Advances in imaging the Alpine crust and mantle

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The dense coverage of the AlpArray Seismic Network and related targeted arrays (LOBSTER, Swath D, EASI) has led to numerous new models of the Alpine orogenic lithosphere, slabs and mantle above the Mantle Transition Zone. We highlight some novel features of these models, how they may help to answer old questions, as well as pose new questions:

(1) P-wave images from teleseismic travel-time tomography (Paffrath et al., 2021a,b; Handy et al., 2021) use an innovative approach to include the highly heterogeneous Alpine orogenic crust in their model. In addition to confirming previous models for partial slab detachment beneath the Western Alps, they find evidence for a long (≥300 km), subvertical slab anomaly underneath the Eastern Alps that is detached from the orogenic lithosphere at 70-150 km depth. The latter corroborates images from surface-wave tomographic studies (Kaestle et al., 2018), but contrasts with other past- and present images indicating deeper slab detachment (Handy et al., 2015) and/or a through-going connection of the slab with Adriatic lithosphere (e.g., Plomerová et al., 2022). Cooperation of the Bochum and Prague groups to explain these disparate features reveal that crucial features, e.g., the connection of slabs with the orogenic lithosphere, depends strongly the geometry of the model area and the chosen crustal model.

(2) New receiver function (RF) studies extracted signals in the Eastern Alps where previous work only imaged a 'Moho gap' (Hetényi et al., 2018; Kind et al., 2021; Mroczek et al., 2023, Michailos et al., 2023). These studies confirm the notion of marked, along-strike variations in structure: in the west (TRANSALP, 11.9°E), the European Moho is clearly down-going (e.g., Kummerow et al., 2004), whereas in the east (14°E), competing interpretations range between an underlying Adriatic Moho (Hetényi et al., 2018) and a downgoing European interface to more than 100 km depth (Mroczek et al., 2023). All methods indicate that the upper-plate Moho shallows from the E. Alps to the Pannonian Basin.

(3) The internal structure of the Eastern Alpine crust is imaged with local earthquake (Jozi Najafabadi et al., 2021) and ambient noise tomography (Molinari et al., 2020; Qorbani et al., 2020; Sadeghi-Bagherabadi et al., 2021; Kästle et al., this vol.). The LET models show a bulge-shaped fast anomaly just to the south of the western Tauern window, possibly indicating stacking of lower crustal nappes, probably of both European and Adriatic affinity (McPhee et al., this vol.), and a fast anomaly east of the Giudicarie Fault that may be related to a Permian magmatic body, as also indicated by gravity studies (Spooner et al., 2021).

(4) AlpArray has opened the door to study crustal and mantle anisotropy in unprecedented detail (Kästle et al., 2022; Soergl et al., 2022; Kästle et al., this vol.). SKS studies (e.g., Hein et al., 2021) suggest that mantle flows around slabs and potentially through slab tears, in the Western and Eastern Alps. Newest results indicate that crustal anisotropy in the Eastern Alps is layered, with an upper layer with fast directions oriented mainly orogen-parallel, approximately following major Neogene oblique-slip faults exposed at the surface. The studies also show a clear distinction between the fast-axis orientations within the Alps and in its foreland. The latter results are in excellent agreement with findings from SKS studies, indicating similar dynamics affecting the entire lithosphere. The detailed analysis of Swath-D data conducted by Link et al. (2021) has further been able to show a sharp transition in SKS splitting orientations at around 13° longitude, that is indicative of the separate evolution of central and eastern Alps.

(5) Preliminary results from the joint inversion of surface- and body-wave data provide a better understanding of the different sensitivities of P- and S-waves to the upper mantle structures under the Alps. Initial results of a P-wave velocity model from teleseismic full-waveform inversion (FWI, Friederich et al., this vol.) provide surprisingly high resolution in the crust and uppermost mantle with clear images of the Alpine orogenic roots and anomalies within the crust (e.g., Ivrea Body, E. Alps lower crustal bulge). The resulting FWI model is independent of any crustal correction and may provide a vital contribution to ongoing discussions on slab origin and detachment.

Taken together, the diversity of seismological images in the same area with often contrasting tectonic implications underscores the need for serious benchmarking of seismological models. Large arrays like AlpArray provide an excellent opportunity to conduct such comparative studies.

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