Imaging structure and geometry of Alpine slabs by full waveform inversion of teleseismic body waves

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The primary goal of this project was to use records of distant earthquakes from the AlpArray Seismic Network to contribute to the controversial debate about the structure, origin, and fate of subducted lithospheric plates in the deeper mantle beneath the Alps, such as possible slab detachments or changes in subduction polarity, to expand our understanding on mountain-building processes.

Originally intended as a preliminary step before full-waveform inversion, we performed a teleseismic P-wave travel-time tomography (Paffrath et al., 2021b) based on waveforms recorded at over 600 temporary and permanent broadband stations of the AlpArray Seismic Network. An algorithm using a combination of automatic picking, beamforming and cross-correlation was developed to extract teleseismic travel times of direct P-waves from 331 events of magnitude > 5.5 recorded between 2015 and 2019 resulting in a database of over 162 000 highly accurate absolute P-wave travel times and travel-time residuals (Paffrath et al., 2021a).

In addition, we developed an automatic picking algorithm based on multi-component autoregressive prediction and properties of the analytic signal. This algorithm was applied to a global data set of waveforms from over 6000 events of magnitude < 6 recorded between 1990 and 2019 at more than 25000 stations to obtain about 3.8 million P- and 3.2 million S-phase arrival times.

We obtained models of P-wave velocities on a grid with 25 km lateral and 15 km depth spacing, encompassing the entire Alpine region, from the Massif Central to the Pannonian Basin and from the Po Plain to the river Main, down to a depth of 600 km. Hardly resolvable crustal heterogeneities were taken into account by a novel approach of direct incorporation of an external 3D a priori model of the crust and uppermost mantle into the starting model of the inversion. For forward travel-time predictions, a hybrid method was developed by combining ObsPy-Taup with the fast-marching code FM3D.

The resulting model provides a detailed image of slab configuration beneath the Alpine and Apennine orogens that differs from previous studies. Major features are: (1) A partly overturned Adriatic slab beneath the Apennines reaching down to 400 km depth exhibiting progressive detachment towards the southeast; (2) a fast anomaly beneath the western Alps indicating a short western Alpine slab that ends at about 100 km depth; (3) a complex deep-reaching coherent fast anomaly beneath the Central Alps generally dipping to the SE down to about 400 km, detached from the overlying lithosphere in its eastern part but suggesting a slab of European origin; (4) a further deep-reaching, nearly vertically dipping high-velocity anomaly beneath the Eastern Alps, laterally well-separated in the upper 200 km from the slab beneath the central Alps but merging with it below, suggesting a slab beneath the eastern Alps of presumably European origin completely detached from the orogenic root so that a change in subduction polarity is not necessary.

Very recent P-wave velocity models from teleseismic full-waveform inversion based on hybrid coupling of GEMINI and SPECFEM3D exhibit, in contrast to travel time tomography, surprisingly high resolution in the crust and uppermost mantle with a superb image of the Alpine and Apennine orogenic root and the Ivrea body; they confirm the general distribution of high-velocity anomalies found by traveltime tomography in the mantle below, but might allow new conclusions about the connection of the subducted slabs.

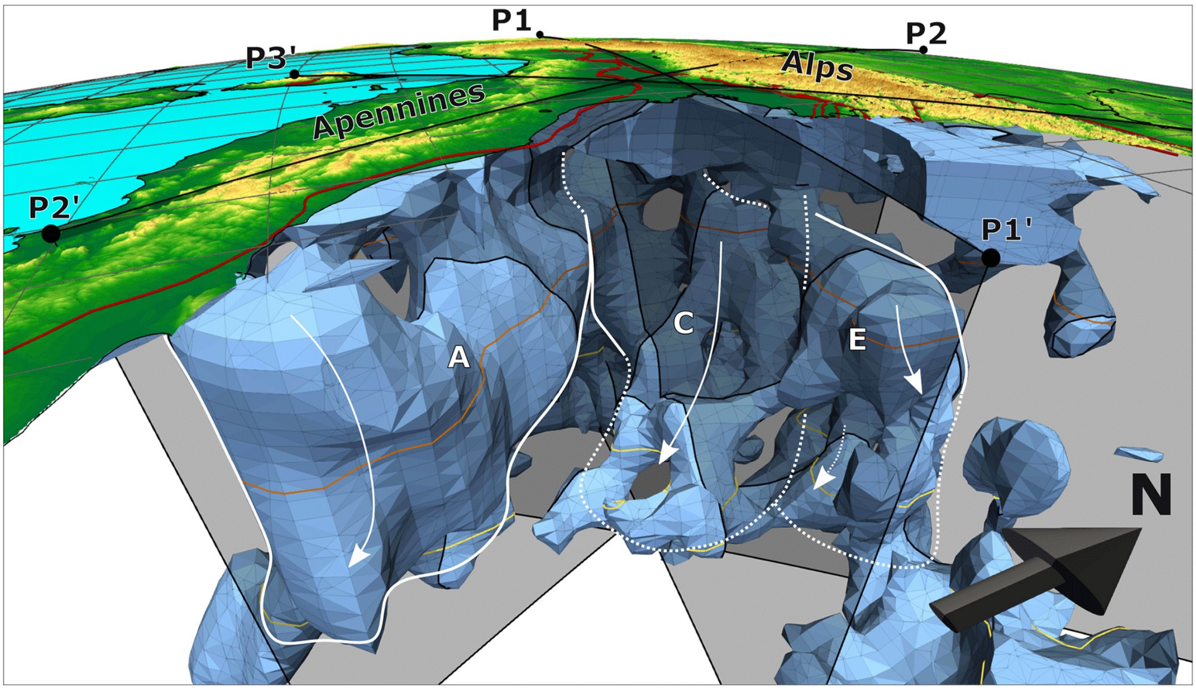

Figure 1: Paffrath et al. (2021b), Fig. 17

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