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University of Colorado Boulder

Water in Silicates: A Combined Shock & Spectroscopy Study

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Can SiO_2 glass preserve volatiles during impacts?

- Water is abundant in planetary building blocks
- Deuterium to Hydrogen (D/H) ratio (Fig 1.) numerically represents the combination of sources of Earth's water
- One potential contribution to D/H ratio is water deposited via impactors (with v_{impact} on Earth ranging from 11 [km/s] to 53 [km/s])

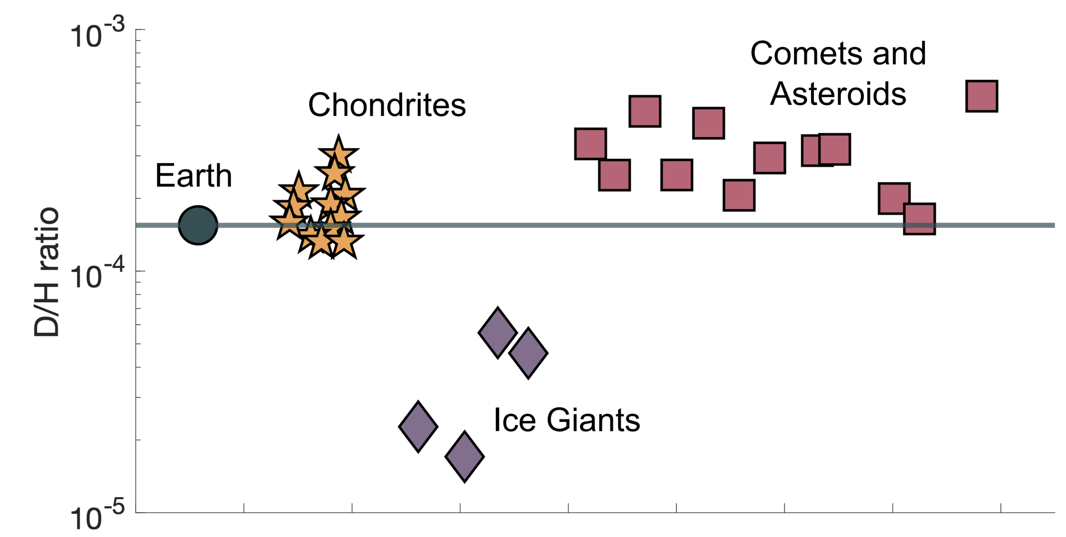


Fig. 1 Sources of water within our solar system

- *Our goal is to experimentally constrain the contribution of impactors to Earth's D/H ratio by shocking hydrated SiO_2 glasses to see what happens to volatile species upon impact*

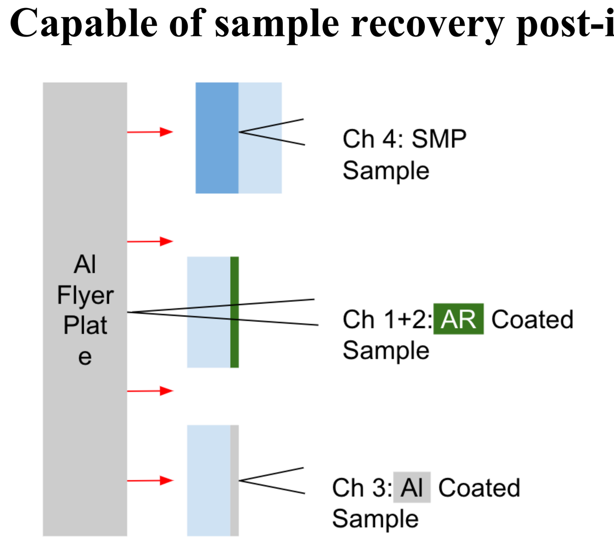
Driving questions

1. Examine effects of hydration on physical properties of silicates
1a. Does impact velocity change material response?
1b. Does OH content change material response?

2. What is the degree of devolatilization that occurred during shock?

Shock quantifies material response properties

- Gas gun housed in the Dynamic Integrated Compression Experimental Facility
- Impact speeds 100, 200, 300 & 400 m/s
- Velocity interferometer system for any reflector (VISAR) collects velocity data from 4 channels (Figs 2 & 3)
- **Capable of sample recovery post-impact**



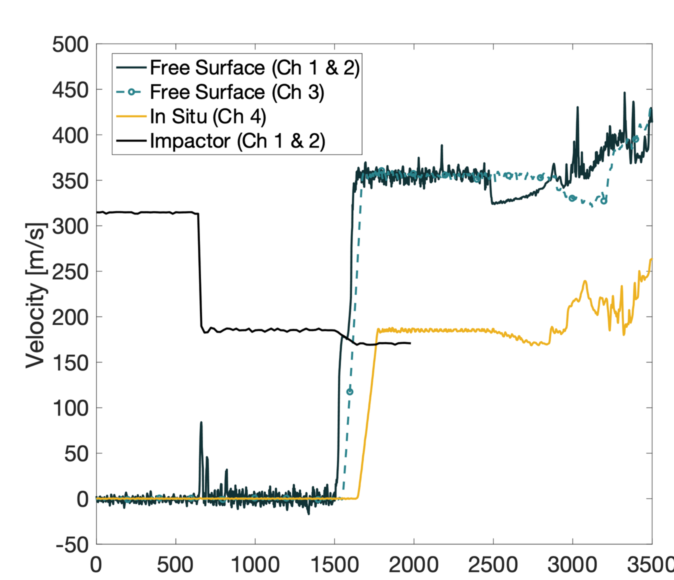


Fig. 2 (Left) Diagram of gas gun experimental setup. Fig 3 (Right) Example of velocities produced from VISAR on each channel

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S.-M. Thomas, et. al. American Mineralogist 93, 10 (2008), E. Stopler, Contr. Mineral. And Petrol. 81, 1-17 (1982), C.-S. Zha, et. al. Phys. Rev. B 50, 13105 (1994), S.-M. Thomas, et. al Front. Earth Sci. 2 (2015) S.P. Marsh, LASL Shock Hugoniot Data (1980)]

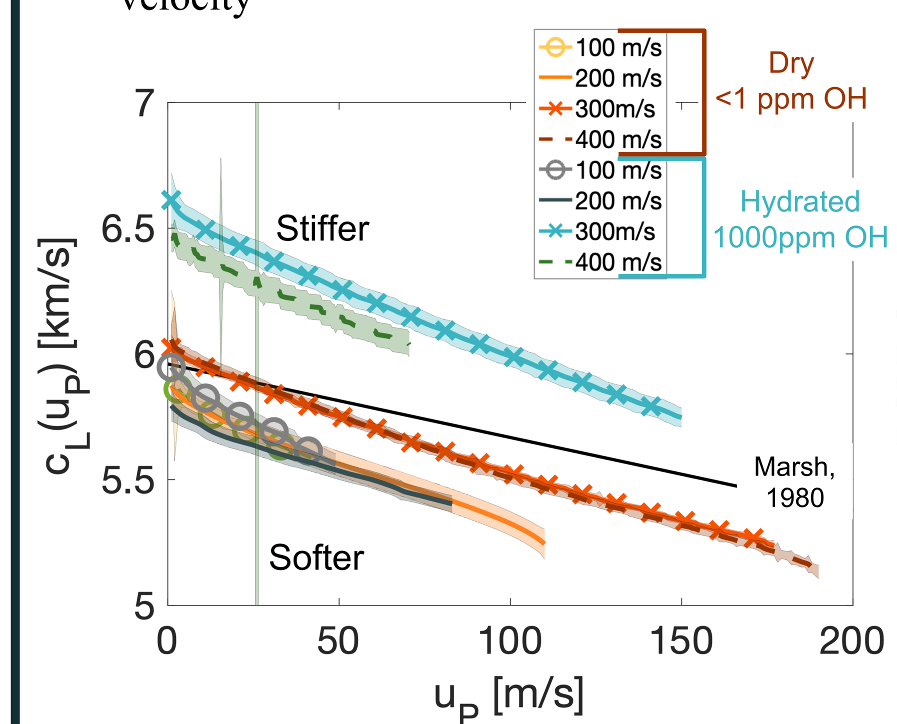
1a. At increased v_{impact}, material stiffness increases

Lagrangian Sound Speed quantifies material response during shock

$$c_L(u_p) = \frac{\Delta x}{\Delta t}$$

$$\delta c_L(u_p) = \sqrt{\left(\frac{\sigma x}{\Delta x}\right)^2 + \left(\frac{\sigma t_0}{z - t_0}\right)^2 + (\gamma)^2}$$

- **Higher impact velocities, independent of OH presence, have stiffer response (higher c_L) than lower impact velocities**
- At high impact velocities, hydrated samples have a stiffer response than dry samples
- Our results (Fig 5) are consistent with static compression experiments (Zha et. al., 1994)
- Error in 400 m/s sample likely due to lack of data points converting VISAR intensity to velocity



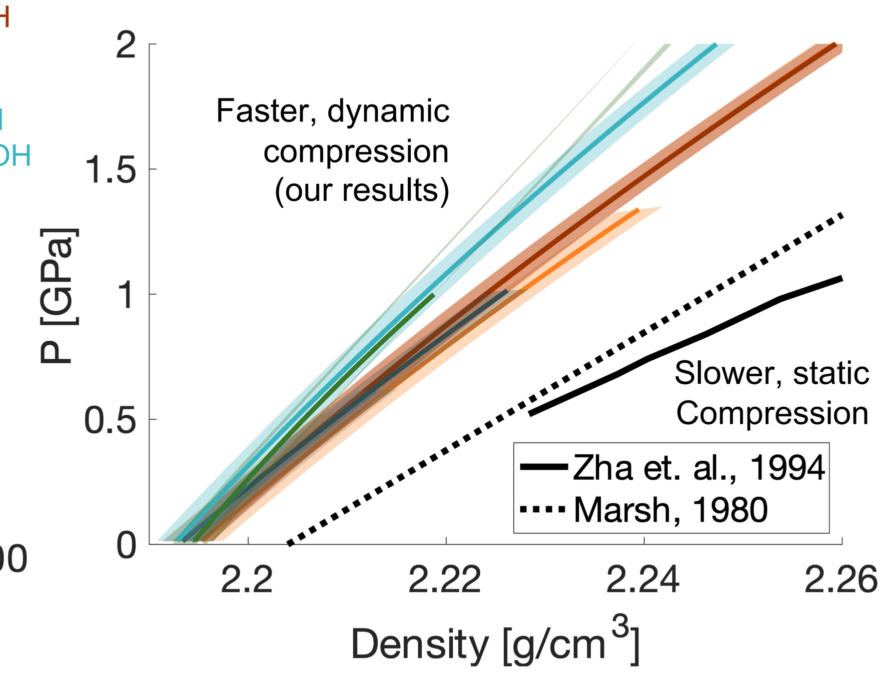


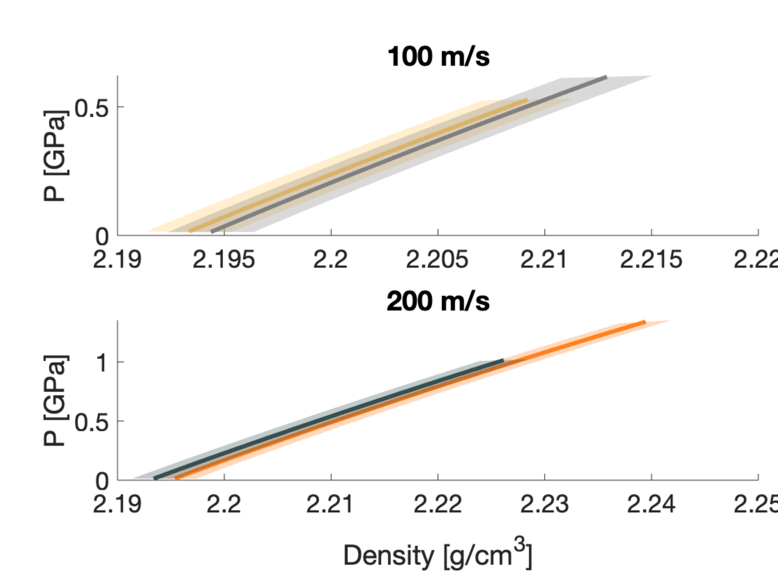
Fig. 4 (left) Lagrangian sound speeds of dry and hydrated glassed over increasing impact velocities. Fig 5. (right) Pressure density curve with both static (black line) and dynamic (colors) experimental results

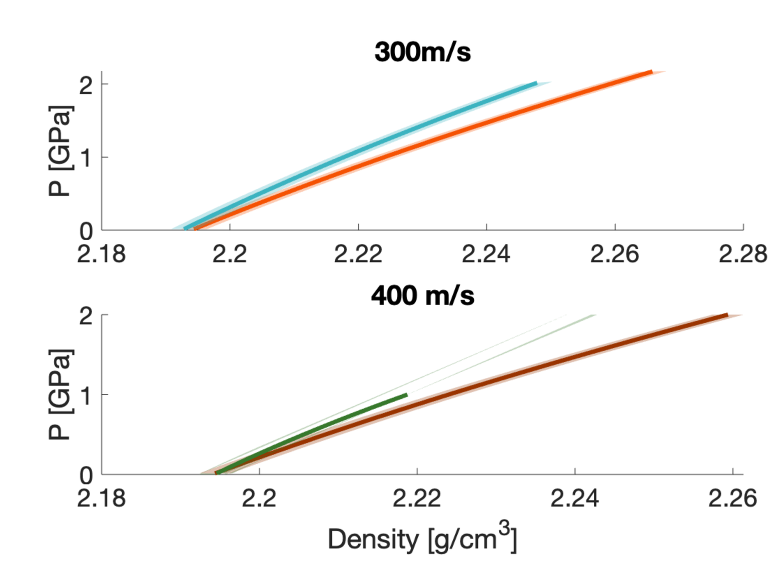
1b. At increased v_{impact}, OH affects material response

Simplified form of Conservation Equations

$$P = \rho_0 \int_0^u c_L \, du \qquad \sigma P = \rho_0 \int_0^u \sigma c_L \, du \qquad \rho = \rho_0 \left(1 - \int_0^u C_L^{-1} \, du\right)$$

- Compressional behavior is calculated from the sound velocity, $c_L(u_p)$
- Dry and hydrated samples behave the ***same at low*** velocities (Fig 6)
- Dry and hydrated samples behave ***differently at high*** velocities (Fig 7)

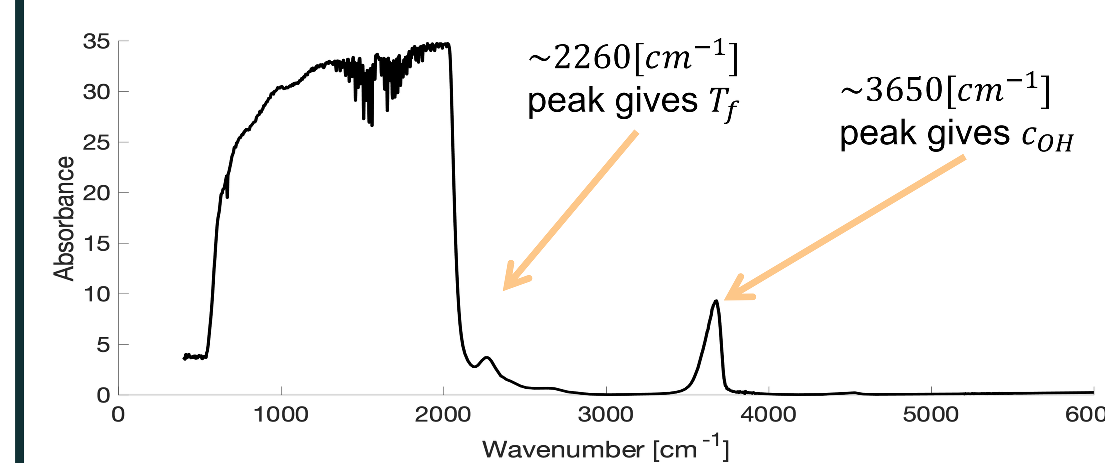




Compositional variation pressure-density curve Fig 6 (left) low impact velocities. Fig 7 (right) high impact velocities.

Spectroscopy reveals post-impact OH content

- Bruker Tensor37 coupled to Bruker Hyperion microscope 15x objective and 10x eyepieces
- Transmission spectra recorded from 6000 to 4000 cm^{-1} at ambient conditions (Fig 8)
- Double polished SiO_2 samples recovered from shock experiments
- Aperture size set to smallest sample and used for all experiments (image)



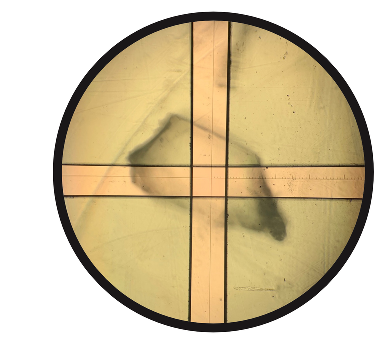


Fig. 8 (left) Normalized FTIR absorbance spectra of water-bearing glass. Image (above) Sample in microscope view with aperture set

2. OH varies in post-impact samples

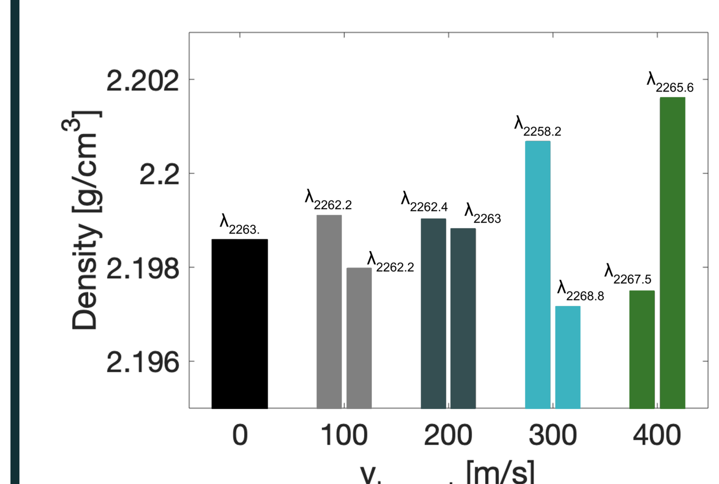
Beer-Lambert Law relates water concentration to OH peak height (Stopler, 1982)

$$\epsilon = \frac{1.8 \cdot A_i}{t \cdot \rho \cdot c_{H_2O}}$$

- Hydrated samples' post-impact ρ determined from fictive temperature

$$T_f \text{ (Fig. 9) } \rho \propto \frac{10^{-6}}{T_f} \propto \frac{10^4}{\lambda_{2260}}$$

- Peak height of the OH band varies between samples of the same initial composition
- Samples impacted at 300 m/s show little to no OH peak



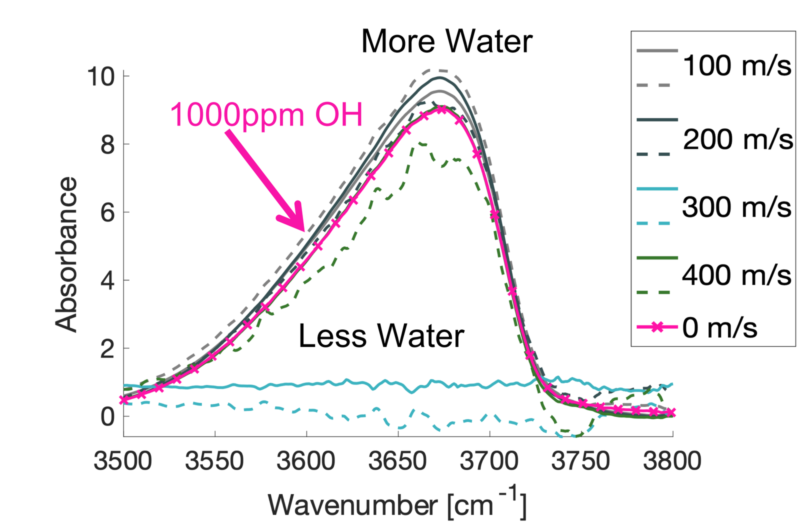


Fig 9 (left) Post-impact hydrated sample densities with λ_{2260} peak location labeled. Fig. 10 (right) OH band at ~3650 [cm^{-1}] background-subtracted, normalized FTIR absorbance spectra of initially water-bearing glasses

SiO_2 glass preserves OH during impacts!

1a. Does impact velocity change mat response?
- Independent of composition, SiO_2 glass has a stiffer response at high v_{impact} (Fig 4)

1b. Does OH content change mat resp?
- Compressional behavior of samples diverges at higher v_{impact} between dry and hydrated samples (Figs 7 and 8)

2. What is the degree of devolatilization that occurred during shock?
- Initial results suggest OH survives impacts within SiO_2 glasses (Fig 10)
- Peak height of OH band varies between samples of the same initial composition
- More work is needed to quantify c_{OH}
- Vary aperture size of FTIR to see if degree of devolatilization varies across the sample geometry
- Future plans to increase sample complexity to chemicals more representative of solar system compositions (basalt)