Applying scattered wave tomography and joint inversion of high density (SWATH D) geophysical and petrophysical datasets to unravel Eastern Alpine crustal structure

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This project harnesses the high density of seismic stations in AlpArray and the AlpArray complementary experiment SWATH D to significantly improve the resolution and reliability of the subsurface models by enabling the use of many different inversion methods to obtain and integrate the different results. These advanced models are vital for resolving the complex Alpine plate configuration and understanding how the crustal structure seen today reflects the dramatic changes in mountain building style and reorganisation of plate boundaries at about 20 Ma. We employ the joint inversion of seismological and petrophysical data sets in order to understand the intra-crustal structure, temperature, and petrophysical properties of crustal layers by inverting seismic data directly for the crust's constituent mineral assemblages. Teleseismic full waveform inversion (FWI) provides a powerful tool for illuminating both the crustal and, complementing the joint inversion, intra-crustal structure. In our application of FWI, we increase the frequency content with the progression of the inversion.

To perform FWI with teleseismic data at low frequencies, we couple the 1D code Gemini (Friederich and Dalkolmo, 1995) with the 3D code SPECFEM3D Cartesian for forward modelling and use the FWI code ASKI (Schumacher and Friederich, 2016) for computing waveform sensitivity kernels and performing the inversion. At higher frequencies we opt for a ray theory-based approach rather than full waveform modelling due to its high computational cost. We calculate high frequency P-phase synthetic seismograms by coupling various codes to obtain travel times, amplitudes and source time functions. ObsPy TauP, a 1D code, is used to determine travel times and ray paths in the bulk earth, while FM3D (de Kool et al., 2006), a 3D code, is employed in the study area. Subsequently, the ray paths are used to calculate amplitudes via dynamic ray tracing. Source time functions are obtained by fitting the recorded data. We intend to use the P-phase synthetic seismograms within the framework of ASKI to compute waveform sensitivity kernels. Subsequent inversion with these kernels could improve the resolution of the resulting models.

First results of FWI at low frequencies up to 0.1 Hz (using the coupled Gemini-SPECFEM3D code for forward modelling) demonstrate a good agreement with the P-wave velocity models obtained from teleseismic travel time tomography by Paffrath et al. (2021) as part of the first phase of the SPP. Though derived from Fourier-transformed waveform data and currently only 24 events, the FWI model reduces the variance of the P-wave travel time residuals data set by 60 percent. Moreover, the FWI models exhibit surprisingly high resolution in the crust and uppermost mantle with a superb image of the Alpine and Apennine orogenic root and the Ivrea body probably by virtue of the presence of reflected and converted P- and S-phases in the considered time windows.

Receiver functions and surface wave dispersion curves, calculated in partner projects, are usually jointly inverted for elastic properties. By utilising the strengths of Markov Chain Monte Carlo inversion, we are able to instead parameterise our model by temperature and mineral assemblage. This allows the introduction of geological-mineralogical constraints, in a probabilistic self-consistent manner, to the inversion. A further significant advantage is in interpretation where the probabilities of certain lithologies being present allows for a more seamless integration of qualitative geological data and a reduction in interpretation biases present when only seismic velocities are presented.

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