Pyrenean mountain buiding:
recent understandings and new questions arisen

Antonio Teixell

Universitat Autònoma de Barcelona

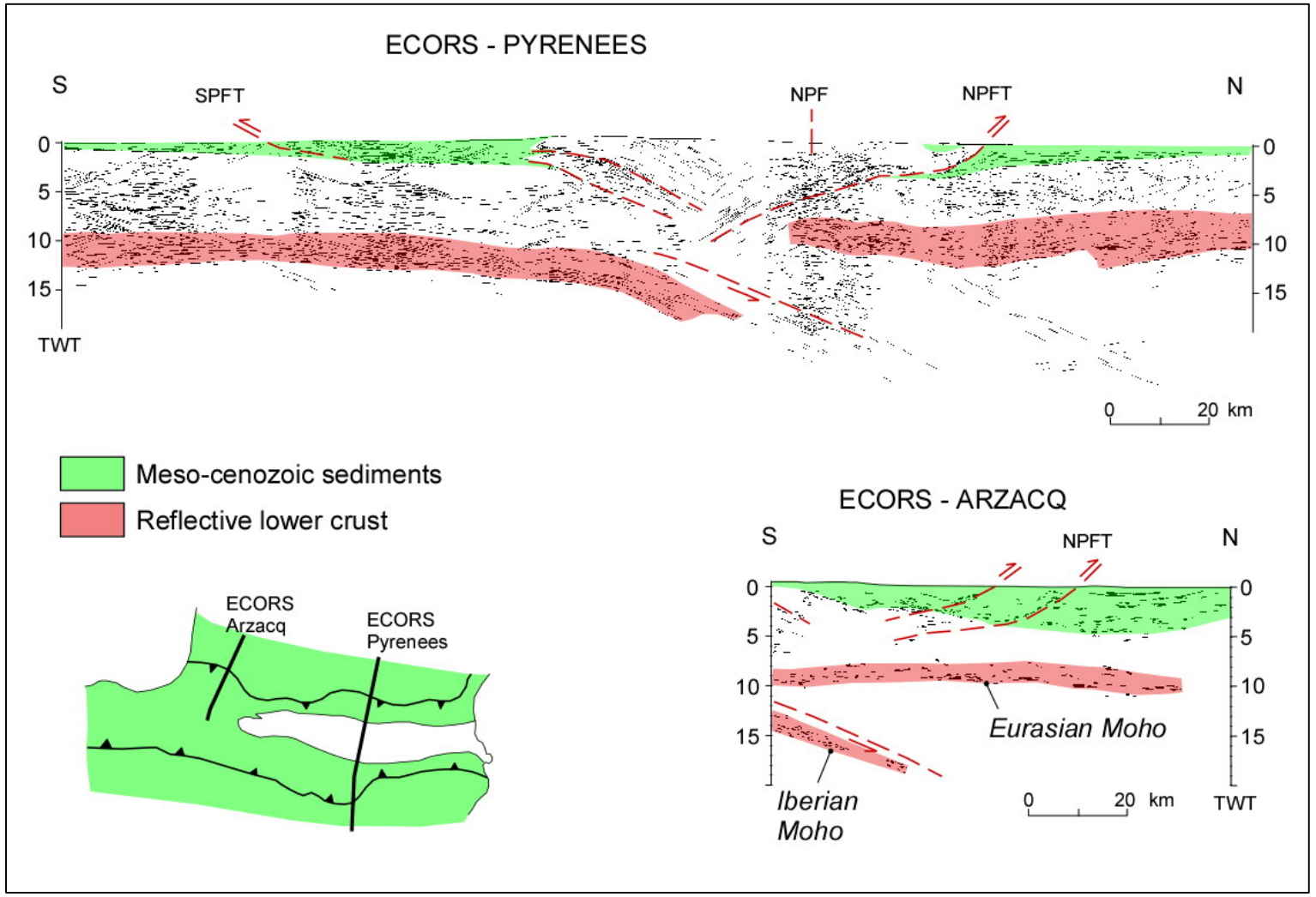
With the collaboration of P. Labaume (Montpellier), Y. Lagabrielle (Rennes)

04 Juin 2019

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable
brgm

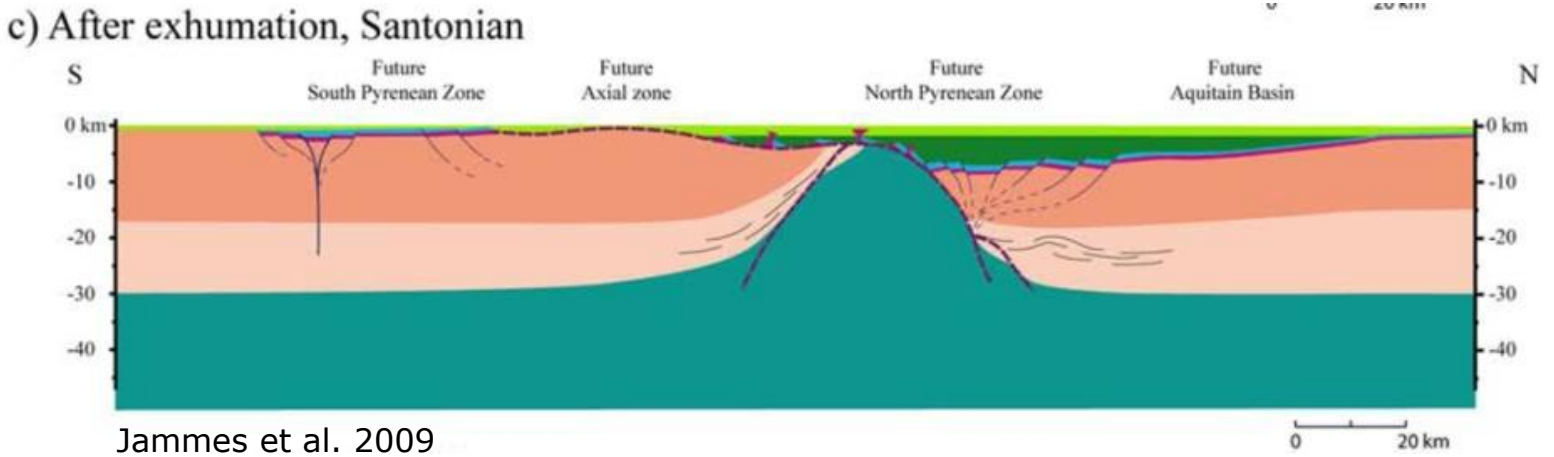
30+ years of the ECORS profiles across the Pyrenees



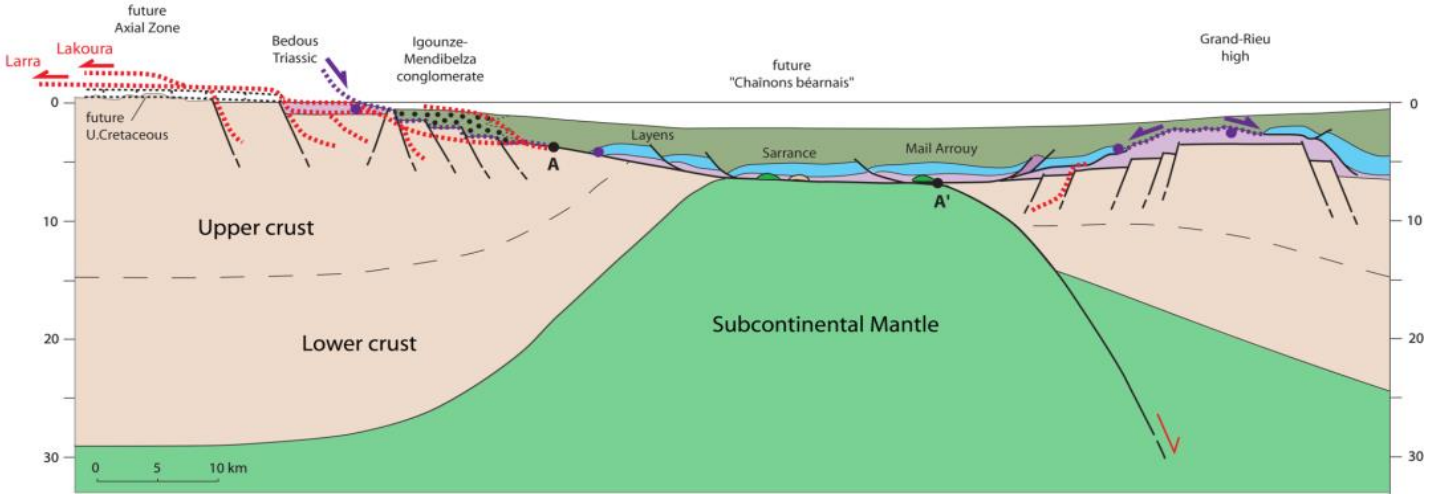
Late 2000´s

- Incorporation of concepts from modern continental margins
- Thermochronology
- Early big programs (TopoIberia/Europe, Margins...)

New models incorporated knowledge of continental margins: hyperextension and mantle exhumation concepts



Jammes et al. 2009



Lagabrielle et al. 2010

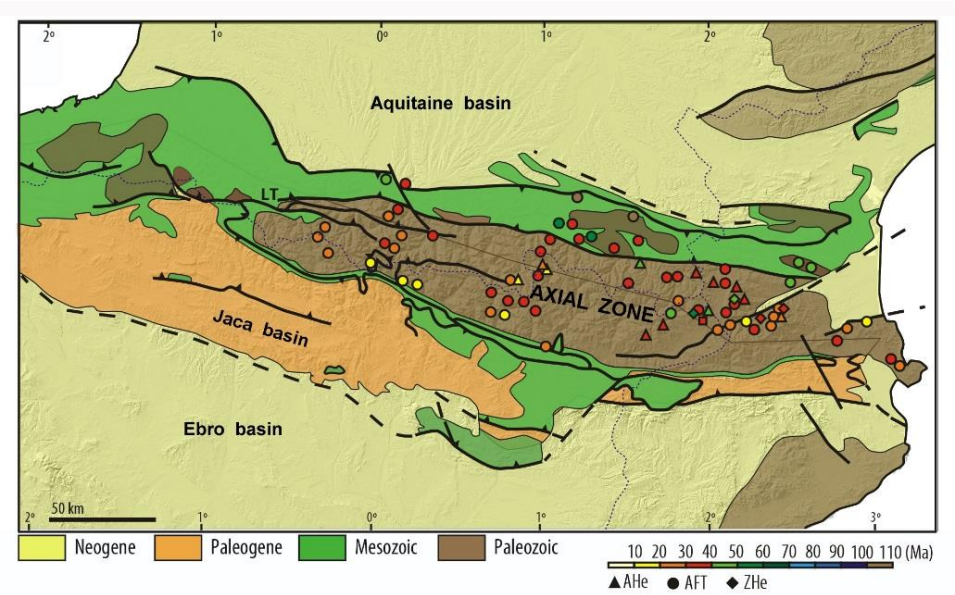
✓ Models account for Pyrenean lherzolites and HT metamorphism

⟶ Thermal isostasy must be considerered

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable brgm

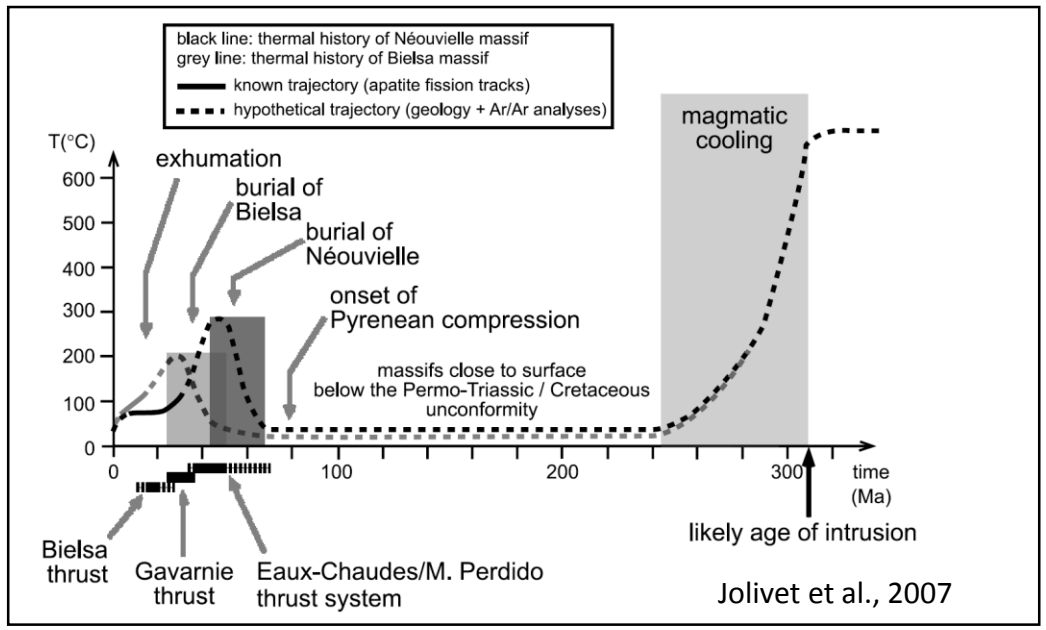
Contributions by low-T thermochronology



Continuously growing AFT and (A, Zr) (U-Th)/He database

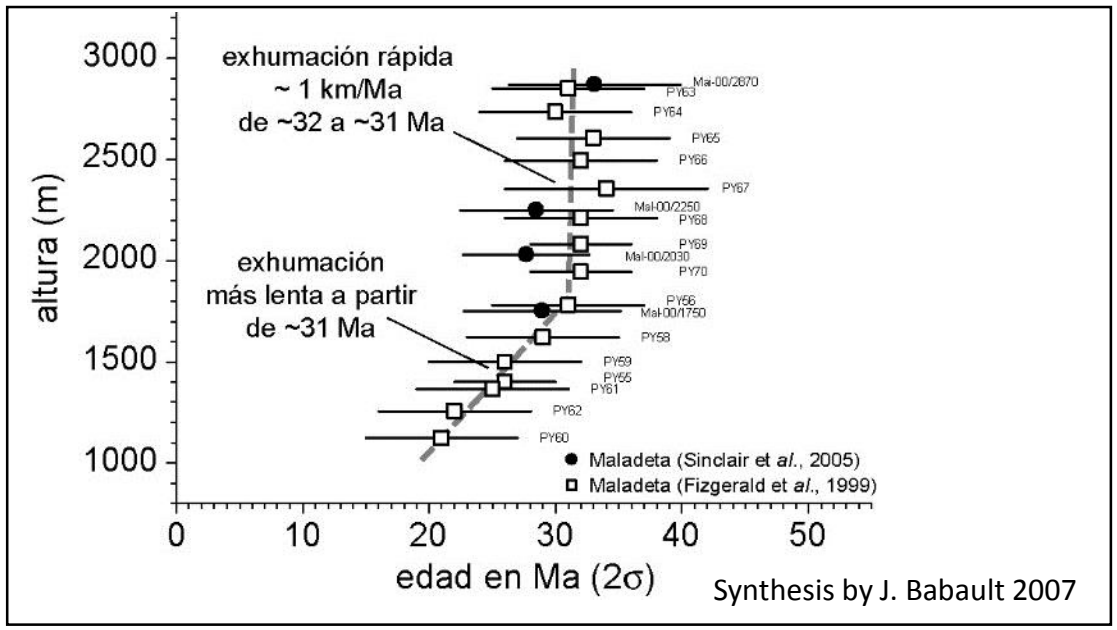
(synthesis to 2015 by G. Bosch et al. 2016)

Timing of thrusting from burial and exhumation



Jolivet et al., 2007

Rates of exhumation from vertical profiles

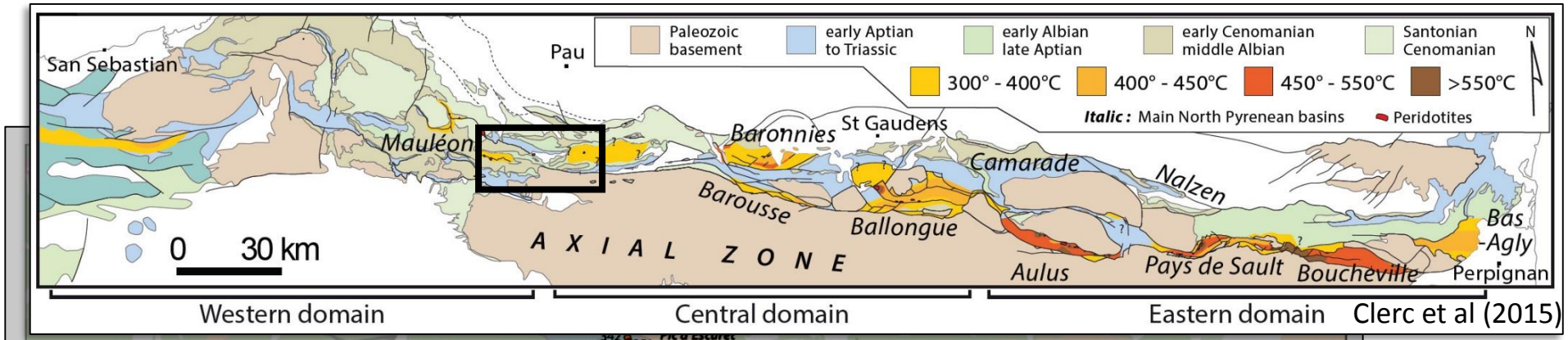


Synthesis by J. Babault 2007

2010´s

- More field geology (Programs: RGF, Pyramid, Orogen...)
- Incorporation concepts of inheritance and salt tectonics
- Paleothermometry
- More thermochronology
- Provenance and detrital geochronology in basins
- New geophysical acquisition (passive seismics)

Paleothermometry: Cretaceous peak T° in the Pyrenean rift axis



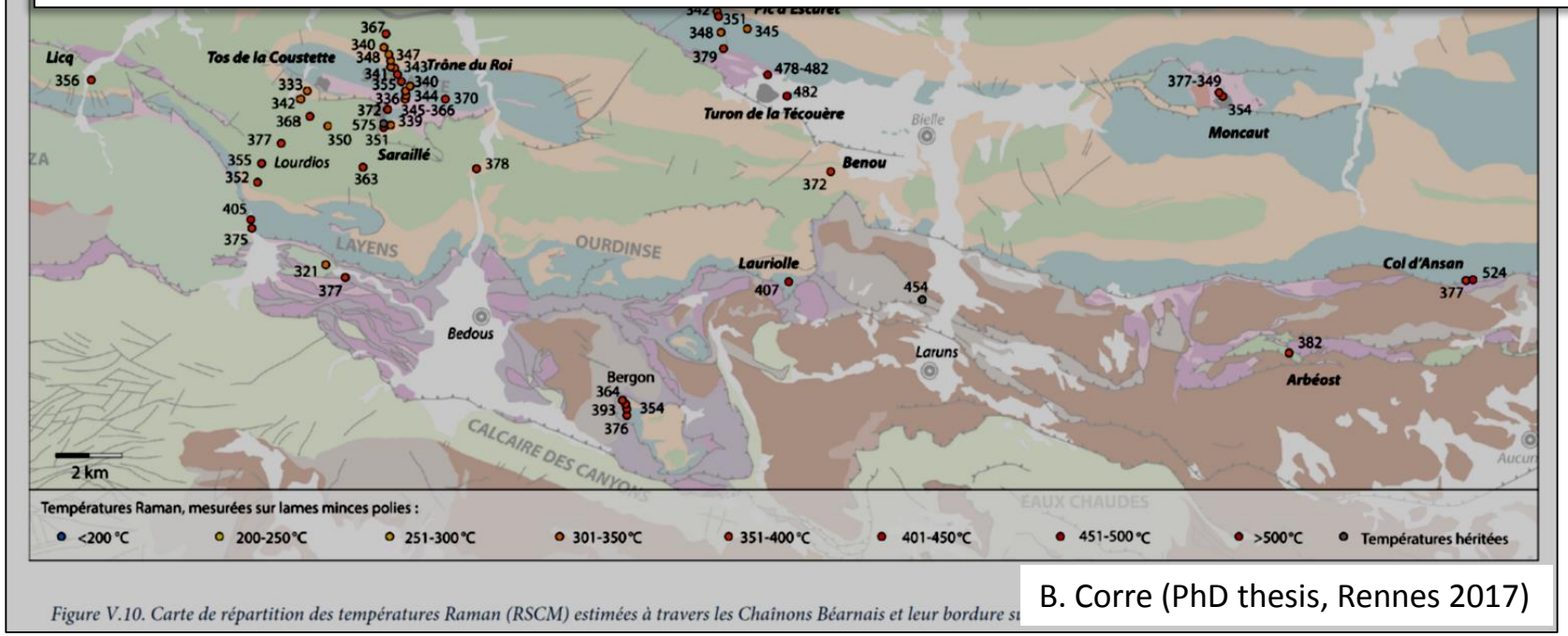


Figure V.10. Carte de répartition des températures Raman (RSCM) estimées à travers les Chaînons Béarnais et leur bordure s

B. Corre (PhD thesis, Rennes 2017)

✓ Attributed to mesozoic thinning

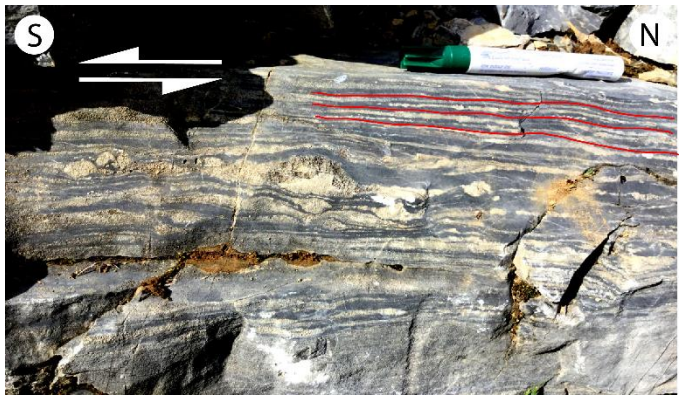
→ *role during the subsequent orogeny?*

Revisiting the structure of the upper Cretaceous of the Eaux Chaudes massif (N Axial Zone): a ductile fold nappe in the alpine Pyrenees

Macro

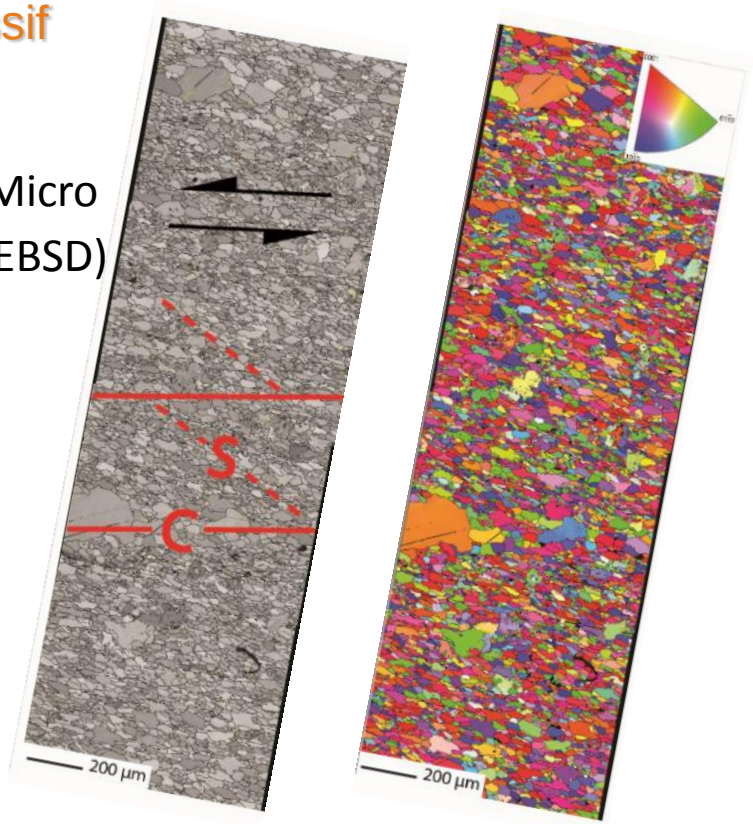
Strong ductility folding

Meso



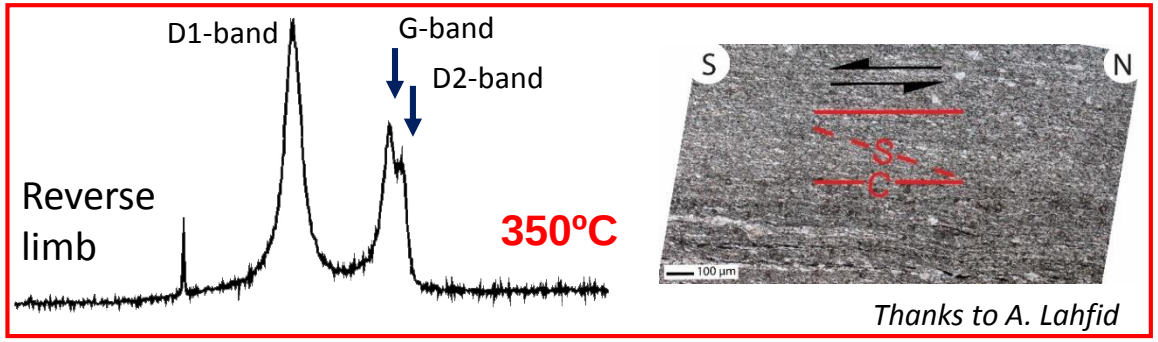
Mylonitic foliation and dolomite porphyroclasts

Micro (EBSD)



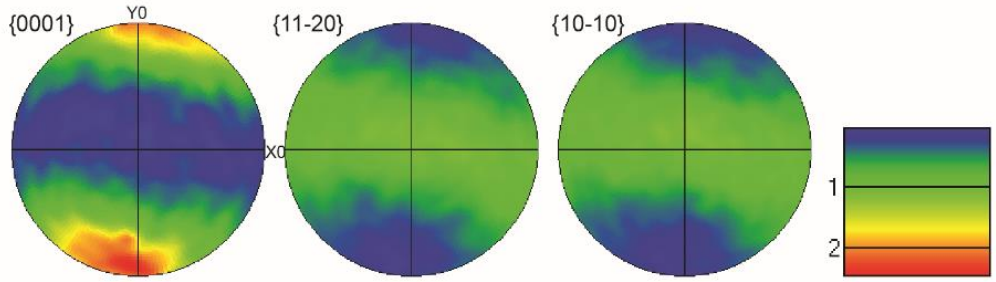
SEM: Band contrast and inverse pole figure (IPF)

RSCM



Thanks to A. Lahfid

PaleoT range of 300-350ºC in upper Cretaceous carbonates



Strong Crystallographic preferred orientation

Norbert Caldera, PhD in progress, UAB

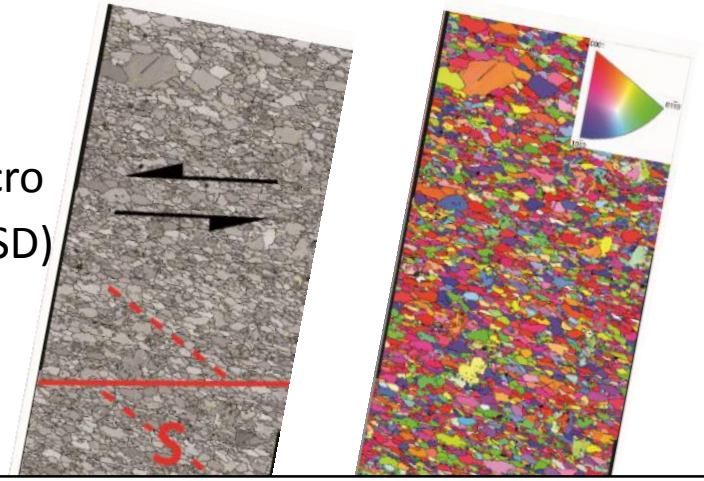
Revisiting the structure of the upper Cretaceous of the Eaux Chaudes massif (N Axial Zone): a fold nappe in the Pyrenees

Macro

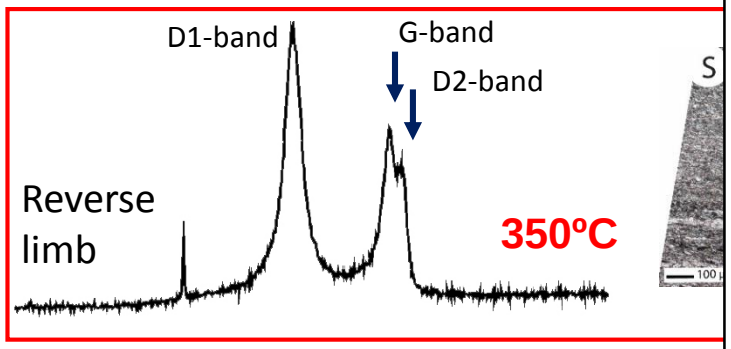
Strong ductility folding

Meso

Micro (EBSD)

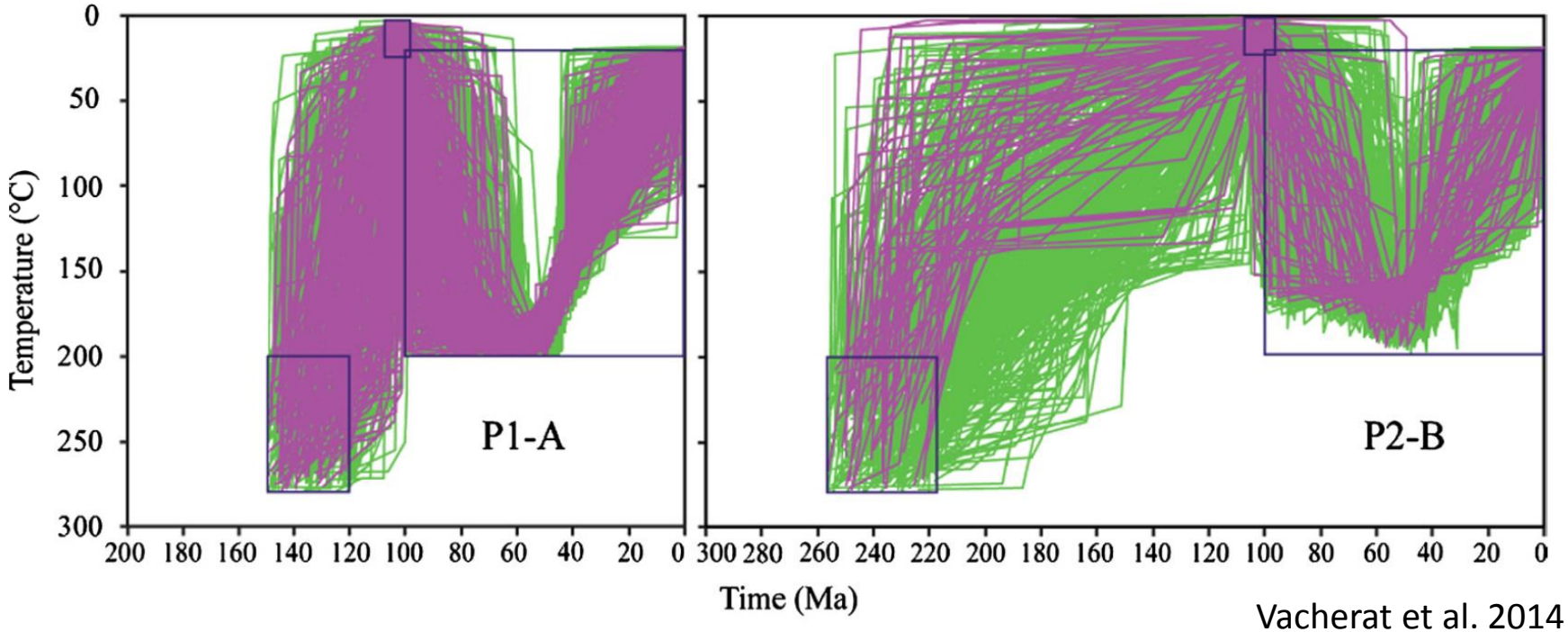


RSCM



PaleoT range of 300-350ºC in upper C

Thermal models, Mauléon basin



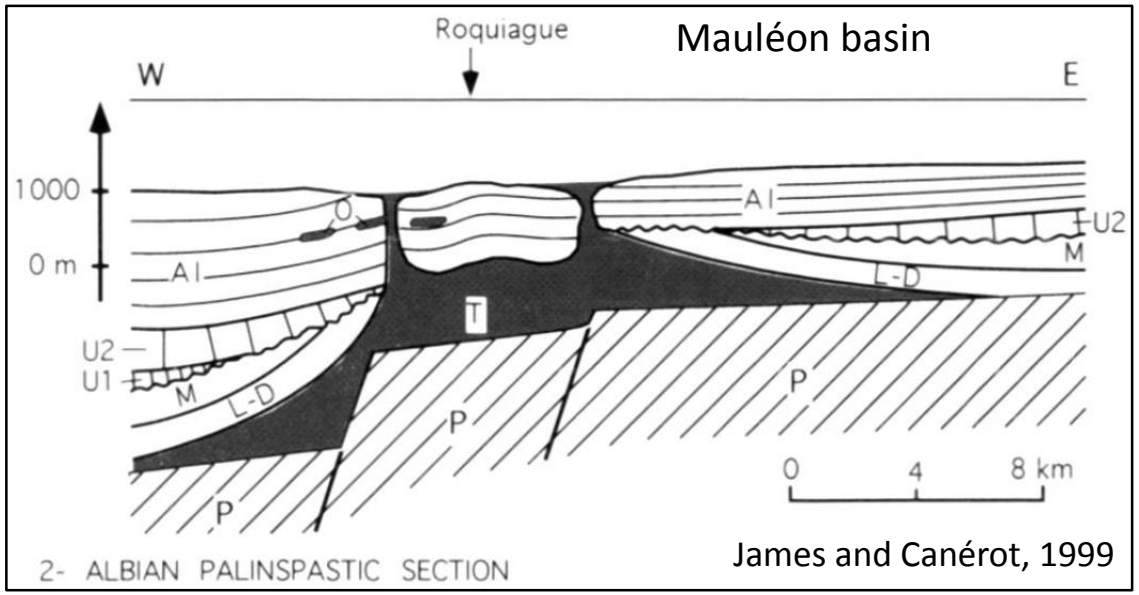
Vacherat et al. 2014

→ Persistence of high geotherm into the convergence phase

Role of salt, beyond simply providing a décollement level

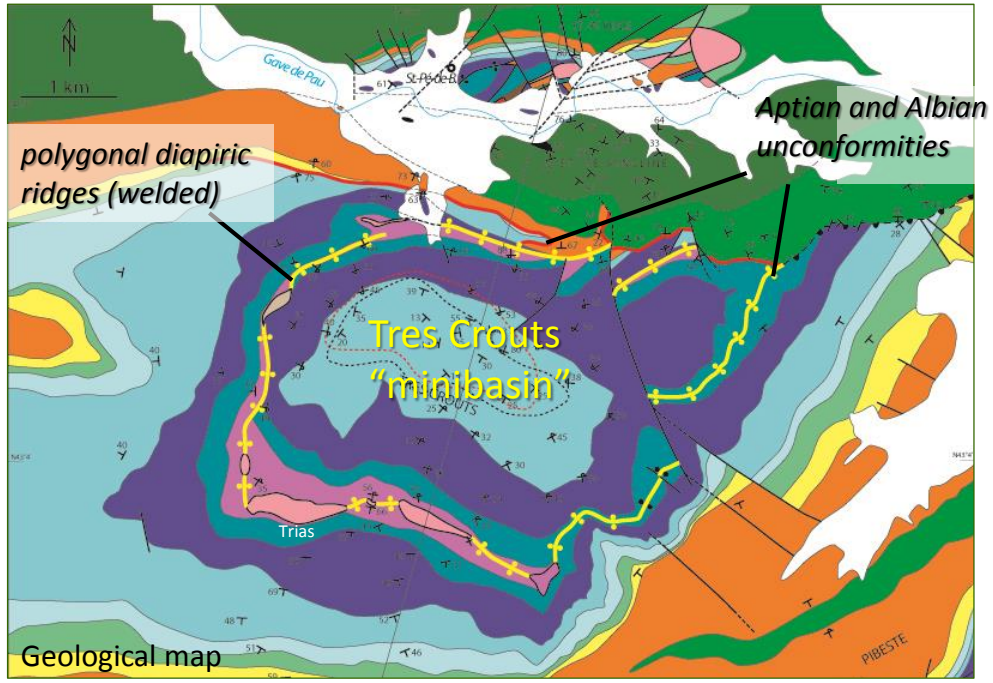
Noguera Ribagorçana valley, Southern Pyrenees
(cf. Saura et al. 2016)

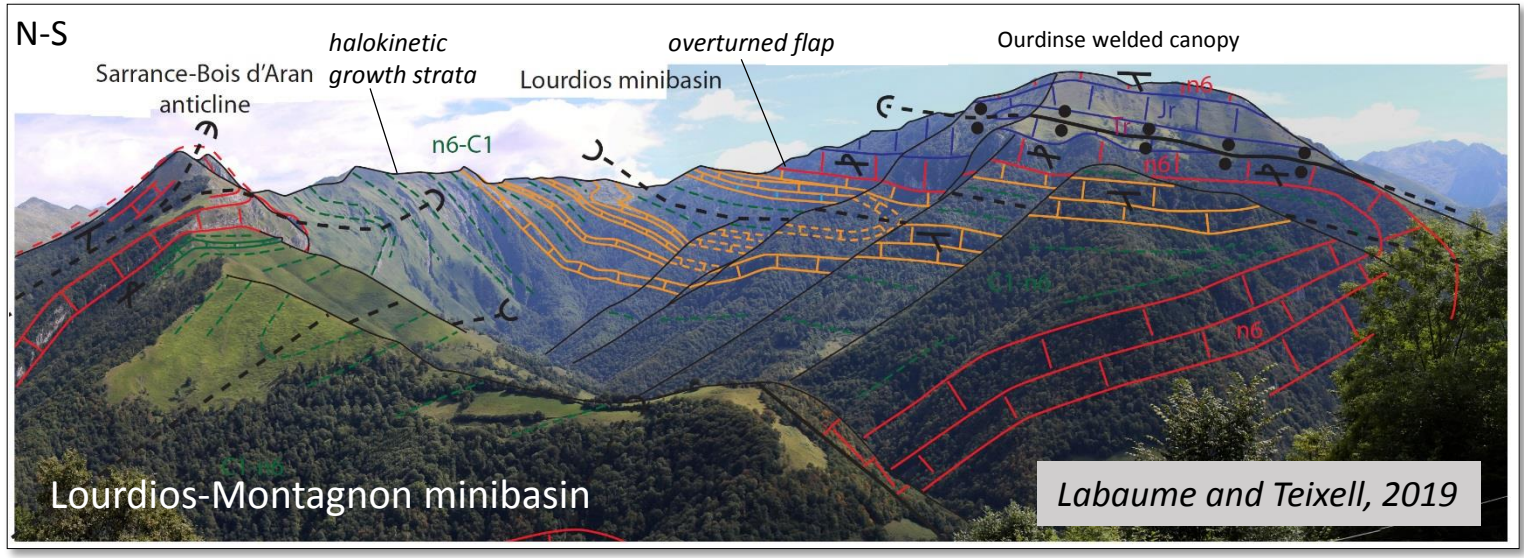
Salt diapirism governing early folding and syn-migration sedimentation during the Mesozoic rifting



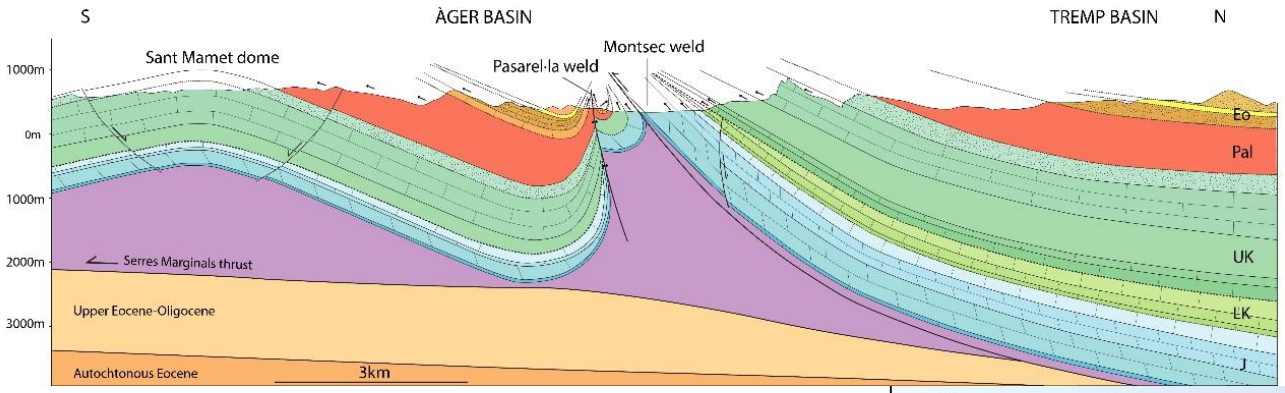
James and Canérot, 1999

Diapirs and growth synclines in the Chaînons Béarnais (ZNP)

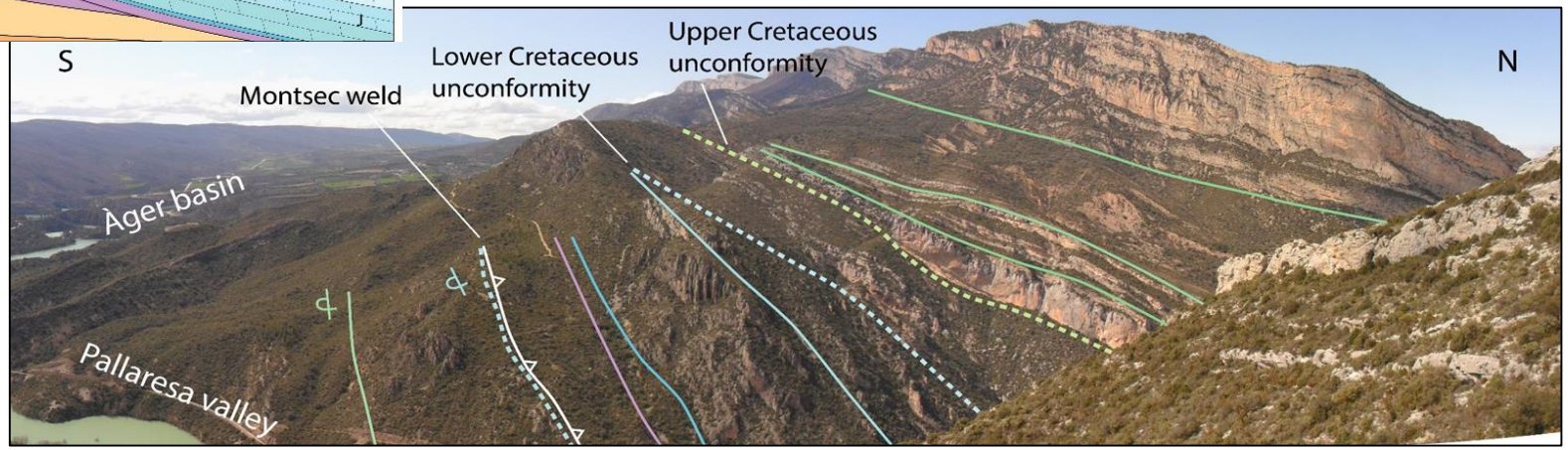




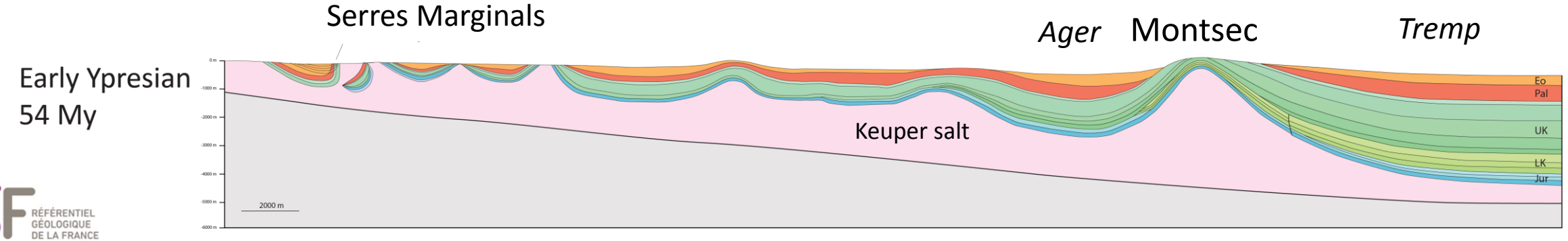
Salt tectonics in compression: the Montsec ridge (South Pyrenean Zone) as a thrusted salt wall



Laura Burrel, PhD work in progress, UAB



Salt enabled rapid propagation of deformation until the present thrust front very early in the history



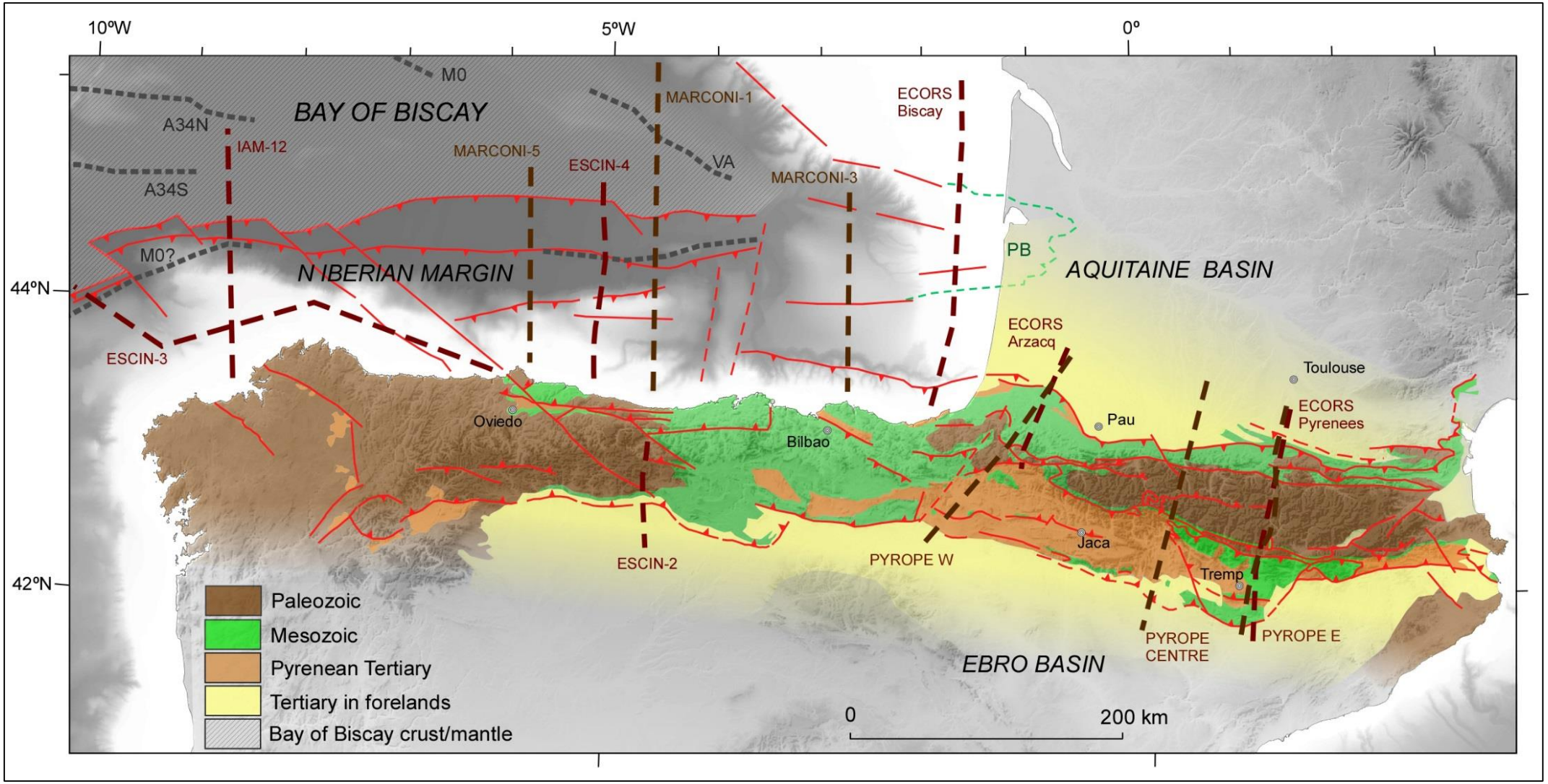
RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Revisiting models of structure at the crustal scale

Questions to address:

- Where are the sutures? Can we identify the ancient continental margins?
- Balanced geological models for the rifted margins?
- How does the inherited structure condition the major steps during the Pyrenean convergence?
- It it time for reassessment of primary thrust relationships?
- How is shortening distributed vertically? What subducts (and why), and what is the backstop?

A unique wealth of deep seismic investigations

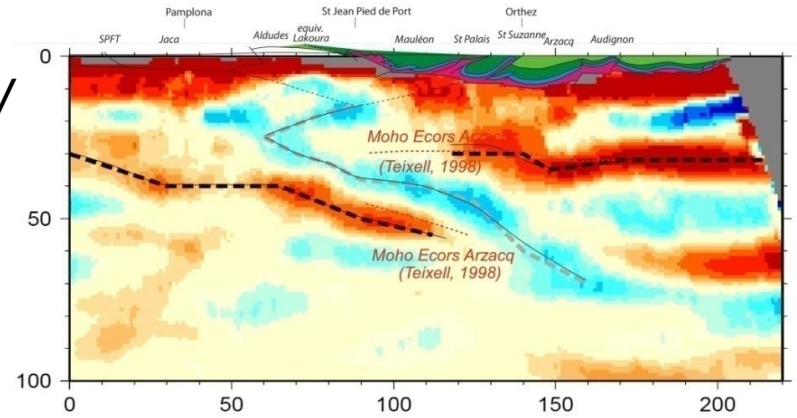


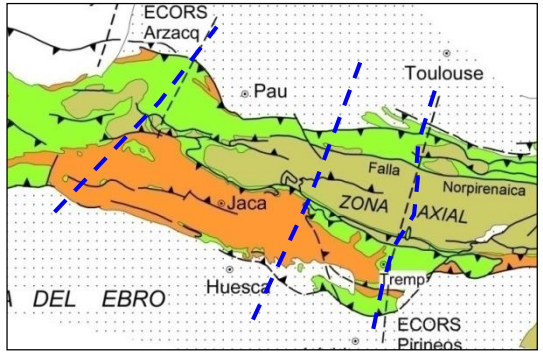
RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable brgm

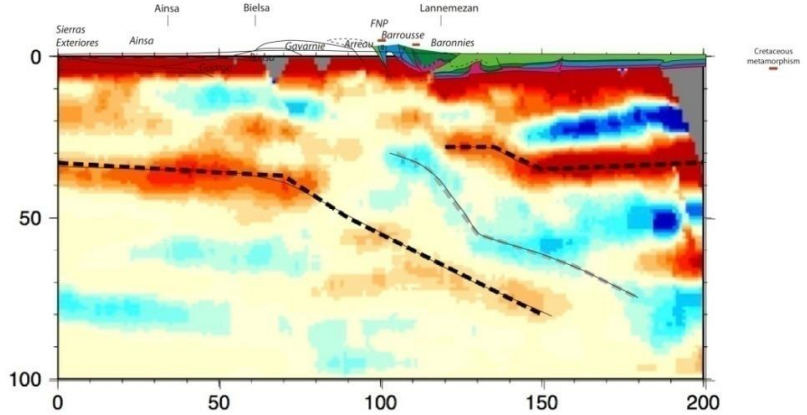
New insights from PYROPE-OROGEN Receiver Function data

Profile W

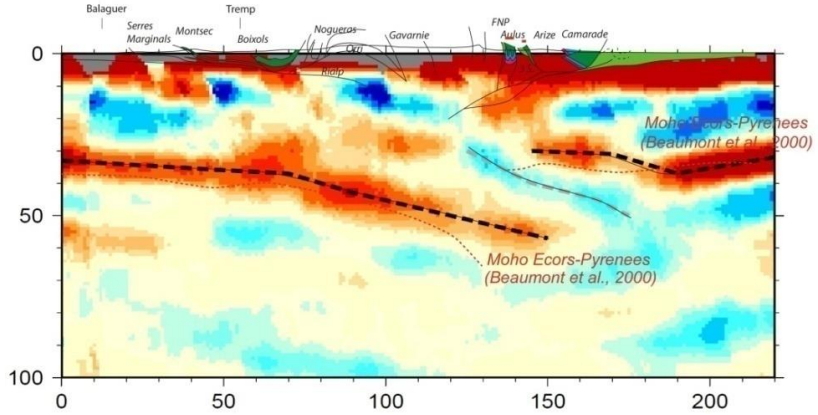




Profile centre



Profile E



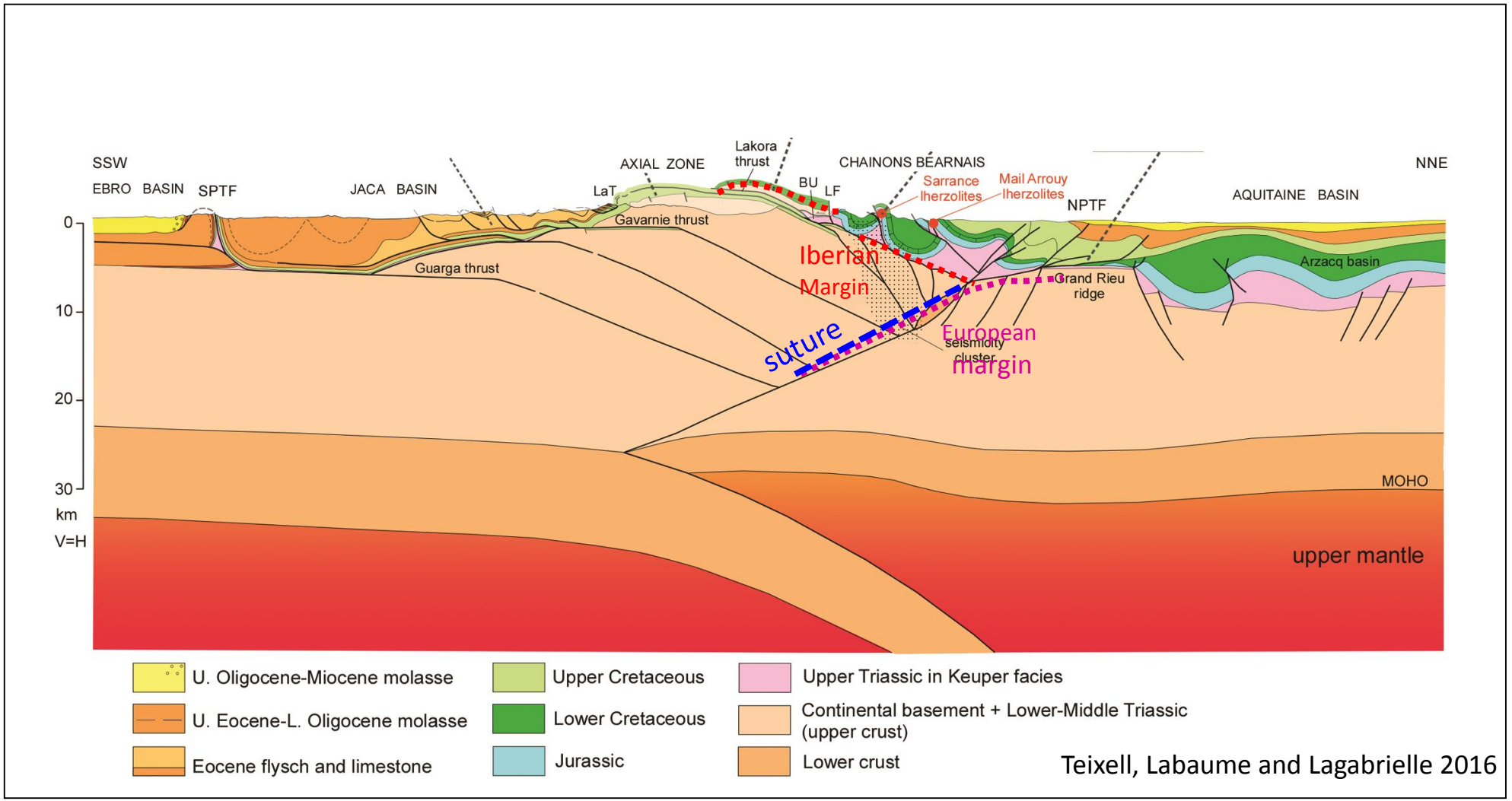
Chevrot et al 2015, 2018

- ✓ Confirm subduction of Iberian lower crustal slab
- ✓ Image the overriding mantle wedge

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable brgm

Pau-Jaca crustal section



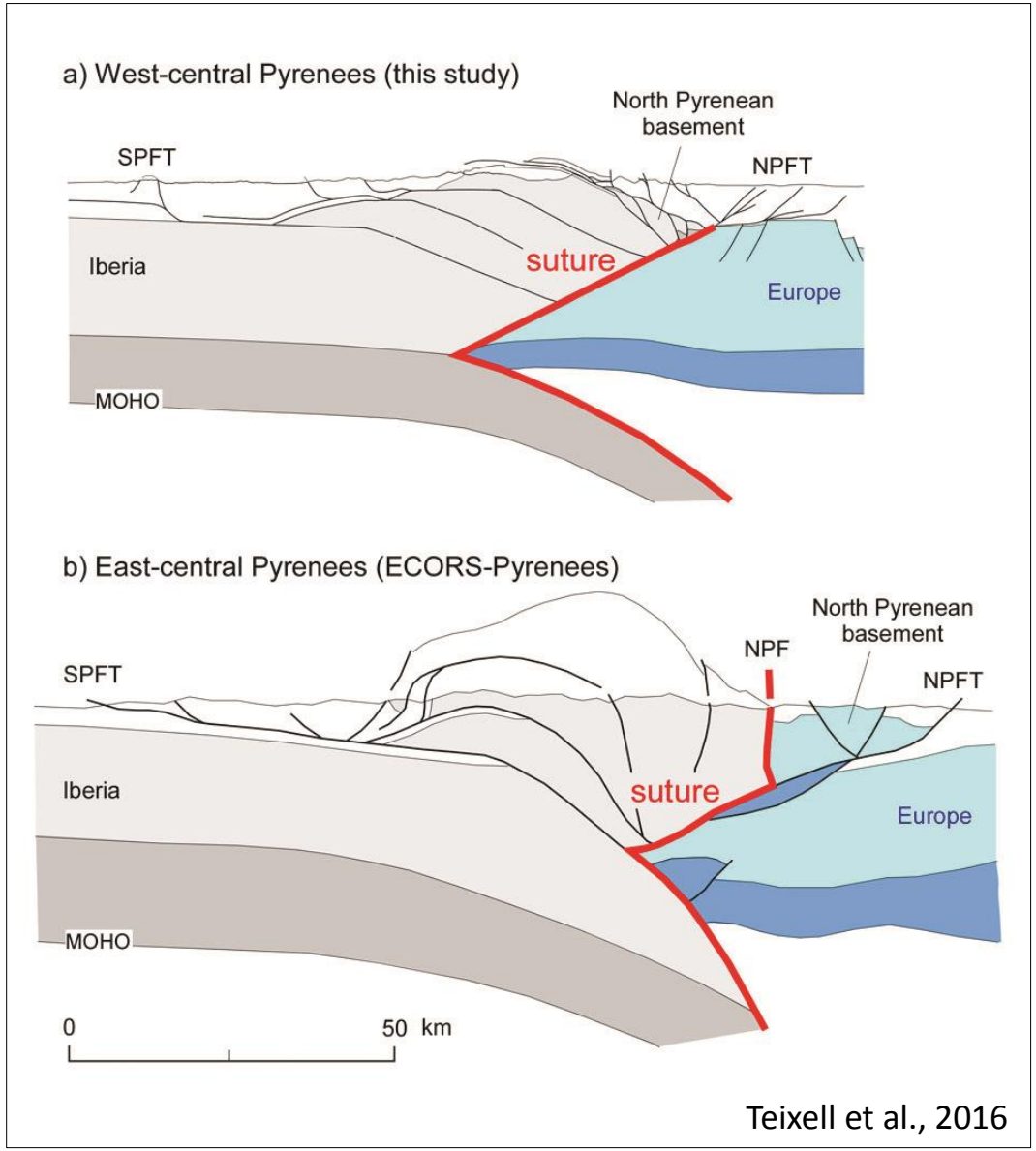
Teixell, Labaume and Lagabrielle 2016

- Suture at crustal ramp of NPFT. Iberian plate thrust system must root into suture
- Lower crust subducts to a depth of ca. 60 km, identified by recent receiver-functions

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable brgm

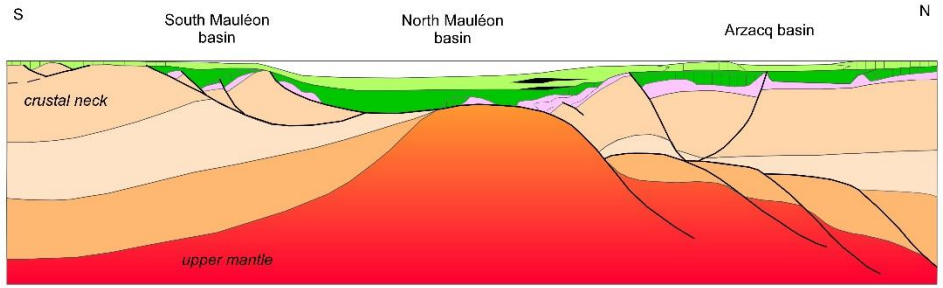
The plate configuration varies laterally



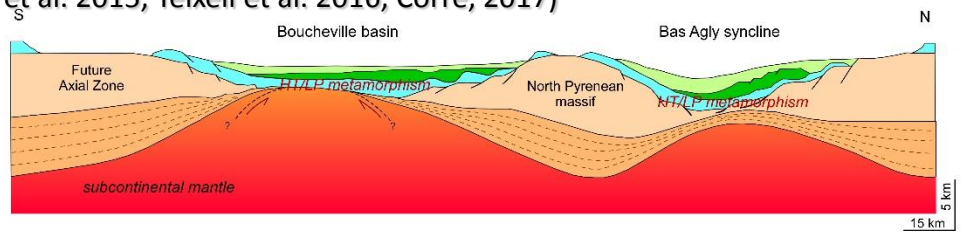
Teixell et al., 2016

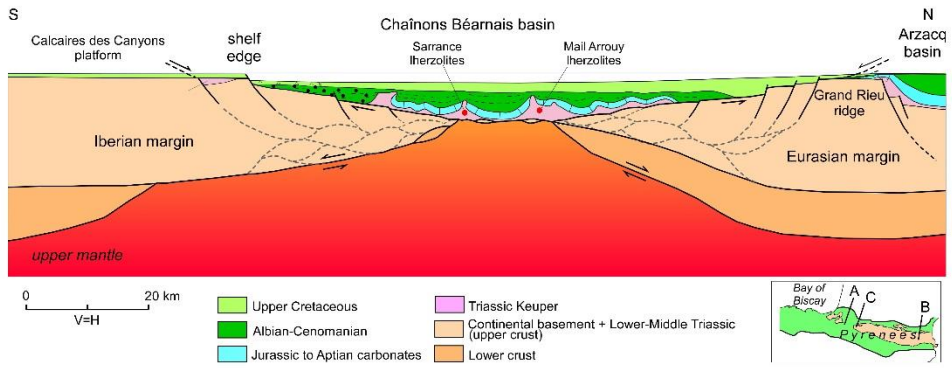
Models for paleomargin structure

Tilted blocks (Masini et al. 2014)



Smoothly boudinaged (“hot”)
(Clerc et al. 2015, Teixell et al. 2016, Corre, 2017)





- ✓Large-scale simple shear, margin asymmetry
- ✓Tilted fault-blocks, rollovers
- ✓No continuity of Triassic salt layer

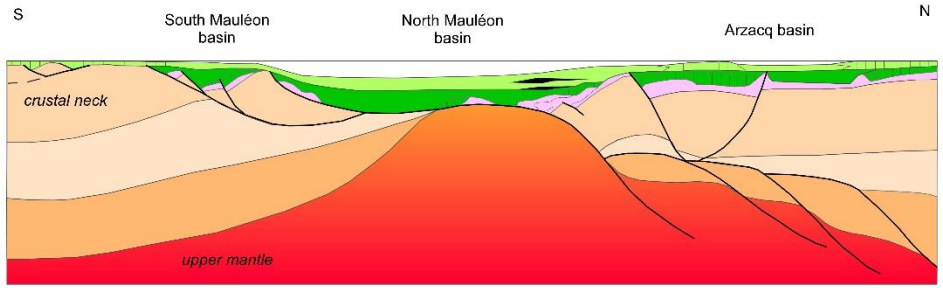
- ✓ Symmetric margins, smooth tops
- ✓Detached sedimentary lid and diapiric system
- ✓ No rollovers, no rafts

- Do these differences express real structural variation along the ancient continental margins?
- Are they controlled by the thermal state of the lithosphere? (hot vs. cold paleomargins)
- Need to map tectonic style laterally

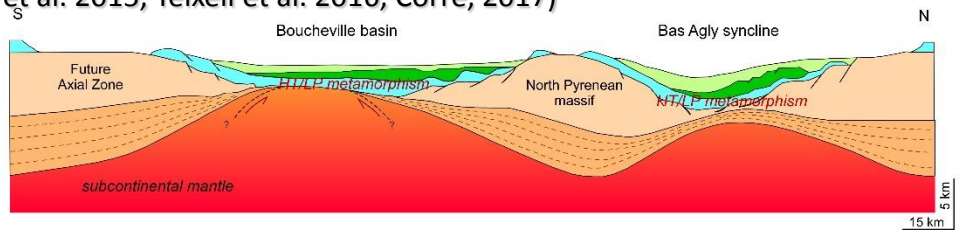
RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

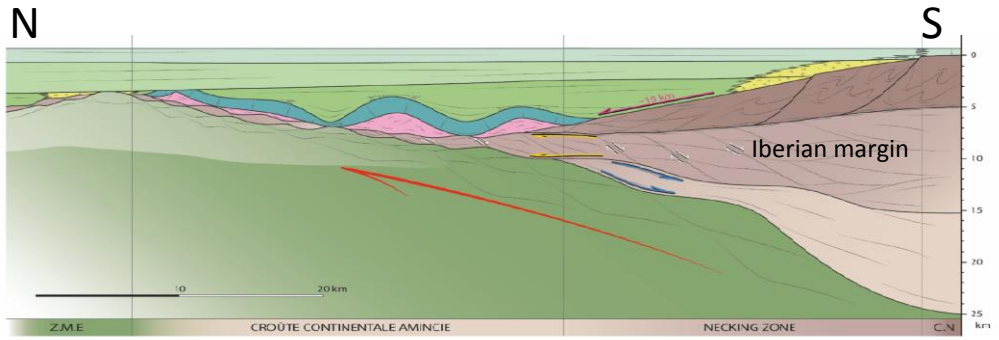
Models for paleomargin structure

Tilted blocks (Masini et al. 2014)



Smoothly boudinaged ("hot")
(Clerc et al. 2015, Teixell et al. 2016, Corre, 2017)





Corre, PhD thesis (2017)

✓Large-scale simple shear, margin asymmetry

✓Tilted fault-blocks, rollovers

✓No continuity of Triassic salt layer

✓ Symmetric margins, smooth tops

✓Detached sedimentary lid and diapiric system

✓ No rollovers, no rafts

- Do these differences express real structural variation along the ancient continental margins?
- Are they controlled by the thermal state of the lithosphere? (hot vs. cold paleomargins)
- Need to map tectonic style laterally

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Steps in the kinematic evolution of orogeny

(Pau-Chaînons Béarnais-Jaca transect)

- Two stages of Pyrenean building:

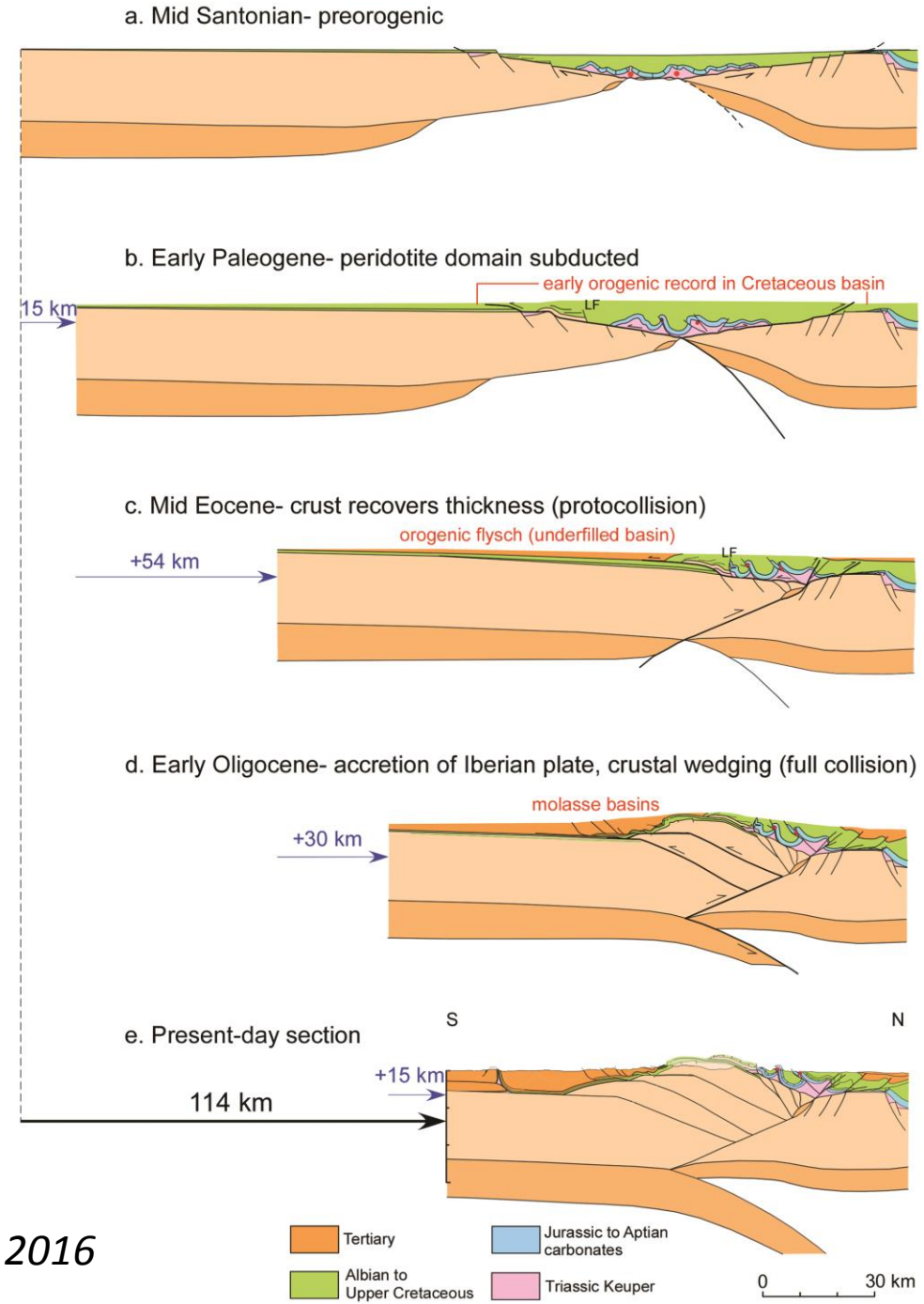
  - Basin inversion –not much structural relief, faint thermochron signal (crust recovers thickness, cover pop-up thrusted)

  - Basement stacking (full “collision”)

- Watch out for:

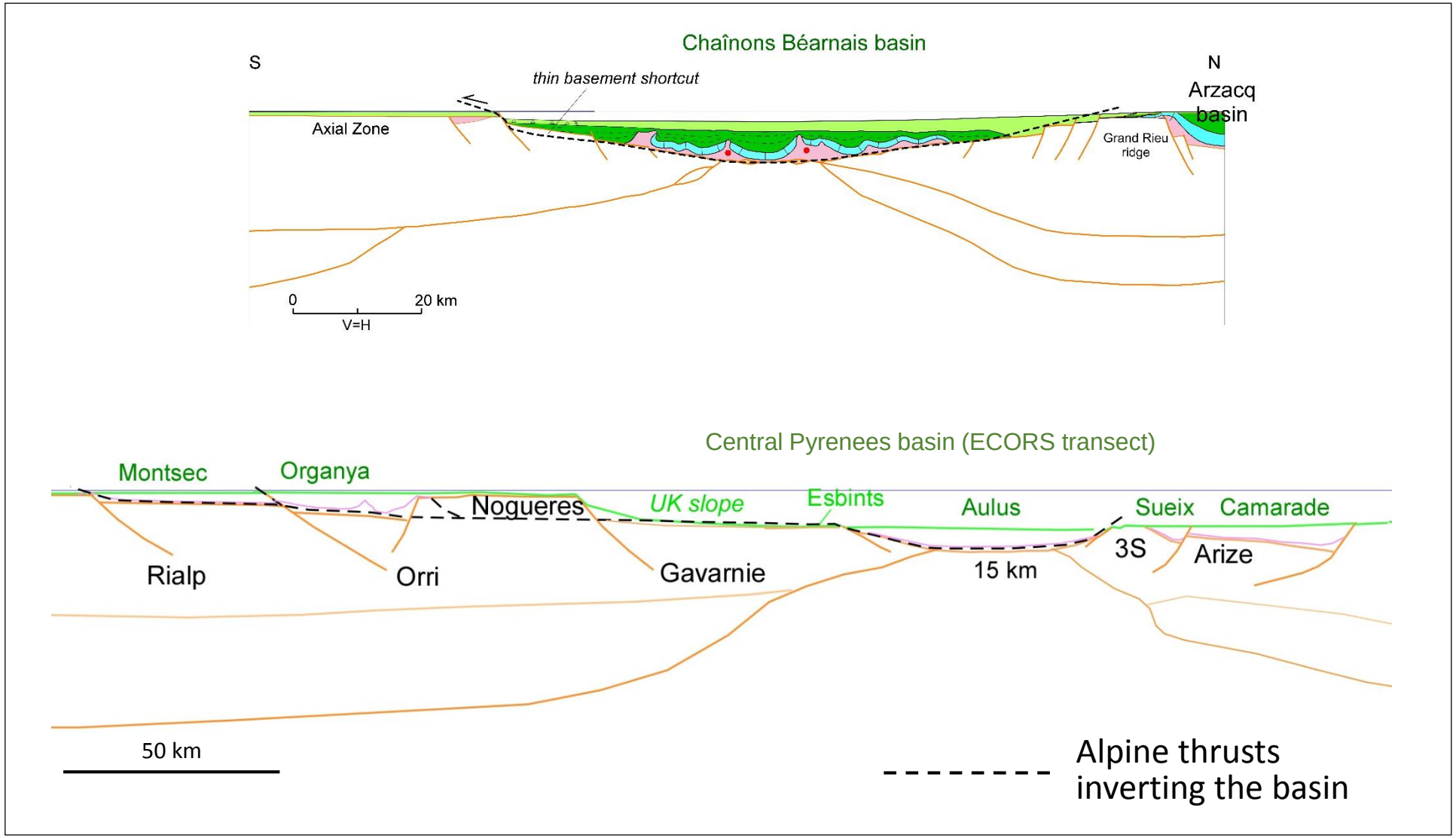
  - Polarity of thrusting (European margin overriding and Iberian lower crust subduction)

  - Upper/lower crustal balance during orogeny –role of inherited differential stretched structure

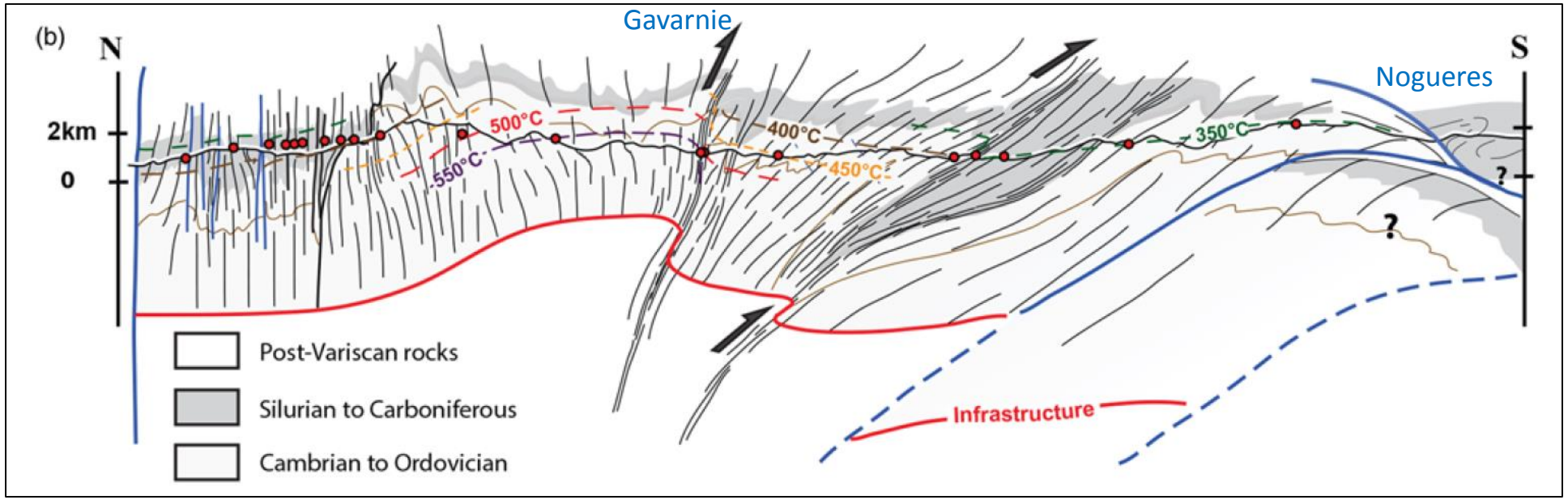


Teixell, Labaume and Lagabrielle, 2016

Comparison: style of early inversion of rift axis

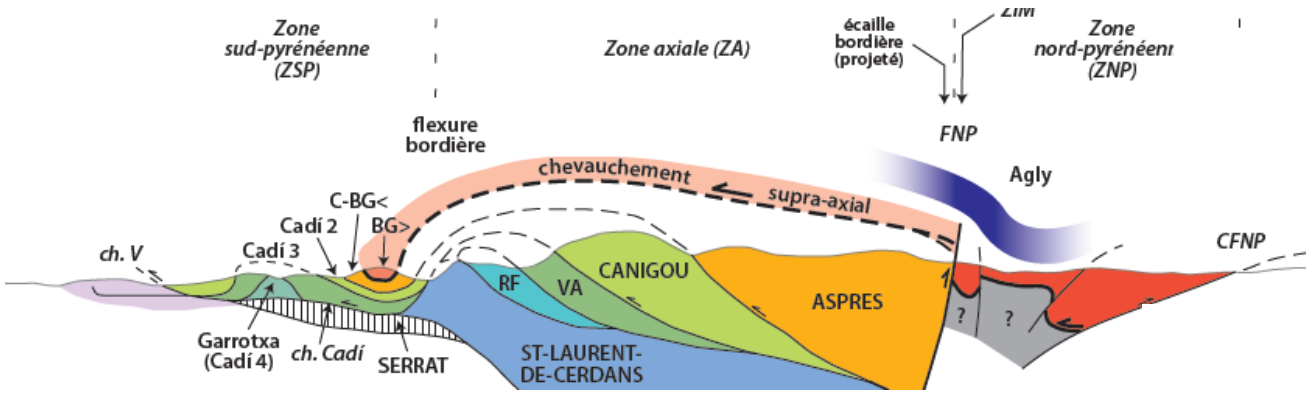


The (outcropping) Axial Zone as an alpine tectonic unit?

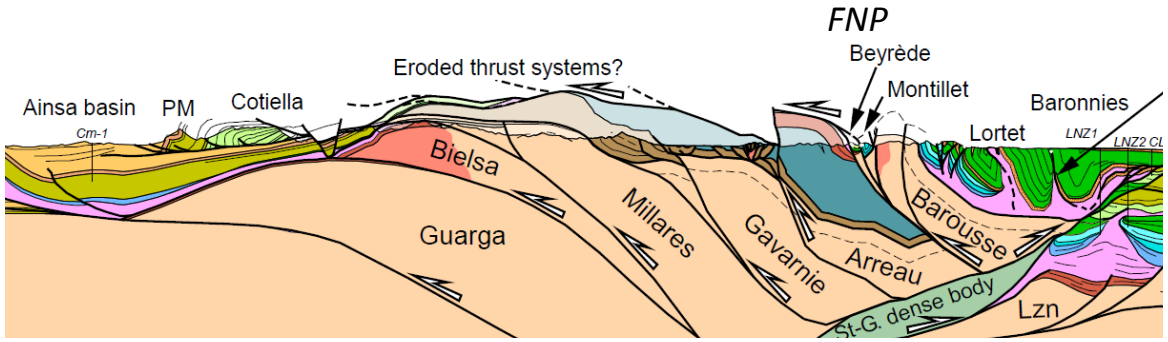


Cochelin et al. (2017)

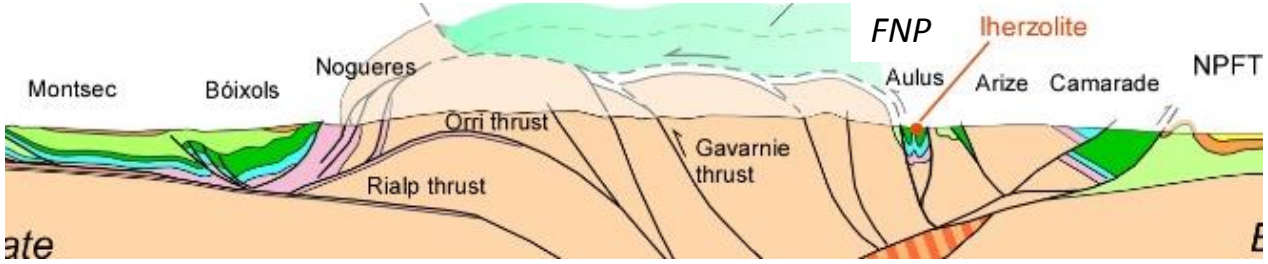
Root zone of the South Pyrenean upper thrust sheets in the North Pyrenean fault



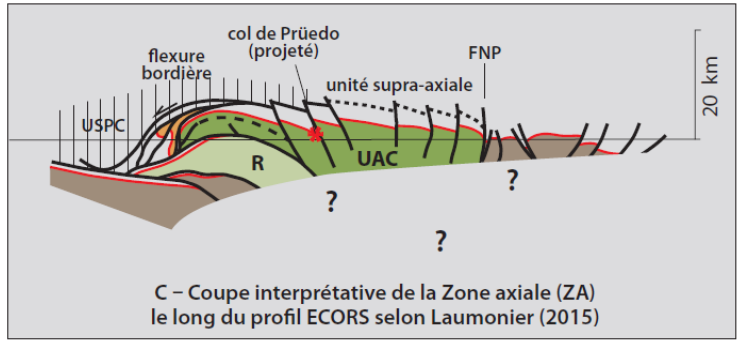
Pyrénées Orientales (Laumonier 2015)



Nestes-Cinca transect (Espurt et al. 2019)



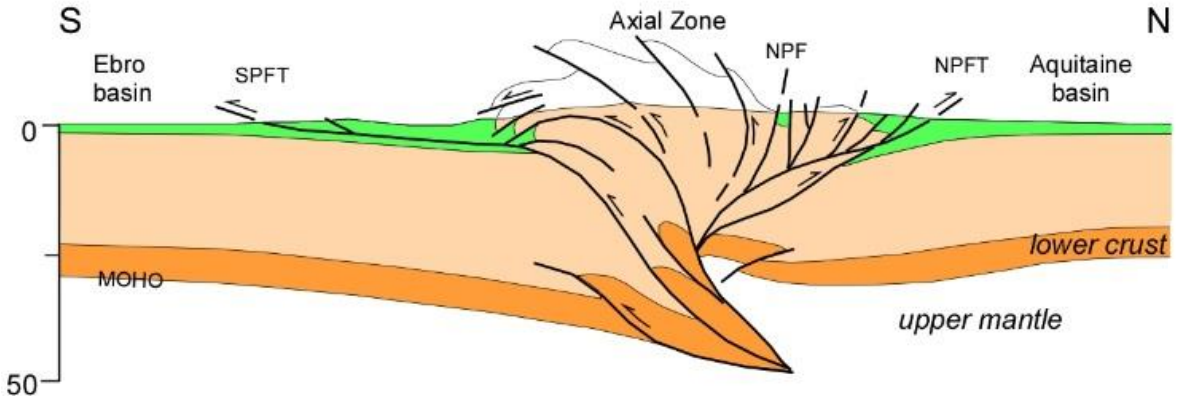
ECORS-Pyrenees transect (Teixell et al. 2018)



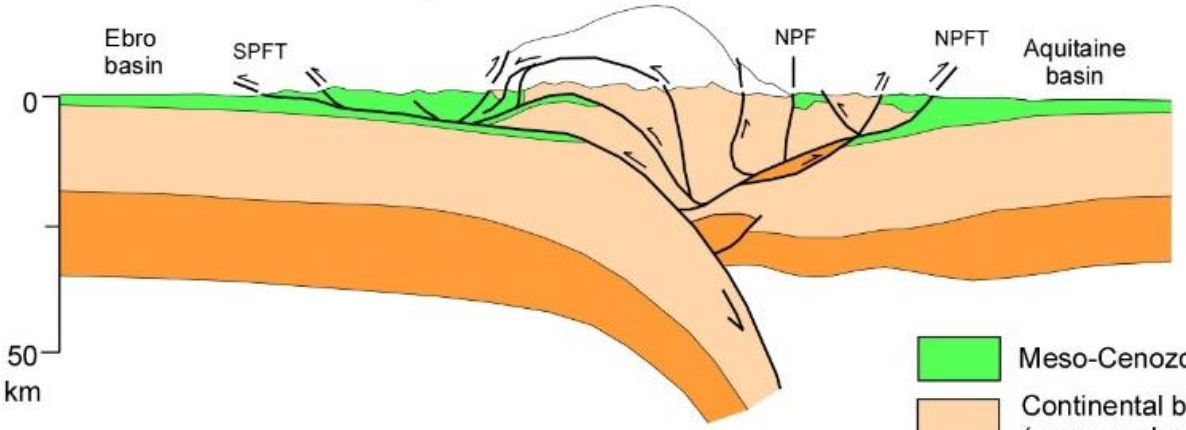
C – Coupe interprétative de la Zone axiale (ZA) le long du profil ECORS selon Laumonier (2015)

Interpretations of thrust relationships at the ECORS-Pyrenees transect

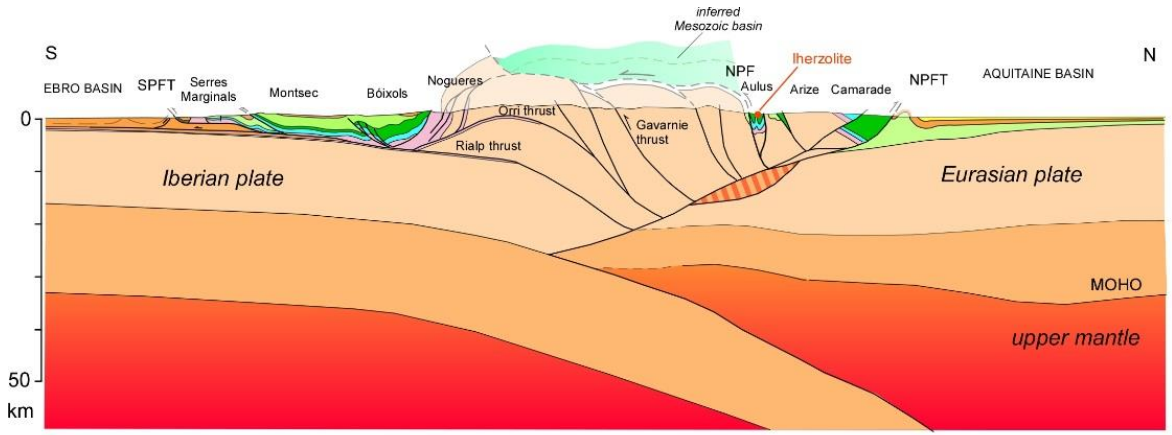
(Roure et al. 1989)



(Muñoz 1992)



(Teixell et al. 2018)

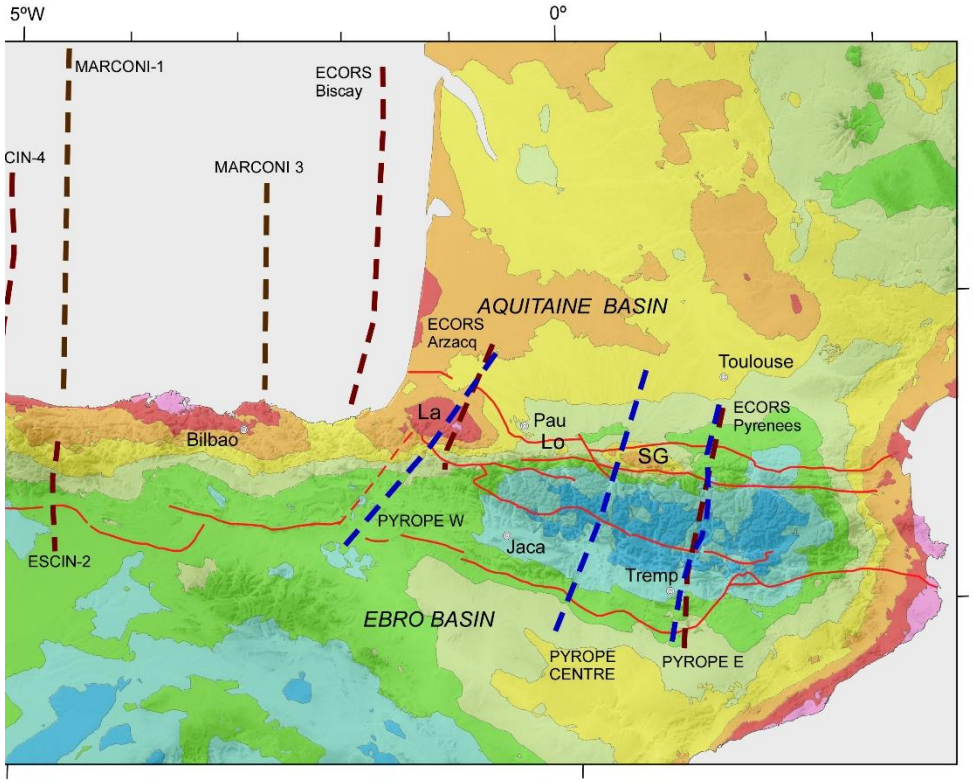


Meso-Cenozoic sediments

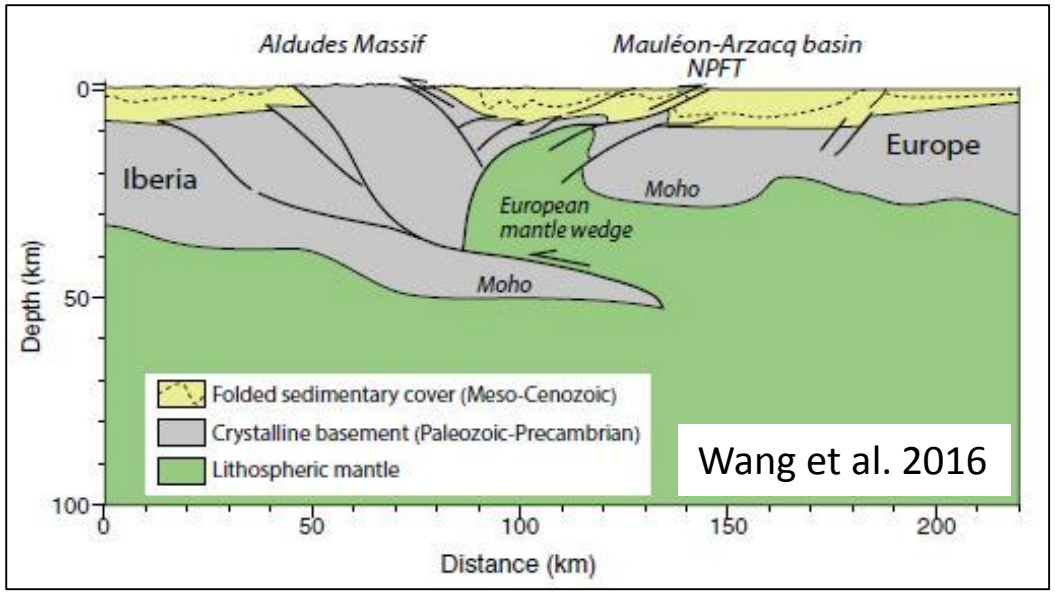
Continental basement (upper and middle crust)

Lower crust

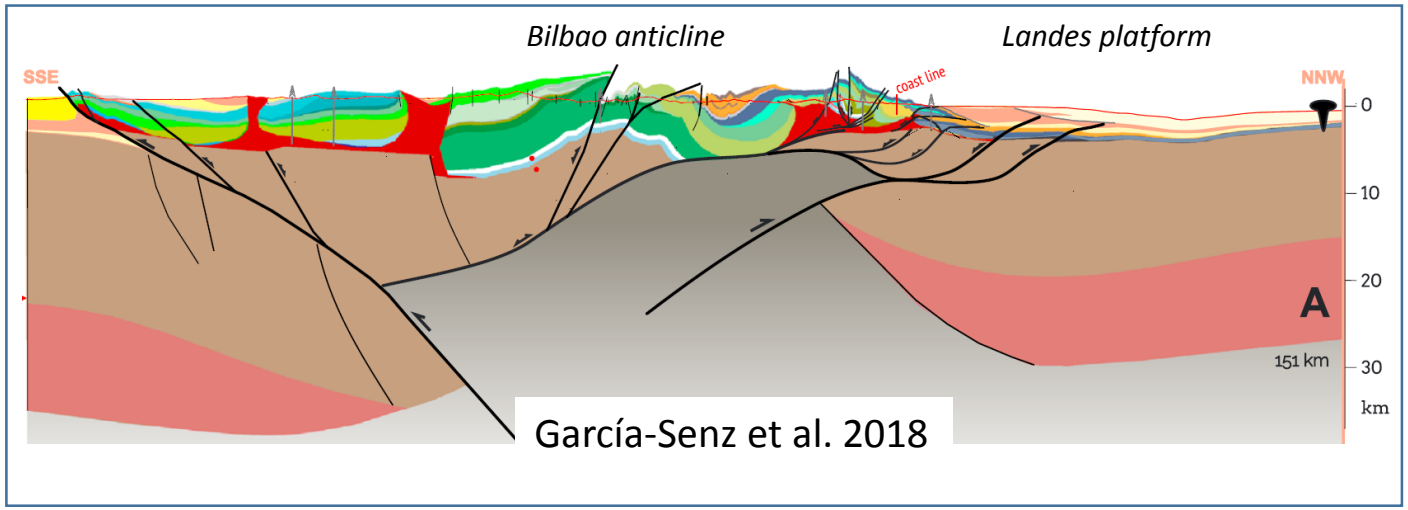
A recent controversy: has the exhumed mantle persisted until today?



Western Pyrenees

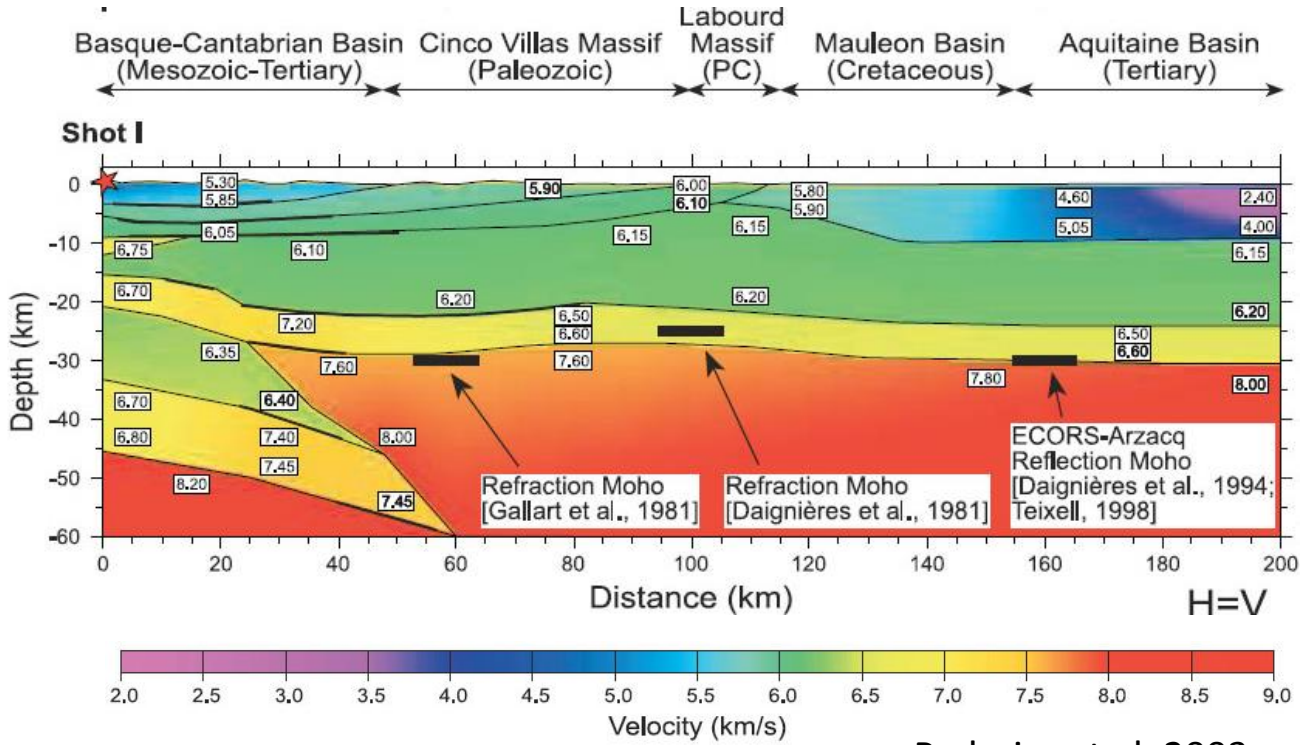


Basque-Cantabrian Pyrenees



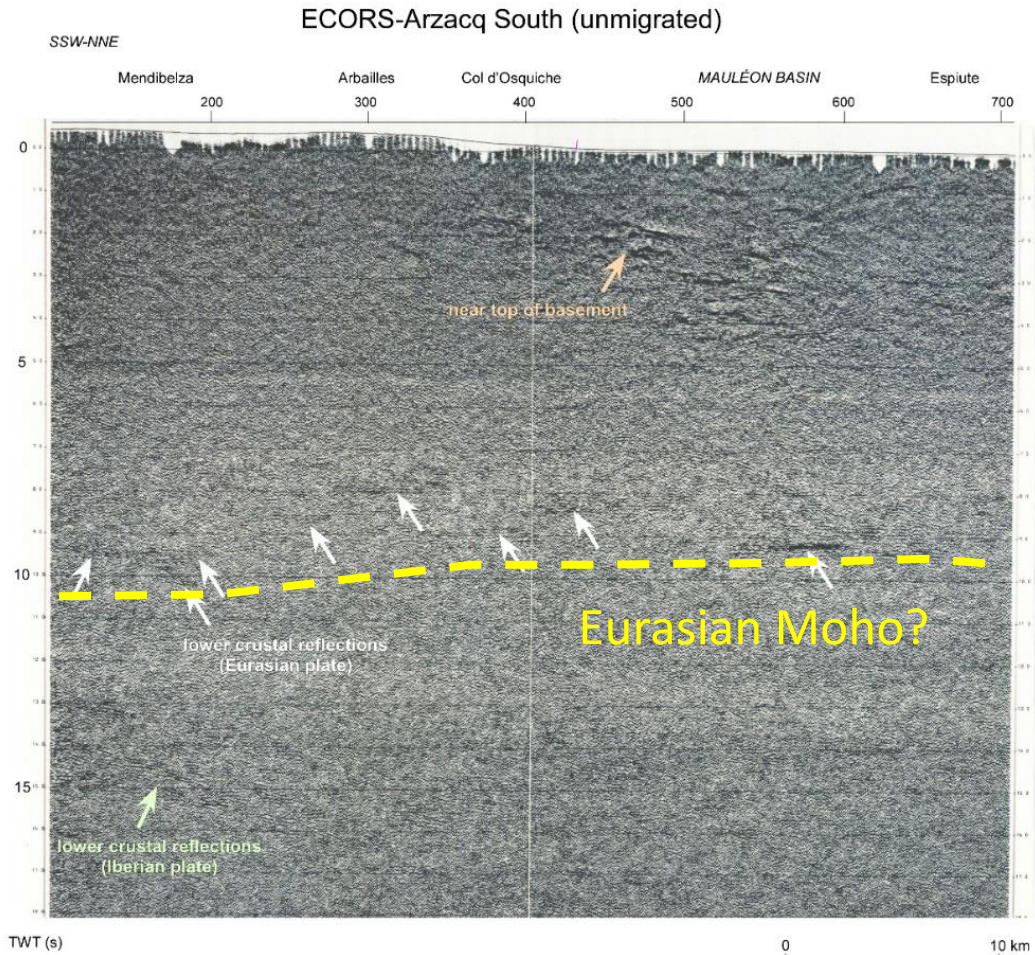
But…

Velocity models from wide-angle data



Pedreira et al. 2003

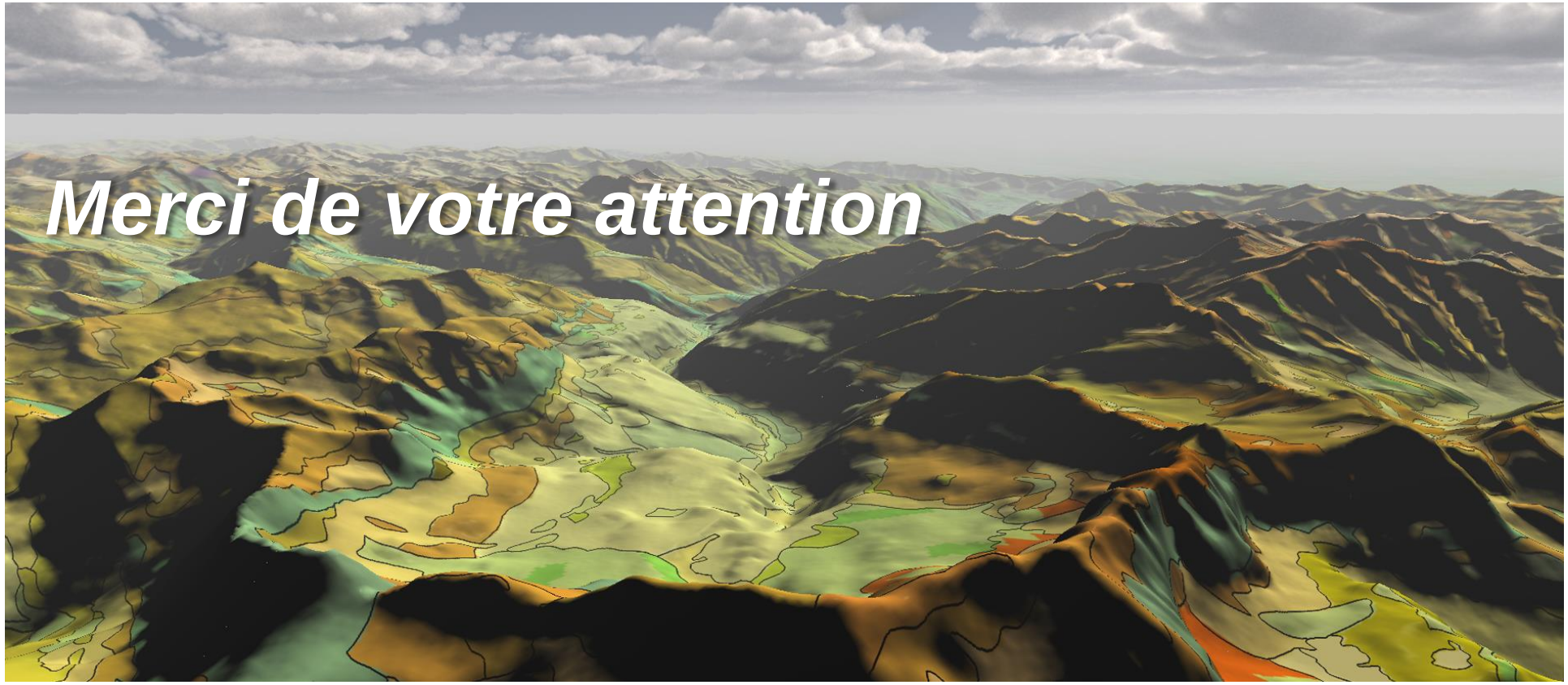
Deep reflections in vertical-incidence profiles



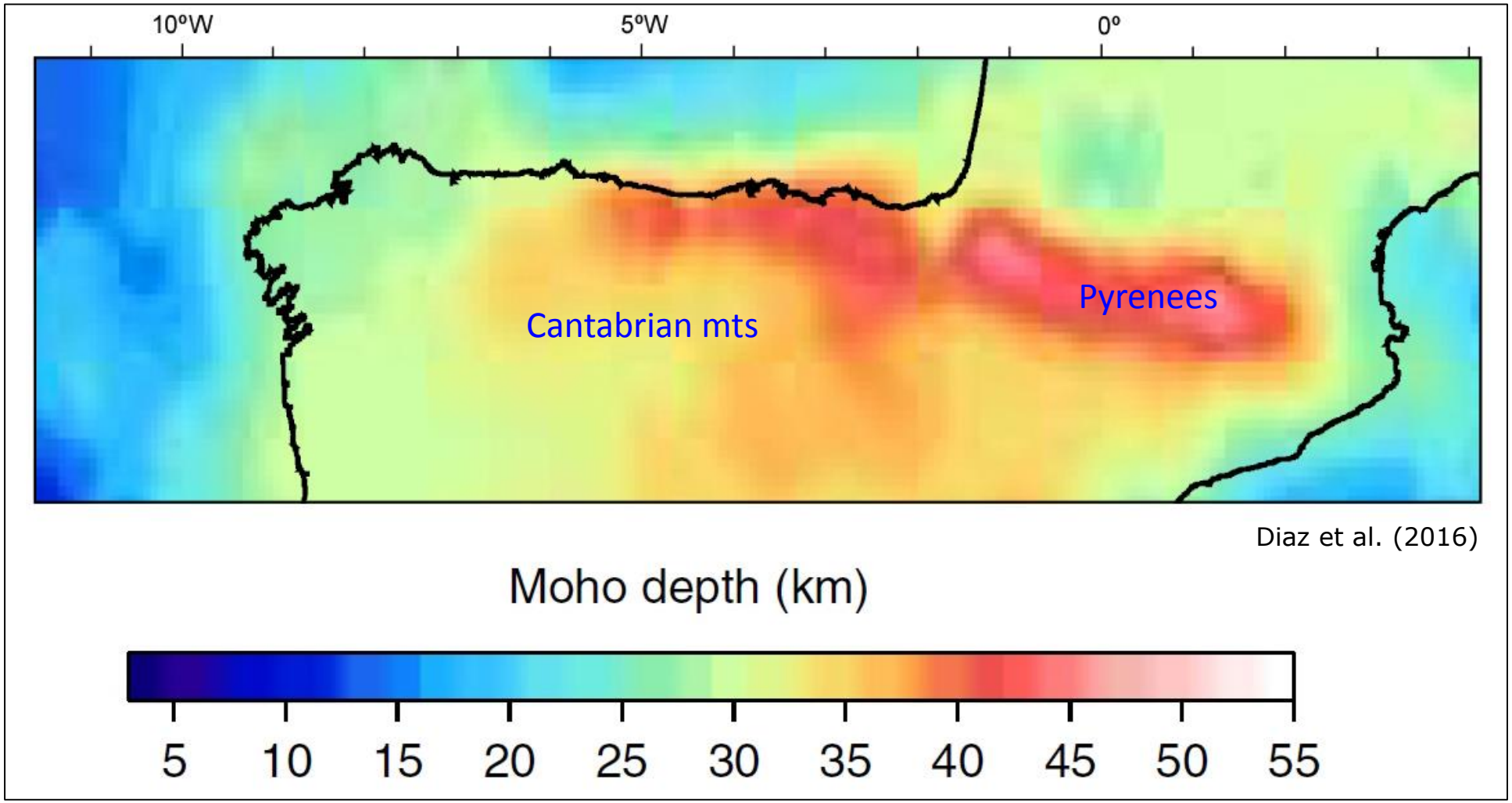
Teixell 1998

RgF RÉFÉRENTIEL GÉOLOGIQUE DE LA FRANCE

Géosciences pour une Terre durable brgm

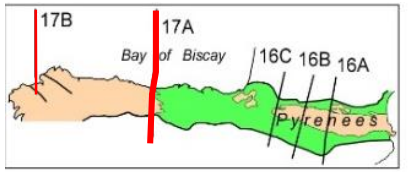

Merci de votre attention

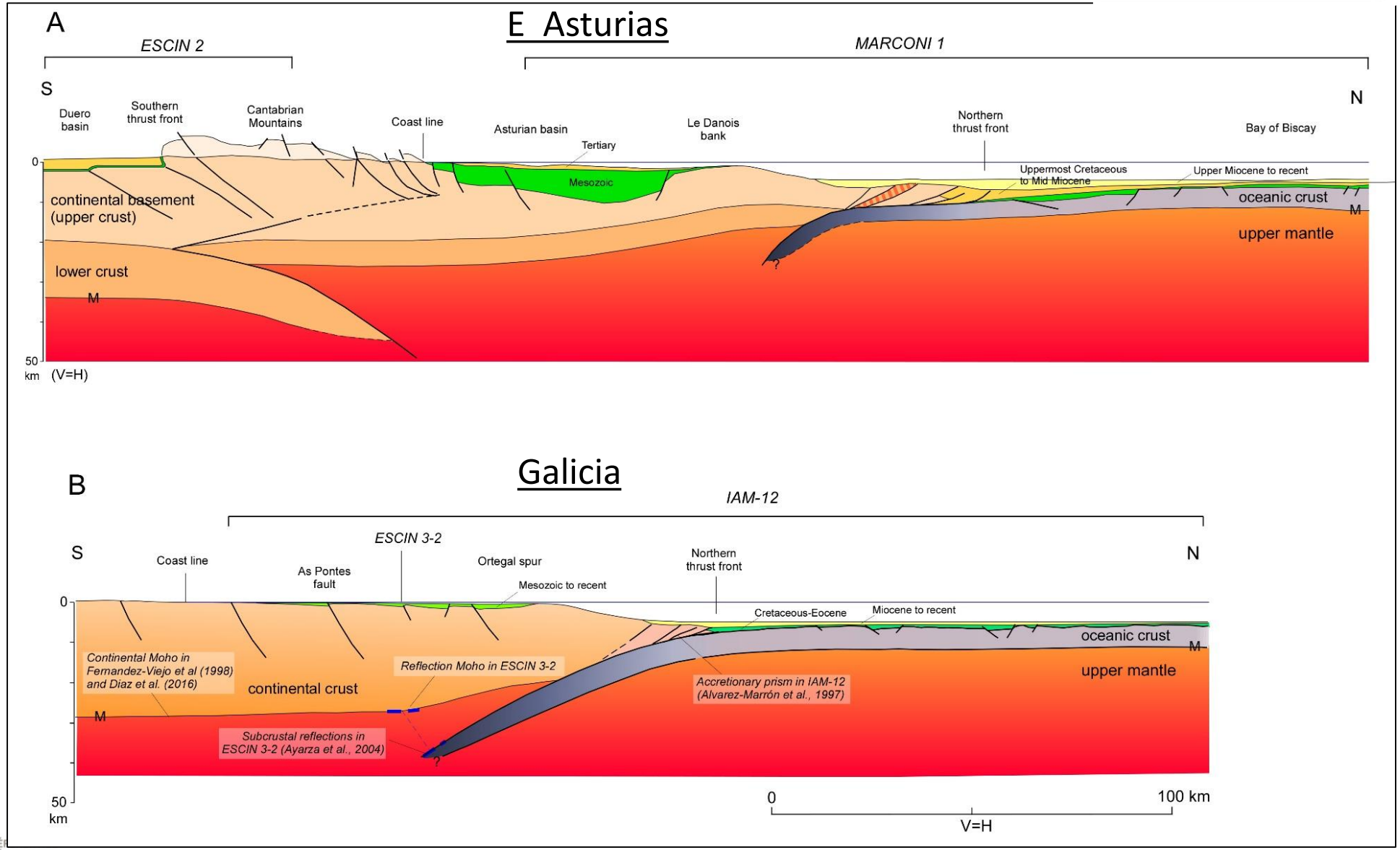
The Cantabrians: persistent thickened structure



Sections for Cantabrian mountains and margin

(Teixell et al., Tectonophysics 2018)





(including oceanic subduction, cf. Boillot 70's)