WATER STORAGE AND TRANSPORT PROCESSES DURING IMPACT EXPERIMENTS ON NOMINALLY ANHYDROUS MINERALS. J. Tielke[1,2], A.H. Peslier[2], R. Christoffersen[2], M. Cintala[3], R. Morris[3], R. Montes[2], and C. Cline, [1]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058, USA, jacob.a.tielke@nasa.gov, [2]Jacobs, NASA Johnson Space Center (JSC), Mail Code XI3, Houston, TX 77058, USA [3]ARES, Mail Code XI3, NASA-Johnson Space Center, Houston. TX 77058, USA.

Introduction: Water, in the form of structurally-bound hydrogen in the crystal lattice of nominally anhydrous minerals (NAMs), strongly influences many important physical processes on terrestrial planets and planetary objects. Water enhances the rates of plastic deformation [1,2] and controls the degree of partial melting [3] in silicate rocks, which influences the generation of melt and therefore the nature of planetary volcanism. Water has also been experimentally demonstrated to influence the nature of lattice preferred orientation in deformed aggregates [4], and thus may be important in the interpretation of seismic anisotropy data collected from planetary bodies, such as from the current InSight mission on Mars. Therefore, much attention has been focused on characterizing the distribution and concentration of water in the planets and rocky bodies of our solar system.

Characterization of chondritic meteorites, our most abundant samples of the rocky bodies in our solar system, reveals the water contents of NAMs are generally 0.5 to 2 times more abundant than those found on Earth [5]. Values of δD ($^2H/^1H$ ‰ relative to ocean water) in meteorites range significantly over micron distances but are generally larger in Martian meteorites [6]. Importantly, all meteorites have been subject to shock, mostly by collisions prior to entering Earth's atmosphere [7]. During shock, minerals are exposed to extreme conditions of stress, pressure, and temperature, resulting in the development of a range of shock-induced defects [7]. These shock-induced defects, which include dislocations and low-angle boundaries, have the potential to significantly modify the diffusion rates of trace elements, such as H [8]. Therefore, understanding how shock modifies the storage capacity and transport properties of water in NAMs during impact is central to understanding the distribution of water in our solar system.

Methods: To investigate the influence of shock on water storage and transport in NAMs, we carried out a series of experiments at the Experimental Impact Laboratory at NASA's Johnson Space Center (JSC). Experiments were carried out using the Flat Plate Accelerator (FPA) to access impact conditions while allowing for retrieval of encapsulated samples. FPA experiments were carried out to achieve impact pressures ranging from 20 to 40 GPa, under vacuum conditions, and using tungsten alloy capsules (Fig. 1). The starting material for the experiments were either single crystals or mm-sized aggregates of olivine (ol), orthopyroxene (opx), or clinopyroxene (cpx). In some cases, crystals were dehydrated prior to impact at 1000° to 1300°C in one-atmosphere gas-mixing furnaces at the Experimental Petrology Laboratory at JSC. These dehydrated samples allowed for assessment of the introduction of water during experiments and to act as a sink for water during the impact.

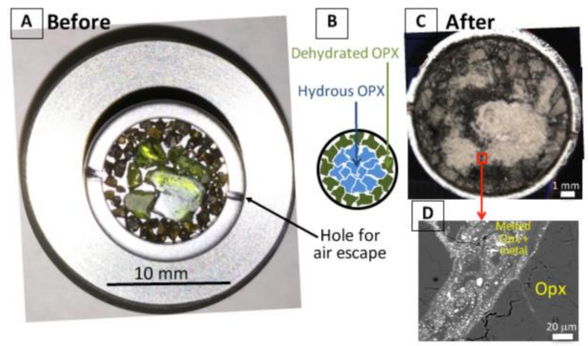

Figure 1: Example of an FPA experiment with a shock pressure of 40 GPa. A and C: photo of the opx before and after experiment. B: sketch of the sample. D: Secondary electron image of melted metal and opx in between the shocked opx grains.

Crystals were analyzed before and after impact using Fourier-transform infrared spectroscopy (FTIR), electron probe micro analyses (EPMA), secondary ion mass spectrometry (SIMS), micro X-ray diffraction, and Mössbauer spectroscopy. Shock-induced crystalline defects will be characterized using high-resolution transmission electron microscopy (TEM). Sectioned samples will be analyzed using electron-backscatter diffraction (EBSD). The density and character of geometrically-necessary dislocations will be determined from EBSD data using the weighted burgers vector approach [9].

Results and Discussion: Results from polarized FTIR measurements on the ol, opx, and cpx starting material reveal peaks in absorbance at wavenumbers characteristic of structurally incorporated hydrogen. Additional peaks observed near 3700 cm^{-1} in olivine suggest the presence of microscopic serpentine (Fig. 2). After dehydration in one atmosphere furnaces, the peaks in the region of OH stretching are absent and the olivine was brown in color (Fig. 2A). Post-impact FTIR measurements carried out on dehydrated crystals reveal small peaks in absorption at a wavenumber of 3560 cm^{-1}, suggesting structurally incorporated hydrogen was added to the crystal during impact.

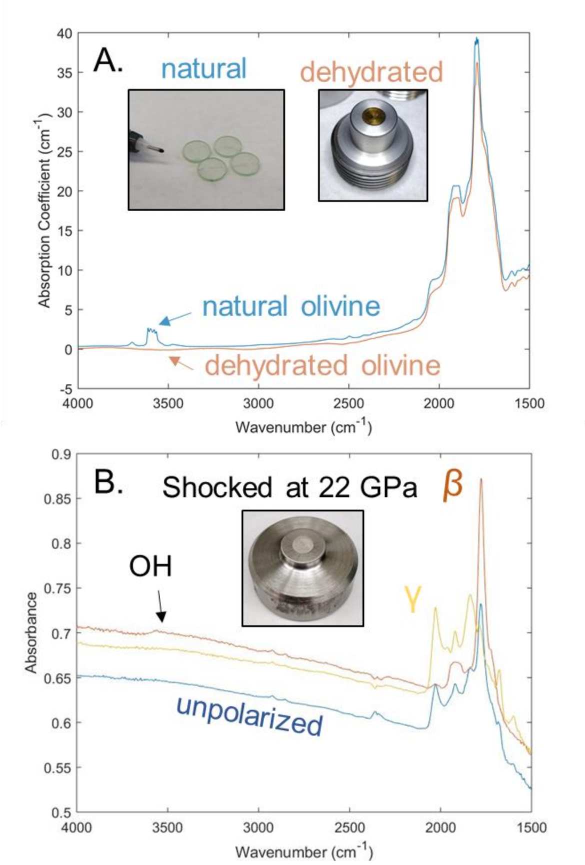

Figure 2: Example of FTIR spectra on natural and dehydrated olivine (A) and olivine shocked in the FPA at 22 GPa (B).

Although precautions were taken to minimize the introduction of atmospheric water during the experiments, including drying the sample and capsule in a vacuum oven overnight prior to the experiment, the potential for contamination cannot be ruled out. A new experimental assembly and procedure that includes baking the sample inside of the FPA at 200°C under vacuum for 12 hours prior to impact will be used. This procedure will ensure that addition of water from atmospheric sources may be ruled avoided in future experiments.

SIMS measurements reveal enrichment in water in shocked portions of the initially water-free orthopyroxene grains. In shock experiments on the water-bearing opx, the opx also acquired water and δD is constant within uncertainties (Fig. 3). An increase in delta may be observed in the dehydrated opx that were co-mounted in experiment HEXP6 with the hydrous opx. This variation may be due to preferential partitioning of ^{1}H relative to ^{2}H via either lattice diffusion or pipe diffusion during impact. Variation in δD may also be the result of the development of partial melts containing microscopic gas bubbles or the sample. These hypotheses will be tested by carrying out microstructural analyses using TEM and EBSD techniques. Our preliminary experiments show that water can very easily be added to nominally anhydrous minerals during shock even if little is present in the system prior to impact.

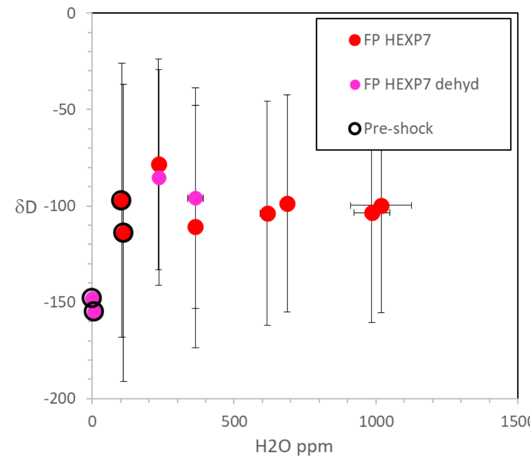

Figure 3: Results of SIMS analyses on natural opx, dehydrated opx, and opx shocked in the FPA at 40 GPa. The δD of the dehydrated pre-shock opx is plotted at typical terrestrial mantle values (~150 ‰ [10]).

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