Geophysical Research Abstracts
Vol. 16, EGU2014-10335, 2014
EGU General Assembly 2014

A numerical and experimental investigation on seismic anisotropy of Finero Peridotite, Ivrea-Verbano Zone, northern Italy

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We present a combined experimental and numerical study on Finero Peridotite to investigate the major factors creating its seismic anisotropy. We extrapolate the ultrasonic seismic wave velocity measured in a hydrostatic pressure vessel to 0 MPa and 250 MPa confining pressure to compare with numerical simulations at atmospheric pressure and to restore the velocity at in-situ lower crustal conditions, respectively. A linear relation between confining pressure and seismic velocity above 80 MPa reveals the intrinsic mechanical property of the bulk rock without the interference of cracks. To visualize the crystallographic preferred orientation (CPO) we use the electron backscatter diffraction (EBSD) method and create crystallographic orientation maps and pole figures. The first also reveals the shape preferred orientation (SPO). We found that very weak CPO but significant SPO exist in most of the peridotite. The Voigt and Reuss bounds as well as the Hill average (VRH) are calculated from EBSD data to visualize seismic velocity and to calculate anisotropy in the form of velocity pole figures.

We perform finite element (FE) simulations of wave propagation on the EBSD crystallographic orientation maps to calculate the effective wave velocity at different propagation angles, hence estimate the anisotropy numerically. In fracture-free models the FE simulation results agree well with the Hill average. In one case of a sample containing fractures the FE simulation yields similar minimal velocity as the laboratory measurement, which lies outside the VR bounds. This is a warning that care has to be taken when using VRH averages in fractured rocks.

All three velocity estimates (hydrostatic pressure vessel, VRH average, and FE simulation) result in equally weak seismic anisotropy. This is mainly the consequence of weak CPO. Although SPO is significantly stronger it has minor influence on anisotropy. Hydrous minerals influence the seismic anisotropy only when their modal composition is large enough to allow waves to propagate preferentially through them. Unlike hornblende, phlogopite is not proven to be a major source for the seismic anisotropy due to its small modal composition.

Seismic velocity is also influenced by the source frequency distribution. A lower-frequency source in the FE simulations results in lower effective velocity regardless of sample orientation. The frequency spectrum of the propagating wave is modified from source to receiver due to scattering at the mineral grains, thus leading to effective negative attenuation factors peaked at around 1–3 MHz depending on the source spectrum. However, compared with other factors, such as CPO, SPO, fractures, or hydrous mineral phases, the effect of the source frequency distribution is minor, but may be influential when extrapolated to seismic frequencies (Hz–kHz).

This study provides a comprehensive method combining laboratory measurements, EBSD data, and numerical simulations to estimate seismic anisotropy. Future work may focus on modeling the influence of different pore fluids or more complex fracture geometries on seismic velocity and anisotropy.

Acknowledgements
This work was supported by the Swiss National Science Foundation (project UPseis, 200021_143319).