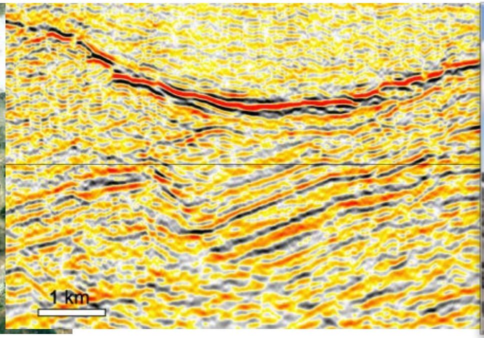
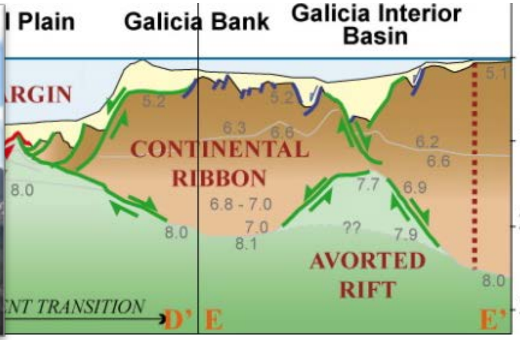
GEOPRISMS 2015

"From rifting to drifting : evidence from rifts and margins worldwide"

Stretching of the Lithosphere

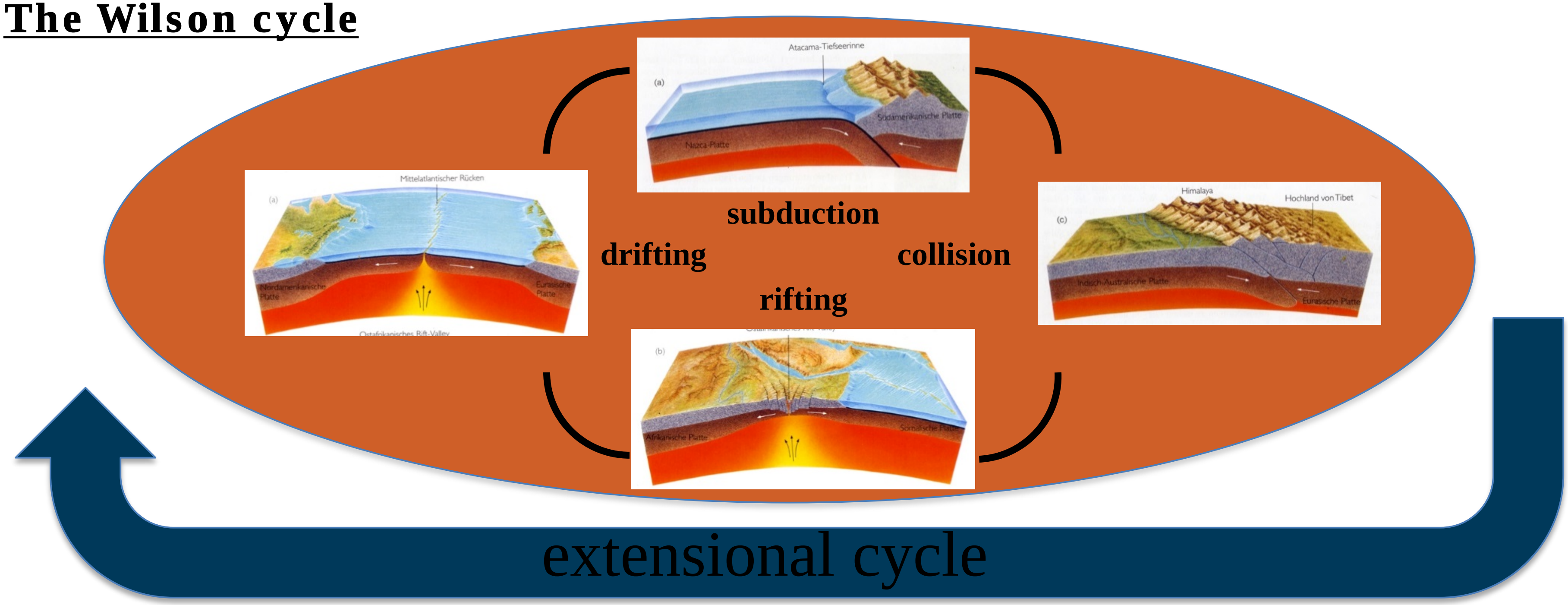



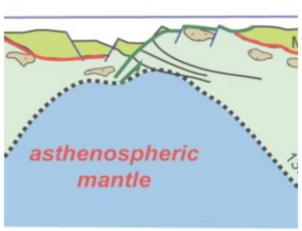
Suzon Jammes

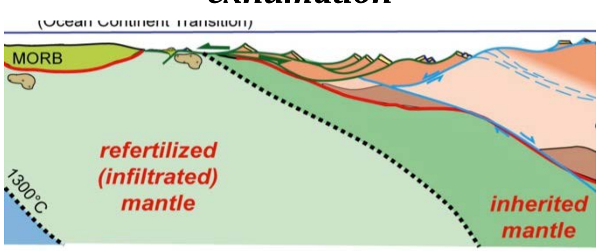
Stretching processes in the Wilson cycle

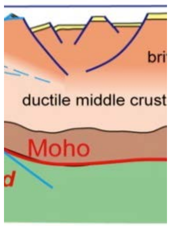
The Wilson cycle

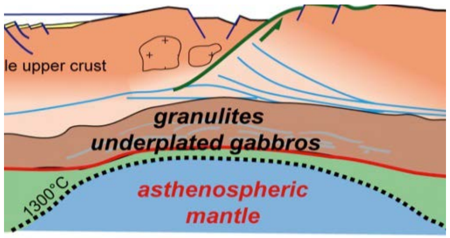


slow-seafloor spreading	**high-ß rifting**	**low-ß rifting**	**orogenic collapse**
(e.g. Mid Atlantic Ridge)	(e.g. Iberia margin)	(e.g. North Sea)	(e.g. Basin and Range)
oceanic crust	***hyper-extended crust & exhumation***	***moderate rifts***	***equilibrated crust***





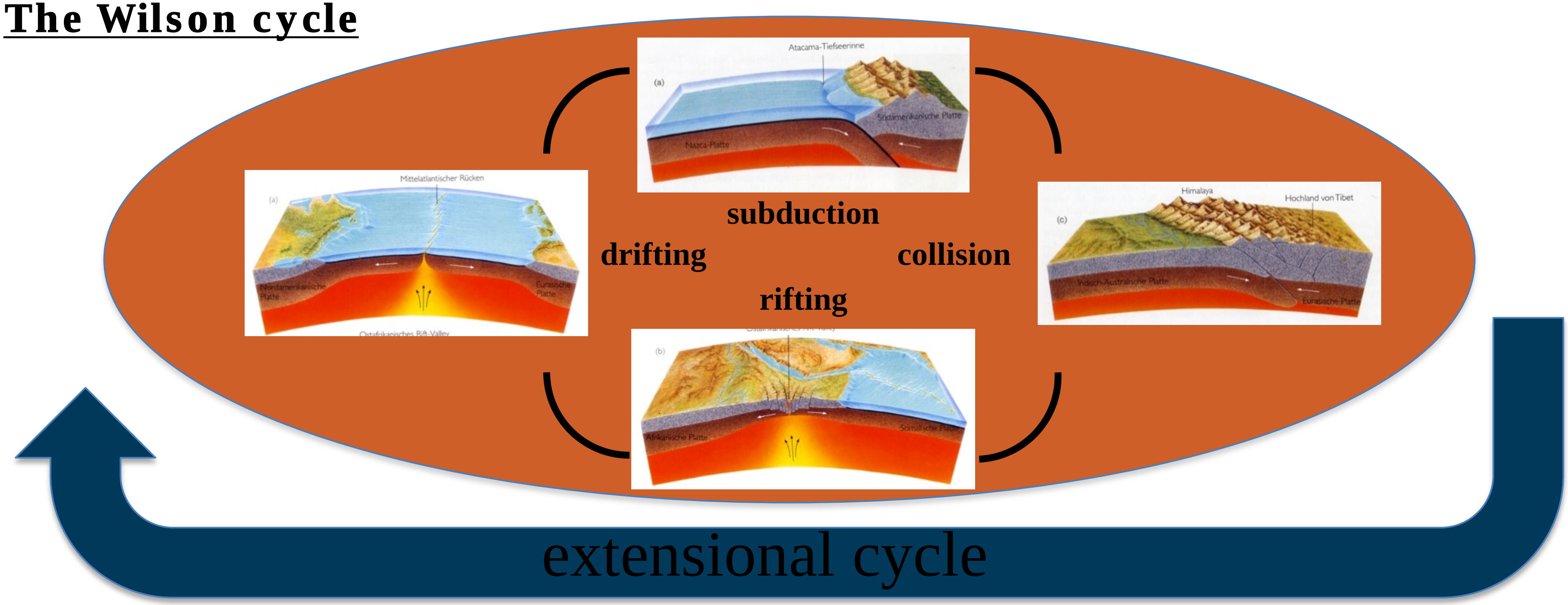




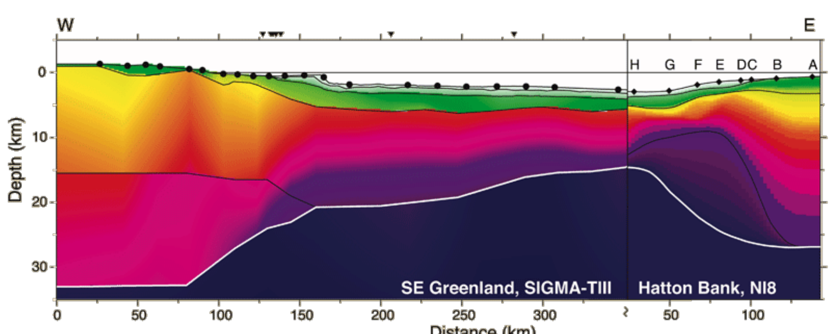
Modified from Masini et al. 2012

Stretching processes in the Wilson cycle

The Wilson cycle

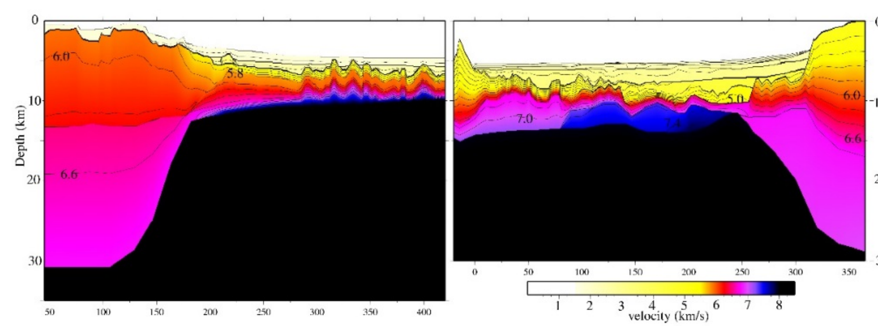


“Magma-rich” systems :
SE-Greenland/Hatton Bank / EARS



Hopper et al. (2003)

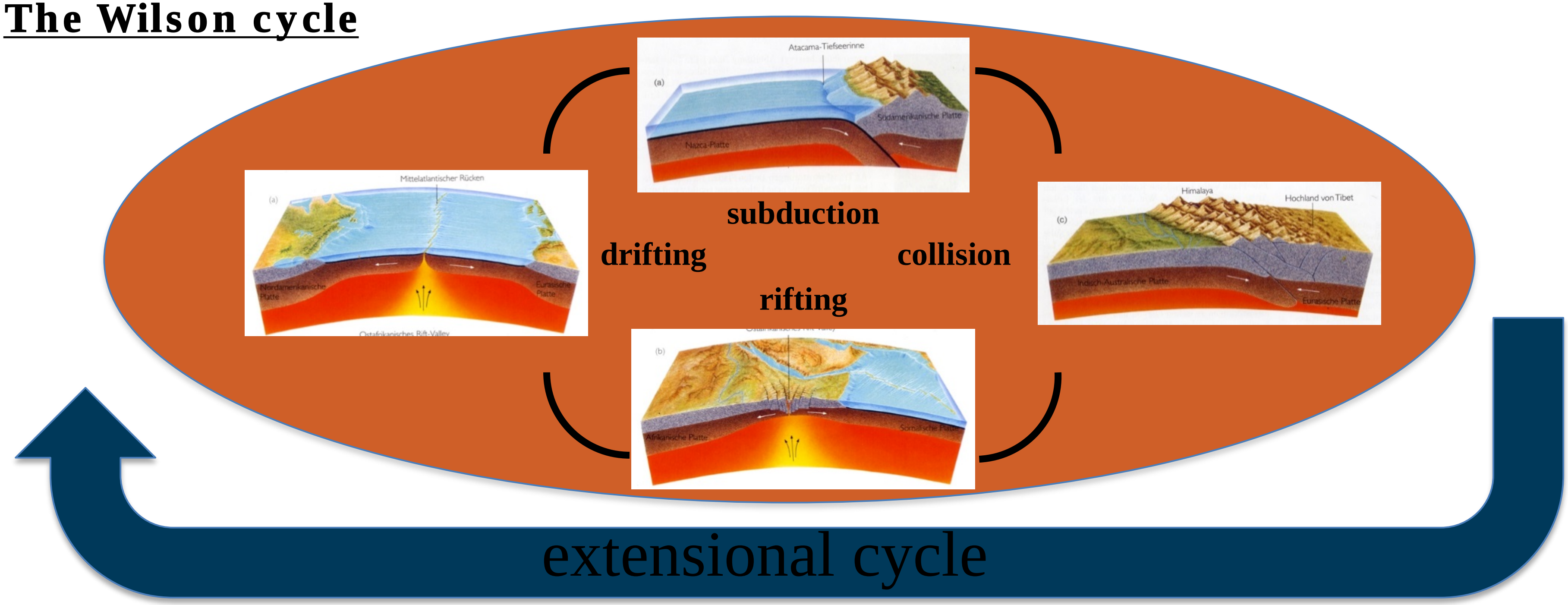
“Magma-poor” systems :
Iberia-Newfoundland



Shillington et al. (2006)

Stretching processes in the Wilson cycle

The Wilson cycle

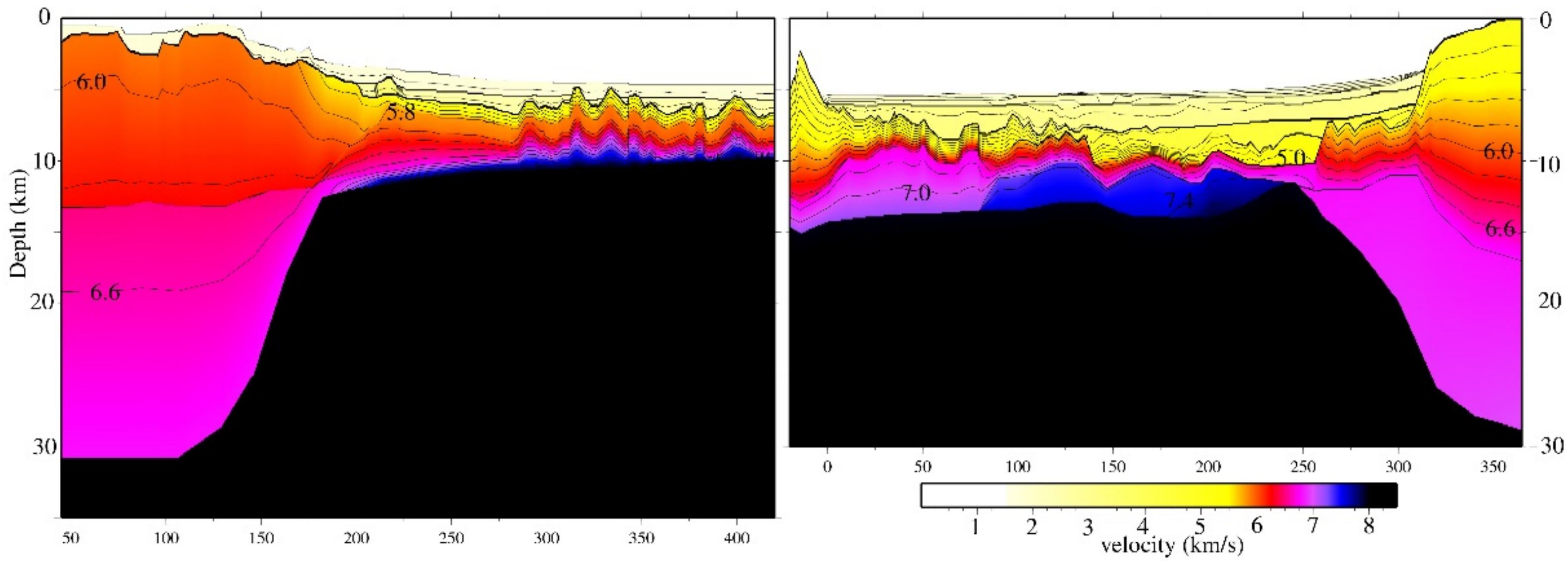


Main questions :

- How can we explain the exhumation of lower crustal and mantle rocks in high-β rifting?
- How do magmatic intrusion and tectonic inheritances affect rifting processes ?
- What is controlling the architecture of continental rifts and margins during and after breakup?

Observation and models in magma-poor systems

“Magma-poor” systems :
Iberia-Newfoundland



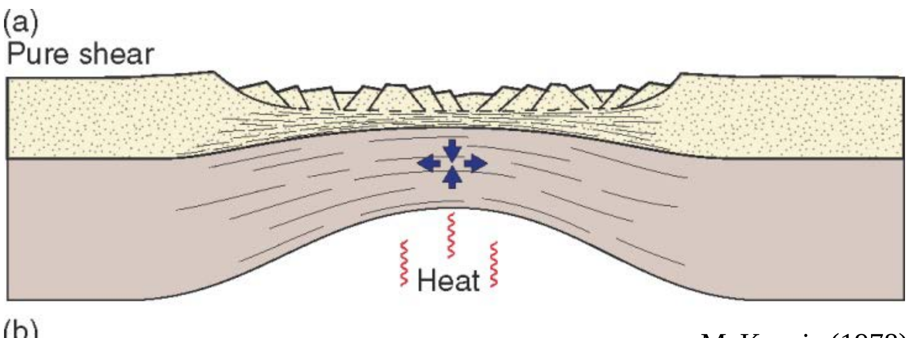
Shillington et al. (2006)

Two classical rifting models

Pure shear (McKenzie 1978) : uniform stretching of the lithosphere with depth

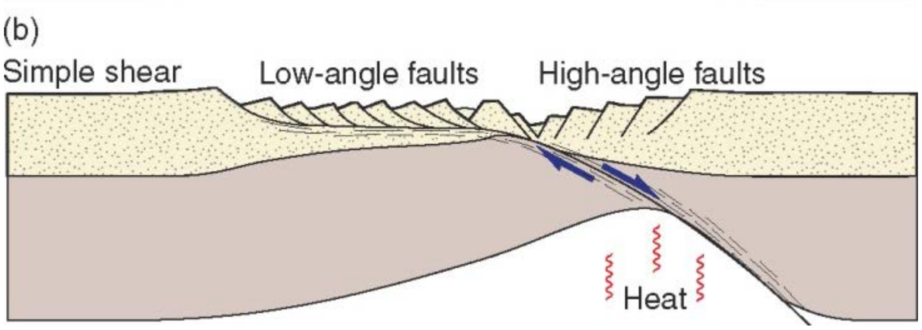
Simple shear (Wernicke 1981) : Extension is controlled by a low dipping detachment fault.

Pure shear model



McKenzie (1978)

Simple shear model

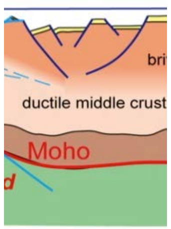


Wernicke (1981)

low-ß rifting

(e.g. North Sea, EARS)

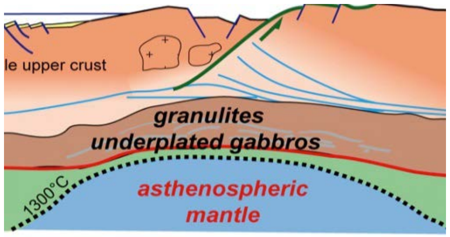
moderate rifts



orogenic collapse

(e.g. Basin and Range)

equilibrated crust



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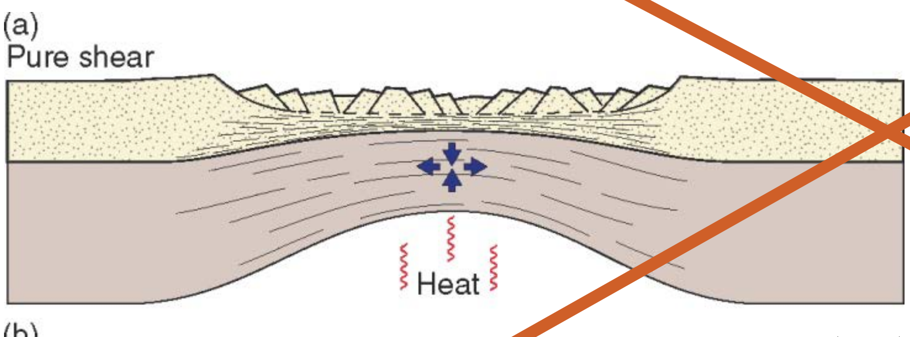

McKenzie (1978)

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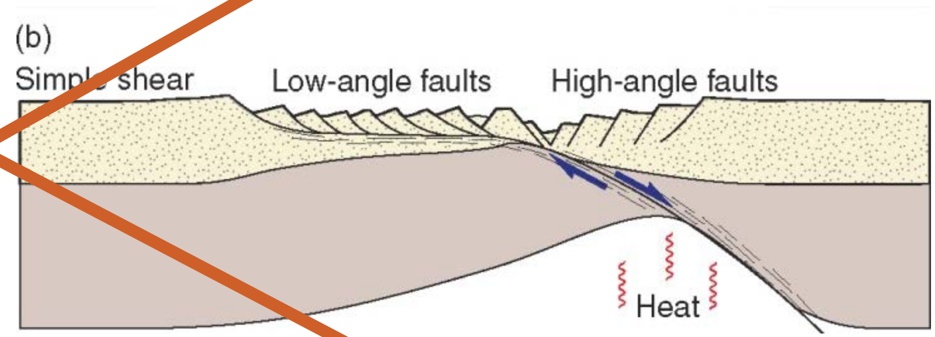
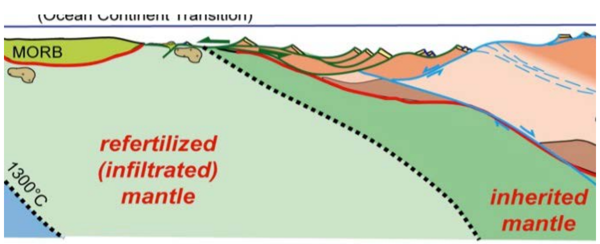


Wernicke (1981)

high-ß rifting

(e.g. Iberia margin)

hyper-extended crust &exhumation

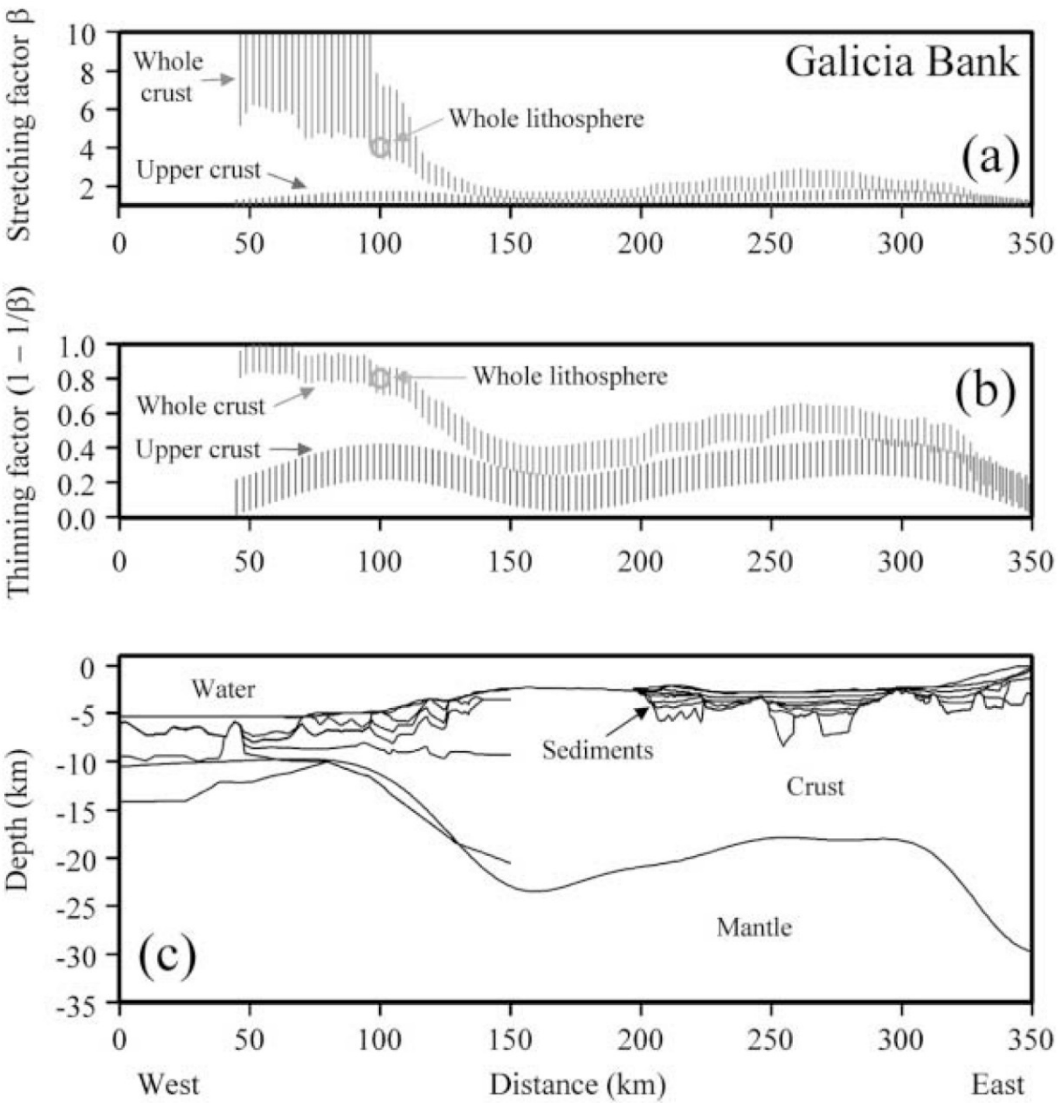


Modified from Masini et al. 2012

Depth dependent stretching

Depth dependent stretching : the magnitude of finite stretching of the upper crust (movement on brittle faults), is lower than total estimates for lithospheric stretching

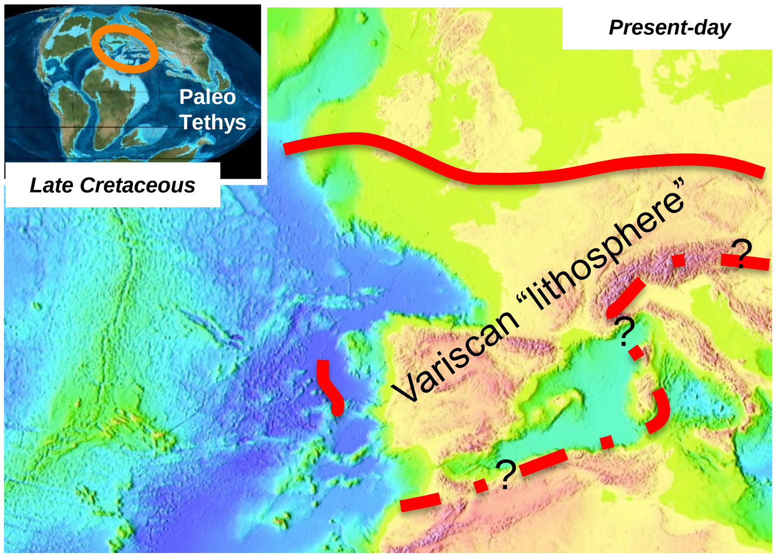
Decoupling of the deformation between the brittle upper crust and brittle upper mantle

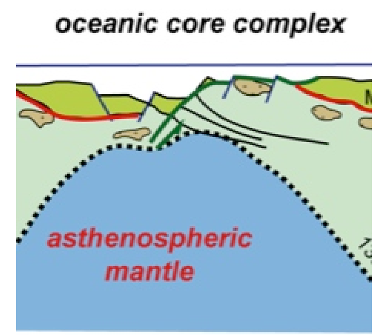


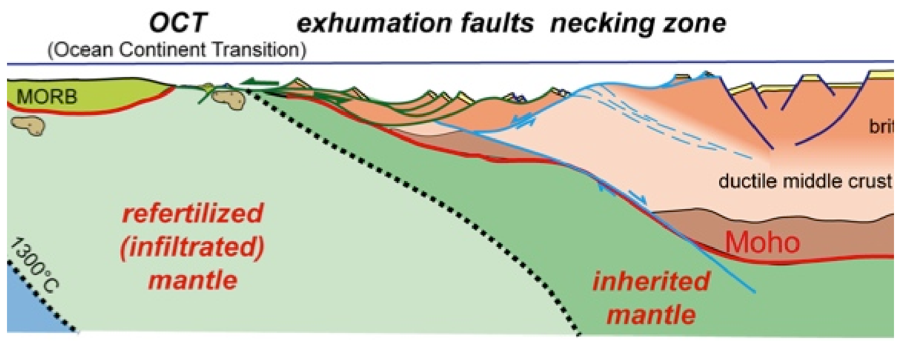
Davis and Kusnir (2004)

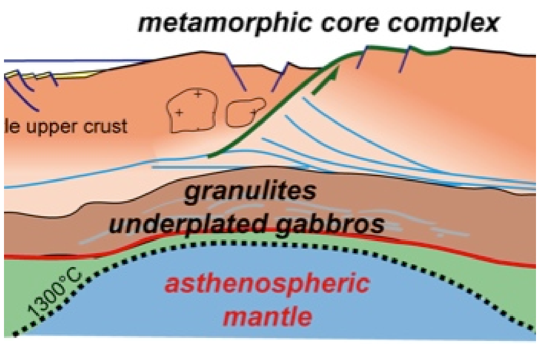
Polyphase deformation

The North Atlantic-Alpine Tethys rift systems are the result of **polyphase extensional cycles** and are controlled by **orogenic and post-orogenic inheritance**







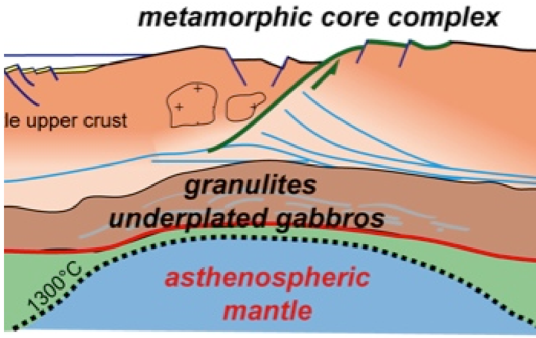


Permian
orogenic collapse

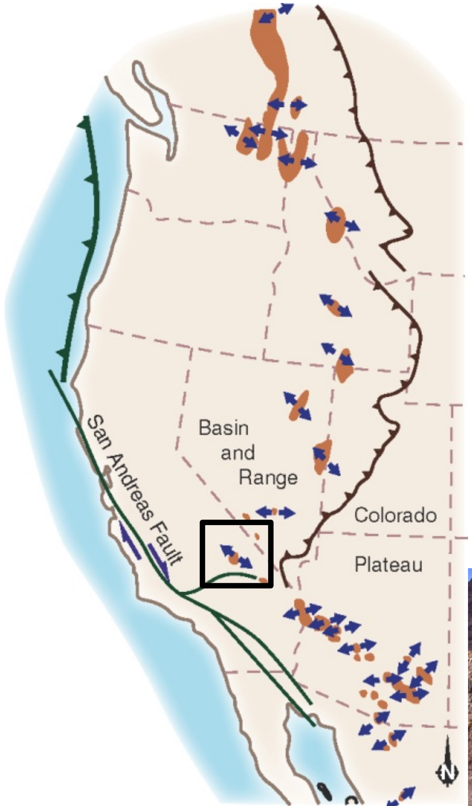
Triassic to E.Cretaceous
hyper-extension (migration)

E.Cret
breakup

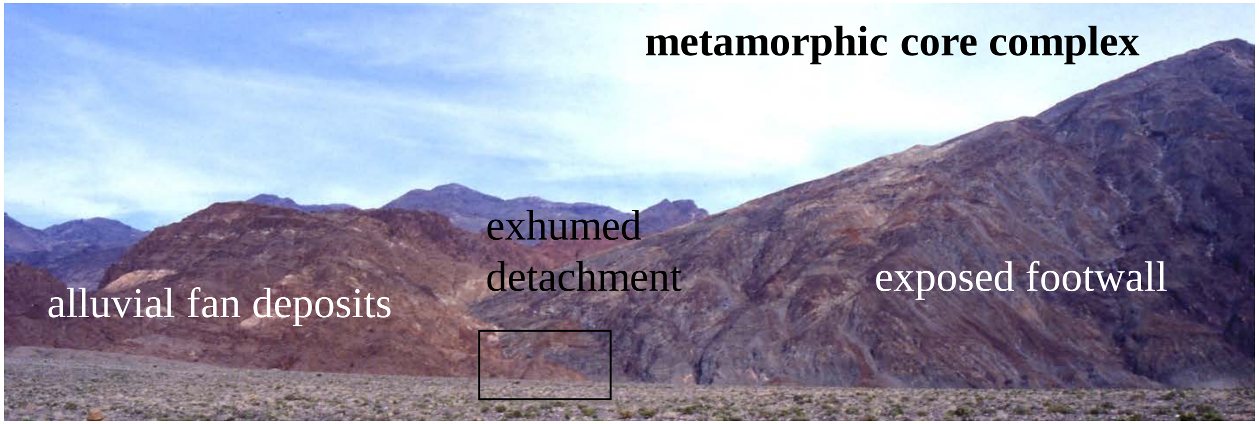
Orogenic collapse

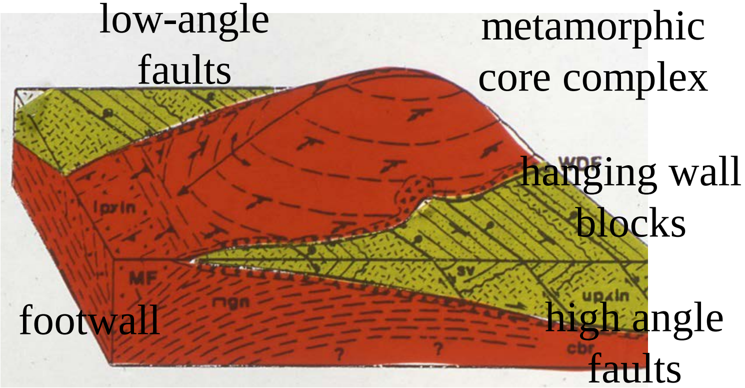


Location of the metamorphic core complexes in the North American Cordillera (Fossen 2010)



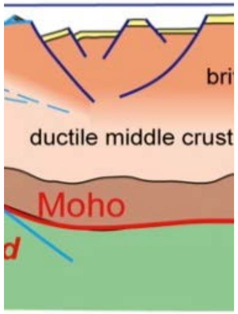
Death Valley (SW-USA)

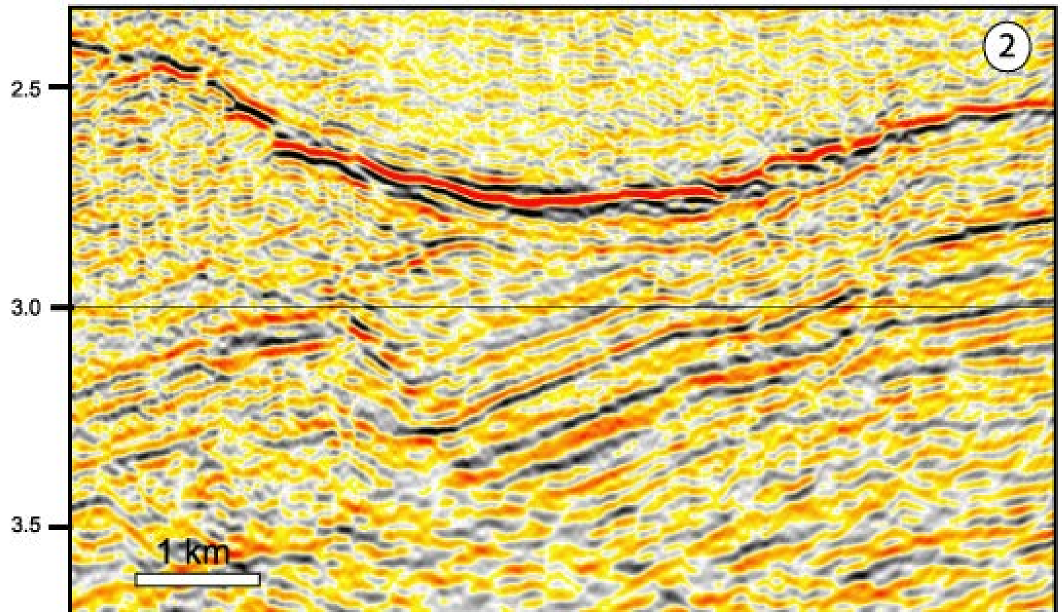




Low-β rifting

Satellite image of the North Sea





Cowie (2004)

- High angle normal fault
- Tilted blocks
- Mechanically decoupled deformation (on a crustal scale)

Low-β rifting

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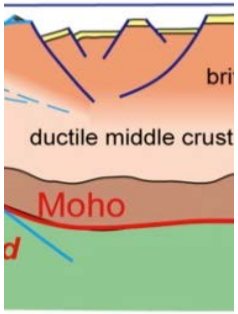
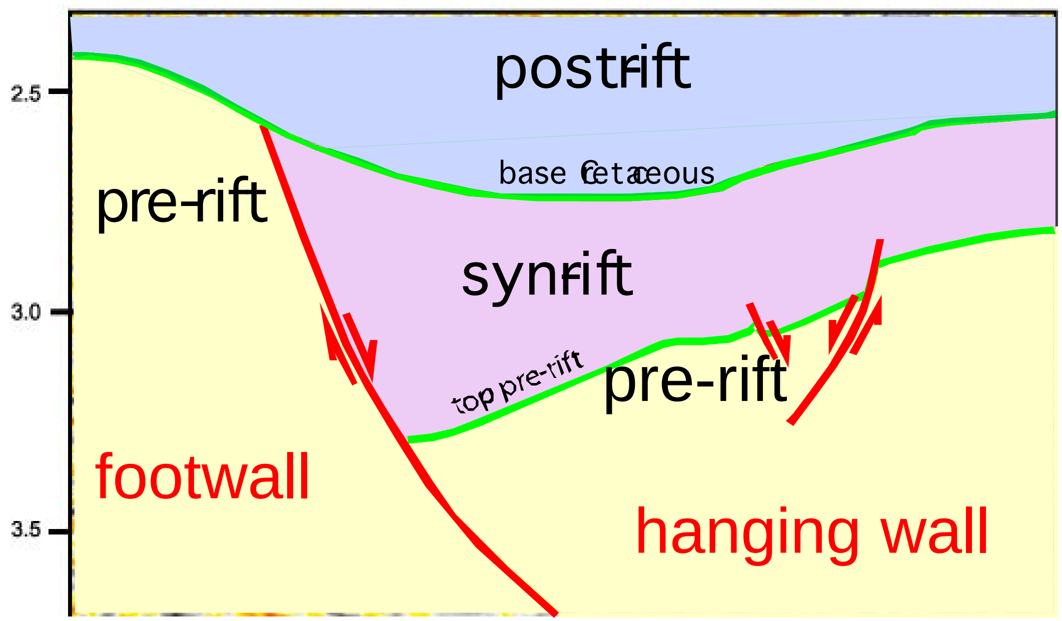


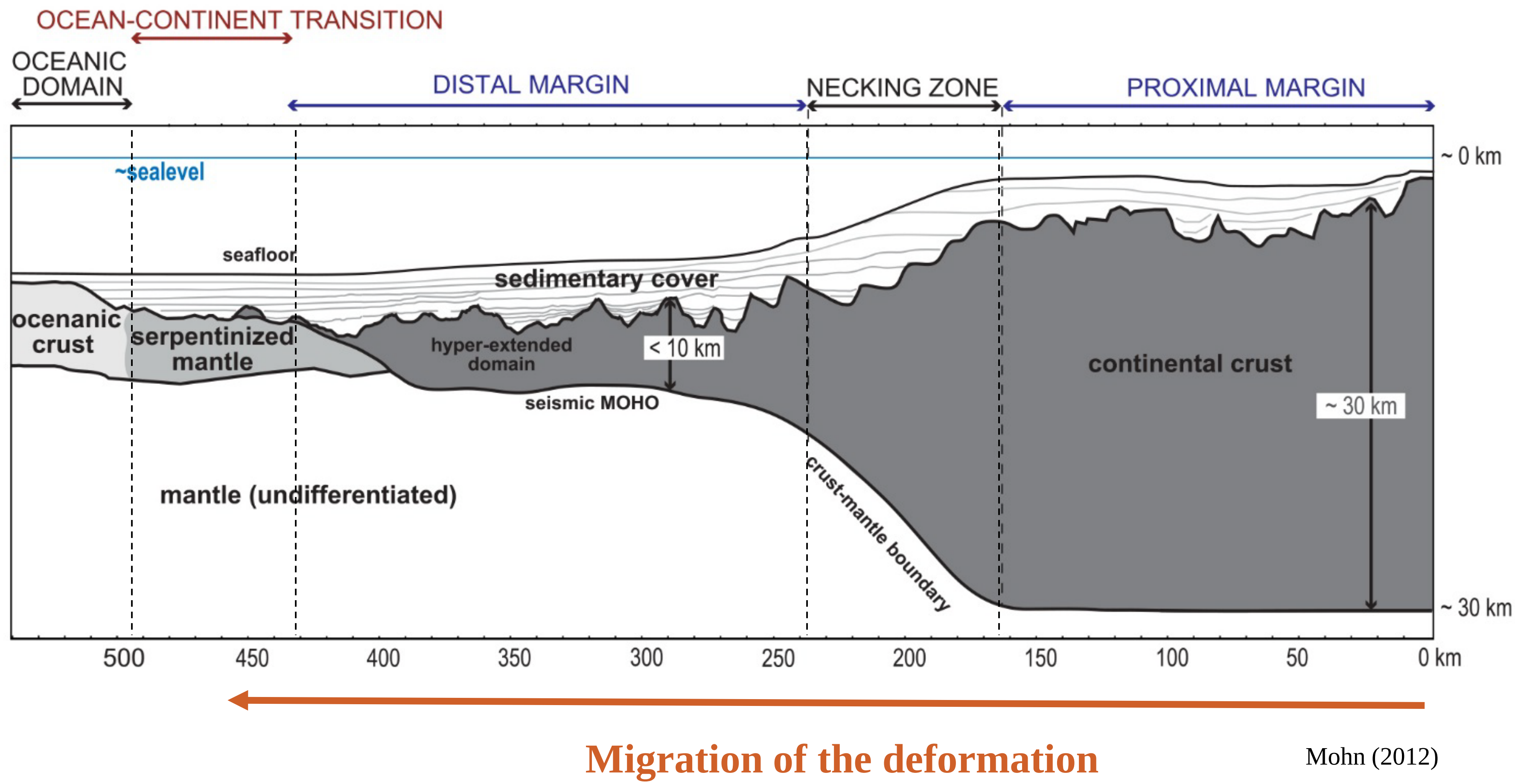


Cowie (2004)

- High angle normal fault
- Tilted blocks
- Mechanically decoupled deformation (on a crustal scale)

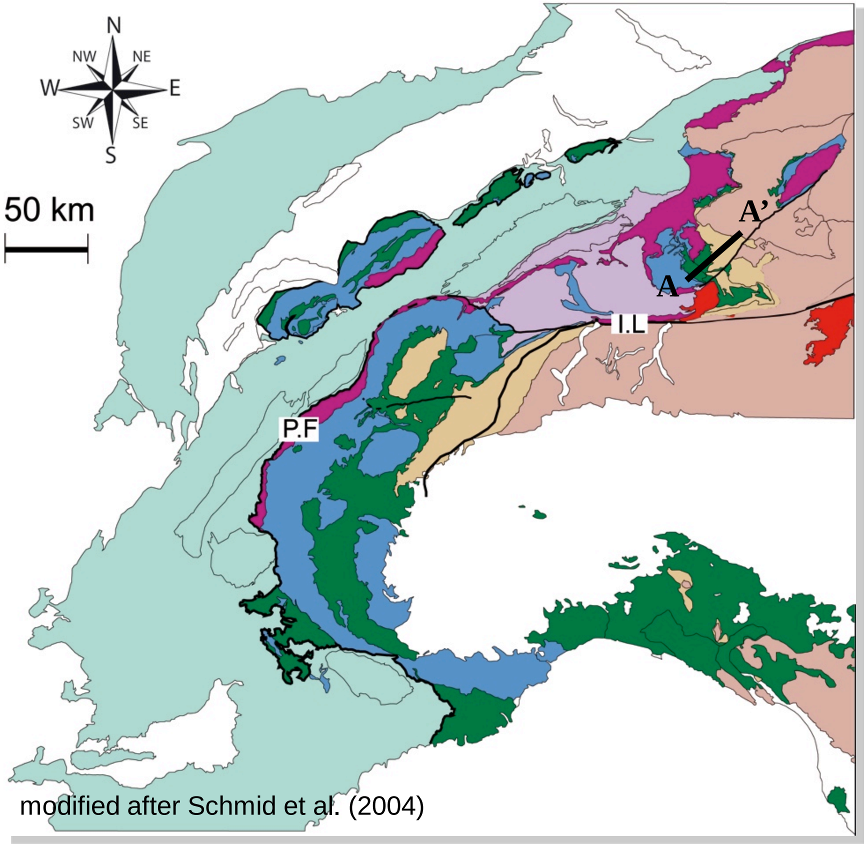
What about high-β rifting system ?

Idealized cross section across a rifted margin

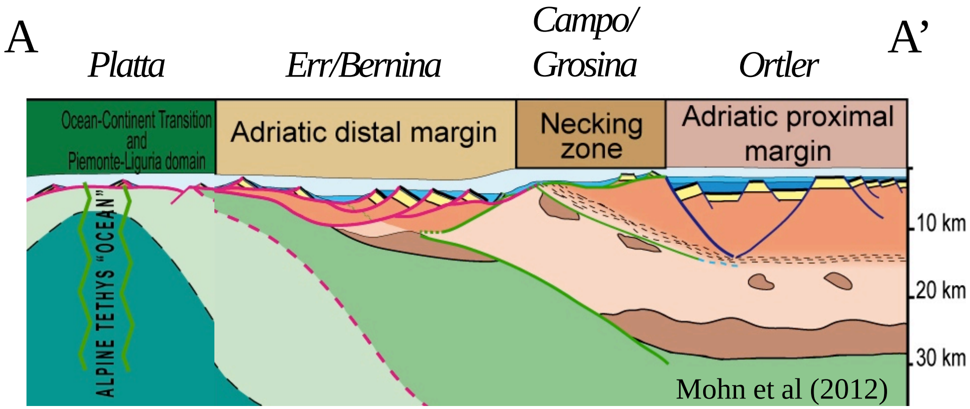


Mohn (2012)

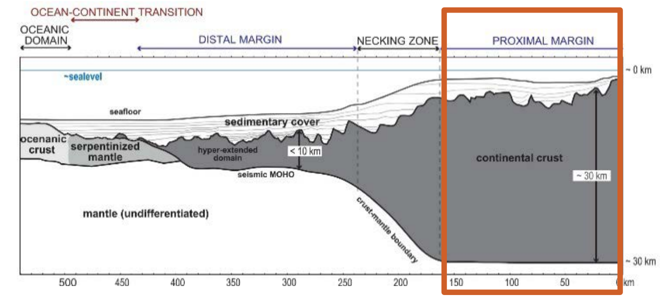
Observation in the Alps



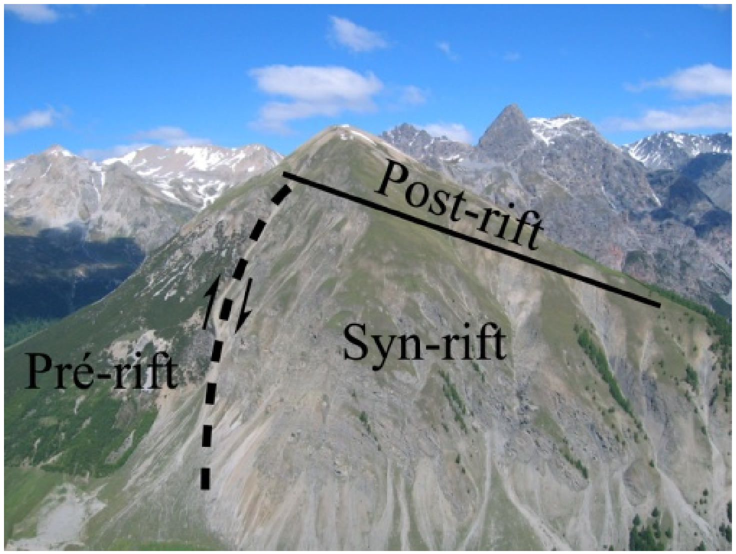
Reconstruction of the Alpine-Tethys hyper extended margin (Late Jurassic)



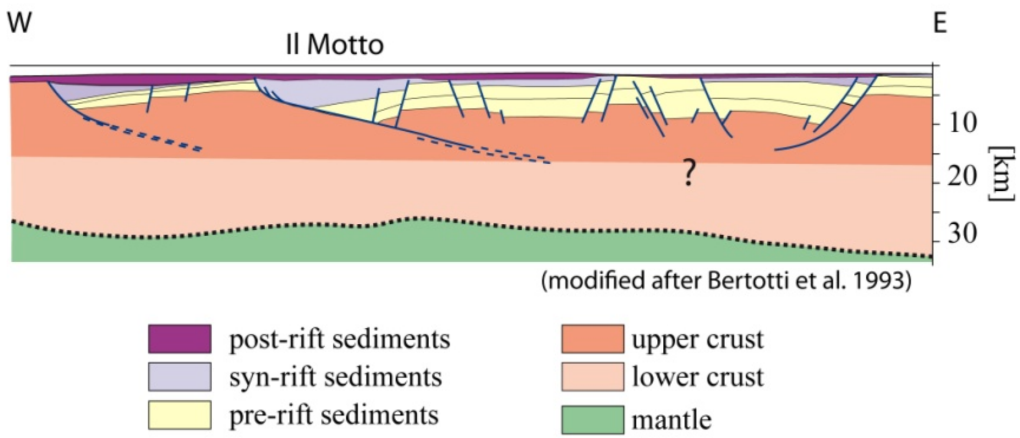
Observation in the Alps



Proximal margin :



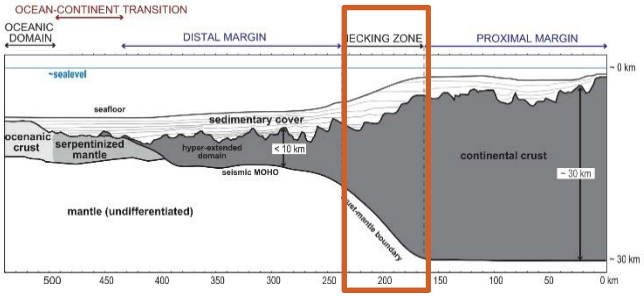
Upper Austroalpine unit



- Age of rifting > 180 Ma
- High angle normal fault
- Tilted blocks
- Exhumation limited to fault scarps
- Thick crust

Distributed deformation accommodated by normal faults in the upper crust (i.e Low-β rifting)

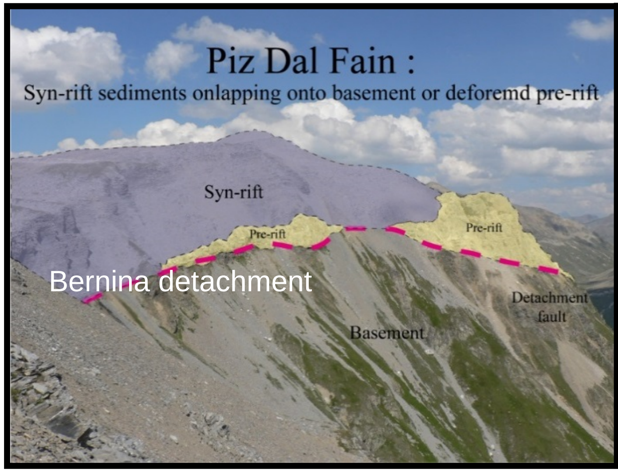
Observation in the Alps

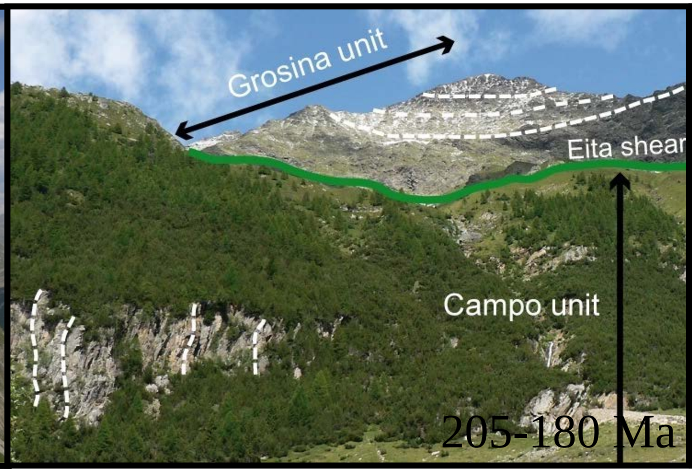


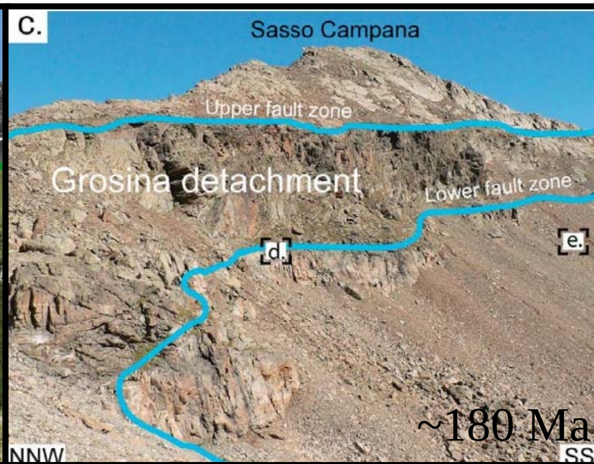
Necking zone :

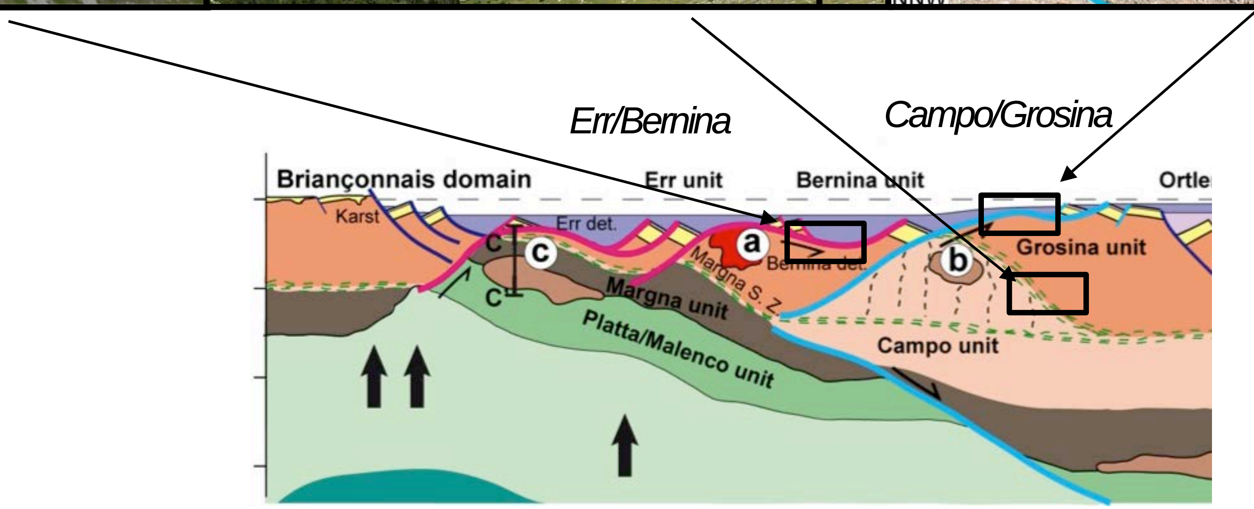
Top-basement detachment faults and extensional allochthons in the upper crust

Mylonitic shear one in the mid-lower crust



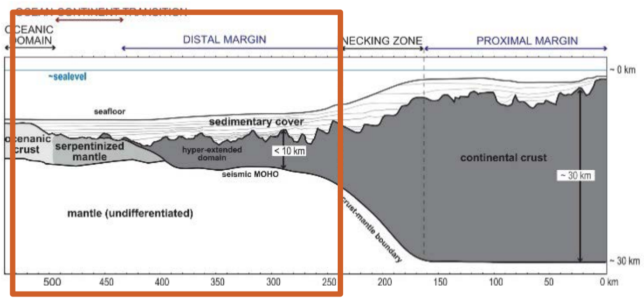






Mohn et al (2012)

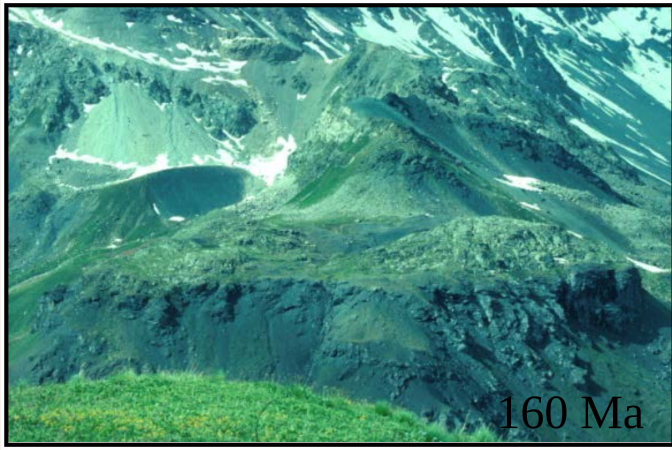
Observation in the Alps

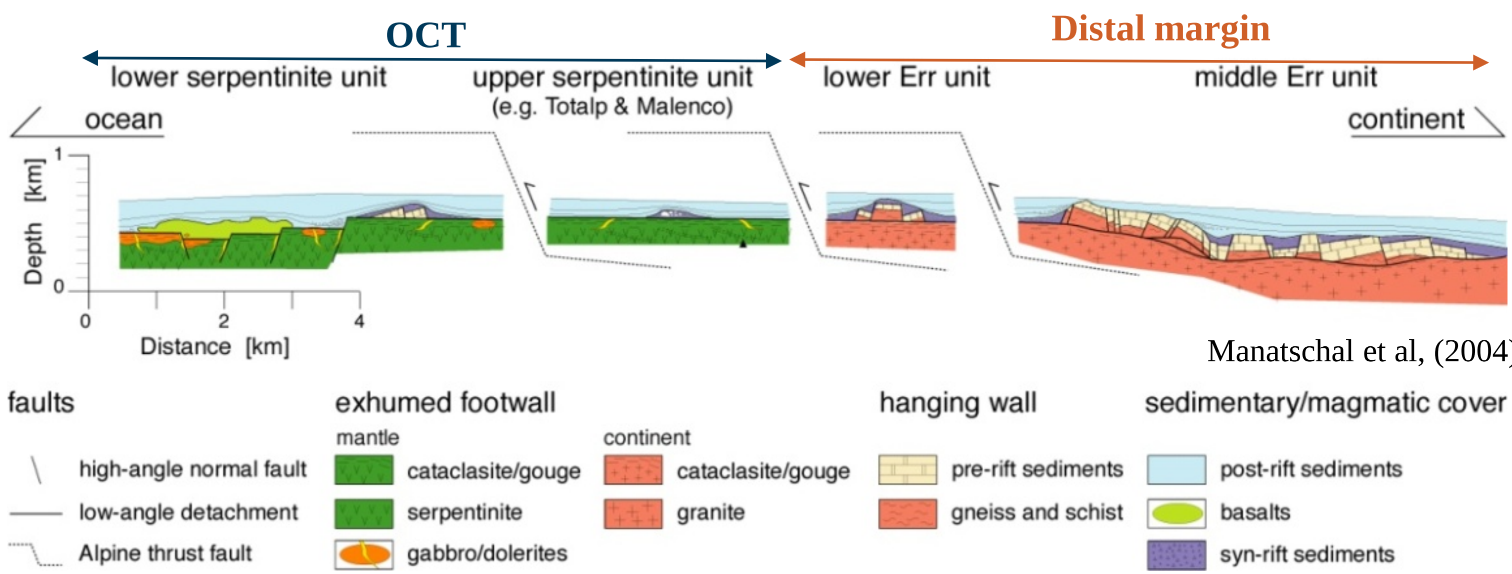


Distal margin and OCT :

Top-mantle overlain by continent-derived blocks

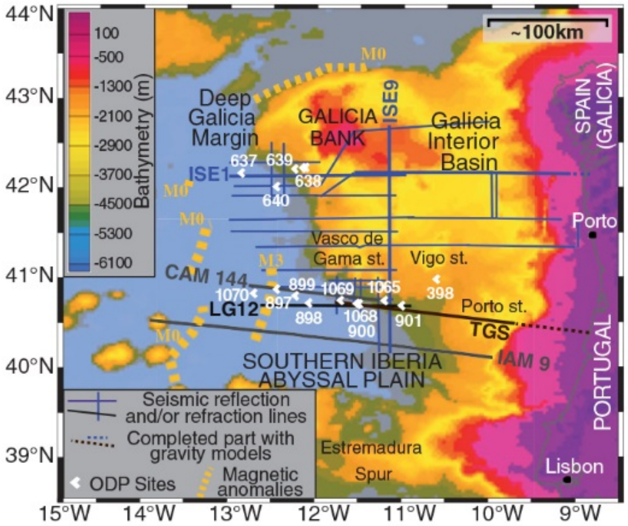
Extensional allochthon on a low-angle detachment fault



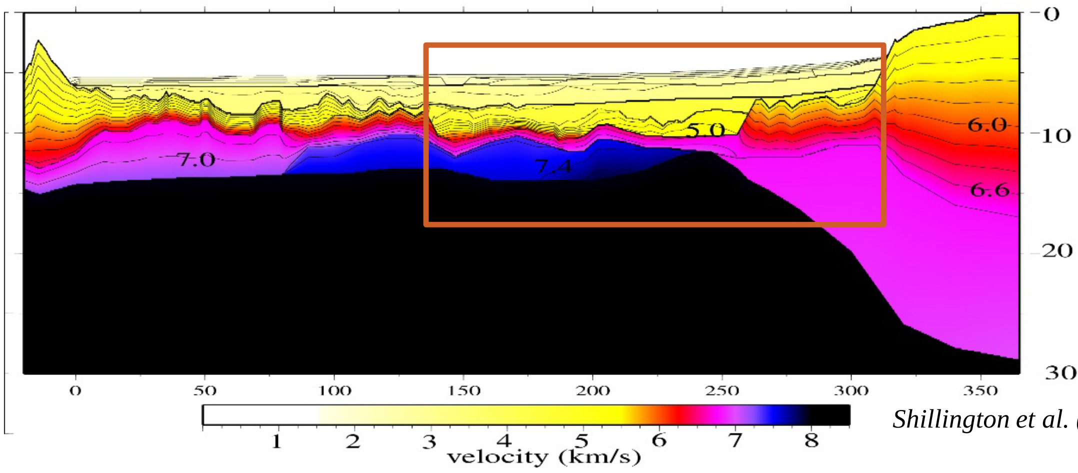


Manatschal et al, (2004)

Observation in Iberia margin

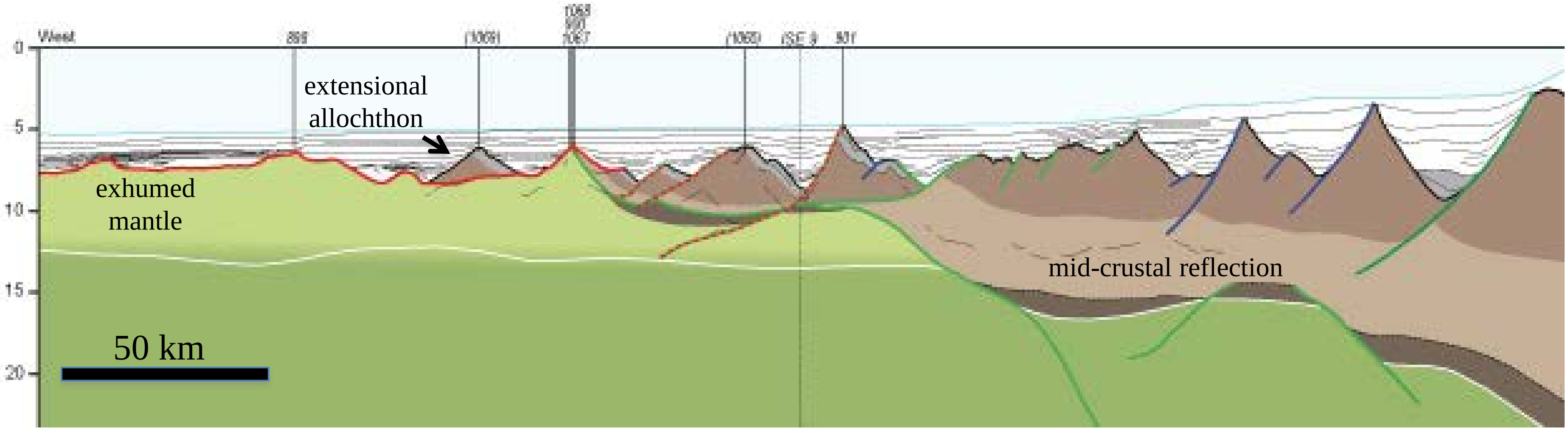


Sutra et al (2012)



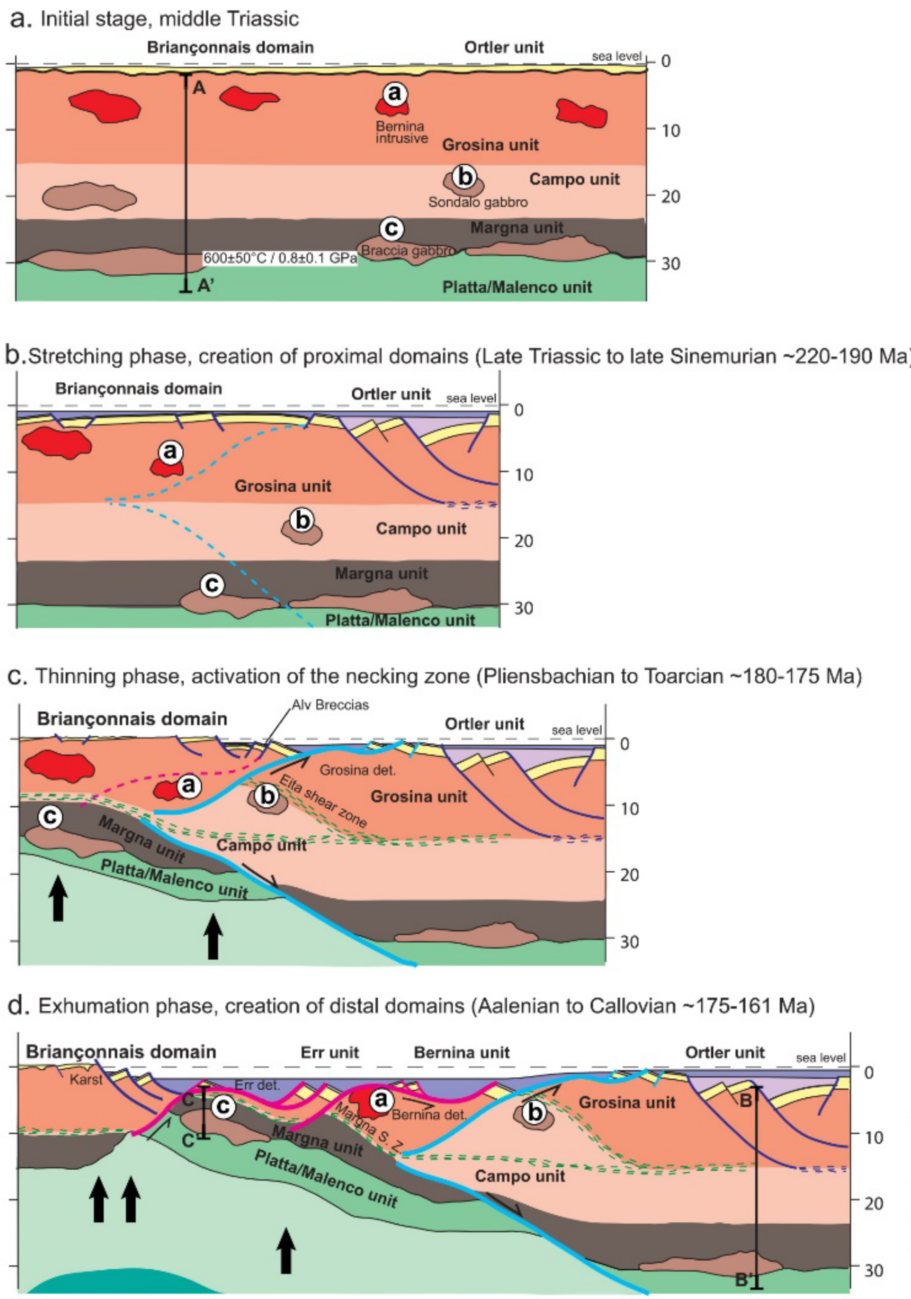
Shillington et al. (2006)

Iberia margin (seismic Line TGS and data from ODP Legs 147 and 173)



for reflection and refraction data see Chan et al, Affilado, Simon, Krawczyk and Alves; interpretation Sutra and Manatschal 2012

Conceptual model showing the evolution of lithospheric thinning as recorded in the Adriatic fossil margin margin



Mohn et al (2012)

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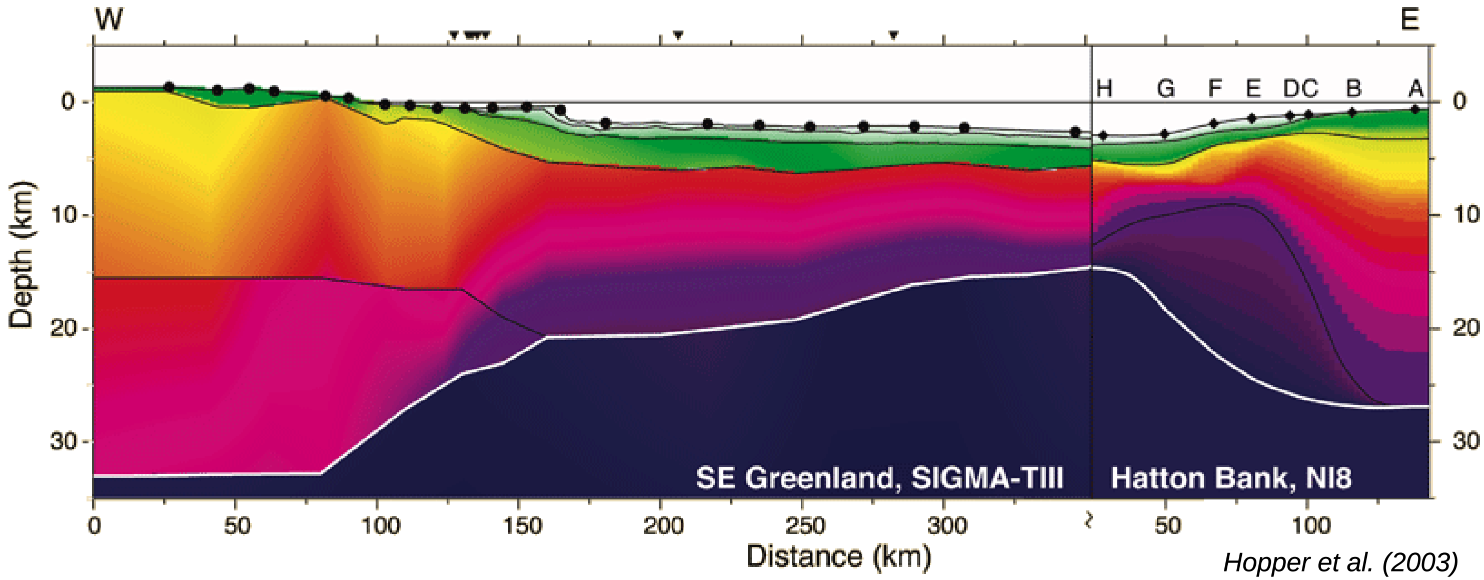
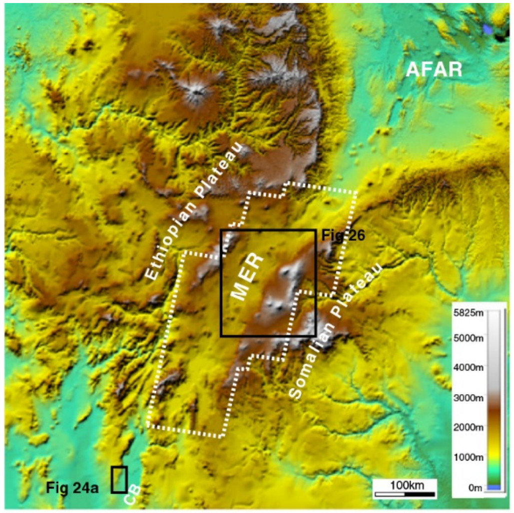
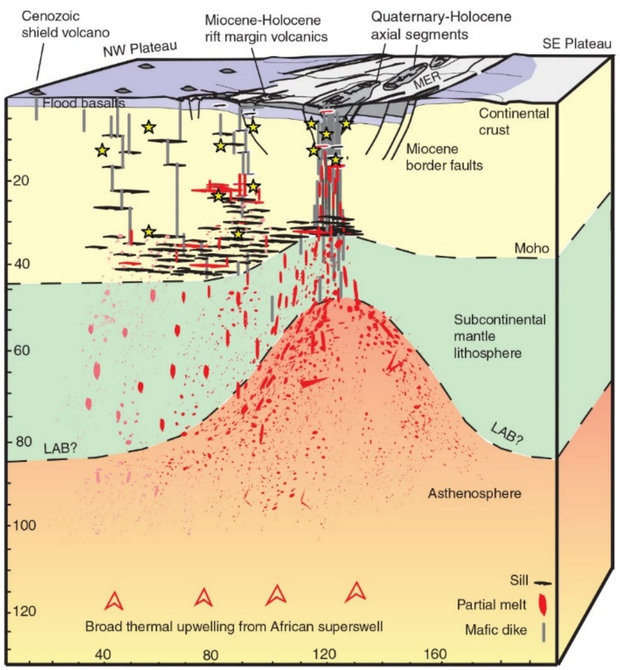


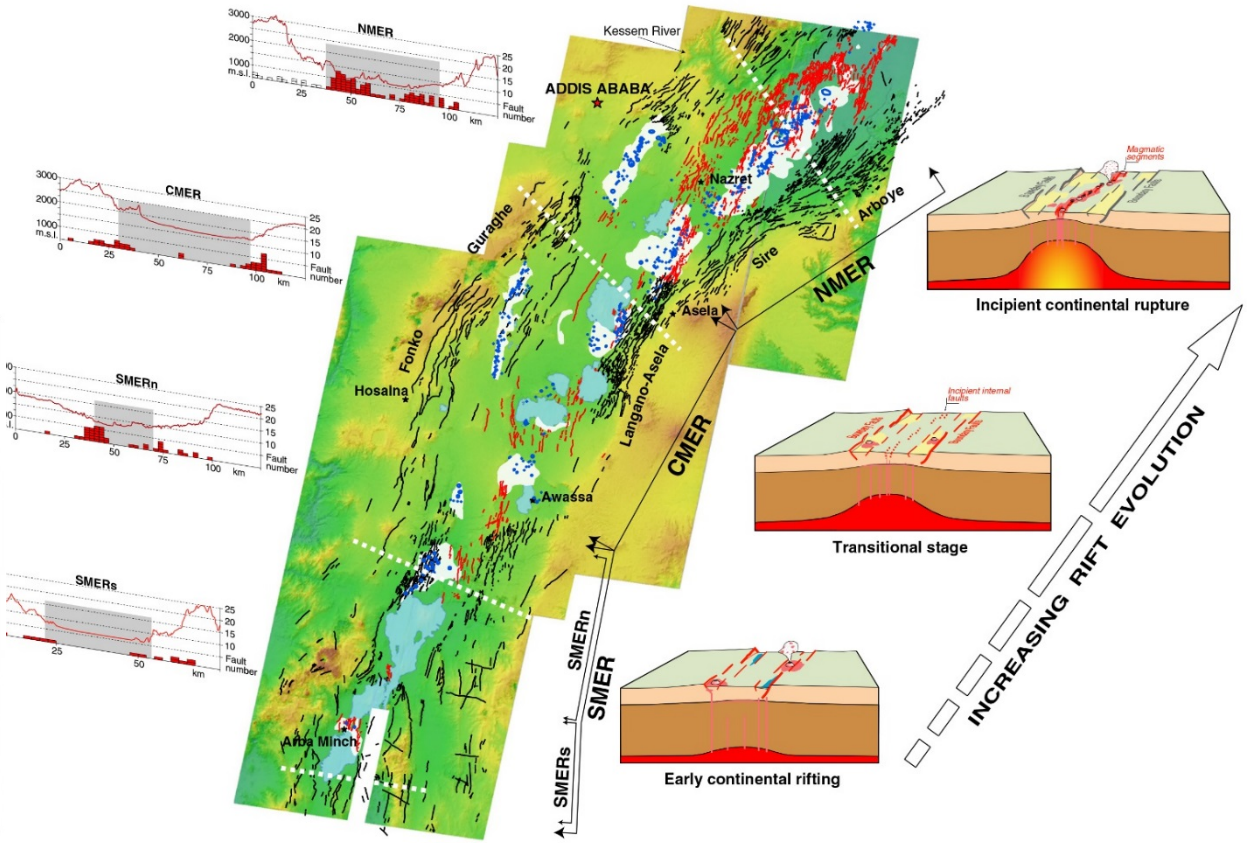
Hopper et al. (2003)

Evolution of the main Ethiopian rift





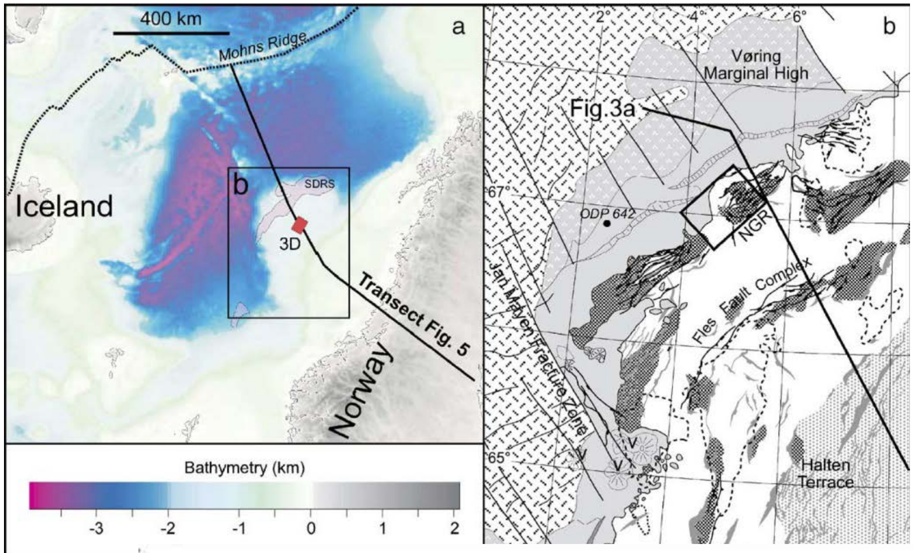
Variable evolution of the rifting process along the axis of the Main Ethiopian Rift



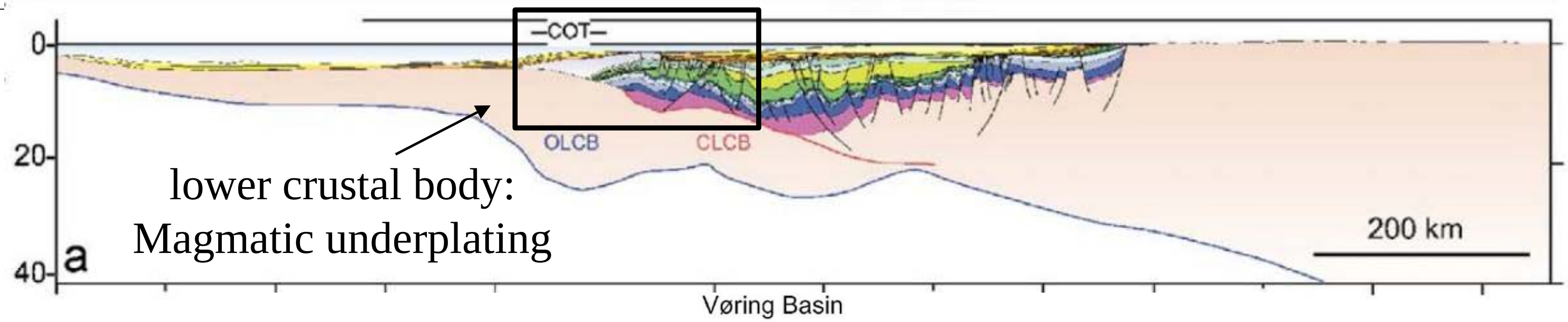
Bastow et al, (2011)

Corti, (2012)

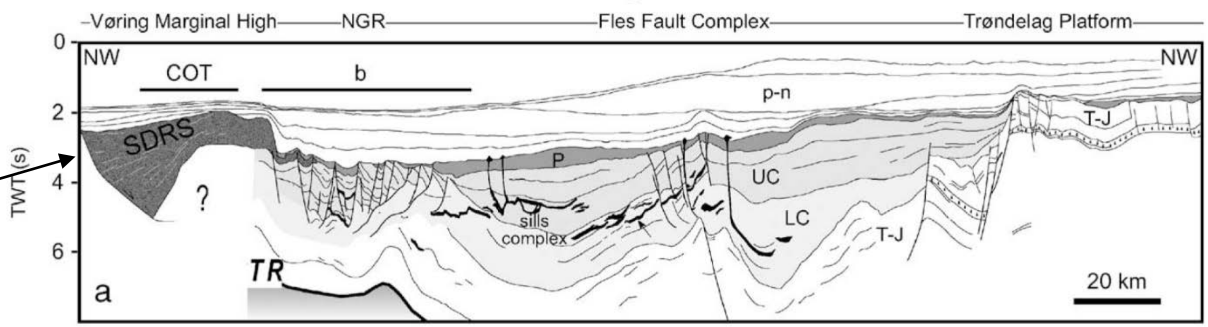
Model for the magma-rich Vøring margin (Norway)



Map of the mid-Norwegian margin and regional transect



lower crustal body: Magmatic underplating



Seaward dipping reflectors

Gernigon et al, (2005)

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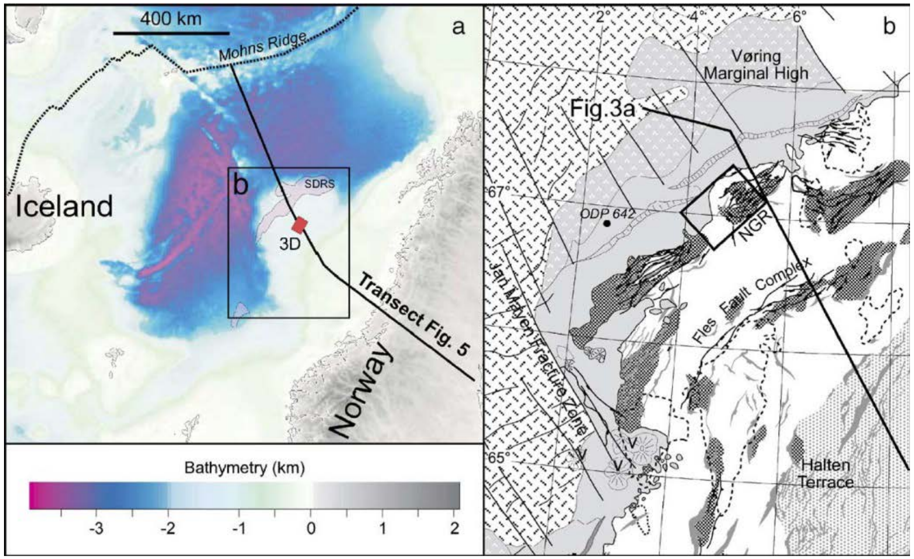
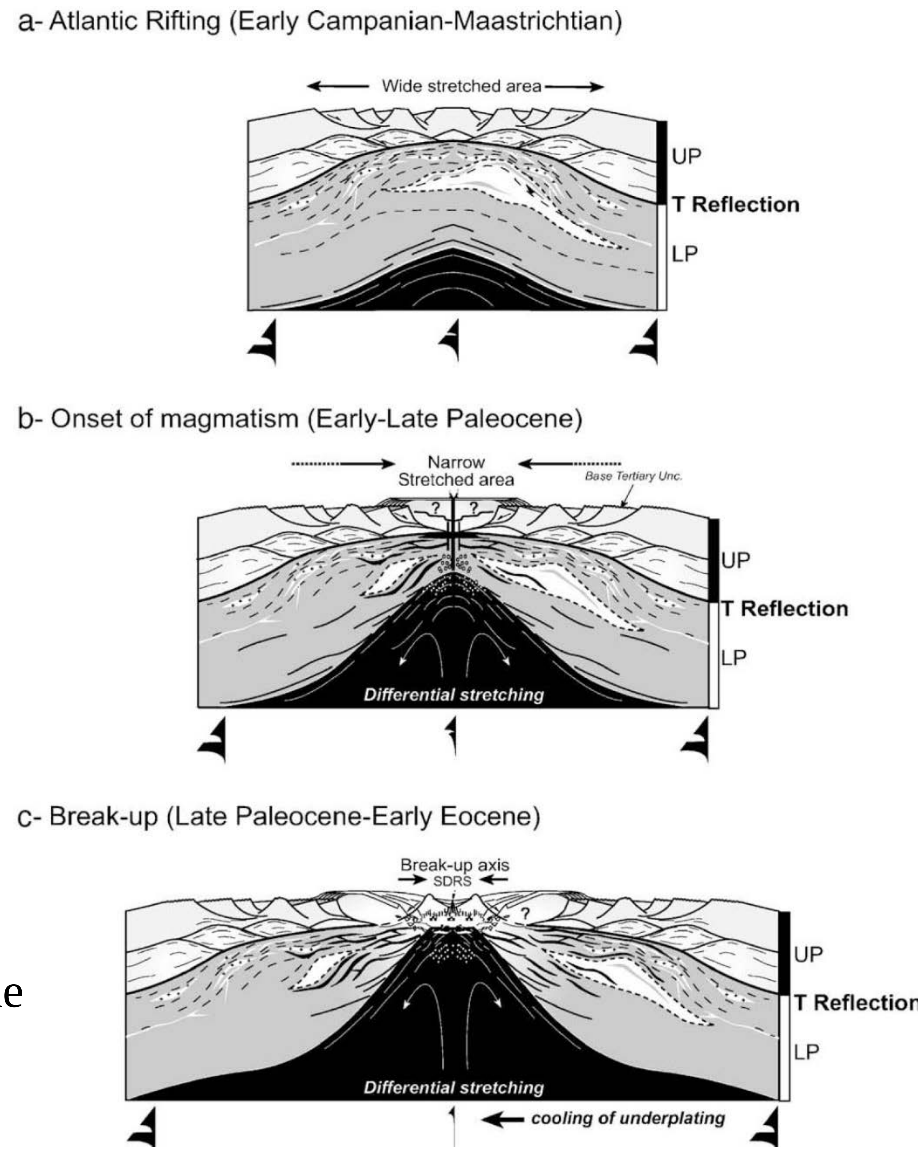
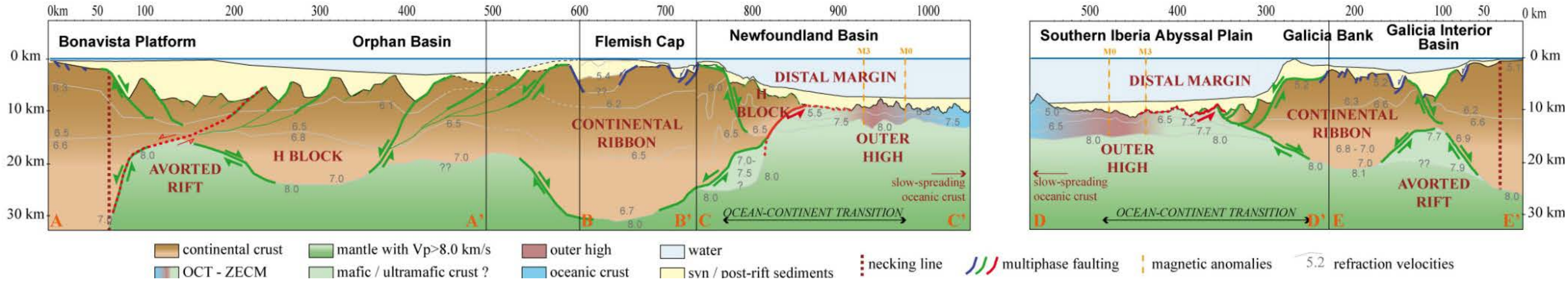




Early Campanian-Maastrichtian: Pre-break up rifting
Paleocene : onset of magmatism and focus of the deformation
Eocene : SDRS emplacement controlled by continentward detachment faults

Gernigon et al, (2005)

What is controlling the architecture of continental rifts and margins during and after breakup?

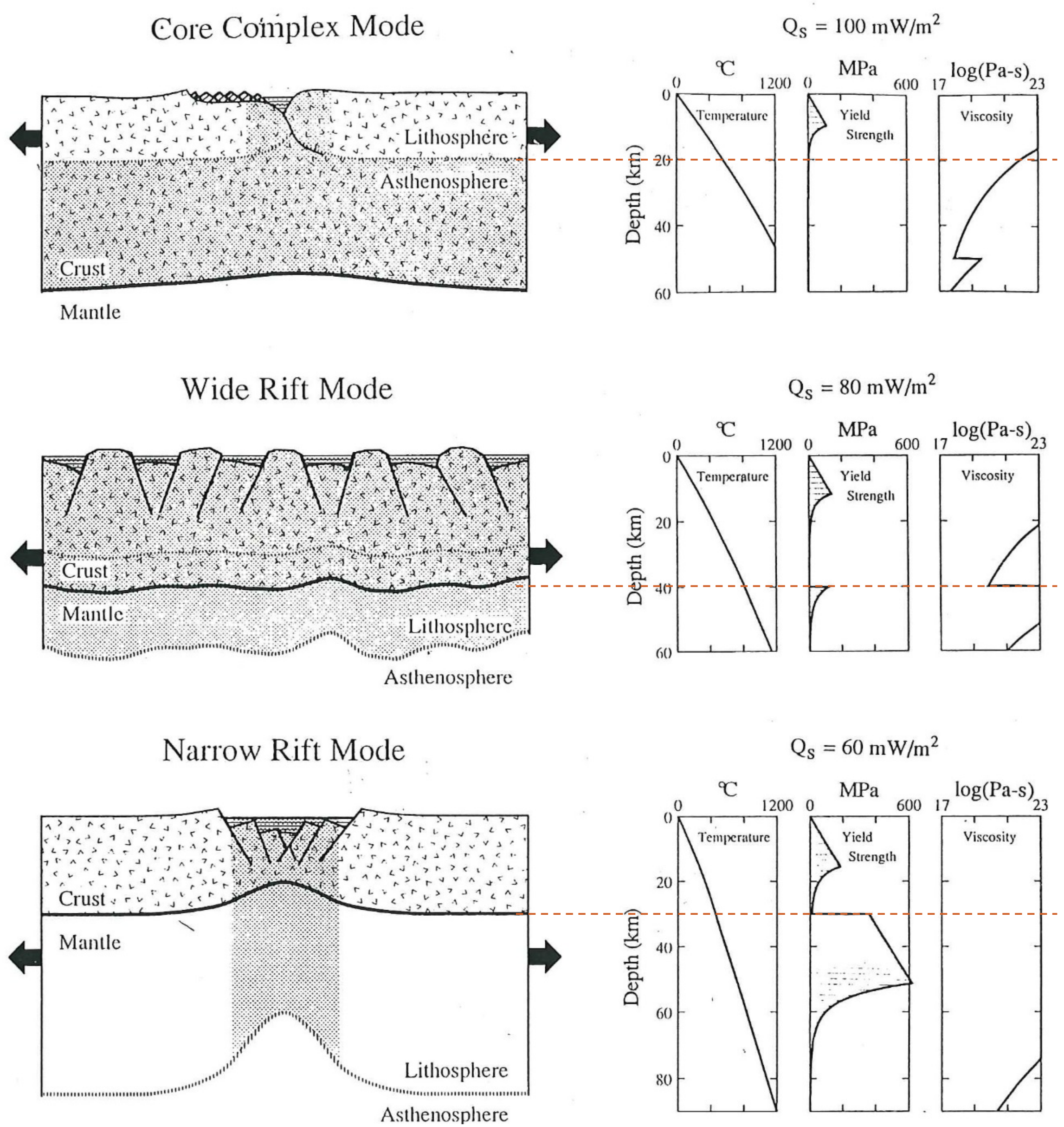


Peron-Pinvidic and Manatschal (2010)

Importance of rheology in modes of extension

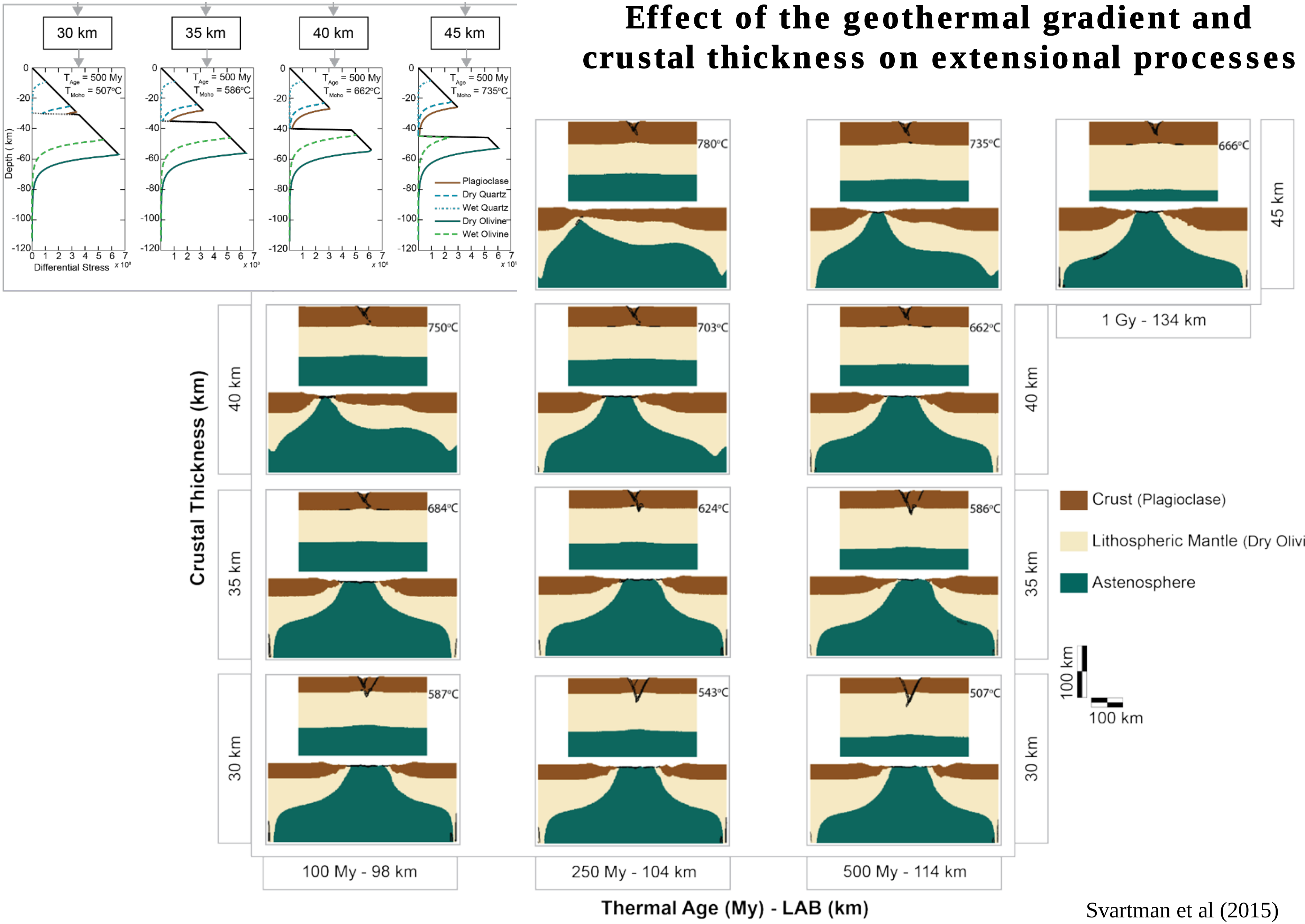
Rifting processes are mainly controlled by :

- Crustal thickness
- Thermal structure
- **Rheological stratification of the lithosphere**
- Strain rates



Buck (1991)

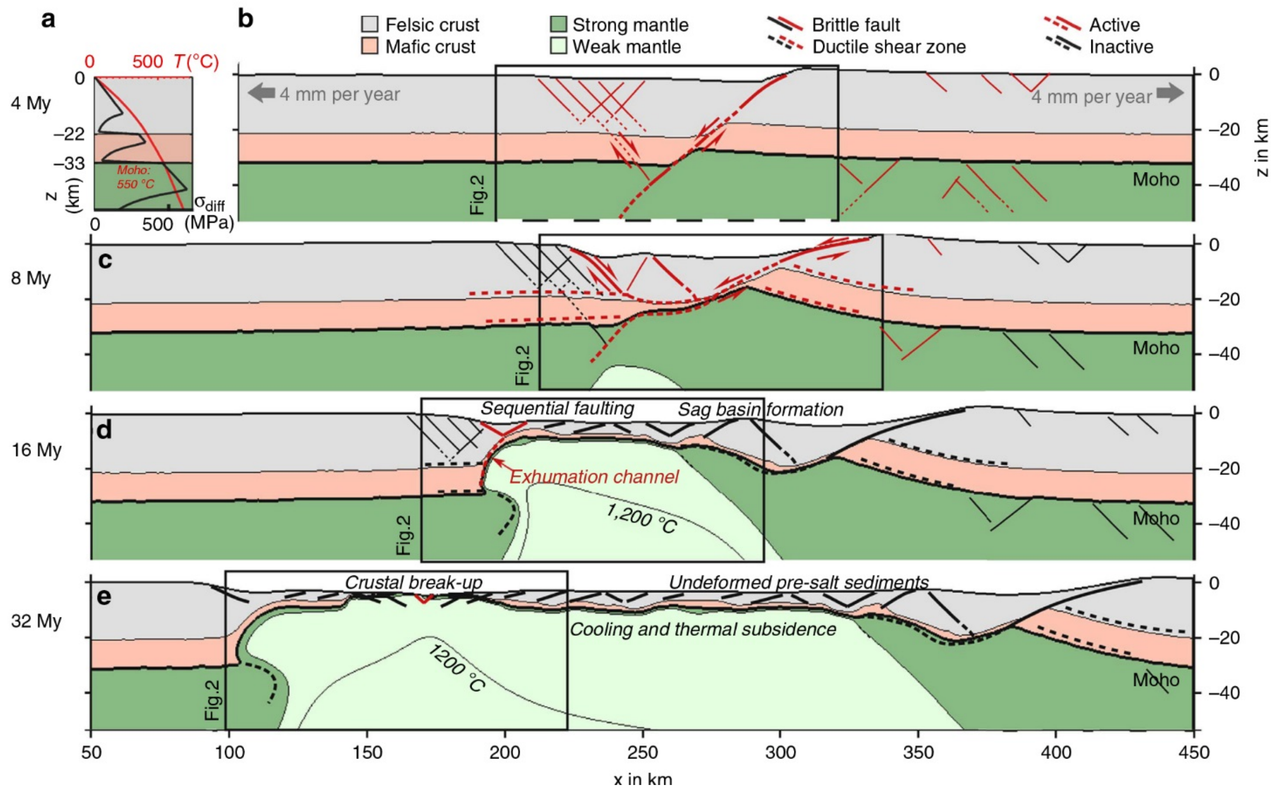
Effect of the geothermal gradient and crustal thickness on extensional processes

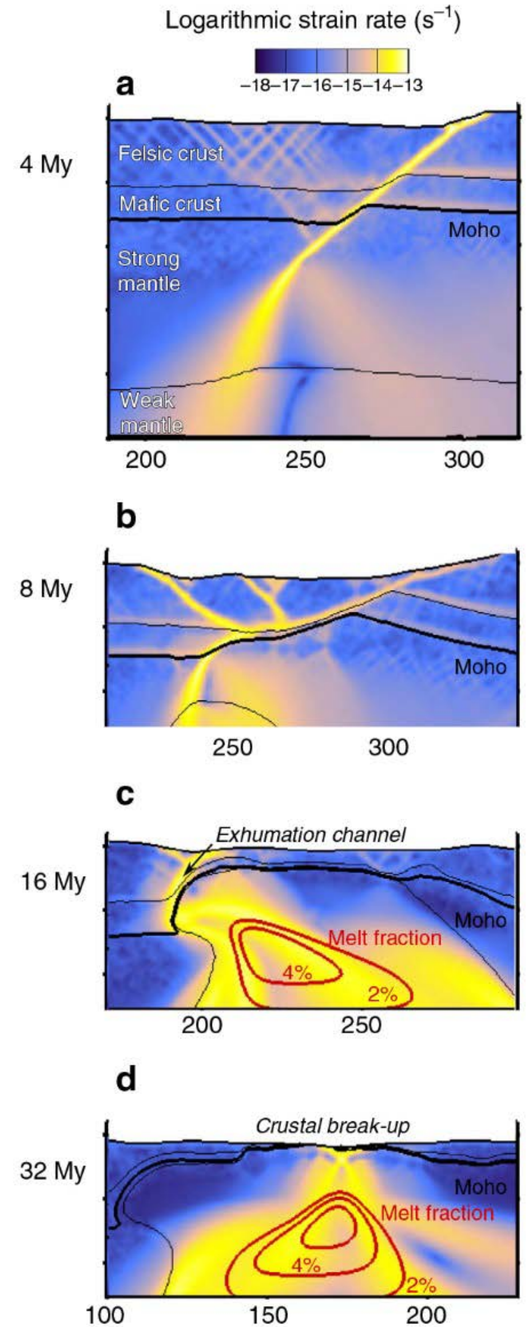


Svartman et al (2015)

Model of rift migration :

Importance of the mantle rheology

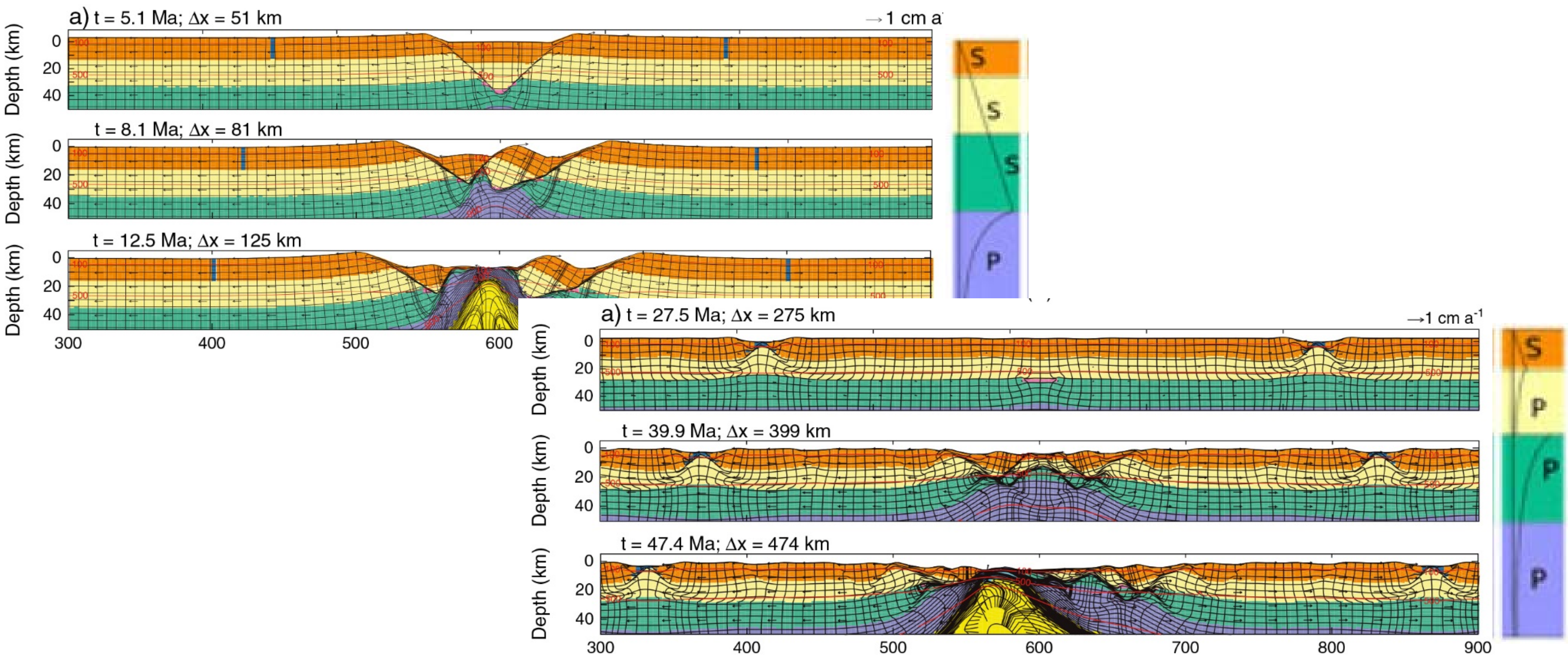




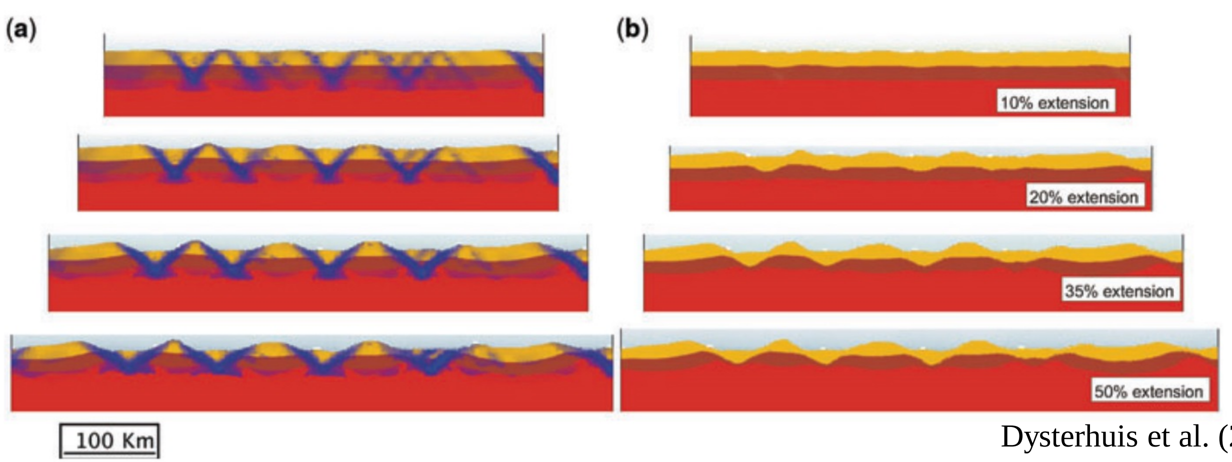
- Formation of asymmetric margins (i.e south atlantic)
- Shortlived, sequentially active normal faults that accomplish lateral rift migration and extreme thinning

Brune et al (2015)

Effect of structural inheritances



Chenin et al. (2013)



Depending of the rheology, structural inheritances can affect the stretching phase

Dysterhuis et al. (2007)

Conclusion

- How can we explain the exhumation of lower crustal and mantle rocks in high-β rifting?
    - ✓ Polyphase rifting and seaward migration of deformation
    - ✓ Decoupling in the middle crust during stretching and thinning
    - ✓ Late phase of exhumation
- How do magmatic intrusion and tectonic inheritances affect rifting processes ?
    - ✓ Magmatic processes → localization of the deformation (break up)
    - ✓ Tectonic inheritances → stretching phase
- What is controlling the architecture of continental rifts and margins during and after breakup?
    - ✓ Rheological stratification of the lithosphere
    - ✓ Compositional inheritances → anastomosing shear zone, boudinage

Thank you !