



2018 Conjugate Margins Conference

Halifax, Nova Scotia, August 19–22, 2018



Newfoundland-Labrador Orphan Basin: Structural key elements for the Northeast Atlantic opening

Thibaud Pichot¹, Erwan Le Guerroué¹, Pierre-Yves Filleaudeau¹, Luca Micarelli¹

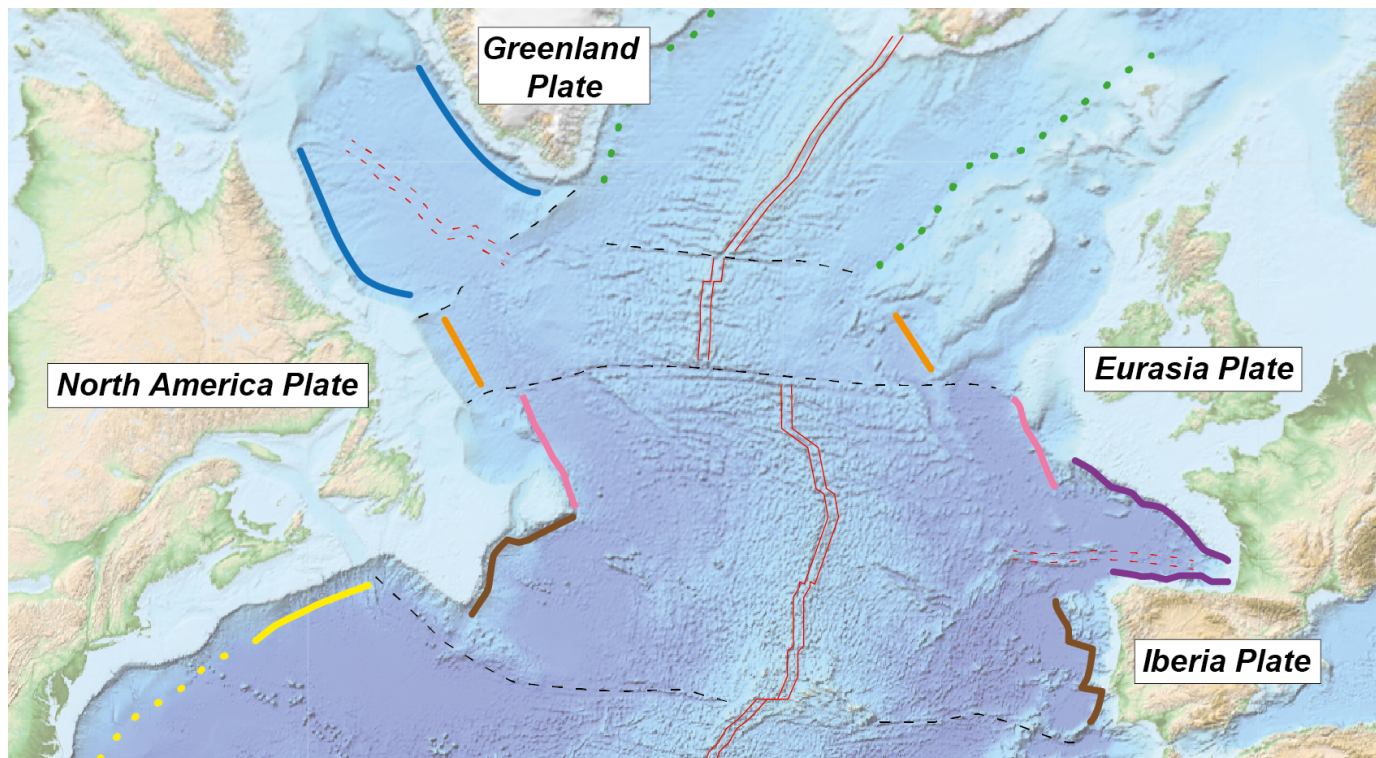
1. Beicip-Franlab, Rueil-Malmaison, France.





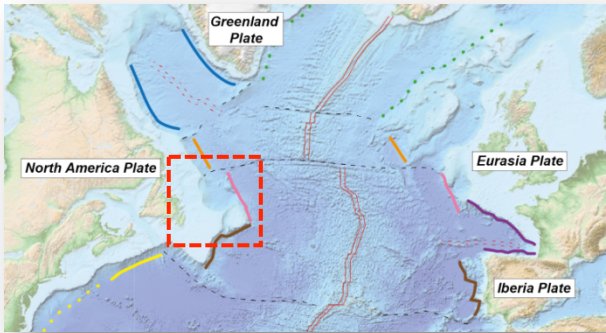
Introduction

- North Atlantic margins are segmented
 - As a results of progressive opening

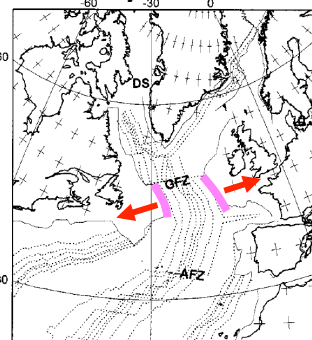
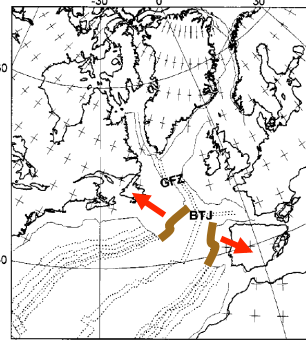
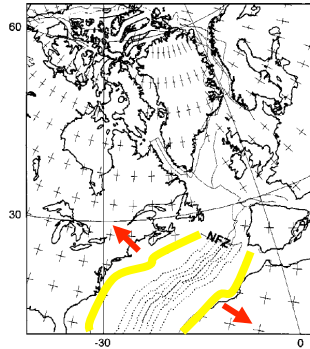


2018 Conjugate Margins Conference

- Newfoundland margins are the results of successive rift episodes

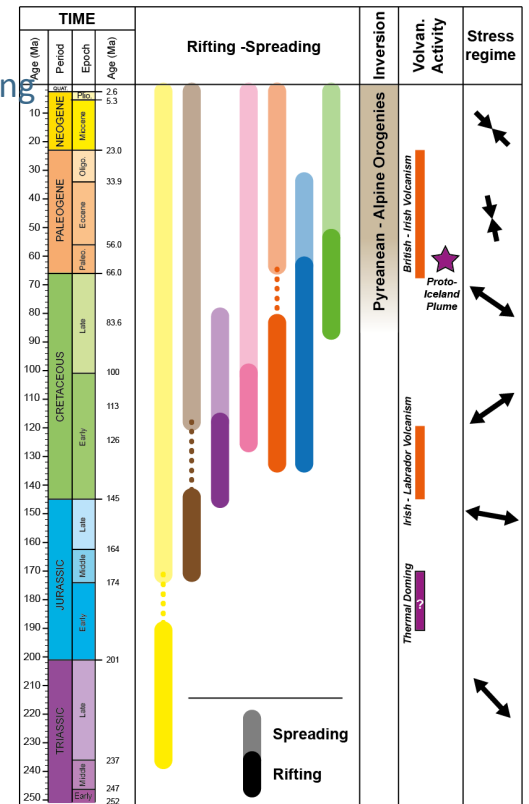


- Records long-lasting rifting processes during the Mesozoic
- Located at the junction between Nwfd-Ib Rift and Nwfd-Ire Rift
- Through 3 main Stages:



2018 Conjugate Margins Conference

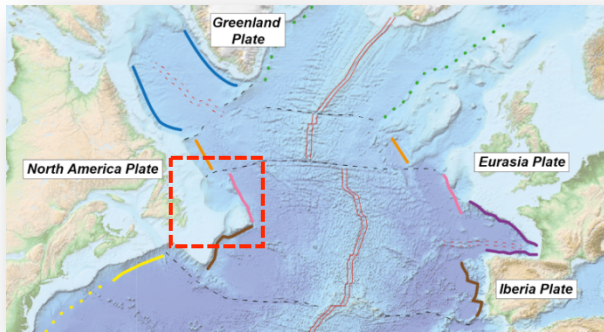
(Louden and Chian , 1999)



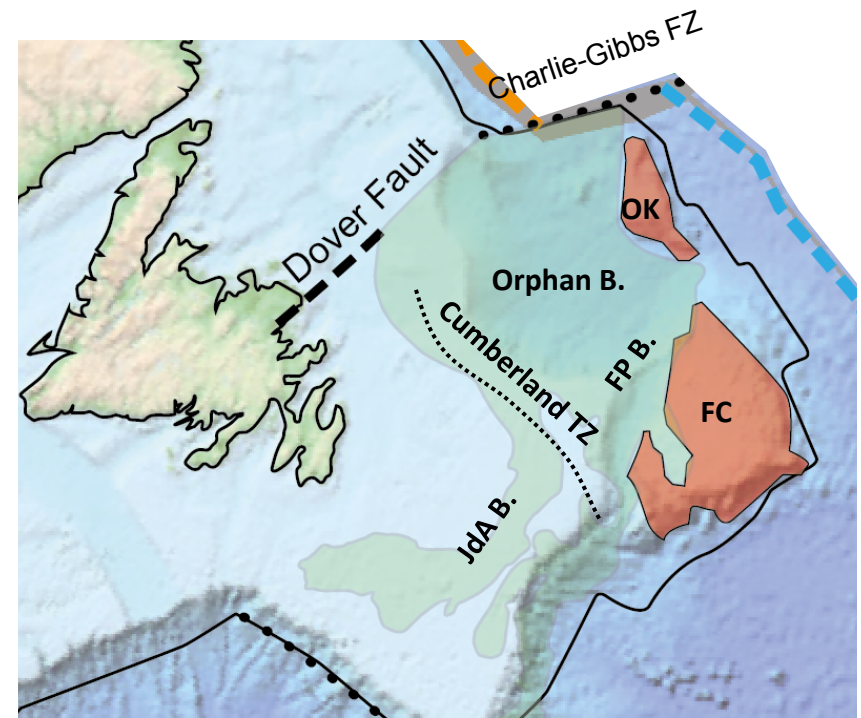
Introduction

The Orphan Basin

- Forms part of a series Mesozoic rift basins, east of Newfoundland



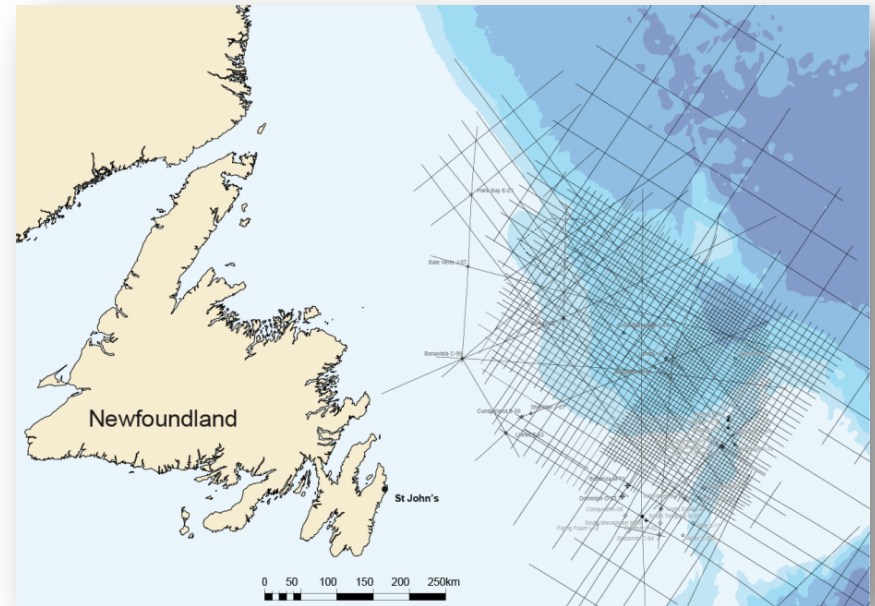
- 400 km long x 350 km wide
- Discoveries in the Jeanne d'Arc Basin and most recently the Flemish Pass Basin (East of Orphan Basin)
- These basins share common evolution with Orphan Basin





Aim of this study

- The recent discoveries have considerably revived the regional interest and provided new perspectives along not only the Newfoundland margin but also the Irish marginal basins
- Within the framework of the petroleum system resource assessment of the offshore Newfoundland and Labrador margin, Nalcor Energy engaged Beicip-Franlab to conduct an independent resource assessment
- The dataset available:
 - 10 wells
 - 38,000 km² of 2D seismic survey
 - 4,600 km² of 3D seismic survey
 - A set of 9 seismic horizons



@Beicip-Franlab



Aim of this study

■ According to its spatial position relative to the Atlantic margins, to study the Orphan Basin would provide key information on:

- How the Newfoundland-Iberia Rift and Newfoundland-Ireland Rift is expressed in this area?
- What does this Basin tell us about the early stages North Atlantic rifting?
- What about the Hydrocarbon potential of this basin?

■ How?

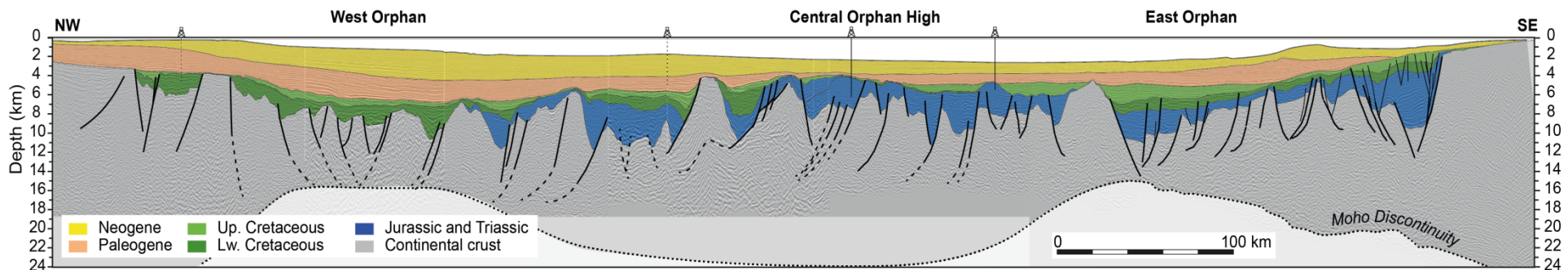
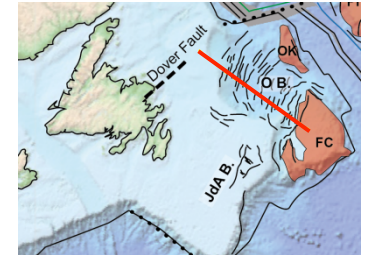
- Within the framework of a coherent plate kinematic model
- Seismic interpretation calibrated at wells
- Tectono-stratigraphic analysis



Tectono-stratigraphy analysis

Regional seismic line across the Orphan Basin

- Major seismic horizons are mapped defining stratigraphic sequence base and/or top, and regional unconformities
- Faults interpretation over the whole area
- The oldest sedimentary sequence recorded in wells in the Eastern and Central parts of the Orphan Basin is Kimmeridgian in age
- A continuous seismic reflector with strong amplitude is observed below the acoustic basement and is interpreted as the Moho discontinuity.



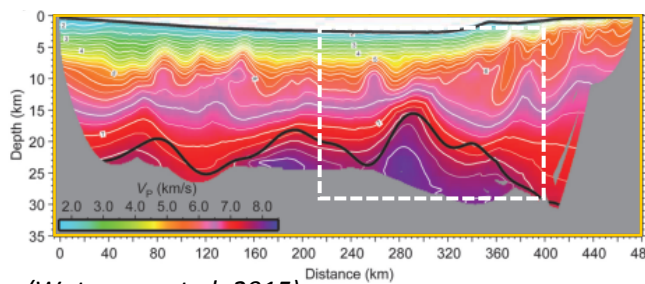
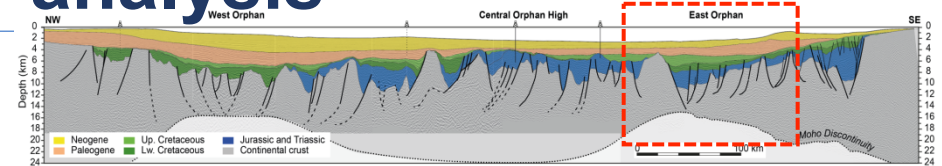


Tectono-stratigraphy analysis

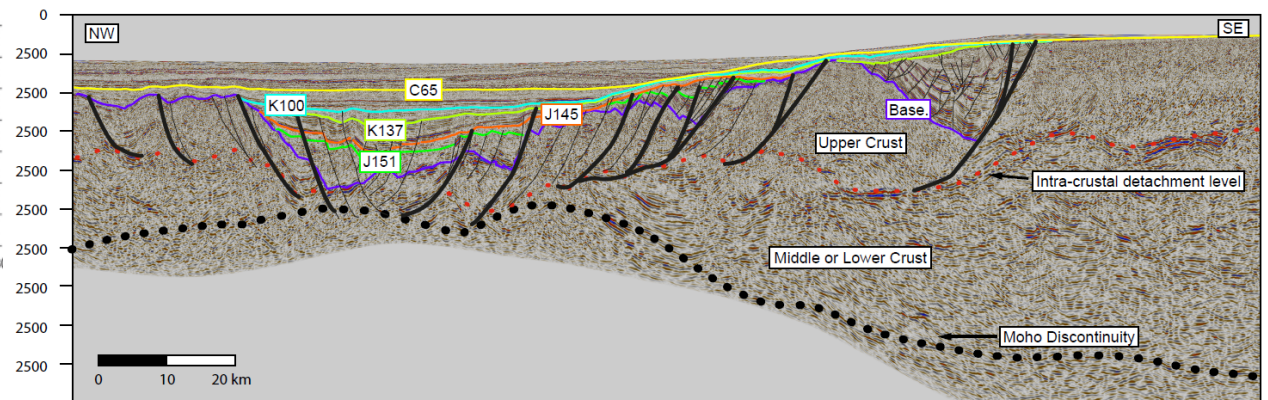
Seismic lines across the Orphan Basin

- Eastern Part

- Late Jurassic sediments is affected by numerous crustal normal faults sealed by the Top Tithonian (J145) and root in a ductile shear level, presumably in the middle or lower continental crust.
- localized hyper-extension is defined along a narrow corridor where the normal crustal faults root at the crust-mantle boundary
- Refraction seismic (Watermez et al., 2015) confirm this interpretation and show that the continental thickness thins to less than 5 km



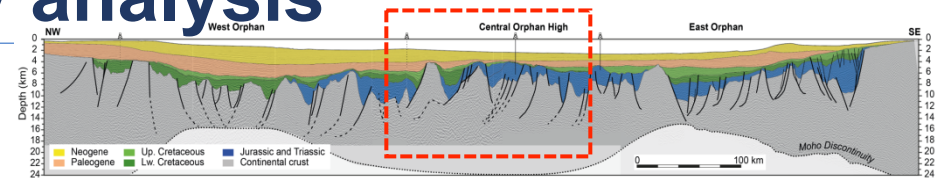
(Watremez et al., 2015)



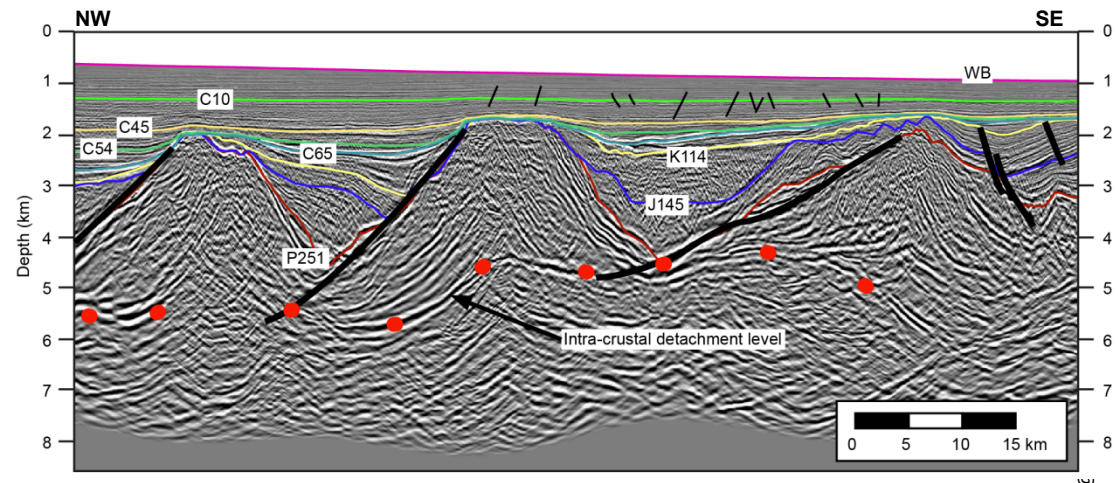
Tectono-stratigraphy analysis

Seismic lines across the Orphan Basin

- Central Part



- Central Orphan High is characterized by shallower Paleozoic basement and deeper Moho (20-25 km depth) (Chian et al., 2001; Watremez et al., 2015).
- Predominance of Late Jurassic large northwest-dipping normal crustal faults defining half-graben structures
- These crustal normal faults root down in the ductile middle or lower continental crust
- Detachment level characterized by strong and continuous amplitudes reflectors
- Early Cretaceous (Neocomian) extension stage less intense than the Late Jurassic one

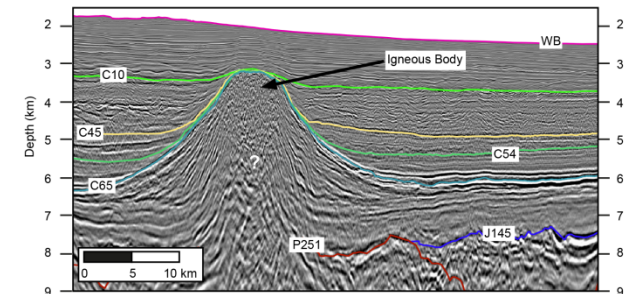
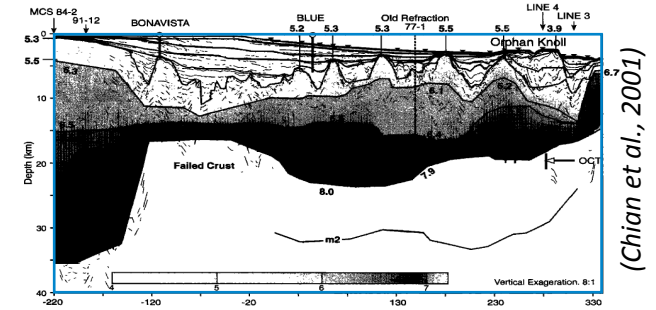
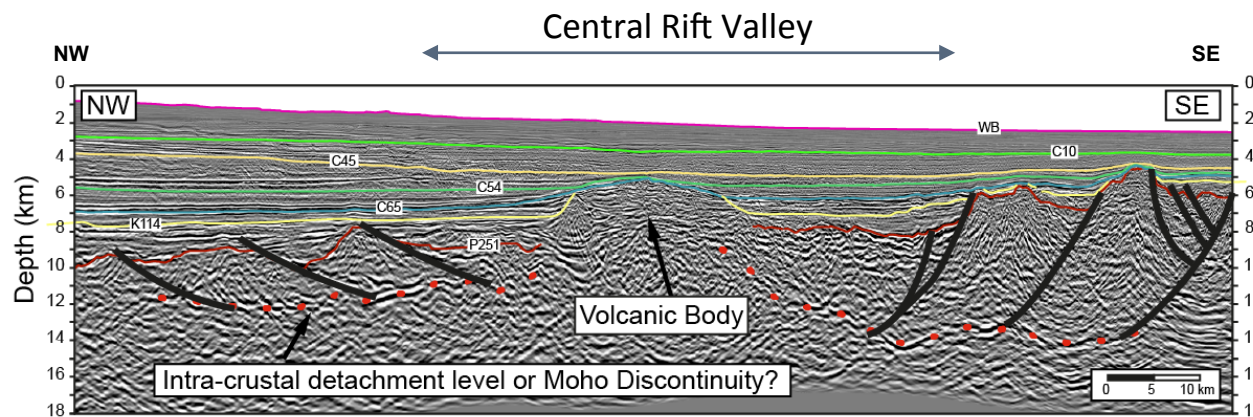
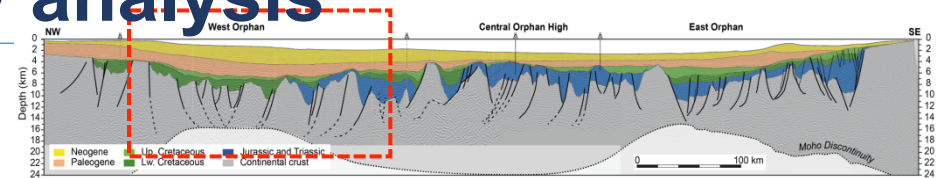


Tectono-stratigraphy analysis

Seismic lines across the Orphan Basin

- Western Part

- Neocomian deformation stage seems to predominate in the western part of the basin
- Hyper-extension along failed rift valley is identified and confirmed by Refraction seismic profile (Chain et al., 2001)
- Early Cretaceous volcanism accompanied the extension

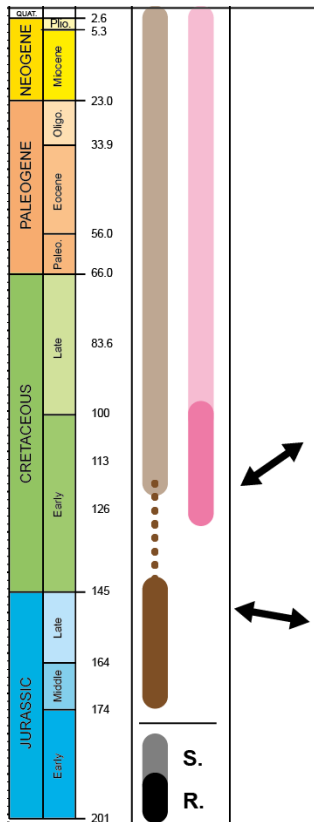


(Chian et al., 2001)

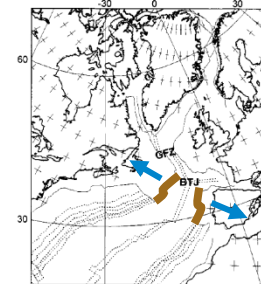
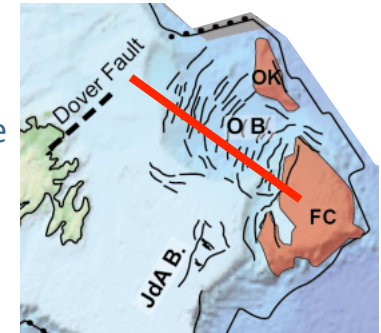


Tectono-stratigraphy analysis

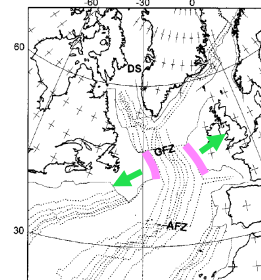
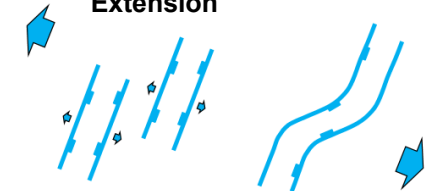
Summary of Extension Stages



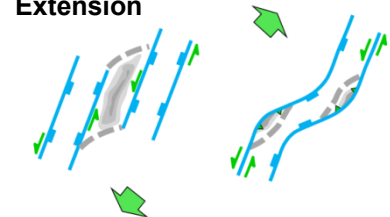
- Most of the deformation affecting the Orphan Basin occurs between the Late Jurassic to Early Cretaceous times
- NNE-SSW deep crustal normal faults are formed mainly in the Late Jurassic time
- coherent with the Newfoundland-Iberia Rift System
- Drastic tectonic stress changes from NW-SE to NE-SW at the end of the Lower Cretaceous
- Intensity of this later deformation is less important than the previous ones; Local inversion features are described along NNE-SSW Upper Jurassic crustal faults



Late Jurassic N°110E Extension



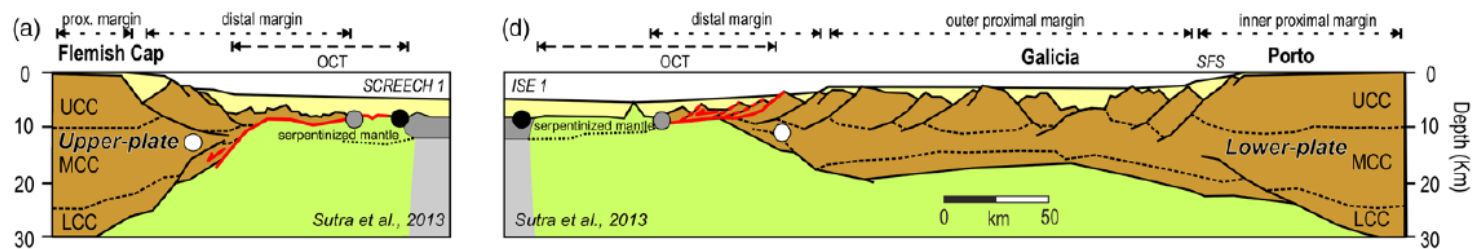
Late Early Cretaceous N°45E Extension





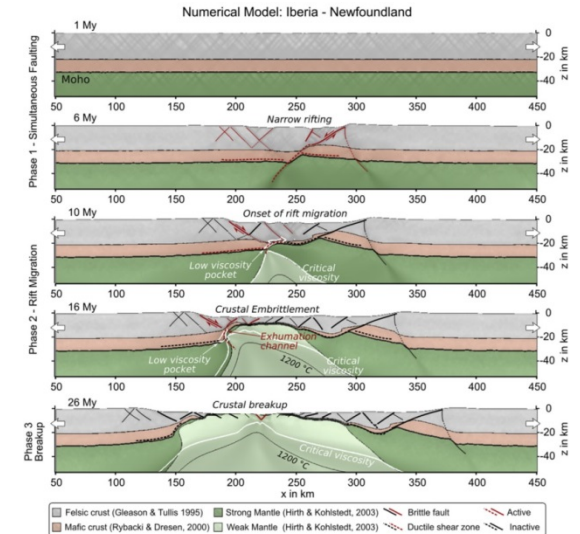
Tectono-stratigraphy analysis

Implications on the Newfoundland-Galicia rifted margins



(Pereira et al., 2017)

- Classical models focus only between the Flemish Cap and the Iberian Coast which correspond only to the late stage of continental rifting. -> a part of the early stage of rifting is missing
- Newfoundland-Galicia rifted margins usually classified as narrow rift system
- However, the deformation associated with the Newfoundland-Iberia rift system extends 400 km west of Flemish Cap
- Orphan Basin must be taken into account



(Brune et al., 2017)

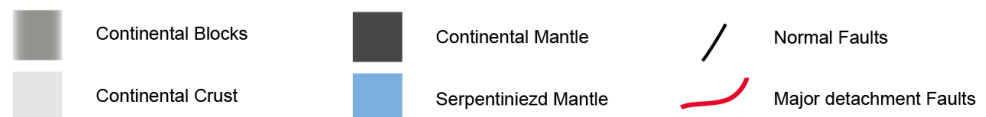
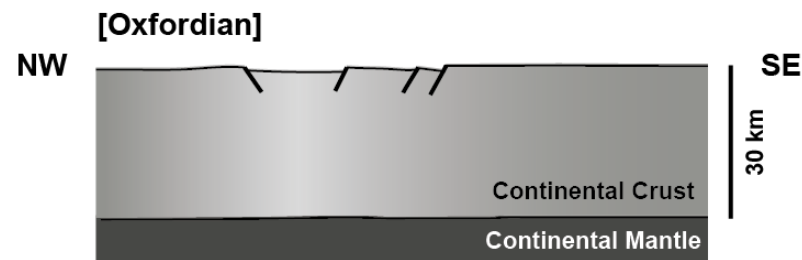
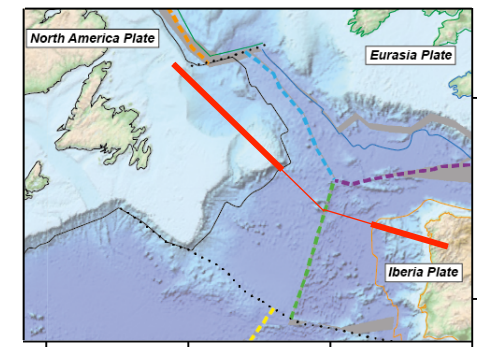
W. Brune et al.

Tectono-stratigraphy analysis

Implications on the Newfoundland-Galicia rifted margins

- Early continental extension may start in the Oxfordian time
- The Flemish Cap and Galicia Bank were still aggregated together

Plate Reconstruction at 83 Ma



2018 Conjugate Margins Conference

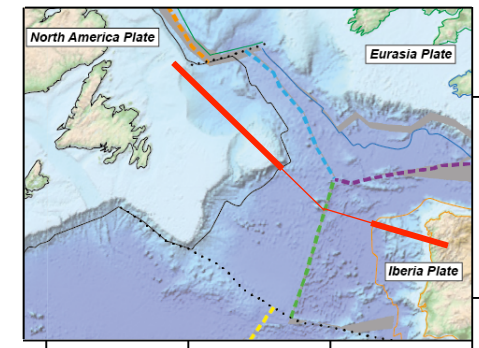


Tectono-stratigraphy analysis

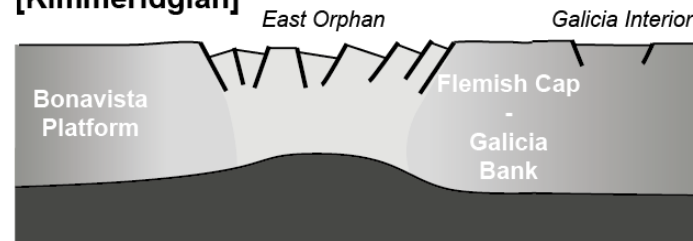
■ Implications on the Newfoundland-Galicia rifted margins

- Extension focused at the eastern and western rims of the Flemish Cap-Galicia Bank
- Both, in the East Orphan Basin and the Galicia interior basin (east of the Galicia Bank), extension initiates in the Kimmeridgian

Plate Reconstruction at 83 Ma



[Kimmeridgian]



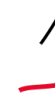
Continental Blocks

Continental Crust



Continental Mantle

Serpentinized Mantle



Normal Faults

Major detachment Faults

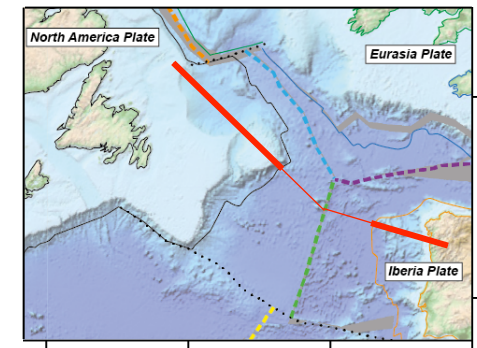
2018 Conjugate Margins Conference

Tectono-stratigraphy analysis

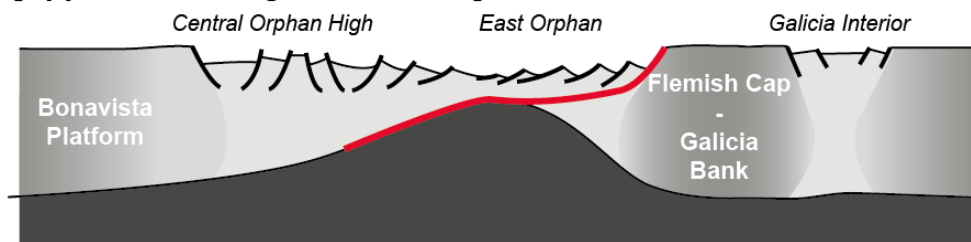
Implications on the Newfoundland-Galicia rifted margins

- The eastern and central parts of the Orphan Basin underwent widespread crustal extension and local hyper-extension from the Kimmeridgian to Upper Tithonian

Plate Reconstruction at 83 Ma



[Upper Kimmeridgian-Tithonian]



Continental Blocks

Continental Crust



Continental Mantle

Serpentinized Mantle



Normal Faults

Major detachment Faults

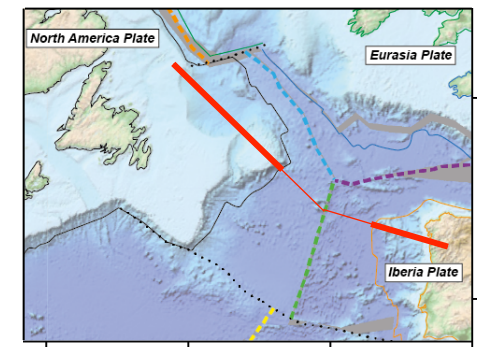
2018 Conjugate Margins Conference

Tectono-stratigraphy analysis

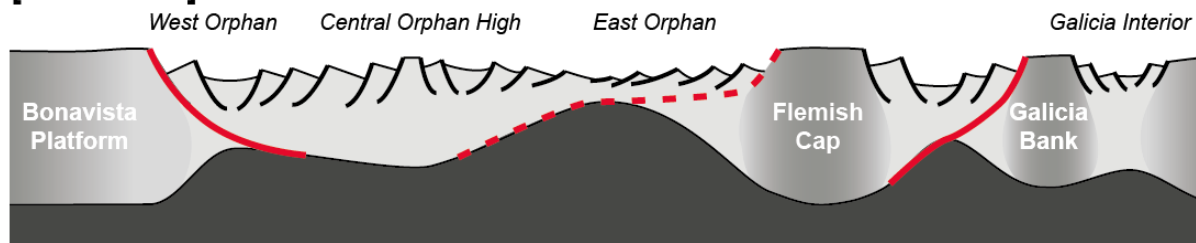
Implications on the Newfoundland-Galicia rifted margins

- Crustal hyper-extension occurred in the western Orphan Basin
- The Flemish Cap-Galicia Bank breaks up
- A rift branch shifts between them within the Deep Galicia Margin after the Valanginian

Plate Reconstruction at 83 Ma



[Neocomian]



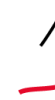
Continental Blocks

Continental Crust



Continental Mantle

Serpentinized Mantle



Normal Faults

Major detachment Faults

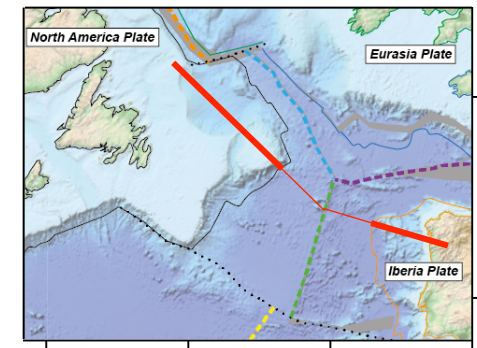
2018 Conjugate Margins Conference

Tectono-stratigraphy analysis

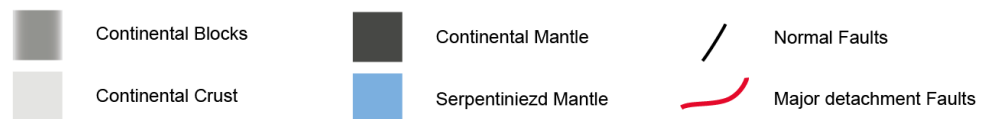
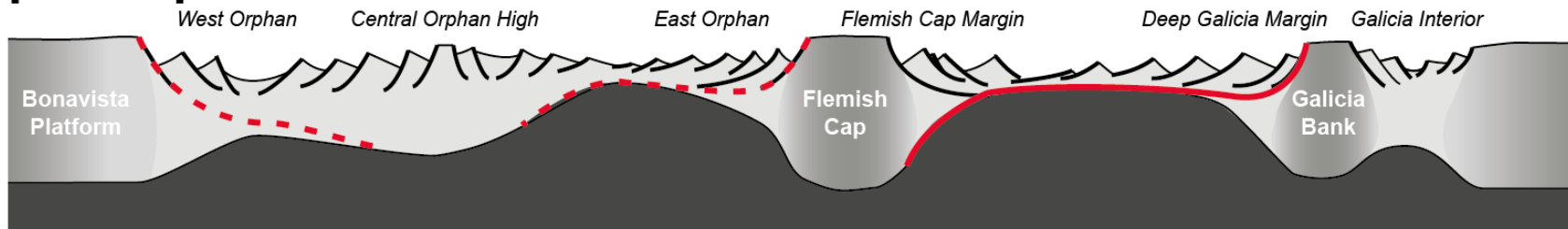
Implications on the Newfoundland-Galicia rifted margins

- Minor extension persists in the western Orphan Basin
- Continental extension focused East of the Flemish Cap and continental breakup was achieved during the Hauterivian

Plate Reconstruction at 83 Ma



[Hauterivian]



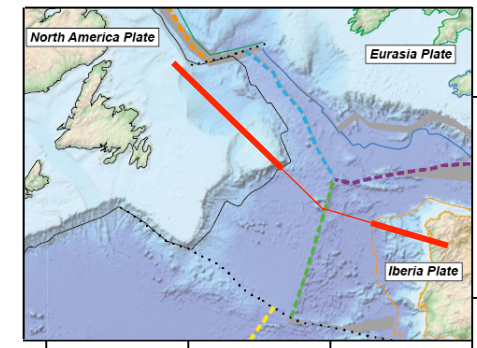
2018 Conjugate Margins Conference

Tectono-stratigraphy analysis

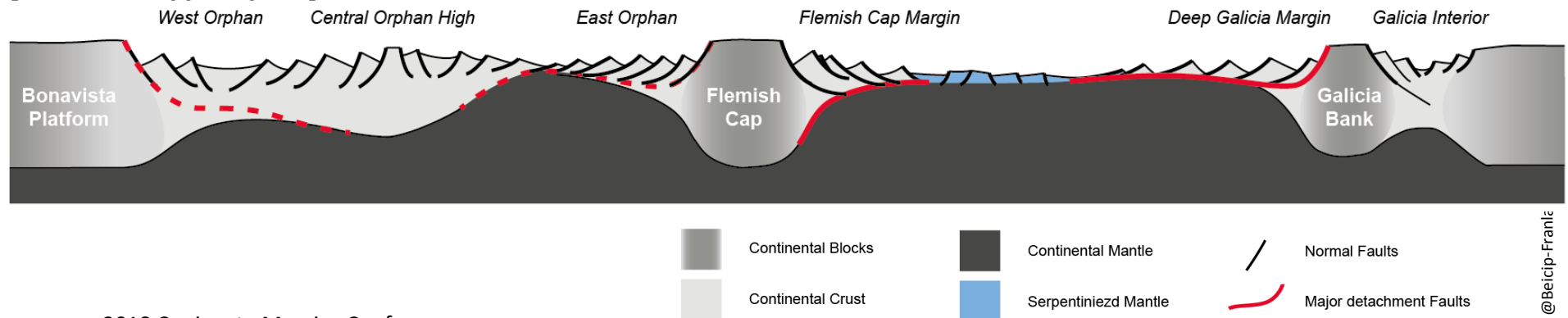
Implications on the Newfoundland-Galicia rifted margins

- Subcontinental mantle exhumation occurred from the Barremian to Upper Aptian

Plate Reconstruction at 83 Ma



[Barremian-Upper Aptian]



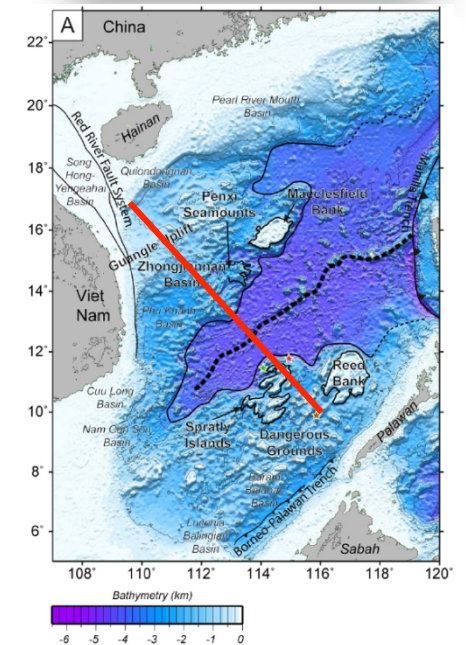
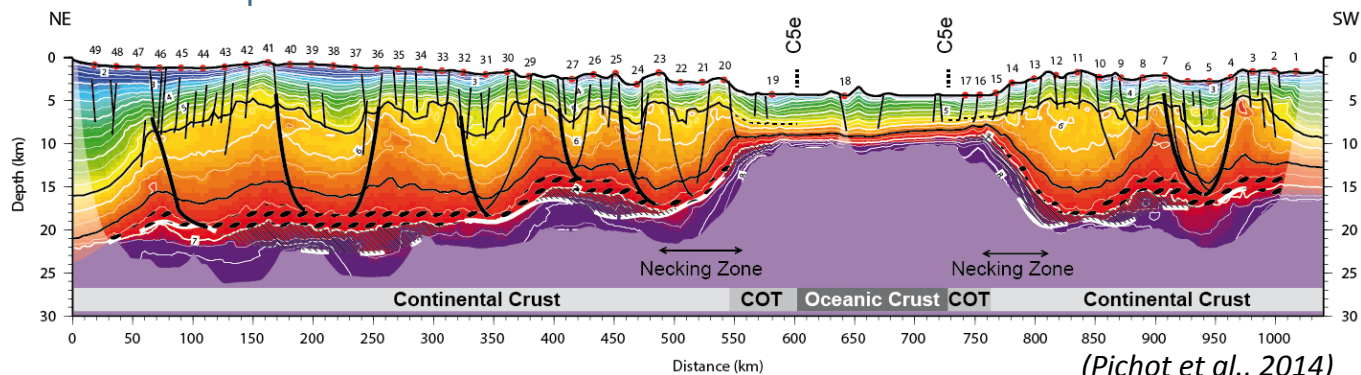
@Beicip-Franl



Discussion

■ Wide extended continental crust in rift propagation rift setting

- South China Sea (SCS) case study
- SCS is a “V-shape” propagation rift
- Presence of continental blocks: Macclesfield Bank and Reed Bank , two unstretched granitic plutons located on each side of the conjugate margins
- More than 800 km of stretched lithosphere in the Southern half part of the SCS

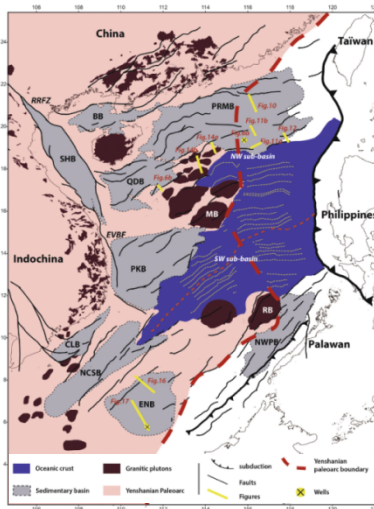




Discussion

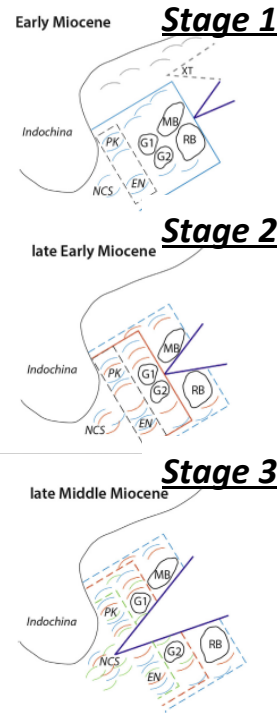
Wide extended continental crust in rift propagation rift setting

- South China Sea (SCS) case study



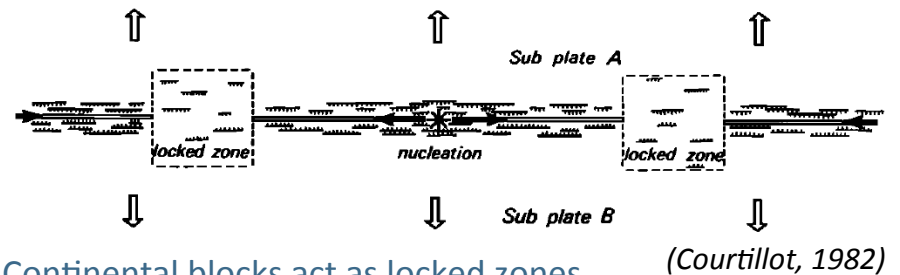
(Sava et al., 2014)

Time



- Rift propagates progressively toward SW
- Granitic blocks may have an influence on the propagation of the rifting

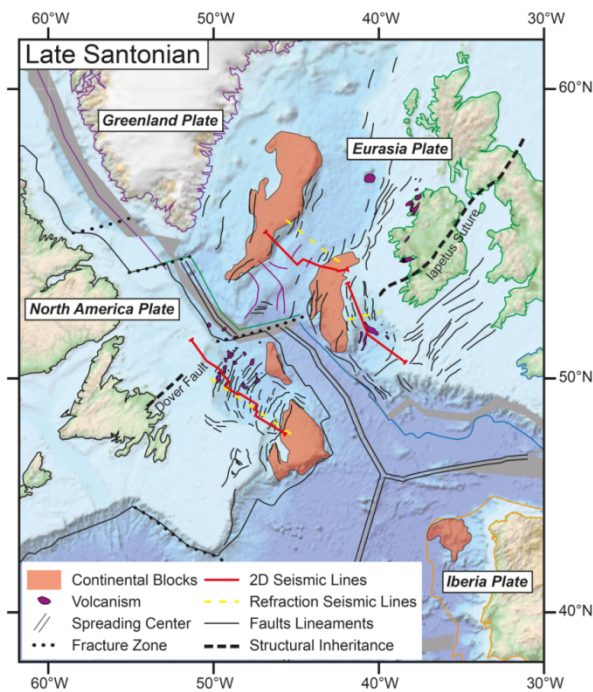
- Tectonic concept



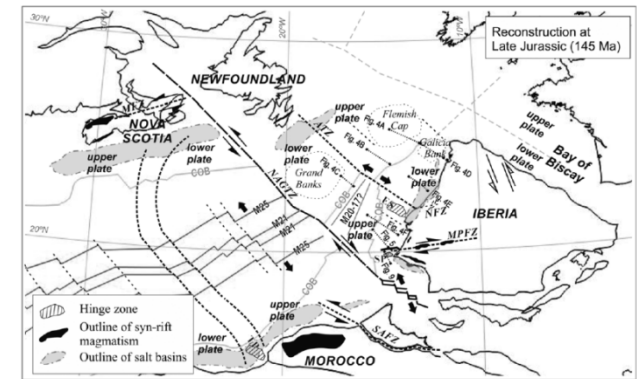
- Continental blocks act as locked zones
- Rift propagates towards the locked zones along thinned lithosphere
- Locked zones present higher strength
- Rift slows down as it approaches one
- The amount of stretched lithosphere is much higher at the vicinity of the locked zones
- The deformation is distributed over larger area

Discussion

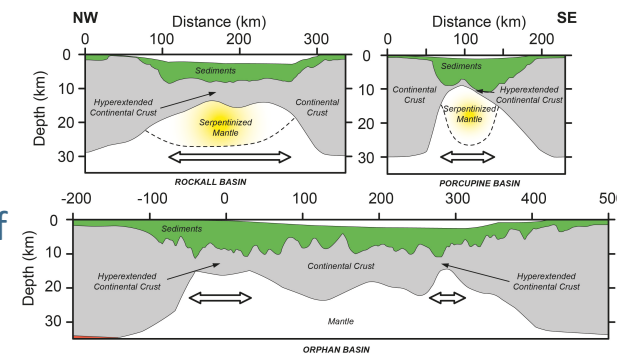
- Wide extended continental crust in rift propagation rift setting
 - Southern North Atlantic margins



- Newfoundland-Iberia rifted margins is a propagation rift
- Hyper-extension areas are systematically located between or at the edge of continental blocks
- Continental blocks act as locked zones favoring the distribution of the deformation over a larger area.



(Pereira et al., 2017)



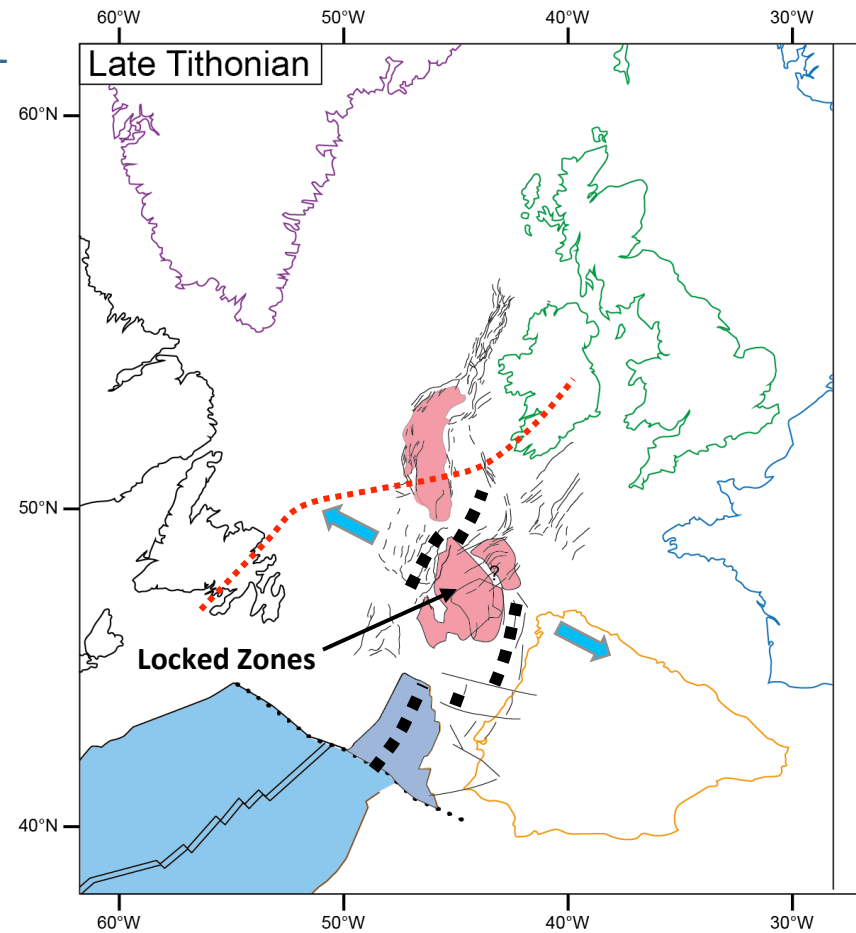
(modified from Lau et al., 2015)



Discussion

■ Early Stage of Rifting Hypothesis in North ATL

- Wide rift from east Orphan to Galicia Interior Basins up to The Southern Porcupine Basin
- Iapetus suture may stop the northward propagation of the Rift further north
- Good Late Jurassic source rocks potential preserved within the hanging wall blocks over a wide area

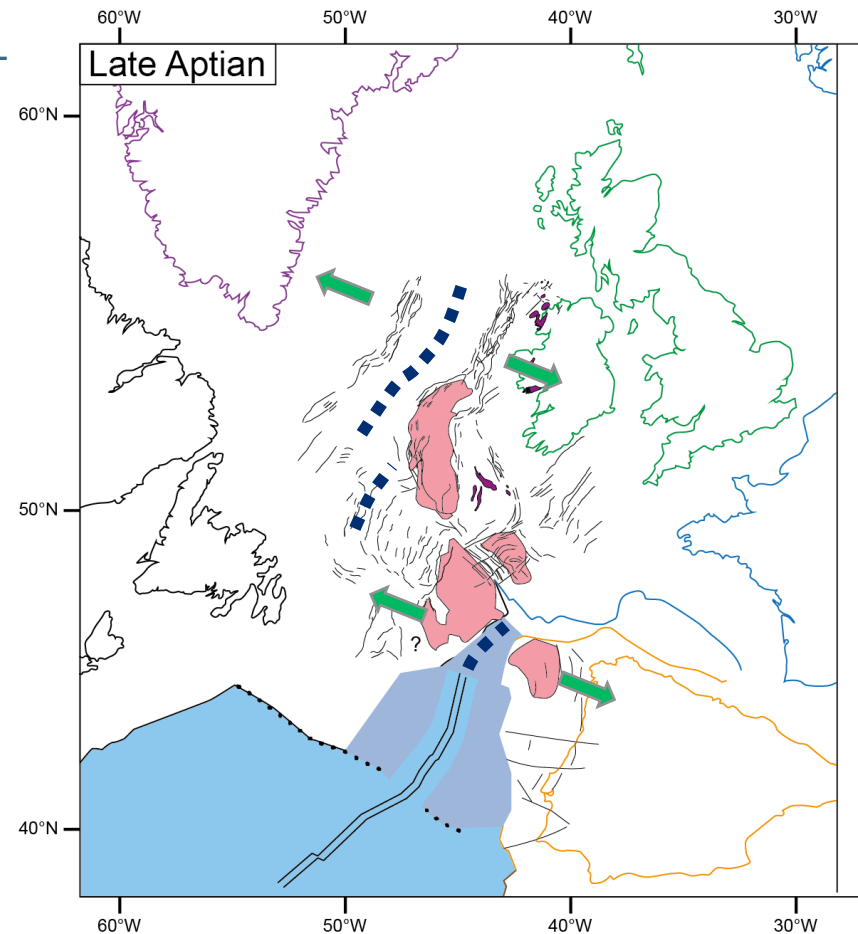




Discussion

■ Early Stage of Rifting Hypothesis in North ATL

- Flemish Cap and Galicia Bank splits apart
- Eastern rift branch focus between these two continental blocks
- Western rift branch occurs from the Western Orphan Basin up to the Rockall Trough
- Large clastic influx providing good Cretaceous Reservoir



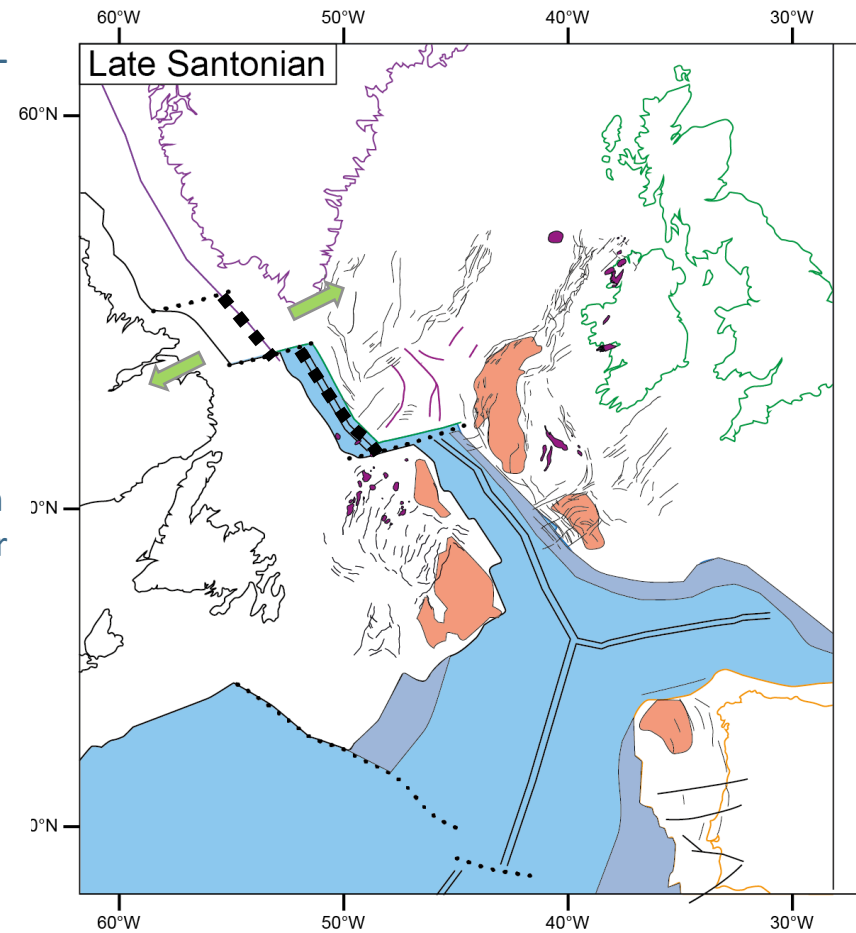


Discussion

■ Early Stage of Rifting Hypothesis in North ATL

- Late Early Cretaceous drastic change of regional stress from NW-SE to NE-SW
- Continental rifting propagates now toward the northwest and led to the continental breakup between North America and Northwest Europe in the late Lower Cretaceous (Aptian-Albian)
- New structural traps formed by the Late Early Cretaceous tectonic reactivation

2018 Conjugate Margins Conference





Conclusion (1/2)

- The tectono-stratigraphic analysis in the Orphan Basin allow to address...

- **How the Newfoundland-Iberia Rift and Newfoundland-Ireland Rift is expressed in this area?**
 - Orphan Basin records a long-lasting rifting process of more than 65 Ma
 - Newfoundland-Iberia rift system explains most of the structural evolution of the Orphan Basin
 - Orphan Basin experienced several hyper-extensional episodes without achieving a continental break-up
 - Newfoundland-Ireland Rift system implies minor deformation in the basin (except in the western part), including tectonic inversion



Conclusion (2/2)

- The tectono-stratigraphic analysis in the Orphan Basin allow to address...
- **What does the Orphan Basin tell us about the North Atlantic opening?**
 - Orphan Basin records the early stages of rift propagation related to the North Atlantic opening
 - The 400 km long of stretched continental lithosphere of the Orphan Basin must be included when studied the Newfoundland-Galicia Rift System
 - Continental blocks and orogenic sutures must act as locked zones during rift propagation and favor wide rift systems development at their vicinity
- **What about the Hydrocarbon potential of this basin?**
 - Becip-Franlap Resource assessment demonstrated have high petroleum system potential



2018 Conjugate Margins Conference

Halifax, Nova Scotia, August 19–22, 2018



Thank you

Thibaud Pichot¹, Erwan Le Guerroué¹, Pierre-Yves Filleaudeau¹, Luca Micarelli¹

1. Beicip-Franlab, Rueil-Malmaison, France.

