HIGH-PRESSURE MINERAL PHASES OF OLIVINE (Mg_2SiO_4) FORMED BY PRE-COMPRESSION FOLLOWED BY LASER-DRIVEN HYPERVELOCITY SHOCK IMPACT.

Amber Turner[1], Oliver Tschauner[1], Elissaios Stavrou[2], Joseph Zaug[2], Michael Armstrong[2], Eran Greenberg[3], Vitali Prakapenka[3]
[1]University of Nevada Las Vegas, Department of Geoscience and High Pressure Science and Engineering Center
[2]Lawrence Livermore National Laboratory, Material Science Division
[3]University of Chicago, GSECARS

Introduction: The high pressure polymorphs of olivine provide important constraints on shock pressure (P) [5], temperature (T), and shock duration [1,6,7] for impacts in chondrite parent bodies, Mars, and Moon.

Correlation of grainsize with shock duration requires knowledge about growth rates at given P and T which can only be obtained through experiments. Since impact conditions are dynamic, the kinetics of transformation and growth is key. Previous studies on synthesizing the high-pressure polymorphs ringwoodite and wadsleyite (γ- and β-Mg_2SiO_4, rsp.) in shock-experiments have either been from dynamically generated melts [1] or have failed [4]. Here, we examine the possibility of solid-solid transformation of olivine into high-pressure polymorphs at very short shock duration but at pressures twice to thrice the thermodynamic boundaries. In order to keep temperatures low enough for solid-solid transformation, we used an approach where statically precompressed samples are subjected to shock compression.

Methods: Two specimens of Fo-rich single crystal olivine ($(Mg,Fe)_2SiO_4$) from San Carlos, AZ, were coated with 2.5 µm thick layers of aluminum and statically pre-compressed in diamond anvil cells to 35 (sample 1) and 25 GPa (sample 2), respectively. Lithium fluoride served both as the pressure-transmitting medium and window material. The specimens were then exposed to single laser-driven hypervelocity shock (400 picosecond duration) to 48.05 GPa and 36.71 GPa respectively. Shock velocities were measured by multichannel phase-shift Doppler velocimetry. Figure 1 illustrates the sample assembly as constructed by Elis Stavrou, Joseph Zaug and Michael Armstrong of the Material Science Division at Lawrence Livermore National Laboratory.

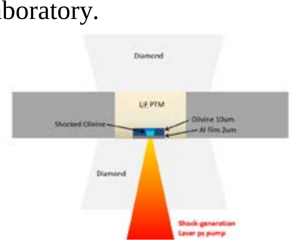

Figure 1. Sample assembly: diamond anvil cell with the addition of hypervelocity shock

Diffraction data were collected at the micro-diffraction beamline 13-IDE, GSECARS, APS. Data were collected at residual static pressure from within the cell (sample 2) and after release to ambient conditions. Sample 2 at 18 GPa was found to be transformed to the non-quenchable high pressure-low temperature phase forsterite-II [3] and a hexagonal disordered phase of structure similar to phase D. In addition, we found Al to be oxidized to corundum. The recovered sample was fully back-converted to olivine, in agreement with the findings by Finkelstein. Sample 1 was examined only at ambient conditions. We observed corundum and spinel as products of oxidation and reaction of the Al coating. Further we observed a Mg-silicate spinelloid structurally related to wadsleyite.

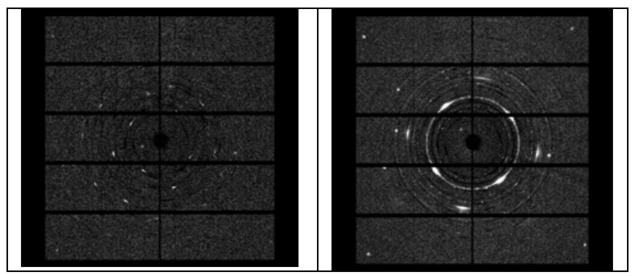

Figure 2. Diffraction images of the sample outside shocked region (left) and within shocked region (right). Outside the directly shocked region only highly deformed olivine is observed. Inside the shocked region Debye fringes of corundum and spinel are visible. Mg-silicate spinelloid generates sharp, faint diffraction spots consistent with lamellar growth within the strained olivine matrix. Intense, round spots are from the diamond anvil. An olivine reference pattern was subtracted from this image to make occurrence of other phases better visible.

Conclusions: In a 400 ps shock compression to 36 GPa, 700-1000 K occurs reversible transformation of olivine to spinelloid phases. At compression to 48 GPa, 1000-1300 K a quenchable Mg-Si-spinelloid has formed. This observation is first evidence for recoverable solid-solid transformation of olivine into a high-pressure polymorph in a shock experiment. The observed spinelloid is a precursor of wadsleyite and ringwoodite. Its occurrence indicates that at pressures about four-times above the thermodynamic phase boundaries, onset of transformation from olivine to spinel occurs even on sub-ns time scales at temperatures below the olivine Hugoniot. The spinelloid grains are oriented in the olivine matrix consistent with lamellar growth [6,7].

Acknowledgement: This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Security, LLC under contract DE-AC52-07NA27344. Part of this work was sponsored by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Cooperative Agreement #DE-NA0001982. GeoSoilEnviroCARS is supported by the National Science Foundation - Earth Sciences (EAR-1128799) and Department of Energy - Geosciences (DE-FG02-94ER14466). Use of the Advanced Photon Source was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

References: [1]Tschauner, O. et al. 2009. Proceedings of the National Academy of Sciences of the United States of America 106.33, 13691–13695. [2]Akaogi, M. et al. 1989. A Journal of Geophysical Research – Solid Earth and Planets. 94(B11): 15671-15685 [3]Finkelstein, G. et al. 2014. American Mineralogist, 35-43 [4]Langenhorst, F. et al. 2002. Meteoritics & Planetary Science. 37: 1541–1553 [5]Stöffler,D. et al. 1991. Geochemica et Cosmochimica Acta. 55 (12): 3845-3867. [6] Chen M et al. 2006. Meteoritics and Planetary Science. 41: 731 – 737.[7] Xie ZD et al. 2007. Earth Planetary Science Letters 254: 433 – 445. [8] Ohtani E. et al. 2004. Earth Planetary Science Letters. 227: 505 – 515.