HYDROGEN MOBILITY DURING SHOCK DEFORMATION IN OLIVINE

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Introduction: Understanding how shock modifies the storage and transport of hydrogen in minerals is central to understanding the evolution of water in the solar system. During shock, crystals are exposed to extreme stress, pressure, and temperature conditions, resulting in the development of a range of defects [1]. Importantly, shock results in an increase in line-defects (dislocations) in crystals [2], which may act as short-circuit diffusive pathways for hydrogen [3]. Enhanced diffusion rates and modification of hydrogen content resulting from increased dislocation densities during shock may complicate interpretations of hydrogen concentrations and isotopic measurements in meteorites and other planetary samples. To investigate the influence of shock on hydrogen mobility, we carried out a series of shock experiments on olivine, which is one of the most common minerals found in the solar system.

Methods: Olivine single crystals were oriented, cored, and sliced parallel to the (010) plane into discs 6.35 mm in diameter and 0.8 mm thick. Some of the olivine discs were dehydrated prior to shock by heating at 1300°C in a one-atmosphere gas-mixing furnace with oxygen fugacity controlled at the FMQ buffer. The olivine discs were shocked under vacuum conditions in tungsten alloy capsules at peak pressures ranging from 22 to 42 GPa in a flat plate accelerator (Figure 1a) at the Experimental Impact Laboratory at NASA's Johnson Space Center. The crystals were analyzed prior to and after shock using Fourier Transform Infrared Spectroscopy (FTIR), Electron Backscatter Diffraction (EBSD), Electron-probe microanalyses (EPMA), Mössbauer spectroscopy, and Raman spectroscopy.

Results: FTIR analyses of the olivine discs prior to and after shock reveal absorbance peaks at wavenumbers indicative of the presence of OH incorporated into the crystal lattice. Prior to impact, the olivine discs contained 60 to 100 ppm H_2O by weight, with the largest concentration in the center of the discs and the lowest at the edges, providing a chemical potential gradient for hydrogen diffusion during shock. Extensive fracturing is observed in the shocked crystals (Figure 1b). Post-shock FTIR analyses of dehydrated olivine reveal no detectable OH absorbance, indicating that no atmospheric water was added during shock. Post-shock FTIR analyses for natural olivine reveal minor variation in the position of peaks of OH-stretching bands compared to those of the starting material. EBSD analyses reveal the development of orientation gradients in the shocked crystals and that the density of geometrically necessary dislocations (GNDs) increases systematically with shock pressure but is independent of hydrogen content.

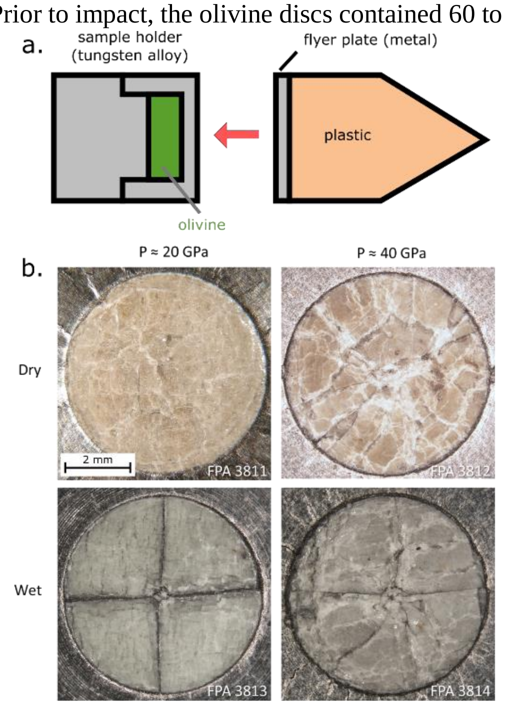

Figure 1: a. Simplified diagram (not to scale) illustrating the geometry of shock experiments using the flat plate accelerator. Shock is induced by the impact of the flyer plate on the capsule containing the olivine crystal. b. Optical micrographs of shocked olivine crystals in this study.

Discussion: The results presented above are consistent with a small influence of shock on the diffusivity of hydrogen in olivine for the studied conditions. Calculations of diffusion distances of hydrogen in olivine that incorporate published hydrogen diffusion coefficients [4, 5, 6] for olivine with the measured density of GNDs reveal that pipe-diffusion is the dominant hydrogen diffusion process during shock. However, diffusion distances of hydrogen during shock experiments are less than 5 µm. Therefore, large olivine crystals are likely to retain their original hydrogen content during shock over the investigated range of conditions, but minor migration of hydrogen is evidenced by changes in the observed position of absorbance peaks associated with intrinsic H in the FTIR spectra.

References: [1] Stöffler et al. (1988) in *Meteorites and the Early Solar System* 165-202. [2] Ashworth & Barber (1975) EPSL *27*, 43-50. [3] Tien et al. (1976) *Metallurgical Transactions A* 7.6 821-829. [4] Mackwell & Kohlstedt (1990) *JGR Solid Earth* 95 5079-5088. [5] Demouchy & Mackwell (2006) *PCM* 33.5 347-355. [6] Demouchy (2010) *EPSL* 295 305-313.