Anologe 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.
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…

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

Collier et al., JGR, 2009
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)
and melt will thermally weaken...

- At mid-ocean ridges, slow extension and melt intrusion match bathymetry.
Could the rift history control magmatism?

Armitage et al., Nature, 2010; Armitage et al., G-cubed, 2011
Rift history effects melt generation

(a) Lithosphere structure at 71 Ma

(b) Lithosphere structure at 65 Ma
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.
1. How do you localise extension – break-up?

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

b) Serpentinisation and a weak lower crust.

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?
What is the fate of a margin?