Understanding subduction by linking surface exposures of subducted and exhumed crust to geophysical images of slabs

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One of the prime goals of 4D-MB is to link surface geological observations to the deep structure of the Alps. The deep structure will be imaged in 3D in unprecedented detail by the densely spaced AlpArray seismic network and further densified associated deployments (SWATH D). A geological interpretation of these images, however, will only be possible on the basis of a plausible model of the rock types and structures causing the seismic observations.

From seismic data and plate-tectonic reconstructions, we can expect to find subducted continental crust currently beneath the Alps. On the small scale, the seismic properties of these subducted rocks depend on (a) changing mineral assemblages as a function of pressure, temperature and fluid availability conditions, and (b) the evolving rock fabric induced by deformation (e.g., mylonitic shearing causing anisotropy). On a larger scale, the pattern of changing seismic velocities is therefore determined by the distribution of high- and low-strain domains and/or lithological changes in the crustal basement. Quantifying seismic properties requires accessible analogues of presently subducted crust, which can be found in high-pressure (HP) and ultrahigh-pressure (UHP) basement rocks now exposed at the surface. In order to address the prime goal of 4D-MB, we aim to link the tectonometamorphic evolution of these (U)HP units to their changing seismic properties.

Work package 1 (**WP1**, doctoral student **Philip Groß**) will focus on the kinematic and thermo-barometric evolution of subducting continental crust, using the Modereck Nappe system (Eastern Alps) as a prime example. WP1 will conduct a combined field, laboratory and modelling study to understand how different end-member-type crustal-scale geometries (Fig. 1) are governed by the evolution of continental subduction. This will involve petrological-geothermobarometric investigations targeting fabric domains that can be attributed to regional deformation phases as well as thermodynamical modelling of phase diagrams. The resulting P and T during individual deformation phases will serve as input for GIS-supported 4D kinematic modelling of the fold. 2D and 3D numerical simulations will be performed and checked against the 4D kinematic model to explore the formation of crustal-scale sheath folds during subduction processes such as reconstructed generically in WP2 and possibly imaged along the Alpine slabs in WP3.

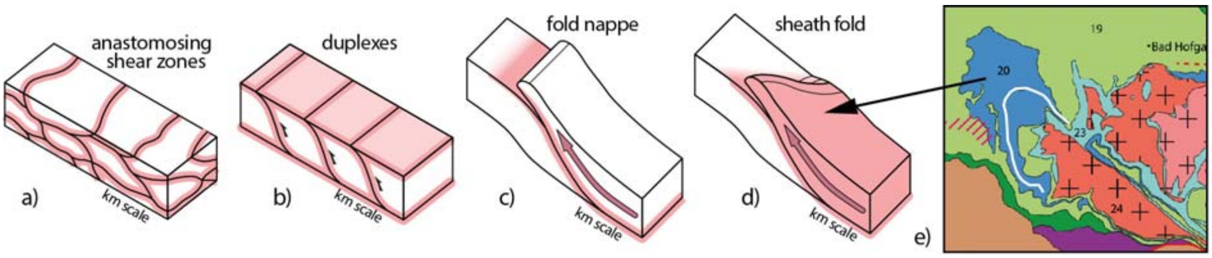

Fig. 1: Sketch of end-member crustal-scale struc-tures (shear zones in red). (a) duplex with shear zones; (b) anastomosing shear zones; (c) cylindrical fold nappe; (d) sheath fold formed by passive amplication of curved fold; (e) Seidlwinkel sheath fold with strongly curved fold hinge (see Fig. 2 for map location).

WP2 (doctoral student **Sascha Zertani**) aims to characterise the seismic properties of crystalline continental crustal (U)HP rocks with the ultimate goal of constructing composite cross section(s) of subducting continental crust that can be used as analogues for the current slabs beneath the Alps. This requires a combination of field work (Fig. 2), lab measurements, and thermodynamic modelling to extract and derive rock physical characteristics such as seismic velocities, temperature and pressure derivatives, density as well as anisotropies at various scales. Together with the structural-kinematic information obtained in WP1, this can be used to construct plausible models for the seismic visibility (synthetic seismic images) of subducting crust in close collaboration with WP3.

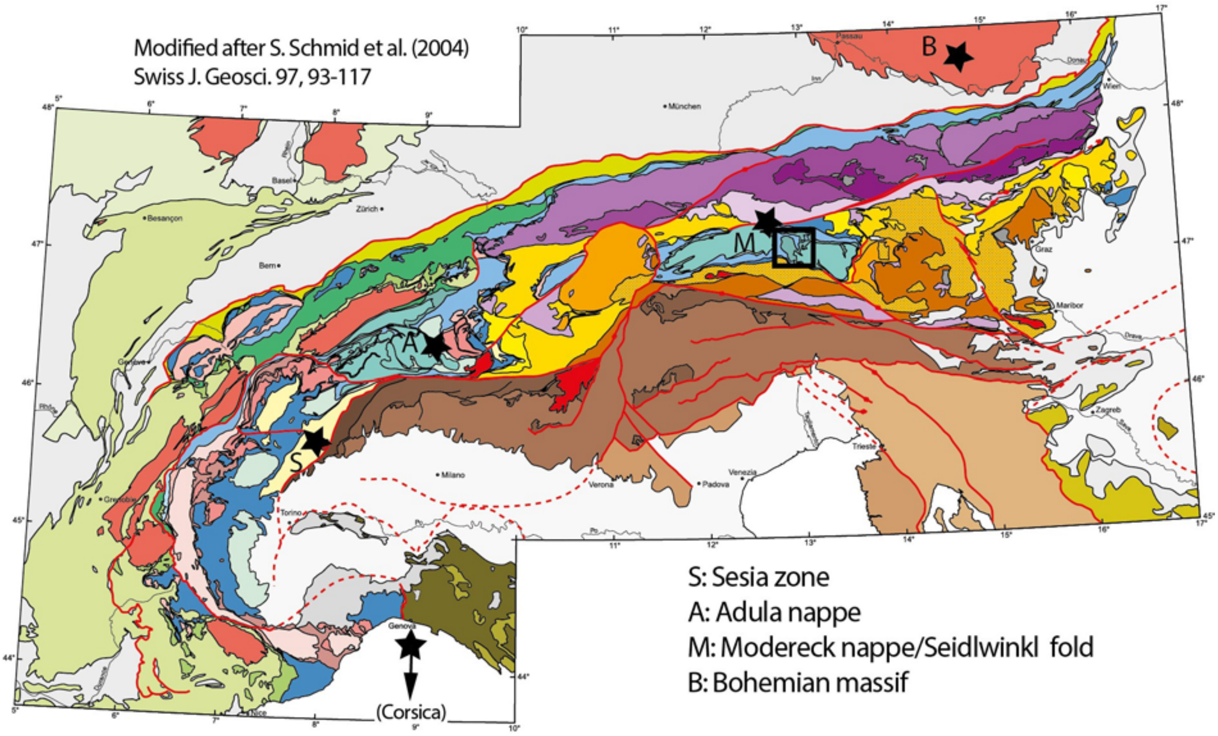

Fig. 2: Tectonic map of the Alps with main study and sampling areas (black stars).

WP3 (doctoral student **Stefan Mroczek**) will construct images (see Fig. 3 for a non-Alpine example) of the subducting crust and the crustal structure below the Eastern Alps from the high-density SWATH D deployment based on converted and reflected teleseismic waves, and local earthquakes if available. We will use established receiver function techniques but also develop and adopt methodologies to make use of the dense array geometry to remove the source signature and enhance the image quality, e.g. by detecting and using out-of-plane arrival directions of converted waves and by stacking redundant data. Wide-angle reflected phases will also be utilised, provided suitable local and regional earthquakes can be identified. We will initially work on developing and adapting imaging algorithms to the swath geometry, then analyse the swath data. In parallel, in close cooperation with WP2, synthetic images will be generated based on whole-crust models with realistic geometries and properties generated by the other WPs.

With this interdisciplinary approach we aim to decipher the state of continental crust currently at U(HP) depth. We especially want to understand how nappe formation and fluid-rock interaction lead to changes in mineral assemblages, which in turn determine the seismic visibility of the deforming and subducting crust. By tackling this question from three different angles, namely the kinematic, petrophysical and seismological views, the project is designed to explore the feasibility, but also the limitations, of resolving crustal-scale structures at mantle depth by seismic methods. It opens the perspective of providing a solid quantitative connection between the geological observations and rock samples collected at the surface to the geophysical images of the deeper structures in the quest to reconstruct the deformation history of the Alpine orogen.

a) b)

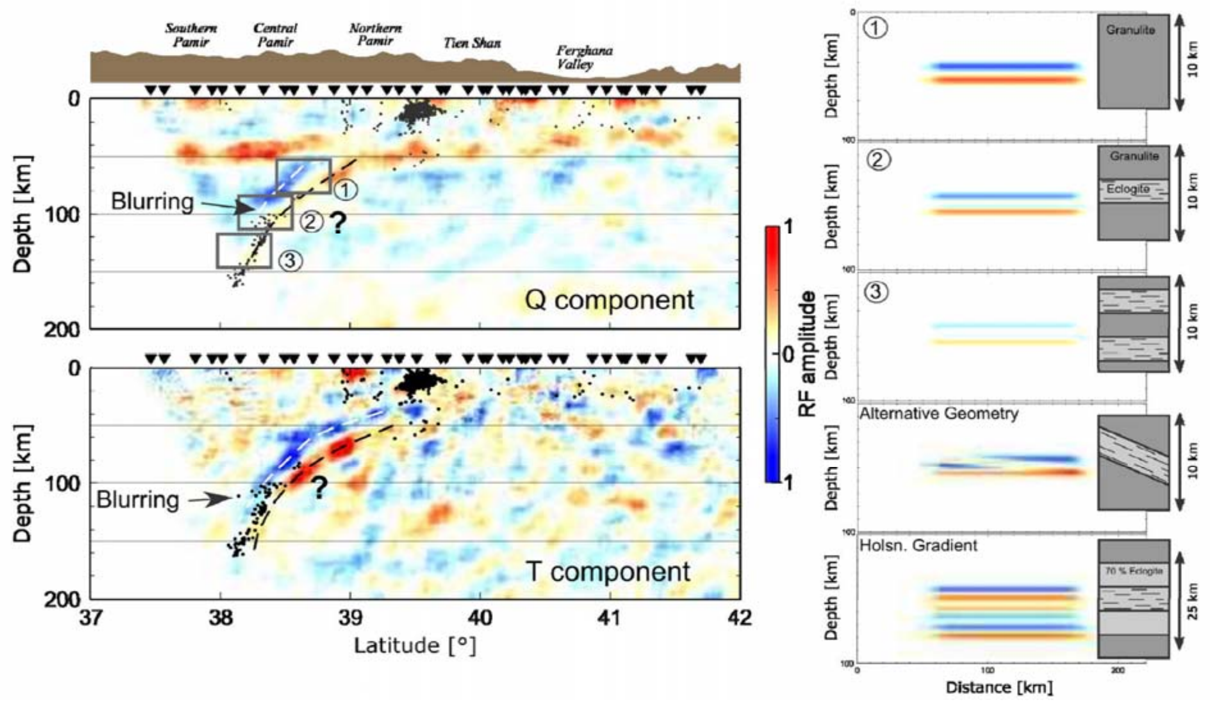

Fig. 3: (a) Cross section through common-conversion-point images for Q (SV) and T (SH) component receiver functions below the Pamirs shows clearly subducted lower continental crust (blue and red bands mark velocity contrasts at top and bottom of subducted crust - after Schneider et al. 2013, Eart Planet. Sci. Letters 375, 101-112). Below about 100 km these bands become poorly defined, 'blurry'. Earthquakes occur within subducted crust below 100 km (black circles). (b) Preliminary synthetic models for Q component for a 10 km thick crustal sliver, with increasing number of eclogitised layers (1-3) showing an increasingly weak conversion at the top of crust (if superimposed on a noisy background in real data, this would appear as 'blurring' or complete disappearance and could explain the pattern seen in the Pamirs but the possibility of imaging artifacts would need to be rigorously tested. The last panel shows a similar fraction of eclogite as panel 2, but as an inclined zone, resulting in a visibly different pattern.

Within the SSPP, we will collaborate with:

Froitzheim, N. & Keppler, R. (Univ. Bonn), SPP Projekt *Slab factory – ocean formation and subduction in the Western Alps*

Keppler, R. (Univ. Bonn) et al., SPP Projekt *Alpine subduction revisited – new structural and elastic wave velocity models for improved geophysical imaging towards greater depth*

Kummerow, J. (FU Berlin) et al., SPP Projekt *From Top to Bottom – Seismicity, Motion Patterns & Stress Distribution in the Alpine Crust*

Schmeling, H. & Rümpker, G. (Univ. Frankfurt), SPP Projekt *Mantle deformation beneath the Alps and the physics of the subduction polarity switch - Constraints from thermomechanical modelling, seismic anisotropy and waveform modelling*

Other collaborators : Prof Dr. G. Hetenyi (Univ. Lausanne), Prof. W. Kurz (Univ. Graz), Dr. R. Schuster (Geologische Bundesanstalt, Wien), Prof. Frank Wuttke (Univ. Kiel)