Mapping Structures of Ancient Exposed Hyperextended Margins in the Alps: A Key to Understand the Evolution of Ultra-Deep Water Passive Continental Margins?*

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Abstract

Research into the formation of passive rifted margins is incontestably undergoing a paradigm shift. The discovery of exhumed continental mantle and hyperextended crust devoid of significant normal faulting directly overlain by shallow marine sediments is proving fundamental in defining the controls and processes that thin continental lithosphere. However, the development of these new concepts critically depends on the access to pertinent geological and geophysical data sets, which remains a key problem. At present, little is known about the depositional environments, sedimentary facies, the kinematics and age of structures, or the subsidence and thermal history of pre-to syn-rift sediments of many distal margins.

Mapping of rift structures and depositional systems in the Alps has helped to identify lithologies and structures similar to those drilled along the Iberia-Newfoundland margins or those supposedly comprising the pre-salt sag basins of the South Atlantic. The most prominent structures observed in the Alps are top-basement detachment faults. These structures can be traced from relatively unextended continental crust across the ocean-continent transition towards embryonic oceanic crust and are overlain by extensional allochthons, tectono-sedimentary breccias overlain by syn- and post-rift sediments and further oceanwards, MOR-basalts. Crucial observations include: 1) detachment faults formed either late in the extension process or after the crust was already thinned to less than 10 km; 2) shallow depositional environments despite major crustal thinning; and 3) even though there is a lack of volcanic activity, magmatic infiltration has occurred in the underlying mantle while the crust was thinning. These crucial observations have major implications for the thermal evolution and thus survivability of syn-to post-rift petroleum systems in hyperextended margins.

Margin Modelling Phase 2

Mapping structures of ancient exposed hyperextended margins in the Alps: A key to understand the evolution of ultra-deep water passive rifted margins

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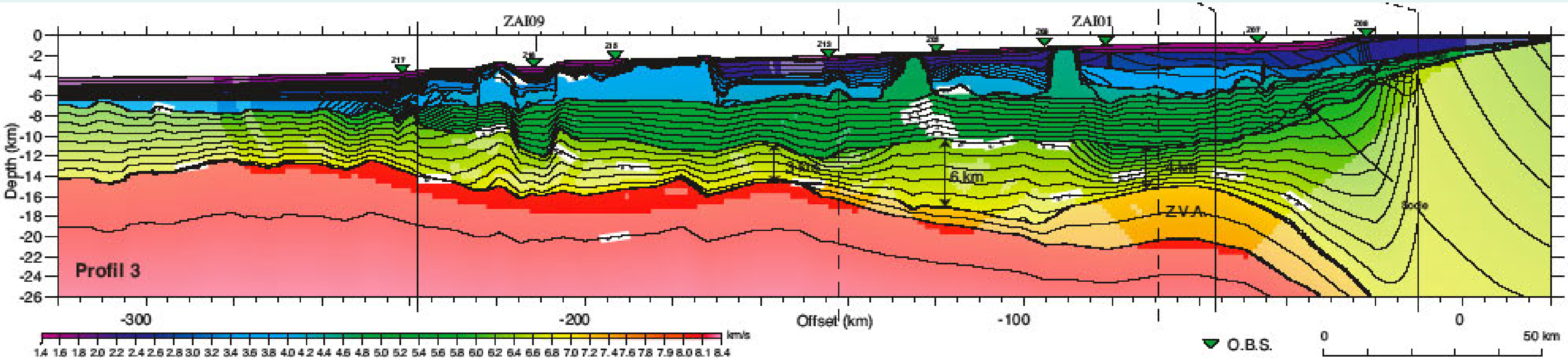
In collaboration with
L.Lavier, O.Müntener, N.Kusznir, Ch.Johnson
and many others

Major new discoveries in magma-poor margins in the last two decades

Refraction seismic data from the West-African margin: Ifremer /TOTAL

Contrucci et al. 2004

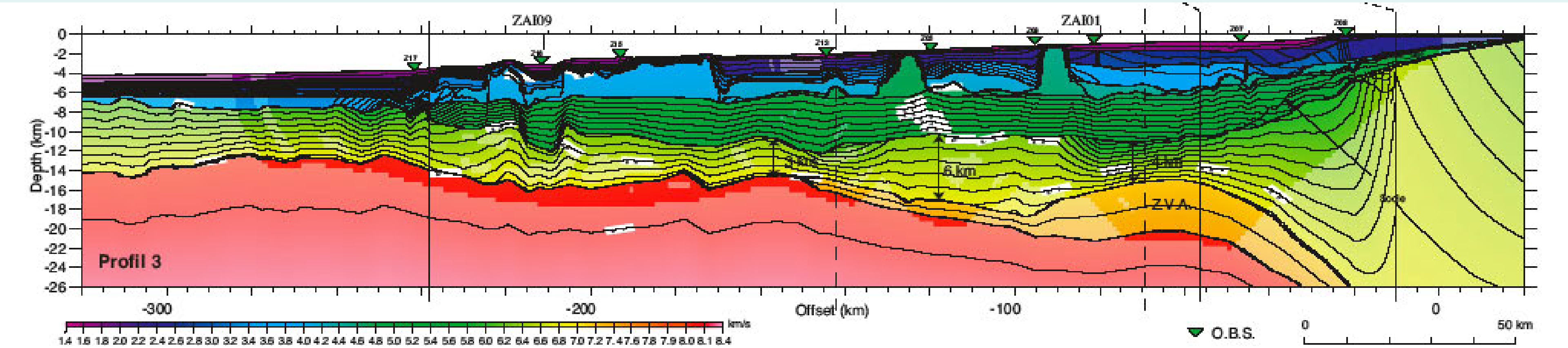


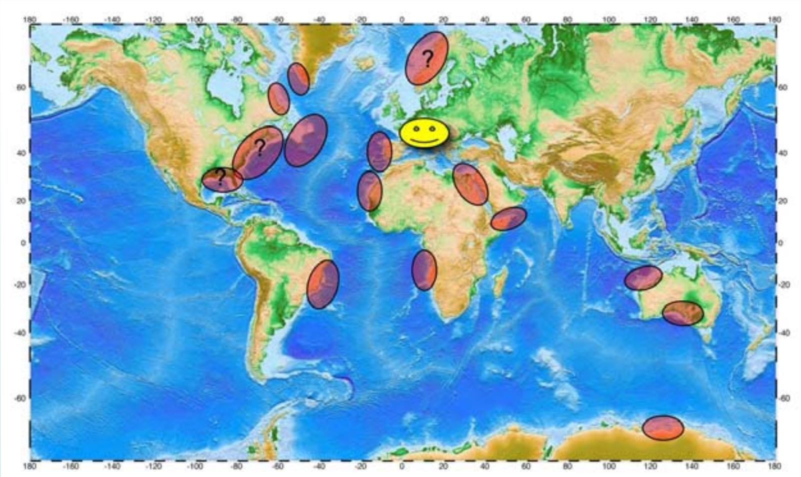
- Mantle exhumation and magma starvation in ocean continent transitions
- Hyper-extended crust with little seismic evidence for normal faulting associated with sag-basins
- Top-basement detachment faults in ocean-continent transitions

Where are the margins that show these features ?

Refraction seismic data from the West-African margin: Ifremer /TOTAL

Contrucci et al. 2004



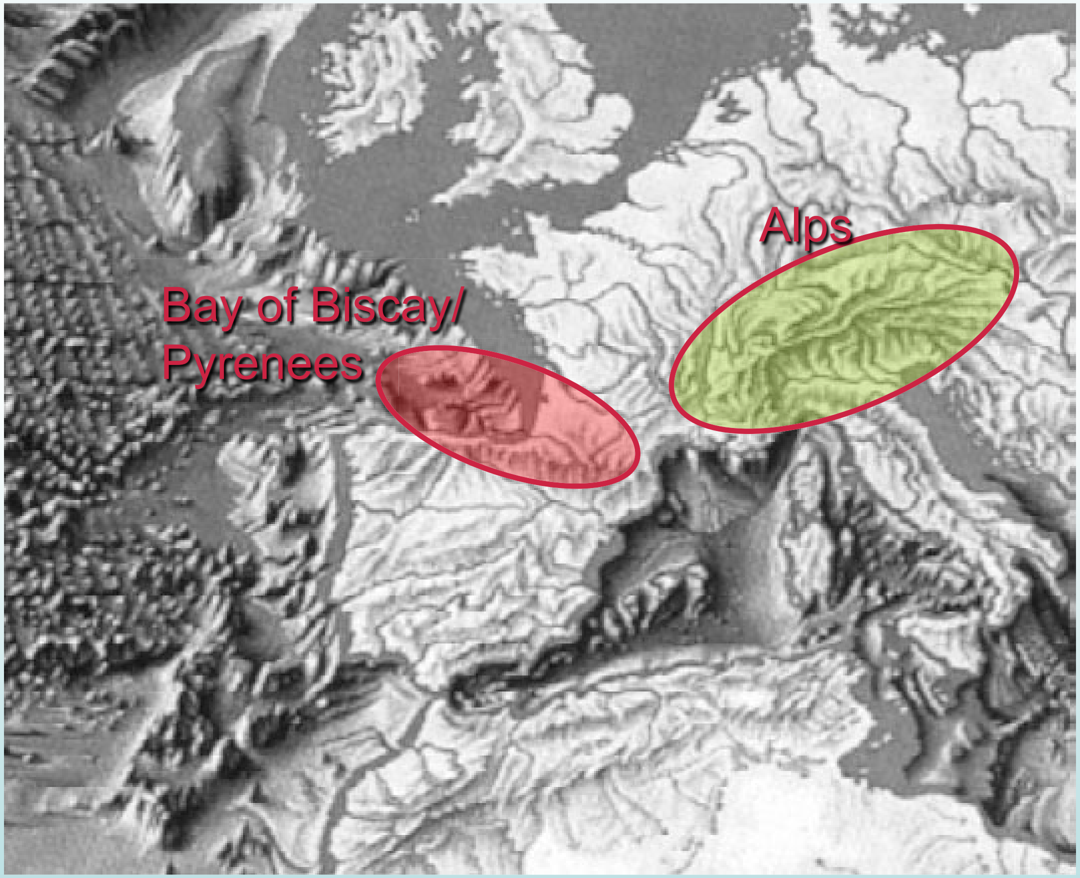


Magma-poor margins with evidence for hyper-extended crust and/or mantle exhumation

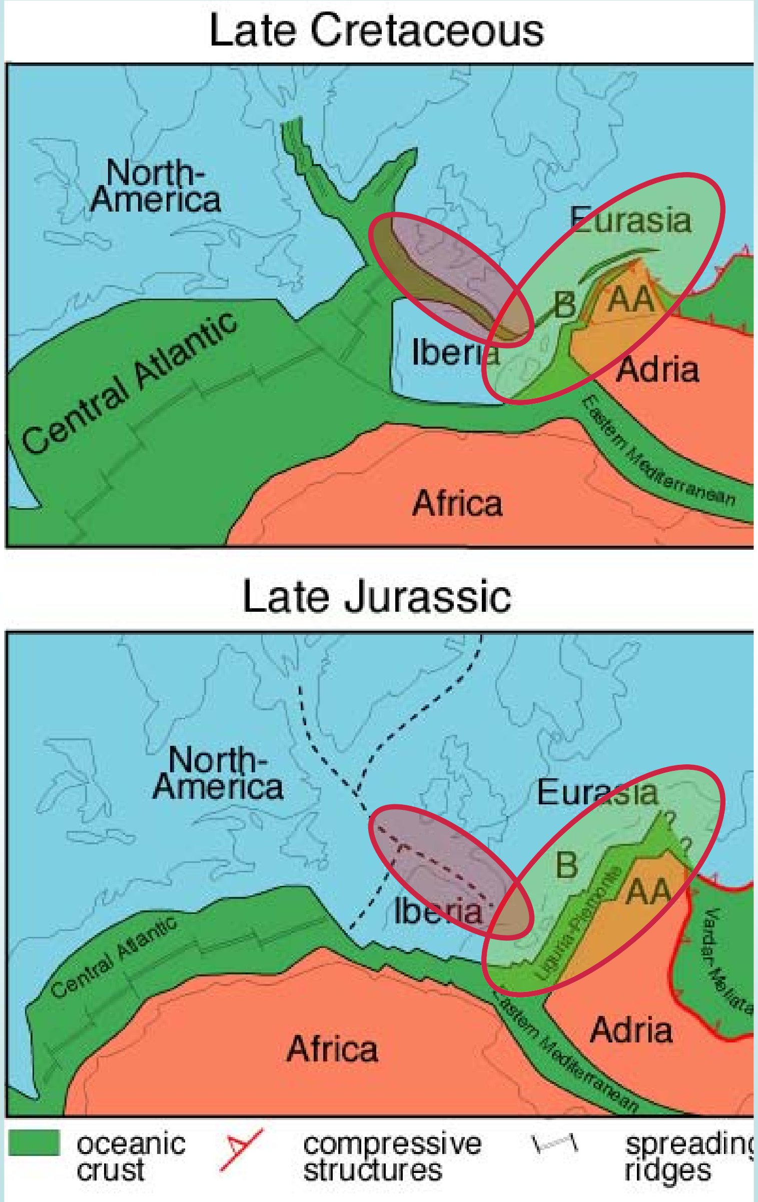
based on high-quality refraction/reflection seismic data, drilling and/or dredging

The Alpine system in W-Europe

Present-day



Paleogeographic evolution

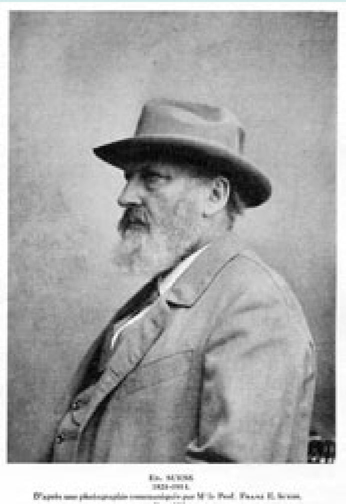


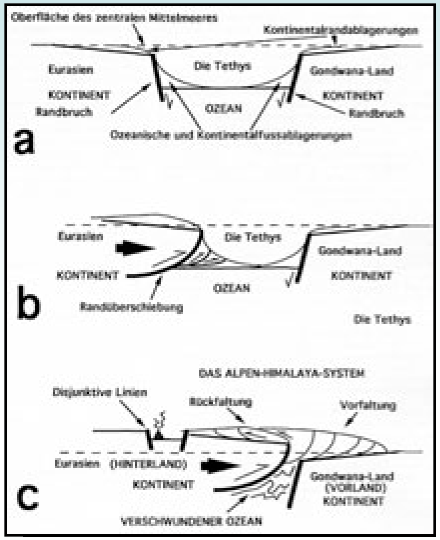
From Manatschal and Bernoulli 1999

Alpine Tethys margins: Historical retrospect

"From oceans to orogens"

Eduard Suess 1831-1914





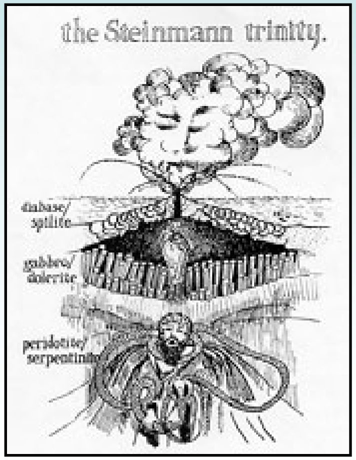
from Antlitz der Erde (after Sengör 1996)

"Oceans in orogens"

Gustav Steinmann

Gustav Steinmann

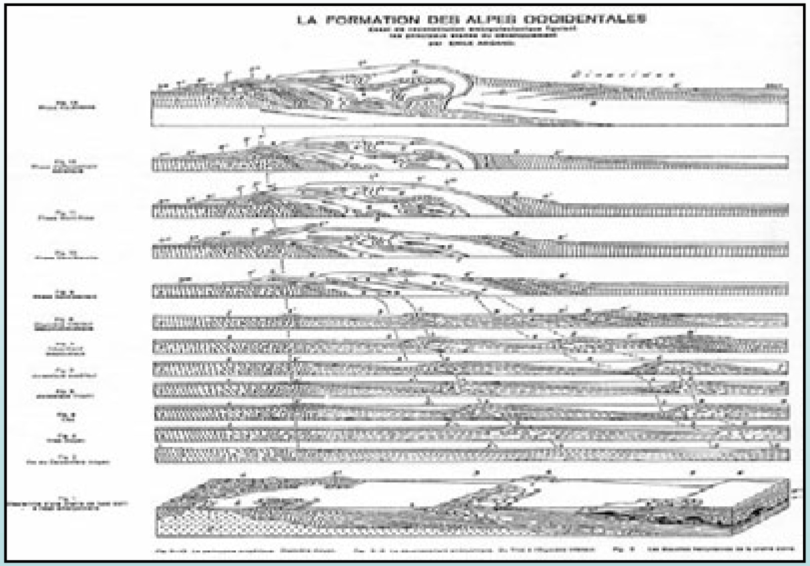
after Bernoulli et al. 2003



"the close association of serpentinites, diabase, and radiolarite is characteristic for the axial part of the "geosyncline" and the deep ocean floor"

"Tectonique embryonaire"

Emile Argand 1916

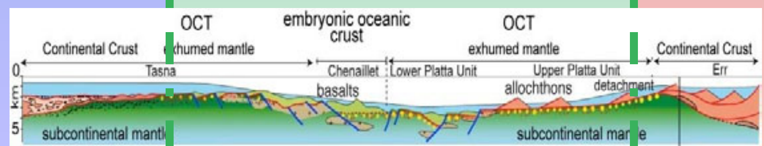


Remnants of the Alpine Tethys margins in the Alps

the result of more than one century of geology

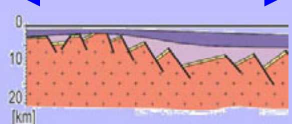
EUROPEAN MARGIN | ALPINE TETHYS | ADRIATIC MARGIN

Brian./Tasna Chenaillet Platta/Err



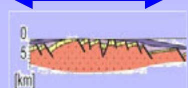
Manatschal and Müntener 2008

Dauphiné



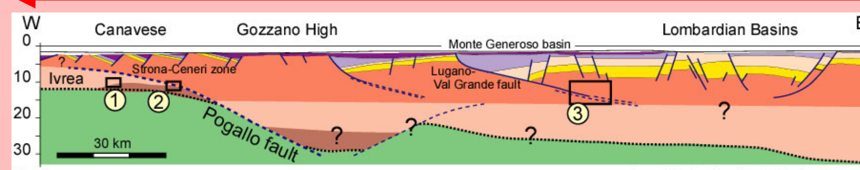
Lemoine et al. 1986

Briançonnais



Lemoine et al. 1986

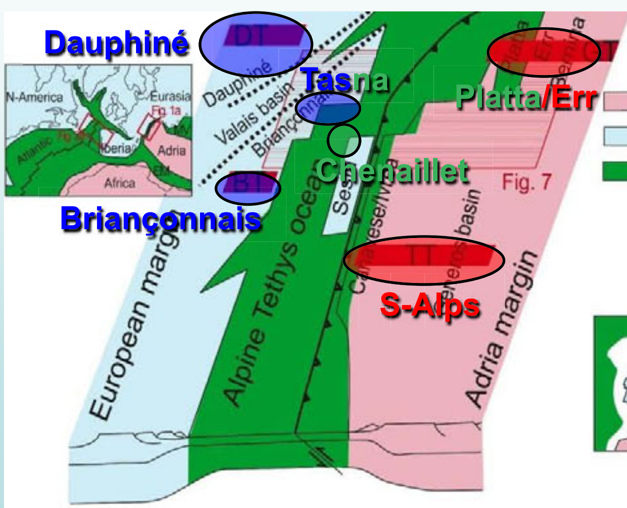
S-Alps



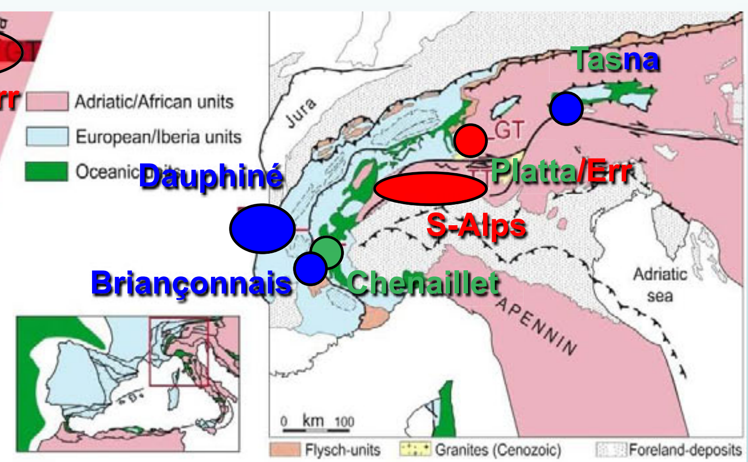
Modified after Bertotti et al 1993

paleo-geography

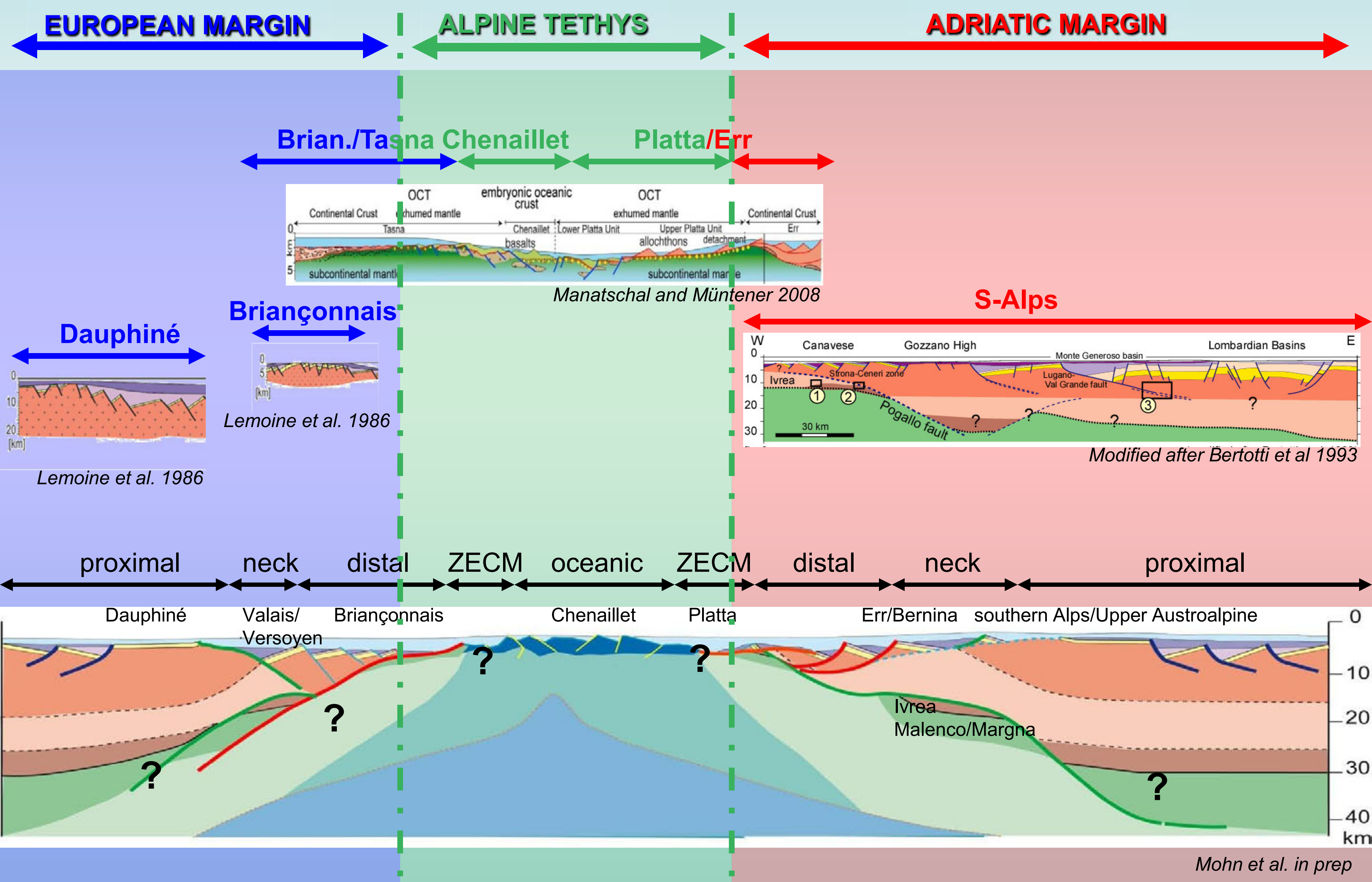
(end of Jurassic)



present-day



Reconstruction of the Alpine Tethys margins in the Alps

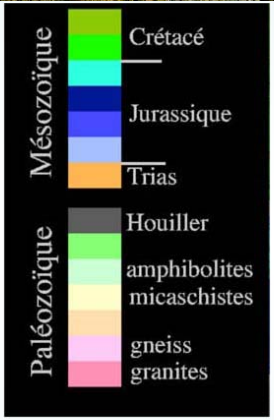


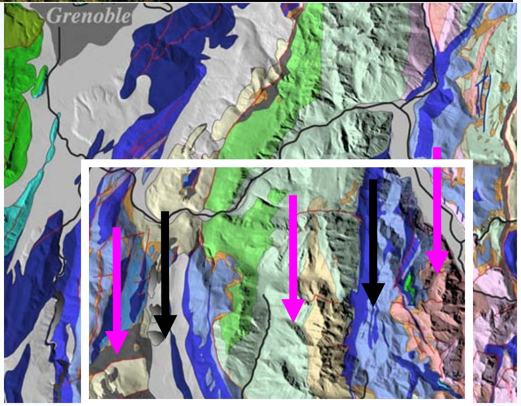
Proximal rifted margins

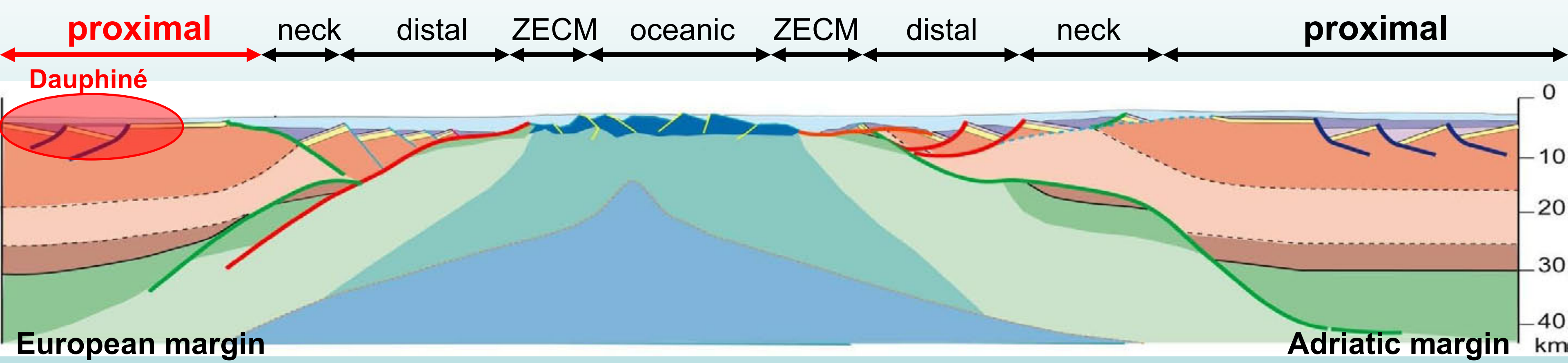
Le Massif du Taillefer

From Thierry Dumont, Grenoble

Preservation of rift-related Early Jurassic fault blocks

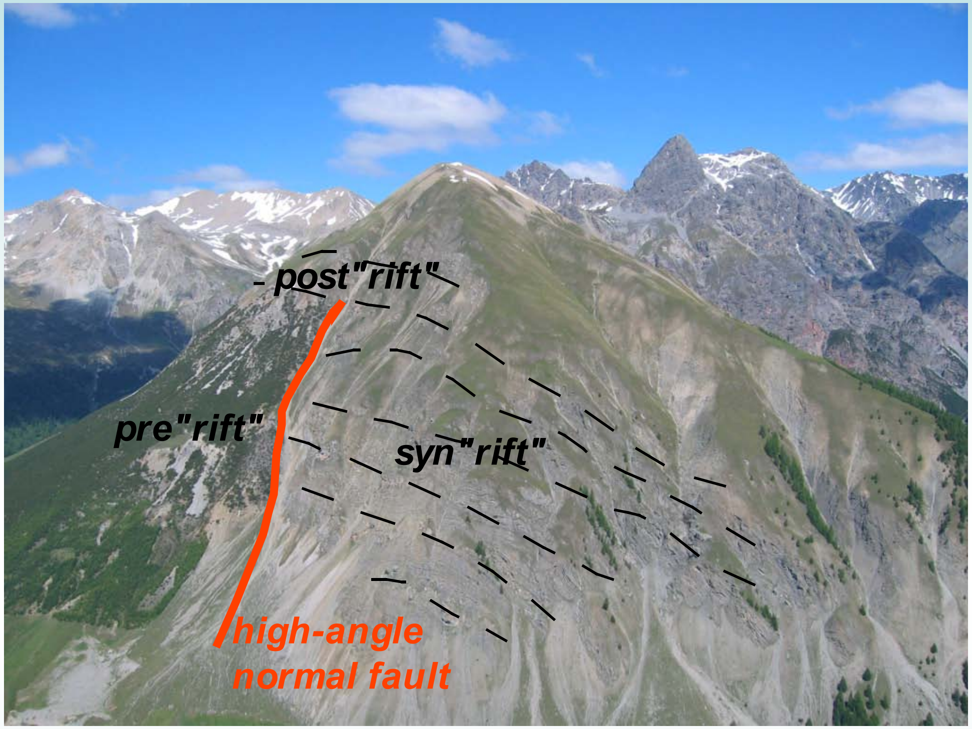




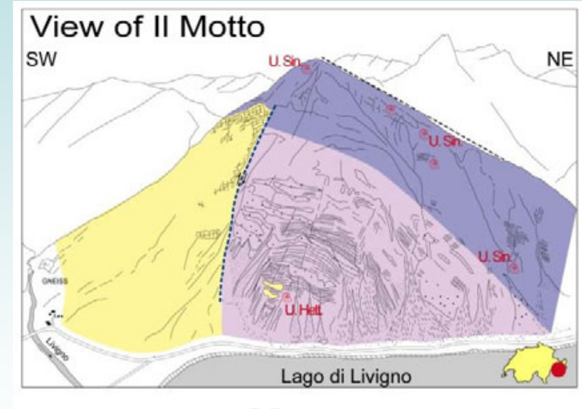


Mohn et al. in prep

Proximal rifted margins



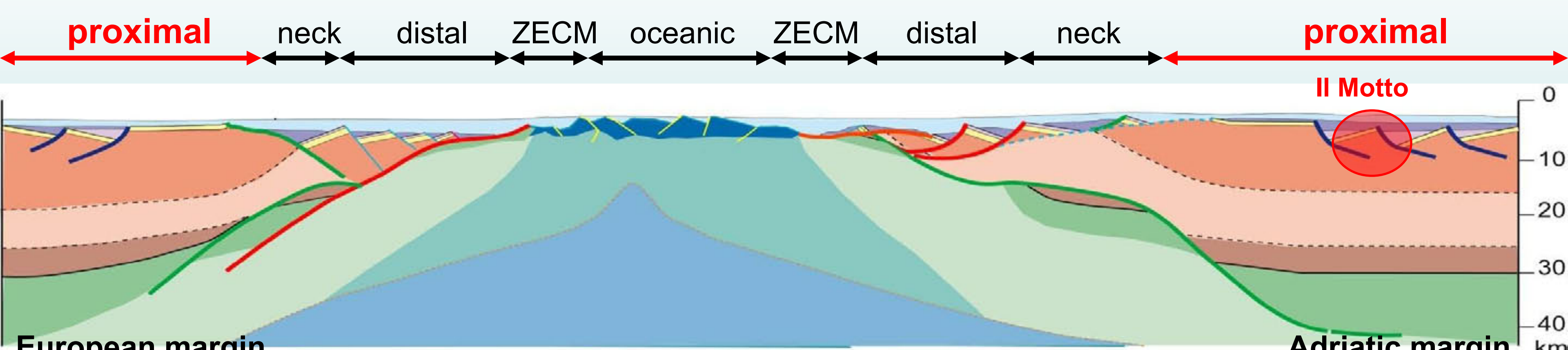
Manatschal et al. 2007



Il Motto

Eberli 1988

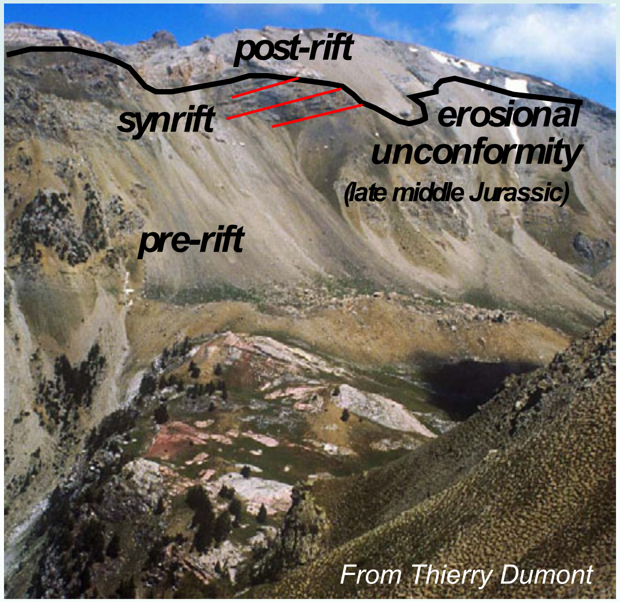
Early Jurassic high-angle normal fault preserving the relationships between pre-, syn- and post tectonic sediments



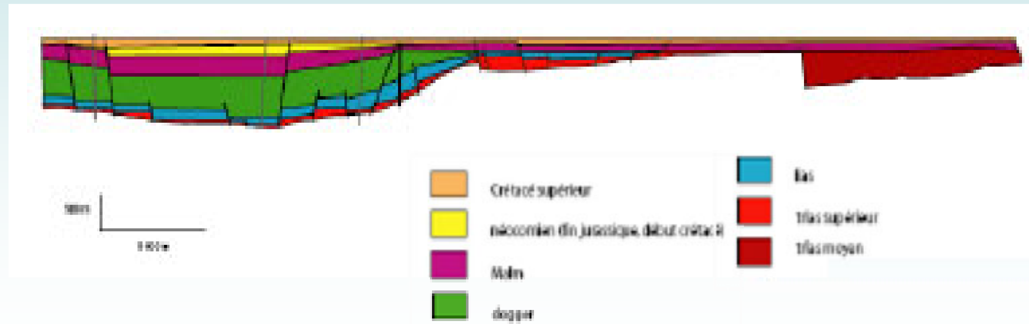
Mohn et al. in prep

Necking zone (Briançonnais domain/H-Block)

Briançonnais near Briançon
(SE France)

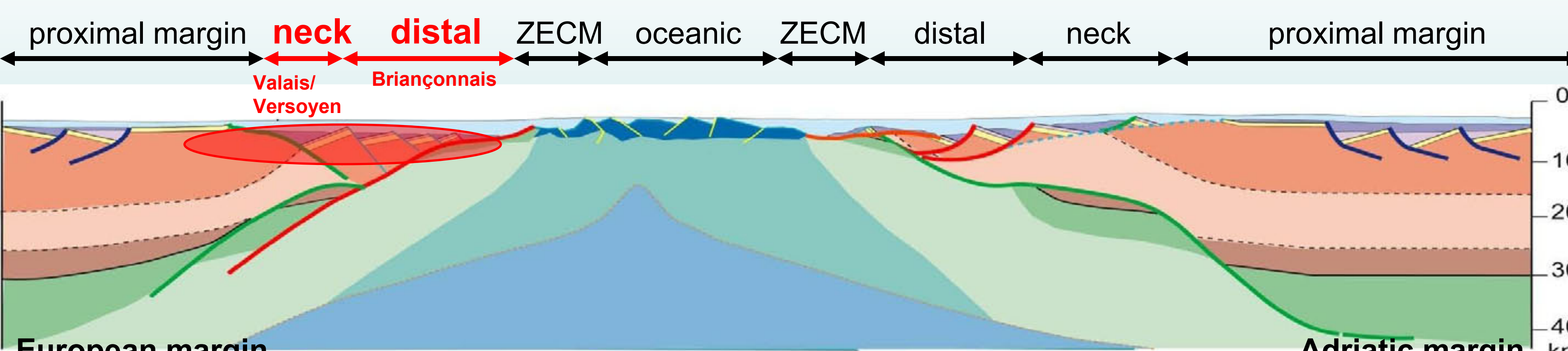


Sub Briançonnais (s 20km) **Briançonnais** (s 25 km)
(Médianes plastiques) (Médianes rigides)



Briançonnais domain
Lemoine et al. 1986, Borel 1995

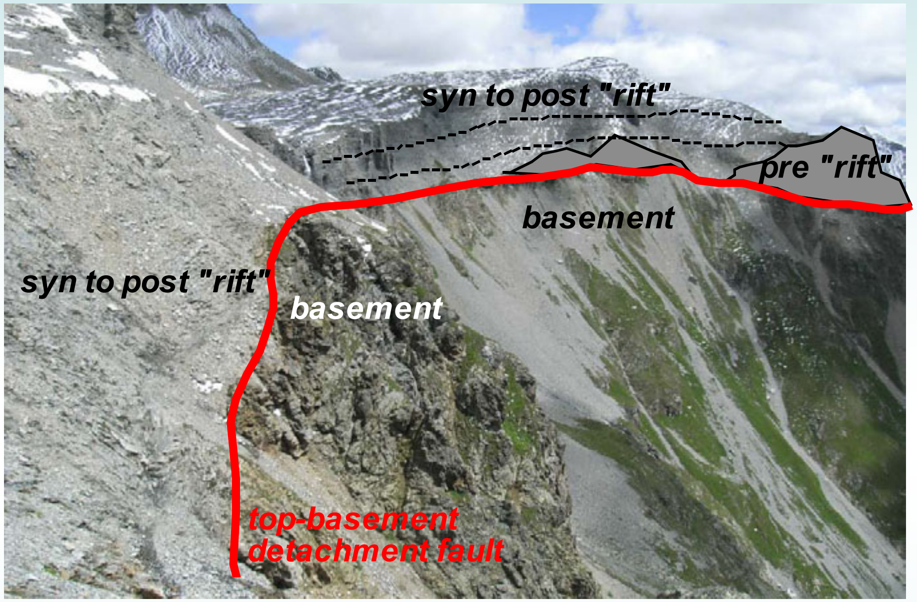
distal domain showing uplift during final rifting and rapid subsidence after continental breakup

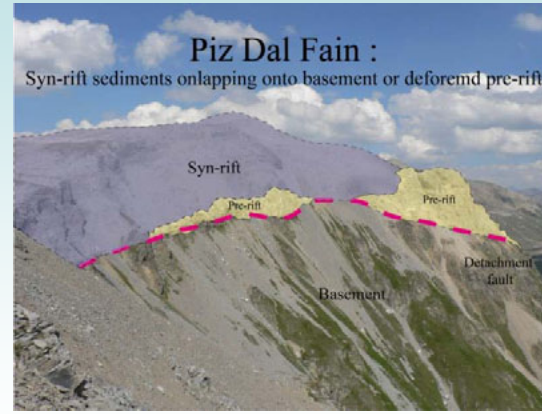


Mohn et al. in prep

Necking zone (Bernina domain)

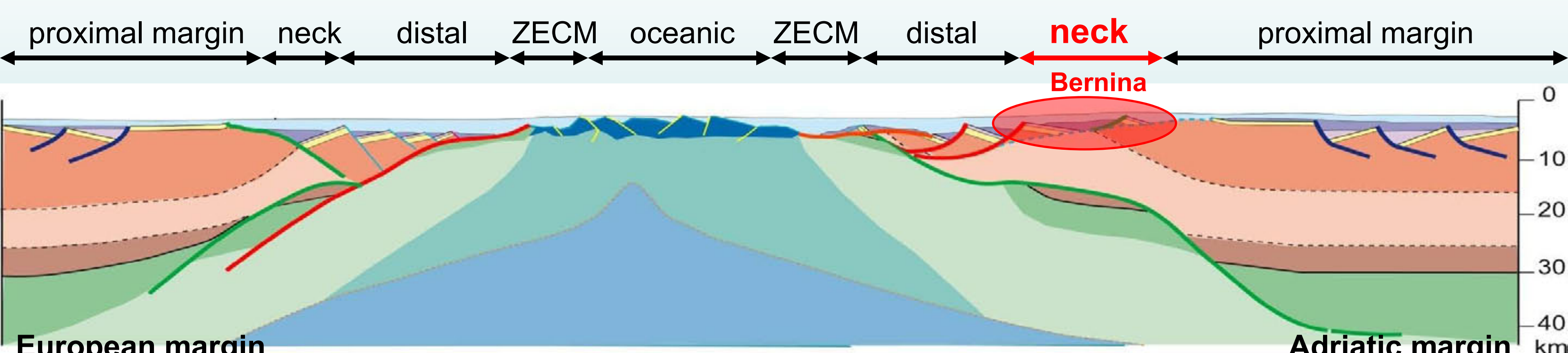
Val dal Fain/Bernina domain
(SW-Switzerland)





Bernina domain
Mohn et al. in prep

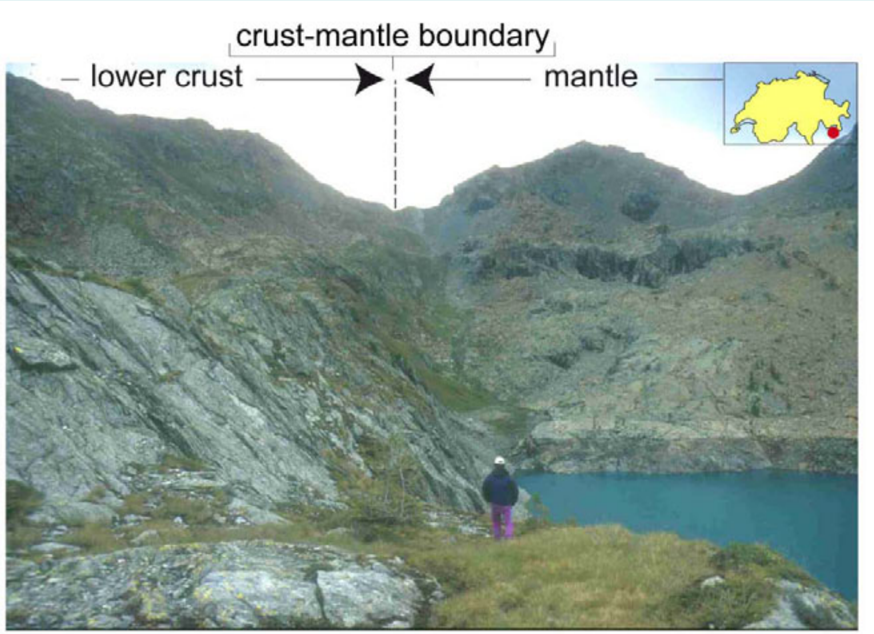
Exhumation of basement along top-basement detachment faults and onlapping of syn- to post-rift sediments



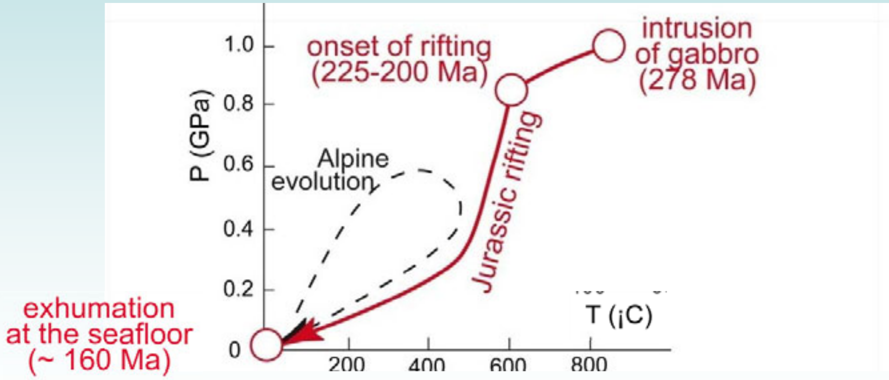
Mohn et al. in prep

Necking zone & distal margin (Malenco/Margna)

Val Malenco **(Italian/Swiss border)**



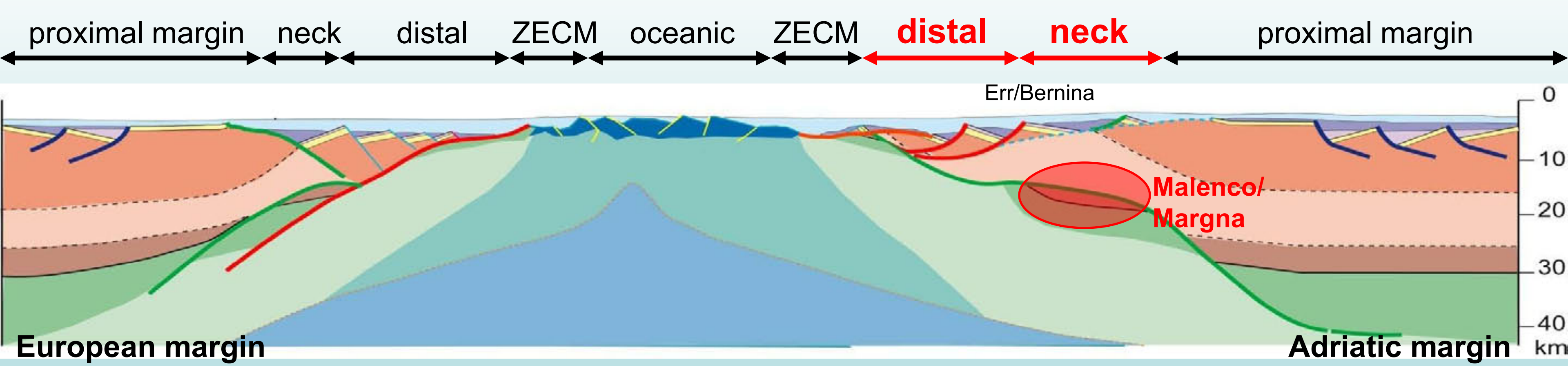
P-T-t path of a Permian crust-mantle boundary



Malenco/Margna domain

Müntener et al. 2000

Exhumation and P-T-t constraints from a Permian crust mantle boundary

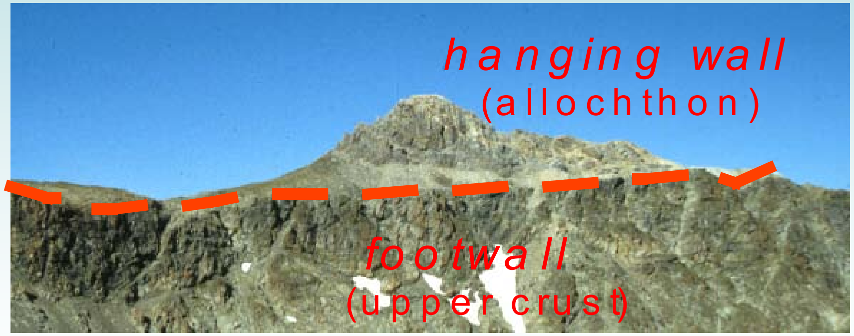


Mohn et al. In prep

Distal margin & ZECM (Err-Platta)

Parsettens (Platta nappe) (SE Switzerland)

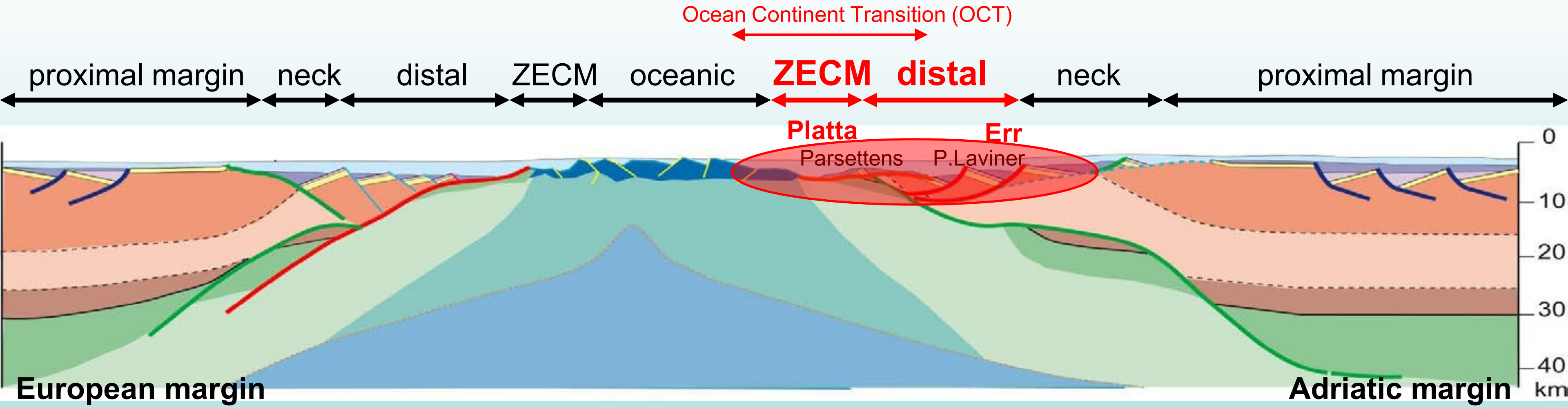
Piz Laviner (Err nappe) (SE Switzerland)



Err/Platta Ocean Continent Transition

Manatschal 2004

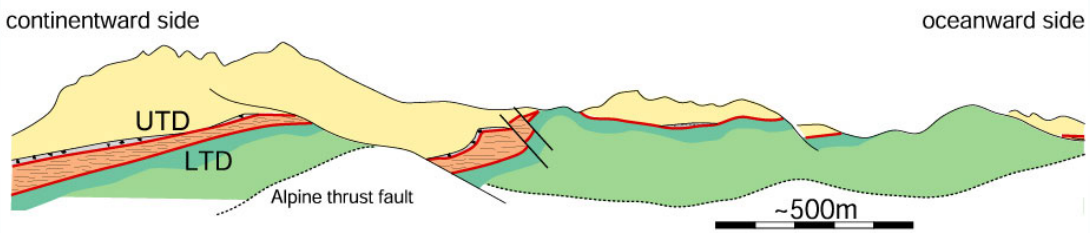
Low-angle detachment faults overlain by extensional allochthons



Mohn et al. in prep

Tasna Ocean Continent Transition (OCT)

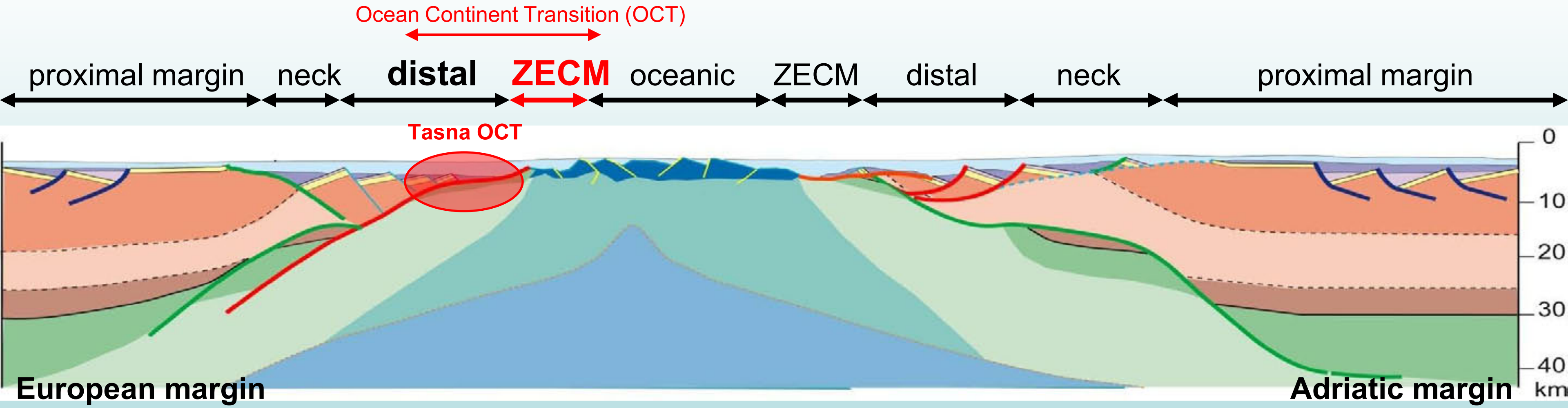
The Tasna OCT **(SE Switzerland)**



Tasna OCT

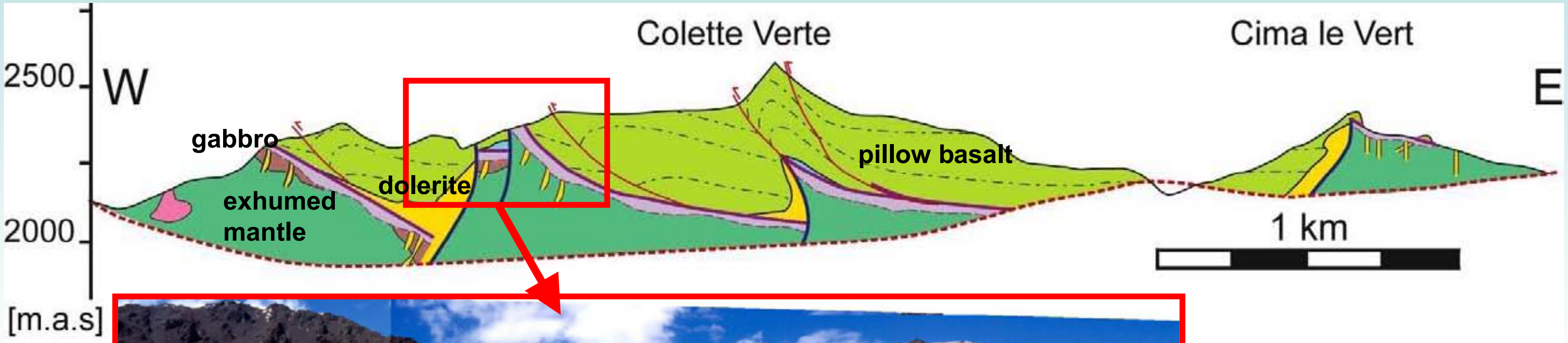
Florineth and Froitzheim 1994, Manatschal et al. 2007

wedge of continental crust and mantle exhumation

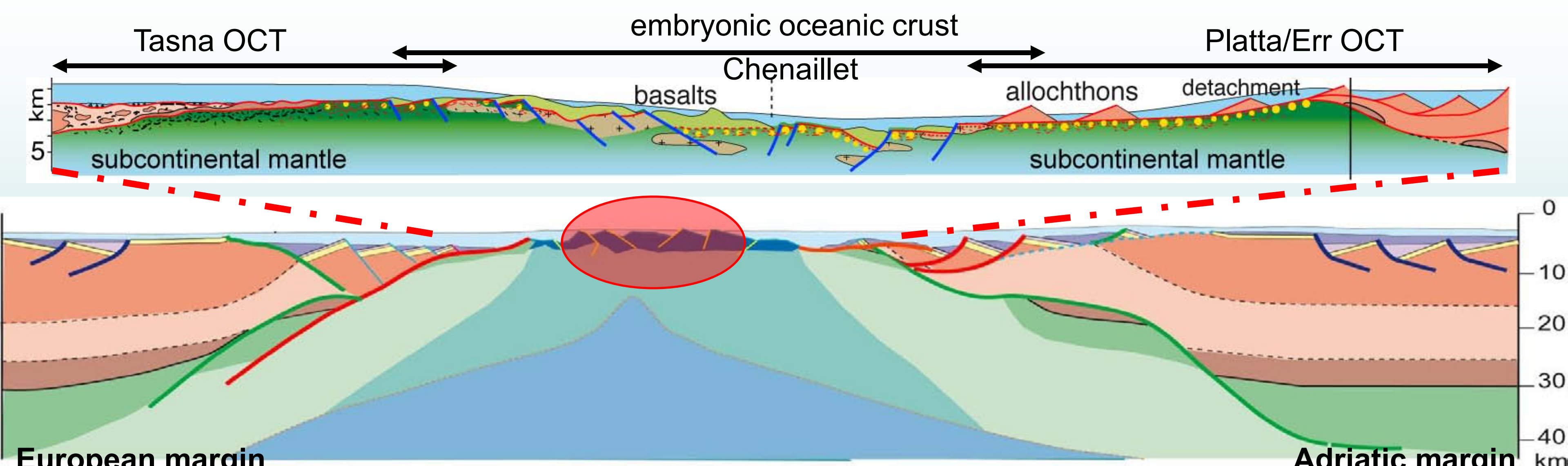


Mohn et al. in prep

Embryonic oceanic crust (Chenaillet)

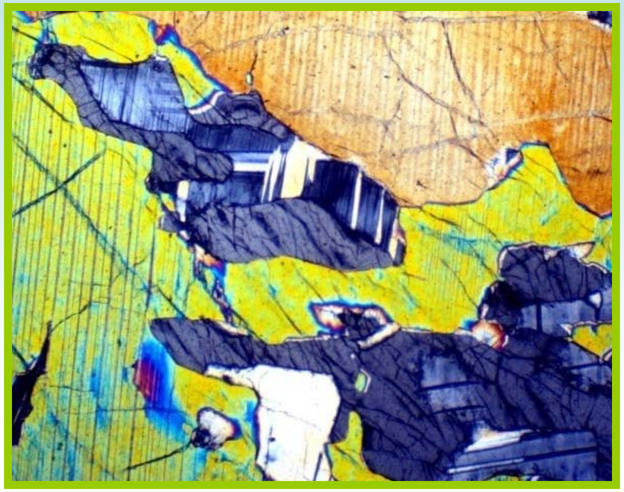


Manatschal & Müntener 2008



Mohn et al. in prep

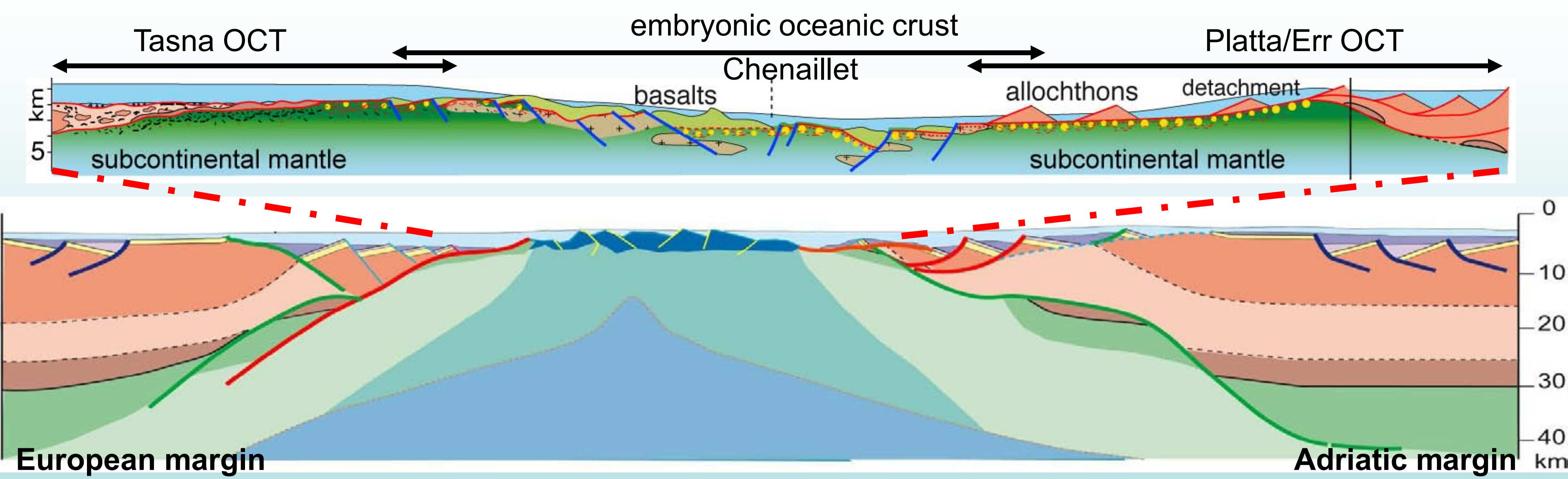
Magmatic processes in the OCT



Melt infiltration/reaction in plg. peridotite

Gabbros in serpentinize mantle

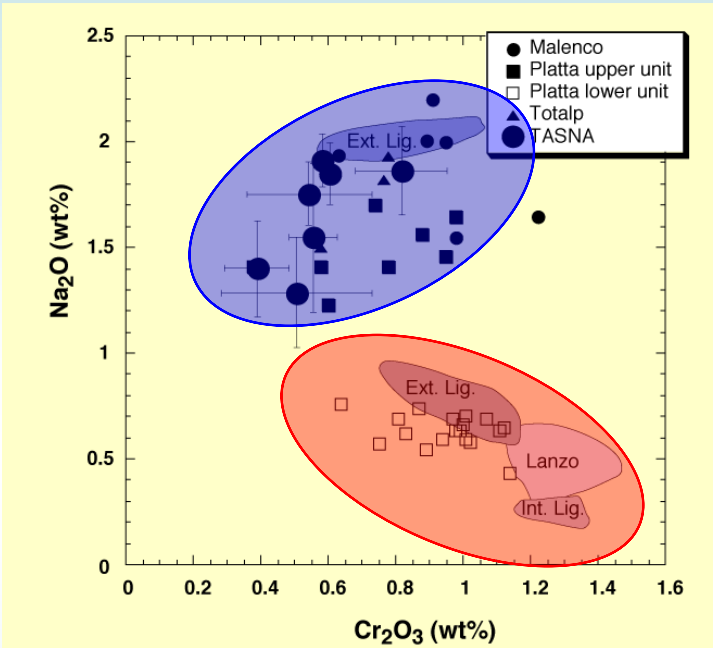
Pillow basalts overlying exhumed mantle



Mohn et al. in prep

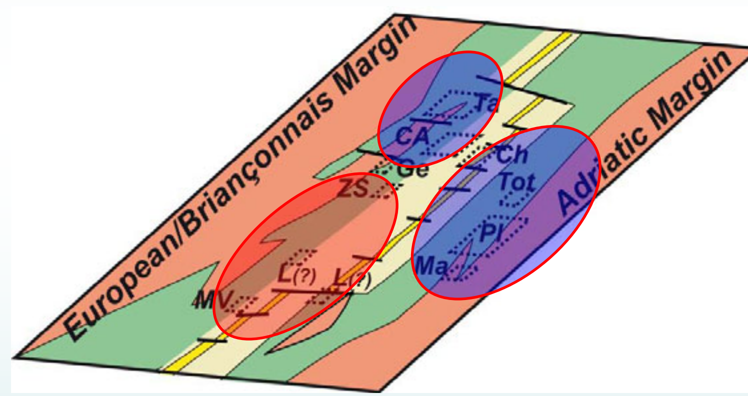
Mantle characteristics in the OCT (from O. Müntener)

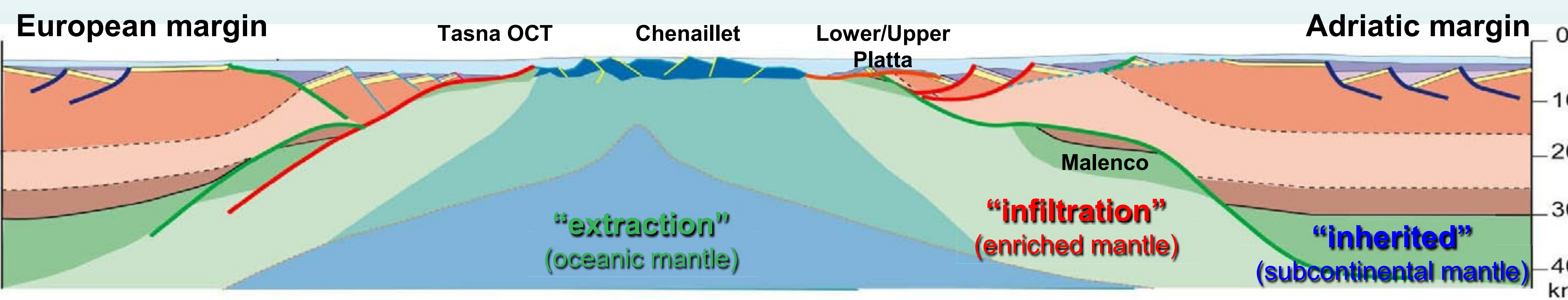
mineral chemistry of cpx



The key observation:
Infiltrated mantle is exhumed by brittle detachment system

Consequence:
Infiltration had to occur already <u>before</u> final mantle exhumation to the seafloor; i.e. infiltration had to occur during thinning phase



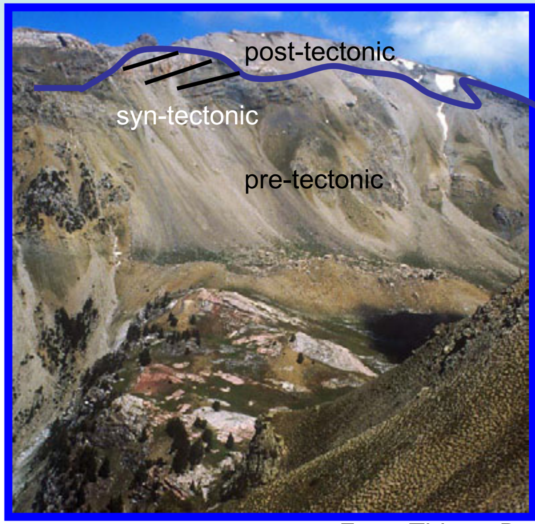


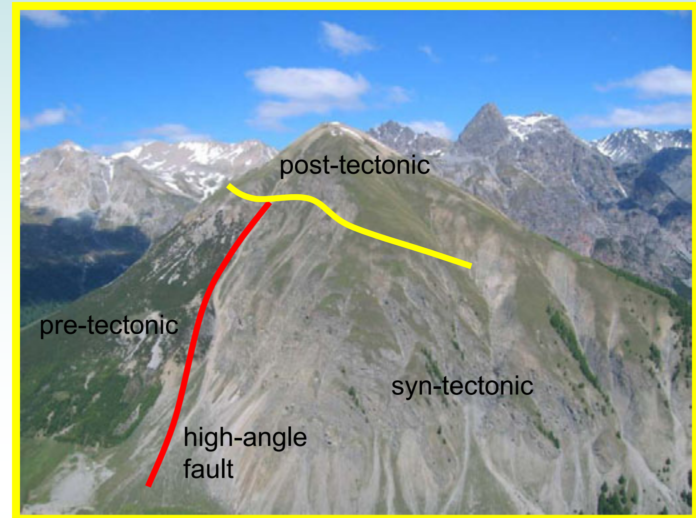
Mohn et al. in prep

Stratigraphic record and isostatic evolution of the margins

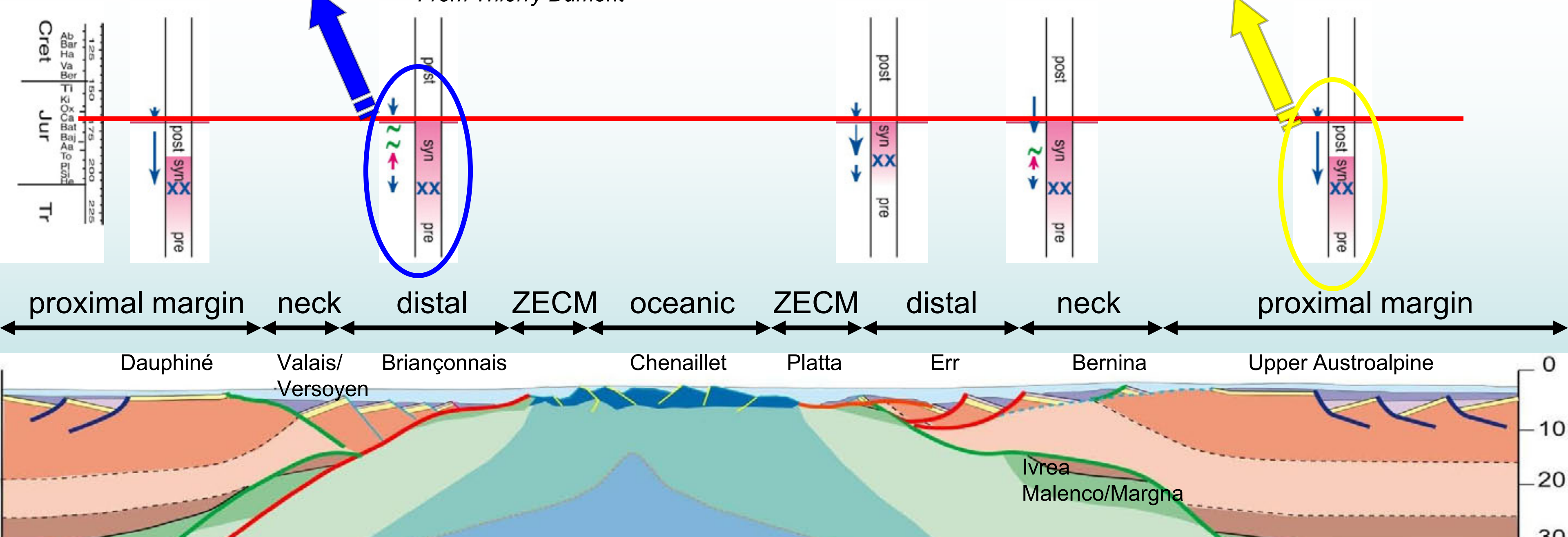
Distal margin (Briançonnais)

Proximal margin (Il Motto)





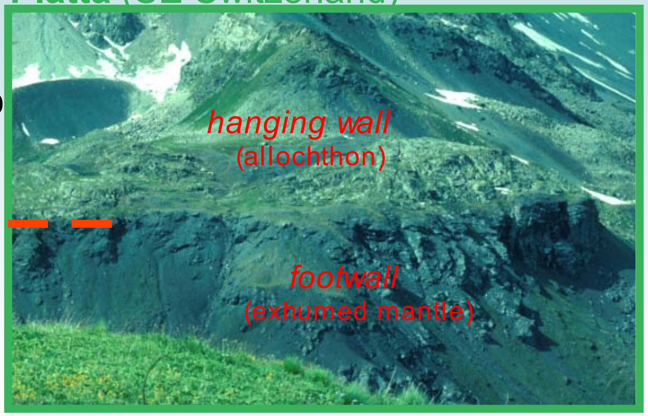
From Thierry Dumont



Rift-related structures observed along the margin

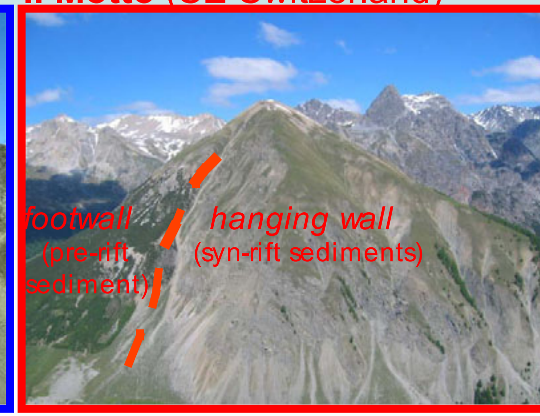
distal margin

Platta (SE Switzerland)



Err (SE Switzerland)

Il Motto (SE Switzerland)



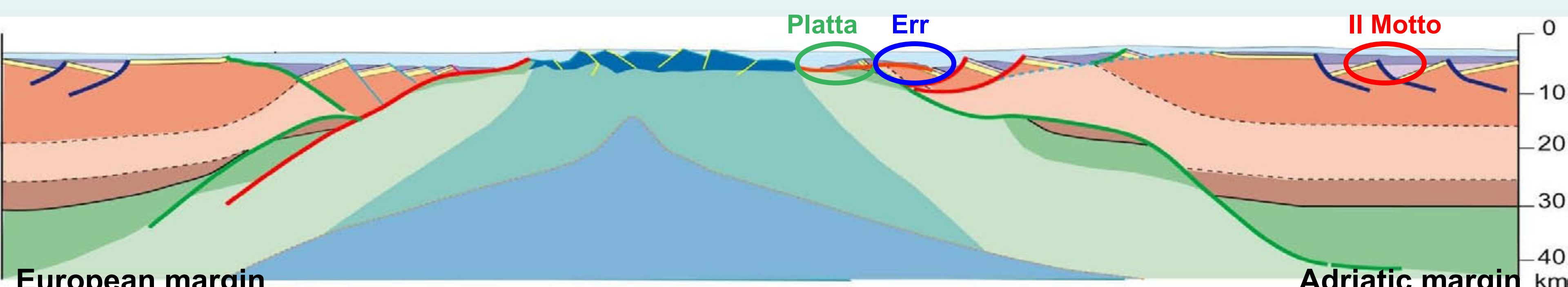
proximal margin

Distal ⟷ **Proximal**

low-angle detachment fault
extensional allochthones
exhumation of continental and mantle rocks

high-angle normal fault
tilted blocks
exhumation limited to fault scarps

distal ⟷ **proximal**



Mohn et al. in prep

Fault-sediment relationship

distal margin

Err (SE Switzerland)

syn-rift onlapping onto low-angle fault

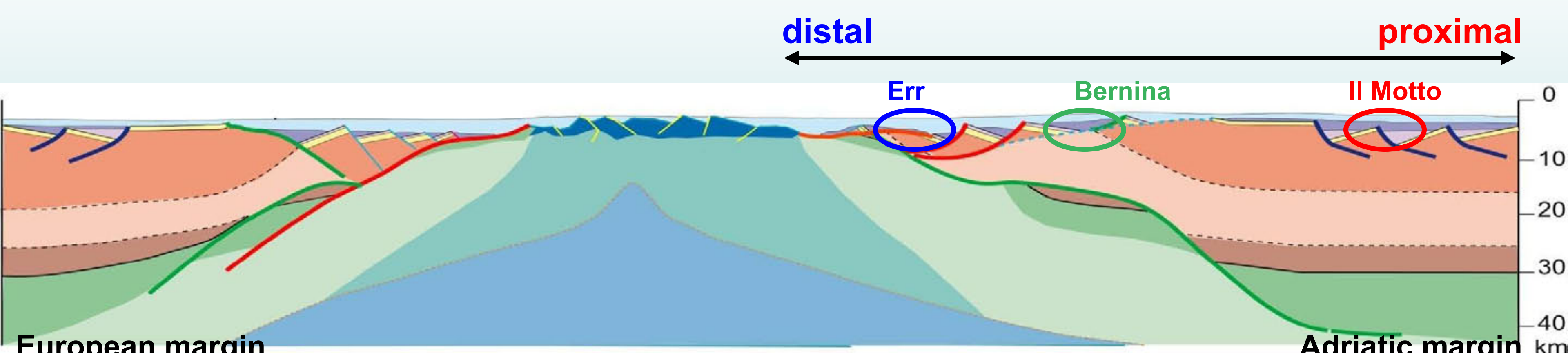
Bernina (SE Switzerland)

pre-rift stretched along low-angle fault and sealed by syn to post-rift

Il Motto (SE Switzerland)

syn-rift terminating against high-angle fault

proximal margin

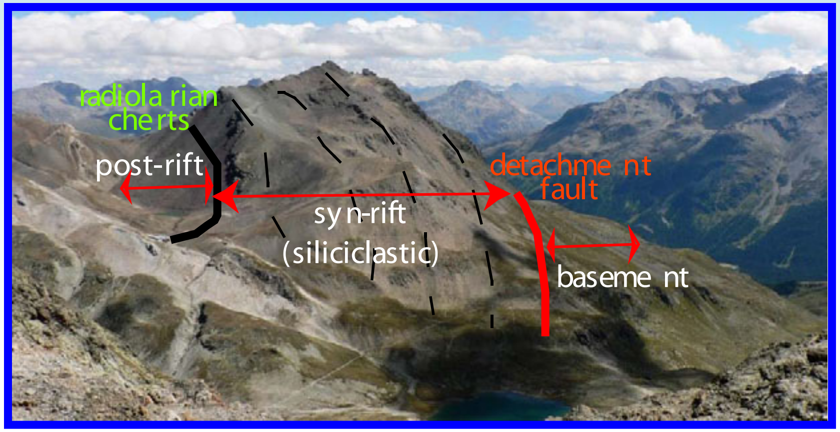


Mohn et al. in prep

Implications of exhumation of crust in the necking zone for the formation of a new silisiclastic source

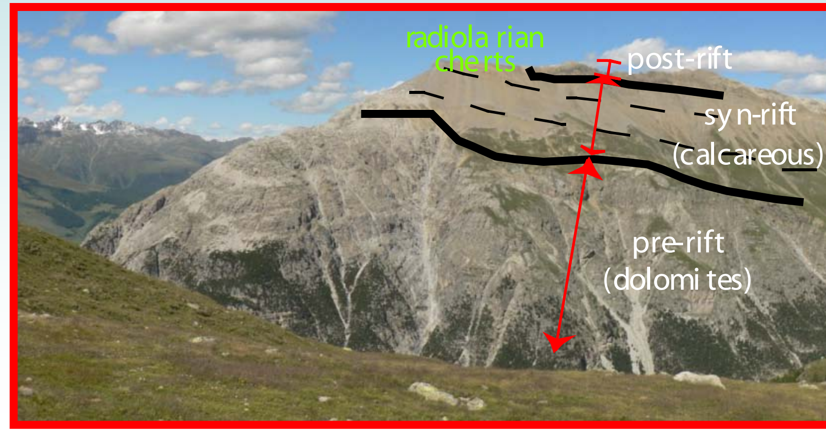
distal margin

Piz Nair (Err)



"silisiclastic" syn-rift sediments

Piz Mezaun (eastern Bernina)



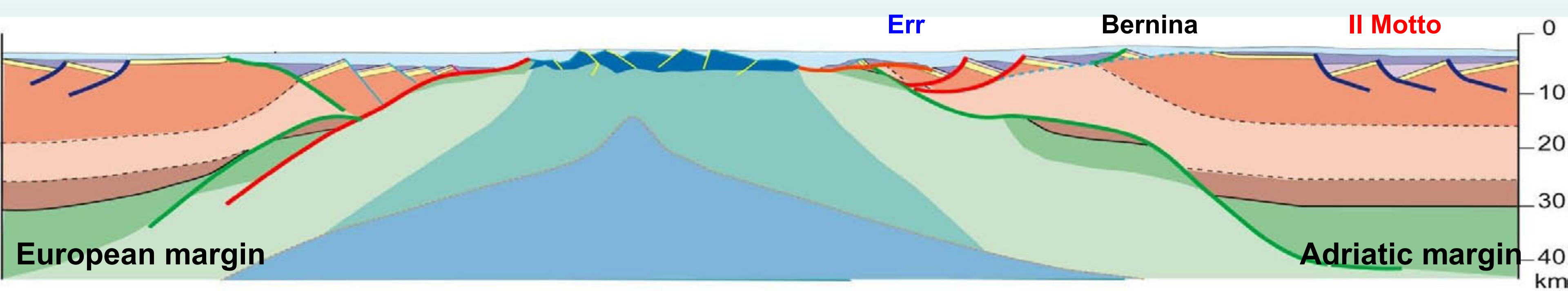
"calcareous" syn-rift sediments

proximal margin

distal "silisiclastic"

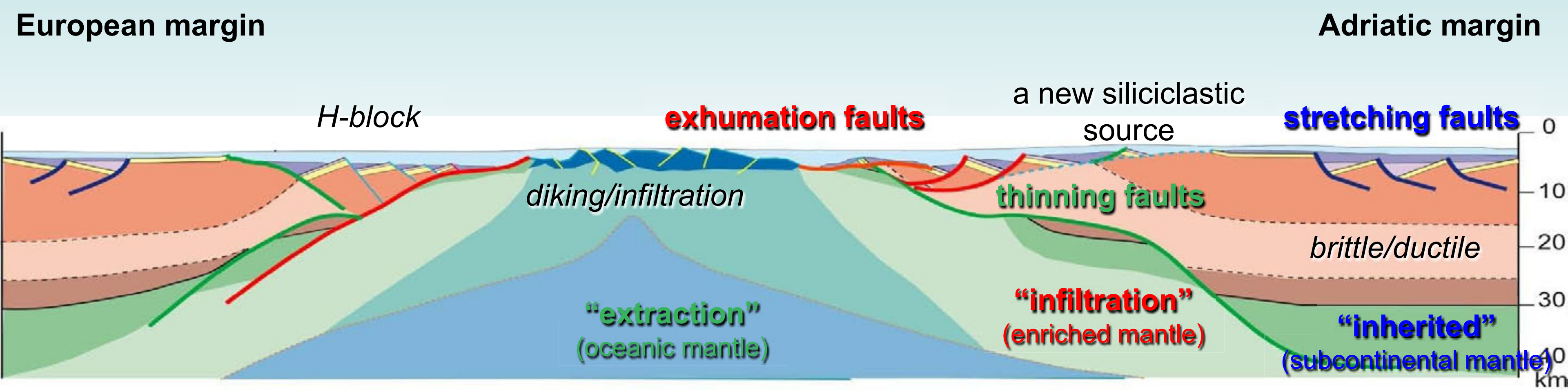
creation of a new "silisiclastic" source due to exhumation

proximal "calcareous"



Mohn et al. in prep

How to reconcile all these observations in a tectonic model

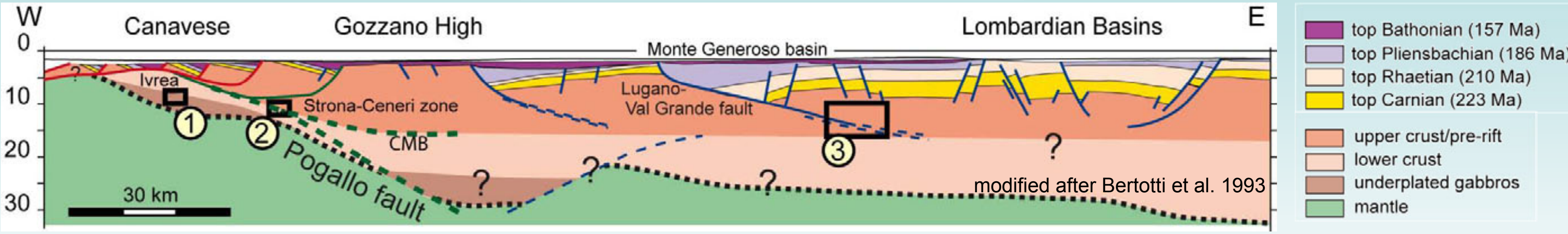


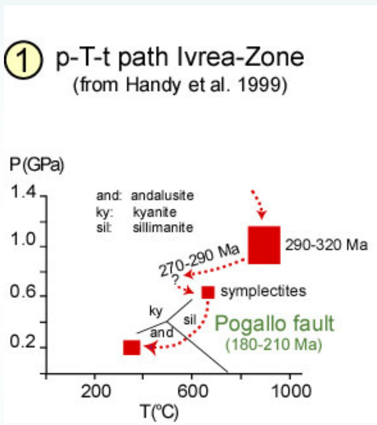
Mohn et al. in prep

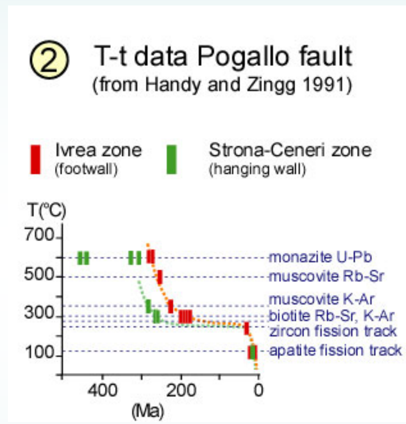
- ***Three mantle domains can be distinguished*** *(inheritance, infiltration, extraction)*
- ***Poly-phase tectonic evolution*** *(how do brittle and ductile deformation interact?)*
- ***Poly-phase magmatic evolution*** *(what controls infiltration vs. diking)*
- ***Complex sedimentary evolution*** *(limits of stratigraphic correlations)*
- ***Complex isostatic and thermal evolution*** *(how important are mantle processes?)*

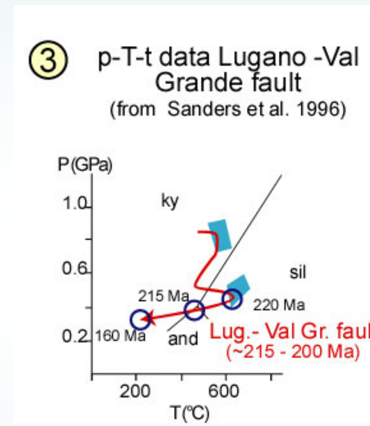
The implications for petroleum systems are obvious

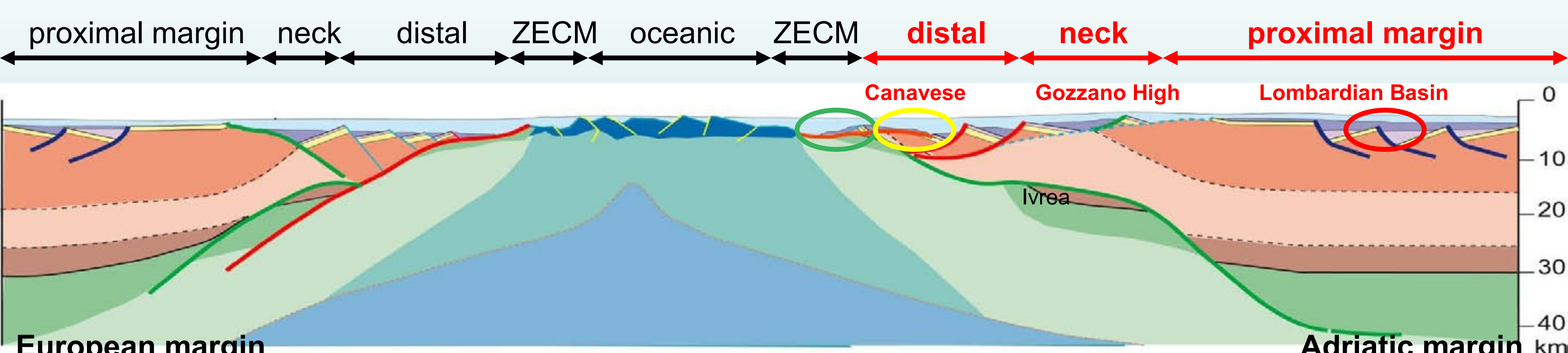
Time constraints









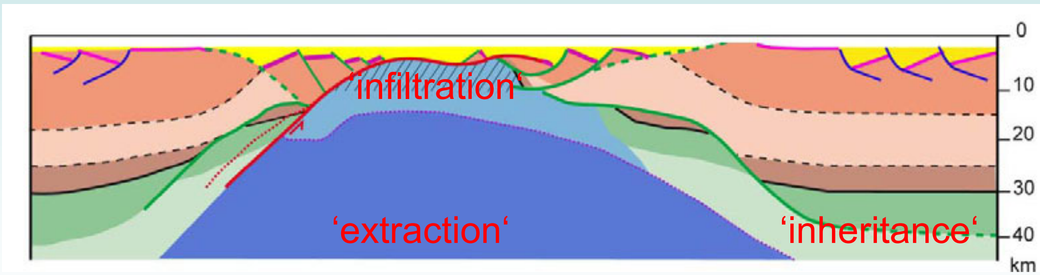


Mohn et al. in prep

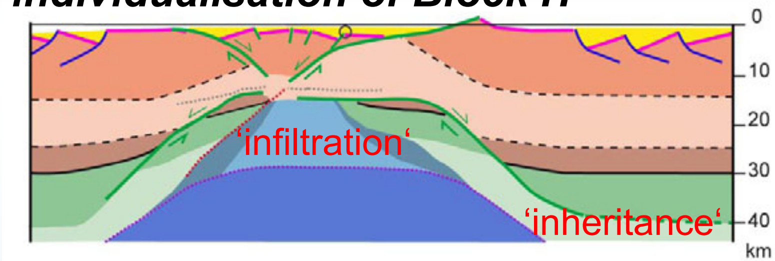
Sequential overprinting of rift-modes

temporal evolution of rifting

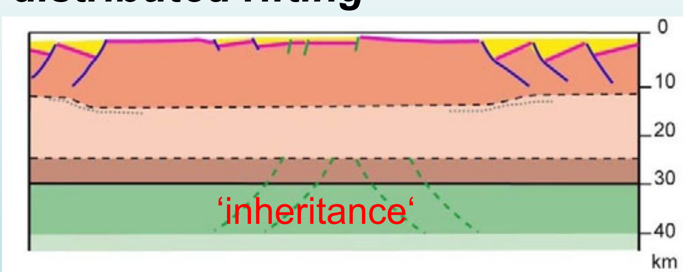
mantle and crustal accretion



individualisation of Block H



distributed rifting

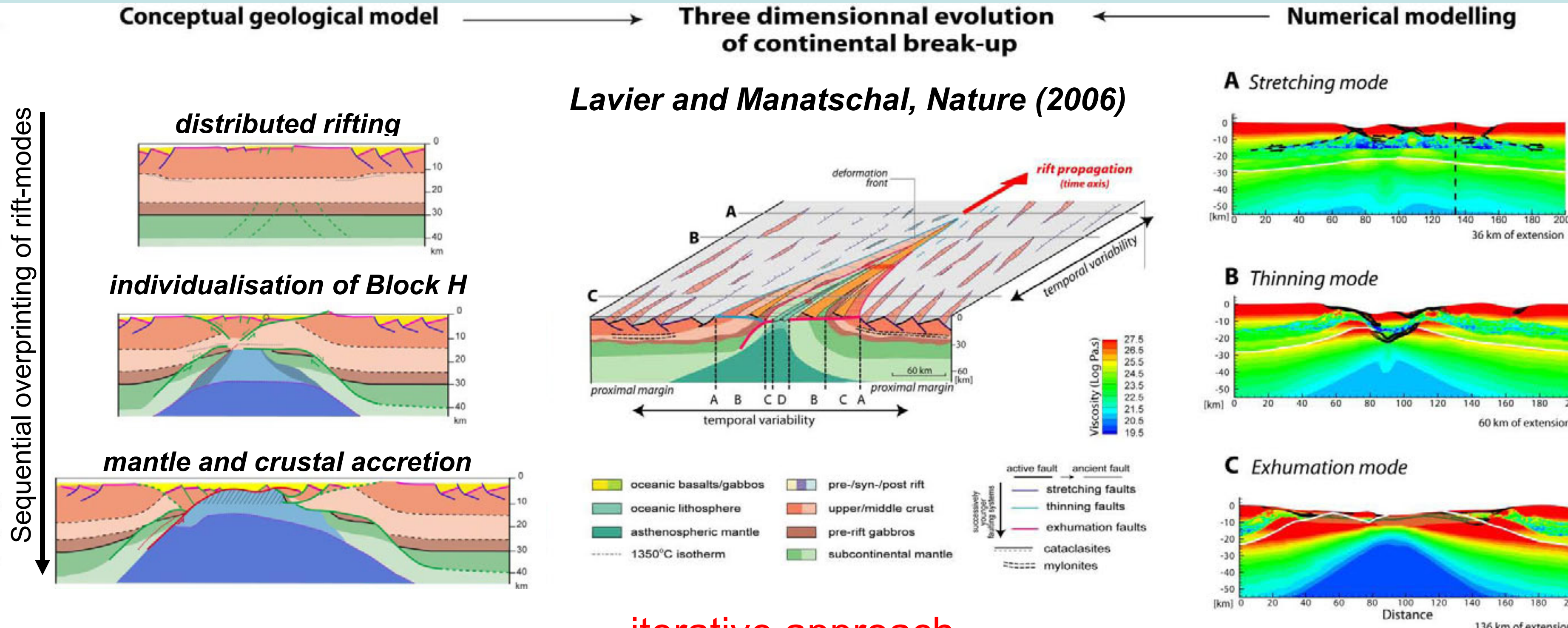


Exhumation phase
"simple shear"
Callovian/Bathomian
(< 165 Ma)

Thinning phase
Toarcian to Callovian/Bathomian
(~180-165Ma)

Stretching phase
"pure shear"
Latest Triassic to Toarcian

From observations to conceptual and numerical models



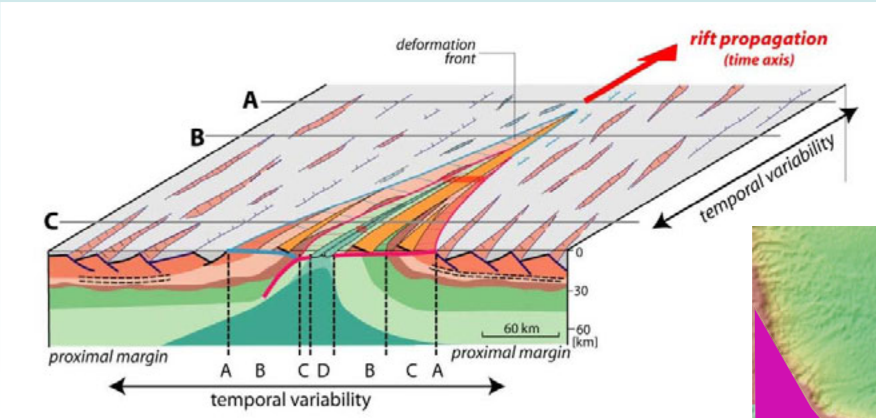
iterative approach

observations ⟷ **modelling**

Major questions that remain to be answered

- What are the processes that control extreme crustal thinning to less than 10 km?
- What is the transition from mantle exhumation to seafloor spreading?

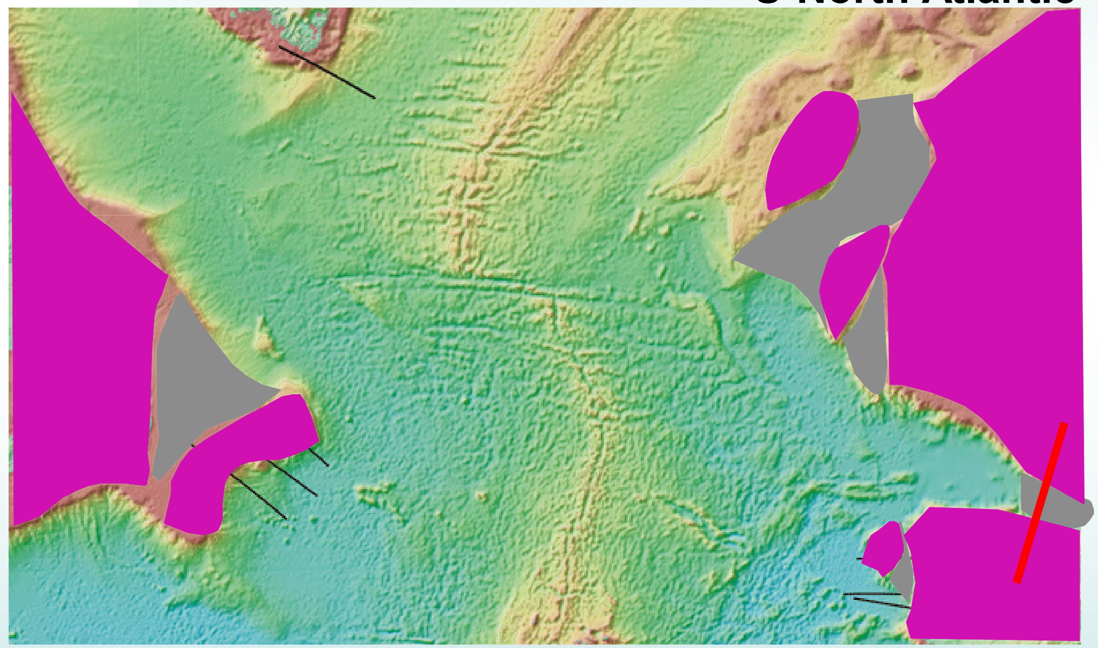
Are there other good field analogues to study extreme crustal thinning and lithospheric breakup?



Lavier and Manatschal (2006)

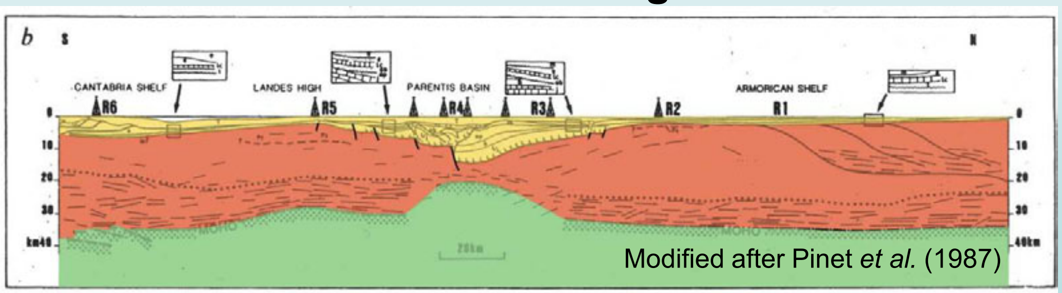
V-shaped basins preserve along strike the complete rift evolution

•**S-North Atlantic**



Péron-Pinvidic and Manatschal (in prep)

Profile ECORS-Golfe de Gascogne



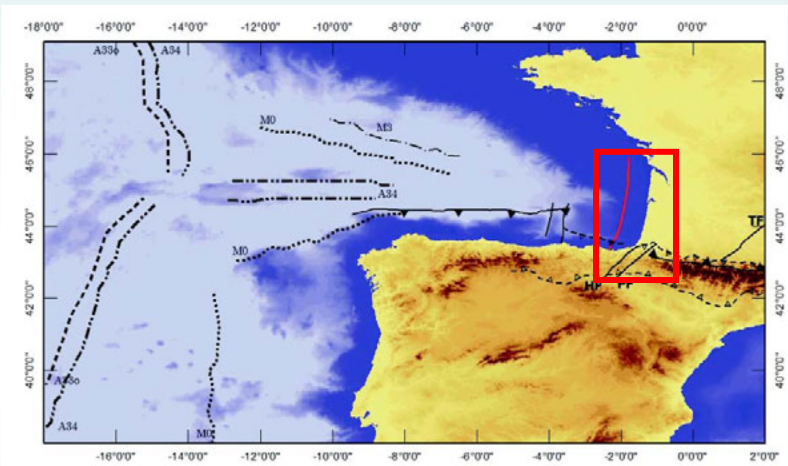
Modified after Pinet *et al.* (1987)

The Bay of Biscay-Western Pyrenees

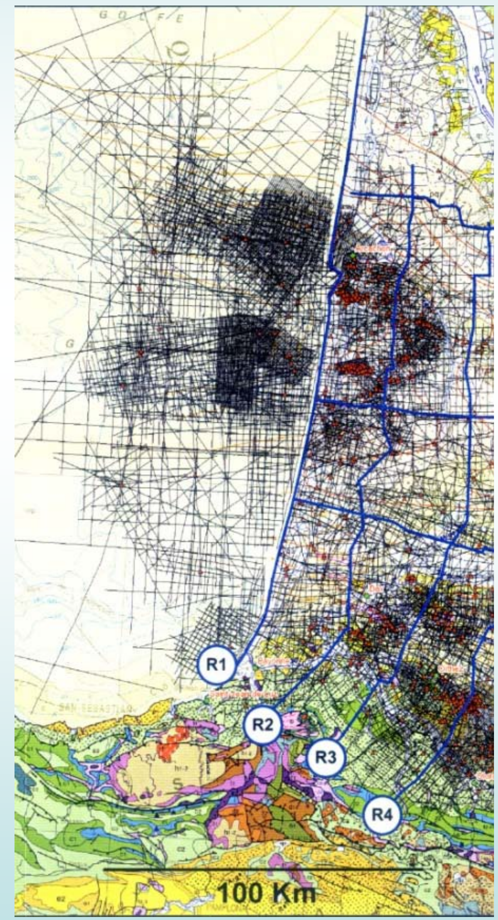
PhD Suzon Jammes

in collaboration with L. Lavier, Ch.Tiberi, Chris Johnson (ExxonMobil), TOTAL and Action Marges

How is extreme crustal tinning accommodated in a transtensional environment at the termination of an oceanic domain?



- **What is the crustal structure ahead of a propagating ocean?**
  Processes related to crustal thinning and mantle exhumation
- **What is the paleogeographic evolution?**
  Timing of partitioning between strike slip and extensional structures
- **How are rift structures reactivated during compression?**
  Importance of structural/lithological/thermal inheritance



Map showing the location of seismic sections and well data (from BRGM)

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