Deformation Microstructures in Lower Mantle Assemblages

H. Marquardt[1], S. Speziale[1], L. Morales[1] and H.-P. Liermann[2]

[1]*Deutsches Geoforschungszentrum, Telegrafenberg, 14473 Potsdam, Germany*
[2]*PETRA III, DESY, Notkestrasse 85, 22607 Hamburg, Germany*

Seismic anisotropy observations at the boundary layers within the lower mantle are likely caused by the result of substantial deformation due to mantle flow, thus mirroring similar observations in the Earth crust that are indicative of regions where significant deformation has taken place. Mantle flow-related deformation can induce anisotropy at the microscopic level (crystallographic preferred orientation, CPO) as well as at the macroscopic scale (shape preferred orientation, SPO) in lower mantle materials. Both can, in principle, lead to an observable seismic anisotropy. There are indications that strain partitions into ferropericlase when a lower mantle assemblage of perovskite and ferropericlase is deformed leading to strong grain elongation within the perovskite matrix [1-3].

Our numerical modeling shows that SPO in an assemblage of disc-shaped ferropericlase inclusions in a matrix of (post-)perovskite is capable of producing detectable seismic anisotropy. For a typical lower mantle assemblage that consists of 80% perovskite and 20% ferropericlase $(Mg_{0.7}Fe_{0.3})O$, an aspect ratio of about 10:10:1 is required to produce a shear wave splitting of about 1-1.5%, consistent with seismological reports. If ferropericlase is enriched in iron as proposed for “hot regions” with anomalously low seismic velocity at the core-mantle boundary [4-6], visible seismic anisotropy can be produced with smaller aspect ratios.

Unraveling the main causes for the observed shear wave splitting is crucial to interpret the seismic observations in terms of deep Earth mantle dynamics. The microstructure of a lower mantle assemblage not only contains information about dynamic processes, but also markedly controls transport properties. A layered structure of ferropericlase lenses in a (post-)perovskite matrix would have a profound impact on viscosity, element diffusivity, thermal conductivity, electrical conductivity.

Two different experimental runs (2 shifts) were performed at both the laser-heating and general purpose endstations of the Extreme Conditions Beamline. The photon energy was 42.7 KeV. In two different experimental runs, we produced microstructures in 12 different DAC-loadings. Either a mixture of fine-ground $MgSiO_3$ enstatite and $(Mg_{.7-.9}Fe_{.3-.1})O$ or natural $(Mg_{0.9}Fe_{0.1})_2SiO_4$ olivine was used as starting material. The sample material was loaded in a DAC along with Platinum as pressure-marker and laser-absorber. At a pressure of about 30 GPa, we rastered the sample chamber using an infrared heating laser available at the ECB in order to convert the silicate phase and obtain a final assemblage of perovskite and ferropericlase. We monitored the progress of conversion using x-ray diffraction which allows us to put constraints on the grain size. Most of the sample loadings with enstatite showed (at least partially) successful conversion (the analysis is still on-going), whereas the attempts to convert samples of olivine was not successful. After conversion to perovskite and ferropericlase, we decompressed some of the loadings in order to evaluate the development of microstructure caused by the laser-heating. All other sample loadings were further compressed to pressures between about 60 and 90 GPa. The samples were continuously monitored by x-ray diffraction during compression which allows for quantifying grain size and characterizing the development of preferred orientation. After reaching the final pressure, all samples were decompressed. The decompressed samples microstructures were than analyzed using a Dual Beam microscope at the German Research Center for Geosciences GFZ. The analysis is still in progress and will also involve the transmission electron microscope (TEM).

In the samples that we have already analyzed, we clearly observe layers of iron-enriched material (ferropericlase?) in a matrix of iron-depleted material (perovskite?) (Fig. 1). The available results seem to indicate that the "bands"-microstructures are indeed caused by deformation. However, at this stage, we cannot rule out the possibility that the bands are caused by iron-migration as a result of temperature gradients present during laser-heating of the sample.

Further analysis will allow us to better understand the origin of the "band"-microstructures. In addition, we envisage follow-up experiments employing the resistive-heating setup that has become available at the ECB and might be capable to reach the temperatures required for the phase conversion.

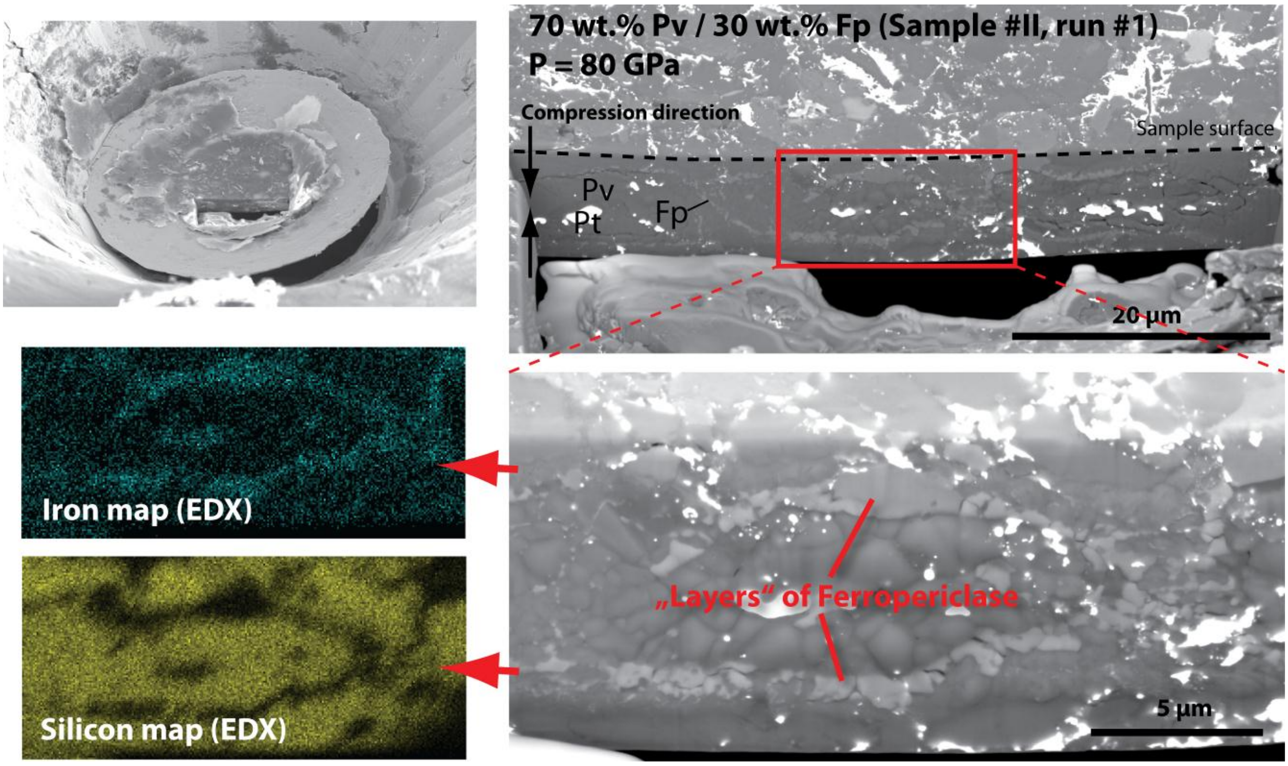

Figure 1: A mixture of $MgSiO_3$ enstatite and (Mg,Fe)O was compressed in the diamond-anvil cell to about 35 GPa. Laser-heating was performed at the Extreme Conditions Beamline P02.2 at Petra III (DESY) to convert enstatite to perovskite. After conversion was verified by x-ray diffraction, the sample was further compressed to about 80 GPa. After decompression, the recovered sample was analysed for microstructure using FIB/SEM imaging and EDS analyses.

References:

1. Yamazaki, D., T. Yoshino, T. Matsuzaki, et al. (2009) Phys. Earth Planet. Inter., **174**(1-4): p. 138.
2. Wang, Y., C. Lesher, G. Fiquet, et al. (2011) Geosphere, **7**(1): p. 40.
3. Madi, K., S. Forest, P. Cordier, et al. (2005) Earth Planet. Sci. Lett., **237**(1-2): p. 223.
4. Wicks, J.K., J.M. Jackson and W. Sturhahn (2010) Geophys. Res. Lett., **37**(15): p. L15304.
5. Bower, D.J., J.K. Wicks, M. Gurnis, et al. (2011) Earth Planet. Sci. Lett., **303**(3-4): p. 193.
6. Nomura, R., H. Ozawa, S. Tateno, et al. (2011) Nature, **473**(7346): p. 199.