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Laboratory seismic anisotropy in mylonites

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Tectonic strain is often accommodated along narrow zones in the Earth's crust and upper mantle, and these high-strain zones represent an important mechanical and rheological component in geodynamics. In outcrop we observe the intense deformation along and across these structures. But at depth, in the mid and lower crust, and in the mantle, we are dependent on geophysical methods for analysis of structures, such as seismic reflection and refraction surveys. A natural progression has therefore been to understand the remote geophysical signal in terms of laboratory ultrasonic pulse transmission measurements on rock cores, collected in the field or from borehole drill core. Here we first present a brief review that consider key studies in the area of laboratory seismic measurements in strongly anisotropic rocks, ranging from calcite mylonites to metapelites. In the second part we focus attention on ongoing research projects targetting laboratory seismic anisotropy in mylonitized rocks, and associated challenges. Measurements of compressional (P) and shear (S) waves were made at high confining pressure (up to 5 kbar). Mineral texture analysis was performed with electron backscatter diffraction (EBSD) and neutron texture diffraction to determine crystallographic preferred orientation (CPO). So-called "rock-recipe" models are used to calculate seismic anisotropy, which consider the elastic properties of minerals that constitutes the rock, and their respective CPO. However, the outcome of such models do not always simply correspond to the measured seismic anisotropy. Differences are attributed to several factors, such as grain boundaries, mineral microstructures including shape-preferred orientation (SPO), micro-cracks and pores, and grain-scale stress-strain conditions. We highlight the combination of these factors in case studies on calcite and peridotite mylonites. In calcite mylonites, sampled in the Morcles nappe shear zone, the measured seismic anisotropy generally match the calculated seismic anisotropy. However, anisotropy may be reinforced by the contribution of grain-boundary effects and calcite SPO, as is indicated by microCT imaging and SEM analysis. This is evident in one case where the measured P wave anisotropy exceeded the calculated anisotropy by more than 5%, and by $\sim$4 % higher shear-wave splitting. An even greater discrepancy can be found when comparing measured and calculated seismic anisotropy in mylonitized peridotites from shear zones in the Lanzo (Italy) and Ronda (Spain) massifs. This is in part related to serpentinization of olivine, which remains a challenge for laboratory measurements of peridotites. Highest values of calculated anisotropy, for both the calcite and peridotite mylonites, are found in near monomineralic specimens (i.e. 8 - 10% P wave anisotropy). In comparison, polymineralic specimens have calculated P wave anisotropy ranging between <2 - 5%. In contrast, the laboratory measured seismic anisotropy do not display a simple relationship as a function of mono- versus polymineralic composition. Seismic properties and anisotropy are discussed in light of conditions and mechanisms of deformation, and the possible role and influence of second-phase minerals. Laboratory measurements offers a venue for exploring the relationship between deformation and seismic anisotropy. Such investigation may, in combination with high-resolution geophysical methods and increasingly sophisticated numerical models, yield further insight on remote active deformation in the mid and lower crust, and in the upper mantle.