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 the AlpArray complementary experiment SWATH D, conducted during the first phase of SPP 2017 "Mountain Building Processes in 4D", and also incorporates the wide transects EASI and the older TRANSALP transect, in order to understand how the crustal structure seen today reflects the dramatic changes in mountain building style and reorganisation of plate boundaries at about 20 Ma. Uniform SE-directed subduction of European lithosphere during the Paleogene gave way to a more complex system involving not only the (partial) continuation of European subduction but the onset of Adriatic subduction below the Carpathians, the Apennines, and possibly the Alps. On the surface this revolution was reflected by laterally migrating subsidence patterns and infill in foreland basins as well as the development of different styles of accommodating shortening across the orogen. Within the crust, these changes must be accommodated by large scale decoupling horizons, but their geometry and relation to the structures seen at the surface, and even whether they are inside the crust or at the Moho, is disputed and probably differs laterally along the strike of the orogen. A still unresolved question concerns the existence of a possible polarity flip in the sense of subduction between the Central and Eastern Alps. If part of the continental crust is subducted, then a characteristic jump in the Moho is expected.

We directly address Theme 1: Reorganisations of the lithosphere during mountain building with a clear focus on mapping the possible reorganisations within the crust and of the topography of the Moho. We address Theme 2: Surface and crustal responses indirectly by constraining the different scenarios of crustal evolution that could have led to the current structure, and thereby providing a guide to those groups studying processes directly observable at the surface. By including experts in both seismological analysis as well as Alpine geology and petrophysics of the continental crust, we aim to go beyond merely delivering images of seismic properties by associating lithology. This proposal is part of a group of proposals with complementary goals and approaches devoted to understanding the Neogene Orogenic Revolution of the Alps.

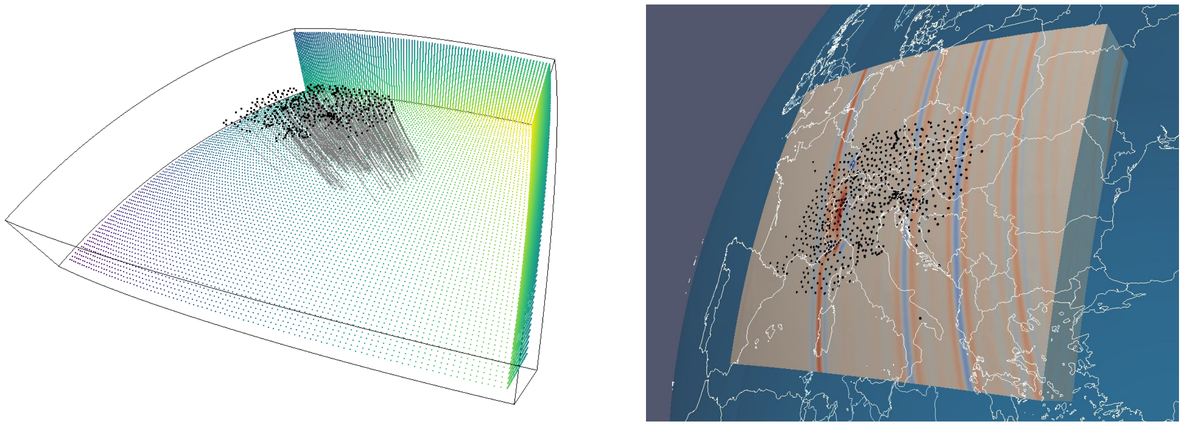

Figure 1: Subdivision of the entire earth model into a subvolume beneath the greater Alpine region and the rest of the Earth. Incident wavefronts and wavefields are continued into the Alpine subvolume based on values and derivatives on its boundary.

WP1: Scattered wave tomography Building on the SPP phase 1 project "Imaging structure and geometry of Alpine slabs by full waveform inversion of teleseismic body waves", synthetic seismograms, using the most up to date velocity/structural models, for teleseismic events will be computed with a hybrid approach with an Alpine crustal model embedded in a full earth model (Figure 1). At lower frequencies full waveform modelling will be carried out in the crust while at high frequencies a ray based method will be used. Beginning at low frequency, residual seismograms will be calculated and then inverted for small scale crustal structures and the model updated. We will update the residual seismograms using the updated background model before increasing the upper frequency limit. This procedure will result in a sequence of crustal models with increasing spatial resolution. The model parameters, expressed in perturbations of density, P-wave velocity, and S-wave velocity, can be used in conjunction with the petrophysical, mineralogical, and lithological properties, established in WP2, to gain additional evidence about the nature and cause of small-scale heterogeneities in the Eastern Alpine crust.

WP2: Joint inversion using mineralogical and geological constraints The goal of this work package is to bring together the seismological and geological-mineralogical constraints in a probabilistic self-consistent way. Receiver functions (calculated in the phase 1 project “Understanding subduction by linking surface exposures of subducted and exhumed crust to geophysical images of slabs”) and the dispersion of surface waves will be jointly inverted using Monte Carlo Markov Chains (Figure 2). Normally these are inverted for elastic properties however we will extend the algorithm to include the plausibility of resulting lithologies into the model assessment. This could either be achieved by including a range of elastic properties as priors into the Bayesian model assessment or by parameterising the model in terms of lithology and structures (instead of elastic properties). Existing geological observations in the region can therefore be used to limit what range of lithology and tectonic structures that will be permissible (i.e. have a reasonable a priori probability in the McMC search).

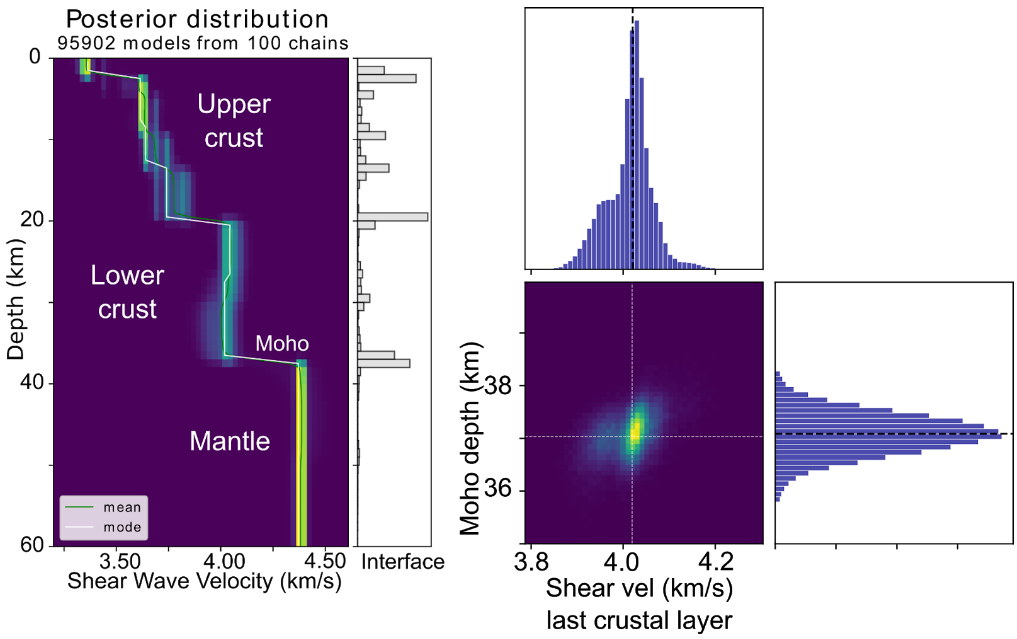

Figure 2: Result of an example output from a probabilistic joint inversion of surface waves and receiver functions, here for a station in Sri Lanka. (a) The heat map on the left shows the posterior distribution of velocities, with the adjacent vertical histogram indicating the relative frequency of discontinuities in the velocity model. (b) It is not only possible to extract the posterior distribution for parameters such as the Moho depth and lower crustal shear velocity, but also to explore the correlations in the posterior distribution (Dreiling & Tilmann, 2019)

Publications

Dreiling, J., Tilmann, F. (2019): BayHunter - McMC transdimensional Bayesian inversion of receiver functions and surface wave dispersion., GFZ Data Services : Potsdam http://doi.org/10.5880/GFZ.2.4.2019.001