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

PIs: Jan Pleuger[1], Timm John[1], Frederik Tilmann[1,2], Xiaohui Yuan[2], Boris Kaus[3], Mark R. Handy[1], James Mechie[2]

Doctoral students: Philip Groß[1], Sascha Zertani[1], Stefan Mroczek[1,2]

[1] FU Berlin, [2] GFZ Potsdam, [3] JGU Mainz

<u>Bullet points:</u>

- Tectonic nappes may form as highly non-cylindrical structures at depths corresponding to high-pressure metamorphic conditions; where the upper plate is sufficiently thick, they form as nappe folds
- In lower continental crust, the seismic velocity contrast between granulite and eclogite is sufficient for seismic imaging; the transitions are, however, gradual, i.e., no sharp boundaries; the thickness of individual shear zones is limited and we thus need better constraints of how such structural associations behave as an effective medium in order to compare to seismological studies (see slide 2 in Appendix)
- A preliminary receiver function migration image along 13 ° East appears to show a subducted European Moho beneath the Adriatic Moho (similar to TRANSALP). The migration contains receiver functions from both SWATH-D stations and stations from the (completed) EASI experiment (see slide 3 in Appendix)

We use high-pressure (HP) and ultrahigh-pressure (UHP) continental basement rocks now exposed at the surface as analogues for rocks presently subducted below the Alps. We aim to link the tectono-metamorphic evolution of these (U)HP units to their changing seismic properties and to test whether or not typical crustal-scale structures (such as fold nappes) can be imaged by seismological methods. The project consists of three work packages (WPs): WP1 deals with the kinematics of nappes under high-pressure (HP) conditions in a relict subduction zone in the Eastern Alps, WP2 with the petrophysical properties (seismic wave velocities and their anisotropies) of typical deformed and undeformed crustal HP rocks, and WP3 with seismic imaging of the deep structure of the Eastern Alps in the area of SWATH D.

The main results of WP1 are: The Seidlwinkl nappe is a sheath fold nappe (Fig. 1) formed under HP conditions that affected the entire nappe. There is no marked difference between peak pressures (c. 2 GPa) in the Seidlwinkl nappe and the overlying part of the oceanic Glockner nappe. The contact between these units is a thrust. This kinematic observation is compatible with end-member models of nappe accretion and subduction (in a slab-top or orogenic wedge). However, to date, we are unable to explain how the HP rocks were exhumed from peak conditions. Peak temperatures were reached probably at different times and shortly after peak pressures in the Seidlwinkl nappe. The distribution of peak temperatures defines isotemperature contours that are folded by the Seidlwinkl fold so that an inverted temperature gradient was “frozen in” in the lower limb of the fold, suggesting that the Seidlwinkl nappe was cooled and exhumed rapidly after reaching its temperature peak. Given its dimensions of c. 10 km width and the post-Variscan age of the lithologies involved, the Seidlwinkl sheath fold probably nucleated on a rheological perturbation that developed during rifting of the European margin (e.g. an extensional allochthon) and was then amplified by largely passive folding. With the help of a student worker, the 3D thermo-mechanical code LaMEM (Kaus et al., 2016) was adapted and shown to be capable of recovering the original flat geometry of a folded layer for both power-law and diffusion-creep rheologies.

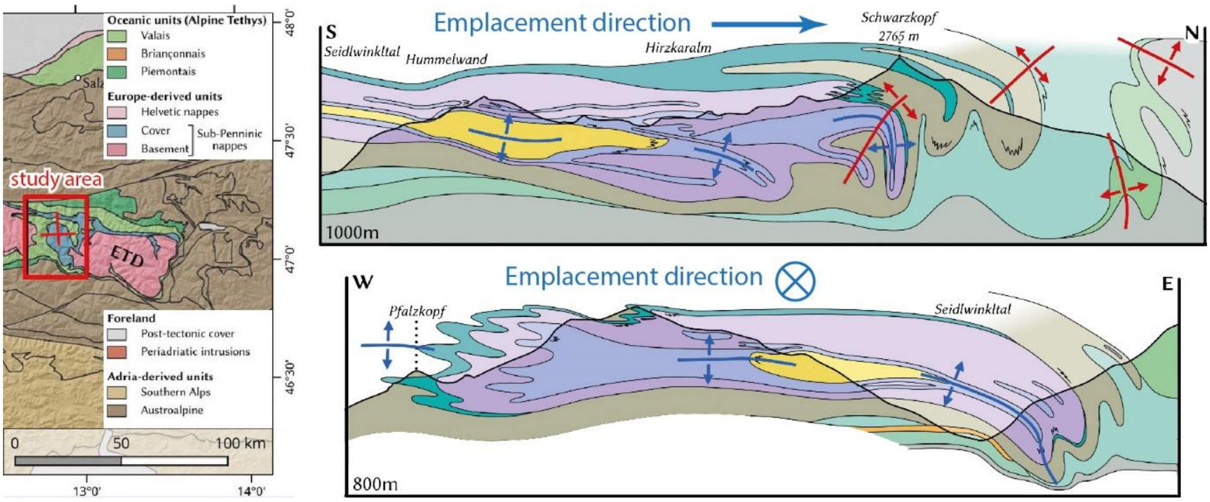

Figure 1: Study area (left) with traces of cross sections through the Seidlwinkl nappe. Cross sections parallel (top right) and perpendicular (bottom right) to the transport direction of the Seidwinkl fold nappe containing assemblages diagnostic of emplacement after the attainment of peak P conditions of up to 2 GPa. Dashed blue line marks the trace of the Seidlwinkl fold deforming the nappe contact.

In WP2, we found that the interplay of metamorphism and deformation of lower crustal rocks produces distinctive variations of the petrophysical properties. These are not only reflected by elevated seismic velocities, but also in distinct changes of seismic anisotropy and V_P/V_S-ratios. For example, eclogitization in combination with ductile deformation leads to increased seismic anisotropies (*Fig*. 2) and decreased V_P/V_S-ratios. Field work in the Tenda Massiv (Corsica) and the Sesia Zone (Western Alps) shows that Alpine deformation is heterogeneously distributed. Here, shear zones and low-strain domains should have distinctly different seismic properties. Analysis of these samples is currently in preparation.

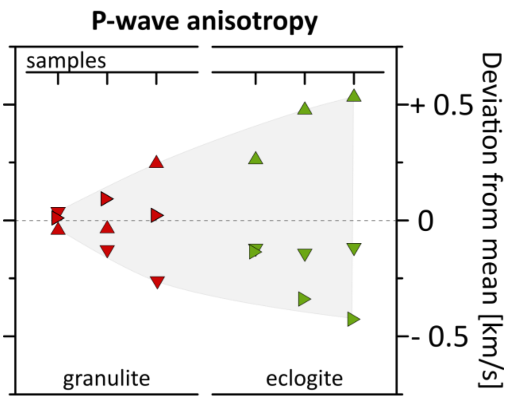

Figure 2: Plot showing P-wave velocity of three granulite samples (red) and three eclogite samples (green) obtained from laboratory measurements. The dashed grey line represents the mean P-wave velocity of each sample. Three values are plotted for each sample which represent the three P-wave propagation directions. The velocities are shown as absolute variations from the mean value. The underlying grey area illustrates the increase of P-wave anisotropy from the granulite to the eclogite.

A main achievement of WP3 is the successful ongoing data collection and maintenance of the SWATH D seismic network. In addition, the ambient noise autocorrelation method was tested on the AlpArray-EASI profile (located at the eastern end of SWATH D; Fig. 3, top) and a secondary transect including SWATH D stations. In many areas we were able to image the Moho and so constrained the crustal average P- to S-wave velocity ratios (Vp/Vs), as well as obtained information on the velocity contrast at the Moho and possibly intracrustal discontinuities. We further have calculated preliminary receiver functions (RF) for the partial dataset, and constructed common conversion point stacks (Fig 3, bottom). Based on these we have constructed a preliminary Moho maps, which are indicative of southward-directed subduction of European Moho. Along some profiles, the Adriatic and European Mohos appear to overlap with vertical offsets up to 20-30 km. Next steps are to carry out a 2D full waveform modelling with progressively more complex structures inspired by the results of WP1, and a refined processing of the RF with the full data set. As part of WP3, seismic wide-angle reflections from local earthquakes are being used to study deeper crustal and Moho structure beneath SWATH D. To date, some local earthquakes to the north of SWATH D have been identified that show relatively prominent wide-angle reflections from the Moho. Presently, analysis is focusing on modelling the structure of the Moho around the region of the Moho trough at the transition from the Eastern to Southern Alps.

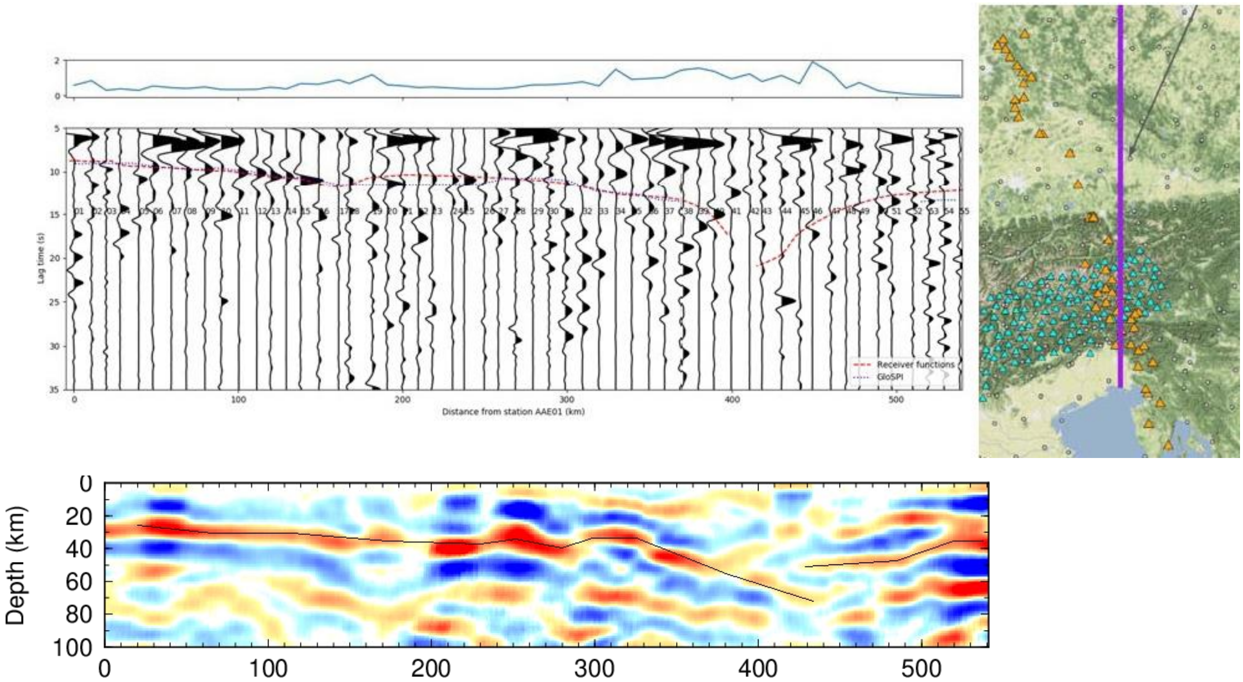

Figure 3: (top) Cross section of vertical auto-correlation function along EASI profile (purple line in map). The dashed lines mark out other results of other analysis methods carried out by the EASI team. There is good agreement in the foreland, allowing a deduction of the Vp/Vs ratio by joint analysis. No clear Moho is imaged below the southern Alps. (bottom) Preliminary receiver function common conversion point stack for partial Swath-D (+EASI) data – note that data acquisition of the Swath-D stations is ongoing. (North is to the left of both profiles). Note the offset between Adriatic and European Moho at ~430 km.

<u>Conference Presentations:</u>

Groß, P., Pleuger, J., Handy, M. & John, T. (2018): Internal structure and evolution of the Penninic subduction channel of the Tauern Window, Eastern Alps. European Geosciences Union General Assembly 8.-13.4.2018, Geophysical Research Abstracts, Vol. 20, EGU2018-8758.

Groß, P., Pleuger, J., Handy, M. & John, T. (2019): Crustal-scale sheath folding at HP conditions in an exhumed Alpine subduction zone (Tauern Window, Eastern Alps). European Geosciences Union General Assembly 7.-12.4.2019, Geophysical Research Abstracts, Vol. 21, EGU2019-5497.

Mroczek, S. & Tilmann, F., (2019) Mapping the Moho with ambient noise autocorrelations: A N-S profile across the Bohemian Massif and Eastern Alps (EASI) European Geosciences Union General Assembly 7.-12.4.2019, Geophysical Research Abstracts, Vol. 21, EGU2019-16092

Zertani, S., John, T., Vrijmoed, J. C., Tilmann, F., Labrousse, L., and Andersen, T. B. (2019) The variation of petrophysical properties during eclogitization of lower continental crust and their influence on geophysical imaging. European Geosciences Union General Assembly 7.-12.4.2019, Geophysical Research Abstracts, Vol. 21, EGU2019-15813

Groß, P., Pleuger, J., Handy, M. & John, T. (2019): Variations in the 3D temperature field in a fossil subduction zone resolved by RSCM thermometry (Tauern Window). 14th Alpine Workshop, Sion, Switzerland, 4.9.-6.9.2019, Abstract volume.

In review:

Zertani, S., John, T., Tilmann, F., Motra, H. B., Keppler, R. Andersen, T. B. & Labrousse, L. (2019) Modification of the seismic properties of subducting continental crust by eclogitization and deformation processes, submitted to J. Geophys. Res.