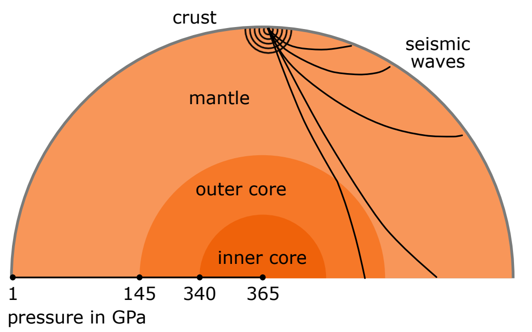
A DEEP LOOK INTO OUR PLANET'S INTERIOR

Determination of the elasticity of ferropericlase in the Earth's deep mantle

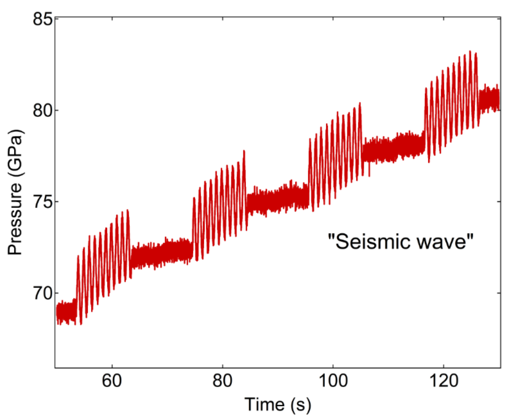
In order to unveil the inaccessible interior of the Earth, researchers rely on remote sensing techniques such as seismic wave travel times. Those depend on the type of material through which the waves propagate. So when researchers obtain seismic wave velocity data, they can use this information to infer the chemical composition and mineralogy of the Earth's mantle. However, they need to know how the materials behave under the high pressures that are present in the interior of our planet, that is, they require information about the materials' elastic properties. This information is gathered in laboratory studies. Ferropericlase ($(Mg_{0.8}Fe_{0.2})O$) is one of the most abundant constituents of the Earth's lower mantle, and lab experiments have shown that its response to pressure increase is not straightforward. The iron that is contained in ferropericlase changes its electron configuration beyond a certain pressure, a phenomenon called the spin crossover. This, in turn, causes a softening of the bulk modulus – a measure of compressibility – and thus significantly affects the speed of waves traveling through it.



The Earth's interior, approximate pressure gradient and paths of compressional seismic waves. (CC by-sa Denise Müller-Dum, awk/jk)

EXPERIMENTAL SETUP

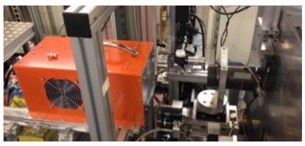
A team of researchers from the United Kingdom and Germany was able to experimentally determine the bulk modulus of ferropericlase across the spin crossover zone at a typical seismic wave frequency, using a setup at the Extreme Conditions Beamline P02.2 at PETRA III, DESY. They placed their sample in a dynamic Diamond Anvil Cell and subjected it to variations in pressure, with cyclic compressions and relaxations at a frequency of 1 Hz. Using a GaAs 2.3 MPix Lambda detector, they obtained continuous X-ray images of the sample at a resolution of 5 ms and 50 ms per image. **"The outstanding X-ray sensitivity of the LAMBDA detector, paired with the excellent time-resolution allowed us to carry out these experiments"**, said Hauke Marquardt, lead author of the study.



Pressure oscillations realized with the dynamic Diamond Anvil Cell as simulation of a seismic wave (© H.-P. Liermann, with kind approval)

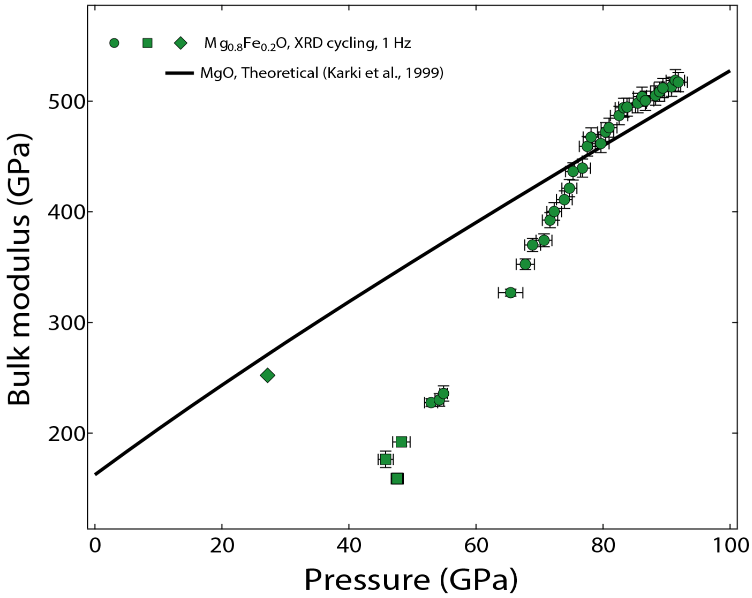
Setup	PETRA III Extreme Conditions Beamline P02.2
Camera	LAMBDA 2M, GaAs detector
Resolution	2.3 Megapixels
Acquisition frequency	up to 200 Hz
Photon energy	25.6 keV

Setup of the LAMBDA 2M detector and the dynamic Diamond Anvil Cell at the Extreme Conditions Beamline (© H.-P. Liermann, with kind approval)



RESULTS

The team collected over 50,000 images during three experimental runs, from which they constrained the sample's lattice parameters. They derived the unit cell volume and by knowledge of the corresponding pressure, were able to calculate the bulk modulus. The data confirmed a softening of the bulk modulus in the spin crossover zone that would slow compressional seismic waves in the Earth's mantle. This finding is of high relevance for the interpretation of seismic velocity data. The study can also be regarded as a proof-of-concept of the setup at the Extreme Conditions Beamline, which allows to simulate seismic waves and study a sample's reaction to it with high-resolution X-ray imaging.



Variation of the bulk modulus with pressure; the line represents the theoretical response of magnesium oxide to pressure increase. The markers refer to measurements obtained on ferropericlase with X-ray imaging, using the setup at the Extreme Conditions Beamline at PETRA III in the presented study. © H. Marquardt, with kind approval.

REFERENCES

- Marquardt, H., Buchen, J., Mendez, A. S. J., Kurnosov, A., Wendt, M., Rothkirch, A., et al. (2018). Elastic softening of $(Mg_{0.8}Fe_{0.2})O$ ferropericlase across the iron spin crossover measured at seismic frequencies. Geophysical Research Letters, 45, 6862–6868. https://doi.org/10.1029/2018GL077982

- Jenei, Z., Liermann, H. P., Husband, R., Méndez, A. S. J., Pennicard, D., Marquardt, H., O'Bannon, E. F., Pakhomova, A., et al. (2019). New dynamic diamond anvil cells for tera-pascal per second fast compression x-ray diffraction experiments. Review of Scientific Instruments 90, 065114. https://doi.org/10.1063/1.5098993

- H. Marquardt & A. R. Thomson (2020). Experimental elasticity of Earth's deep mantle. Nature Reviews Earth & Environment 1: 455-469. https://doi.org/10.1038/s43017-020-0077-3

This information sheet illustrates a real-world application of the LAMBDA 2M camera, developed and manufactured by X-Spectrum. We gratefully acknowledge the voluntary support by the scientists mentioned in this sheet.