Alpine subduction revisited - new structural and elastic wave velocity models for improved geophysical imaging towards greater depths

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The goal of this study is to constrain deeper structures within the Alps by providing data on elastic properties of different crustal units, which can be used as input parameters in seismic models. A large sample set was collected in different areas within the Central and Western Alps providing sample lithologies representative of lower crust, as well as oceanic and continental upper crust. Bulk crystallographic preferred orientations (CPO) of these rocks were measured using time-of-flight neutron diffraction and used to calculate seismic anisotropies. Furthermore, ultrasonic measurements in a triaxial press were performed at pressures of up to 600 MPa to determine experimental elastic anisotropies of the same samples.

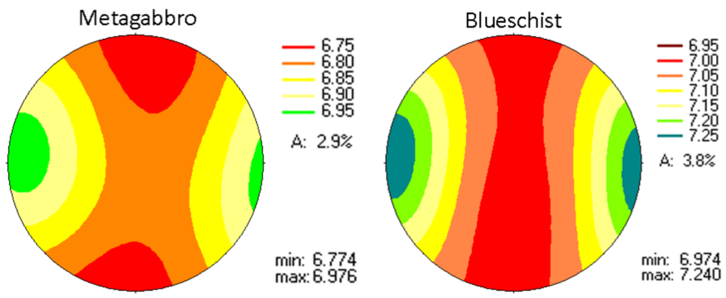

Fig. 1: P-wave velocities in km/sec of a lower crustal and an oceanic rock; A: Anisotropy.

Rocks collected in the Zermatt-Saas zone are blueschists and eclogites. They represent subducted oceanic crust currently found at depth within the Alps. Samples collected in the Ivrea Zone are metagabbros and felsic granulites representing lower crust. Samples representative of upper crustal rocks deformed during the Alpine Orogeny were collected in the Adula Nappe and comprise metasediments and orthogneisses.

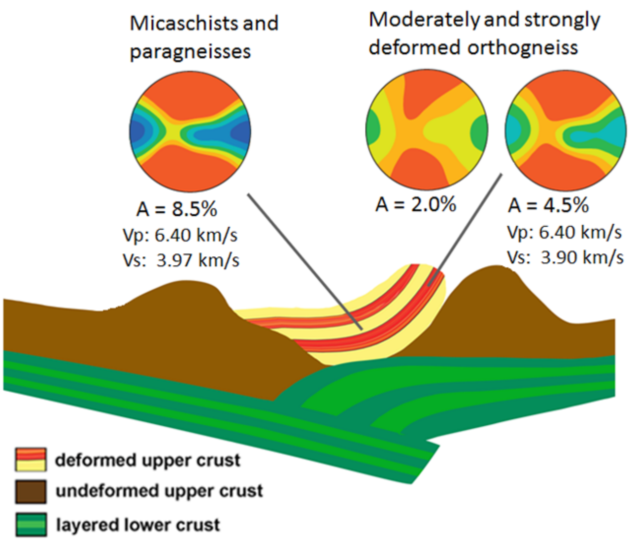

Fig. 2: Simplified tectonic structure of the Alps. Average elastic anisotropy patterns of typical upper crustal rocks are illustrated; A = elastic anisotropy; Vp = P-wave velocity; Vs = average S-wave velocity.

P-wave anisotropies of oceanic crustal rocks are 1- 4 % and mostly determined by CPO of omphacite, glaucophane and hornblende. They show highest velocities aligned in lineation direction. P-wave anisotropies of mafic lower crust are about 3 %, while felsic lower crust yields values below 1%. The mafic rocks are also strongly influenced by CPO of pyroxene and amphibole, hence exhibit high velocities within the lineation direction (Fig. 1).

Determining representative elastic anisotropies for the upper crust is more complicated, since the upper crust within the Alps is strongly heterogeneous, both in lithology and grade of deformation (Fig. 2). We therefore investigated the high- to ultra-high pressure Adula Nappe in the eastern Central Alps. We have produced a texture data set of about 50 samples of deformed gneisses and schists. These textures were all acquired during exhumation of the nappe from the subduction zone. Microstructural and strain analysis using the Fry-method in orthogneisses additionally constrain the deformation of these rocks. This dataset of unprecedented resolution shows that the nappe experienced complex flow during exhumation, associated with extrusion of a strongly non-cylindrical body into the surrounding, less deeply subducted rocks.

Samples within this study area are representative of deformed upper crust of the Central Alps, which is found north of the Insubric Line. Average anisotropies were calculated from representative CPO of metasediments and of both strongly and weakly deformed orthogneisses yielding 8.5%, 4.5% and 2.5% for P-wave anisotropies, respectively (Fig. 2). They are influenced by both mica and quartz CPO and show a stronger distribution of high velocities within the foliation plane compared to the basic rocks. However, maxima for P-wave velocities are also mostly aligned in lineation direction.

The ultrasonic measurements of the same samples show similar patterns concerning the distribution of maxima and minima of P-wave velocities. The experimental elastic anisotropies, however, are 3 - 8 times higher than the calculated ones. This shows the strong influence of microcracks at lower depths. The microcracks are frequently parallel to mica basal planes, which in turn are mostly aligned in the foliation plane causing lower P-wave velocities normal to the foliation plane.

The results of this study will be implemented by our cooperation partners within the SPP and used for interpretation of seismic data.

Publication list:

Conference abstracts:

Keppler, R., Stipp, M., Froitzheim, N., 2017. Microstructures and crystallographic preferred orientations from the exhumation of the high-pressure Adula Nappe (Switzerland). DRT 2017, Inverness, UK.

Keppler, R., Stipp, M., Kossak-Glowczewski, J., Froitzheim, N., 2017. Subduction zone processes: Microstructural deformation during the exhumation of the high-pressure Adula Nappe (Switzerland). GeoBremen 2017.

Keppler, R., Stipp, M., Schmidtke, M., Kossak-Glowczewski, J., Froitzheim, N., 2018. Modeled average elastic anisotropies of upper and lower crustal units in the Alps using crystallographic preferred orientations of rocks of the Adula Nappe (Switzerland) and the Ivrea Zone (Italy). Talk at the GeoBonn 2018 (Bonn).

Kossak-Glowczewski, J., Froitzheim, N., Keppler, R., Leiss, B., Kuehn, R., 2017. Quartz texture analysis – a powerful tool for understanding complex tectonic processes of the Vals-Scaradra Shear Zone at the front of the Adula Nappe (Central Alps, Switzerland). Poster at the Conference for Condensed Matter Research at the IBR-2, Dubna, Russia.

Kossak-Glowczewski, J., Froitzheim, N., Keppler, R., 2018. Quartz textures related to exhumation of subducted continental crust: The northern range of the Vals-Scaradra Shear Zone at the front of the Adula Nappe (Central Alps, Switzerland) preliminary results. Poster at the GeoBonn 2018 (Bonn).

Schmidtke, M., Keppler, R., Stipp, M., Frotzheim, N., 2018. Determining elastic properties of rocks for a representative cross section through the Western Alps. Talk at the GeoBonn 2018 (Bonn).

Schmidtke, M., Keppler, R., Stipp, M., Frotzheim, N., 2018. Elastic anisotropies of rocks from oceanic and continental crust and the upper mantel. Poster at TSK 2018 (Jena).

Tasdemir, B., Keppler, R., Kossak-Glowczewski, J., Froitzheim, N., 2018. Strain analysis of the Zervreila Orthogneiss of the northern Adula Nappe, Central Alps, eastern Switzerland. Poster at GeoMünster 2019 (Münster).

Journal article:

Schmidtke, M., Keppler, R., Lutterotti, L., Kossak-Glowczewski, J. (submitted to Journal of Applied Crystallography). Processing time-of-flight neutron diffraction texture data of SKAT in MAUD using Rietveld texture analysis.