Mantle deformation beneath the Alps and the physics of the subduction polarity switch: Part I - constrains from seismic anisotropy

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Part II of the project focuses on the geodynamic modeling of the subduction polarity switch (PI: Harro Schmeling; PhD: Jan Philip Kruse)

The aim of our study is a comprehensive understanding of the dynamics in the mantle beneath the area of the European Alps covered by the AlpArray seismic network, also shedding light onto small-scale features using the data of the SWATH-D complementing experiment. We use seismic anisotropy as a proxy for mantle deformation and flow, as intrinsic anisotropic minerals in the mantle, such as olivine, are likely to align in response to deformation. The bulk mantle and crustal anisotropy can be determined by polarization analysis of teleseismic shear waves. The dense and wide-spread AlpArray network provides for an unprecedented high lateral resolution for this technique in the region, while its vertical resolution is systematically low. In previous seismological studies on mantle anisotropy a possible role of the crust has largely been ignored, while recent studies provide evidence for significant crustal anisotropy.

Our project is organized in five work packages. We first apply a rapid, semi-automatic analysis of shear-wave splitting (SKS, PKS-phases) to derive the bulk anisotropy of crust and mantle beneath the entire Alpine regions (WP1). Then, the crustal anisotropy is determined using a robust Ps-splitting analysis applied to converted crustal phases in receiver functions (WP2). The next step involves the inversion of “crust-corrected” XKS-waveforms to isolate the anisotropic signature of the mantle (WP3). Waveform modeling for anisotropic mantle models derived from geodynamic modeling (see Part II of the project) is also performed (WP4). The waveforms and the resulting synthetic splitting parameters will be compared with the seismological observations to identify for the most plausible models of subduction within an iterative process (WP5).

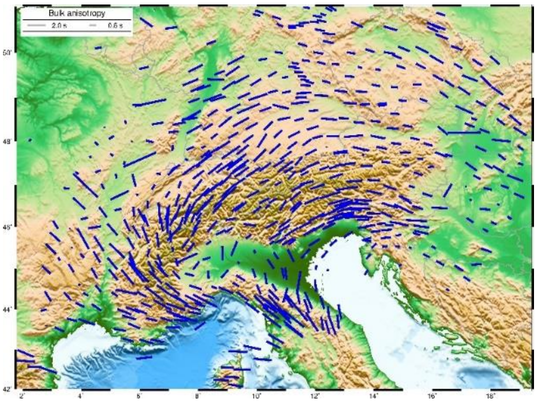

Figure 1: Bulk anisotropy of crust and mantle from a joint inversion of XKS-measurements in the Alpine region. The length of the bars corresponds to the measured splitting time, while the direction coincides with the measured fast axis polarization at the station.

For WP1 we fully automatized the SplitRacer-code (Reiss and Rümpker 2017) to allow for a more objective analysis of the large AlpArray data set. The application (Figure 1) shows a good agreement with results from former studies with fast polarization directions parallel or subparallel to the strike of the mountain range and the boundaries of the collision. We identify generally significant seismic anisotropy ranging from 0.8 up to 2 seconds with growing splitting times in highly-deformed regions. While the fast axis polarization on the side of the European plate shows the described parallel to subparallel feature coinciding with the shape of the mountain range, we observe a rotation in the Po basin on the Adriatic side with relatively low anisotropy (splitting times) in the center. In the transition to the Dinarides the fast axis orientations miss the parallel strike to the tectonic boundaries of the collisions, which may be related to a possible slab gap within the Adriatic plate.

In the central part of the Alps the complementary experiment SWATH D is placed in a region where, based on previous studies, a polarity reversal of the subduction is expected. Our analysis of the XKS-waveforms (Figure 2) shows a continuous rotation of the fast polarization parallel to the axis of the orogeny not showing a deviation of the mantle flow as it would be expected in such a case. However, the measurements of the AlpArray data (Figure 1) show a deviation from this feature west of the SWATH D network, which may possibly be related to a subduction reversal.

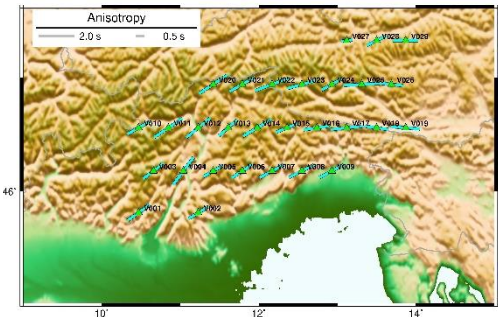

Figure 2: Bulk anisotropy of crust and mantle for a joint inversion of the XKS-splitting measurements of the SWATH-D data set. The individual measurements are projected along their ray-path to a sub-crustal depth of 50 km and re-arranged to a virtual station set-up to suppress effects from noise.

In WP2 we developed an approach to analyze the splitting in the crustal Ps- and PpPs-phase to determine the crustal anisotropy. As there is considerable topography of the Moho in the range of the Alpine collision, we also introduce the possibility of analyzing and considering a dip of the Moho below the individual station. A first analysis of the crustal phases without considering a possible layer dip gives a detailed Moho-map indicating the mentioned considerable topography (Figure 3a), as well as a preliminary estimate of the move-out and splitting present in the receiver functions. We also separated the crustal anisotropic contribution from the XKS-waveforms and re-analyzed the data set to get a first estimate of its effect on the XKS-measurements and the true mantle anisotropy (Figure 2b).The crustal effect is generally small with growing size to the center of the orogeny. A possible effect of a layer dip due to the Moho-topography is still possible and subject of further investigation.

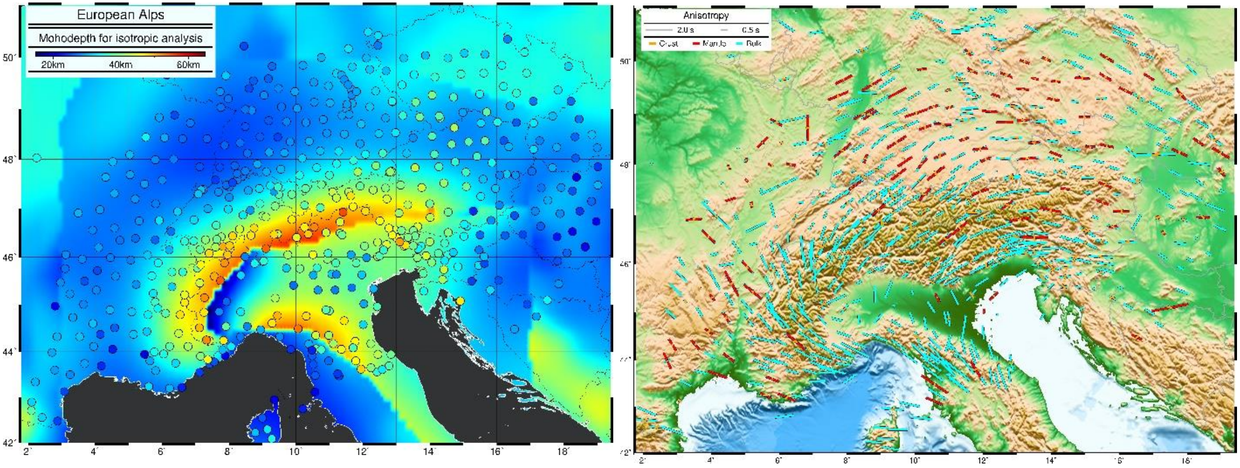

Figure 3: a) (left) Moho-depth from a classical receiver function stacking analysis (Zhu & Kanamori 2000) shown by filled dots. The background shows a compilation of the Moho-model from Spada et al. (2013) and EuCrust-07 of Tesauro et al. (2008). b) (right) XKS-measurements of the bulk (cyan), crustal (orange) and isolated mantle anisotropy (red).

Publication list:

Link, F., Rümpker, G. and Kaviani, A., 2017. Crustal anisotropy in different tectonic regimes inferred from the stacking of radial and transverse receiver functions. *IASPEI 2017,* S21-5-03.

Link, F., Rümpker, G., 2018. Crustal anisotropy inferred from a single receiver-function splitting analysis – a tool for temporary seismic stations. *EGU general assembly 2018*, EGU2018-6428.

Link, F., Rümpker, G., 2018. Crustal anisotropy in the European Alps inferred from an improved splitting analysis of crustal phases in receiver functions. *EGU general assembly 2018*, EGU2018-6337.

Link, F., Rümpker, G., 2018. Crustal thickness and Anisotropy inferred from a multiple phase splitting analysis of receiver functions – a tool for temporary seismic stations. *General assembly of the ESC 2018*, ESC2018-S10-333.

Link, F., Rümpker, G., 2019. Crustal anisotropy in the European Alps inferred from crustal phases in receiver functions and first implications for the mantle dynamics. *EGU general assembly 2019*, EGU2019-7235.