

# Status and expected results from the ANR project



## ***Multiscale seismic imaging of MAssif Central focusing on recent Intraplate Volcanism***

Anne Paul<sup>1</sup>, Aurélien Mordret<sup>1</sup>, and the MACIV Team<sup>1, 2, 3, 4</sup>

<sup>1</sup> ISTERre, Univ. Grenoble Alpes & CNRS, Grenoble (C. Aubert, G. Scheiblin, N. Shapiro, ...)

<sup>2</sup> IRAP, Univ. Paul Sabatier & CNRS, Toulouse (H. Pauchet, M. Sylvander, F. Grimaud, ...)

<sup>3</sup> GET, Univ. Paul Sabatier & CNRS, Toulouse (S. Chevrot, ...)

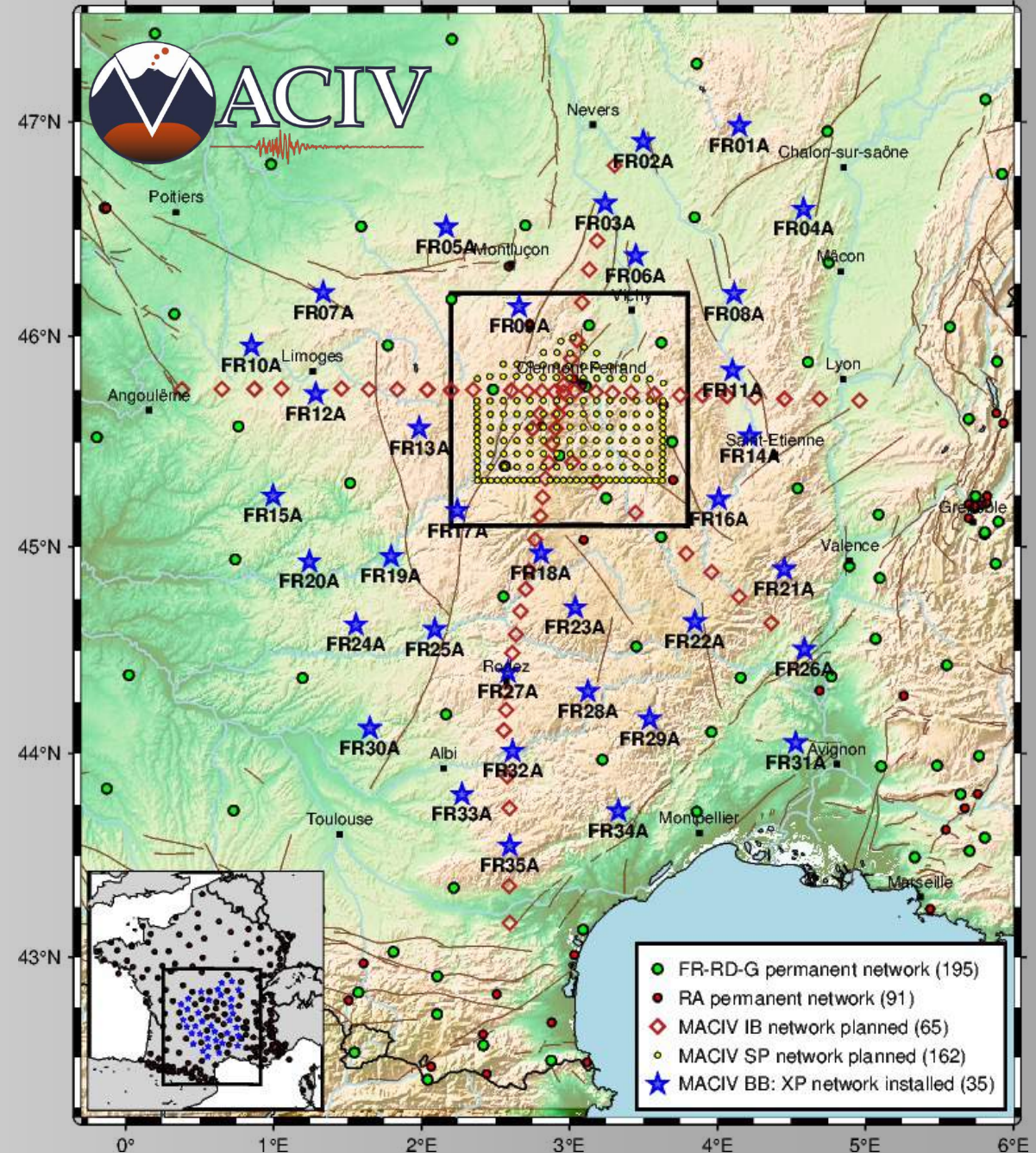
<sup>4</sup> LMV, Univ. Clermont-Auvergne & CNRS, Clermont-Ferrand (J. Battaglia, N. Cluzel, D. Laporte, T. Souriot, ...)

<https://maciv.osug.fr/>



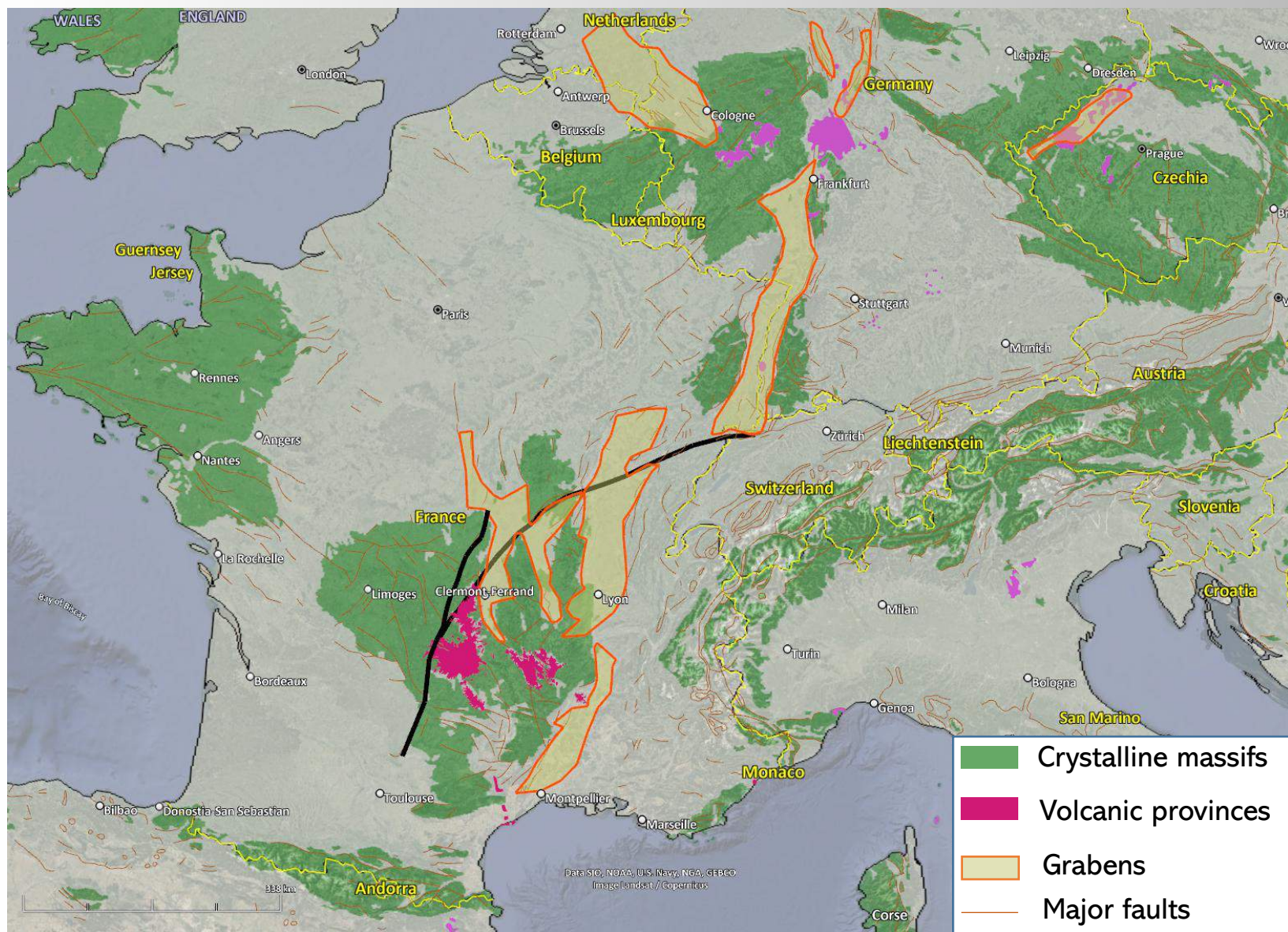
MACIV ANR project:

- ✓ PRC project funded by AAPG 2022
- ✓ ISTERre (coord.), LMV, GET, IRAP
- ✓ 01-03-2023 to 29-02-2028
- ✓ Work packages:
  - **WP1: Seismic data collection and distribution**
  - WP2: Seismic tomography using leading-edge methods
  - WP3: Seismicity detection and localization
  - WP4: Joint interpretation of seismic and geological data





# Why studying Massif Central with seismology?



- Complex geological target with >600 Ma history
- Largest intraplate volcanic province in Europe
- Last eruption 6700 ya (Lac Pavin)
- General structure poorly known at all scales, from mantle to shallow crust
- Similarities with other european volcanic provinces (inc. Eifel, [see talk by T. Dahm](#))
- **Last seismic imaging project more than 30 years ago!**



# Crustal structure from the 1970's active seismic profiles

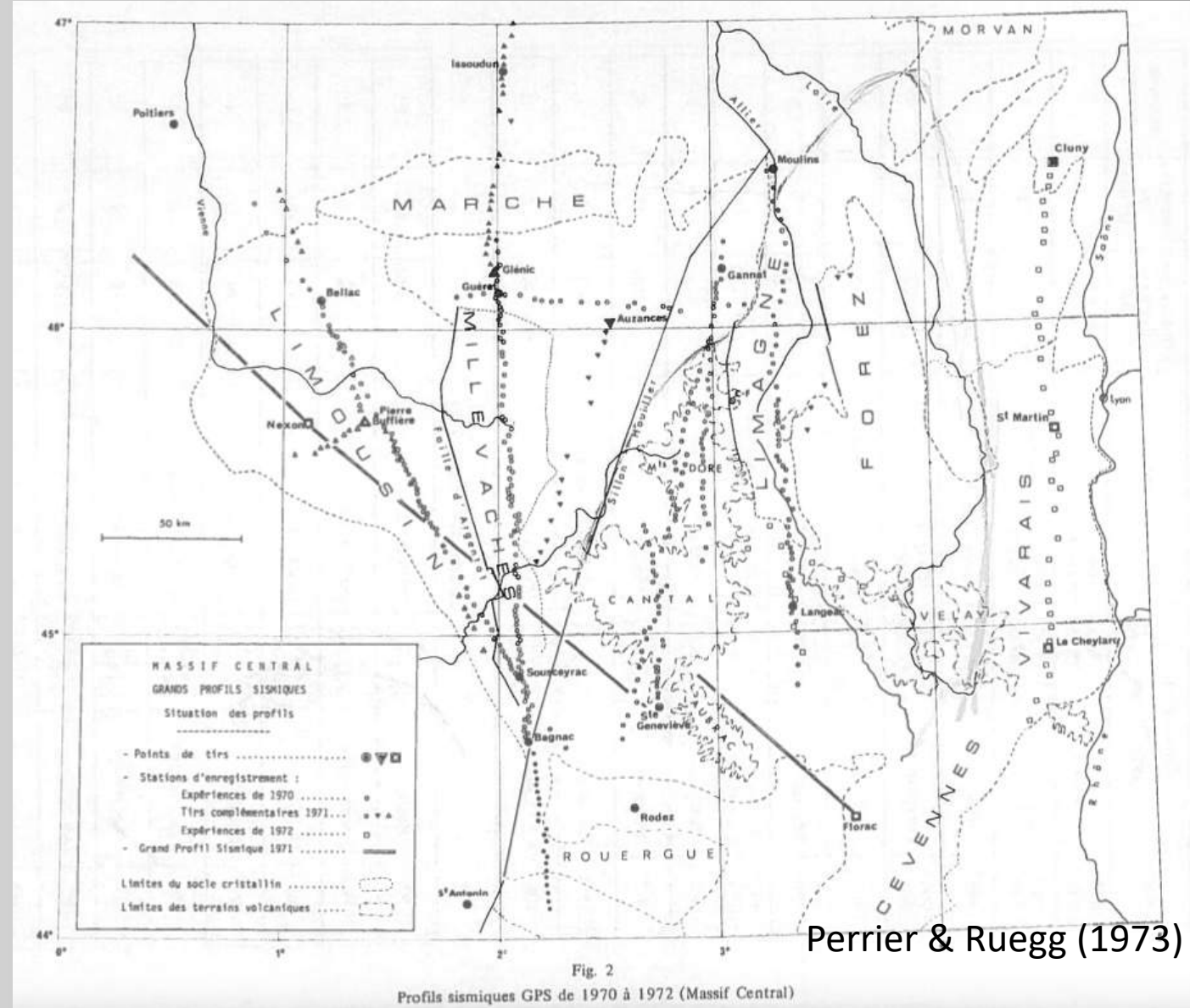
*Ann. Geophys., t. 29, fasc. 4, 1973, p. 435 - 502*

## Structure profonde du Massif Central français

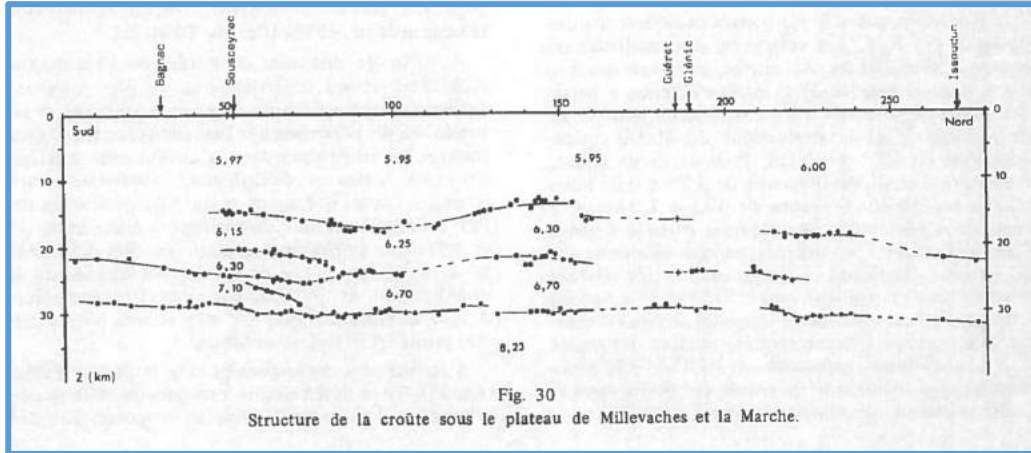
par G. PERRIER et J.C. RUEGG (1)

Institut de Physique du Globe, Université de PARIS VI, 4, place JUSSIEU, 75230 PARIS CEDEX 05

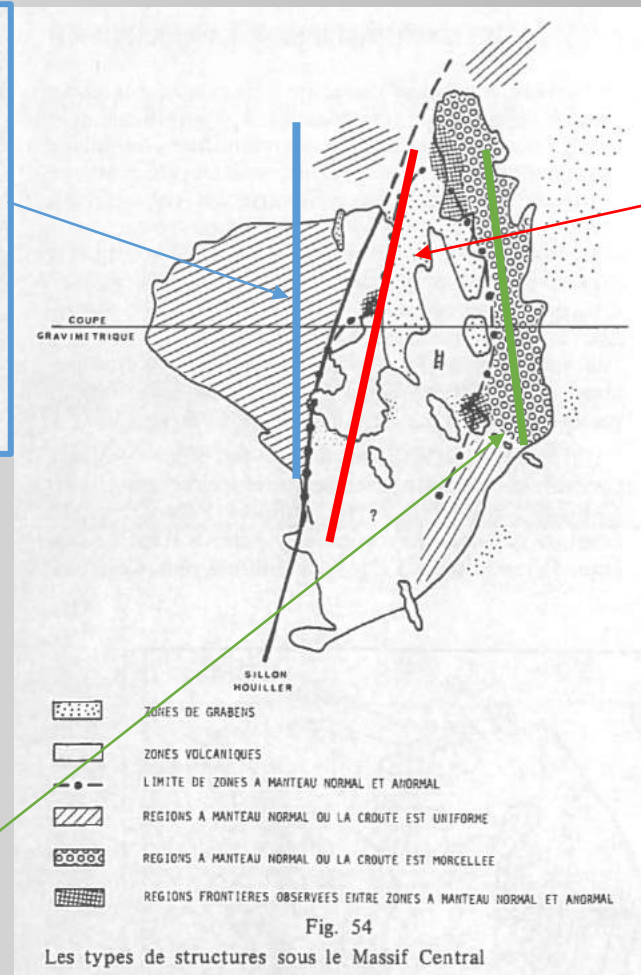
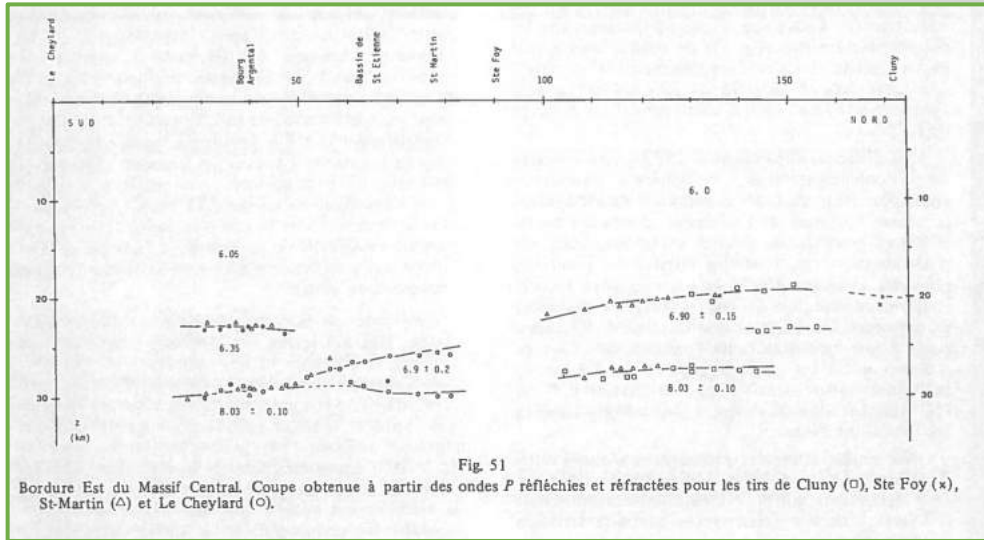
- ✓ Refraction-reflection long-range active seismic profiles
- ✓ ~1000 short-period stations (analog recorders)
- ✓ 400-2000 kg dynamite shots, 1970-1972



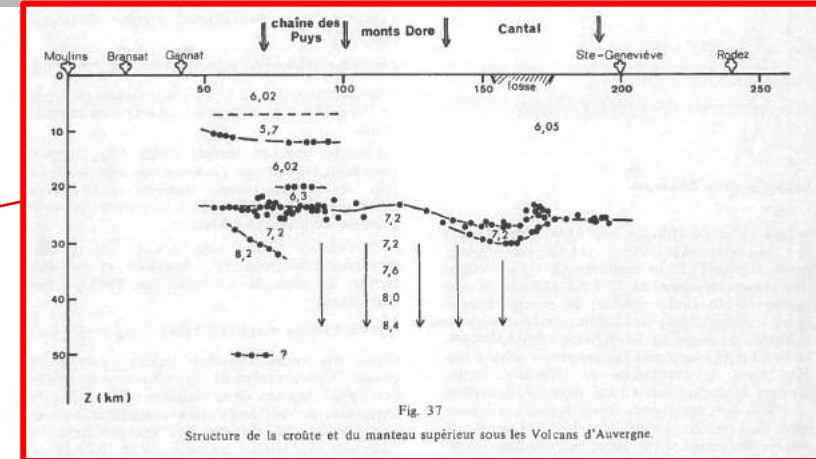
# Crustal structure from the 1970's active seismic profiles



W of Sillon Houiller: Uniform 30-km thick crust, with 3 layers above normal upper mantle (8.2 km/s)



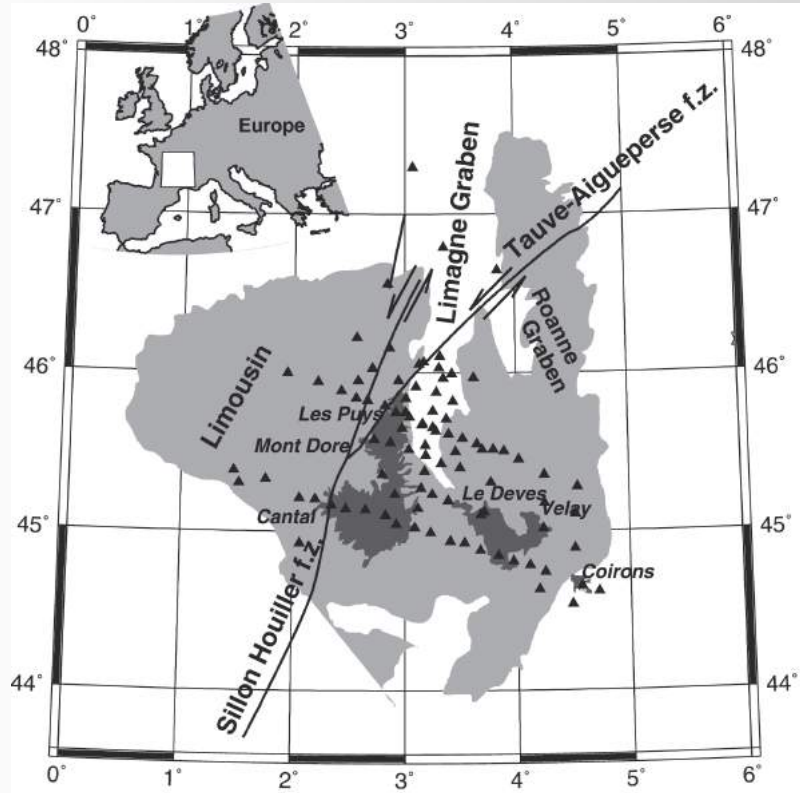
E. side of Massif Central: Slightly thinner crust (27 km), with 2 layers above normal upper mantle (8.2 km/s), laterally heterogeneous



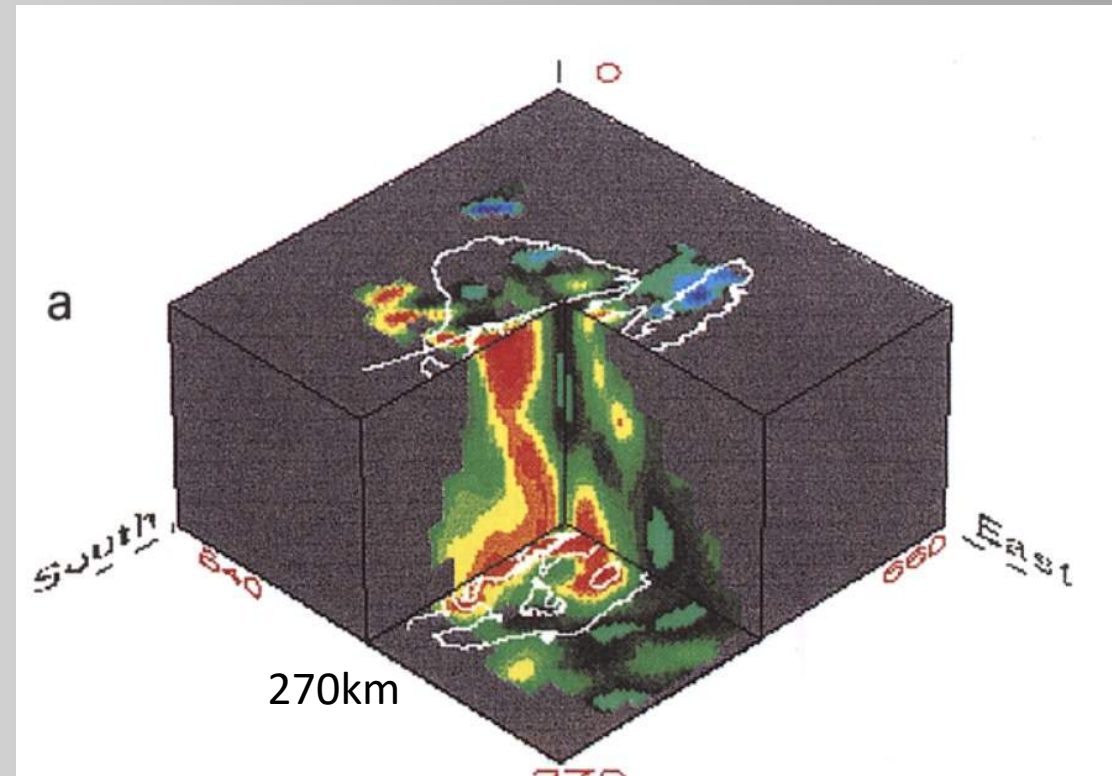
Oligocene grabens : thin crust (24 km) above low-velocity upper mantle (7.3 km/s) and vel. gradient to 8.4-8.5 km/s at 45 km

Perrier & Ruegg (1973)

# Origin of the volcanoes at mantle depth: The « baby plume » model?



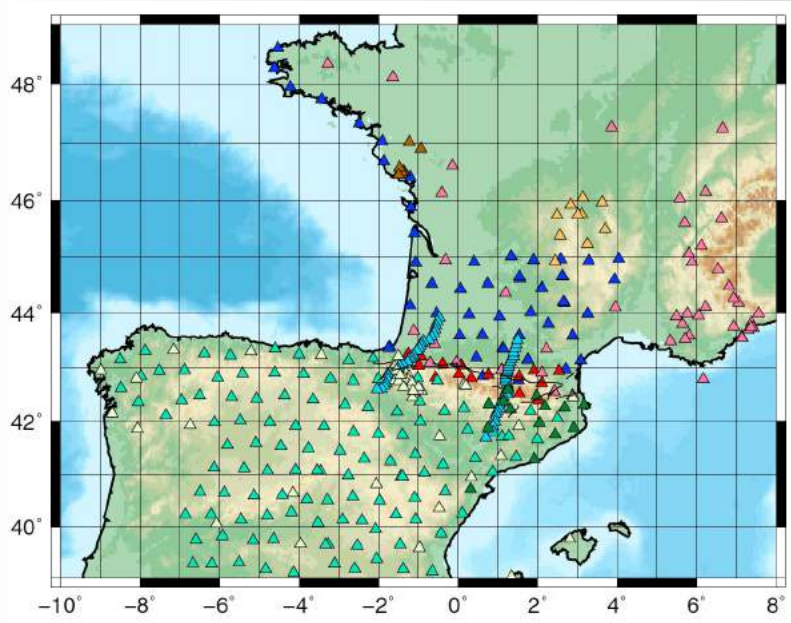
- ✓ Last dedicated seismic experiment in 1991-1992: 6 months, 79 temporary short-period stations + 14 permanent
- ✓ Teleseismic traveltime tomography
- ✓ Limited spatial coverage
- ✓ Preferential orientation of the array (smearing?)



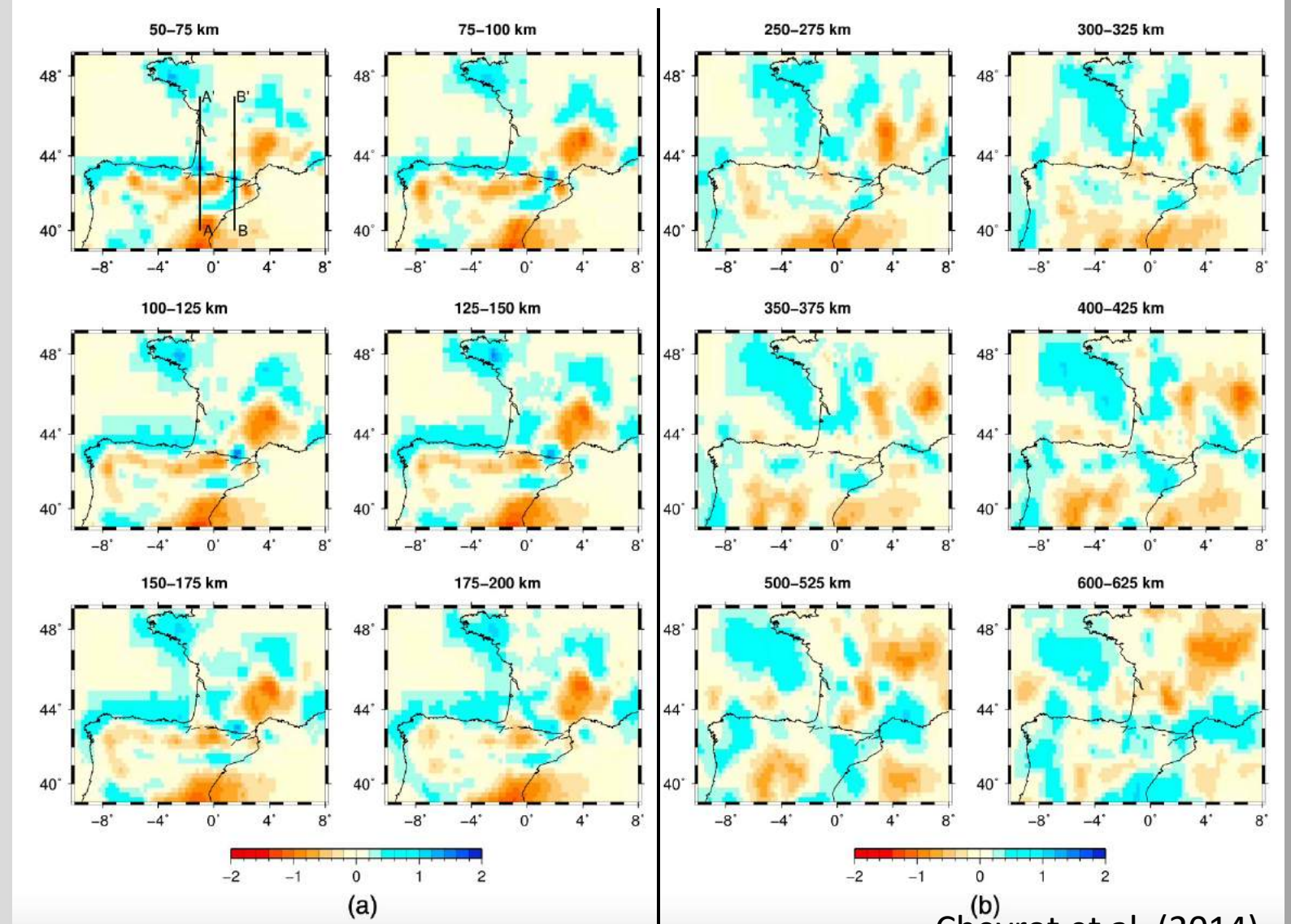
Granet et al. (1995)



# Origin of the volcanoes at mantle depth: The « baby plume » model?



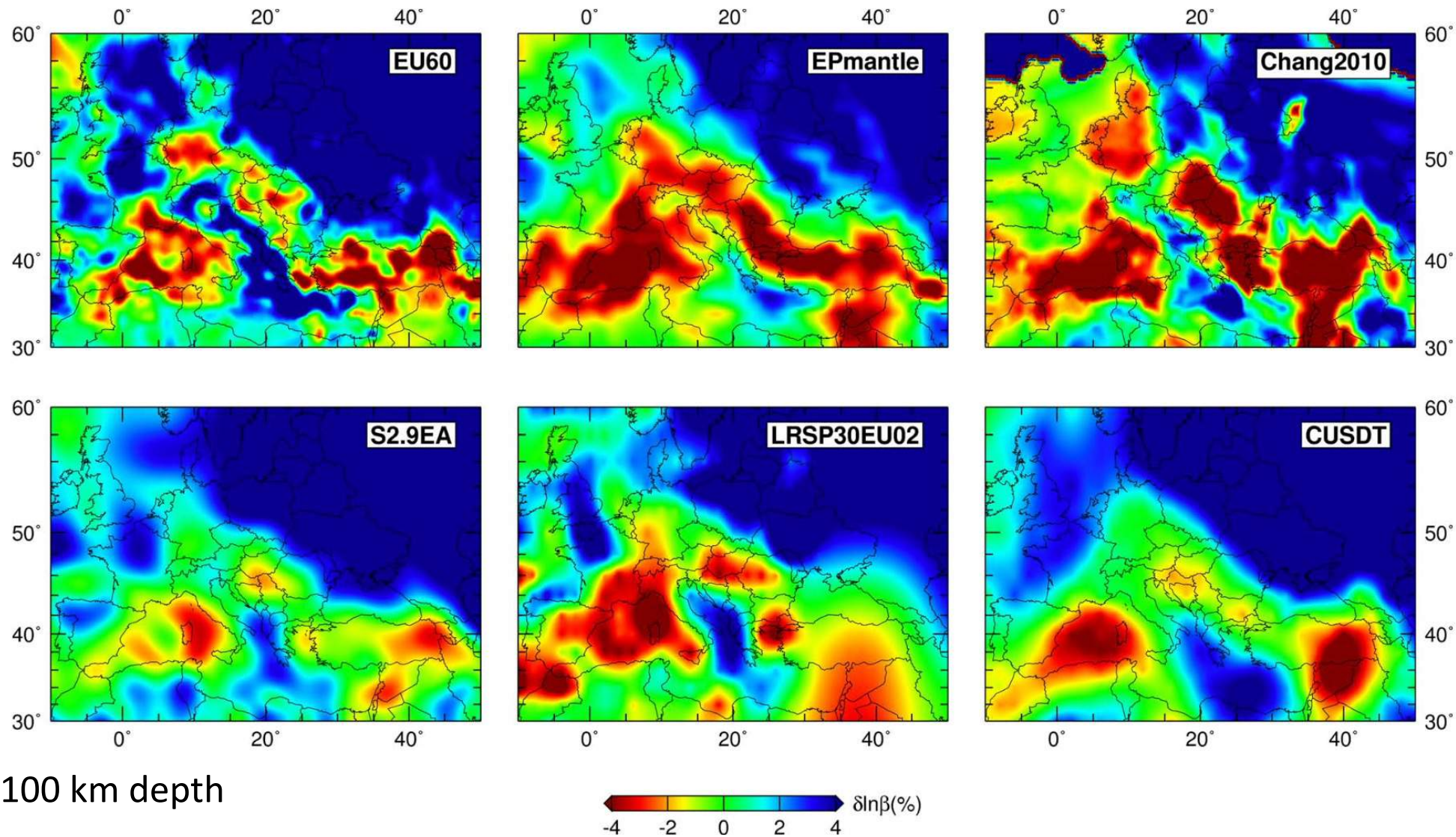
- ✓ PYROPE temporary experiment designed for investigating the deep structure of the Pyrenées
- ✓ Teleseismic traveltime tomography with crustal corrections



(b)  
Chevrot et al. (2014)



# Large scale upper mantle Vs tomography: variability!



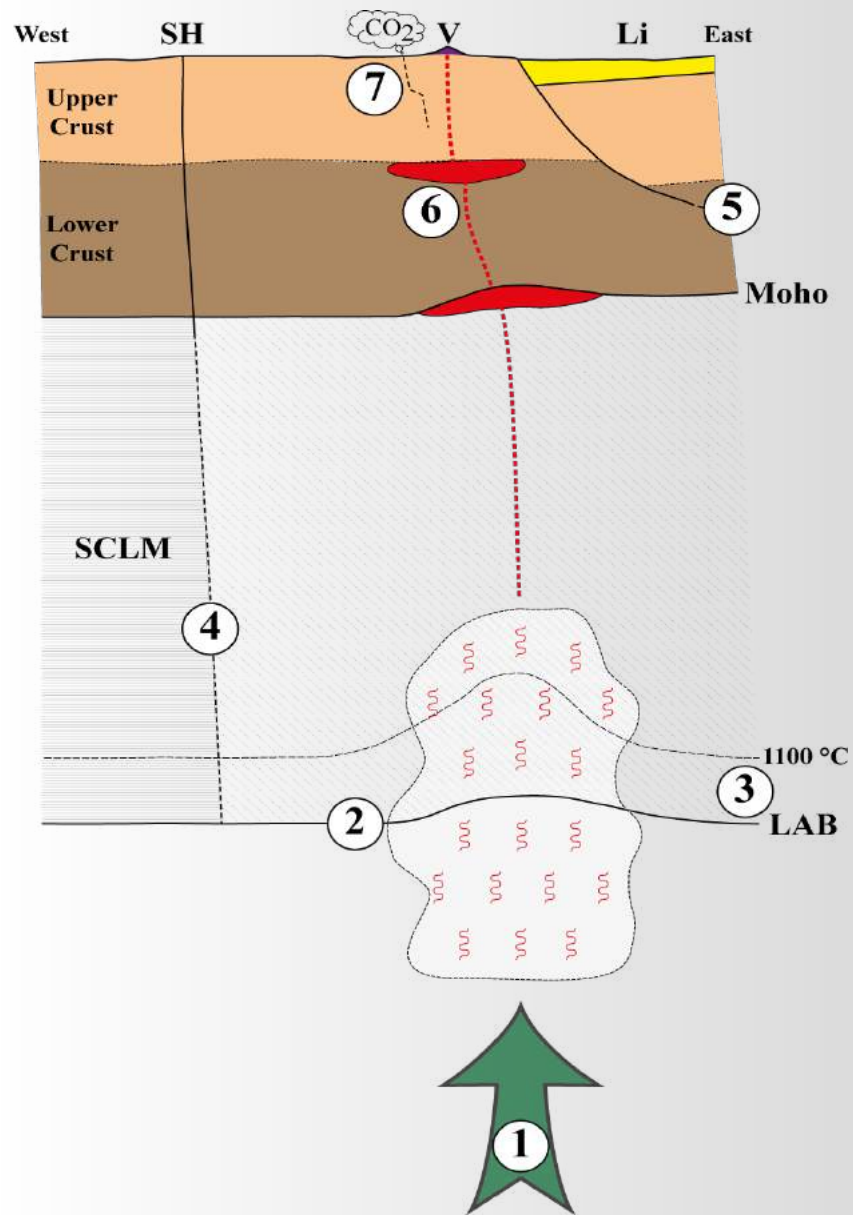
100 km depth

- EU60: Zhu et al. 2015
- EPmantle: Schivardi & Morelli 2011
- Chang2010: Chang et al. 2010
- S2.9EA: Kustowski et al. 2008
- LRSP30EU02: Boschi et al. 2009
- CUSDT: Shapiro & Ritzwoller 2002

*Zhu et al. (2015)*



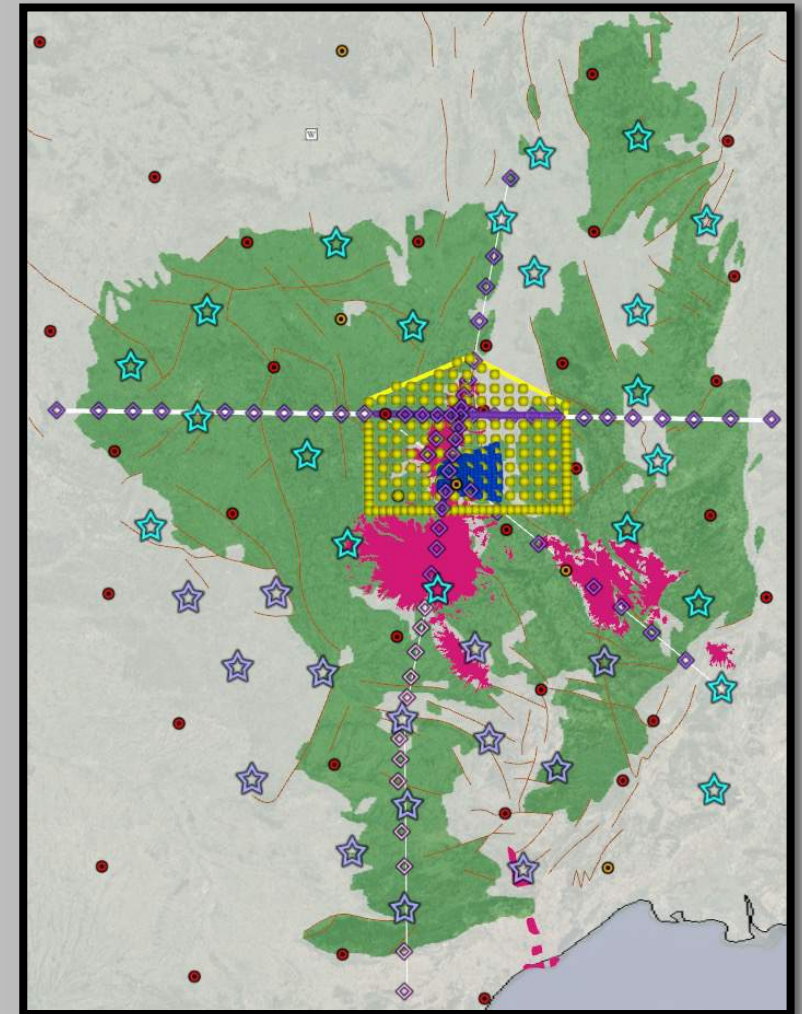
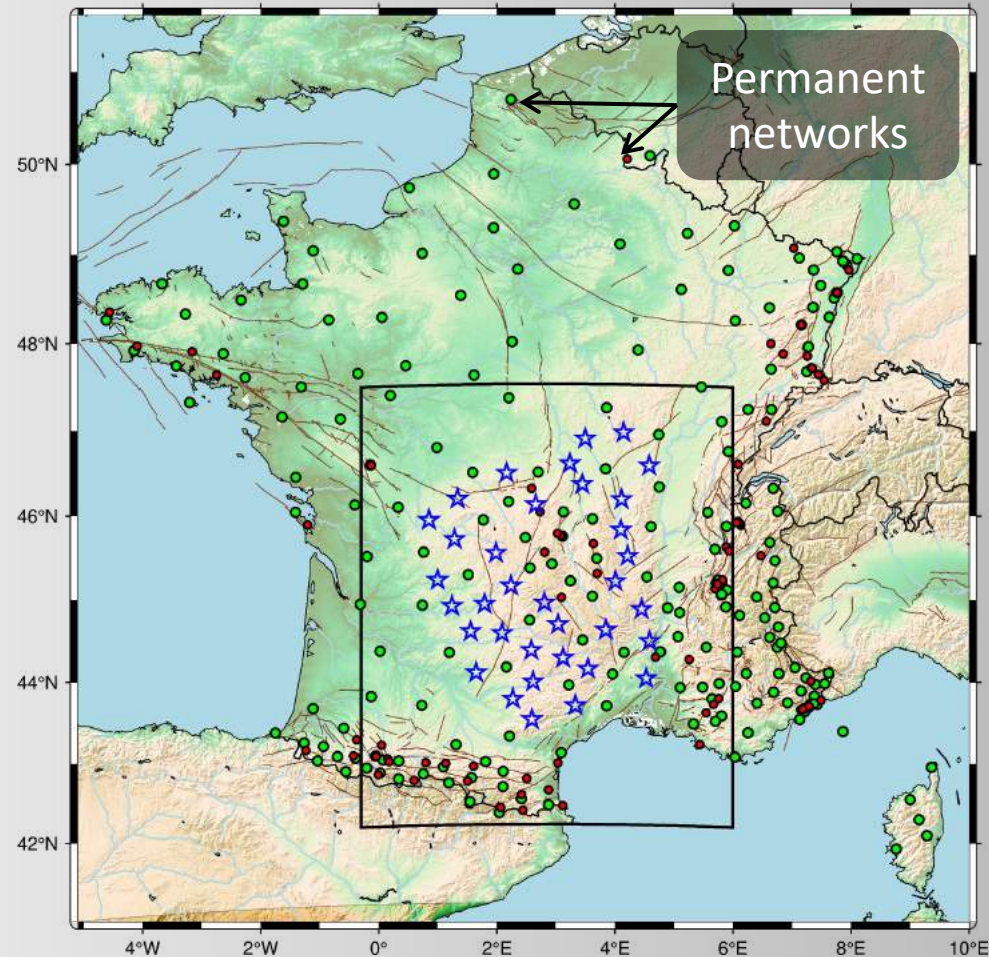
# Questions motivating a multi-scale seismic experiment in the FMC



1. Causes and geometry of the mantle upwelling under the Massif Central?
2. Mantle sources depth, mineralogical and geochemical characteristics?
3. P-T conditions of the melt?
4. Internal structure of the Sub-Continental Lithospheric Mantle (SCLM), control of lithospheric scale discontinuities and Variscan legacy on Cenozoic geodynamics and volcanism?
5. Internal structure of the crust, geometry of Moho?
6. Magma conduit systems, depth of magma chambers and hypothesis of their activity under the Chaîne des Puys?
7. CO<sub>2</sub> degassing at the Escarot mofette and mantle gas conduits?

# A need for high-quality seismic data from multi-scale arrays

- [35 km] Densification of permanent network over FMC: **MACIV-backbone** (35 broadband stations, 2023-2026)
- [5-20 km] 3 profiles crossing the main magmatic centers: **MACIV-profiles** (65 medium-band stations, 2025-2026)
- [0.5-7 km] Dense nodal arrays over the youngest volcanoes **MACIV-nodes** (~650 nodes, 1 month, Oct. 25)



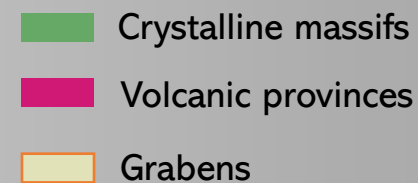
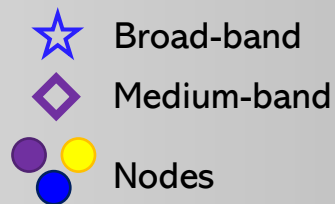
BB



MB



Node

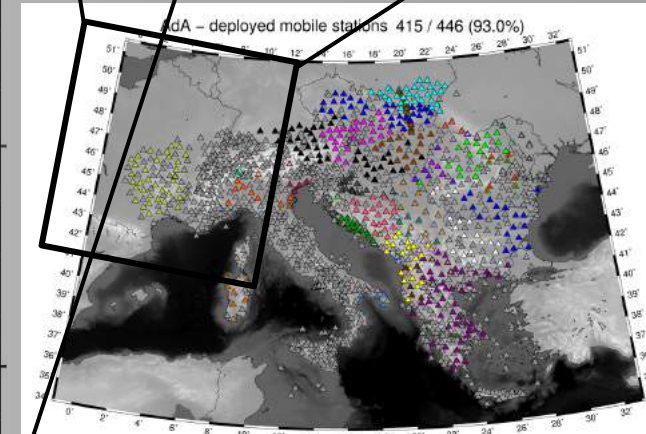
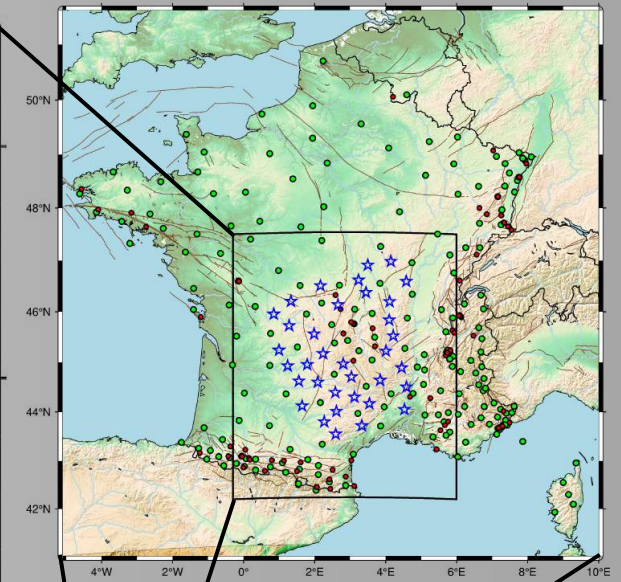
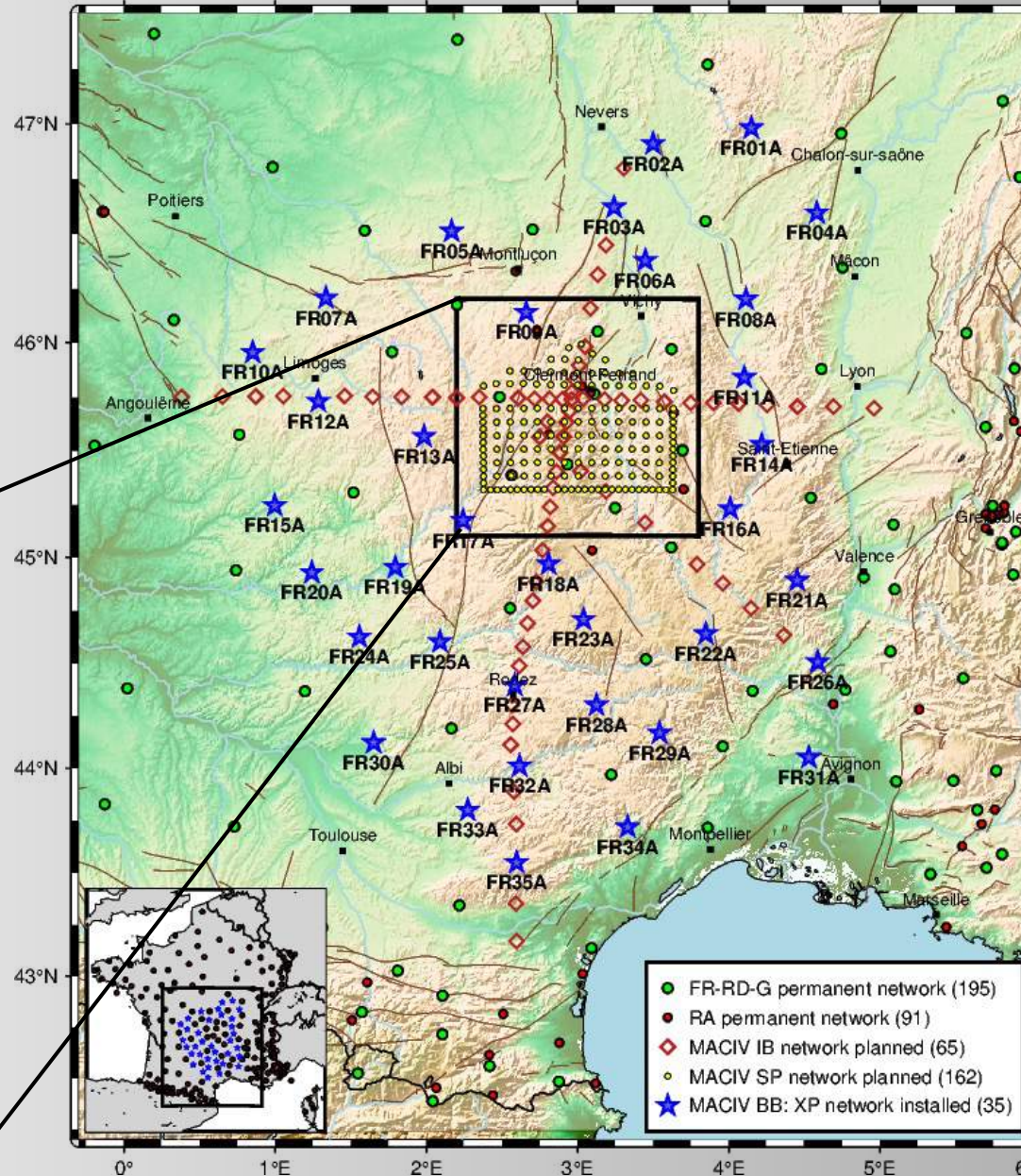
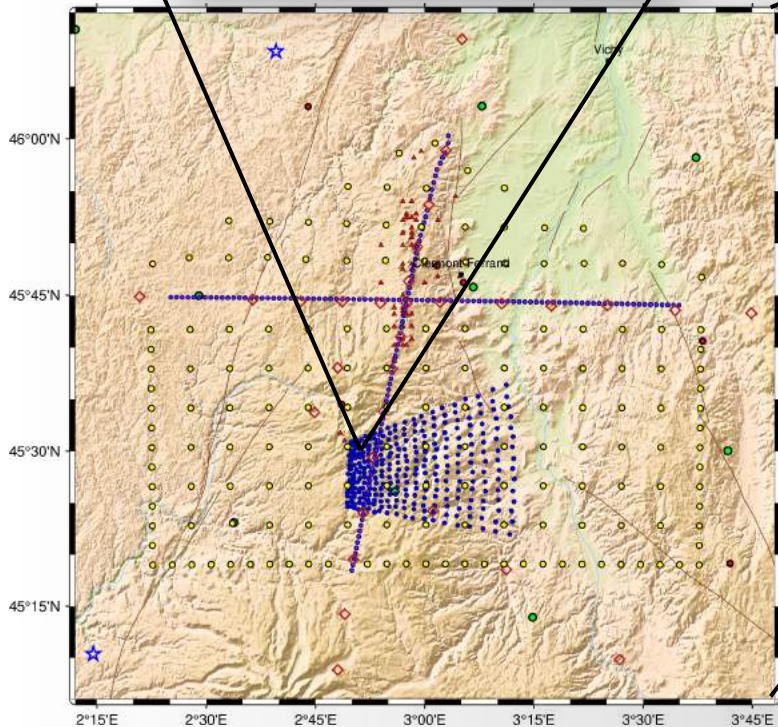




# MACIV multi-scale arrays

MACIV PROJECT - 20/03/2024

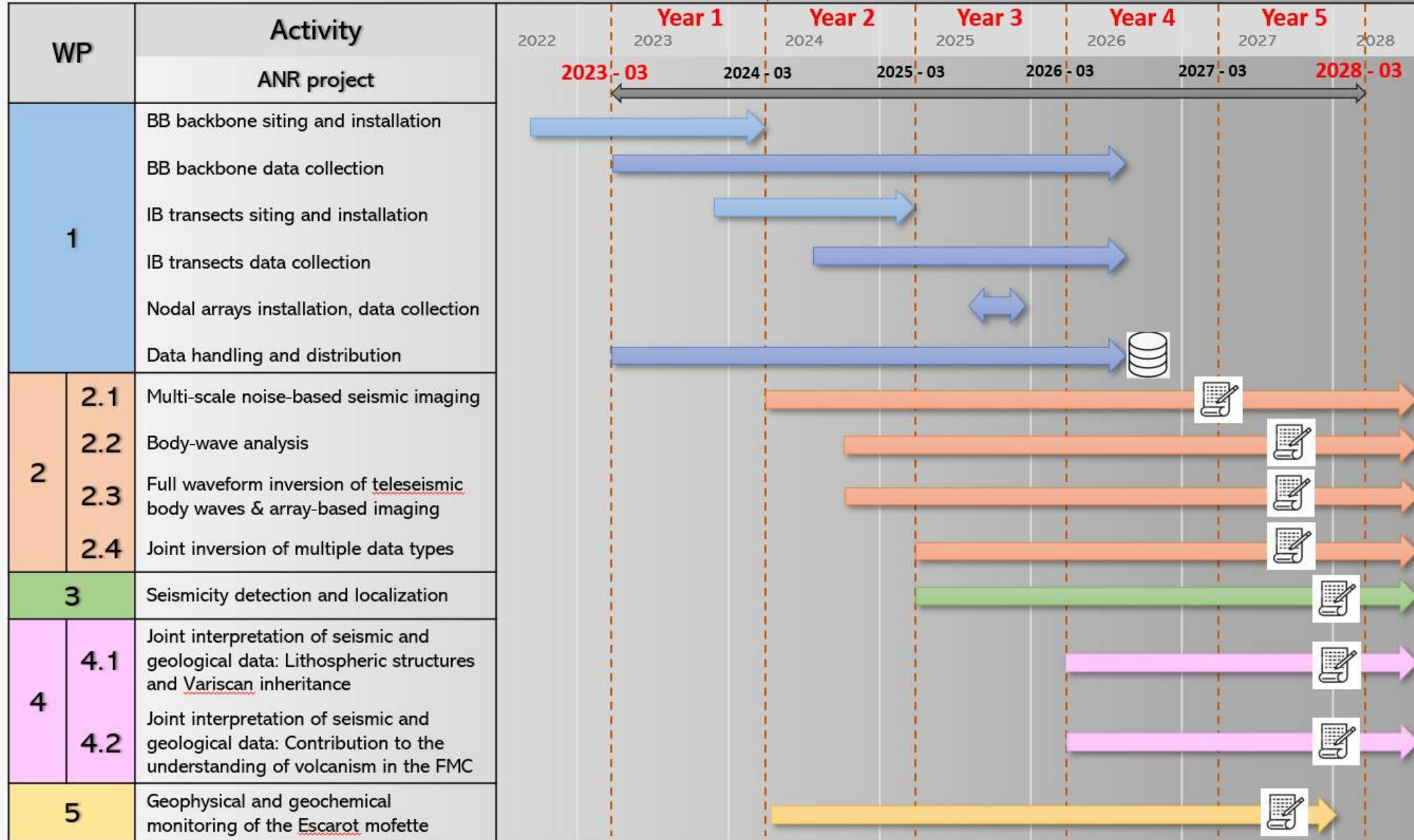
RLBP + RAP + MACIV BB PROJECT - 20/04/2023





# PROJECT ORGANIZATION

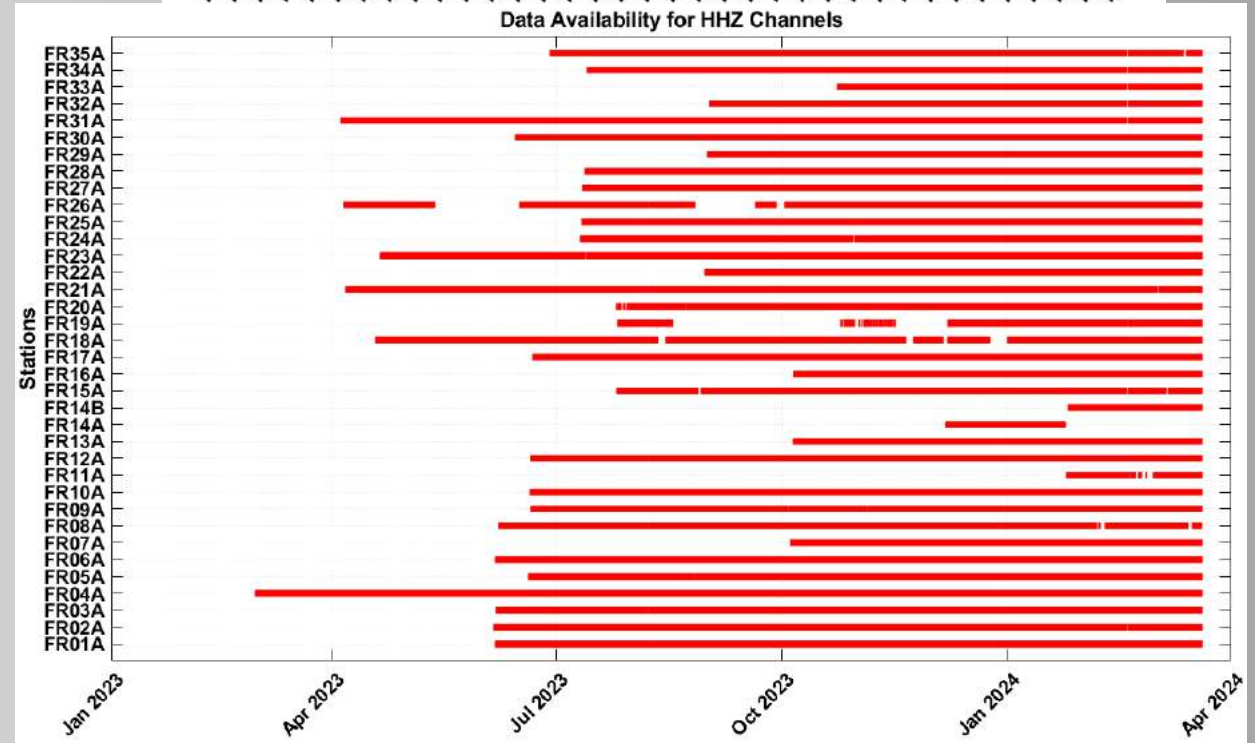
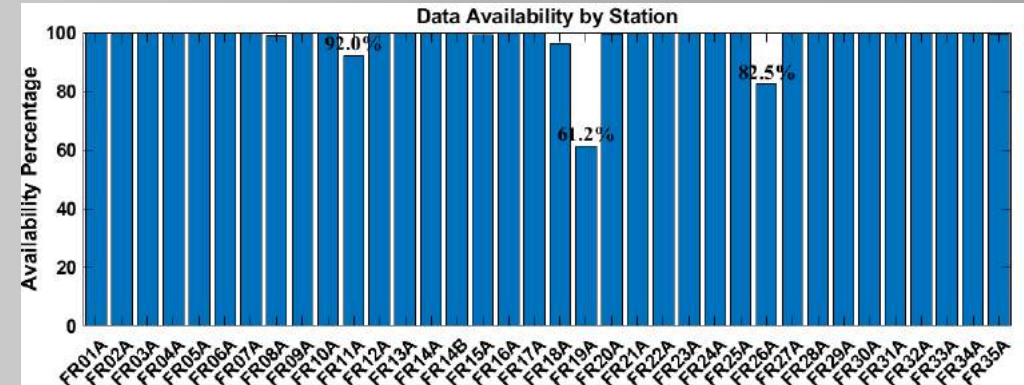
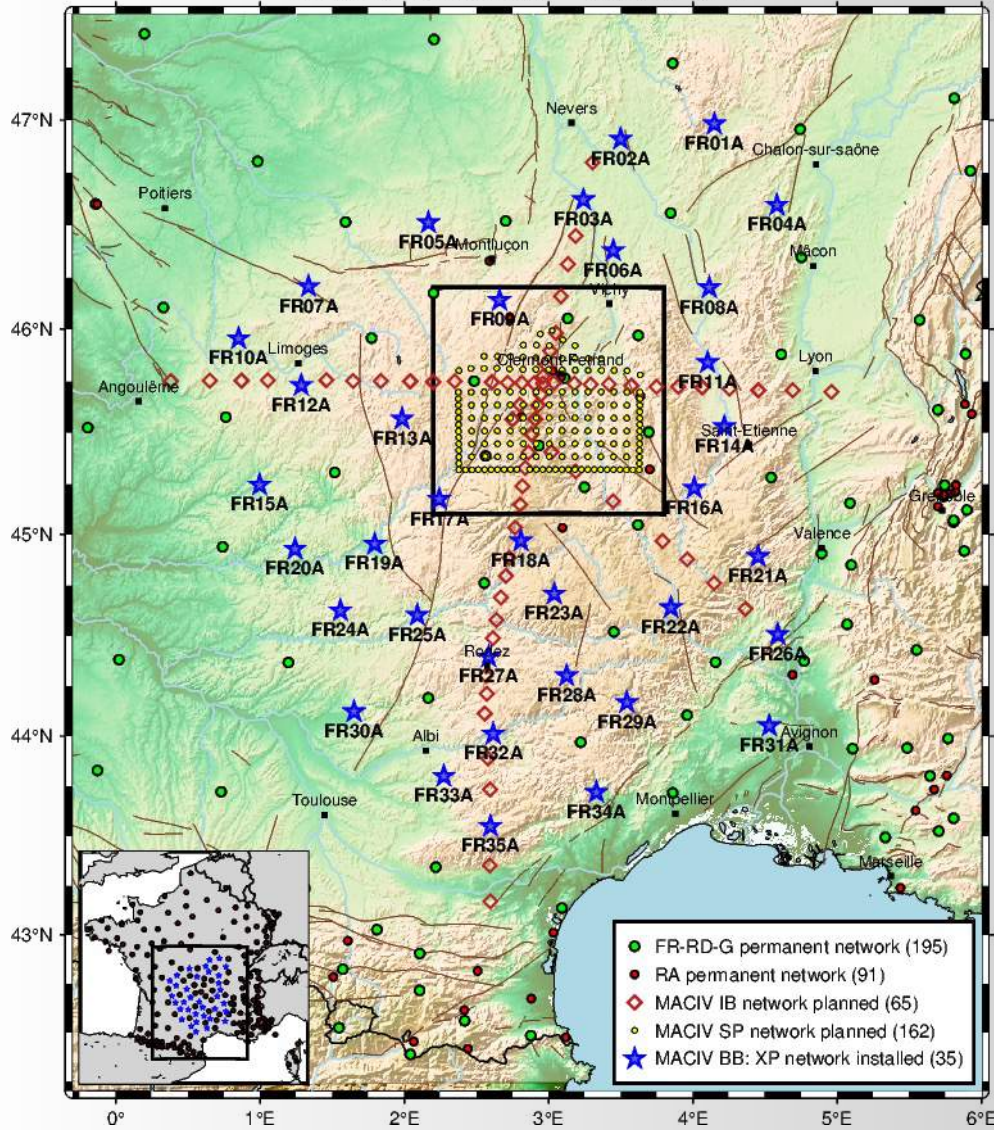
We are here!





# DATA AVAILABILITY

MACIV PROJECT - 20/03/2024

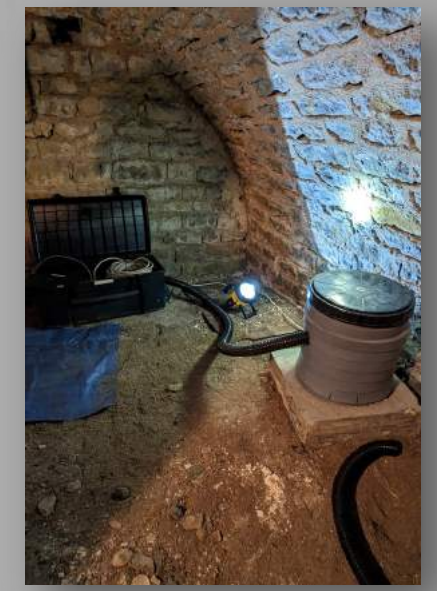
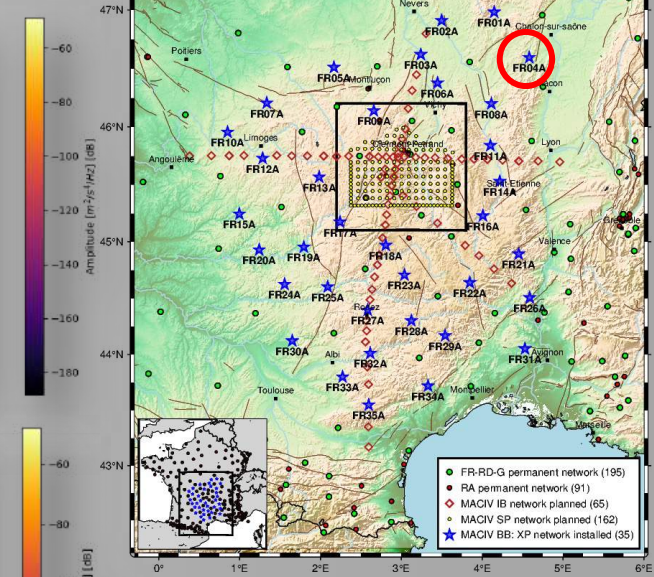
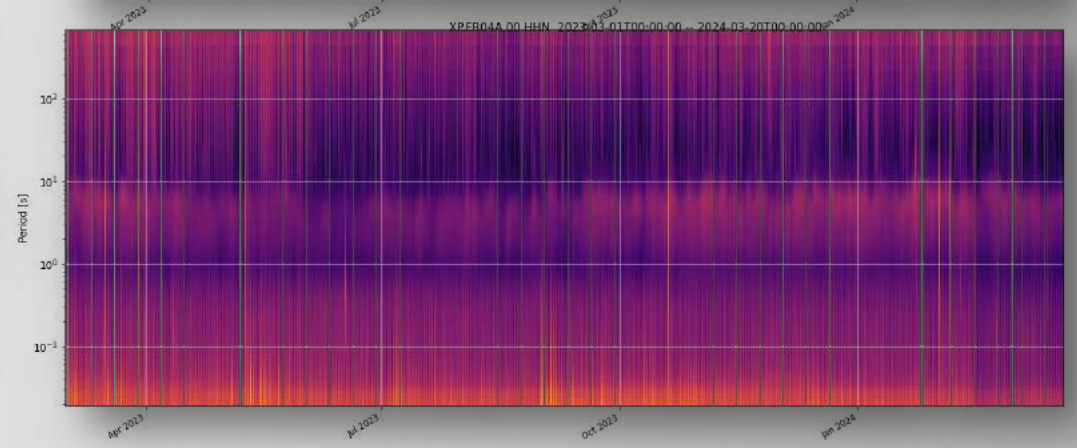
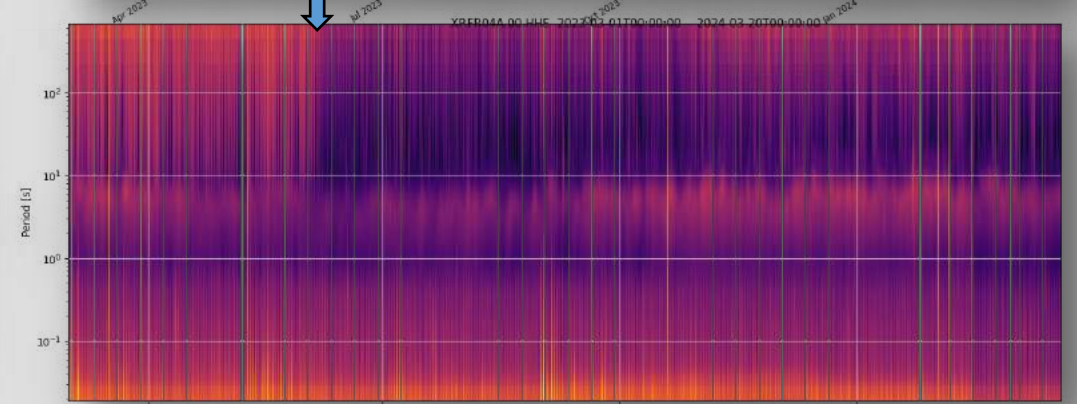
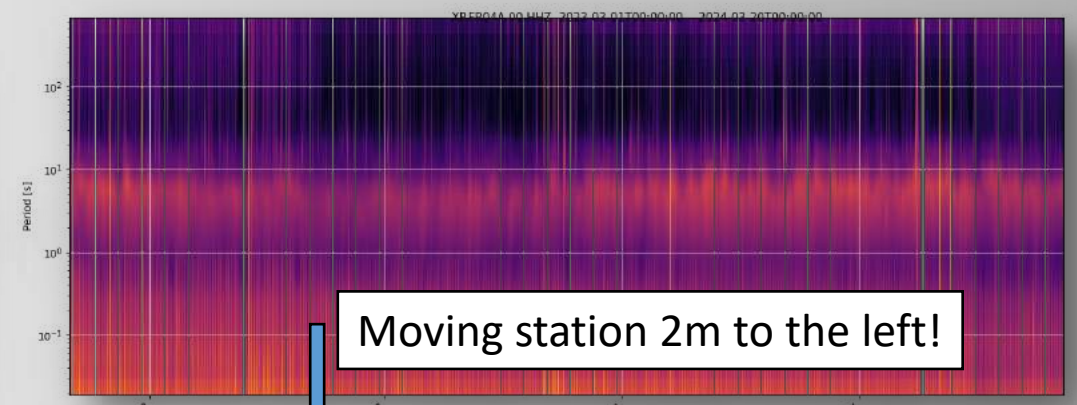
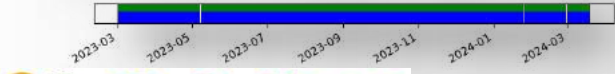
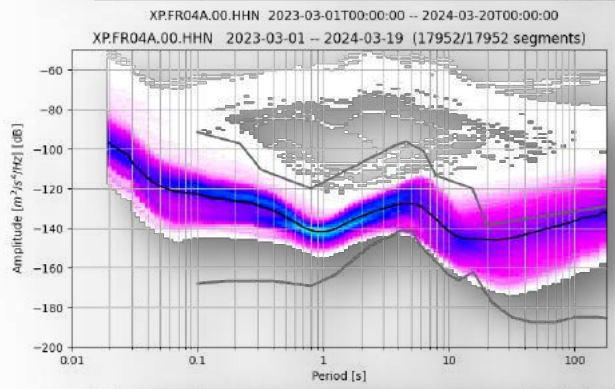
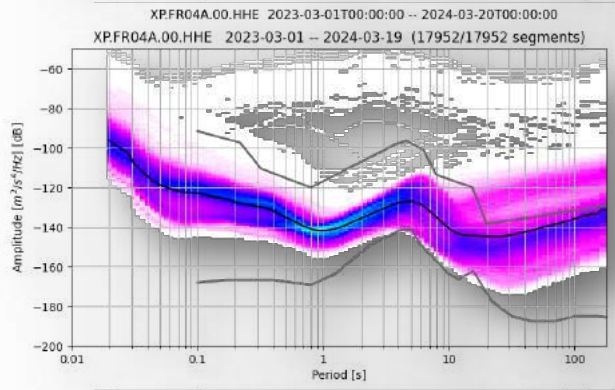
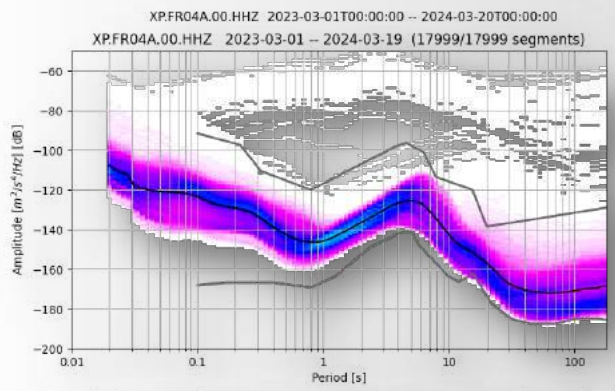


<https://seismology.resif.fr/networks/#/XP>  
doi:10.15778/resif.xp2023



# DATA QUALITY

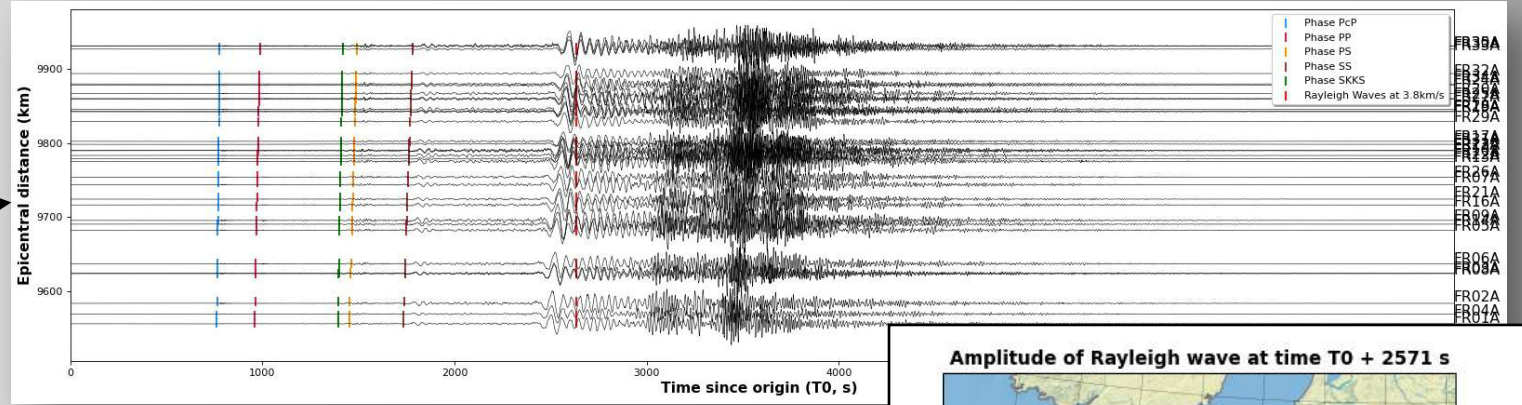
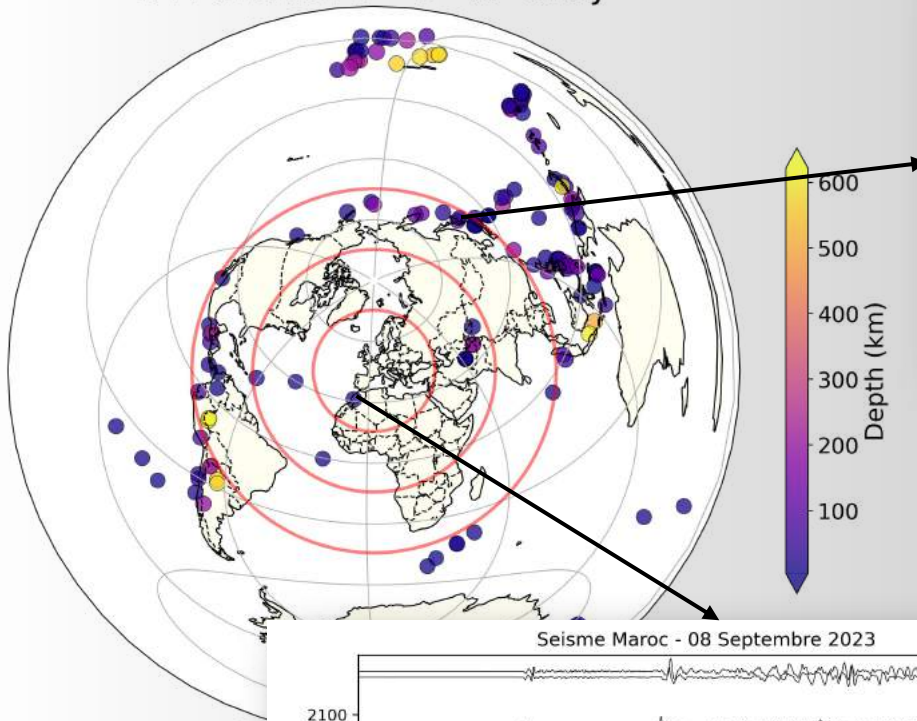
MACIV PROJECT - 20/03/2024



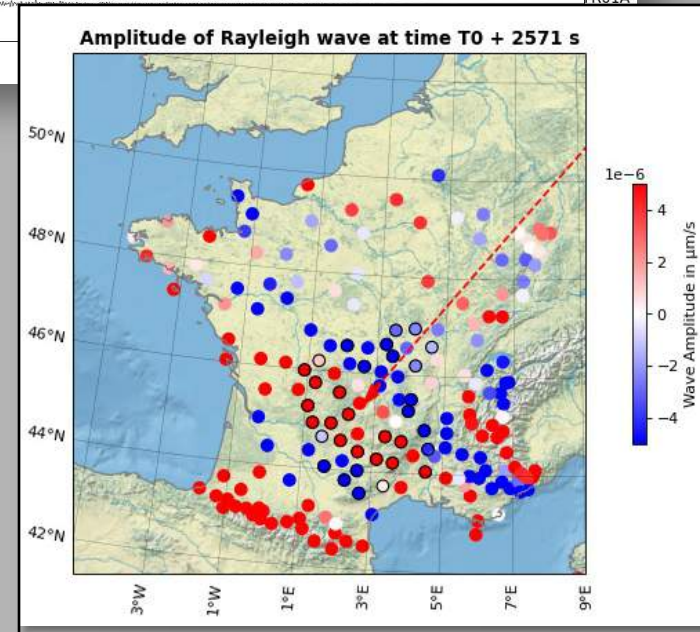
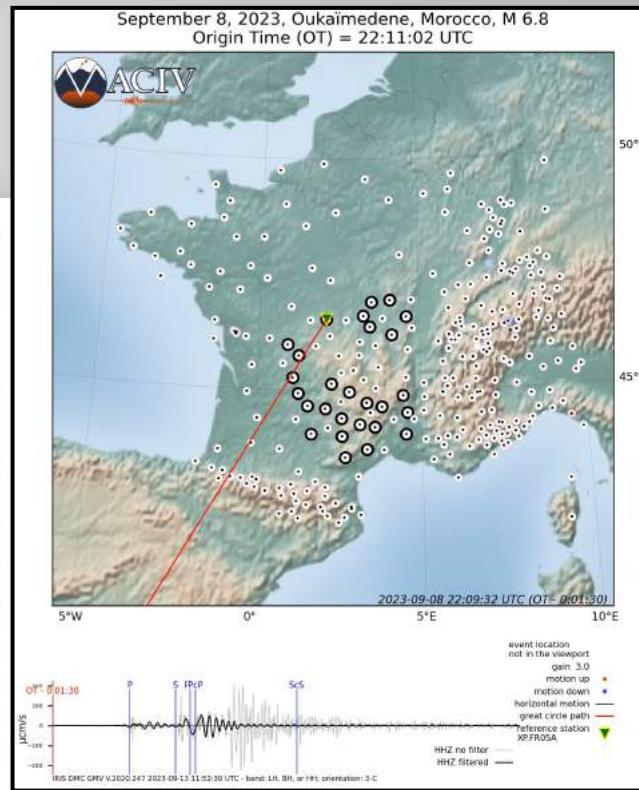
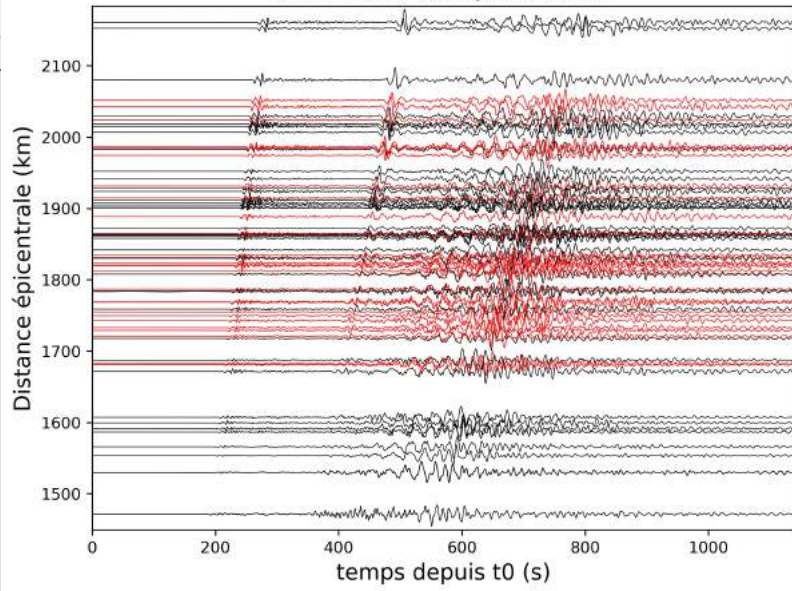


# TELESEISMIC EARTHQUAKES

144 events  $M \geq 6$  - XP array



Seisme Maroc - 08 Septembre 2023

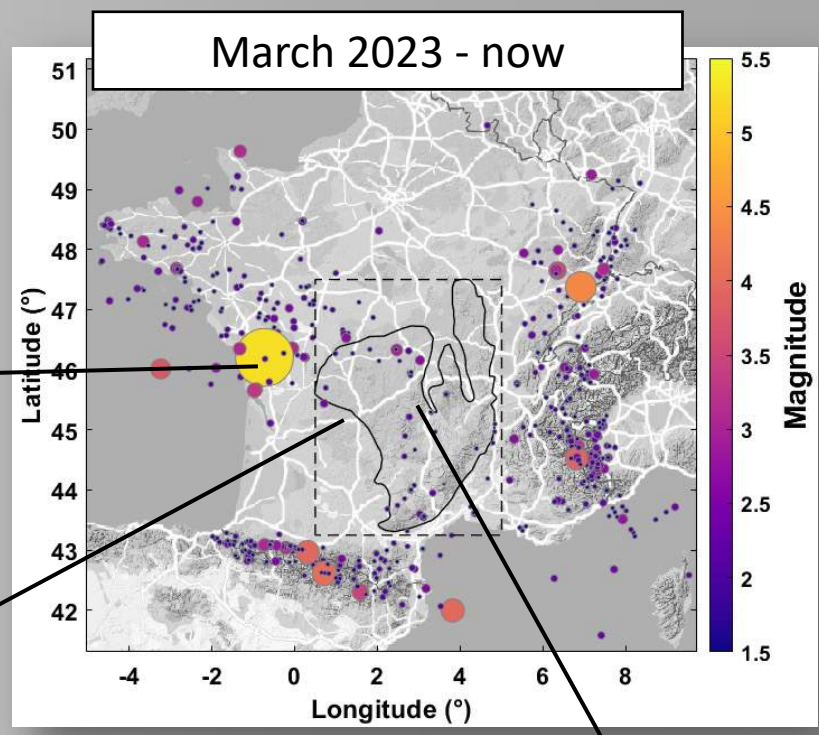
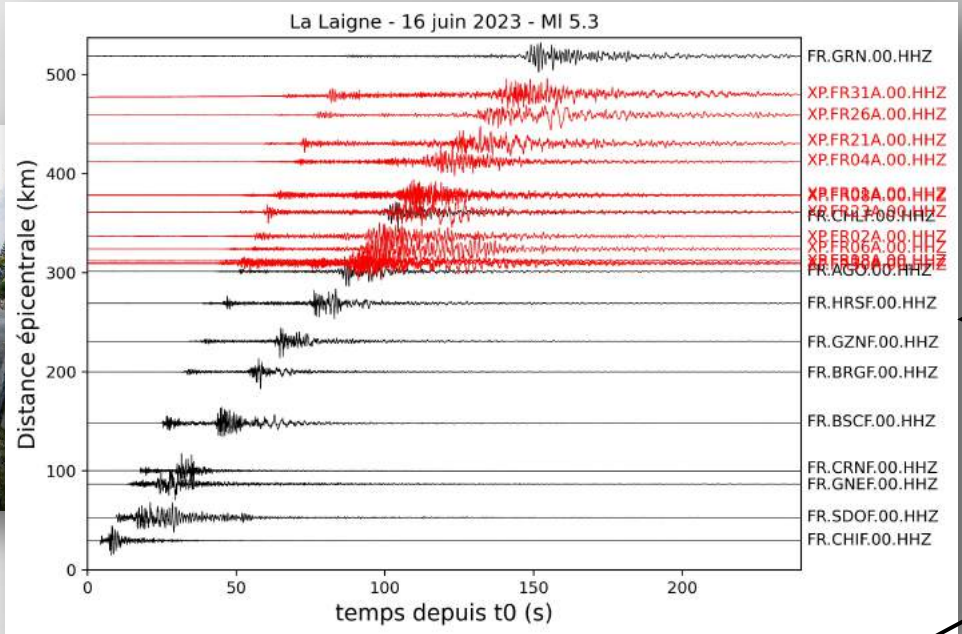


Mw7.5 Noto earthquake, Japan

Mw6.8 Morocco earthquake



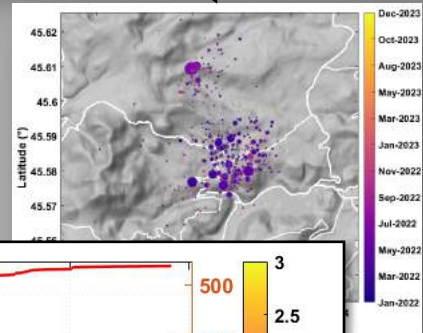
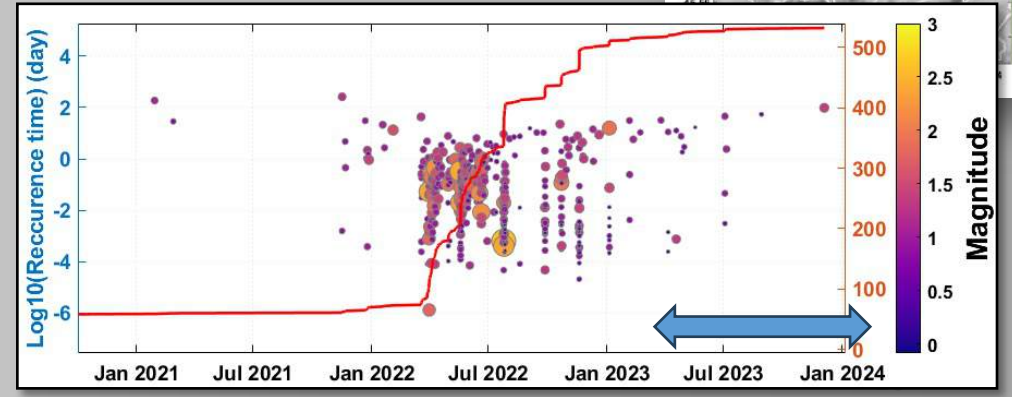
# LOCAL EVENTS



2.000 m<sup>3</sup> rock fall  
Feb. 02, 2024

Only 1 station  
recorded it

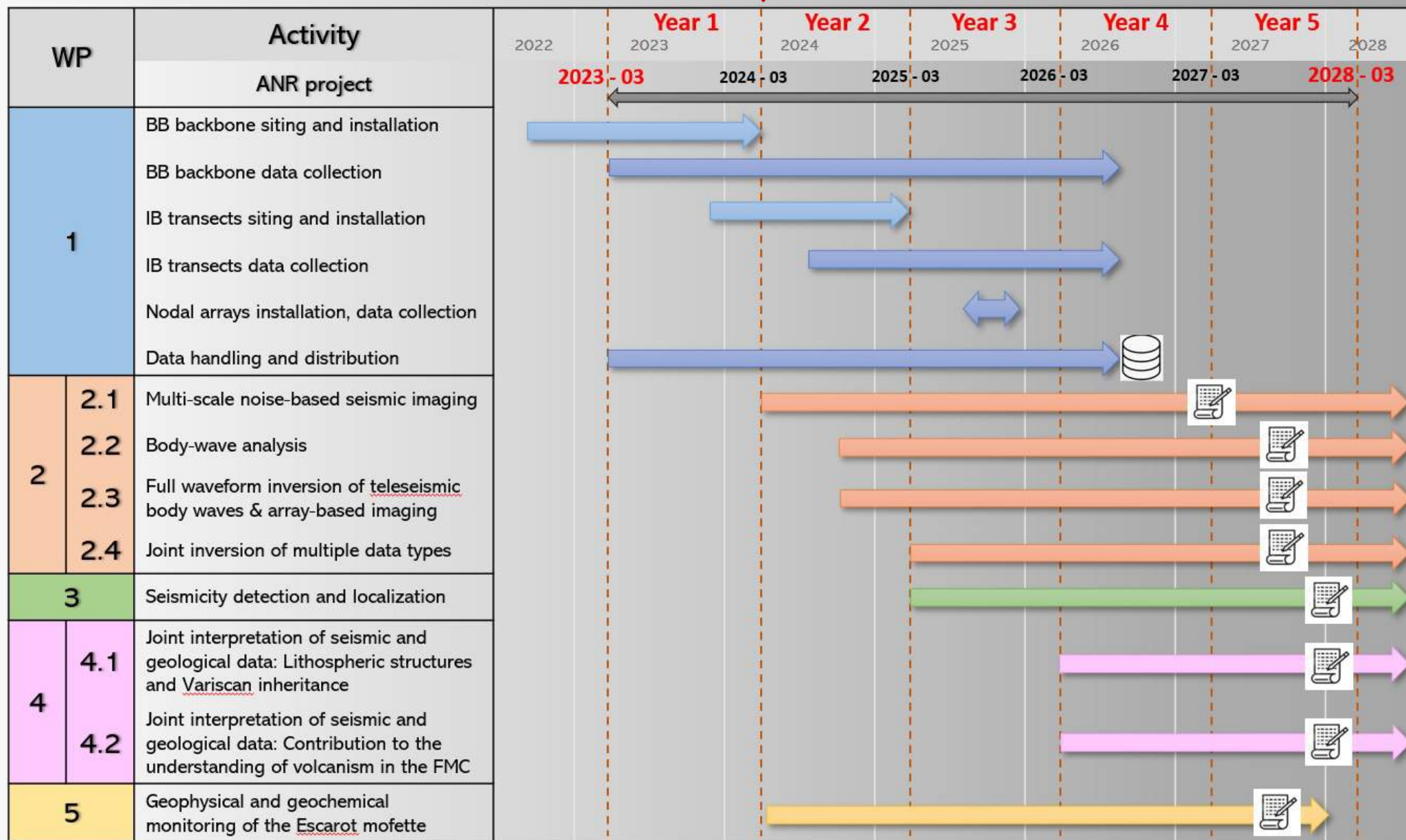
500 events swarm near  
Mt-Dore (see talk by  
Boudoire et al.)



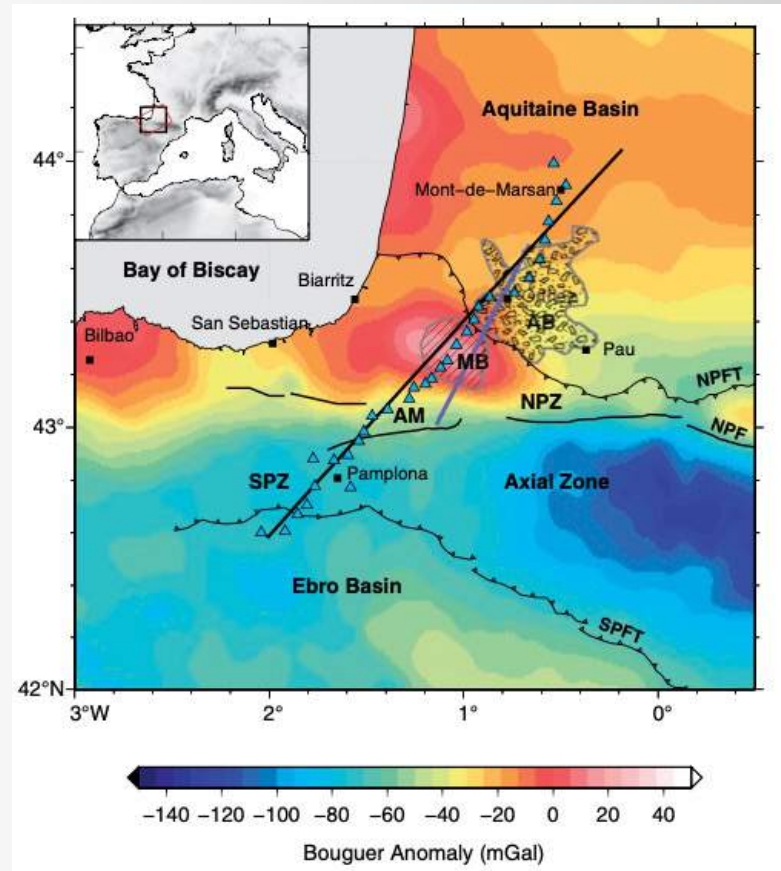


# PROJECT ORGANIZATION

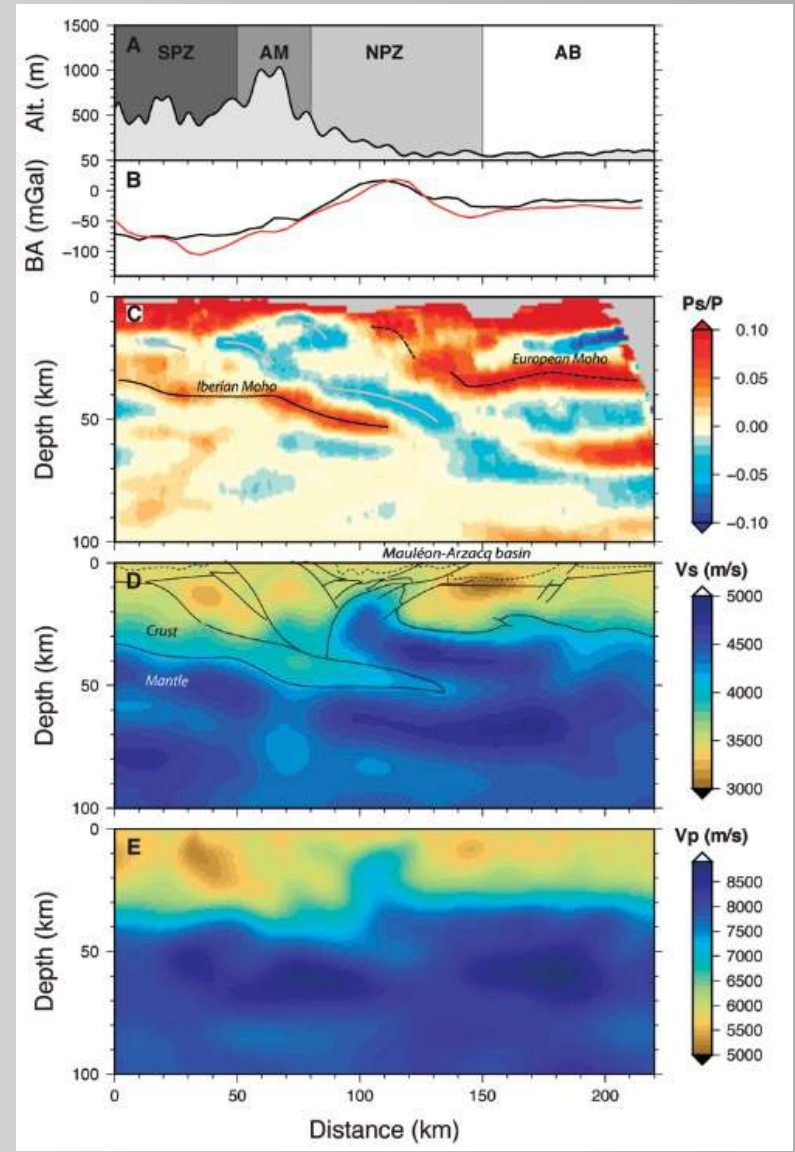
We are here!



# Examples of data analyses that will be conducted on MACIV data



Western profile of the PYROPE temporary seismic experiment



Modeling of Bouguer anomaly

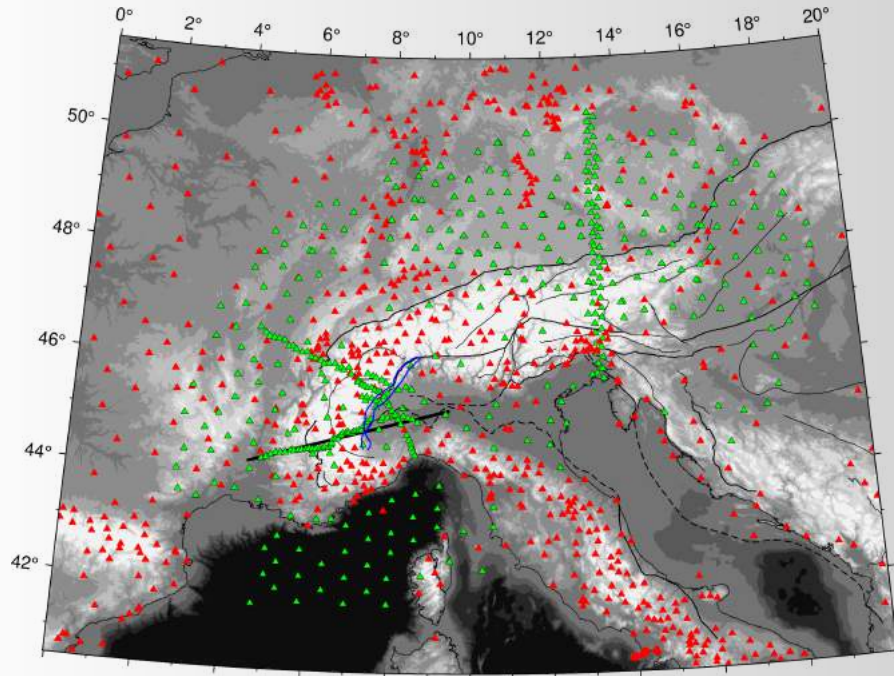
Receiver function analysis: imaging of velocity discontinuities

Full waveform inversion of teleseismic P waves: Vs and Vp absolute velocities

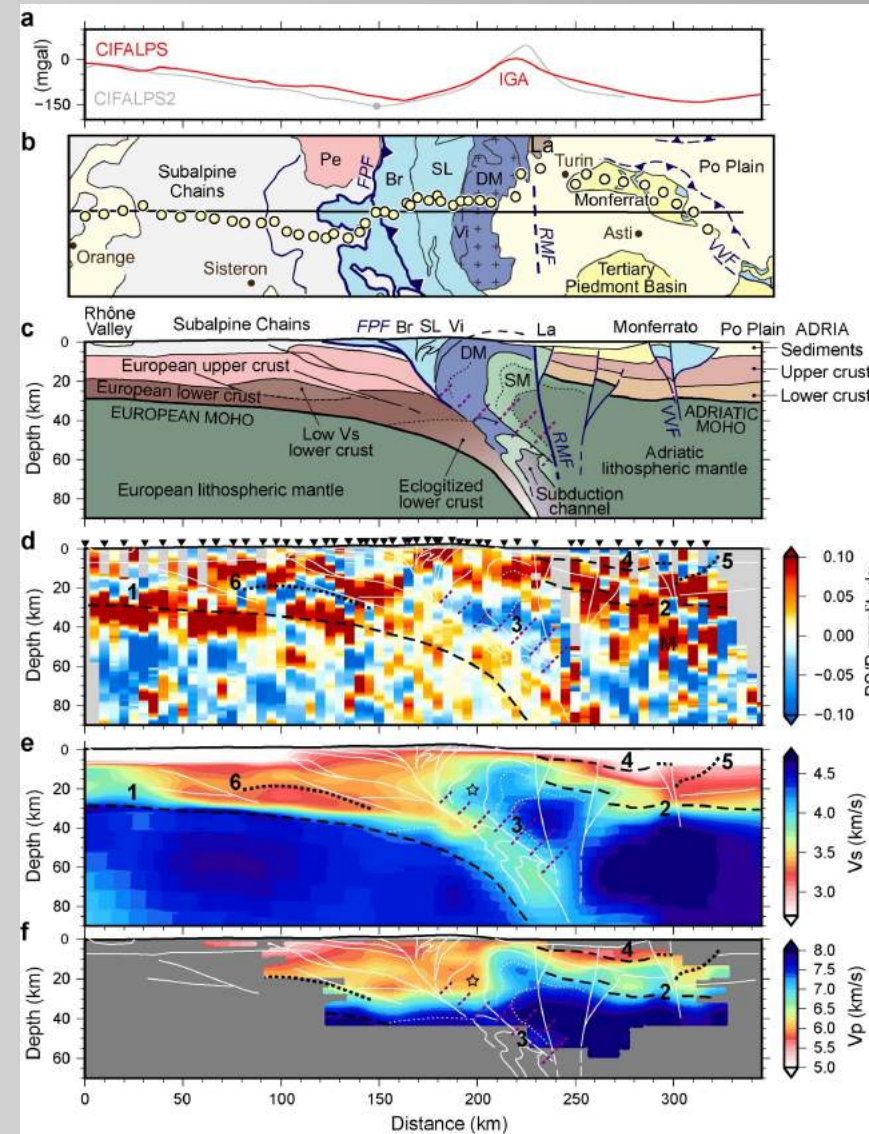
Wang et al., 2016



# Examples of data analyses that will be conducted on MACIV data



AlpArray and CIFALPS temporary experiments



Geological interpretation

Receiver function analysis

Ambient-noise tomography: Vs model

Local-earthquake traveltime tomography: Vp model

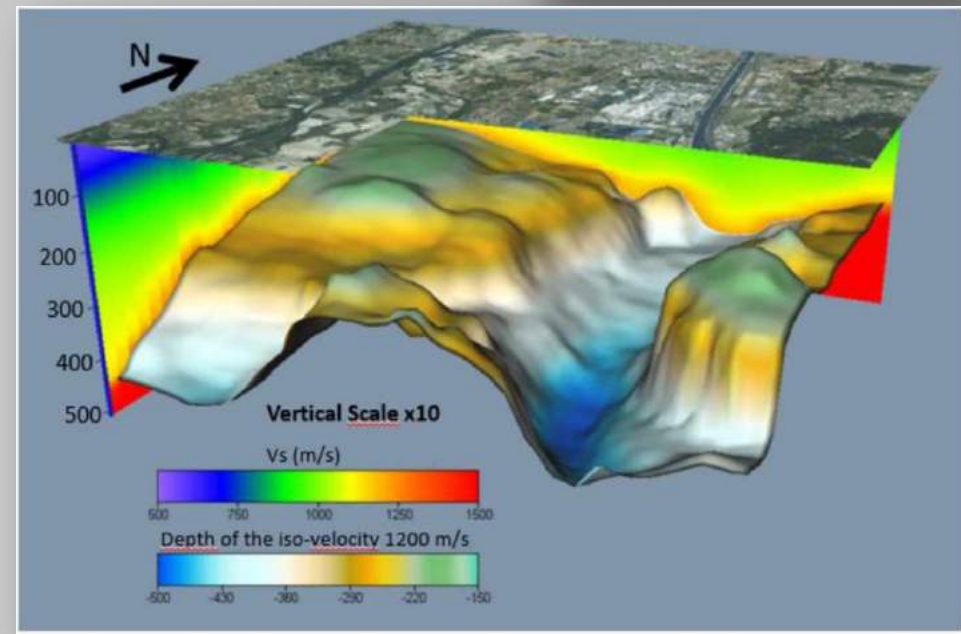
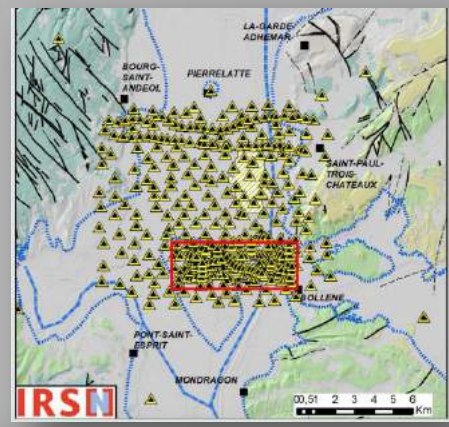
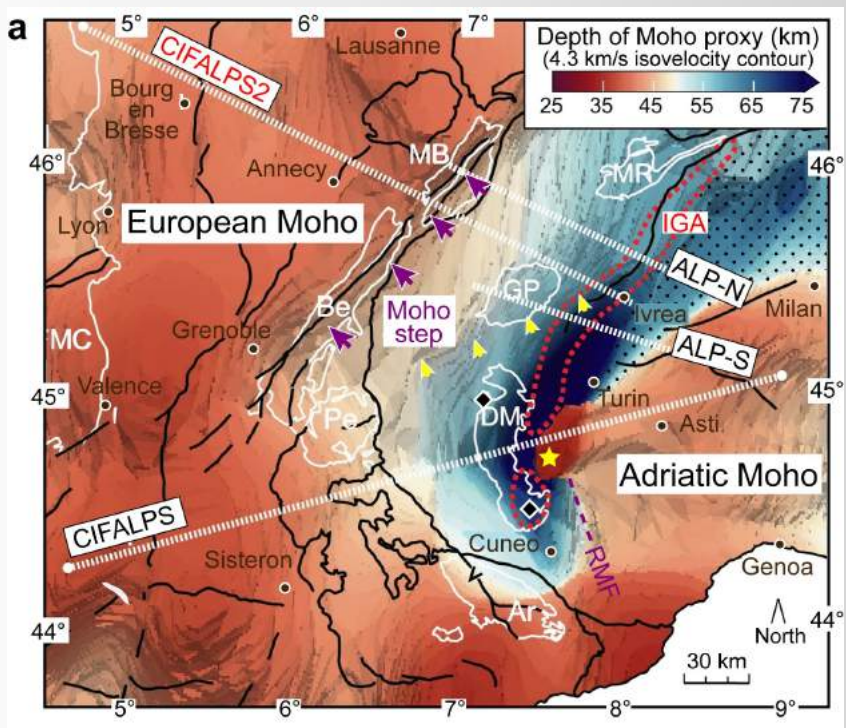
Paul et al., 2022

# Examples of data analyses that will be conducted on MACIV data

## Ambient noise tomography: 3-D Vs model

From AlpArray data: crustal scale

From large-N array:  
near surface imaging



Depth map of velocity contour  $V_s=4.3$  km/s (Moho proxy)

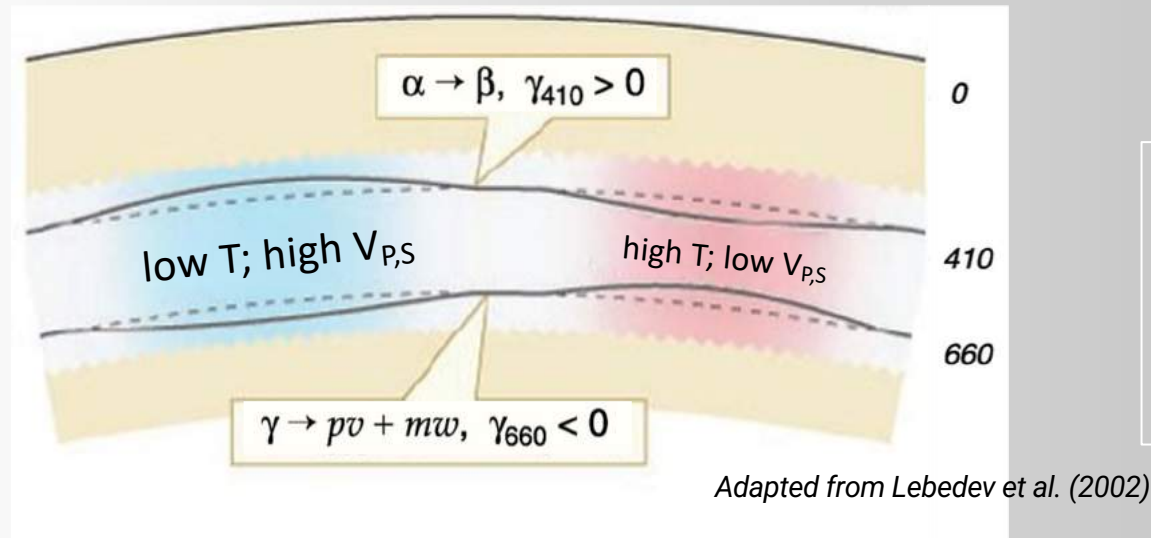
➔ See talk by A. Nouibat



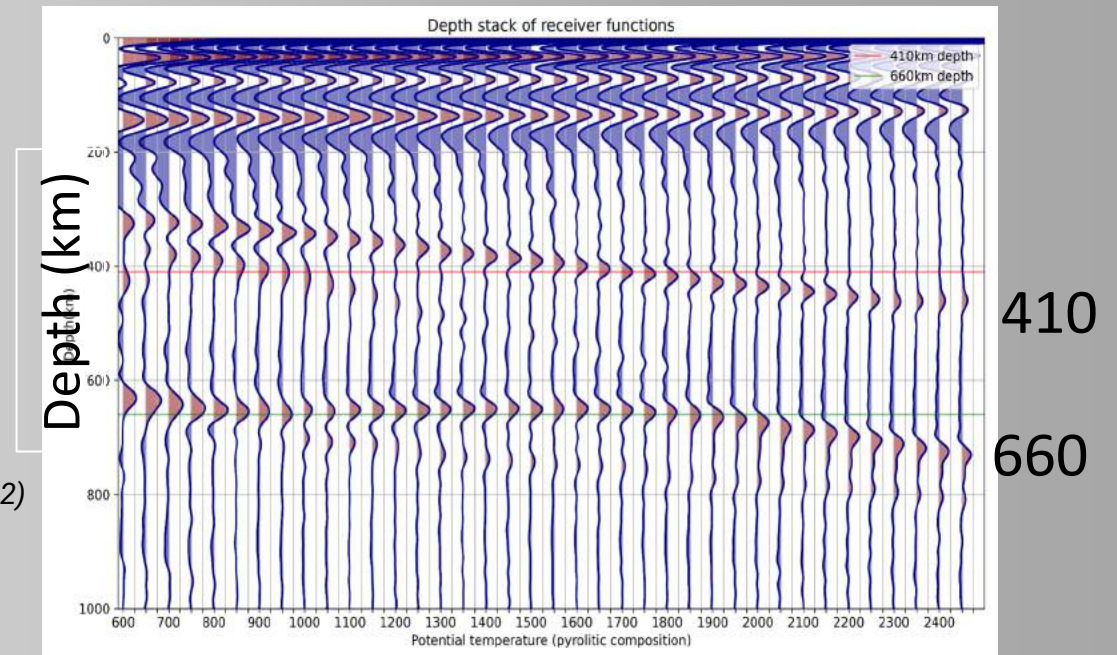
# Examples of data analyses that will be conducted on MACIV data

→ Imaging of mantle structure: see next talk by S. Chevrot

## Imaging of the mantle transition zone



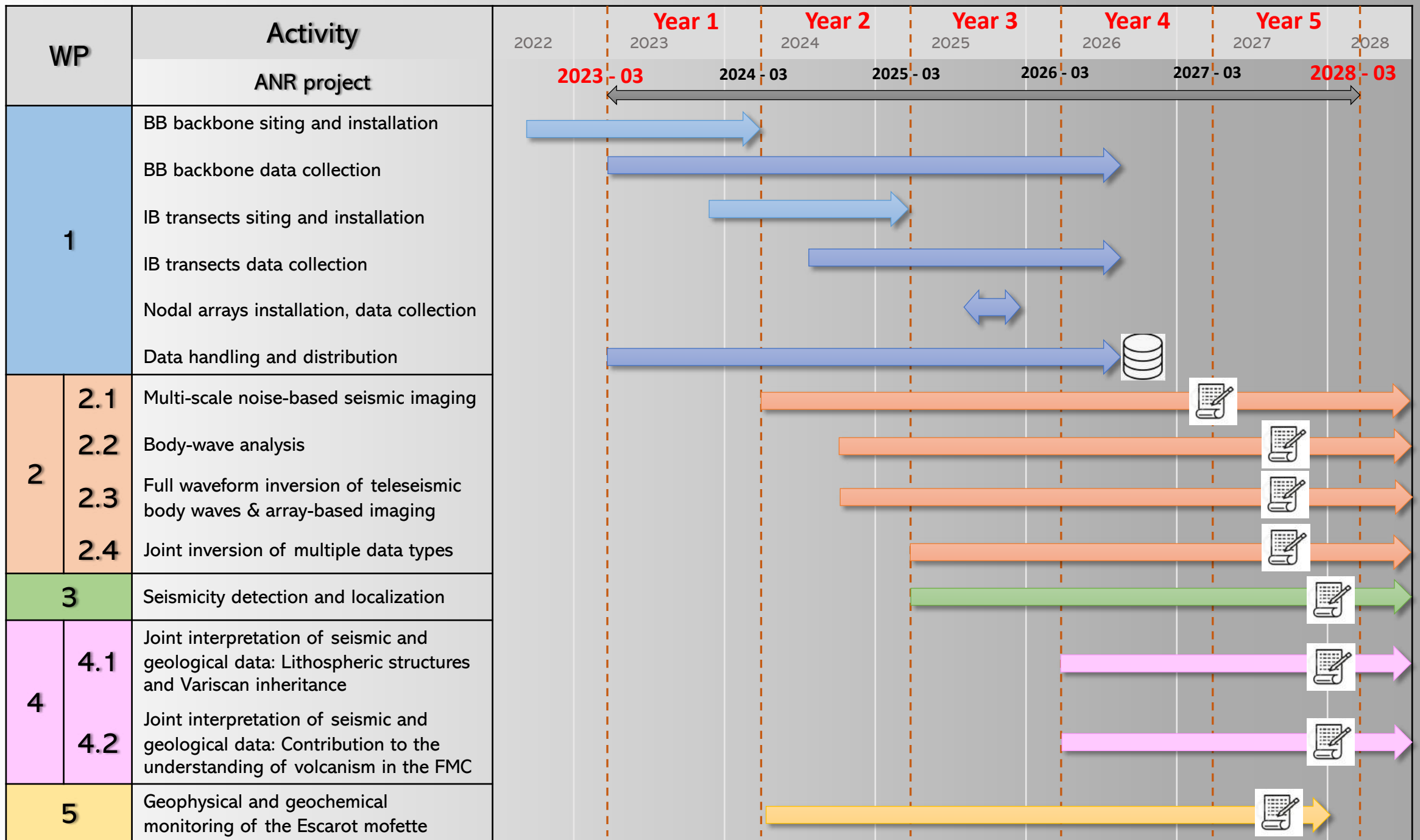
## Seismic signature of T changes



→  
Increasing T, pyrolitic composition

Goal: develop methods to estimate temperature and composition in the MTZ; application to MACIV backbone data (plume?) → **focus group: see Helle Pedersen**



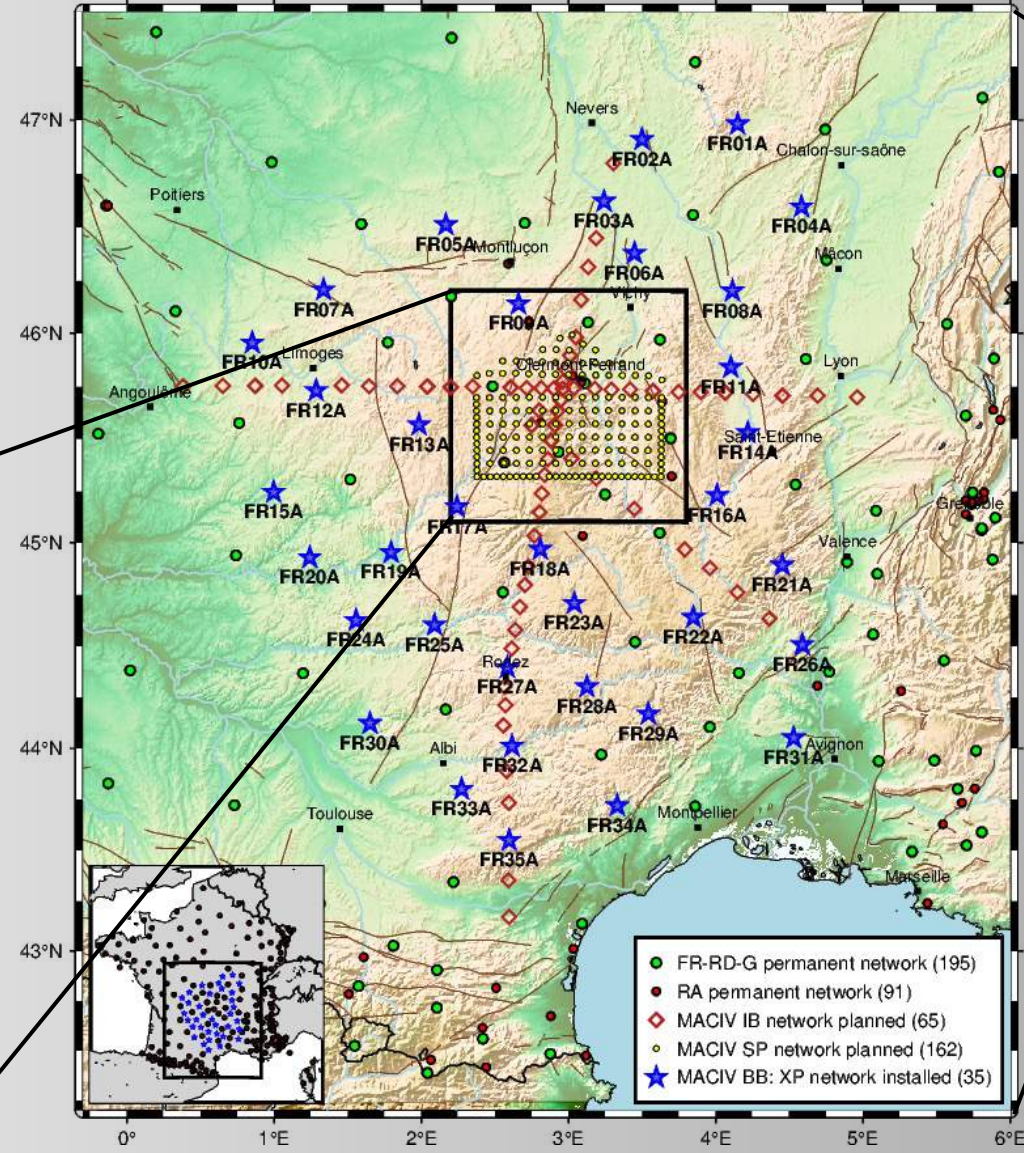




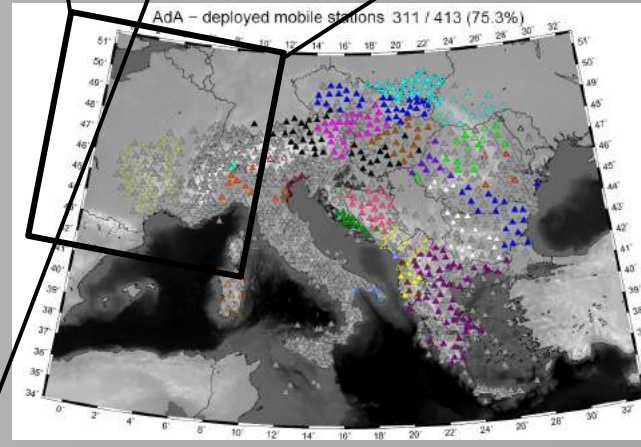
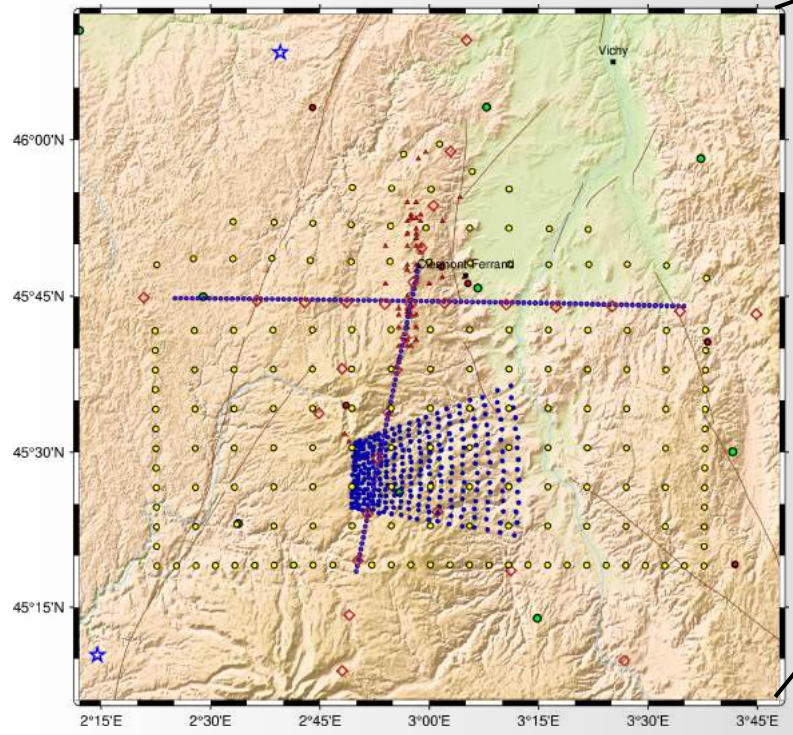
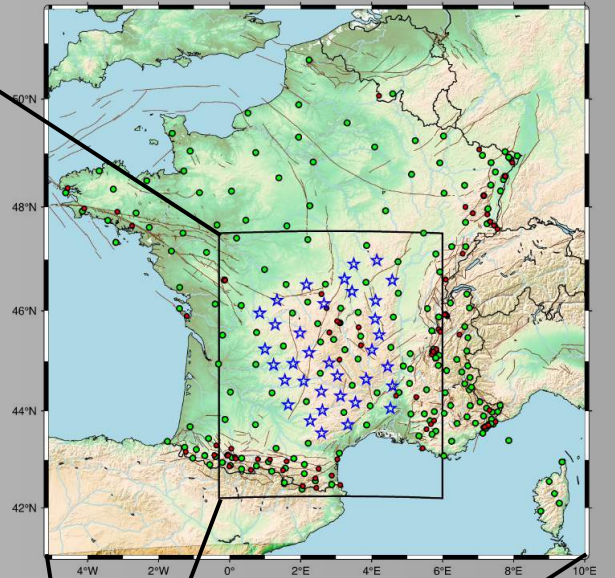
# MACIV multi-scale arrays

- 35 broad-band (35 km) *XP network on RESIF*
- 65 medium-band over 3 transects (5-20 km)
- ~ 650 Nodes GeoSpace 3C
  - Sparse : 162, 7 km
  - Dense : 300, 0.5 – 2 km
  - Line NS : 55, 1 km
  - Line EW : 90, 1 km

MACIV PROJECT - 20/03/2024



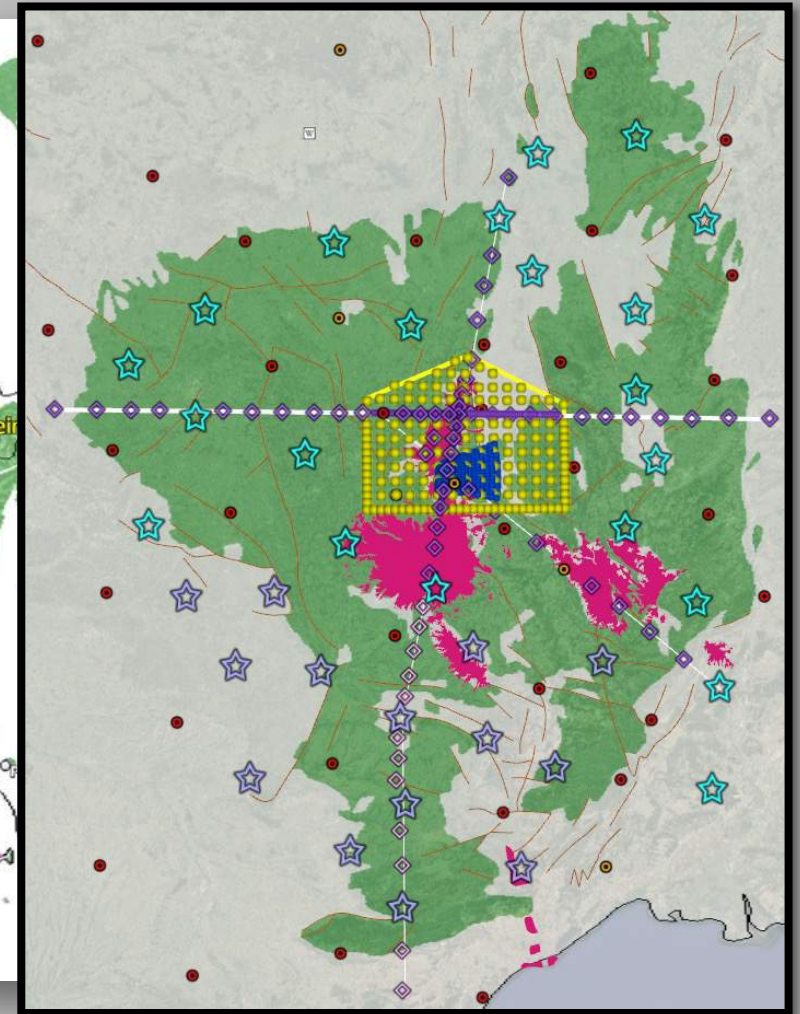
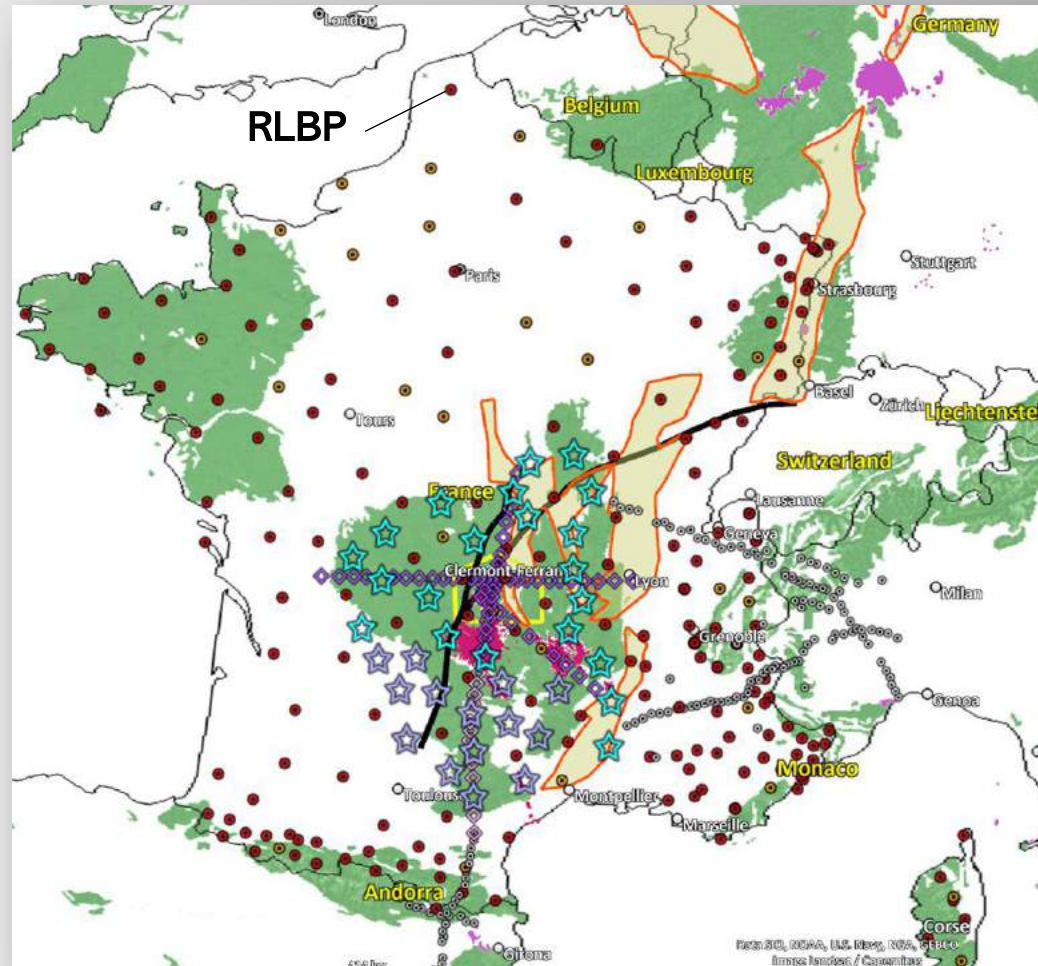
RLBP + RAP + MACIV BB PROJECT - 20/04/2023





# A need for high-quality seismic data from multi-scale arrays

- [35 km] Densification of permanent network over FMC: **MACIV-backbone** (35 broadband stations, 2023-2026)
- [5-20 km] 3 profiles crossing the main magmatic centers: **MACIV-profiles** (65 medium-band stations, 2025-2026)
- [0.5-7 km] Dense nodal arrays over the youngest volcanoes **MACIV-nodes** (~650 nodes, 1 month, Oct. 25)



BB



MB



Node

