IMPACT-INDUCED DEVOLATILIZATION OF MURCHISON CARBONACEOUS CHONDRITE; J. A. Tyburczy*, B. Frisch, and Thomas J. Ahrens, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125
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Introduction. Impact-induced volatile release during planetary accretion may have played an important role in planetary development and in atmospheric and oceanic formation (1,2,3,4). Previous experimental results indicate that the minerals serpentine and calcite begin to devolatilize (i.e. lose H_2O and CO_2, respectively) upon impact at initial shock pressures of 10 to 15 GPa and completely devolatilize at initial shock pressures of 30 to 40 GPa (5,6). We report here results of shock recovery experiments on Murchison carbonaceous chondrite (C2M) performed to determine the conditions for H_2O and other volatile loss upon impact from material more representative of an accreting planetesimal than single minerals. It is reasonable to postulate that the volatiles of the terrestrial planets arrived in a form similar to carbonaceous chondrite. It is important to study this material directly because shock propagation, and therefore shock-induced devolatilization, in a heterogeneous medium is complicated by local variations in mechanical properties that can lead to localized heating, chemical reaction, and other types of anomalous behavior. Furthermore, the phyllosilicates that comprise the bulk of the matrix of Murchison include a significant proportion of Fe-rich members (7), whereas the serpentine shock recovery work performed to date is confined to Mg end members (6,8).

Experimental Details. The experimental procedure used was similar to that employed in previous solid recovery shock-induced devolatilization studies (6). Vented target assemblies were employed that exposed the samples to the ambient atmosphere during impact. Sample shock pressure was calculated using a one-dimensional impedance match method. In this work we report initial shock pressure P_i as opposed to peak (reverberated) shock pressure P_p because the entire entropy increase of a sample during a shock recovery experiment occurs during the first shock, and because current theoretical models are formulated in terms of shock entropy calculations (3,9,10).

Shock-induced H_2O and total volatile loss were obtained by comparison of analyses of shocked and unshocked material. Total volatile content was measured by thermogravimetric analysis (TGA) using a Mettler Thermoanalyzer 2000C. A heating rate of 5 °C/min, a maximum temperature of 1200 °C, and a N_2 flow rate of 20 ml/min were employed. Water content was determined using a DuPont Moisture Evolution Analyzer with a maximum temperature of 1000 °C using N_2 as carrier gas.

Results and Discussion. Total volatile loss and H_2O as a function of P_i are shown in Figure l. Incipient devolatilization occurs at an initial shock pressure of about 11 GPa; complete devolatilization occurs at about 30 GPa. There is no discernible difference between H_2O loss and total volatile loss as a function of initial shock pressure. Therefore, there is no fractionation of H_2O relative to total volatiles caused by impact-induced devolatilization of chondritic material. The atmospheric (or surficial) complement of volatiles in an atmosphere created by impact-induced degassing of planetesimals will have the same bulk elemental composition as the volatiles contained in the incident material. This conclusion applies strictly only to those volatiles released in an analysis carried out using an N_2 carrier gas. Analysis under oxidizing or reducing conditions would liberate a different complement of volatiles. Furthermore, there are strong indications that the degree of impact-induced devolatilization depends on the ambient atmospheric conditions during the shock experiment (6,10,11). Figure 2 also shows impact-induced H_2O loss for crystal-density (6) and 20% porous (8) serpentine. These data bracket that for Murchison, consistent with the observation that septechlorites are the major H_2O-bearing phase in Murchison.

Figure 2 is a plot of shock-induced volatile loss versus fractional radius for Earth, Venus, and Mars based on the results presented here. For the Earth and Venus, impact-induced devolatilization would have begun when the planetary radii were about 12% of their present day values, and complete devolatilization would have occurred when the planets reached about 27% of their present-day radii. For Mars, incipient and complete devolatilization of incident planetesimals would occur at about 26 and 58%, respectively, of its present day radius.

Conclusion. Impact-induced devolatilization of incident planetesimals would create an extremely non-uniform volatile distribution in an accreting planet. In the absence of thermal effects, the net result would be a core with the volatile content and volatile elemental composition of the incident material, a volatile-depleted 'mantle', and a volatile-rich veneer at the planetary surface. Integrating the curves in Figure 2 with respect to mass indicate that for the Earth, Venus, and Mars, 99.4, 99.2, and 93.2 mass%, respectively, of the incident volatiles end up at the planetary surface at the end of accretion. The possible existence of a planetary magma ocean in the later stages of accretion does not alter the conclusion that a volatile-containing core surrounded by a volatile depleted region exists early in planetary accretion. The existence and longevity of this volatile-rich core will, of course, profoundly affect, and be affected by subsequent planetary differentiation and metallic core formation.

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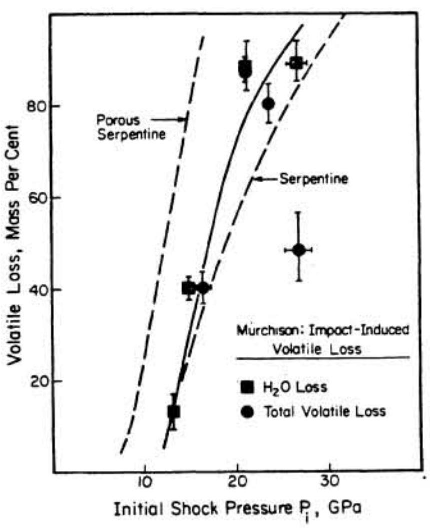

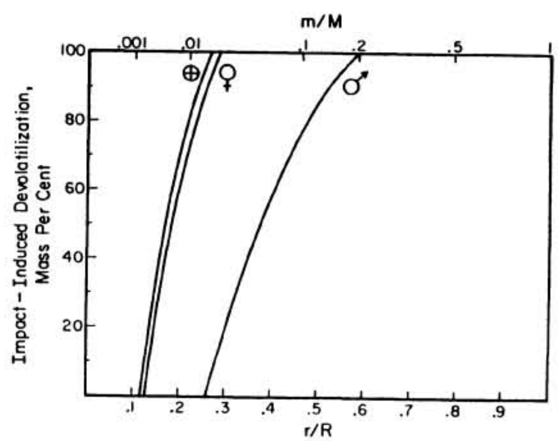

Figure 1. Shock-induced mass loss as a function of initial shock pressure for Murchison. Squares represent H_2O loss; circles, total volatile loss. Solid line is a polynomial fit to the data. Dashed lines are fits to data on impact-induced dehydration of 20% porous serpentine (8) and crystal-density serpentine (6).

Figure 2. Impact-induced devolatilization of Murchison as a function of fractional planetary radius and mass for the Earth, Venus, Mars, respectively.