Upper Mantle Structure of the transition between Alps and Apennines Revealed by Shear Wave Splitting from the CIFALPS Project

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Science Against Barriers
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EGU2016-7968 @ TS6.2/GD6.6/SM6.16

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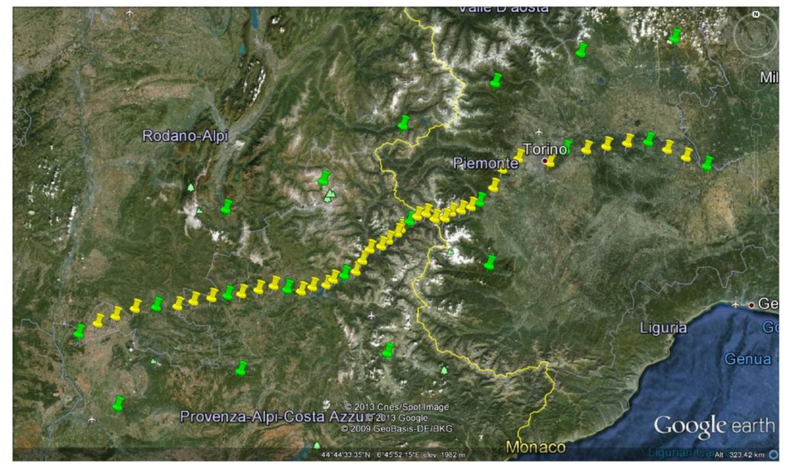
ABSTRACT

Northern Apennines, Alps and surrounding regions are often studied separately. The structure of their upper mantle has been studied repeatedly in the past and some studies reported on the seismic anisotropic properties in the litho-asthenosphere. However, a joint interpretation of the Alps-Apennines transition zone is still lacking, mainly at depth. The China-Italy-France Alps seismic survey (CIFALPS, 2012) provided an improved image of the crust and upper mantle beneath the southwestern Alps and the transition to the Apennines. Here we show the SKS shear wave splitting results obtained from the analysis of teleseismic data recorded by 55 temporary seismic stations along the CIFALPS profile and by some other permanent stations. The strain-induced lattice preferred orientation of olivine minerals within the upper mantle, expressed by the analysis, confirms the NW trending fast polarization directions parallel to the strike of the orogen, in good agreement with the results of previous studies all along the Alpine chain. On the contrary, in the Po-Plain, new shear wave splitting measurements show a scattered distribution; the coexistence of both NNE-SSW and E-W directions provides new insights on upper mantle deformation in the complex transition zone between the Alpine and Apenninic subductions. The comparison of this new dataset with recent tomographic studies and geological improvement should compose a more complete picture of the mantle structure and deformation of this puzzling region.

China-Italy-France Alps Seismic Survey

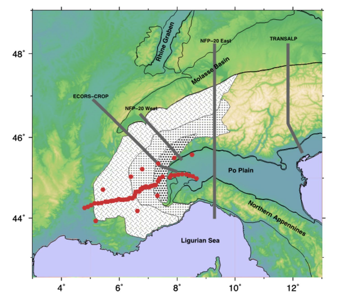
CIFALPS project



A 350-km-long dense seismic profile across the Western Po-Plain/Southern Alps to the Rhone Valley was installed from May 2012 to September 2013. 45 stations were installed along a main transect crossing perpendicular the Alps chain, while 10 stations were installed north and south this main profile. Along the transect, the spacing between stations is 10 Km becoming smaller (~5 Km) for those near the Alps. All stations were equipped with very broad band sensors (Trillium 120 PA), Taurus digitizer and with a sample rate of 100 Hz.

The China-Italy-France Alps Seismic Survey is an international collaboration between Institute of Geology and Geophysical Chinese Academic of Science (IGGCAS), Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy, and the Institut des Sciences de la Terre (ISTerre), Grenoble, France, in order to build a common scientific project on high-resolution probing the crust and upper mantle structure of the Western Alps by mean a passive seismic transect.

Scientific Goals:
- Image the **crustal structure** of the SW Alps with high-resolution
1) deep geometry of the frontal Penninic Thrust
2) deep geometry of the Viso ophiolitic massif
- Image the **mantle structure** of the SW Alps, addressing to:
1) geometry of the subduction beneath the Western Po Plain
2) mantle flow pattern beneath the Western part of the Alpine



The high-quality data recorded by stations of the CIFALPS project help to extend the knowledge of the crust and mantle structure to the Western Alps and Northern Apennines previously not interested by old seismic experiments as the ECORS-CROP project.

GEODYNAMIC SETTING

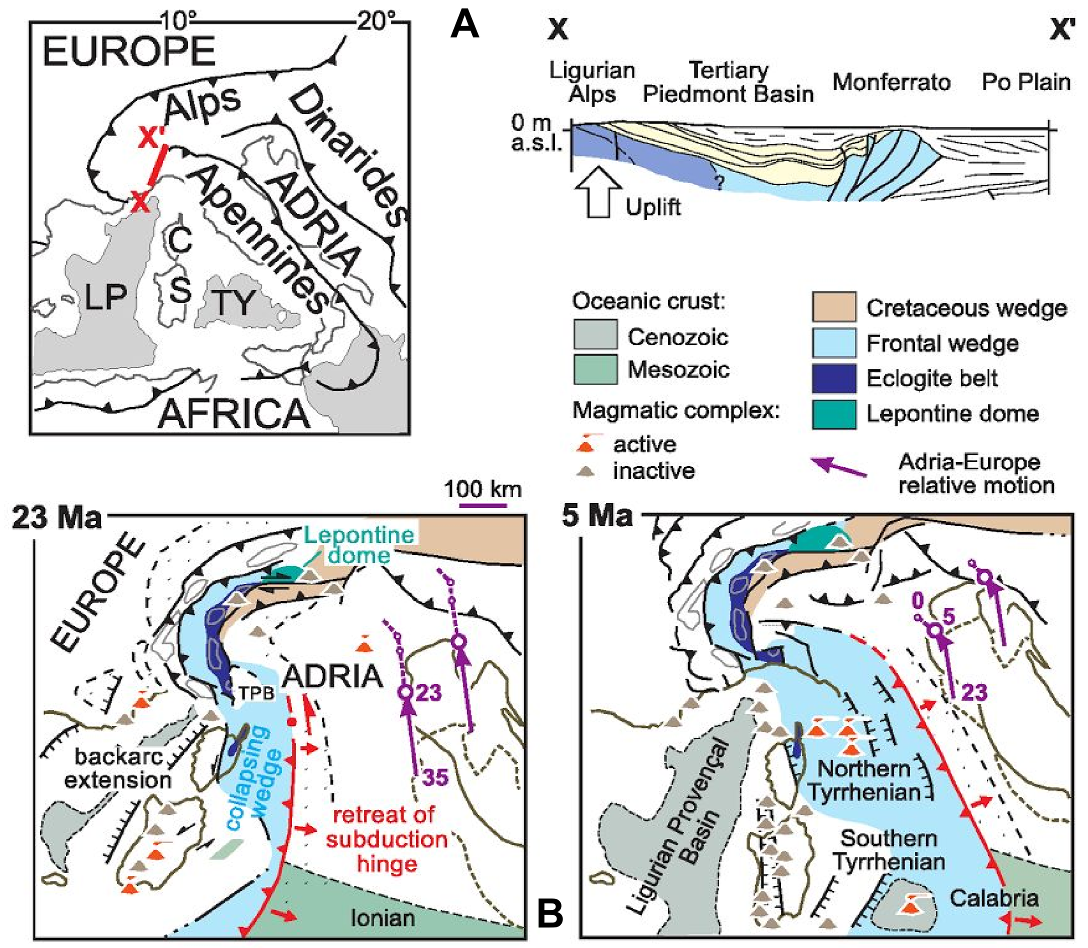
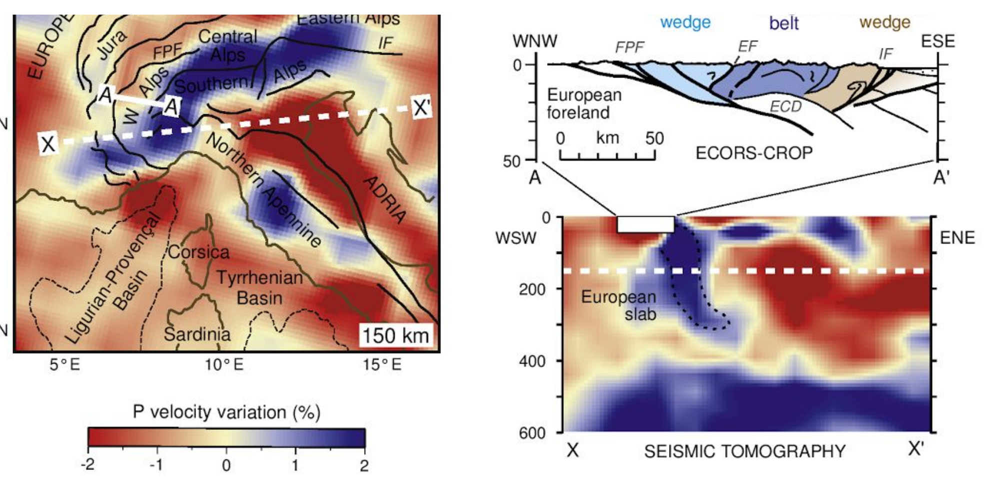
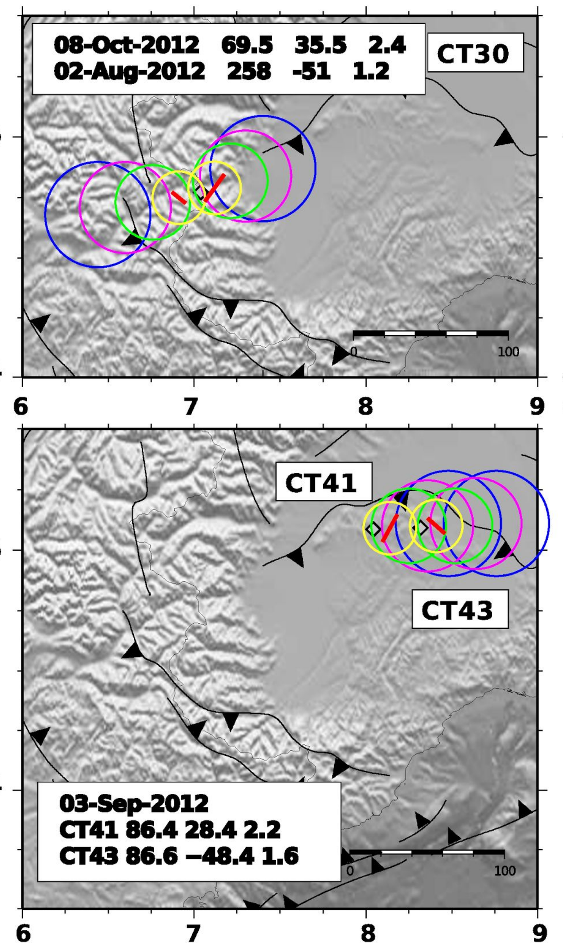


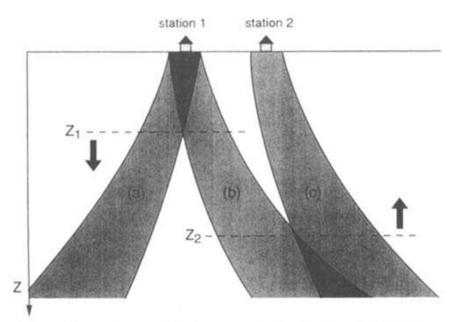
Plate-tectonic setting of the Alps and Apennines region and geologic section across their transition zone (A). In (B) palinspastic reconstructions at 23 Ma and 5 Ma, showing the progressive retreat of the Adriatic slab during backarc extension in the Ligurian Provencal and Tyrrhenian basins.



Tomography map of the Alps-Northern Apennines at 150 Km of depth (after Piromallo and Morelli, 2003, JGR), tomography section (X-X') across the Western Alps (after Piromallo and Faccenna, 2004, GRL) and simplified crustal section (A-A') based on seismic data along the Ecors-Crop traverse (modified after Malusà et al., 2005, Tectonics). ECD, European crust duplex; EF, Entrelor shear zone; FPF, Frontal Pennine Fault; IF, Insubric Fault. (Figure 2 of Malusà et al., 2011, EPSL)

FRESNEL ZONE





Modified from Alsina and Snieder (1995)

Rf *= diameter of Fresnel Zones*
h *= 50, 100, 150, 200 Km depth*
T *= dominant S-wave period (10 sec)*
v *= S-phase shear wave velocity, from IASP91 model (4.476 Km/s at 50 Km depth, 4.49 Km/s at 100 Km depth, 4.45 Km/s at 150 Km depth and 4.51 Km/s at 200 Km of depth)*

Retrieving the ray path of two teleseismic events arriving at the same station, coming from opposite back-azimuths and sampling different fast axes directions, allows to define the ***depth Z1*** *above which rays samples the same upper mantle region or below which lateral anisotropic variations occur. This is the case for stations CT30 and CT33, for which rays coming from NE sample a fast axis oriented around 30° from North and event coming from SW sector sample an anisotropic direction around -50° from North. For both stations, the Z1 depth could be defined between 50 (yellow circle) and 100 Km (green circle), depth below which anisotropic properties changes.*

A simple back-tracing of one event arriving at closely stations, sampling different anisotropy, could help to define the ***depth Z2****, above which rays separate and sample different (shallow) anisotropic region. For stations CT41 and CT43, located both in the Po-Plain area around the Monferrato Hills, different fast axes direction are detected for one event coming from Est; in CT41 the fast axis direction is 28° from North, while in CT43 is oriented -48°. In this case, the depth above which rays separate is shallower than 50 Km.*

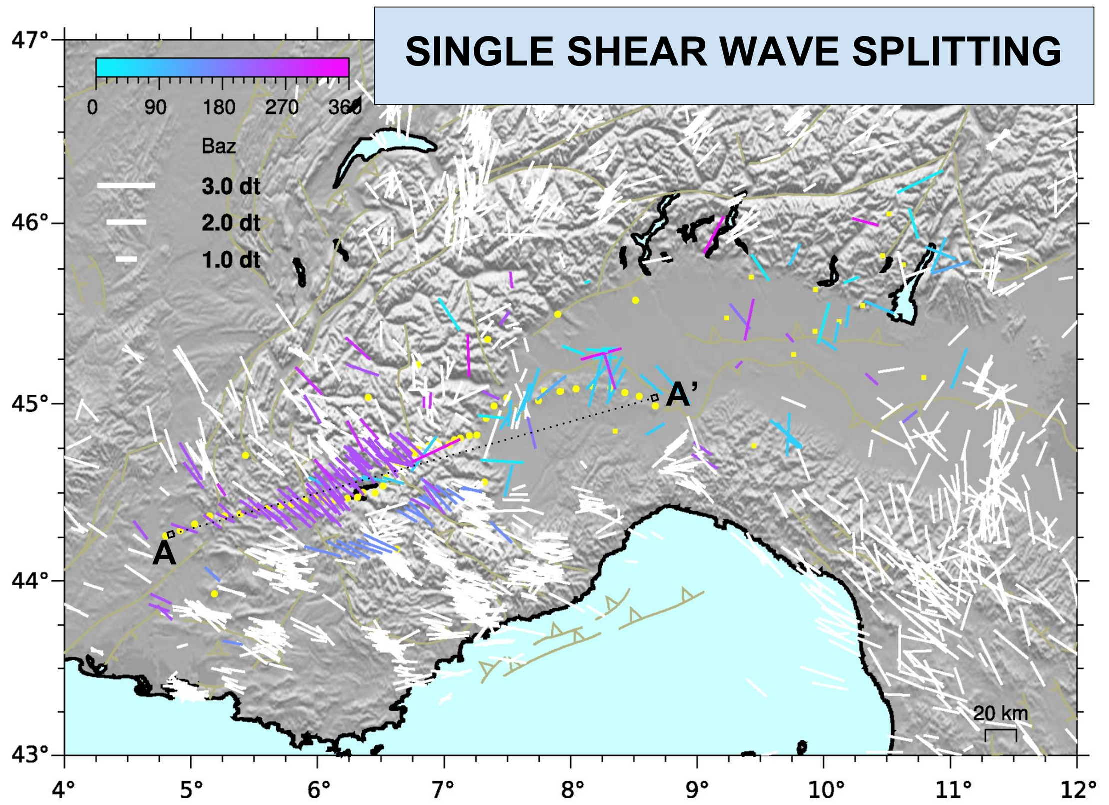
THE SHEAR WAVE SPLITTING ANALYSIS

From the entire array, we have selected **24 teleseismic** events occurred from May 2012 and September 2013, with M>5.8 and occurred in an epicentral distance between 80° and 120°. The SKS splitting analysis was performed in two-separate steps:

Step 1 - **9 events** were analyzed with an **automated SKS-splitting code** working minimizing the energy on the transverse component (Silver and Chan, 1991), obtaining **90 new SKS-splitting measurements**.

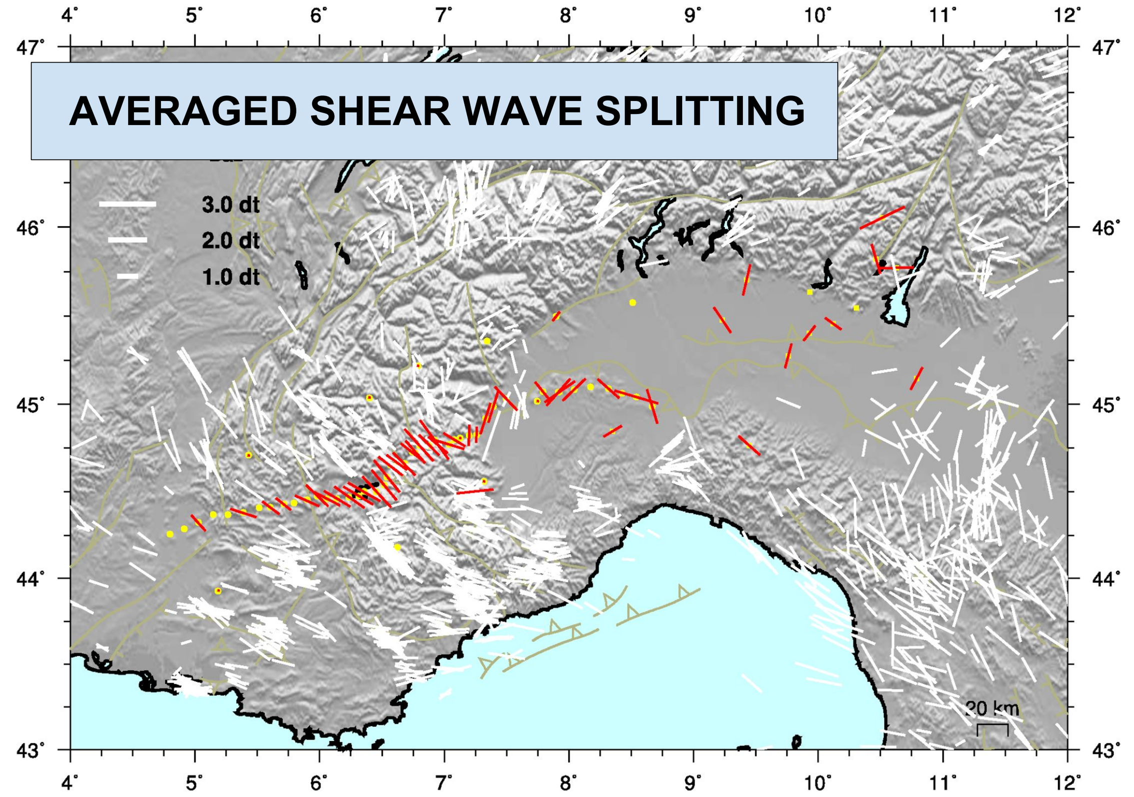
Step 2 - A manual analysis of **15 events** are performed using the **SplitLab Code** (*Wüstefeld et al., 2008*) on stations located in the eastern termination of the array and on the permanent ones located in the Po-Plain. Selecting results with SNR>3, an automatic quality factor of 0.75 (corroborated by the experience of the operators) and limiting the anisotropic contribution to 3 sec of delay time, a total of **68 SKS-splitting** measurements are obtained.

SINGLE SHEAR WAVE SPLITTING



In the map on the left are plotted ***158 new shear wave splitting measurements*** *obtained at the end of the second step of the analysis. Each stick represents a single shear wave splitting result, oriented parallel to the fast axes and scaled with the delay time value. The scale color used to plot the measurements is designed in agreement with the back-azimuth of the events analyzed. Measurements in white are taken from previous works and collected in the SplitLab database (Wüstefeld et al., 2009). All results plotted on the map are projected into the upper mantle at a 150 Km of depth. On the right, the average measurement for each station is plotted in red.*

AVERAGED SHEAR WAVE SPLITTING



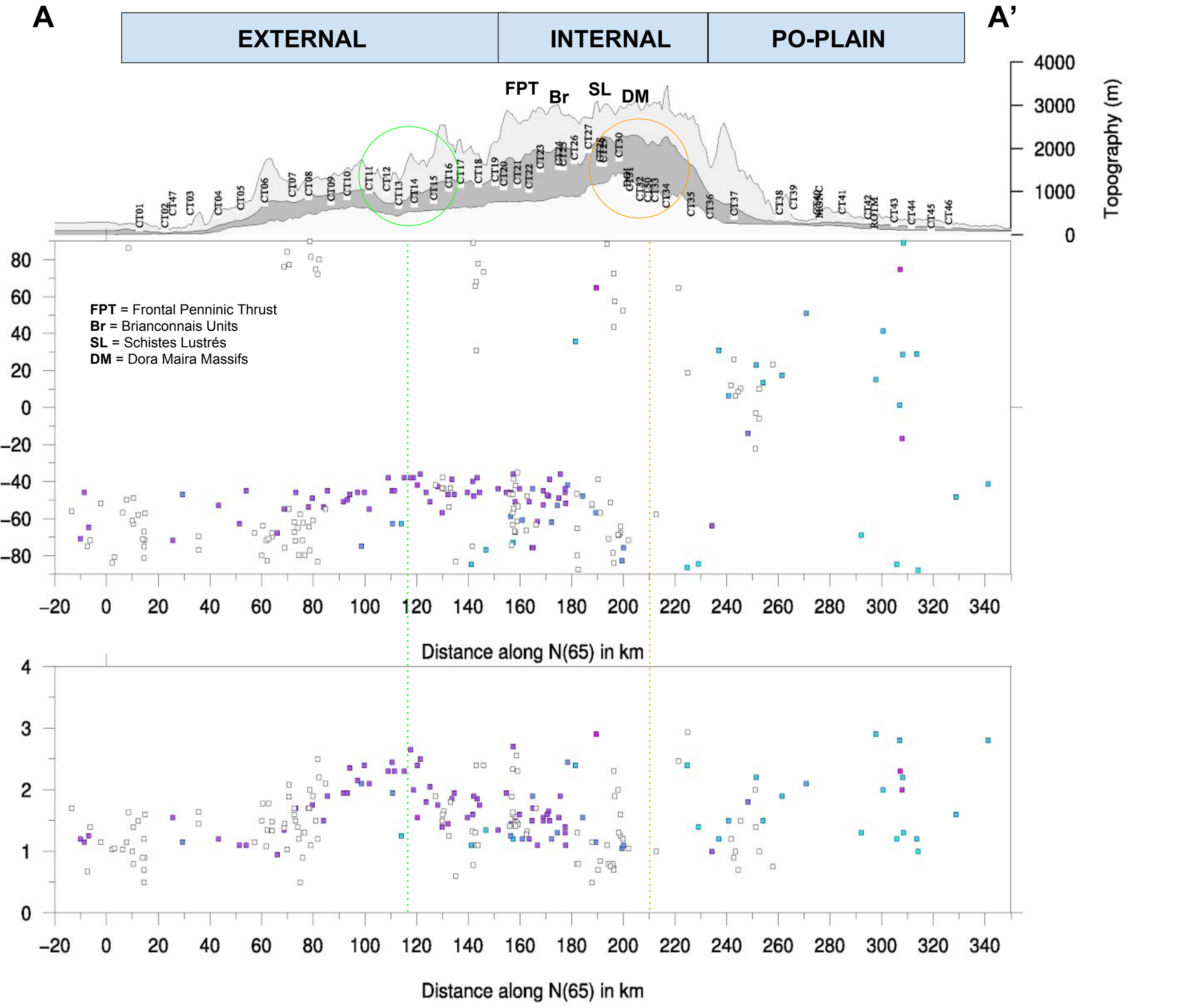
Western Alps Domain:

Starting from point 0 of the array (point A of section AA') moving toward NE, it seems that approximately at station CT30 (orange circle and line), located approximately 200 Km from CT01 and around 40 Km from the Frontal Penninic Thrust (FPT), is located the boundary between different patterns. West of this stations, dominant fast-axes directions are from NW-SE to E-W nearly following the belt shape and in agreement with the previous distribution found by *Barruol et al. (2011)*. In this region delay times increase up to CT14-CT16 (120 Km from 0, green circle and line), reaching the value of 2.5 sec, followed by a gradual decrease toward CT30, where dt is about 1 sec.

Po-Plain Domain:

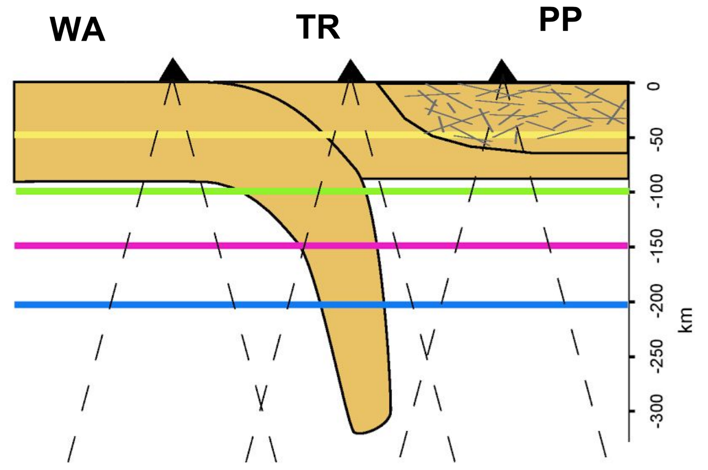
Behind station CT35, the NW-SE directions become less frequent, being substituted by a N-S and NE-SW prevailing directions. In addition, even if clearly sparse and less frequent, some E-W trending data are present. In the Po-Plain, delay times are slightly smaller with respect to the values measured in the outer part of Western Alps and are mostly lower than 2.5 sec. The presence of a lateral variation of the anisotropic properties in the shallower part of the area (<50 Km) could be the source of the scattering in the distribution of the fast axes and delay time values in this area.

The variation of shear wave splitting parameters along the CIFALPS profile (A-A' in the single shear wave splitting figure) in a swath box of 40 Km of width. In color are SKS-splitting of CIFALPS stations (see color scale in map), in white for other stations from previous works.



Transition between W-Alps (WA) and Po-Plain (PP):

From Fresnel zone analysis we identify that the change in anisotropic direction from WA to PP occurs in a narrow zone, 20-25 Km wide, from stations CT30-CT35. Beneath this transition is located the slab, that separates the European and Adriatic upper mantles, that we identify with the two recognised anisotropic domains. Scattered results from the PP side, in addition with the shallow anisotropic source found through Fresnel zone beneath Monferrato range (stations CT41-CT43), do not still allow to draw a consistent pattern.



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