# Tectono-Magmatic Evolution of Atlantic Type Rifted Margins

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**Magmatic Rifting & Active Volcanism Conference**
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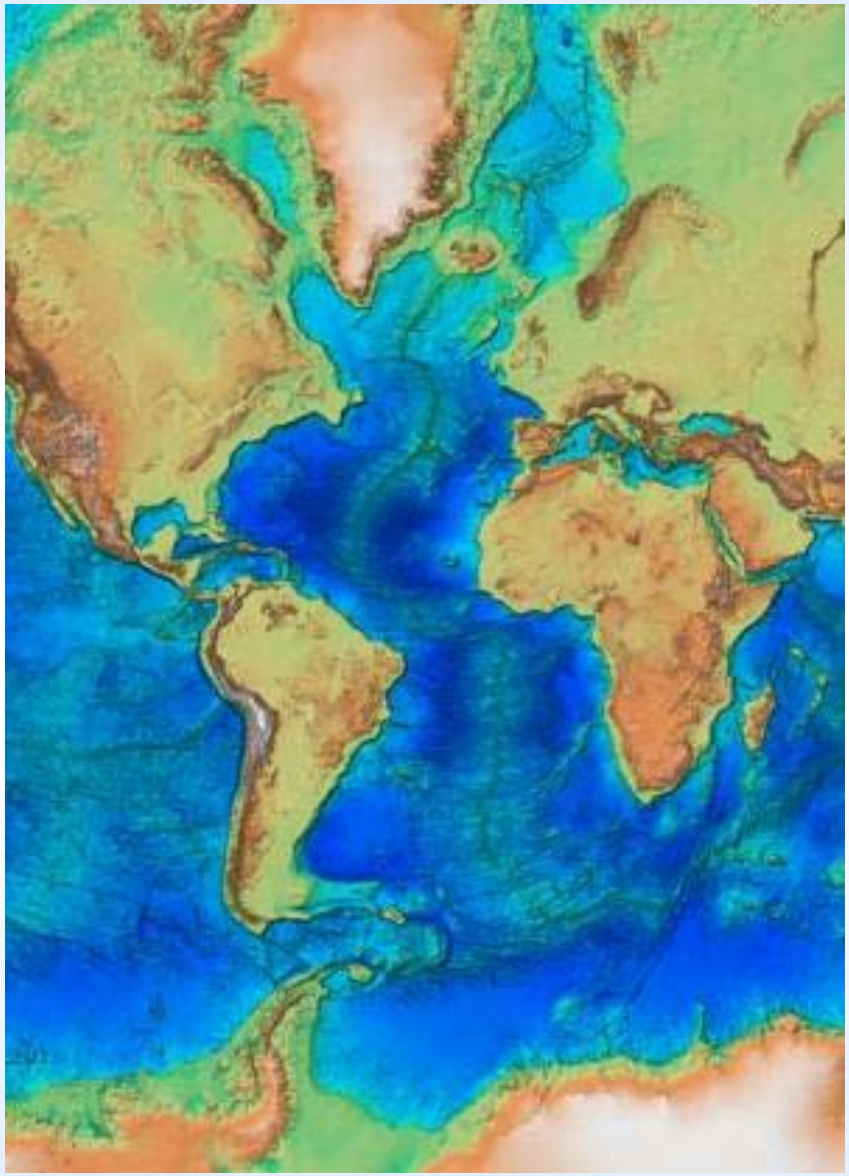
*Image: GeopoliticusChild by Salvador DALI*



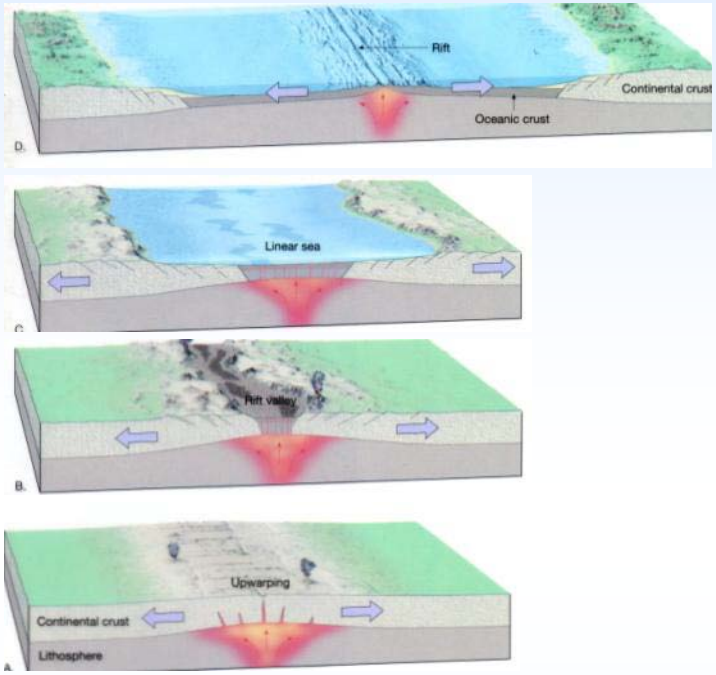
Major questions addressed in this presentation:

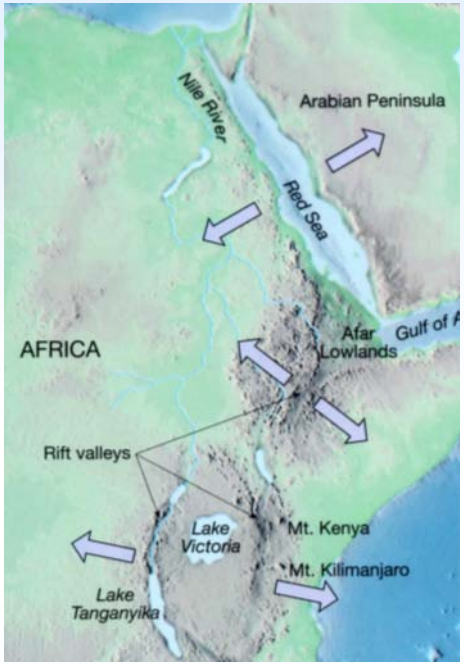
- ***What makes plates so weak that they can break?***
- ***Where, when and how does continental breakup occur?***
- ***What are the processes controlling rifting, continental breakup and seafloor spreading?***

# The “text book” rifted margin

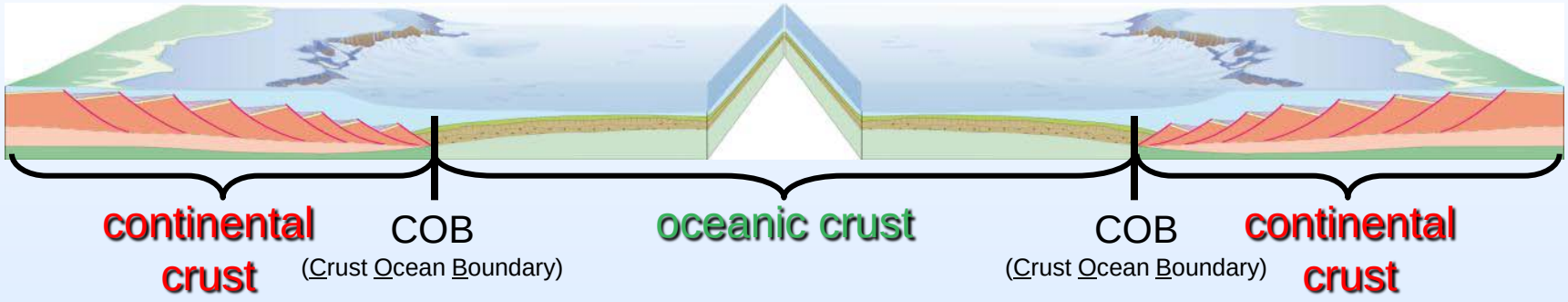
*A model inspired from the E-African and Red Sea rift system*

evolution of a rift system

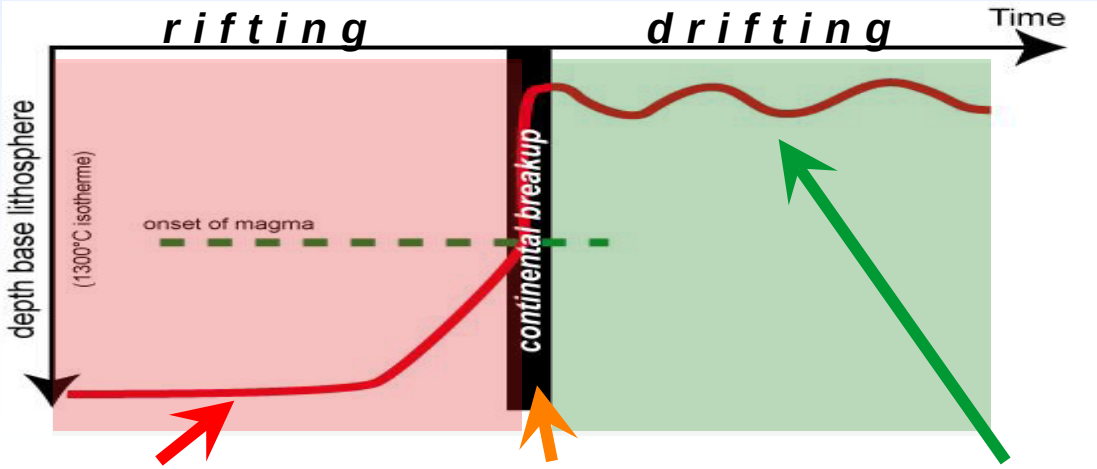



## Architecture of the “text book” rifted margin



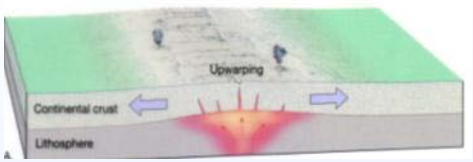
# *Evolution and architecture of rifted margins*
# *"the classical rift model"*

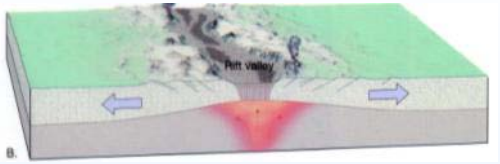


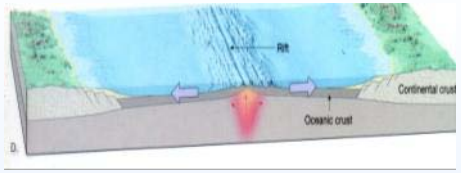

**onset of rifting**
inherited, equilibrated continental lithosphere

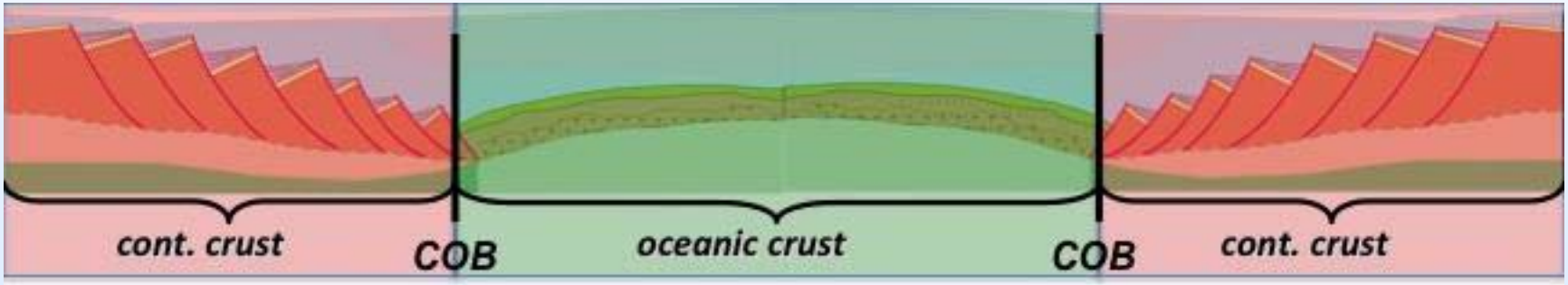
**onset of melting**
*Decompression melting*

**seafloor spreading**
controlled by active heat balance

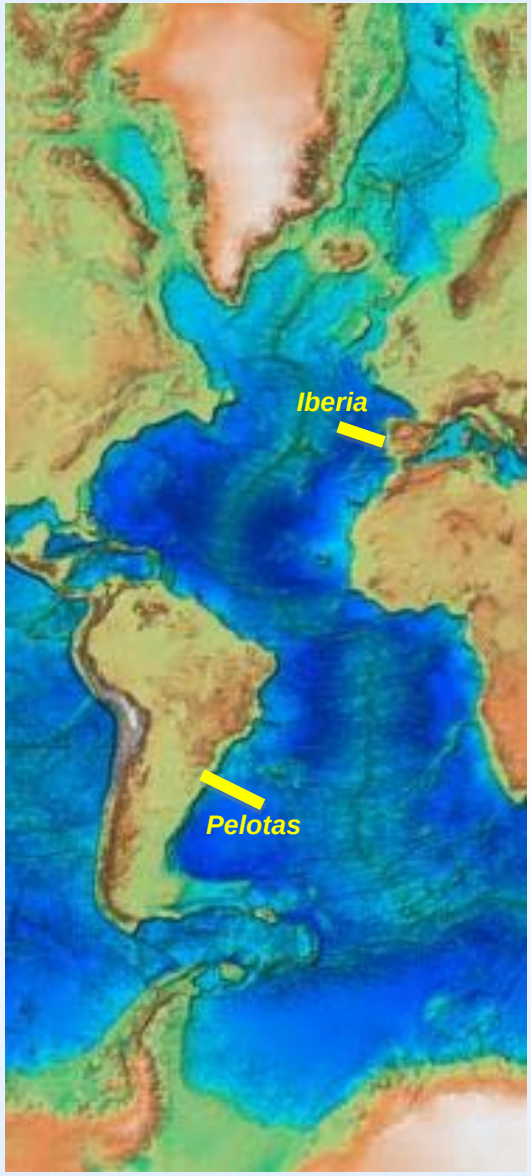


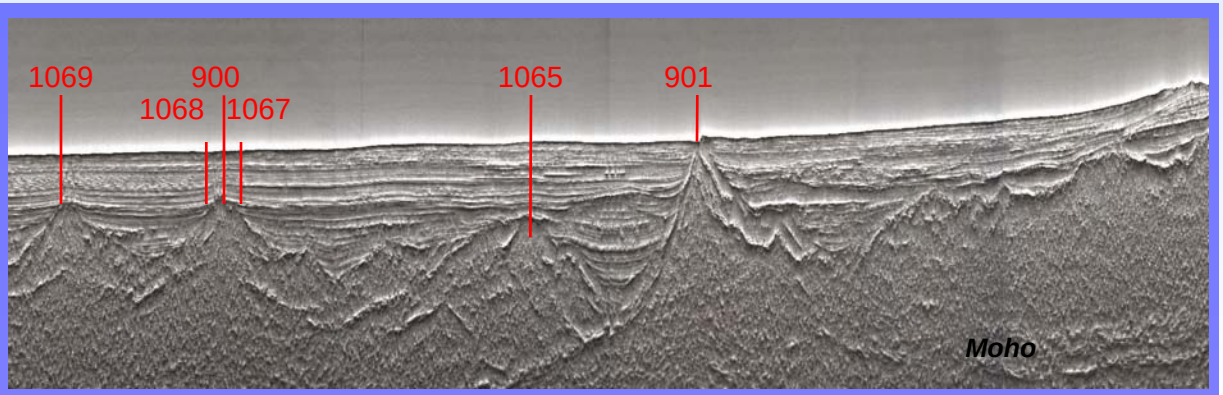



# The "real" view

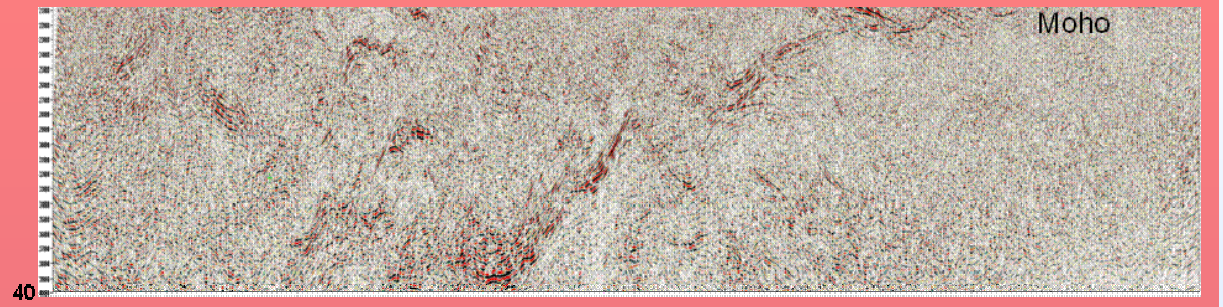



***"non"- magmatic***



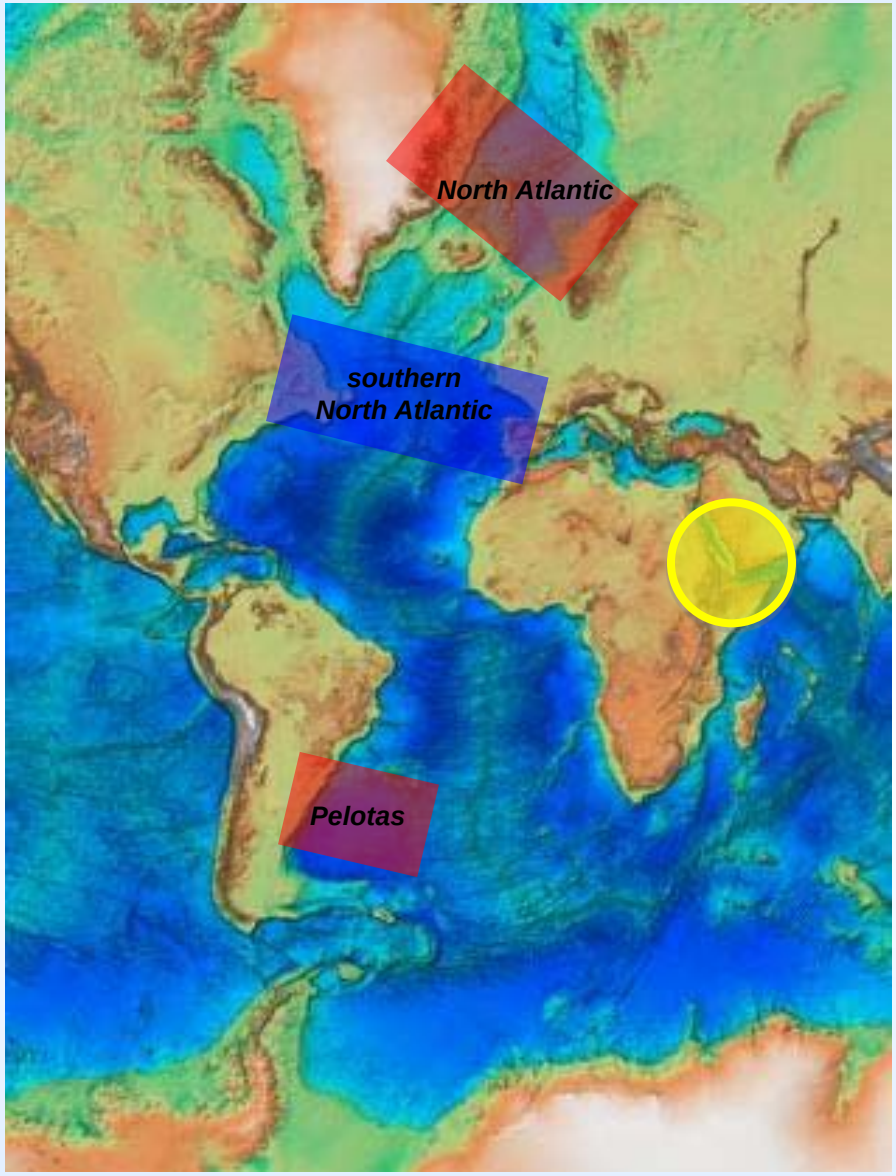

***TGS reflection seismic line*** *(migration by Petrobras), with permission of Petrobras)*

***magmatic***




***PelotasSPAN (ION-GXT)*** *(taken from their homepage)*

***High-quality reflection seismic data show a divergent style of margin architecture in which quantity and distribution of syn-rift magmatism and fault structures are the most variable features***




## *Major question*

*do rifted margins operate as either magmatic or non-magmatic or do tectonic and magmatic processes interact before, during and after continental breakup?*

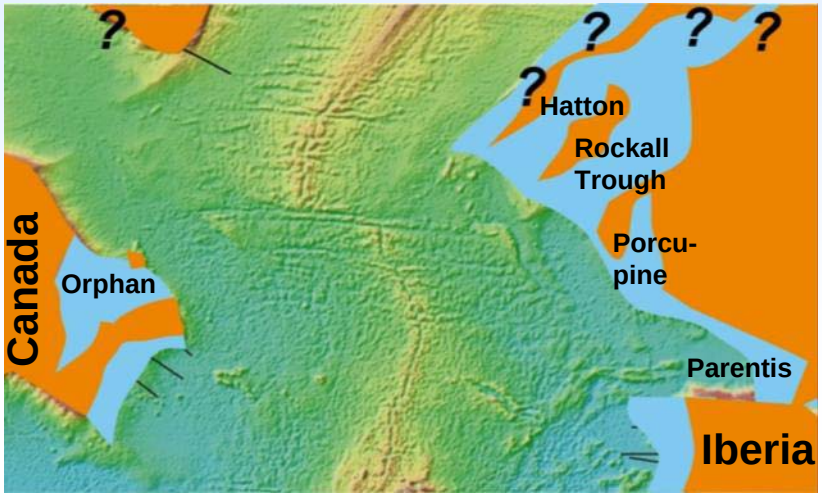
## *In my presentation*

*discuss the structural and magmatic evolution of so called "magma-rich" and "magma-poor" rifted margins using examples from the South and North Atlantic*

***and***

***I will try to apply the lesson we learned in the Atlantic to the Afar-system***

# The southern North Atlantic rift-system




little or not extended crust

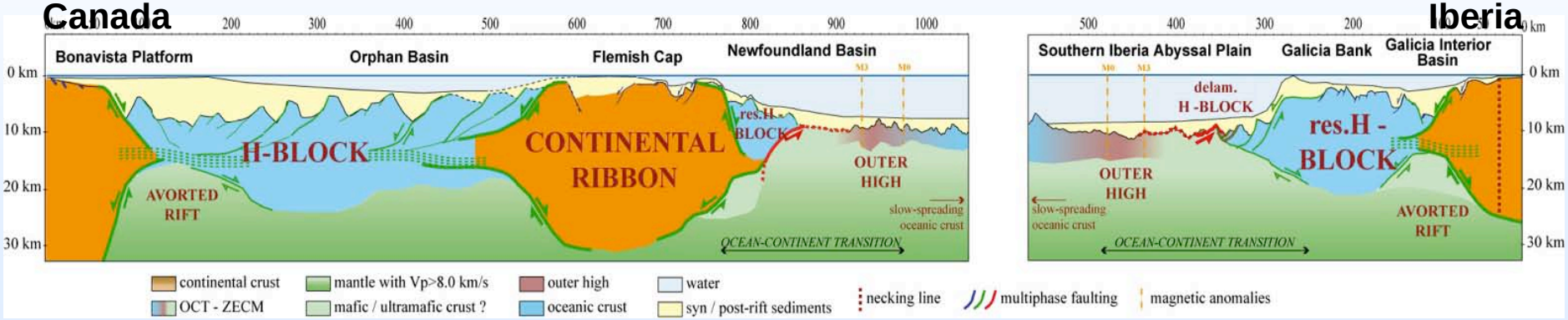
hyper-extended crust

oceanic crust

## *Major observations*

- Three major crustal domains
- Complex, 3D and polyphase rift structures
- Locale occurrence of aborted rifts floored by lower crust and/or mantle rocks associated with MORB magmatism
- Occurrence of continental ribbons, H-blocks, extensional allochthons and outer highs

## *Section through the Orphan-Newfoundland-Iberia rift system*




*modified after Péron-Pinvidic and Manatschal (2010)*

# Mantle rocks in the OCT

Drilled mantle lithologies

ODP Legs 149, 173 and 210

- *Very heterogeneous and strongly serpentinized*
- *Always deformed at the top (cataclasites and gouges)*

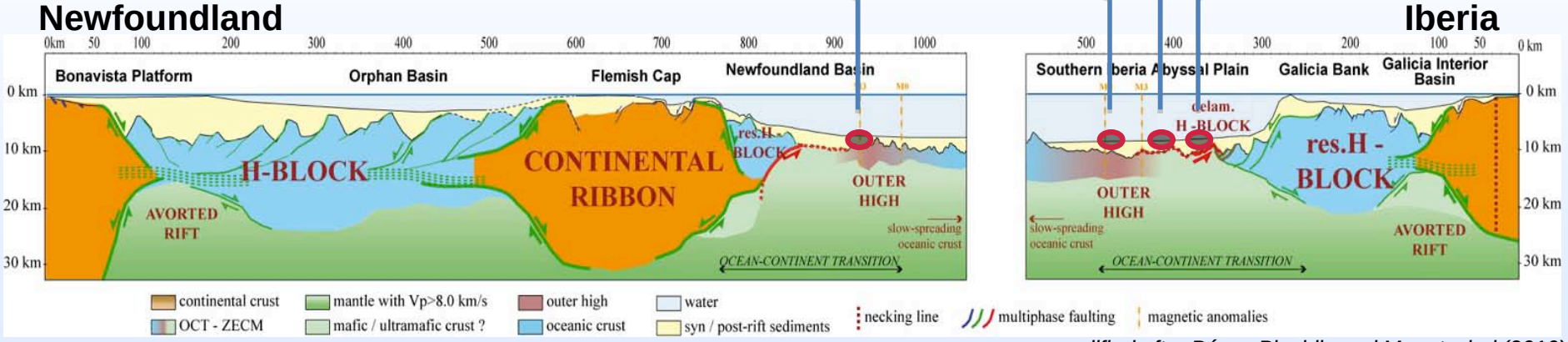
***But only highs have been drilled!**

*Site 1277*

*Site 1070*

*Site 897C*

*Site 1068*

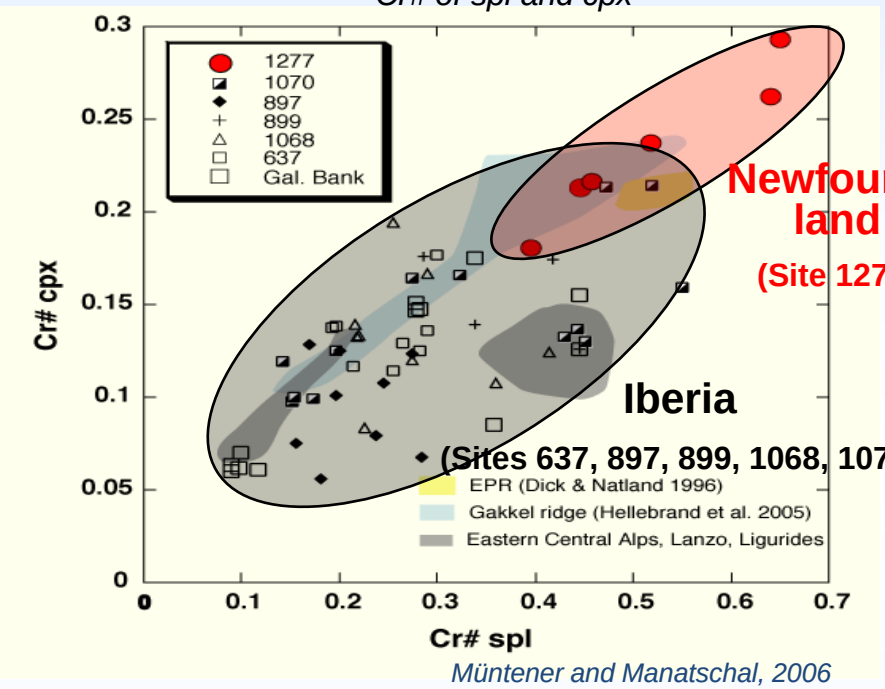



*modified after Péron-Pinvidic and Manatschal (2010)*

# Composition of the mantle rocks

## Chemistry of mantle rocks

*Cr# of spl and cpx*

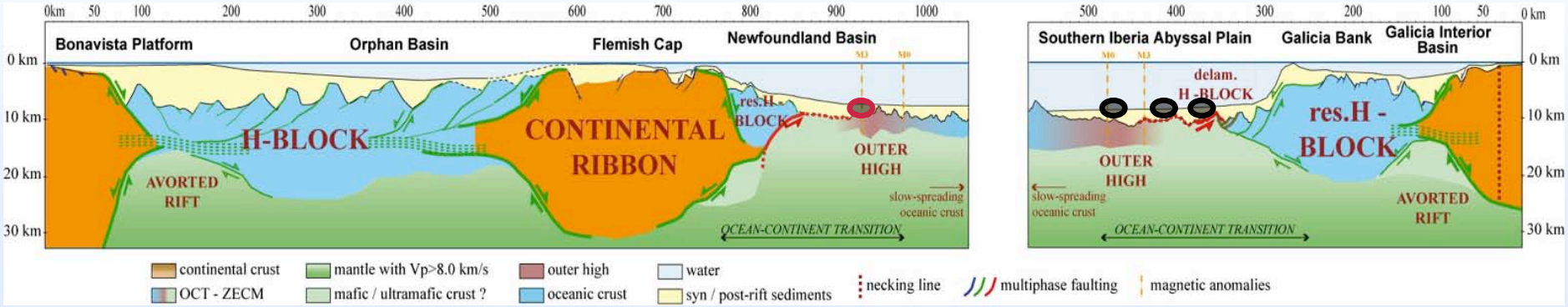



*Müntener and Manatschal, 2006*

## Major conclusions

- *Newfoundland peridotite more depleted than Iberia (higher degrees of melting)*
- *All holes from Iberia show some deviations from Cr# correlation (equilibration with plagioclase)*
- *Newfoundland peridotite among most depleted peridotites drilled (inherited mantle domain)*
- *Some similarities with sub-arc mantle (imprint of old subduction?)*

**Newfoundland** **Iberia**

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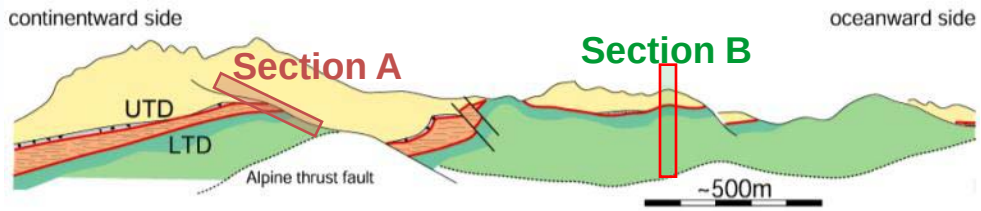
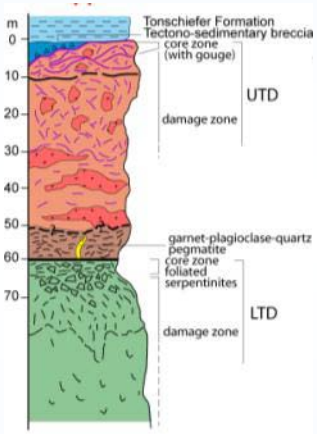
# Example of exhumed mantle in the Alps


**Tasna Ocean Continent Transition (OCT)**

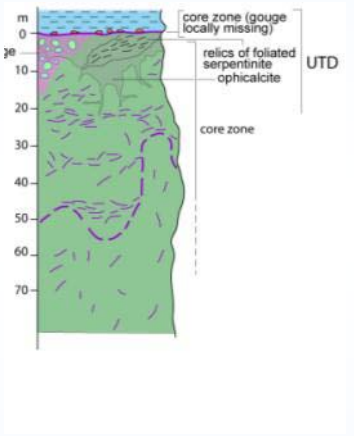



*Florineth and Froitzheim 1994, Manatschal et al. 2006*

Section A

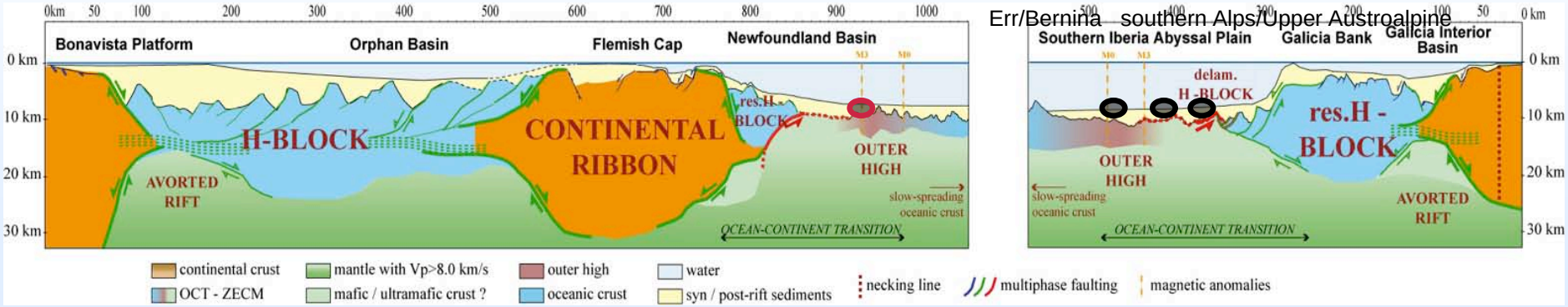



Section B




## Newfoundland

## Iberia




Err/Bernina southern Alps/Upper Austroalpine

*modified after Péron-Pinvidic and Manatschal (2010)*

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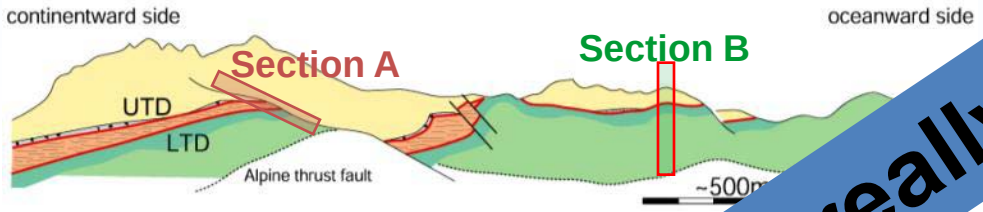
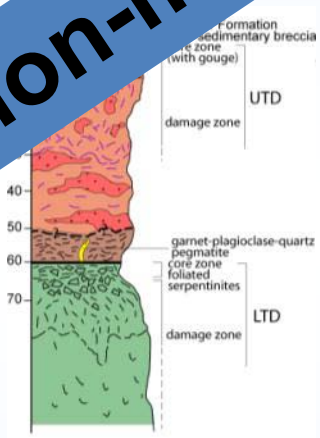



*Florineth and Froitzheim 1994* *2006*

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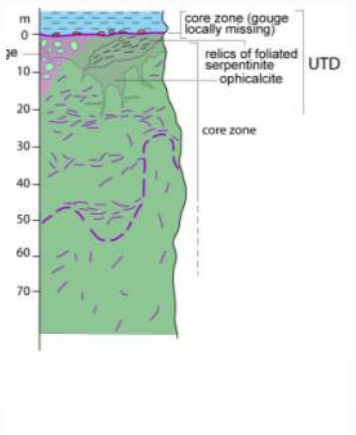
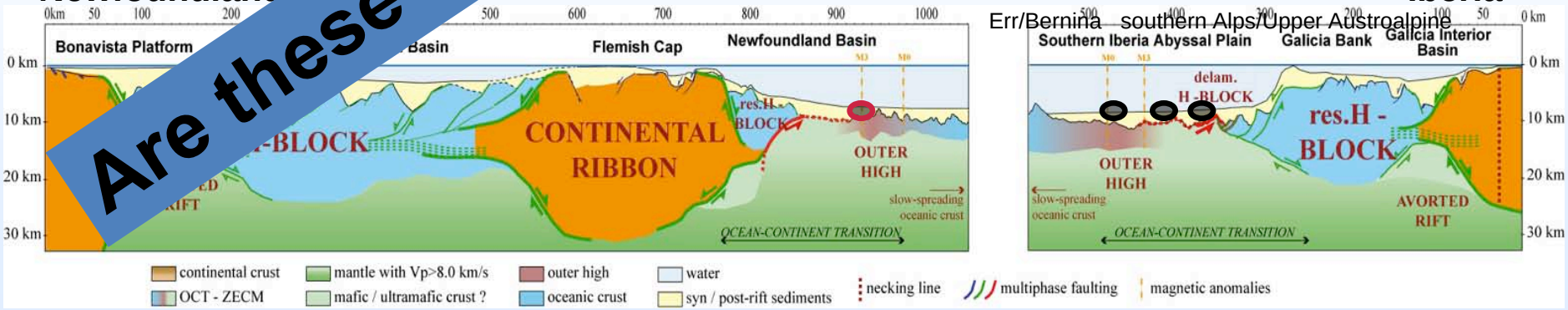



**Are these systems really non-magmatic ?**

**Newfoundland** **Iberia**




Err/Bernina southern Alps/Upper Austroalpine

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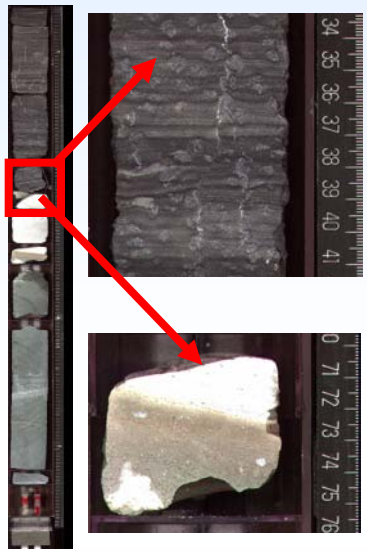
# Magmatic rocks in the OCT *(Iberia-Newfoundland and Alpine Tethys)*

## Drilled magmatic rocks

*(ODP Sites 897, 1070, 1276, 1277)*

- *Magmatic rocks are present but rare*
- *Syn-rift as well as post-rift magmatic activity*
- *Apparent increase in magma oceanwards*
- *Alkaline as well as MOR signatures*

**Sill in sediments**

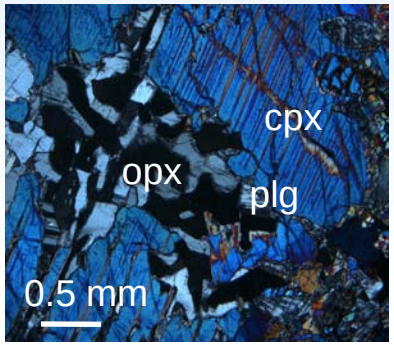


Core *1276-87-6*

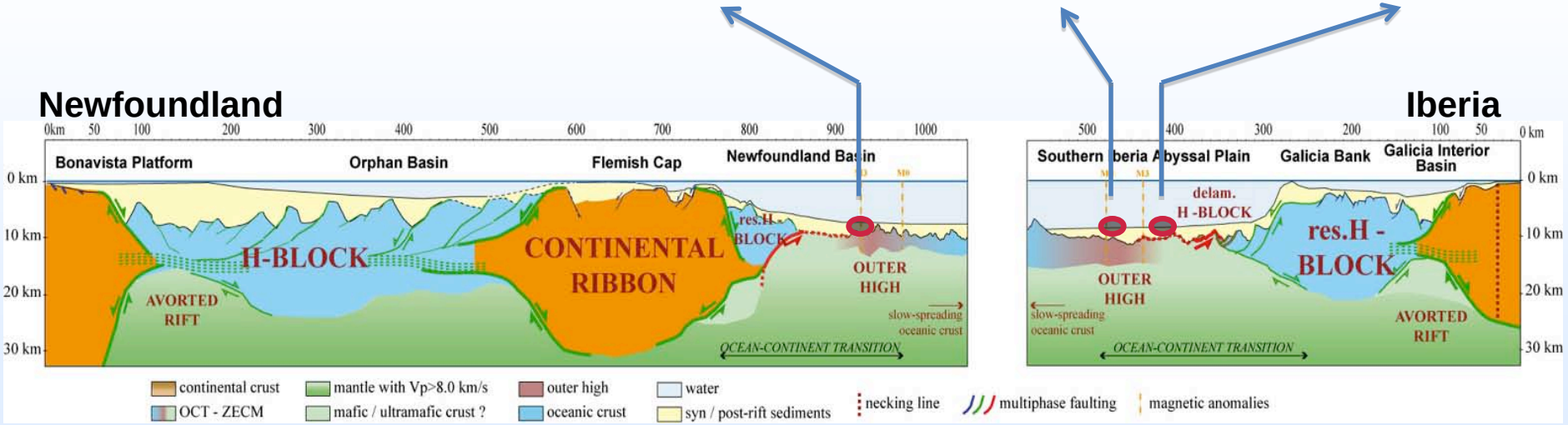
**Gabbros in exhumed mantle**

*Site 1070*

**Infiltrated mantle**




*Site 897 4R-1*

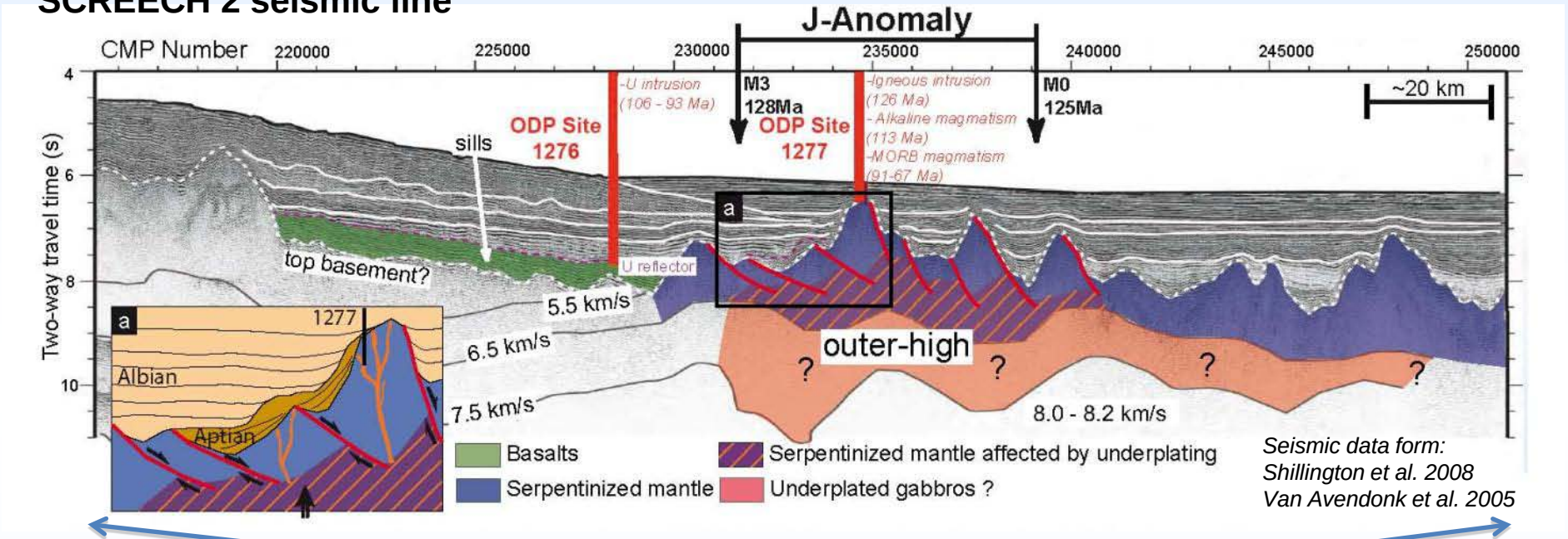



*modified after Péron-Pinvidic and Manatschal (2010)*

# Where and when did breakup occur?

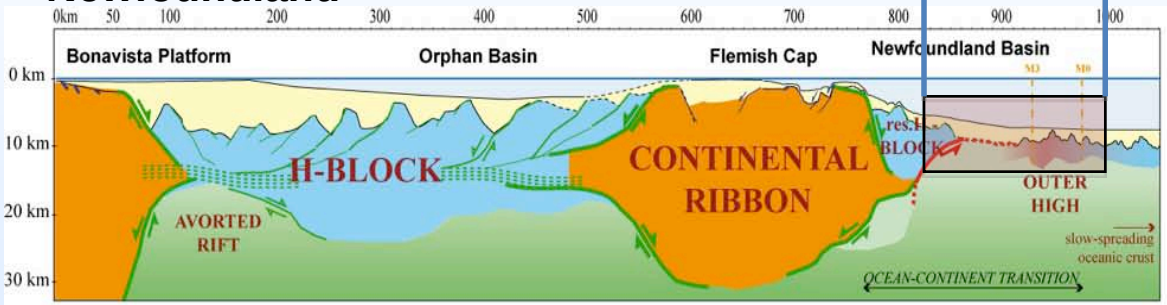
***Bronner et al. 2011(Nature Geoscience)***

## SCREECH 2 seismic line

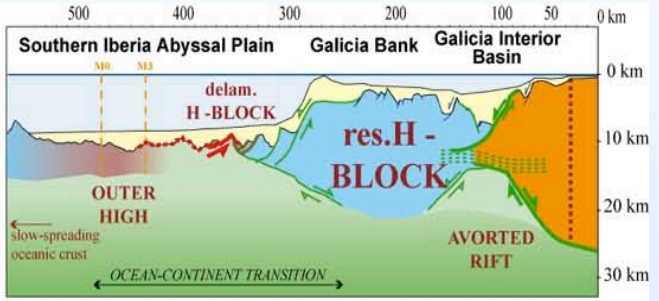


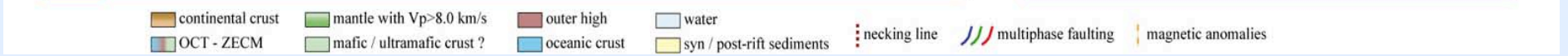

*Seismic data form:*
*Shillington et al. 2008*
*Van Avendonk et al. 2005*

## Newfoundland




## Iberia

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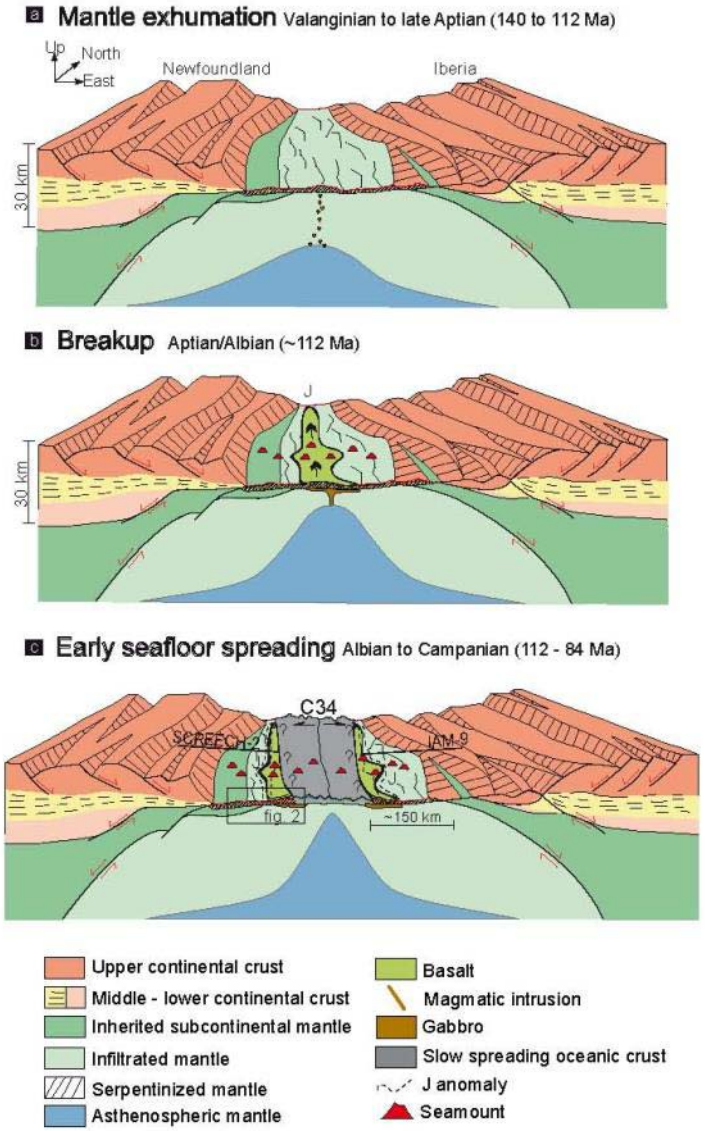
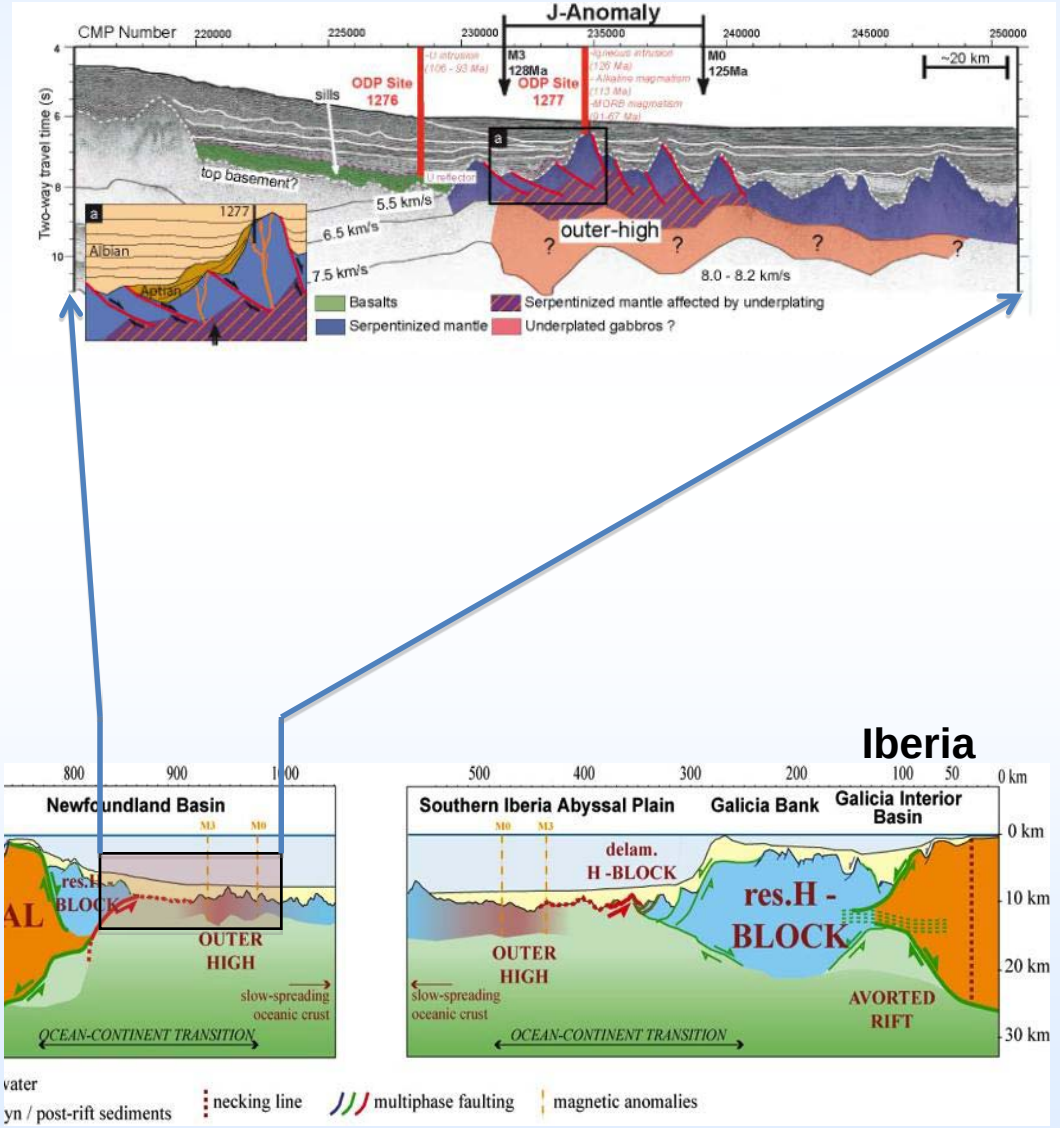


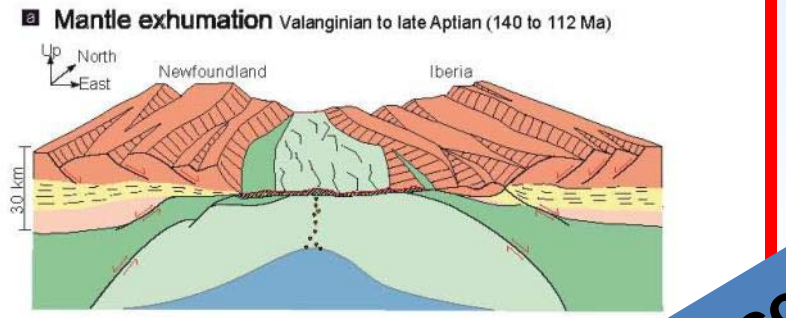

*modified after Péron-Pinvidic and Manatschal (2010)*

# Where and when did breakup occur?

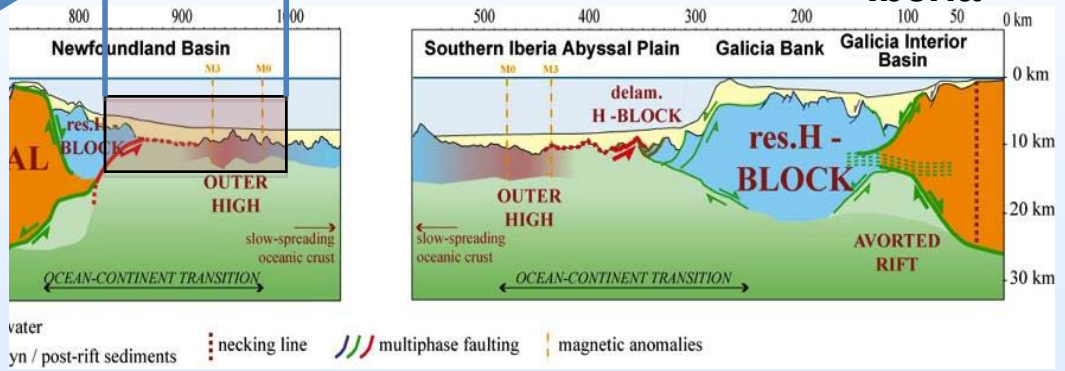
***Bronner et al. 2011(Nature Geoscience)***

**major conclusion:**

**an excess magmatic event at the Aptian-Albian boundary is at the origin of continental breakup**

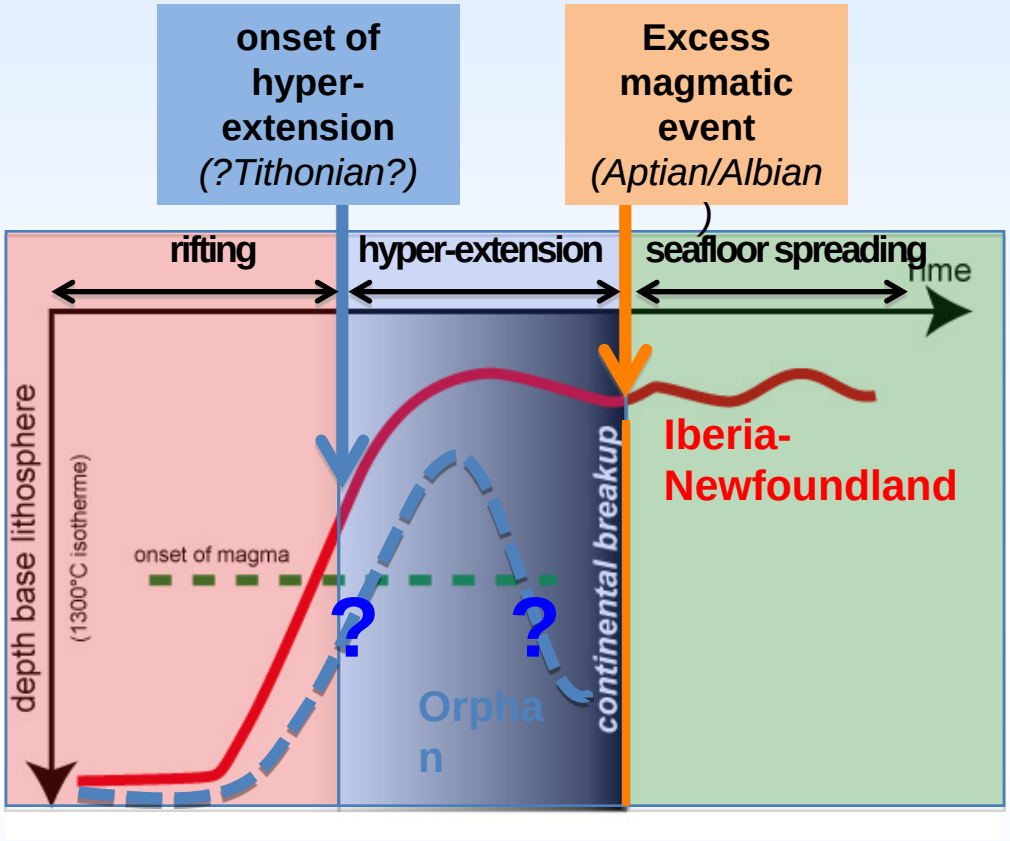







*modified after Péron-Pinvidic and Manatschal (2010)*

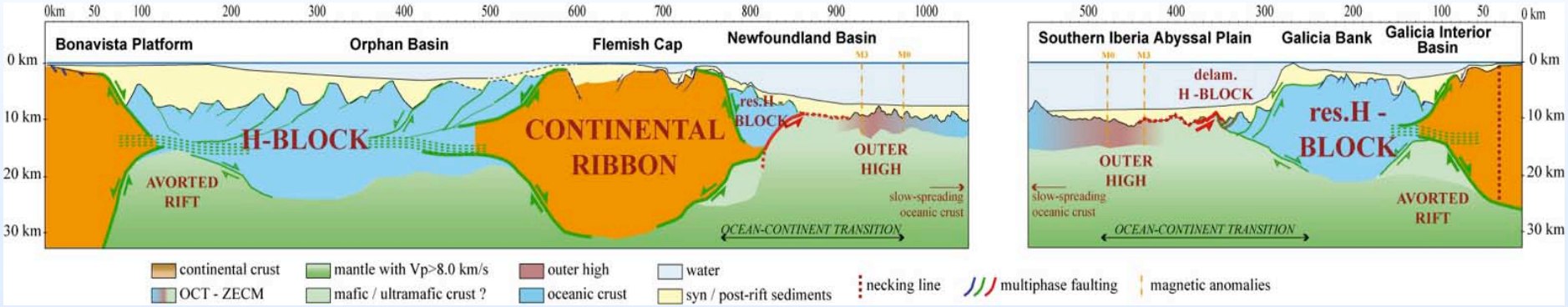
# The southern North Atlantic: conclusions




## Major conclusions:

- *Magma is of subordinate importance during hyper-extension*
- *Breakup is linked with excess magmatic event*
- *More than 150 km of exhumed mantle*

**Newfoundland** **Iberia**

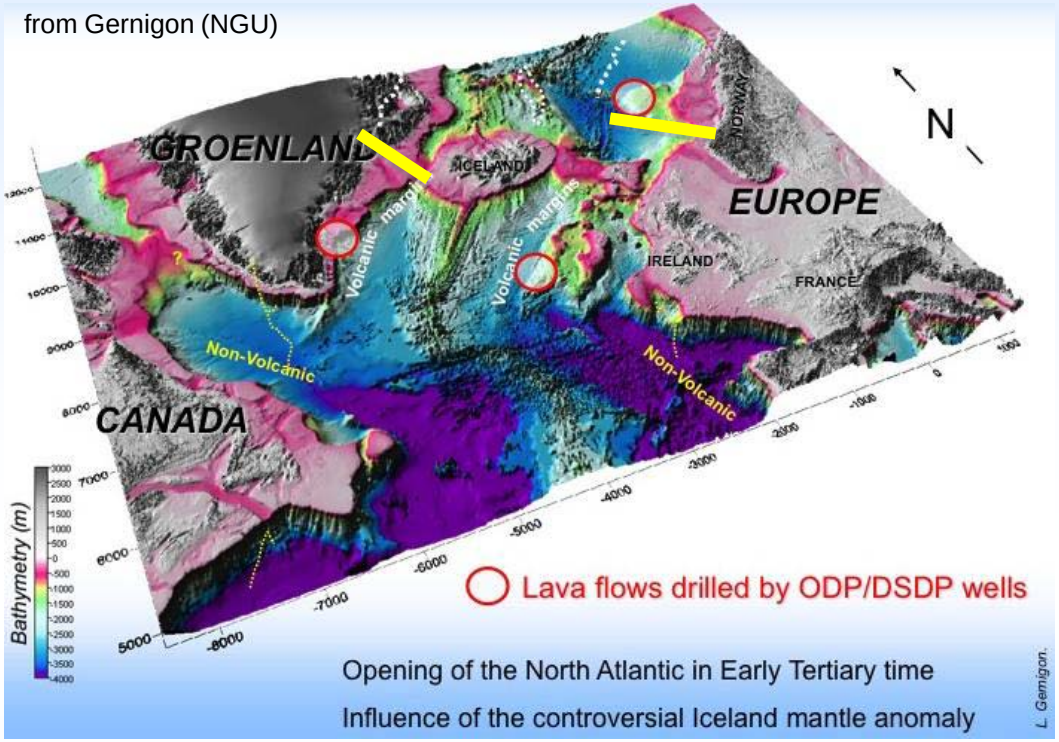



*modified after Péron-Pinvidic and Manatschal (2010)*

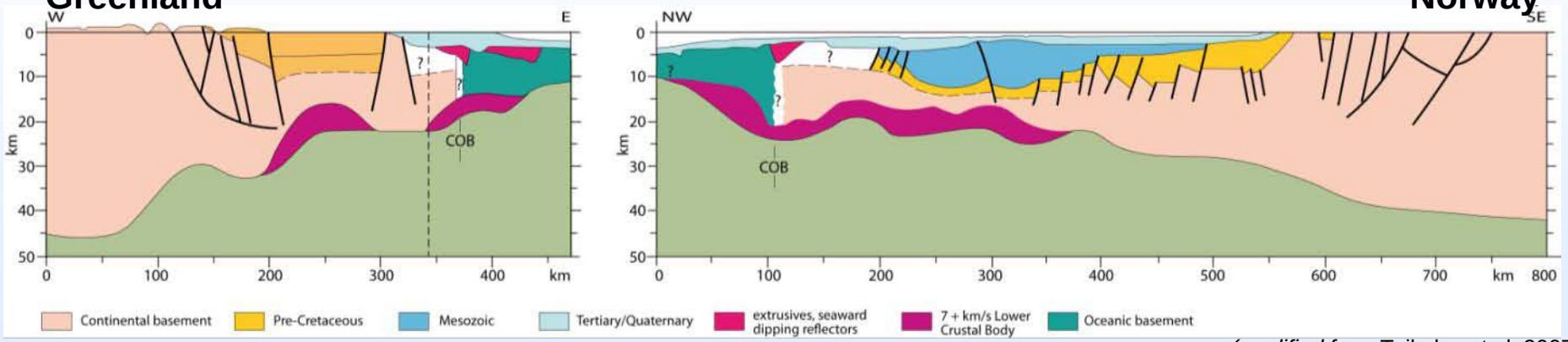
# The North Atlantic rift-system

## *Major observations*

- Prominent magmatic event during continental breakup related to the arrival of the Island plume
- Present-day rift structure is dominated by magmatic breakup




## *Section through the East Greenland – mid-Norway conjugate margins*




*(modified from* Tsikalas et al. 2007)

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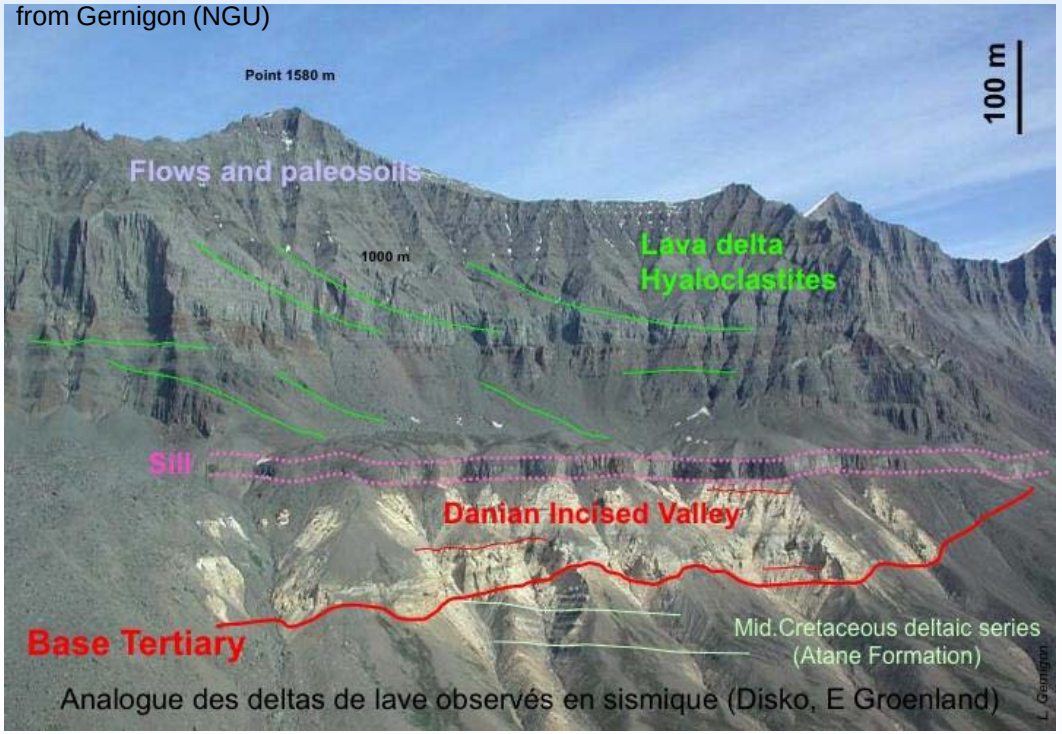
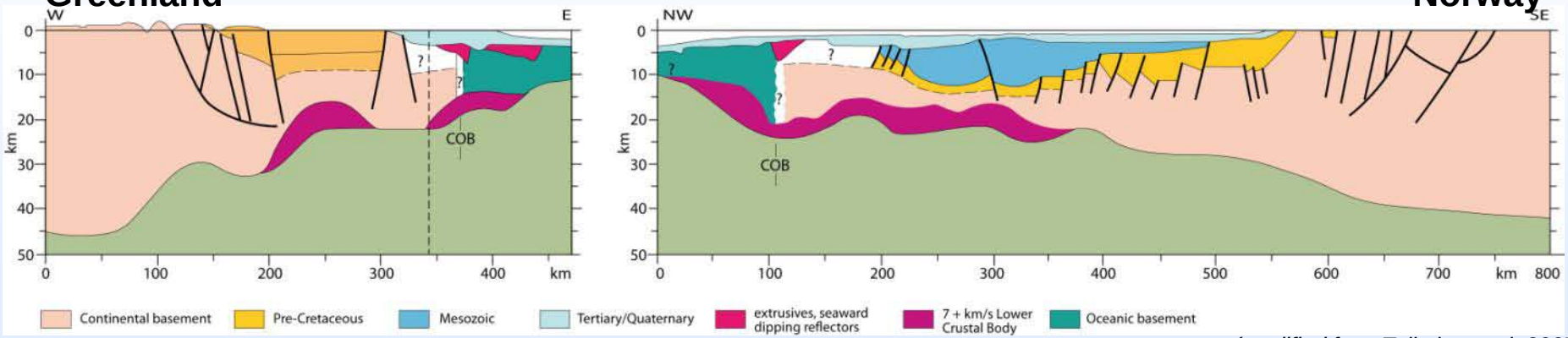



**Greenland** **Norway**

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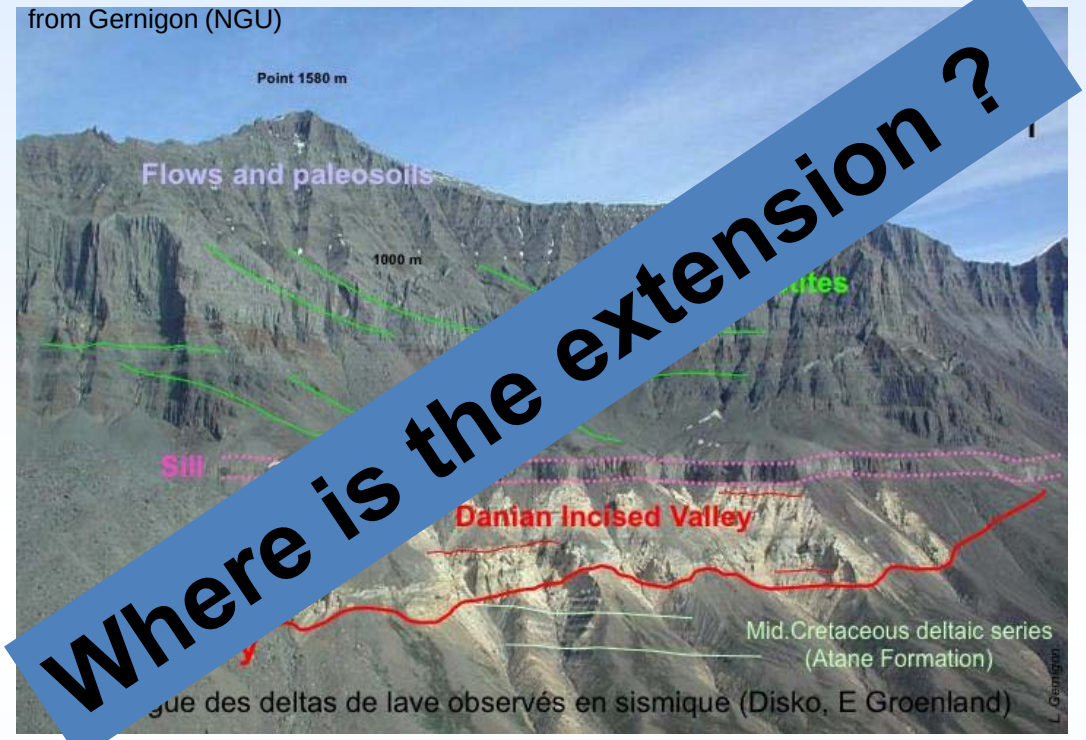


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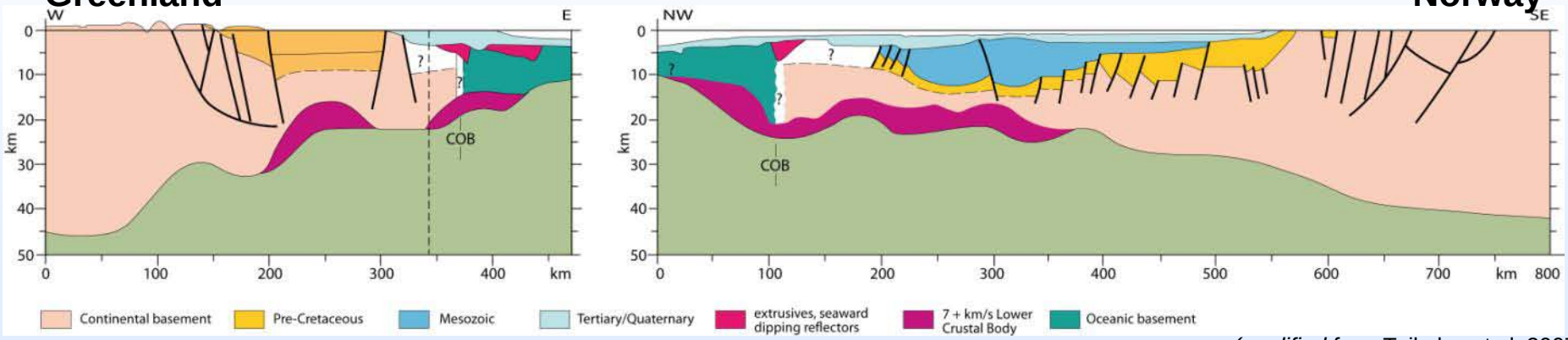


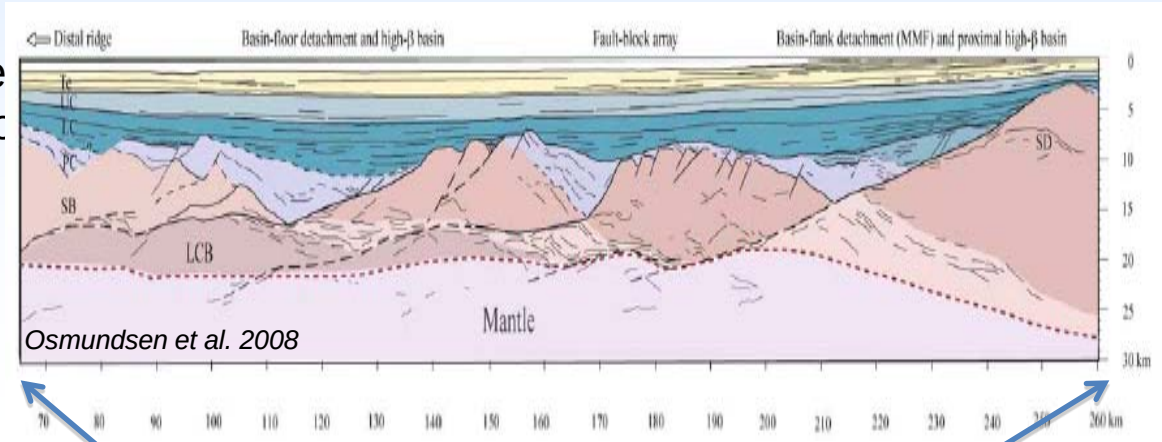

*(modified from* Tsikalas et al. 2007)

# The North Atlantic rift-system

## *Major observations*

•Late Jurassic – Early Cretaceous hype
extension resulted in extreme thinning c
the continental crust in the present-day
Møre and Vøring basins

•Excess magmatic event overprints
hyper-extend continental crust

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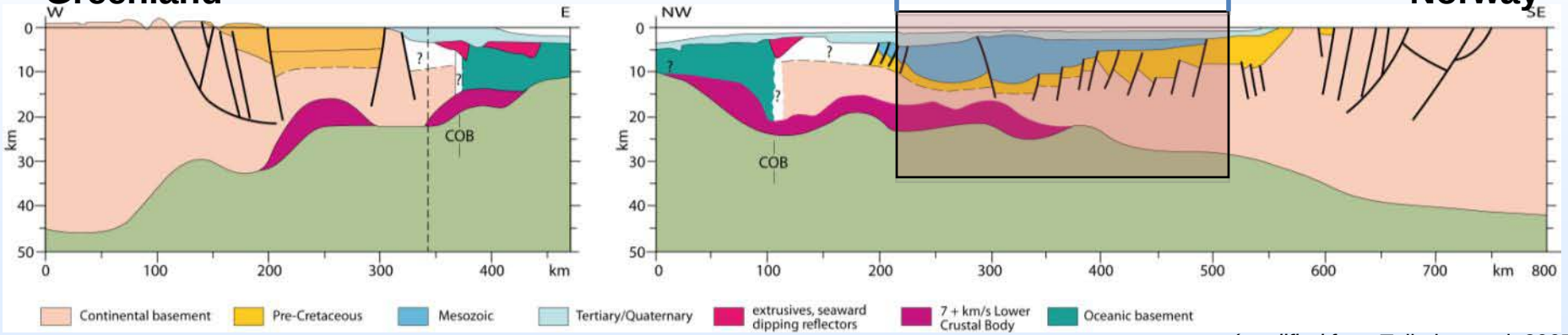
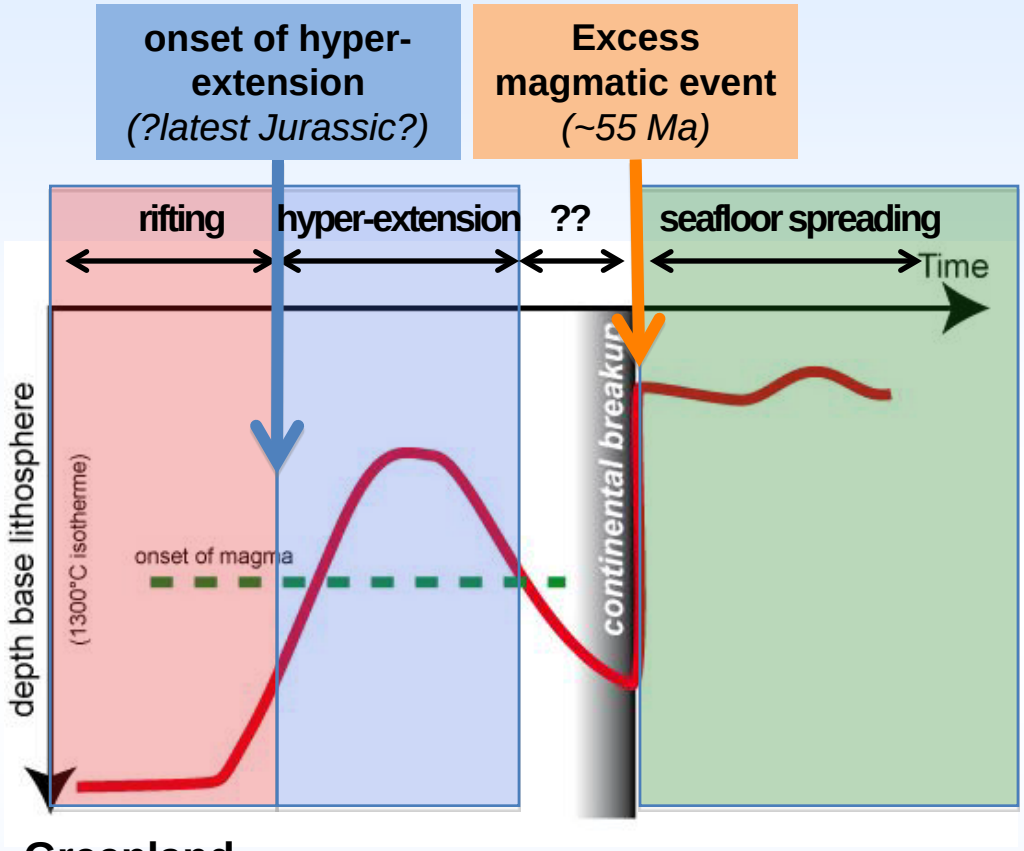



*(modified from* Tsikalas et al. 2007)

# North Atlantic rift-system: conclusions



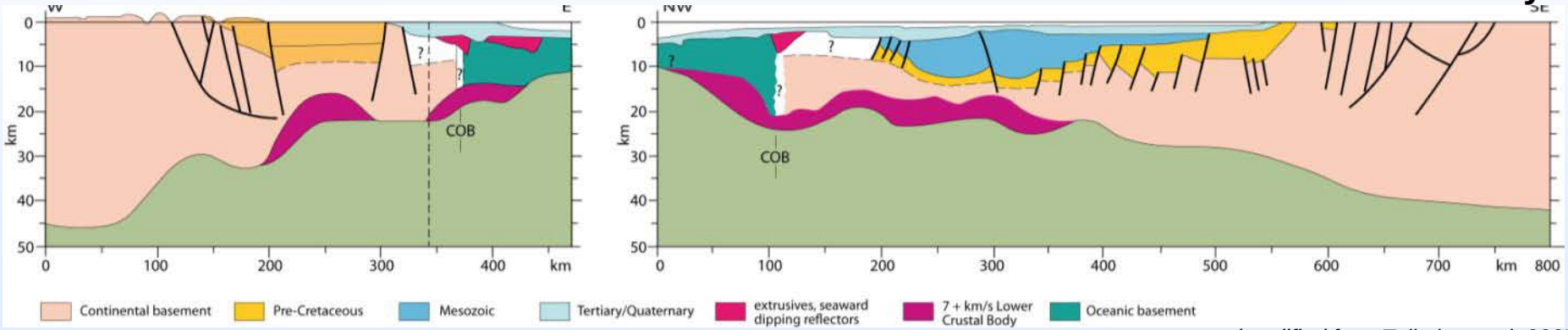

## *Major observations*

- Late Jurassic – Early Cretaceous hyper-extension
- Breakup (~55 Ma) related to excess magmatic event (SDRs and Low Crustal Magmatic Bodies)

## *Major question*

- Why did the Late Jurassic – Early Cretaceous event not form more magma, and why did the North Atlantic not open during this stage?

**Greenland** **Norway**

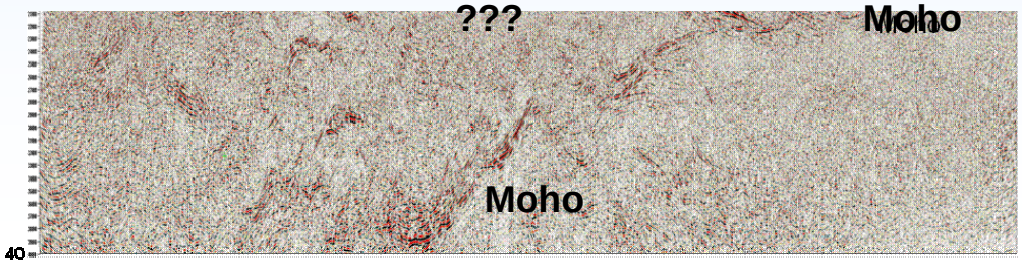



*(modified from* Tsikalas et al. 2007)

# The Pelotas rift system (S-Brazil)

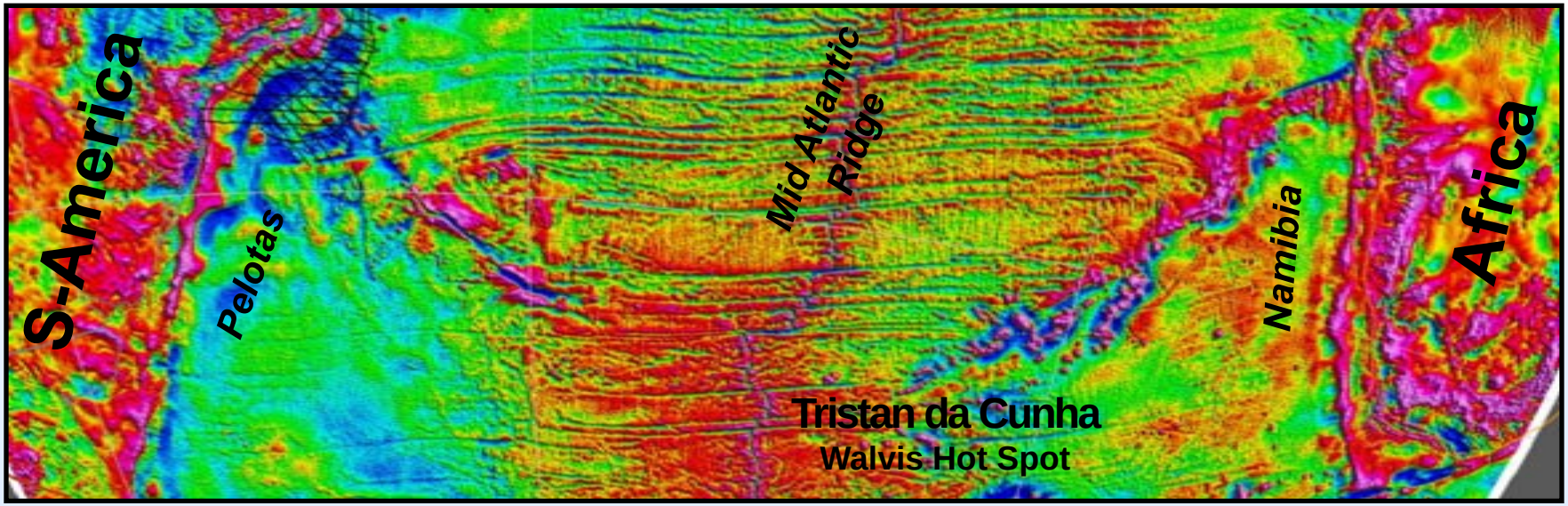
## Major observations

- Well developed SDR sequences
- Strong Moho-reflections
- What is underneath the SDR?

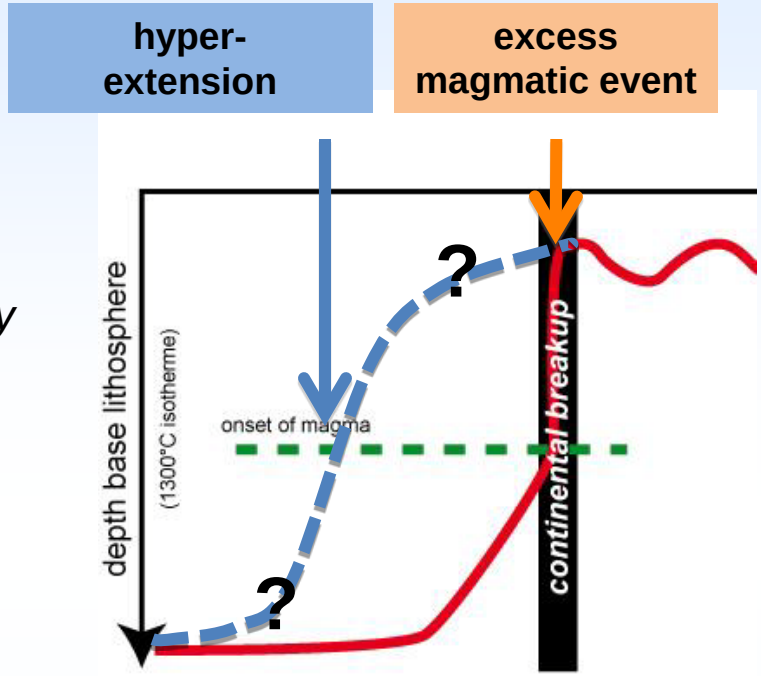



***PelotasSPAN (ION-GXT)*** *(taken from their homepage)*

## Gravimetric Free-air Map *(Sandwell and Smith (2009))*



# South Atlantic (Pelotas – S-Brazil)



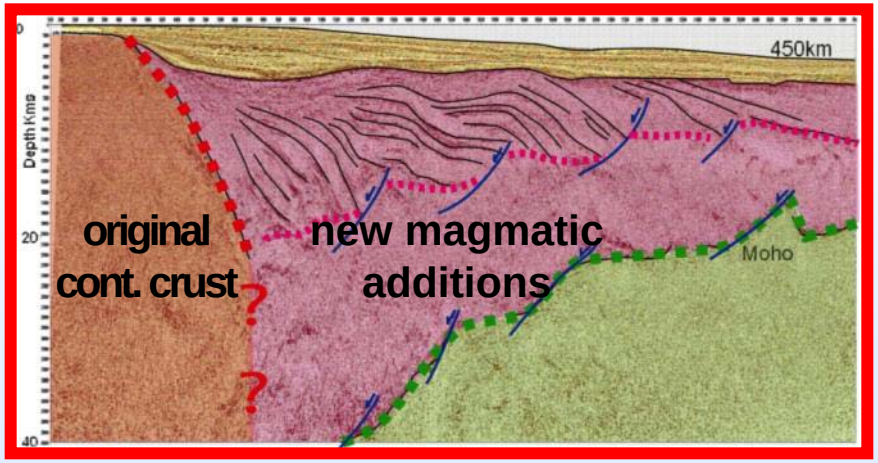

## Interpretation I

- *Whole crust is formed by newly formed magmatic crust*

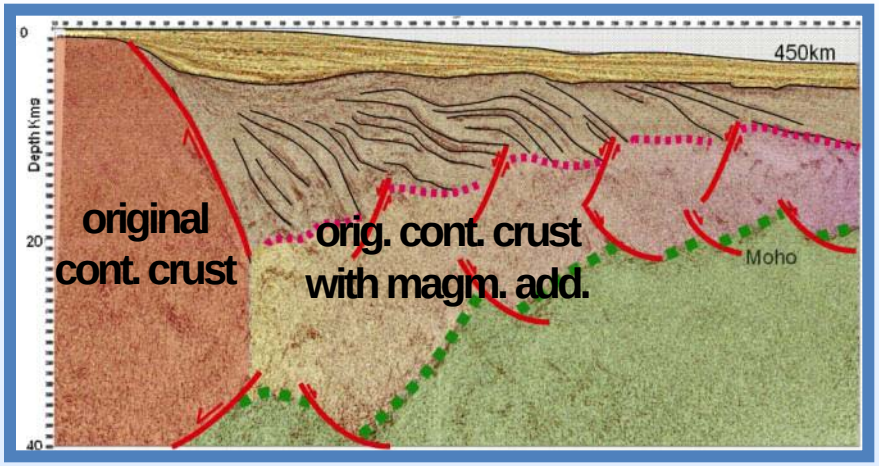
## Interpretation II

- *Rifting initiates by hyper-extension*
- *Breakup is linked with excess magmatic event overprinting hyper-extended crust*

## Purely magmatic



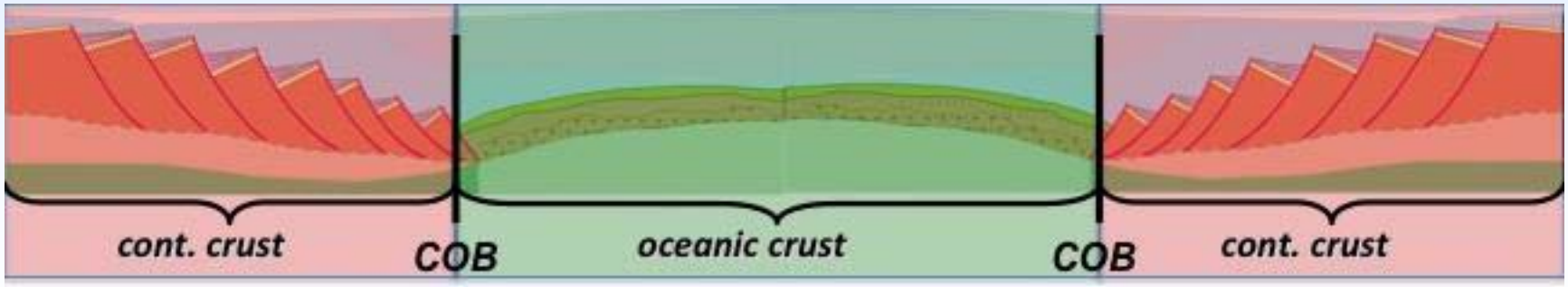

## Hyper-extension with magmatic additions




**PelotasSPAN (ION-GXT)** (taken from their homepage)

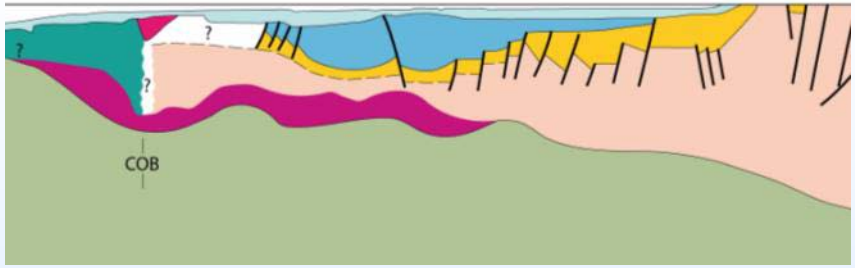
# How do continents breakup?

## *The classical rift model*



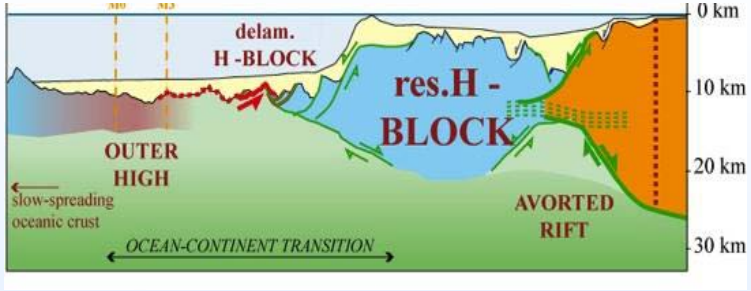

## *Results of the Ocean Drilling Program and seismic imaging*

### *magmatic margins*




- Seaward Dipping Reflection Sequences (SDR)
- Thickened crust (magmatic additions)

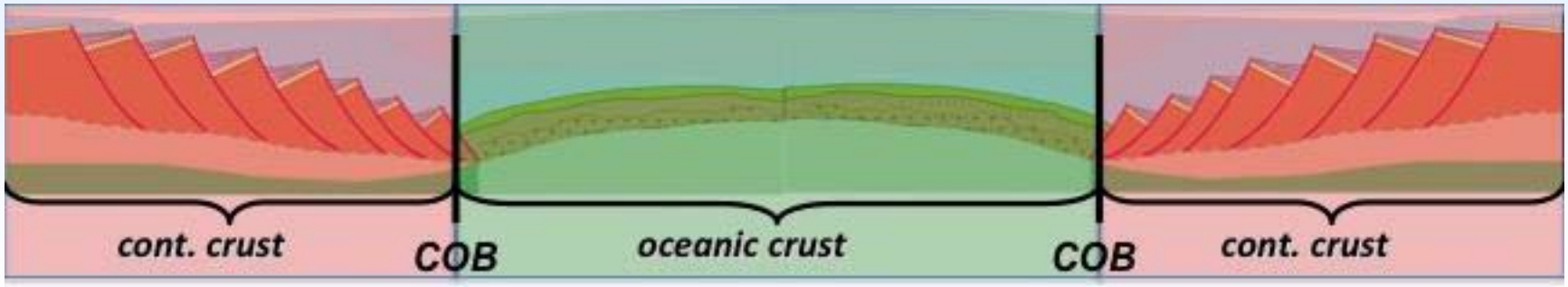
### *“non”-magmatic margins*



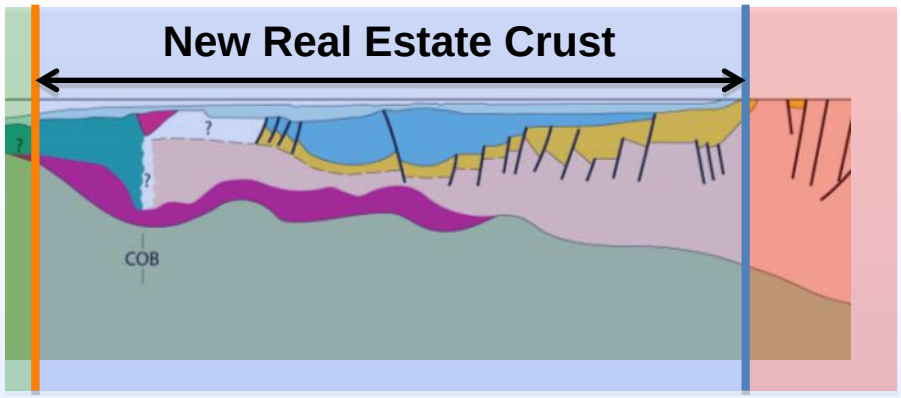

- Exhumed mantle
- Necking zones
- Detachment faulting and extensional allochthons

# How do ocean breakup?

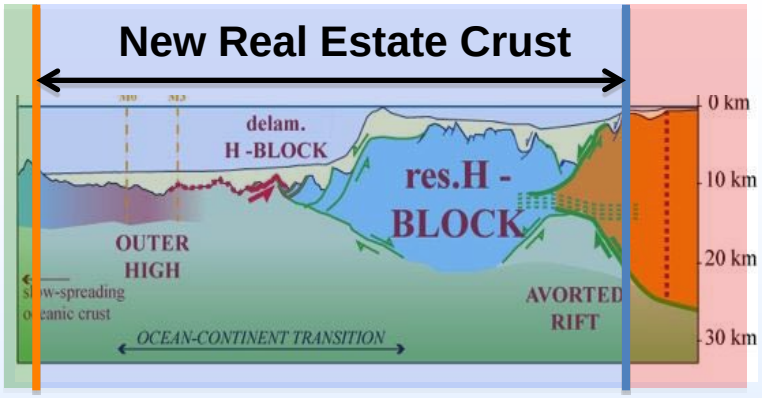
## *The classical rift model*




***another approach to describe rifted margins***

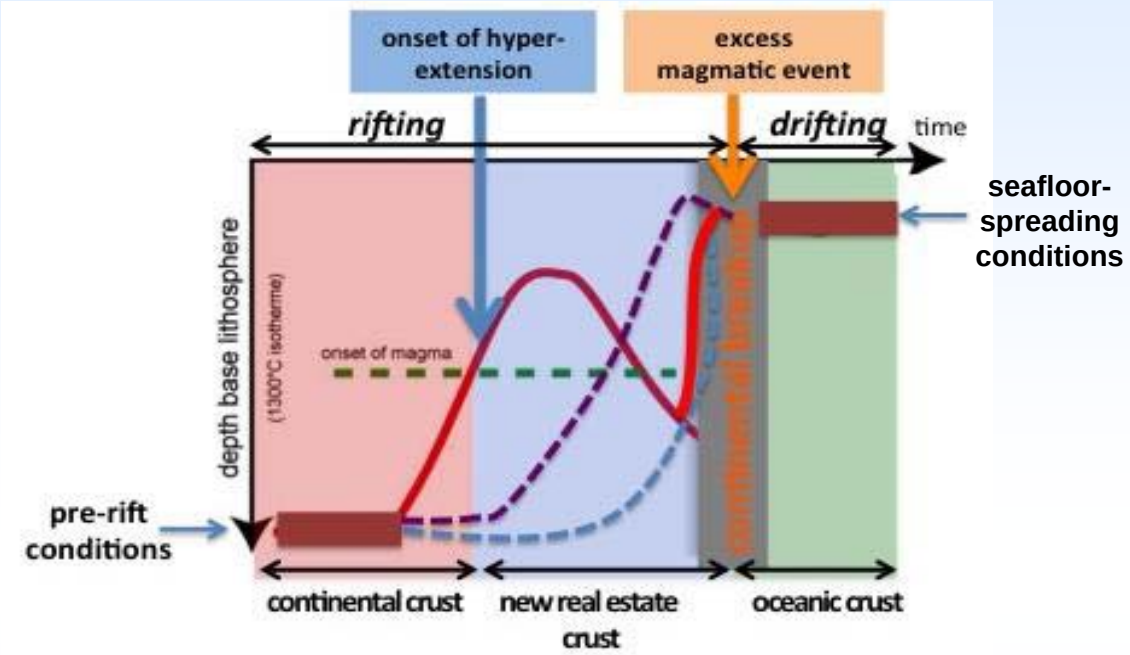


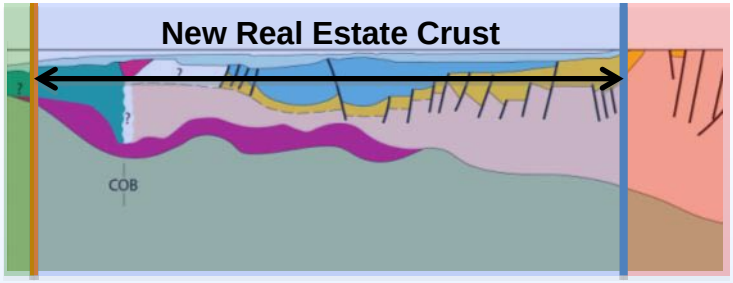

**excess magmatic event** | **onset of hyper-extension**




**excess magmatic event** | **onset of hyper-extension**

# How do continents breakup?



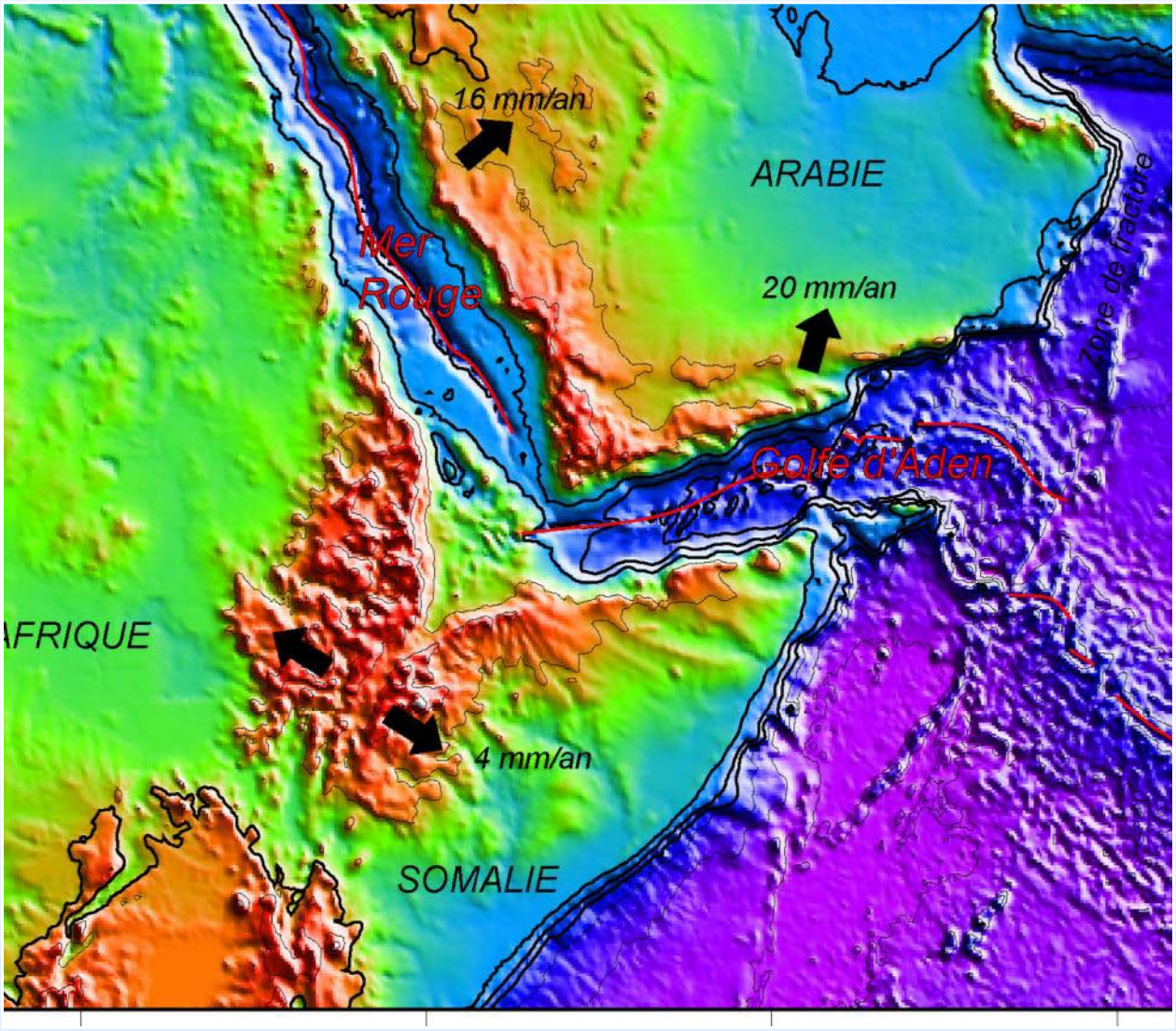





***Major conclusion***

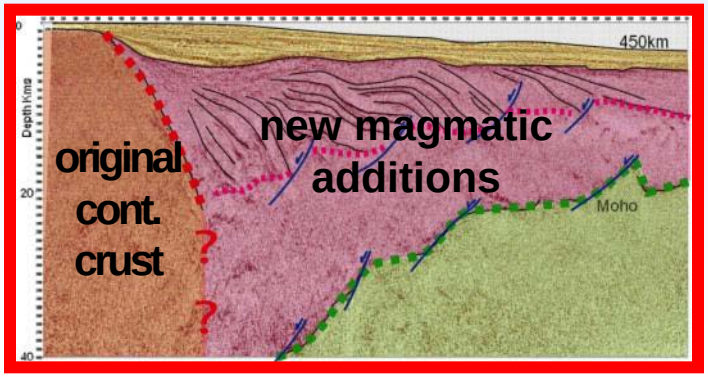
*Most rifted margins may have undergone hyper-extension during earlier stages of rifting (also "magma-rich" systems), however, excess magma seems to be a prerequisite to breakup continental lithosphere (also in magma-poor margins)*

# How can we apply the lesson we learned in the Atlantic to the Afar system?

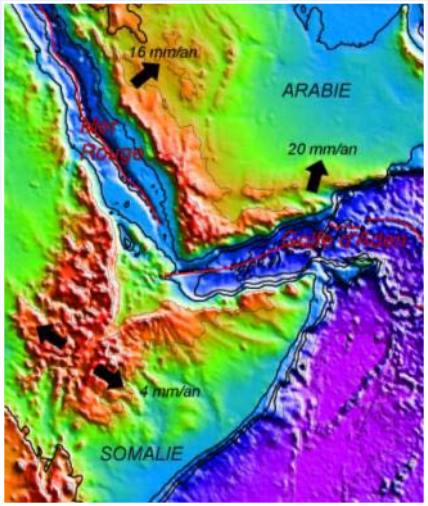


# Two possible interpretations

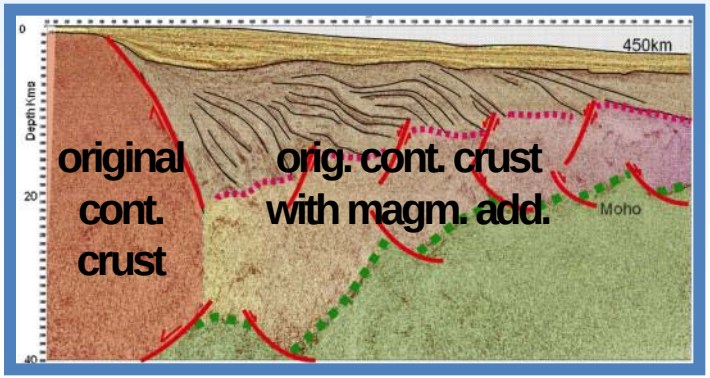
## Purely magmatic




PelotasSPAN (ION-GXT) (taken from their homepage)




## Hyper-extension with magmatic additions



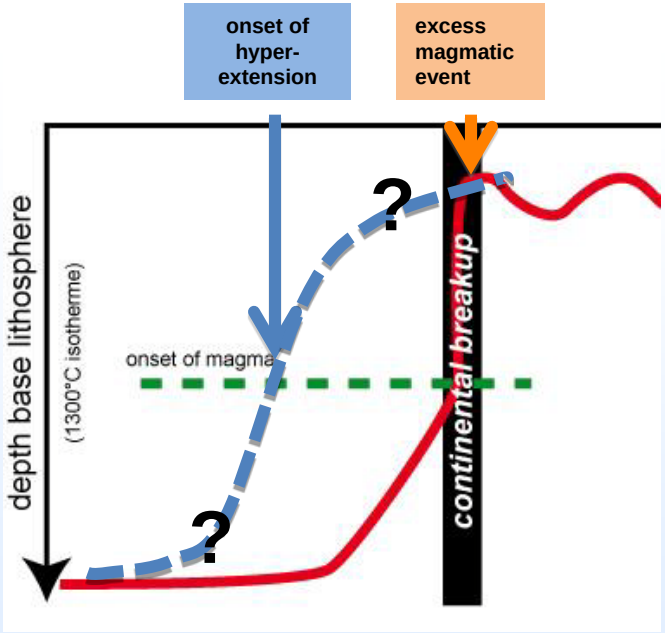

PelotasSPAN (ION-GXT) (taken from their homepage)

## Interpretation I

- *Whole crust is formed by newly formed magmatic crust*

*(e.g. Island)*

*where are the margins and why the abrupt transition?*




## Interpretation II

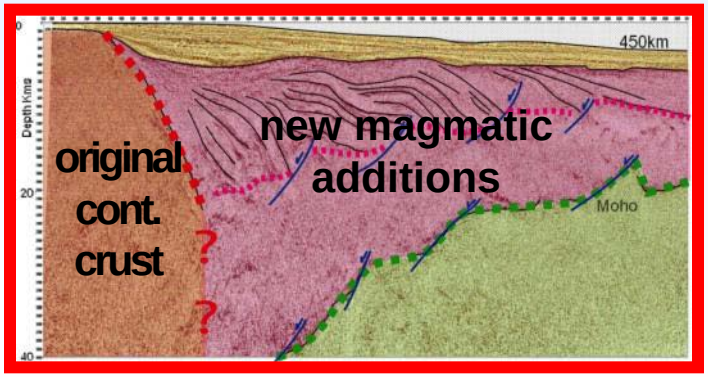
- *Rifting initiates by hyper-extension*
- *Breakup is linked with excess magmatic event overprinting hyper-extended crust*

*(e.g. San Paolo Plateau)*

*Is there evidence for hyper-extended crust and thinned lithosphere underneath AFAR ?*

# Two possible interpretations

## Purely magmatic




PelotasSPAN (ION-GXT) (taken from their homepage)


## Hyper-extensio… …matic




PelotasSPAN (ION-GXT) (taken from their homepage)

**What is the nature of the crust/mantle underneath Afar?**

my questions:

## Interpretation I

- *Whole crust is fo… newly forme… crust*

*(e.g. …*

*where … why the … on?*


## Interpretation II

- *Rifting initiates by hyper-extension*
- *Breakup is linked with excess magmatic event overprinting hyper-extended crust*

*(e.g. San Paolo Plateau)*

*Is there evidence for hyper-extended crust and thinned lithosphere underneath AFAR ?*