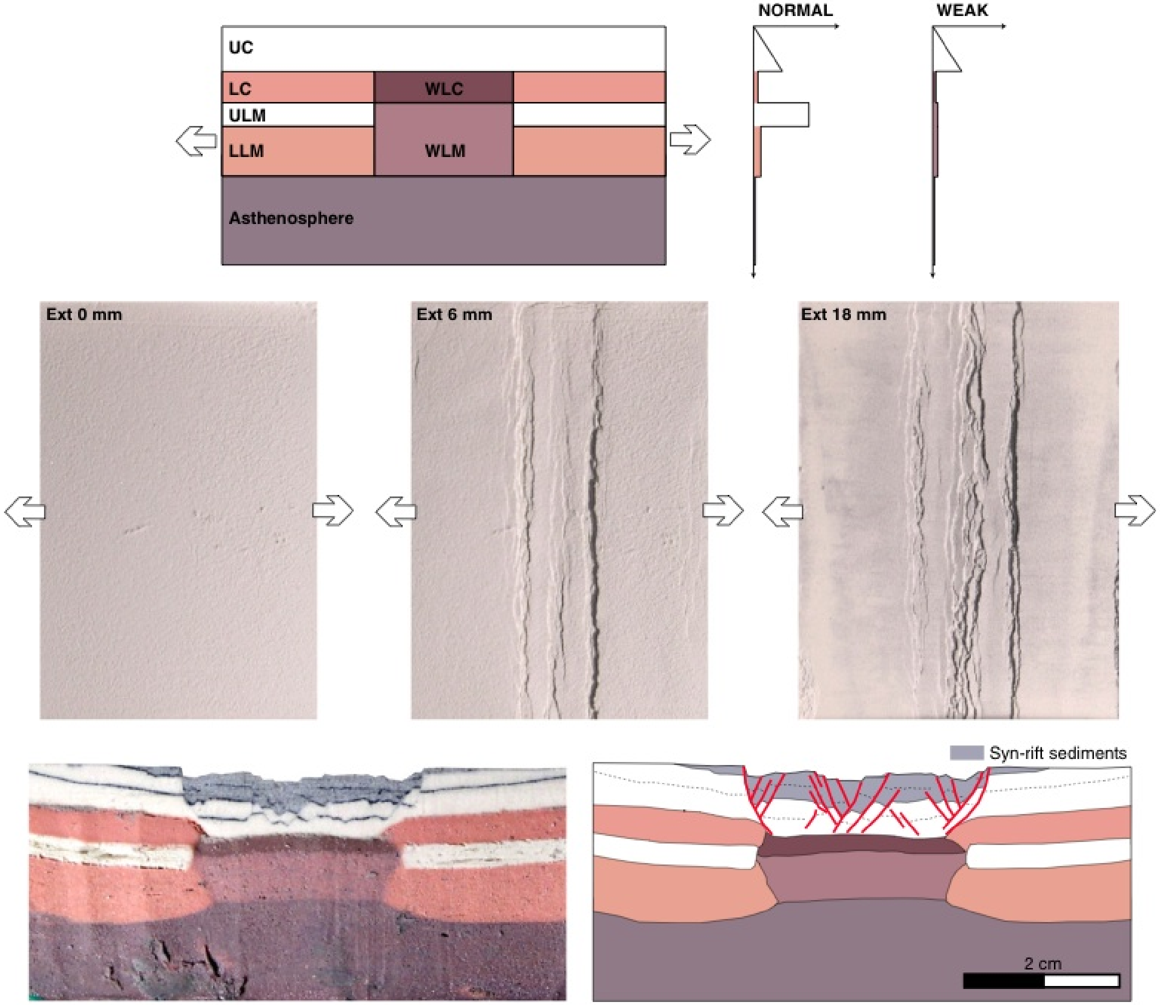
Furthermore, is break-up not by definition volcanic?

- Sills observed in the Newfoundland margin. Evidence for post-rift magmatism (Peron-Pinvidic et al., JGI, 2010).
- The magnetic J-anomaly is possibly associated with magmatic intrusions (Bronner et al., N. Geo., 2011).
- What comes first, melting or exhumation and serpentinisation?

How do you thin lithosphere without melting (too much)?

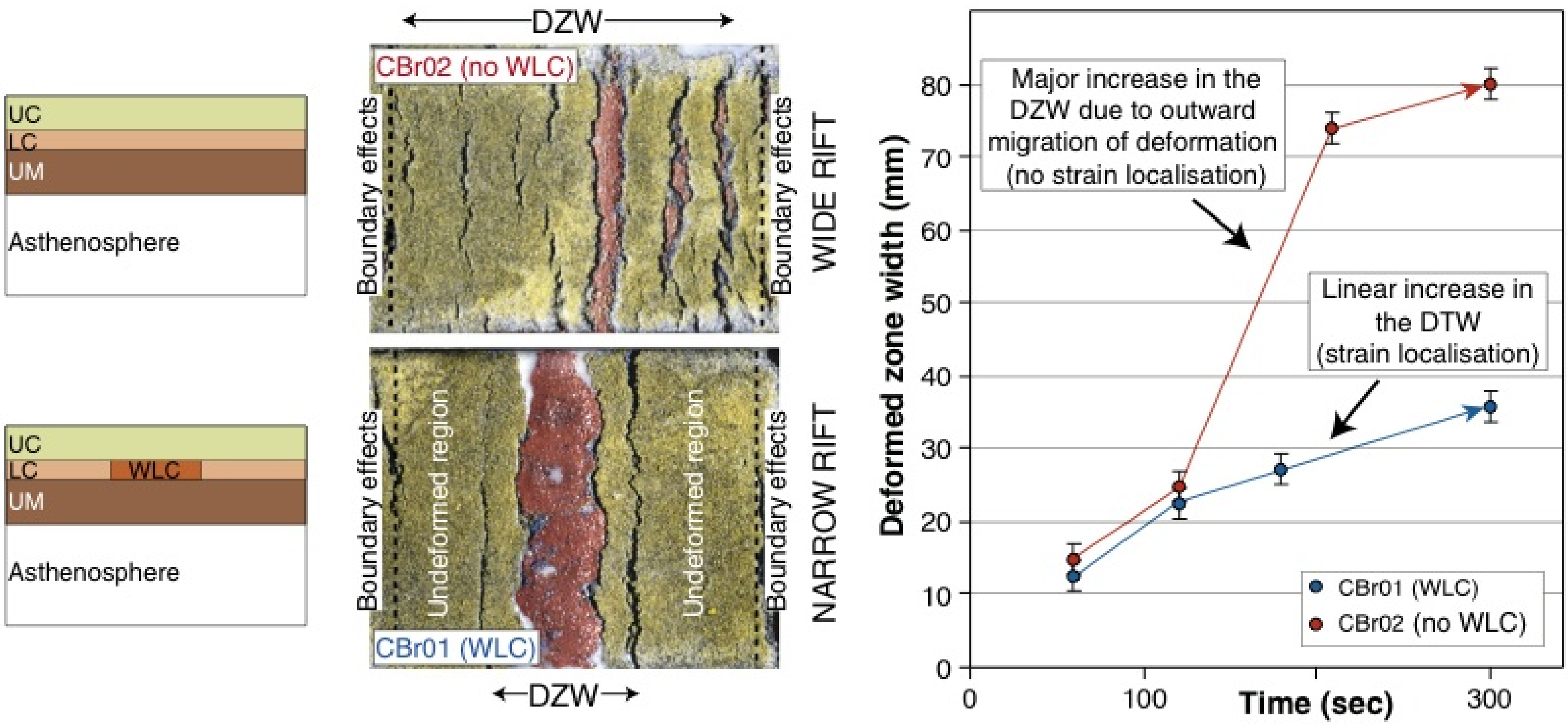
- In the right circumstance:
  - The lack or not of pre-existing weakness.
- With the right sort of lithosphere:
  - Serpentinisation of upper mantle.
  - Strain rate softening.
- *Or, is the mantle that upwells a spent force – depleted.*

A pre-existing weak zone?



Corti, Tectonophysics, 2011

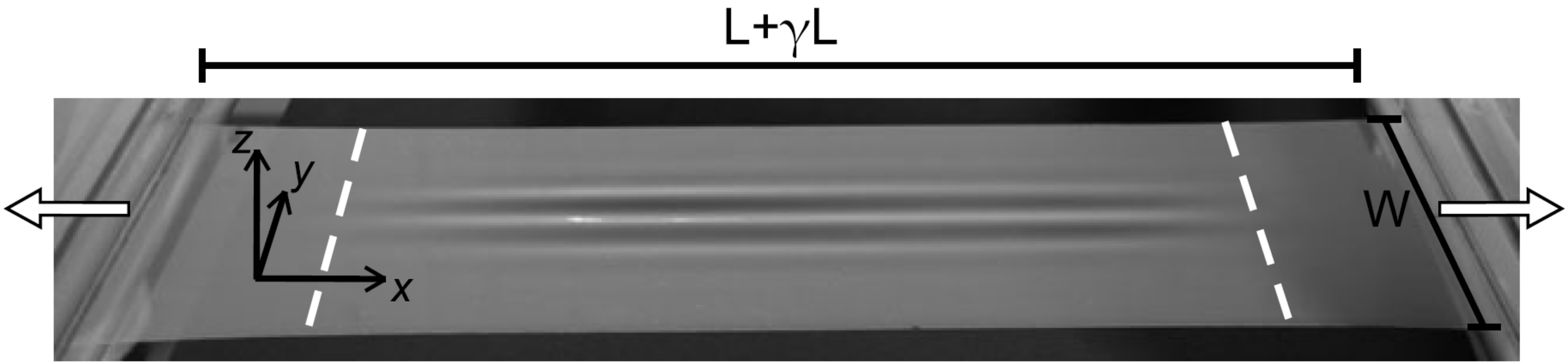
Or no pre-existing weakness



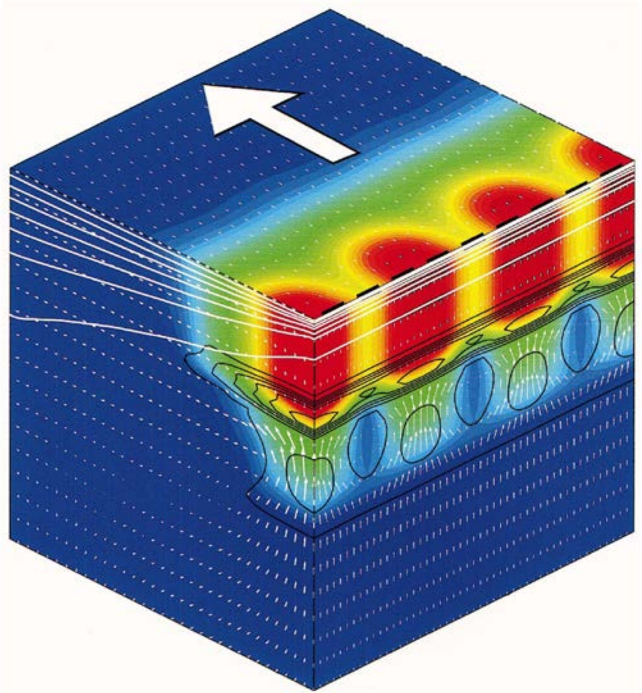
DZW – deformed zone width

Corti et al., GRL, 2003

Wrinkles due to stretching

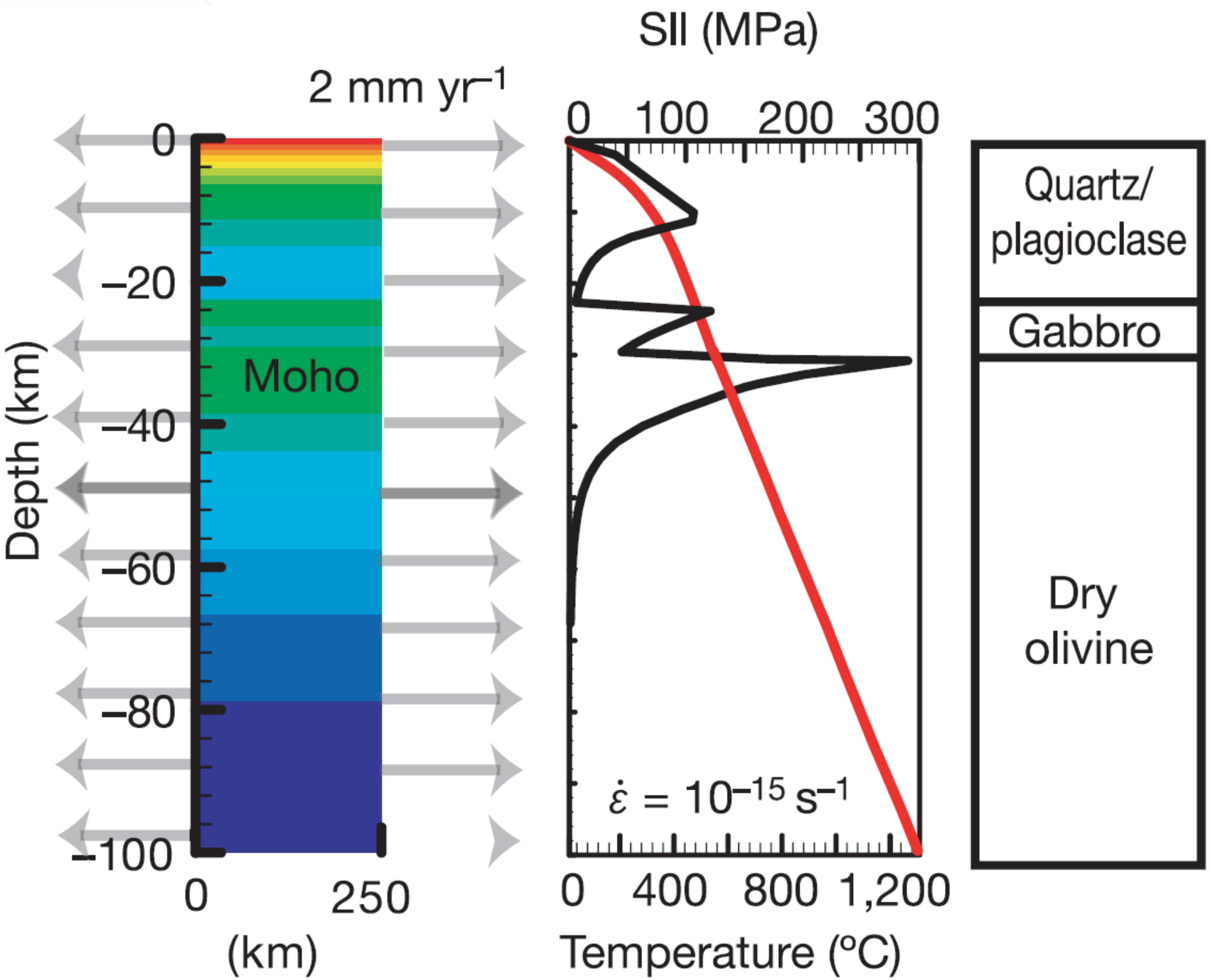


Levy & Jaupart, JGI, 2011



Choblet & Parmentier, EPSL, 2001

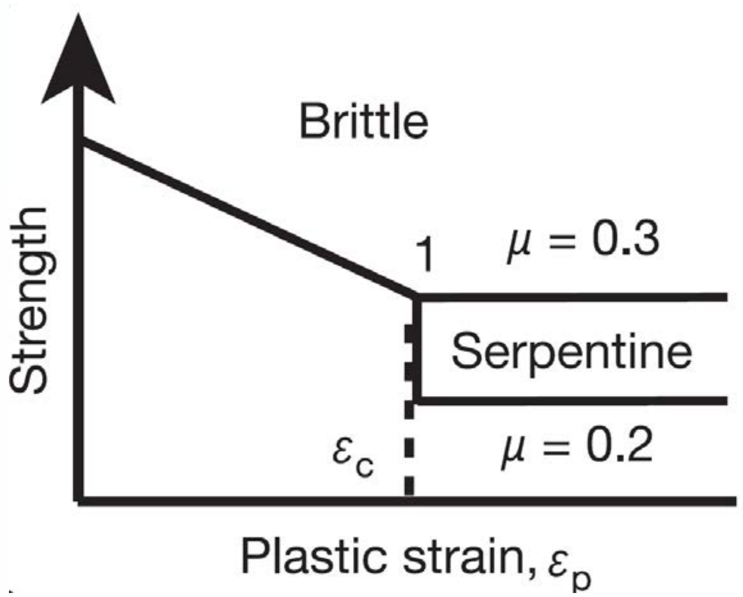
Weak lower crust



Lavier & Manatschal, Nature, 2005

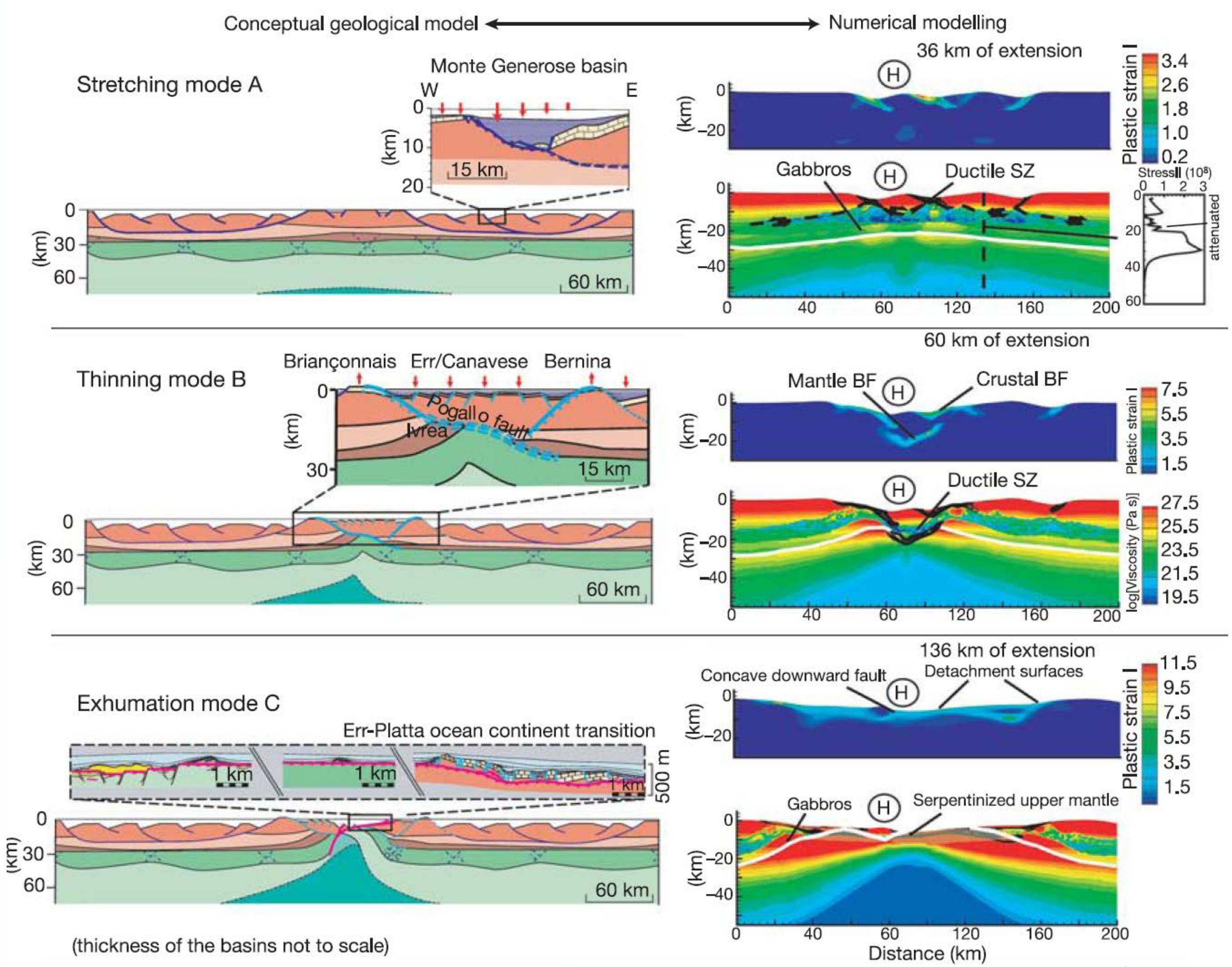
Serpentinite

- Weakens the upper mantle as it is formed as it lowers the friction coefficient within the Mohr Coulomb yield criterion.



Lavier et al., Nature, 2005

Stretch, thin and exhume

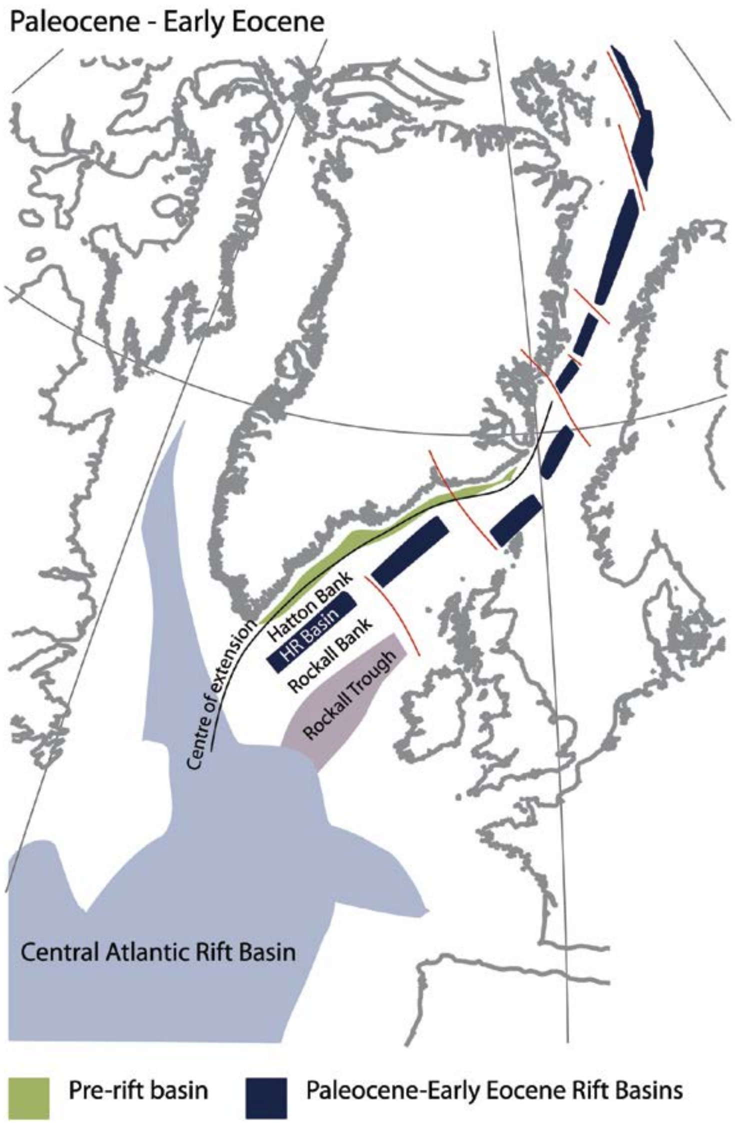


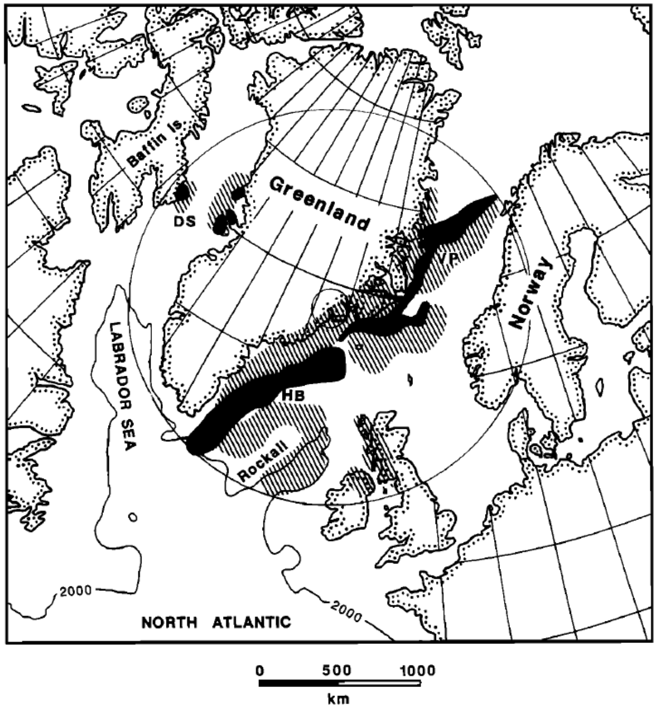
Lavier et al., Nature, 2005

So what is it to be?

- Weak layers to facilitate thinning/shearing of the continental lithosphere.
- Pre-existing weakness in the crust and lithosphere, rifts form in old suture zones, don’t they?
- Or is melt key?

After all, not all rifts succeed...

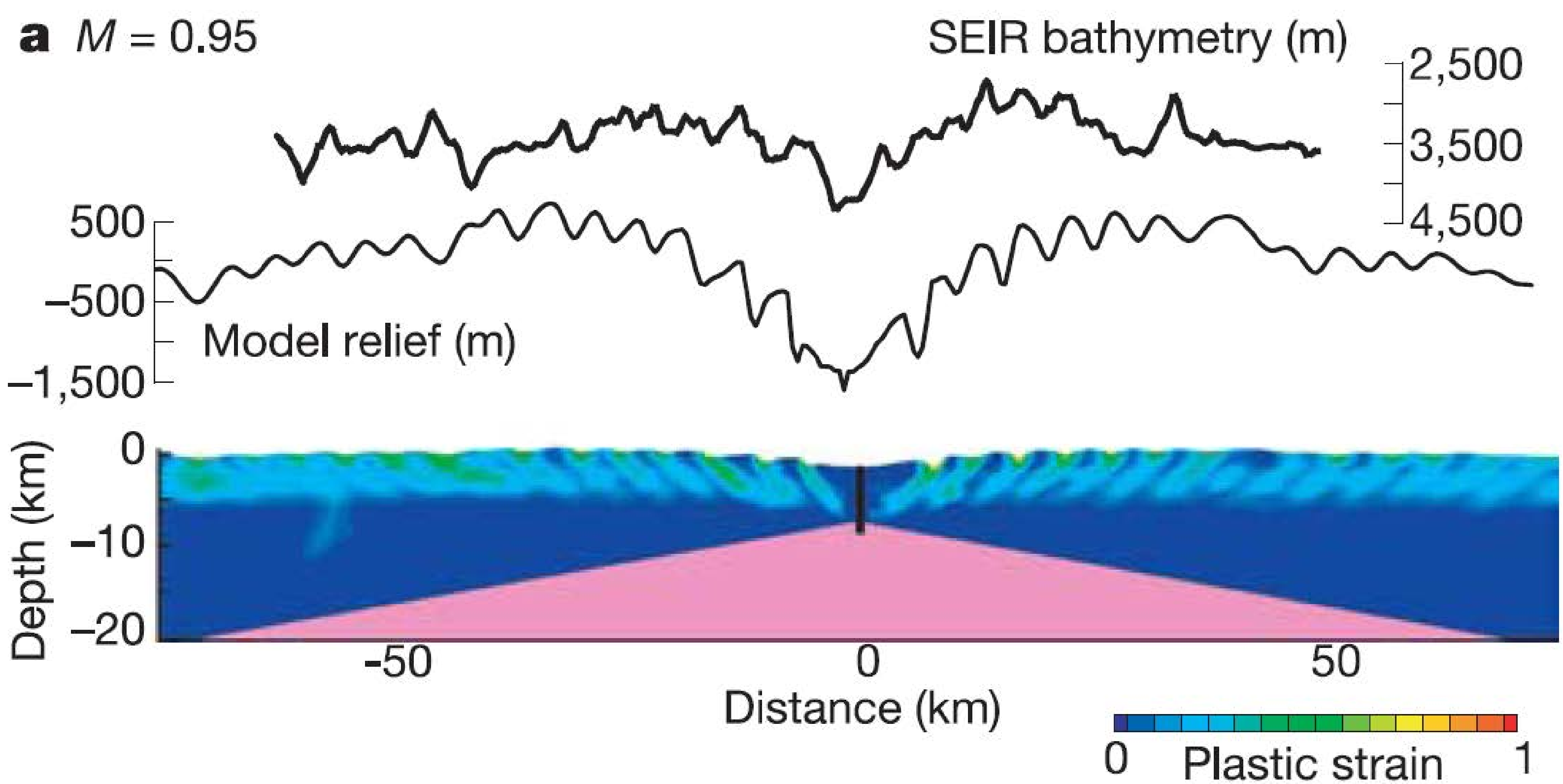




Armitage *et al.*, G-cubed (2009)

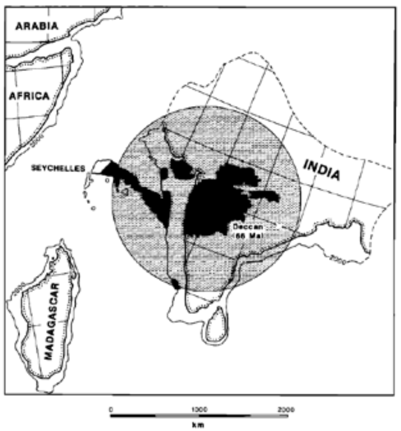
White & McKenzie, *JGR* (1989)

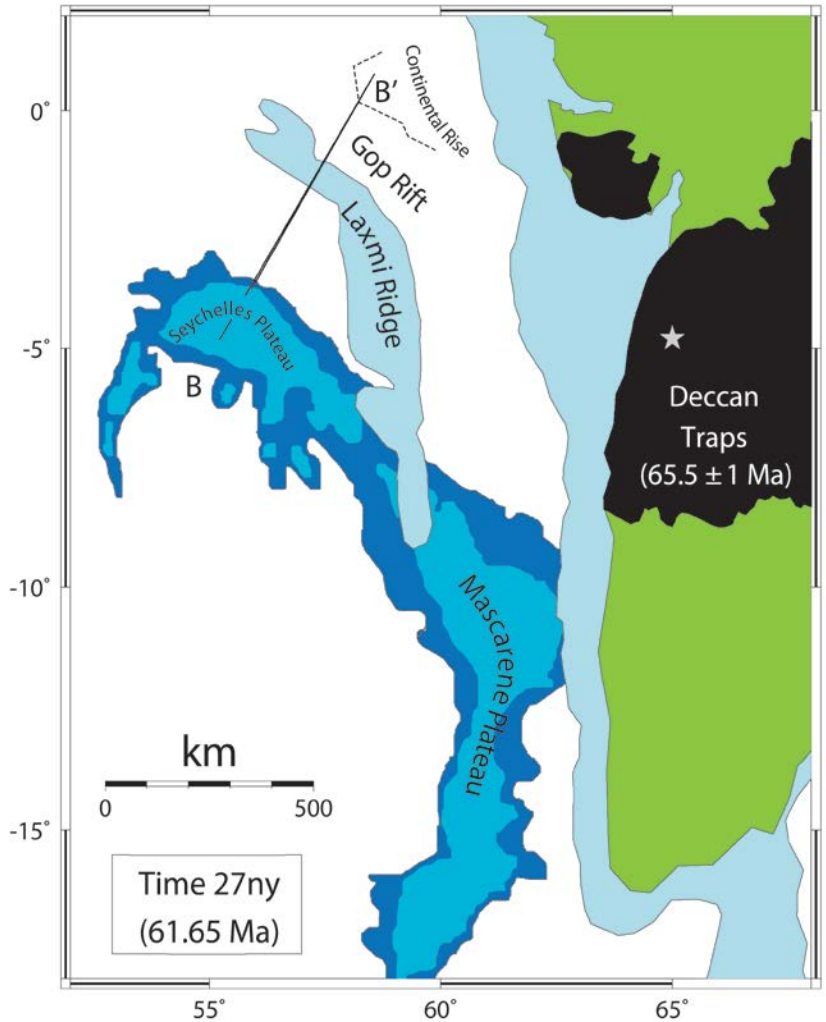
and melt will thermally weaken...

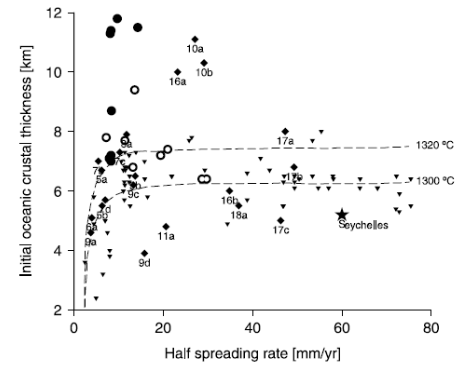


- At mid-ocean ridges, slow extension and melt intrusion match bathymetry.
- Buck et al., Nature, 2007

Could the rift history control magmatism?

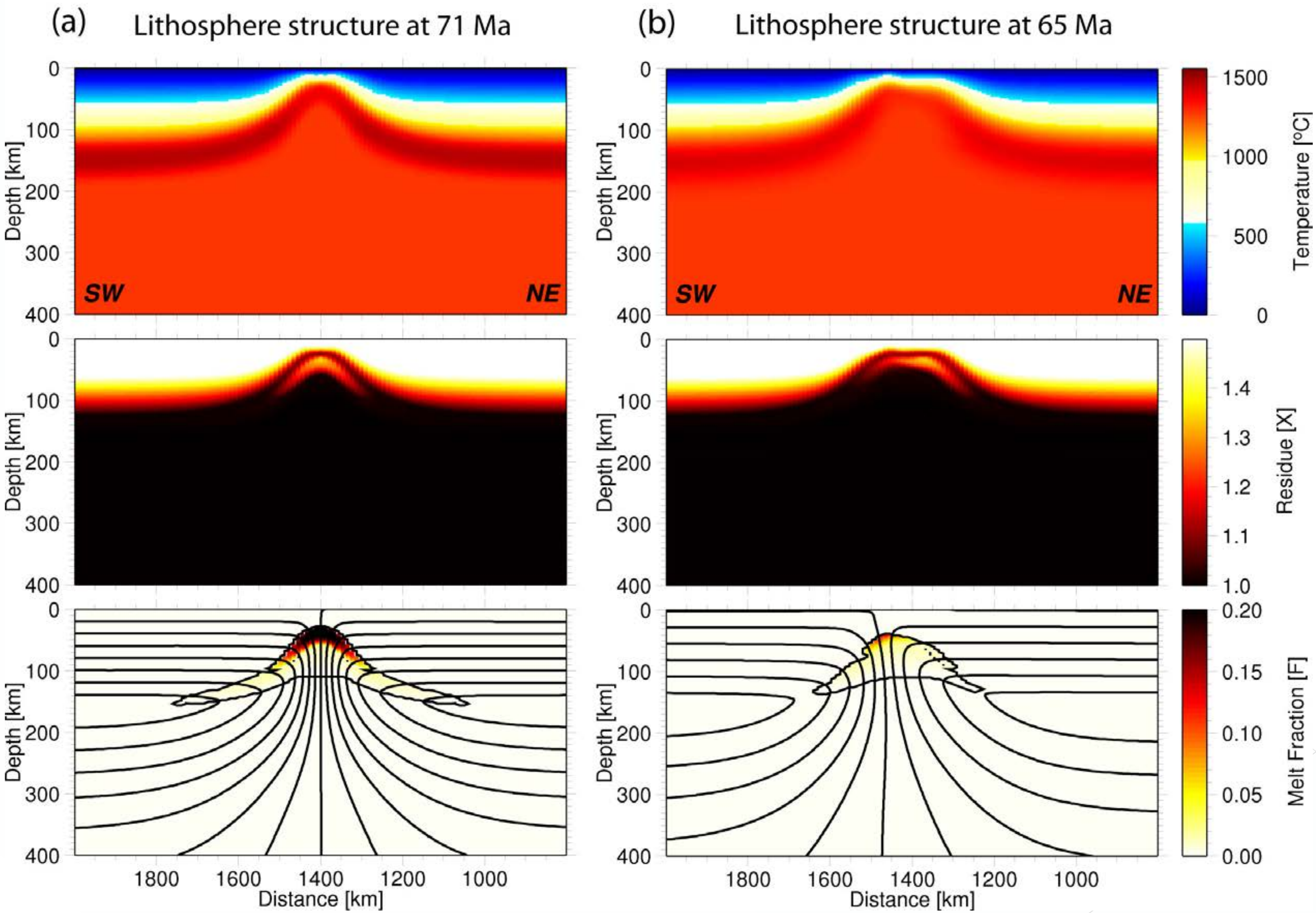




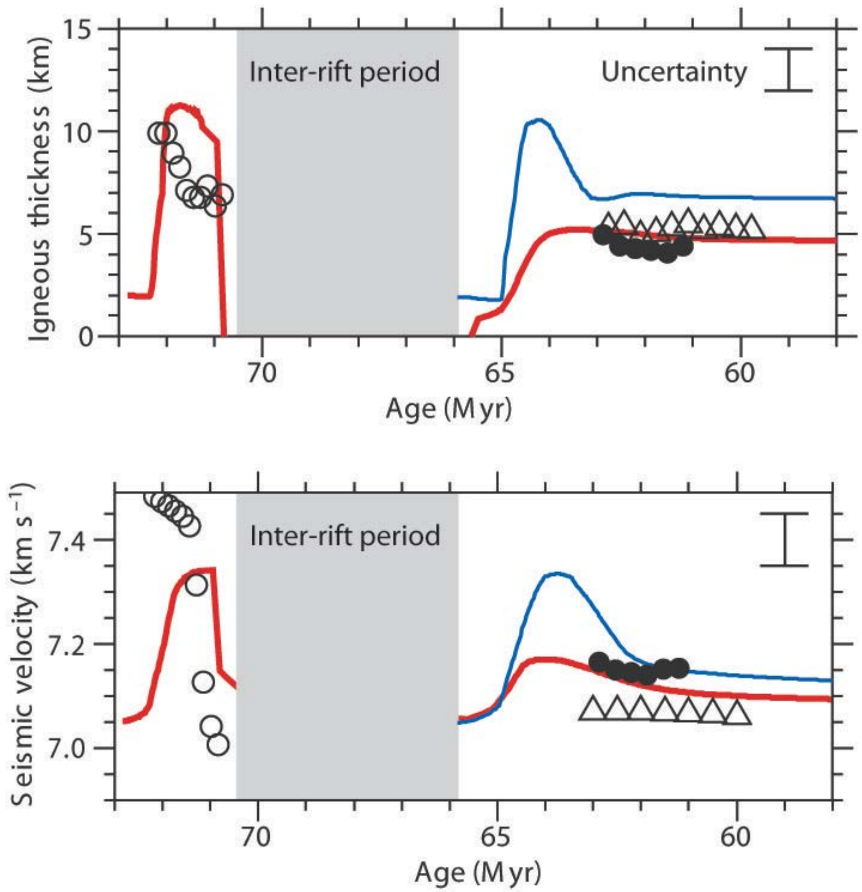


Armitage et al., Nature, 2010; Armitage et al., G-cubed, 2011

Rift history effects melt generation



Such that break-up goes with a bang or a whimper?



- Prior extension depletes the asthenosphere such that once break-up is achieved the mantle is depleted.
- The Seychelles margin is thin despite an association with flood basalts.
- Armitage et al., Nature , 2010.

1. How do you localise extension – break-up?

a) Pre-existing local weakness in the upper lithosphere.

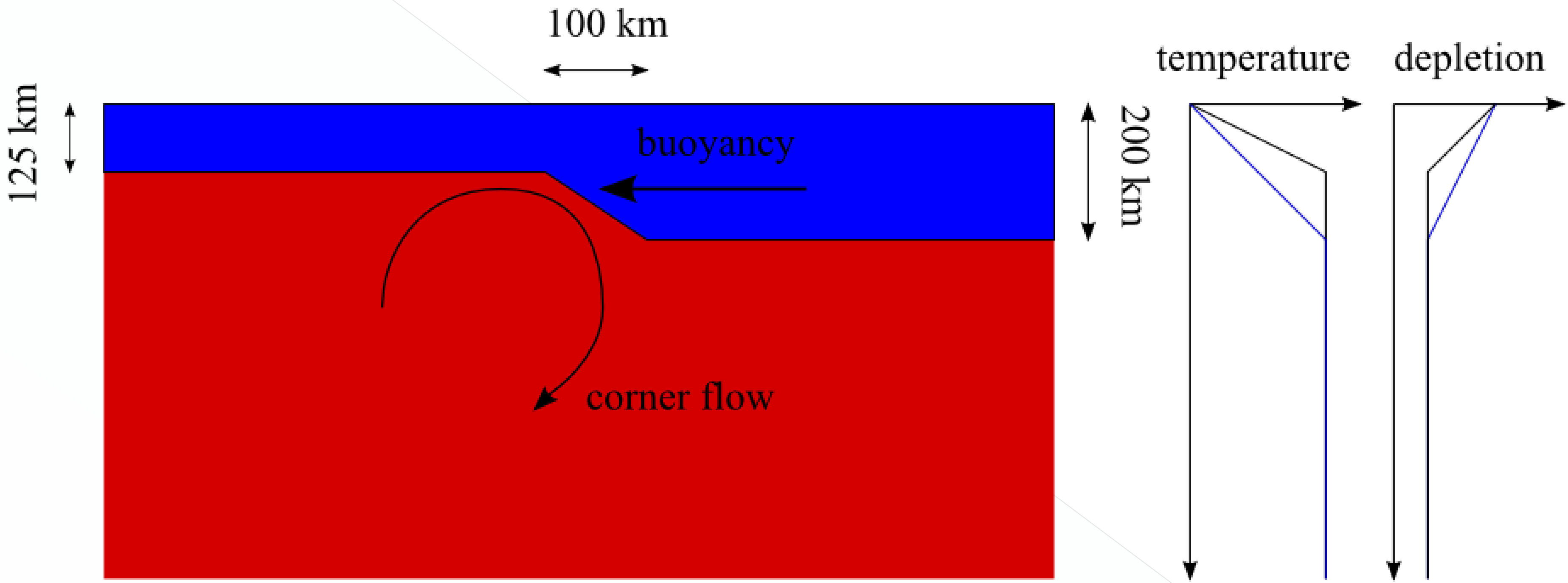
b) Serpentinisation and a weak lower curst.

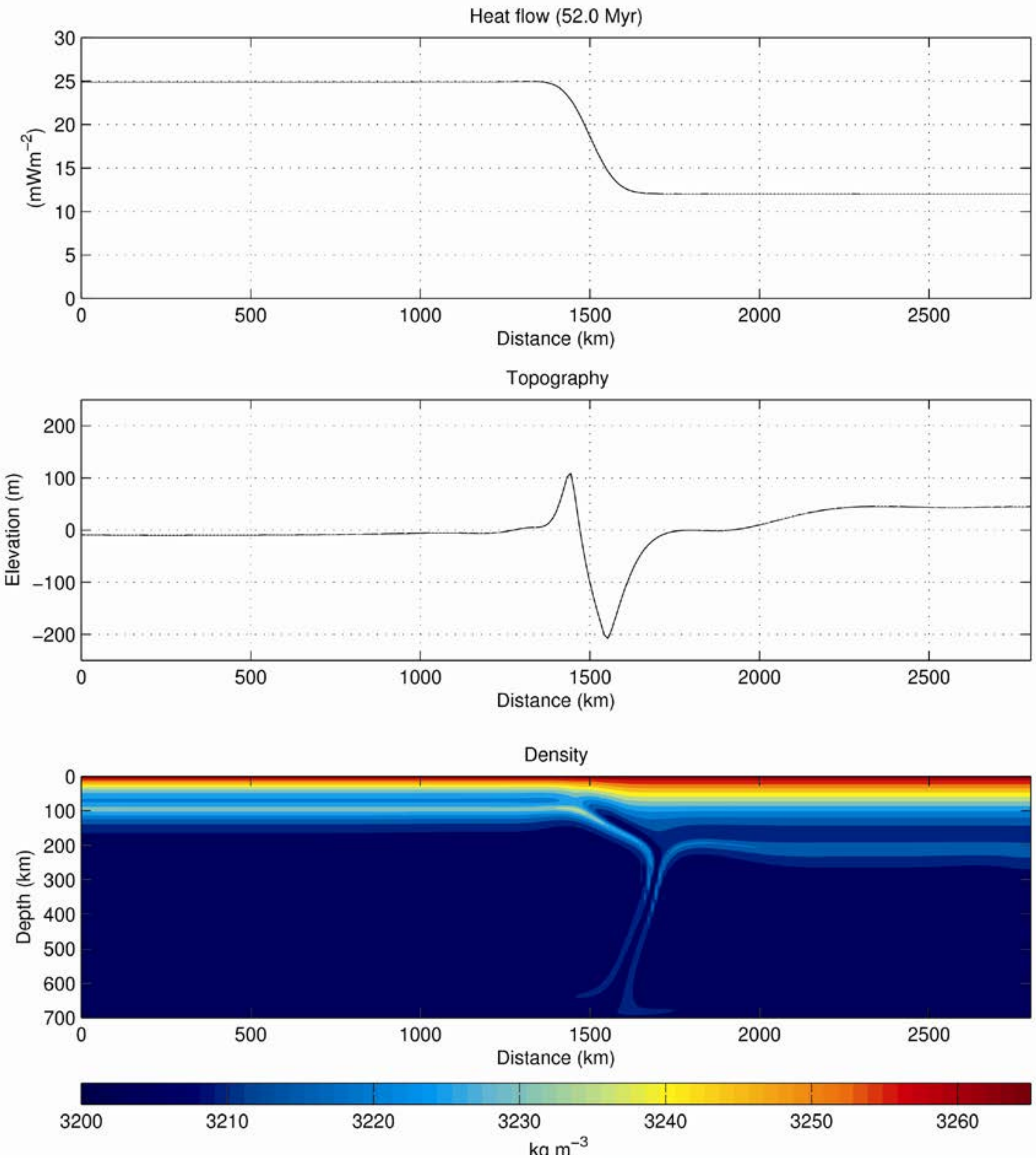
c) Melt intrusion and so at least some melt generation.

2. What controls melt generation?

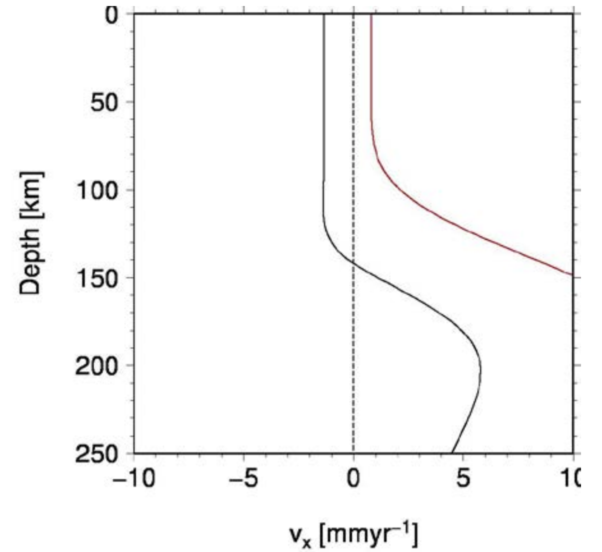
a) Temperature. But a-magmatic margins exist near flood basalts (Seychelles)
b) Rate of extension. But not all a-magmatic margins extended slowly (Seychelles)
c) Inherited structure of the lithosphere, but is this relevant for the slow forming North East American margins?

What defines the steady-state shape of a margin?

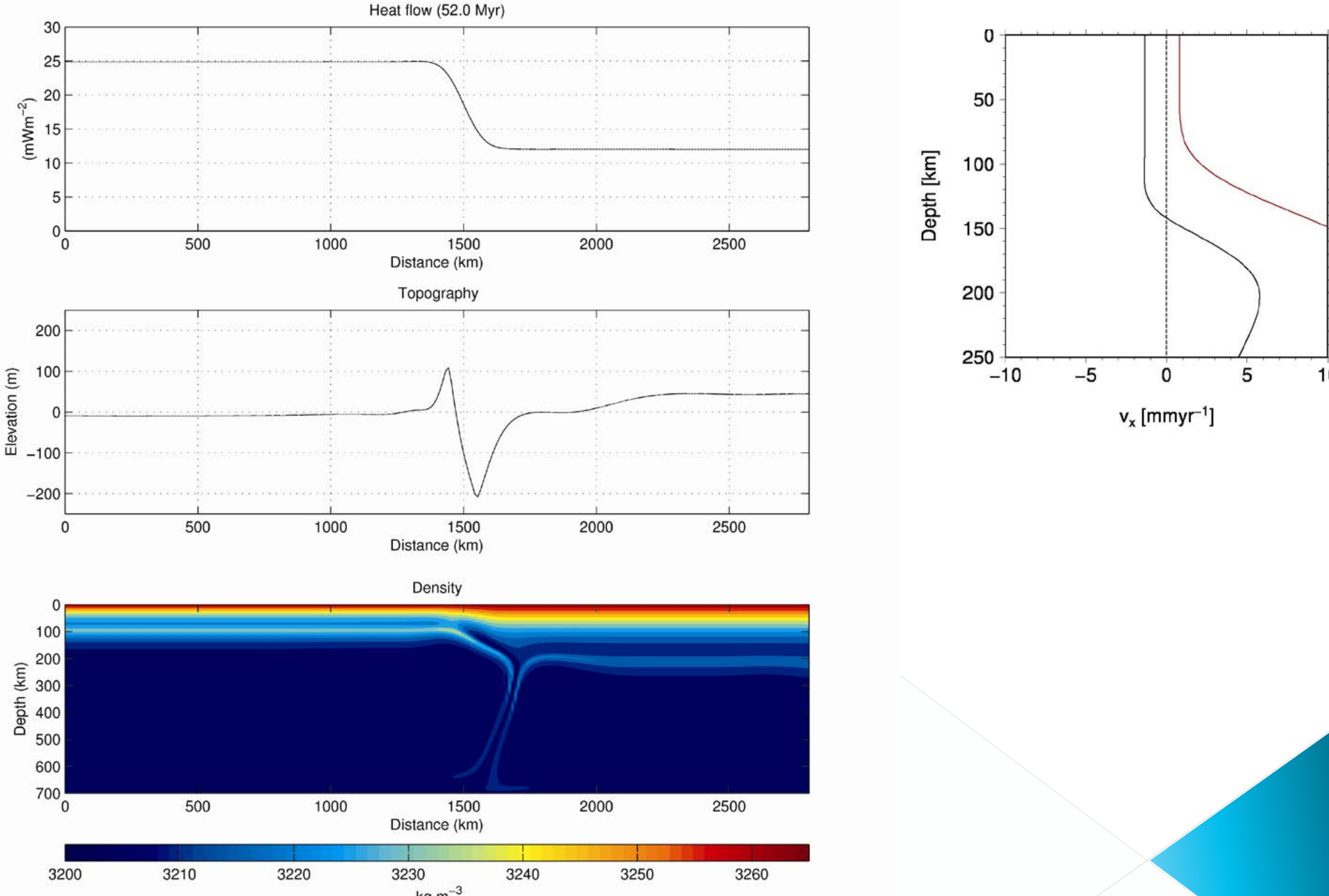




Heat flow (52.0 Myr)
(mWm^{-2})
Distance (km)
Topography
Elevation (m)
Distance (km)
Density
Depth (km)
Distance (km)
kg m^{-3}



Depth [km]
v_x [mmyr^{-1}]



Heat flow (52.0 Myr)
(mWm−2)
Distance (km)
Topography
Elevation (m)
Distance (km)
Density
Depth (km)
Distance (km)
kg m−3
Depth [km]
vx [mmyr−1]

What is the fate of a margin?

Levy & Jaupart