VAPORIZATION OF PLANETESIMAL CORES DURING ACCRETION.

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Introduction: The iron rich cores of planetesimals will vaporize at the end stages of Earth's accretion. This is not obvious as the previous estimate for the critical shock pressure to vaporize iron was extremely high, 887 GPa [1]. The implications are significant as a partially vaporized core will generate a small size distribution (think spherules) of iron droplets that can easily mix with the mantle of the growing Earth. The added expansion velocity from the vaporizing iron will also decrease the accretion efficiency of iron on the Moon, relative to Earth, generating a difference in HSE abundance between the Earth and Moon [2].

Here we present a new technique that we implemented at the Sandia Z machine to determine the entropy on the Hugoniot and thereby the critical shock pressure to vaporize iron. We find that the shock pressure to vaporize iron is only 507(+65,-85) GPa, which is significantly lower than the previous estimate and is readily achieved during the high velocity planetesimal impacts at the end stages of accretion [3,4].

Experimental Method: The Z machine at Sandia National Laboratory was used to launch aluminum projectiles into pure iron samples at velocities from 15 to 19 km/s. The impacts generated strong shock waves in the iron samples, from 440 to 620 GPa. The iron samples decompressed upon the shock wave arrival at the downrange free surface. The decompressing iron expands across a gap of known distance and impacts a downrange quartz window. Because the impact properties of quartz are so well known [5], the density of iron can be determined by measuring the shock state generated in the quartz.

Density on the liquid-vapor dome Using the technique described in Kraus et al. 2012 [6], we determined the density of iron that is inertially trapped at a state on the liquid-vapor dome. As seen in Figure 1, we constrain the critical shock pressure required for the decompressing iron to reach the 1-bar boiling point by comparing our measured densities on the liquid-vapor dome to the known density of liquid iron at its 1-bar boiling point [7,8].

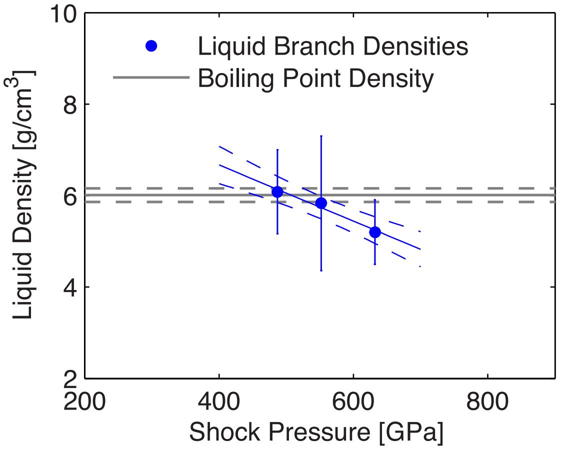

Figure 1: Measured density of iron isentropically decompressed to the liquid branch of the liquid-vapor dome from a shock state on the principal Hugoniot (points) and the density of liquid iron at the 1-bar boiling point (line) [7,8] The intersection between the release densities and the density at the boiling point determines the critical shock pressure for incipient vaporization, 507(+65,-85) GPa. Figure from [2]

Results: The cores of planetesimals will reach a shock pressure of 507 GPa for a collision velocity of 15 km/s [2]. If the plantesimal cores have an initial temperature of ~1500 K, which is reasonable for early in the history of the solar system, then the critical shock pressure for vaporization reduces to 390 GPa, which is attained at an impact velocity of only ~13 km/s. In Figure 2, we present the vaporized fraction of iron core as a function of impact velocity. Also plotted is a histogram of impact velocities for the planetesimal impacts at the end stage of Earth's accretion [3,4].

Discussion and Conclusions: One can see that nearly all of the iron cores will at least be partially vaporized. The large volume change associated with partial vaporization will act to accelerate core material away from the impact site. The expansion velocities will be large enough to gravitationally escape the Moon but not the Earth [2]. Thus, we expect that shock induced vaporization during a high-velocity late veneer leads to a lower concentration of HSEs being retained on the Moon compared to the Earth.

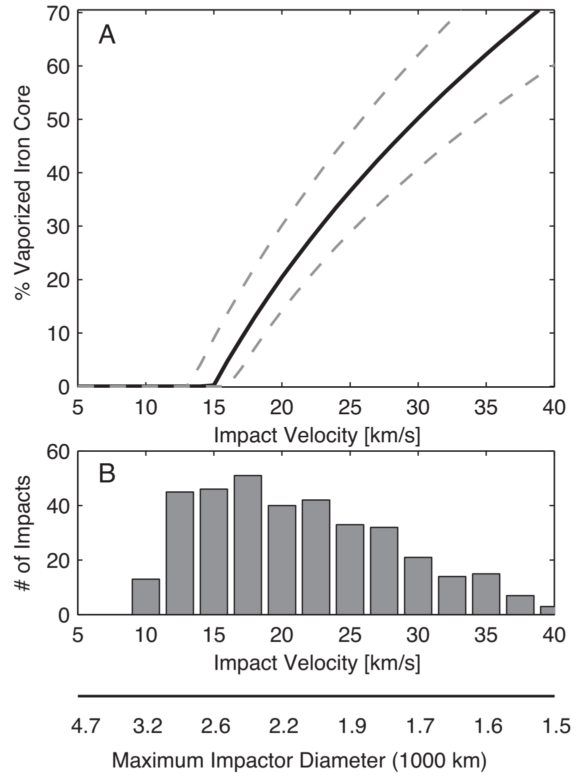

Figure 2. A. Vaporization fraction of iron cores as a function of impact velocity for 300 K initial temperature with 1σ confidence interval. For an initial temperature of 1500 K, the core begins to vaporize at 13 km/s. B. Histogram of impact velocities onto Earth-mass planets from *N*-body simulations of planet formation[ref]. Most impactors onto the Earth and Moon achieve partial vaporization of their cores. At each impact velocity, bodies larger than the estimated maximum impactor diameter may penetrate through Earth's mantle to the core [9]. Figure from [2].

Impact vaporization of plantesimal cores changed the way iron was incorporated into the Earth. Impact generated vapor will condense into small particles (mm to cm length scales) that are distributed globally in a nearly homogeneous manner [10]. This particle size range is small enough to rapidly equilibrate in a magma ocean [11], and the wide dispersal of core material over the surface of the growing Earth greatly increases the volume of magma ocean that interacts with the accreting iron core material. Thus, our results provide a physical mechanism in support of geochemical arguments that moderately siderophile element abundances in Earth's mantle are not inherited from planetesimal mantles [11] and substantial re-equilibration occurred on the growing Earth.

For impacts at the end stages of accretion, shock induced vaporization of planetesimal cores is a relevant and important process that needs to be considered in the study of the early Earth and Solar System.

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