

The arc of the Western Alps : understanding its kinematics and formation mechanisms based on new structural and paleomagnetic data, and thermo-mechanical modelling.

Q. Brunsmann ; C. Rosenberg ; N. Bellahsen ; L. Le Pourhiet

Other units

- Foreland Basins
- Adriatic and ligurian sea

Adria derived-nappes

- South-Alpine
- Austro-Alpine

Briançonnais-derived nappes

- cover
- basement

Europe-derived nappes

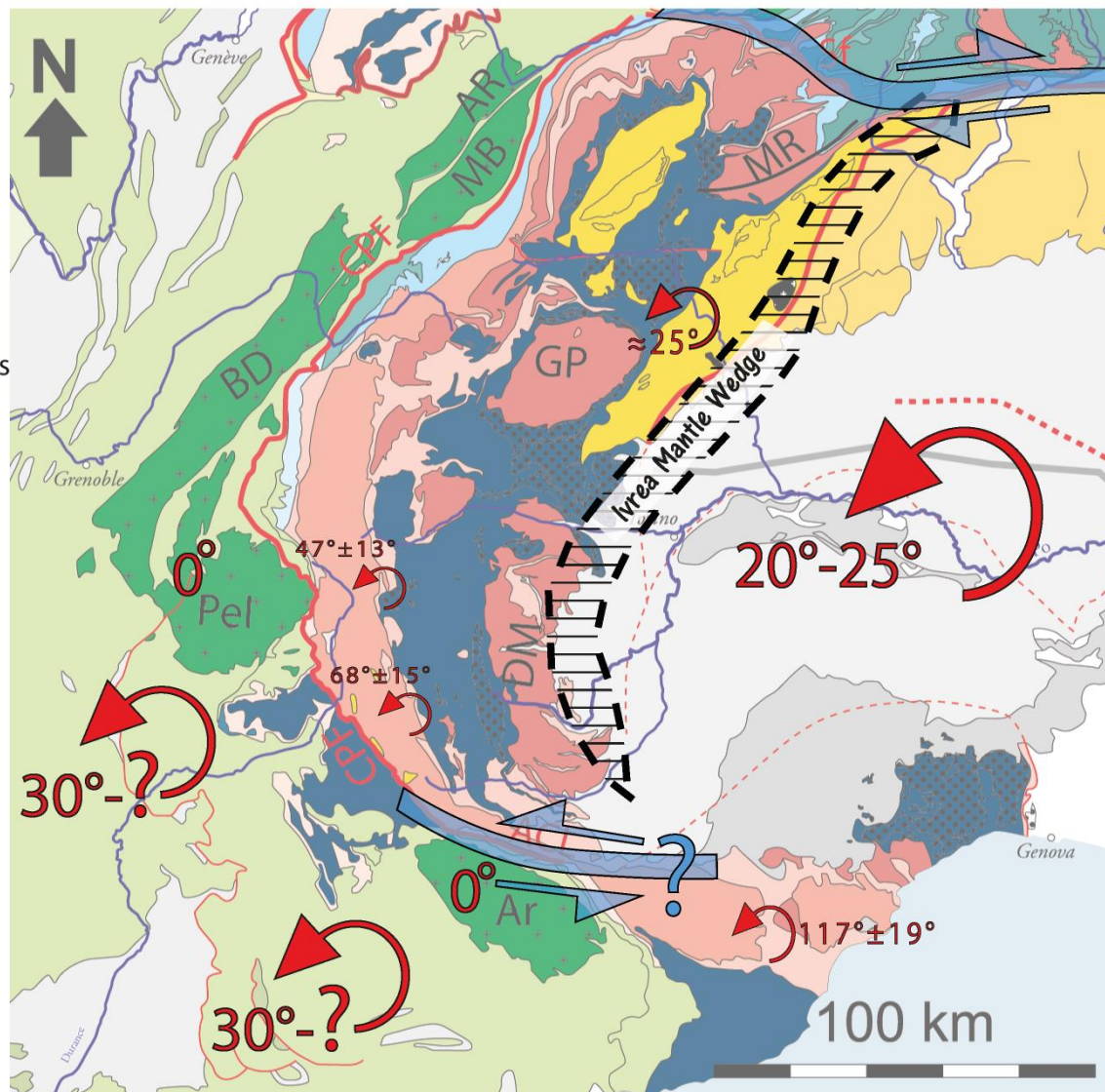
- cover
- basement

Oceanic-derived nappes

- Liguro-Piemont
- Valaisan

Rotations after Collombet *et al.* (2002) ; Aubourg & Chabert-Pelline (1999) ; Sonette *et al.* (2014) ; sinistral strike-slip movements according to Ricou & Siddans (1986) ; Ceriani *et al.* (2001) ; Schmid *et al.* (2017)

Modified from Bousquet *et al.*, 2012.



- Indentation of the Adriatic Plate :

- Westward indentation probably accomodated by a dextral strike-slip zone at the North of the arc and by a sinistral strike-slip one at the South of the Arc along the poorly defined « **Stura Corridor** ».

- Counterclockwise rotation of the Adriatic plate and of the Arc :

- No rotation in the External crystalline massifs.
- Coupling between External and Internal Zone ?

➡ **3D Thermo-mechanical Modelling.**

SINISTRAL STRIKE-SLIP MOVEMENT SOUTH OF THE ARC.

In the literature

Sinistral shear of the Briançonnais zone between late Oligocene and Miocene.

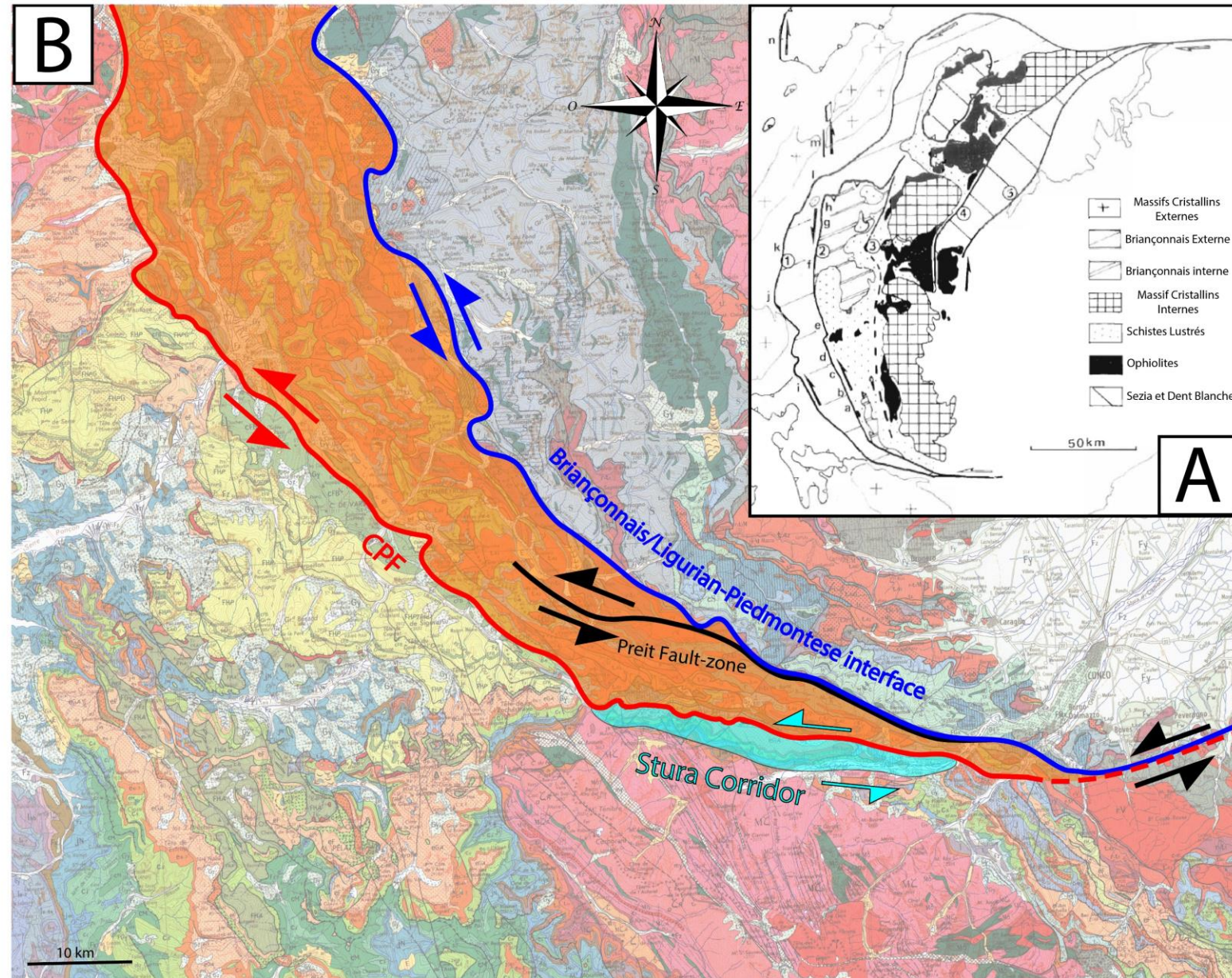
From 100km to 250km of sub-meridian sinistral strike-slip movements along the CPF. Inconsistent with the known amounts of shortening in the Western Alps.

Sinistral strike-slip along the Briançonnais/Ligurian-Piedmontese interface.

Sinistral strike-slip movement of tens km at the Southern termination of the arc, maybe along the E-W Stura valley → « **The Stura Corridor** ».

According to Ricou, 1980 ; Ricou, 1981 ; Ricou, 1984 ; Ricou & Siddans, 1986.

10 km



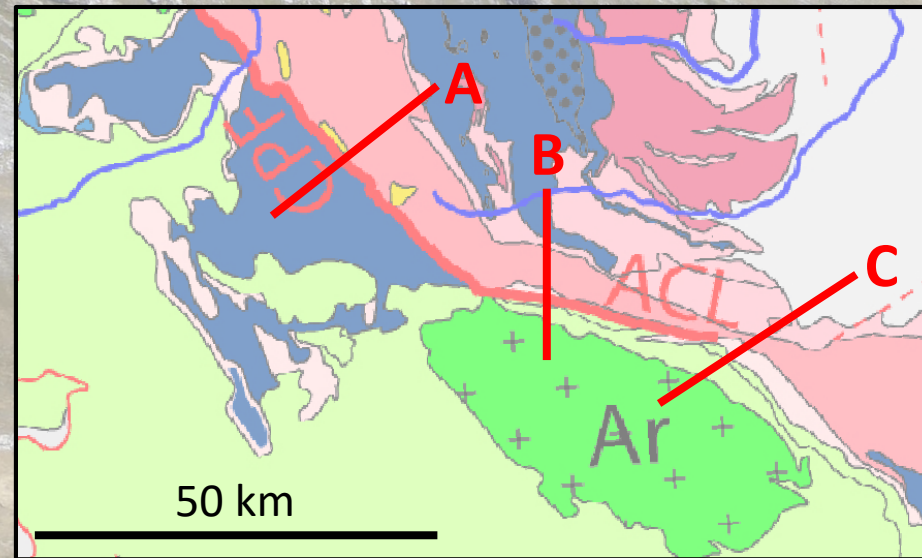
No evidence in the field...

SINISTRAL STRIKE-SLIP MOVEMENT SOUTH OF THE ARC.

Own field-work

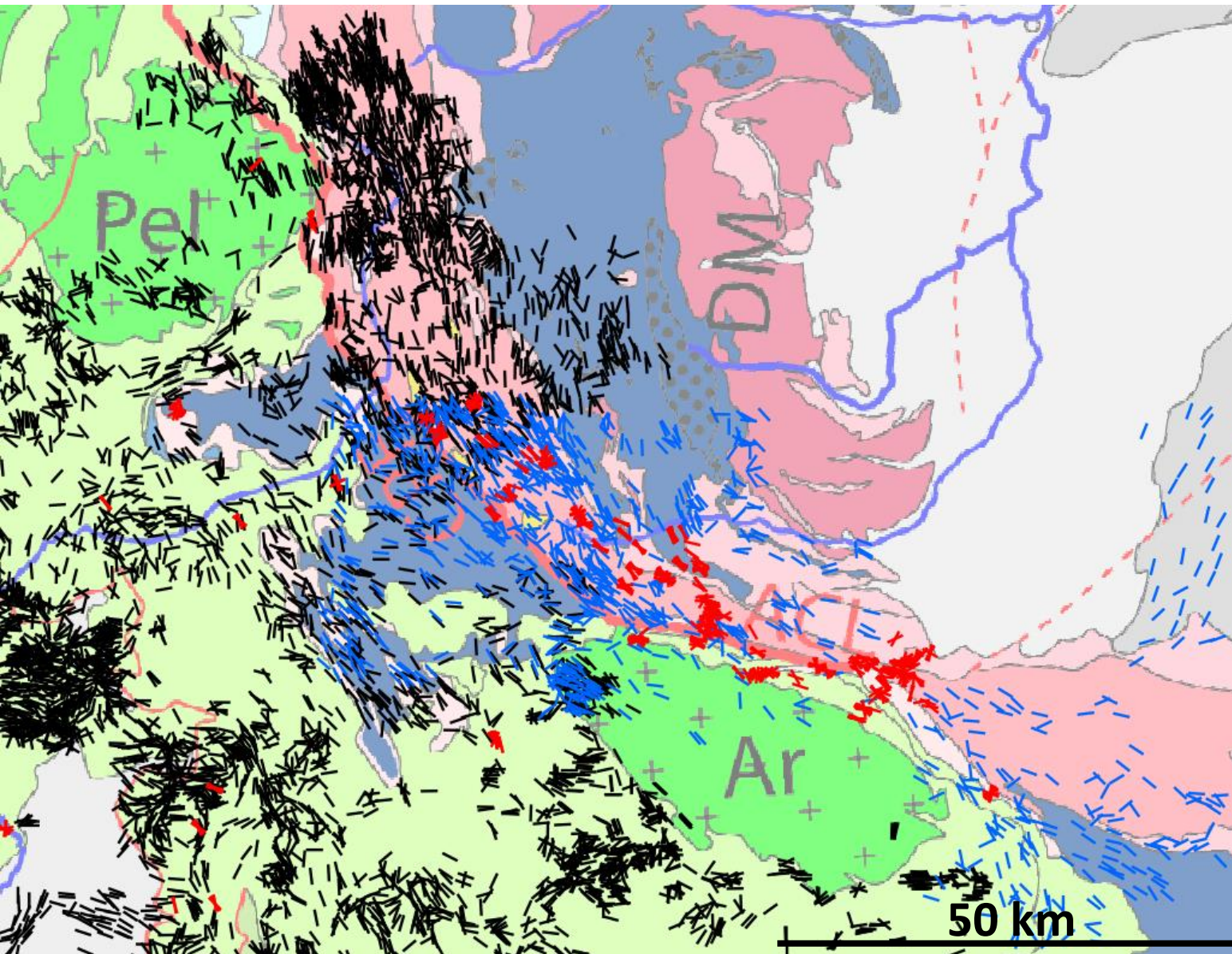
Structurale analysis in the southern termination of the arc :

- No clear sinistral kinematic indicator at the southern termination of the arc.
- A small strike-slip component of the kinematic of the CPF has been measured but its sens, in places sinistral and in others dextral, does not seem to highlight a sinistral E-W zone as described in the literature.
- 3 cross-sections through the arc are currently being constructed.



SINISTRAL STRIKE-SLIP MOVEMENT SOUTH OF THE ARC.

Data analysis

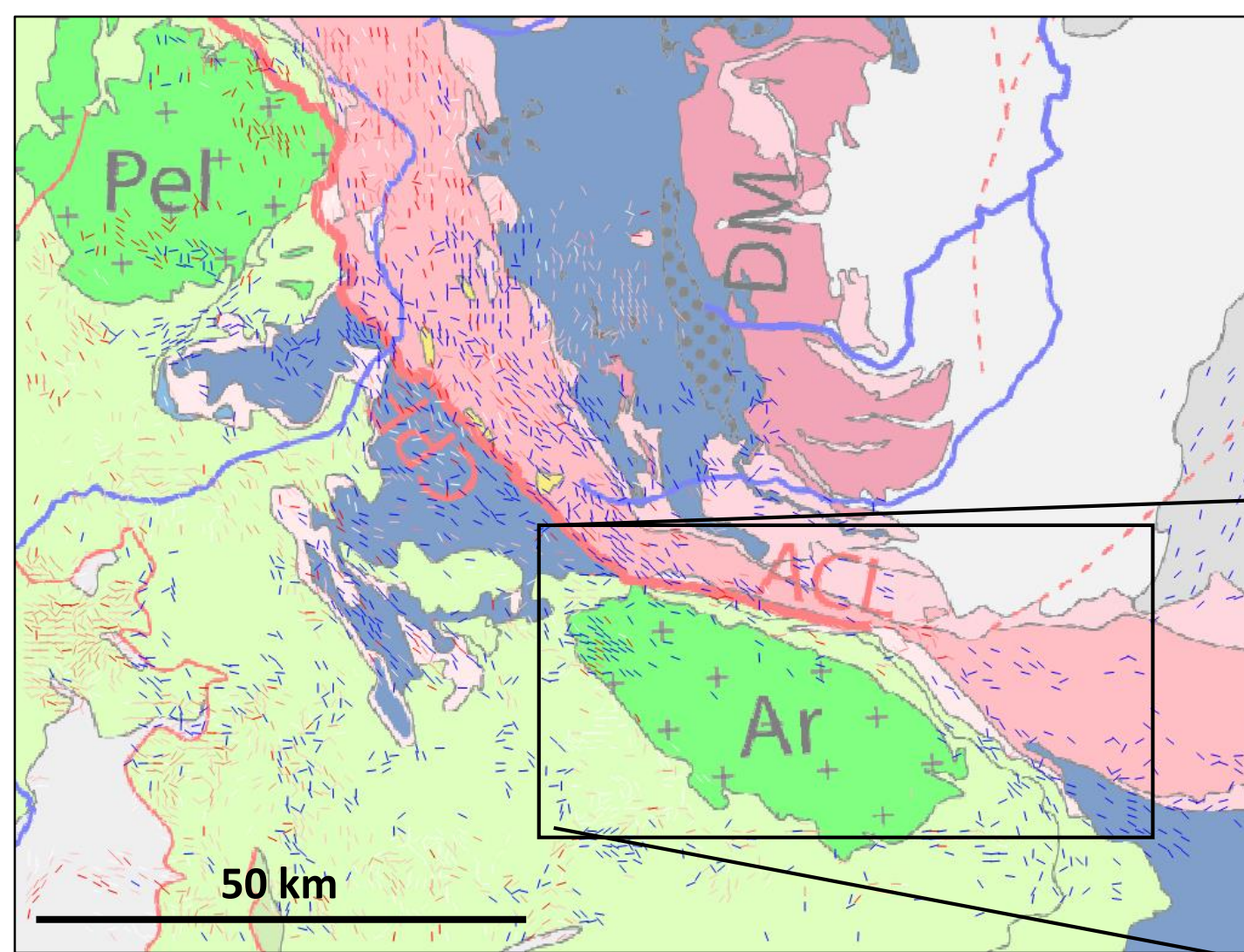


Compilation of data from :

- « Infoterre » (BRGM) **in black**.
- Data from published french and italian geological maps **in blue**.
- Own field-work **in red**.

SINISTRAL STRIKE-SLIP MOVEMENT SOUTH OF THE ARC.

Data analysis



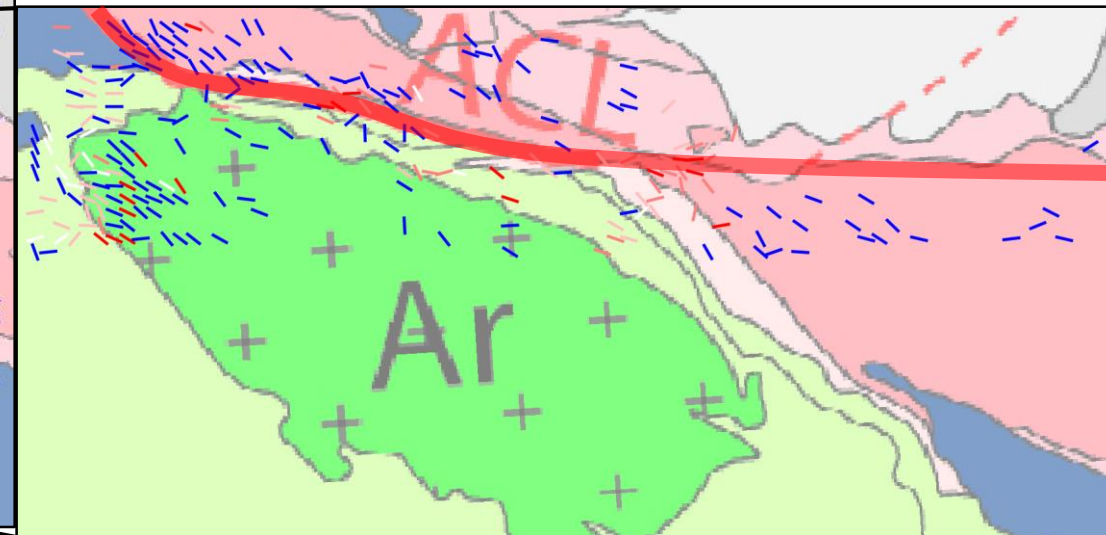
Foliation map with one average data per 1 km².

Compilation of foliation maps of various scales :

Does the evolution of the foliation (S0-S1) orientation allow to identify major strike-slip zones ?

At first sight it seems that the variations in the orientation of the foliation are consistent with the E-W shearing of the southern arc.

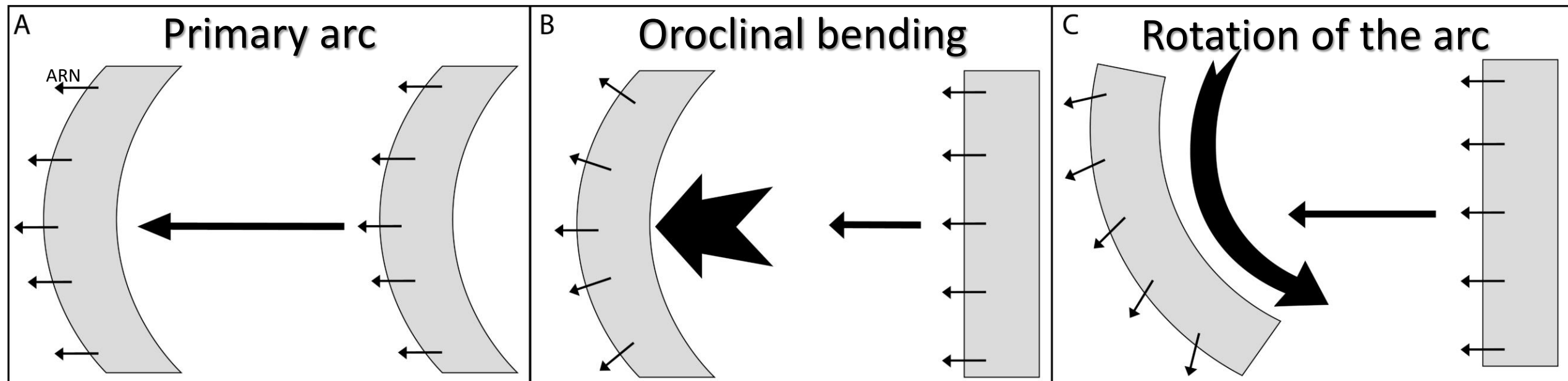
→ Work in progress.



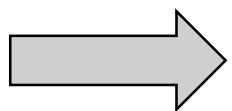
Zoom on the Acceglio-Cuneo Line (ACL $\approx$ « Stura Corridor »).

PALEOMAGNETISM AND ROTATIONS

ARN, formation of orogenic arc and rotations.



- **Primary arc** : No rotation = no NRM deviation.
- **Oroclinal bending** : Symmetrical rotations on both sides of the arc.
- **Rotation of the arc** : Rotation of the NRM orientations in the direction of the arc's rotation.



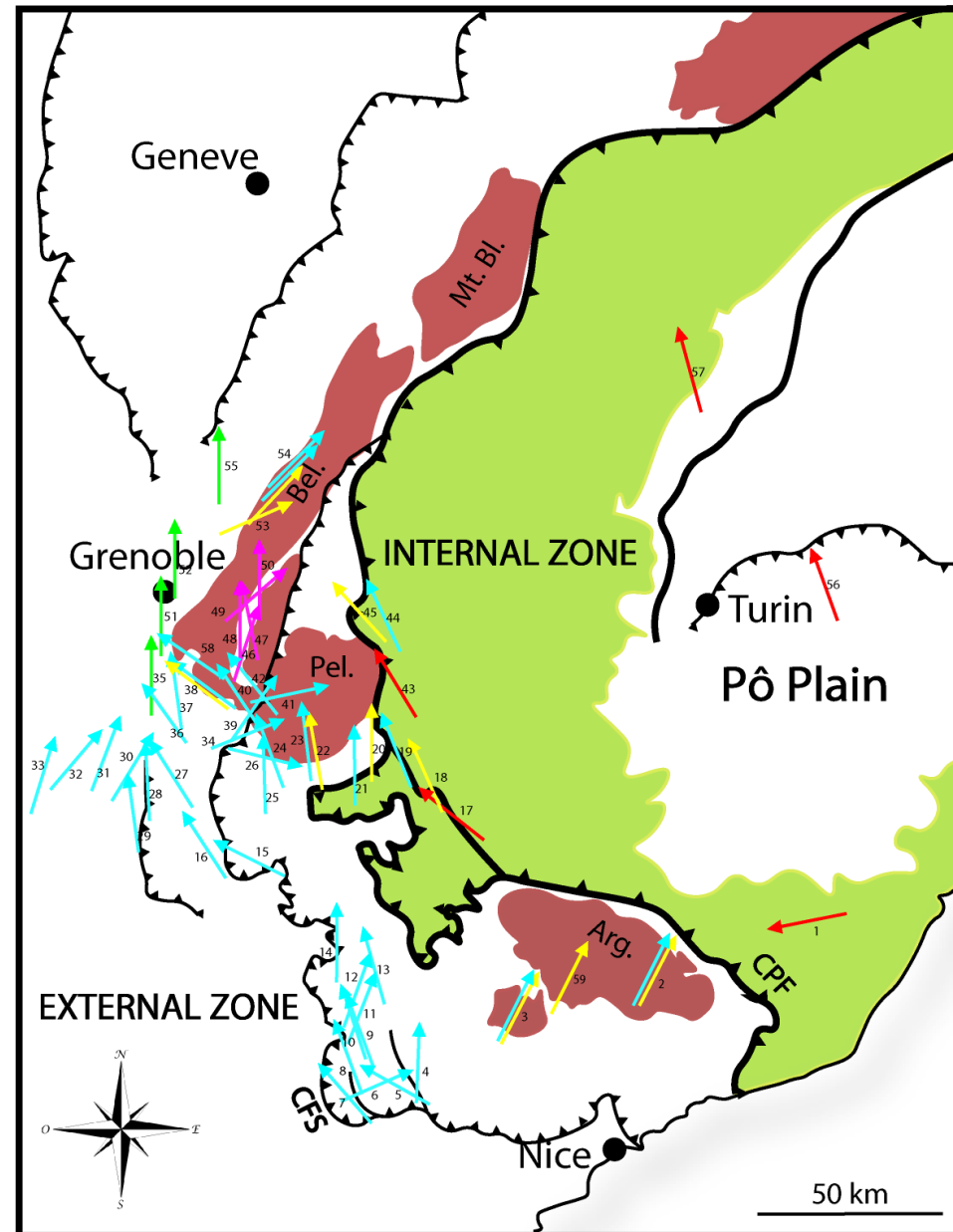
What are the vertical axis rotations in the Alps ?

What are the mechanisms of formation of the arc ?

PALEOMAGNETISM AND ROTATIONS

Paleomagnetic data

Compilation of paleomagnetic data from Aubourg & Chabert-Pelline (1999) and Collombet *et al.*, (2002).



Cre.
Ter.
Per.
Reference NRM direction for
stable Europe at Permian,
Cretaceous, and Tertiary ages.

Unfolded NRM directions

Collombet *et al.*, 2002 ; Thomas *et al.*, 1999 ;
Lanza 77 ; 79 ; 84 ; Bornioli & Lanza 1994)

Aubourg et Chabert-Pelline 1999 ;
Heller *et al.*, 1989 ; Henry, 1992

Aubourg et Rochette, 1992

Westphal, 1973 ; Bogdanoff et Schott, 1977 ;
Cogné et Perroud , 1985

Non-unfolded NRM directions
(Crouzet 1996)

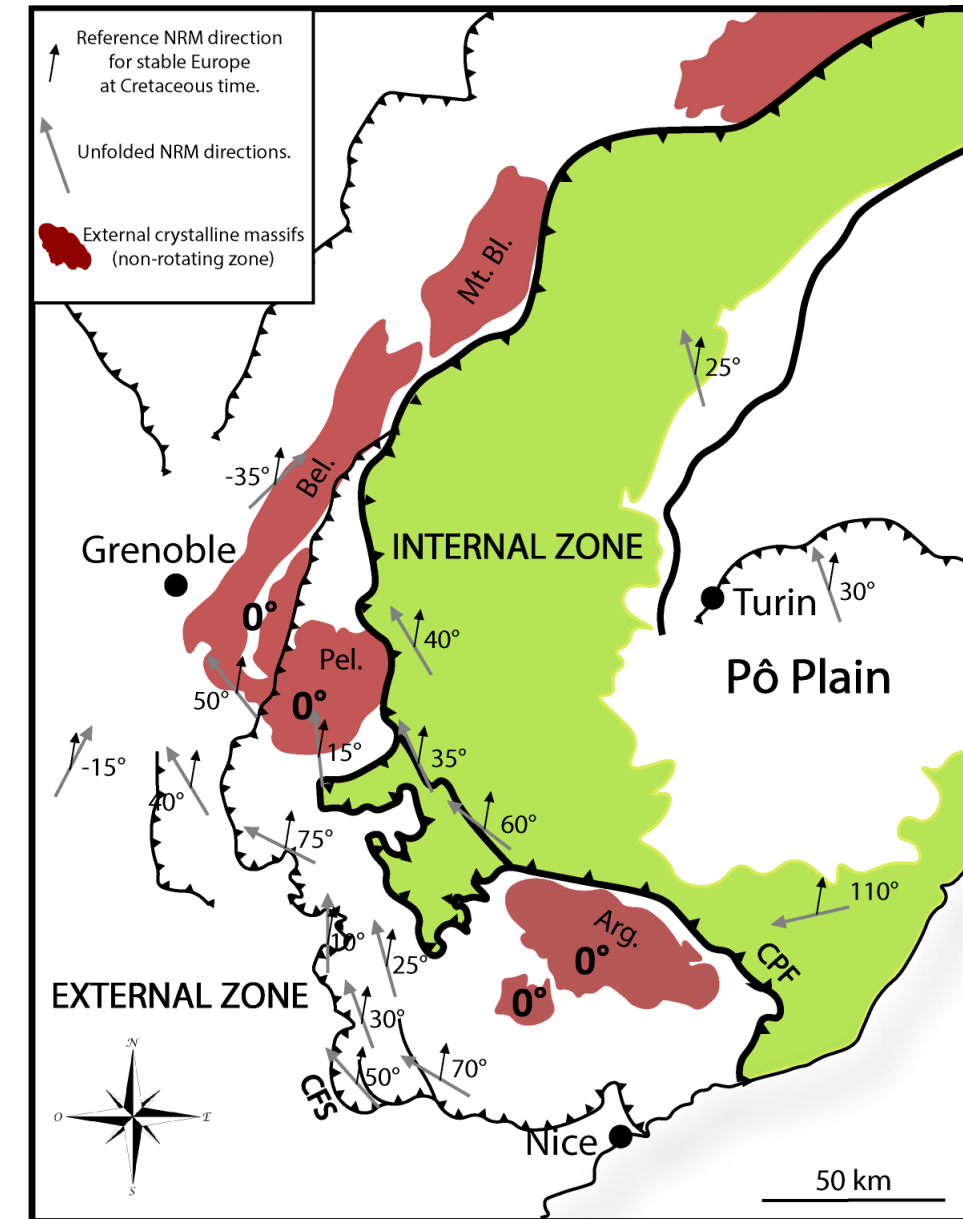
Modified from Collombet *et al.*, (2002) completed with the data from Aubourg & Chabert-Pelline (1999).

PALEOMAGNETISM AND ROTATIONS

Rotations

The analysis of the **NRM** (Natural Remanent Magnetization) allows the characterization of tectonic displacements and in particular **rotations of vertical axis**. The angle between the orientation of the current NRM and the reference magnetization direction at the time of deposition of the rock and at the sampling location correspond to these rotations.

The various data allow us to observe counter-clockwise rotations in both the Internal and the External Zone. Between the two zones, the outer crystalline massifs would not have been rotated.



Modified from Collombet *et al.*, (2002) completed with the data from Aubourg & Chabert-Pelline (1999).

PALEOMAGNETISM AND ROTATIONS

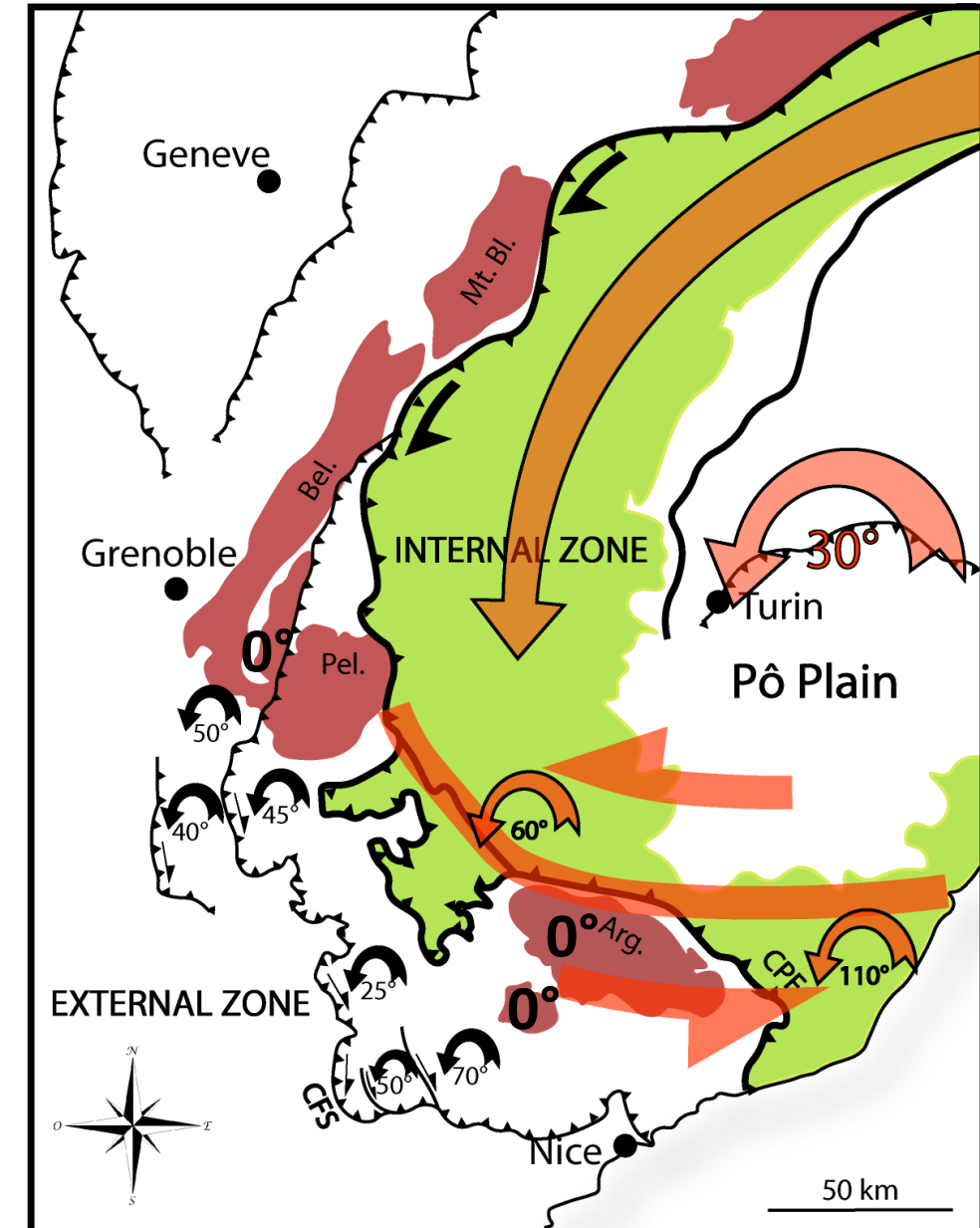
Rotation models

Collombet *et al.* (2002) propose a major counterclockwise rotation of about 30° of the Adriatic indenter coupled with the Internal Zone of the Alps.

One of their suggested interpretations for the southward directed increase of rotation in the southern part of the arc, from 30° to 110° , with a widely distributed sinistral shear zone.

Aubourg & Chabert-Pelline (1999) explain the counterclockwise rotations in the External Zone with the same wide sinistral shear zone which leads to the rotation of smaller blocks, accommodated by a dextral kinematics of the CFS.

Sonette *et al.* (2014) interpret their data from the « Dôme de Barrôt » (South-West of the Argentera) as rotations related to cover-substratum decoupling. It seems likely that this interpretation is valid for the whole External Zone but raises the question of the relationship between these rotations and those of the Internal Zone.



Modified from Collombet *et al.*, (2002) completed with the data from Aubourg & Chabert-Pelline (1999).

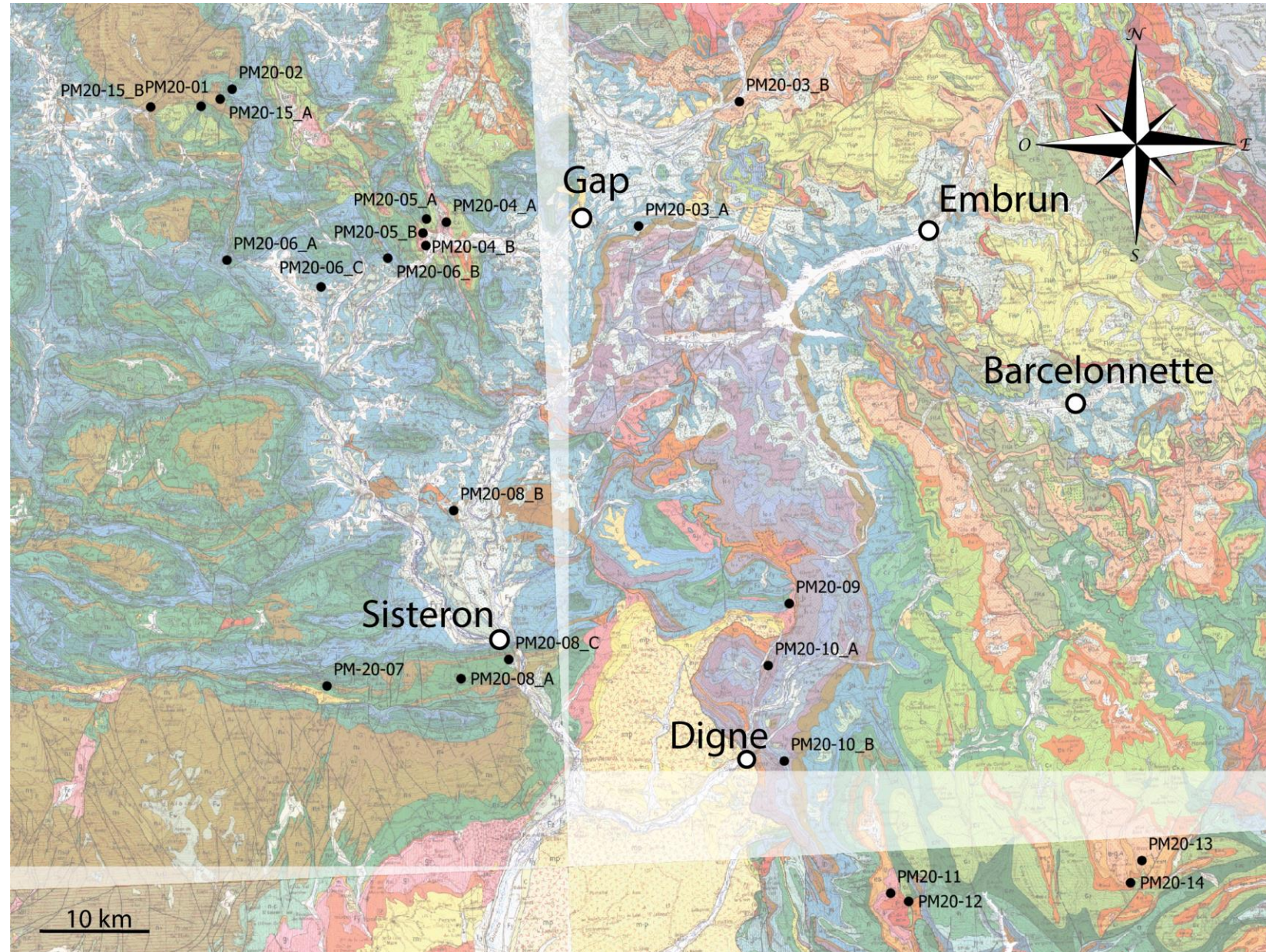
PALEOMAGNETISM AND ROTATIONS

Sampling.

A first sampling was carried out in the External Zone in rocks ranging in age from Cretaceous to Oligocene.

The variety of rock ages will better constrain the timing of rotations and the problematic reaimantations described in the previous analyses.

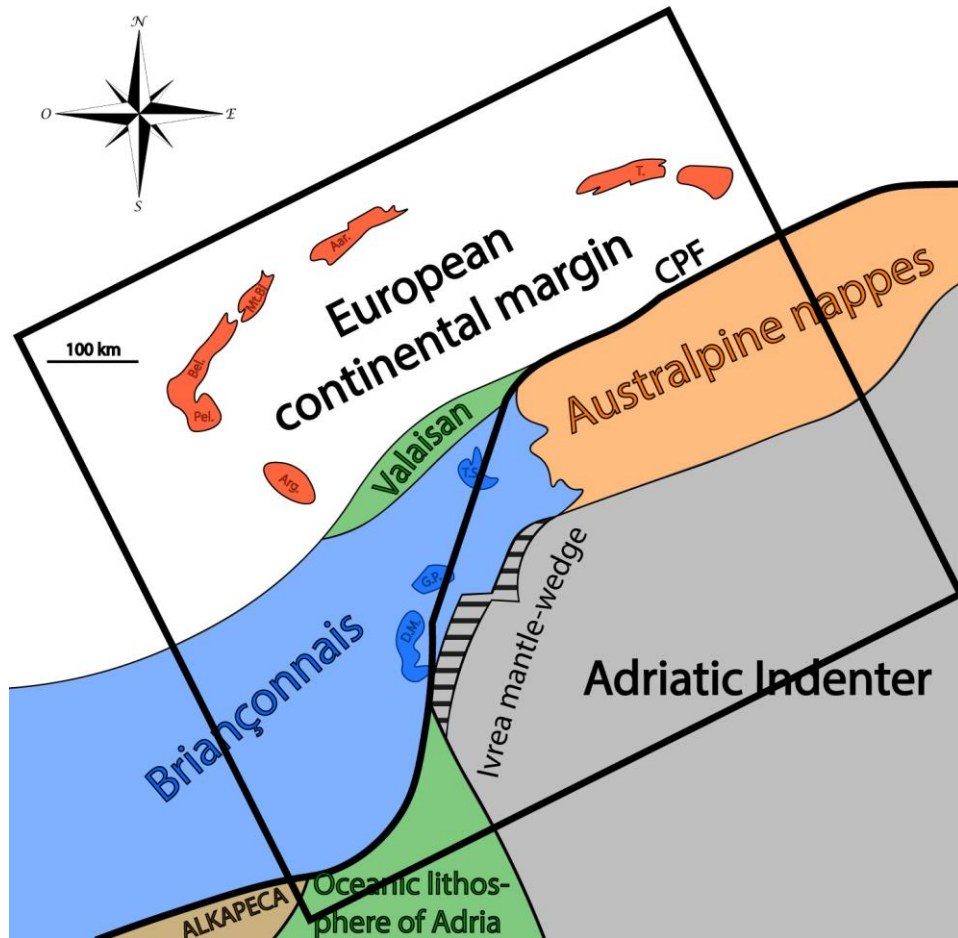
The next sampling will be carried out in the Internal Zone (Briançonnais) and in the External Zone closer to the CPF.



3D THERMO-MECHANICAL MODELLING

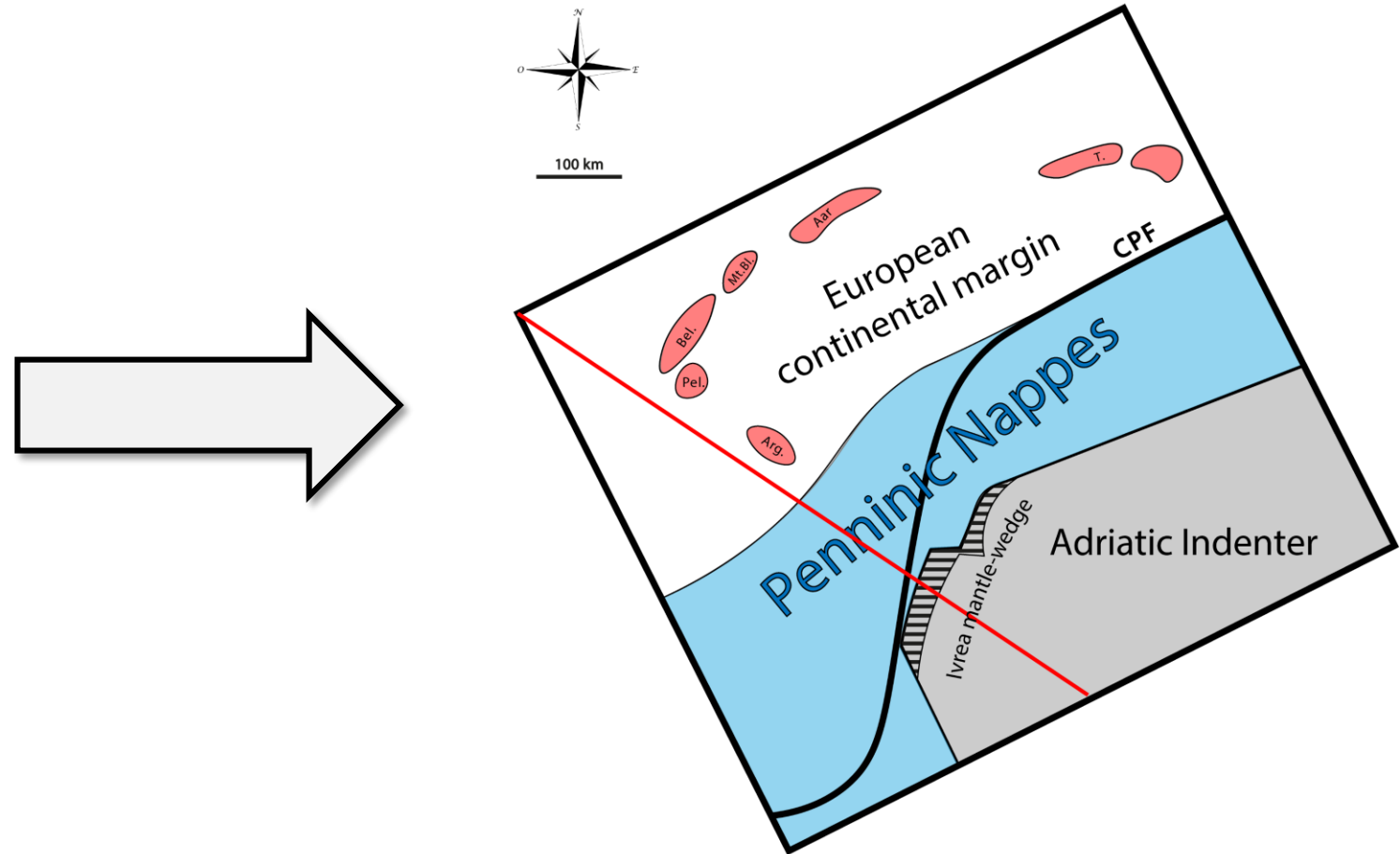
Initial geometry of models

Geometry of the Alpine region at **45 Ma** according to Schmid *et al.* 2017.



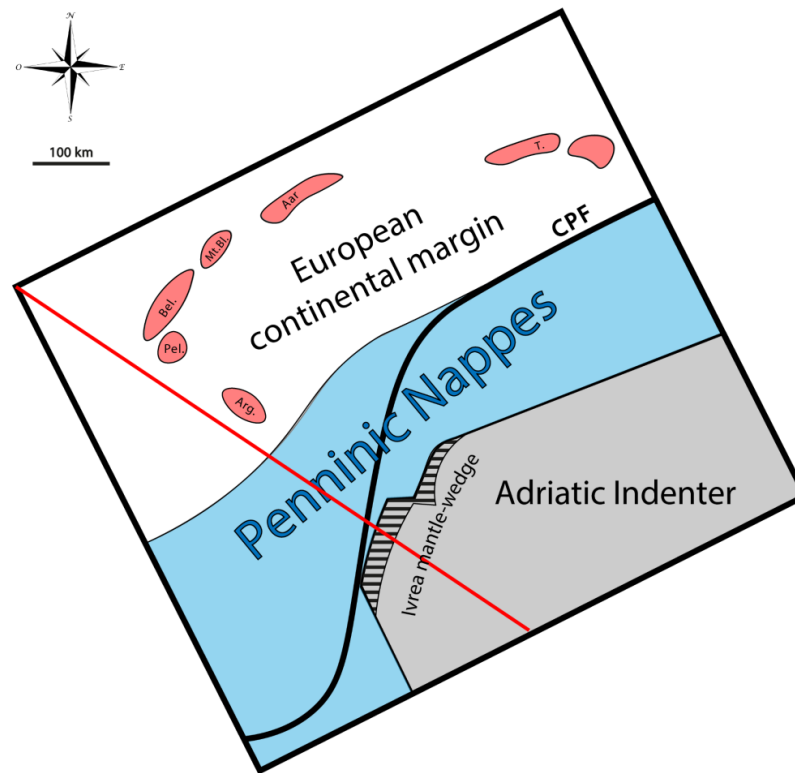
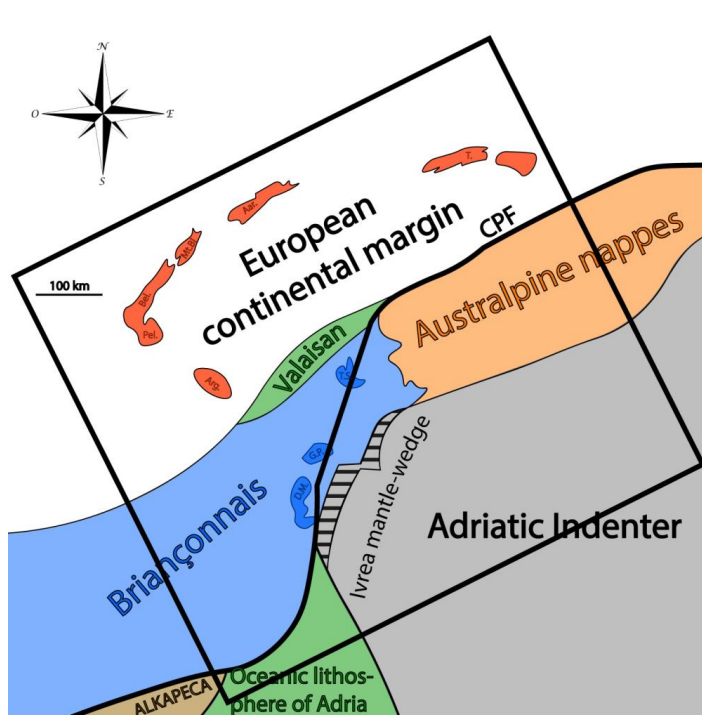
Modified from Schmid *et al.*, (2017)

Simplification of the Alpine region at 45 Ma from the kinematic restoration of Schmid *et al.* 2017. to determine an initial model geometry.



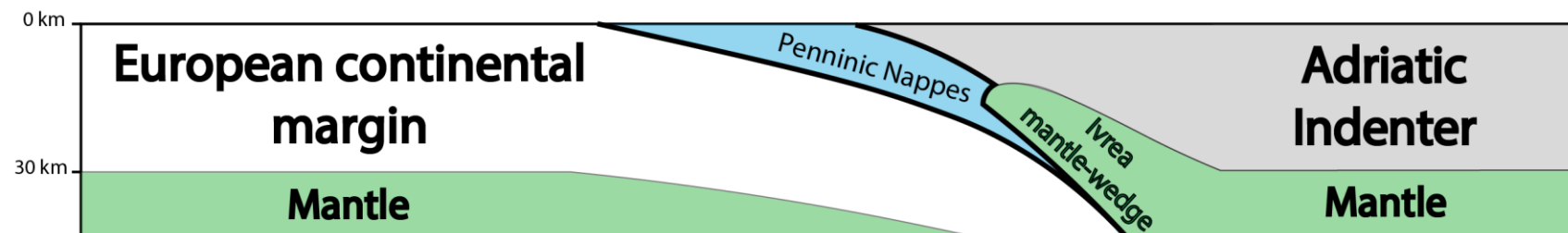
3D THERMO-MECHANICAL MODELLING

Initial geometry of models



Simplification of the Alpine region at 45 Ma from the kinematic restoration of Schmid *et al.* 2017. to determine an initial model geometry.

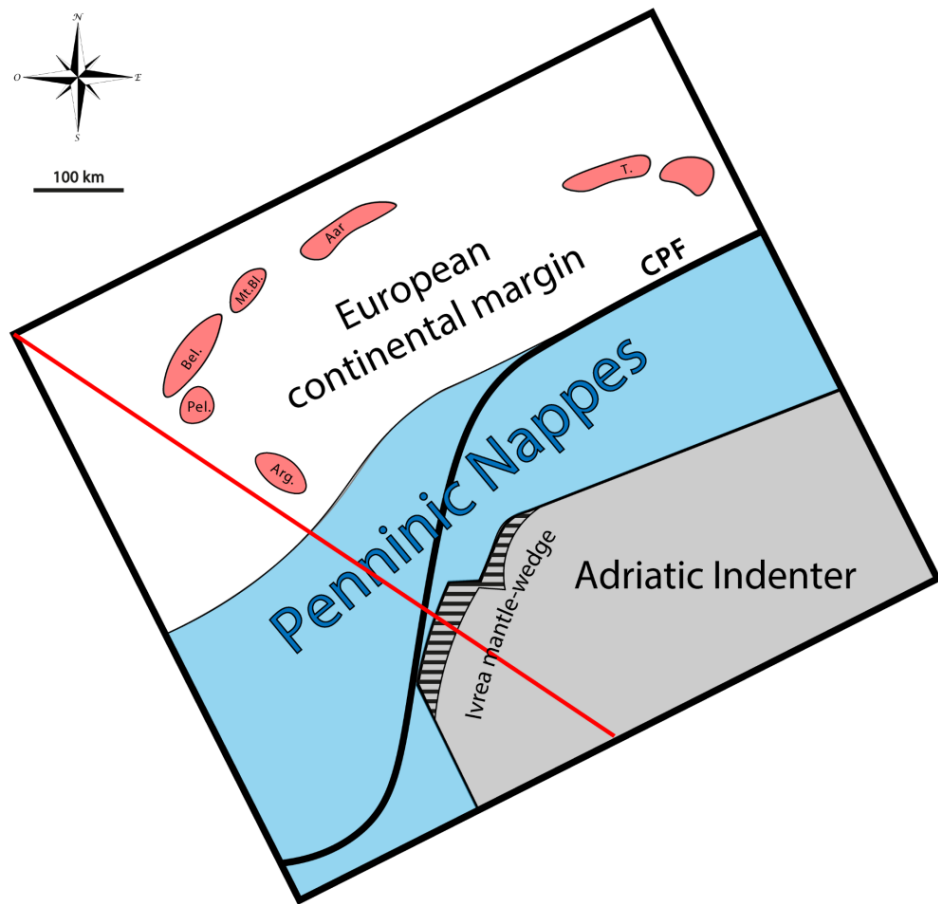
Modified from Schmid *et al.*, (2017)



Pseudo cross-section in the Western Alps at 45 Ma to illustrate the structures in the depth of the model.

3D THERMO-MECHANICAL MODELLING

Initial geometry of models



- How is a 180° arc formed in collision ?
- Which Geometrical and Rheological parameters controlled the present-day structures and kinematics of the Arc of the Western Alps ?
- Which translation and rotation of the Adriatic Indenter are involved and what are their implications ?

