Geophysical Research Abstracts
Vol. 19, EGU2017-1502-1, 2017
EGU General Assembly 2017

Anisotropic grain growth and modification of 'frozen texture' in the lithospheric mantle

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Seismic anisotropy is widely observed in both the lithospheric and asthenospheric upper mantle, and is mainly caused by flow-induced alignment of anisotropic olivine crystals. Crystallographic preferred orientation (CPO) in the asthenosphere is thought to reflect the dynamics of current mantle flow. In contrast, the lithosphere is relatively viscous, and, it is assumed that texture in the lithosphere retains a memory of past flow (e.g., lithospheric mantle in an oceanic basin preserves texture that originated from corner flow at the mid-oceanic-ridge). Although the viscosity of the lithosphere is high in comparison to the asthenosphere, temperatures are high enough that non-deformational, microstructural processes may still be significant for texture evolution. Here we use an experimental approach to simulate a textured mantle annealed under high temperature, high pressure, and hydrostatic conditions, in order to investigate whether microstructural evolution due to static annealing could modify texture in the lithospheric mantle.
Starting material for the experiments was a synthetic Fo50 olivine aggregate that was previously deformed in torsion (Hansen et al., 2016) to shear strains up to $\sim$10. The sample has a mean grain-size of $\sim$15 microns and a narrow, unimodal grain-size distribution, high dislocation-densities, and exhibits a strong A-type CPO. Sub-samples of the deformed specimen were annealed under hydrostatic conditions using a piston cylinder apparatus at T = 1250º C, P = 1 GPa for up to one week. After annealing, the samples were cut into thin sections and the crystal orientations were measured by electron backscatter diffraction (EBSD). The samples show clear evidence for abnormal grain growth due to annealing (with maximum grain sizes of $\sim$1 mm). The abnormally large grains grew at the expense of the smaller matrix grains, and grain-size distributions became distinctly bimodal. The small grains not consumed by abnormal grain growth have similar CPO strength, symmetry, and orientation compared with the starting material's CPO. The orientation of the abnormally large grains is typically 10–30 degrees away from the original CPO on the X-Z plane. This observation is consistent with predictions that abnormal grain growth favors grains with low initial Schmid factors. Seismic anisotropy of both deformed and annealed mantle layers were calculated and compared. We conclude that reorientation and weakening of olivine CPO is expected during periods of tectonic quiescence, which will modify the anisotropic signature imposed during the primary deformation event.

Hansen, L.N., Warren, J.M., Zimmerman, M.E., Kohlstedt, D.L., 2016. Viscous anisotropy of textured olivine aggregates, Part 1: Measurement of the magnitude and evolution of anisotropy. Earth and Planetary Science Letters 445, 92-103.