

**SHOCK THERMODYNAMICS OF MANTLE ROCKS: ROCKPORT FAYALITE.** W. M. Steinhardt and S. T. Stewart, Department of Earth & Planetary Sciences, Harvard University, 20 Oxford Street, Cambridge MA, 02138 (wsteinhardt@fas.harvard.edu)

**Introduction.** In order to address questions related to giant impacts and impact cratering on terrestrial planets, we need robust equations of state (EOS) and thermodynamic data for major mantle minerals (e.g., the olivine series and enstatite) and rocks under a wide range of pressure-temperature conditions. It is important to accurately characterize the amount of impact-induced heating that occurs in order to understand a range of planetary problems, including the mechanics of basin formation, the formation of the Martian crustal dichotomy, the origin of Earth's moon, and the depths of magma oceans on the early Earth during accretion.

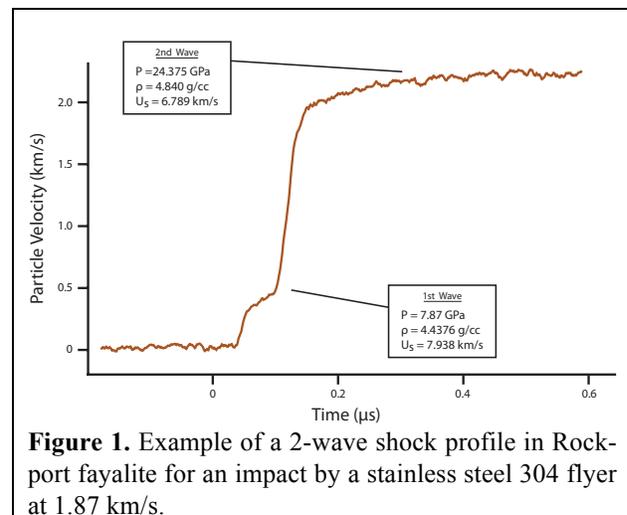
The long-term goal of this work is to develop comprehensive EOS for the most important mantle minerals for use in impact modeling and to understand the heterogeneous distribution of shock and post-shock temperatures in rocks. Here we present the results from new post-shock temperature experiments on Rockport fayalite and comparisons to previous post-shock measurements on rocks.

**Experimental methods.** Planar shock experiments were performed in the Harvard Shock Compression Laboratory with a 40-mm single stage powder gun that can achieve shock pressures up to about 50 GPa in mantle materials. Simultaneous measurements of free surface velocity and thermal emission were made with a co-aligned velocity interferometer (VISAR) and absolutely calibrated multi-channel pyrometry system as in previous work [9]. The post-shock temperature measurements were made at 0.65, 0.81, 1.8, 2.3, 3.5 and 4.8  $\mu\text{m}$ . Additionally, empirical estimates of wavelength-dependent emissivity were made by heating a sample in a rough vacuum in order to convert the post-shock thermal emission to true temperature.

The fayalite rock specimens, from Rockport MA [2], have a mean density of  $4.32 \pm 0.03 \text{ g/cm}^3$  and longitudinal wave speed of  $6.7 \pm 0.2 \text{ km/s}$ . A hand specimen from the Harvard Museum of Natural History was cored and cut into nominally 32-mm diameter discs. The fayalite and stainless steel 304 driver plate were lapped plane parallel and polished to an optical ( $<1 \mu\text{m}$ ) finish.

**Results.** In all experiments, we observe multi-wave shock compression profiles in the VISAR data (Figure 1). Multi-wave profiles have not been reported in previous experiments on Rockport fayalite due to different experimental techniques [3,4]. First and second wave arrivals are shown in Figure 2 with previous shock Hugoniot data on Rockport fayalite [4], synthetic poly-

crystalline fayalite and synthetic single crystal fayalite [3]. Broadly, the fayalite shock data display the characteristic segments for an elastic shock, mixed phase, and high-pressure phases (e.g., stishovite + FeO). This work is the first to record the elastic shock. The shock velocities in the first wave are consistent with extrapolated longitudinal wave speeds for fayalite. The first wave speeds are also consistent with the bulk sound speed of iron end member ringwoodite within its stability field, but it is likely that fayalite is being dynamically driven beyond its equilibrium phase space.

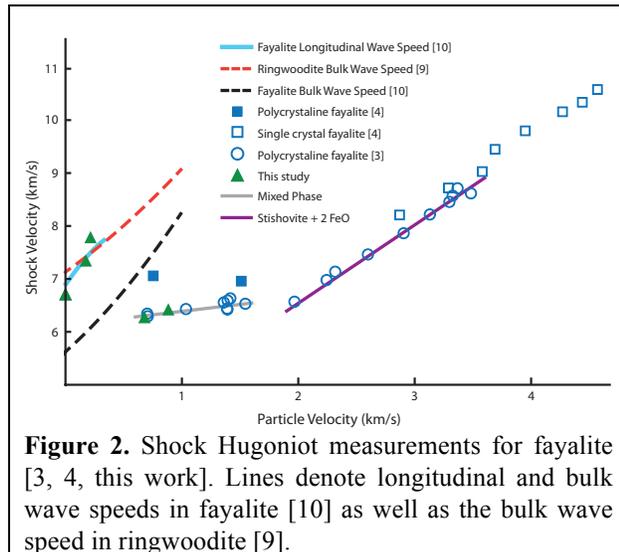


**Figure 1.** Example of a 2-wave shock profile in Rockport fayalite for an impact by a stainless steel 304 flyer at 1.87 km/s.

Coincident with the shock breakout at the down-range free surface, we observe thermal emission corresponding to the irreversible work from the shock. Previous data on Columbia River basalt found that the wavelength-dependent thermal emission was well fit by a two component system: a continuum temperature with a small area fraction of 'hot spots' originating from pores or cracks [5,6]. In contrast, the thermal emission from Rockport fayalite is not consistent with a two-component temperature field. Instead, a broad range of temperatures are inferred. We speculate that the difference arises from the increased effects of grain boundaries due to the longer shock break out time associated with the multi-wave shock front.

Here, we report an upper bound on the post-shock continuum temperature based on the temperature recorded by the 4.8  $\mu\text{m}$  channel (Figure 3). The post-shock temperature upper limits are plotted against the amplitude of the second shock wave in the multi-wave

profile, assuming that the heating from the elastic shock is negligible. The results are consistent with calculations of the post-shock temperature in fayalite from [4]. The heating from irreversible work is a lower in Rockport fayalite than observed in Columbia River basalt [5,6] and comparable to the inferred post-shock temperatures in martian meteorites [7].



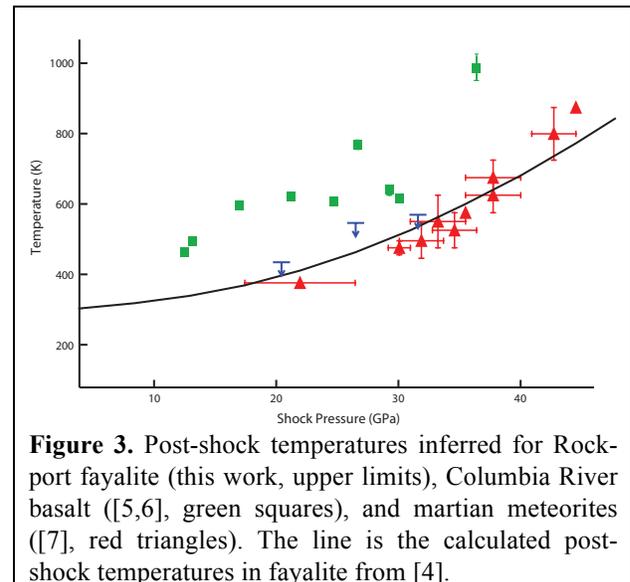
**Figure 2.** Shock Hugoniot measurements for fayalite [3, 4, this work]. Lines denote longitudinal and bulk wave speeds in fayalite [10] as well as the bulk wave speed in ringwoodite [9].

**Results and future work.** Our preliminary experiments have found a dynamic phase change occurring within Rockport fayalite. Previous experiments that did not resolve the first wave have too large an amplitude particle velocity in the tabulated Hugoniot points in the mixed phase region (e.g., see multi-wave profile analysis for H<sub>2</sub>O in [10]). In the mixed phase region, the second wave velocity is consistent with the bulk sound speed in fayalite following the loss of strength in the second shock. Some of our VISAR data display a small amplitude third wave (not shown) that could be a transformation to the high-pressure phases following the shock in the initial structure. Future work will also investigate single crystal measurements of shock and post-shock temperatures for the olivine series.

**Acknowledgements.** This work was supported by NASA MFRP grant NNX11AE96G.

**References:** [1] R. G. Kraus et al. (2010) *EPSL* **289**, 162., [2] S. L. Penfield and E. H. Forbes (1896) *Am. J. Sci.* **1**, 129., [3] S.P Marsh (1980) *LASL Shock Hugoniot Data*, U. California Press., [4] G.Q. Chen and T. J. Ahrens (2002) *PEPI* **134**, 35. [5] S.T. Stewart et al. (2007) *LPSC* **38**, 2413. [6] S.T. Stewart et al. (in prep.) *EPSL*. [7] L.E Nyquist et al (2001) *SSR* **96**, 105. [8] S.T. Stewart & T.J. Ahrens (2005) *JGR* **110**, E03055. [9] S.V Sinogeikin et al. (2003) *PEPI* **136**, 41., [10] S. Speziale and T.S Duffy (2004) *JGR* **109**

B12202



**Figure 3.** Post-shock temperatures inferred for Rockport fayalite (this work, upper limits), Columbia River basalt ([5,6], green squares), and martian meteorites ([7], red triangles). The line is the calculated post-shock temperatures in fayalite from [4].