IMPACT-INDUCED VOLATILE LOSS FROM A CARBONACEOUS CHONDRITE: IMPLICATIONS FOR PLANETARY ACCRETION; B. Frisch, J. A. Tyburczy, and T. J. Ahrens, Seismological Laboratory 252-21, California Institute of Technology, Pasadena, CA 91125.

Introduction. Impact-induced volatile release experiments on the carbonaceous chondrite Murchison indicate that H_2O loss as a function of impact velocity is similar to that of serpentine, whereas the other volatile materials in the meteorite (hydrocarbons, graphite, sulfur) are volatilized less efficiently than H_2O.

Impact-induced volatile release during planetary accretion may have played an important role in atmospheric and oceanic formation (1,2,3). Previous experimental results indicate that the minerals serpentine and calcite begin to devolatilize upon impact at shock pressures of about 10 GPa and completely devolatilize at pressures of 40-50 GPa (4,5). Assuming homogeneous accretion, infalling planetesimals could have achieved impact velocities sufficient to generate these pressures when the Earth's radius was 10 to 15% and 40 to 50%, respectively, of its present value.

We report here results of shock recovery experiments on Murchison carbonaceous chondrite performed to determine the conditions of H_2O and other volatile loss from accreting planetesimals during the formation of the Earth. Preliminary results were reported earlier (1). Devolatilization of chondritic material is of interest for two reasons. First, it is likely that the Earth's volatiles came to the Earth in a form similar to carbonaceous chondrite. Secondly, the previous shock devolatilization studies have been performed on single mineral species; the devolatilization of a heterogeneous material is complicated by variations in shock properties which may lead to localized heating and anomalous behavior.

Experimental Details. The experimental procedure was the same as that employed by Lange and Ahrens (4) in their study of serpentine devolatilization. The Murchison samples were discs 4.4 mm in diameter, 0.5 mm thick, with the surfaces polished flat and parallel. Vented target assemblies were employed that exposed the samples to the ambient atmosphere during the impact event. The assemblies were made of steel (SS304) and projectiles with steel flyer plates were propelled at the target assemblies using the 20 mm propellant gun at Caltech. Impact velocities were between 1.08 and 2.5 km/sec.

The shocked material was removed from the target and metal pieces from the assembly were picked out of the sample. Color segregation of the shocked material occurred; bands of white, grey, and black material were embedded in the steel container. The initial sample shock pressure was calculated using the impedance match technique (6) using the equation of state parameters for serpentine (7). Initial shock pressures are reported rather than peak (reverberated) pressures because most of the internal energy increase (heating) of the sample during the experiment occurs as a result of the initial shock.

Total volatile content was measured thermogravimetrically on a Mettler Thermoanalyzer 2000 C and water content was obtained using a Dupont Moisture Evolution Analyzer. The total volatile and H_2O contents of the recovered, shocked material were compared to analysis of unshocked sample of similar grain size. The total volatile and H_2O losses due to the impact were obtained by difference.

Results and Discussion. Devolatilization data for Murchison are presented in Table 1. Volatile loss as a function of initial shock pressure for calcite and serpentine are shown in Figure 1, along with the data for Murchison. In Murchison, H_2O loss is nearly a factor of two more efficient than total volatile loss. Water loss from Murchison is very similar to water loss from shocked serpentine. Serpentine and other layer silicates comprise 70-80% of the meteorite (8). The large difference between total volatile loss and H_2O loss in Murchison must be attributed to the lack of volatilization of the other major volatile materials in Murchison; graphite, hydrocarbons, and sulfur. Further work is needed on the shock volatilization of these materials.

Laboratory shock pressures can be related to planetesimal impact velocities by assuming uniform, homogeneous accretion, and employing the free surface approximation (9). Minimum impact velocities onto a planetary surface are equal to the escape velocity of the planet. Figure 2 is a plot of shock-induced volatile loss versus fractional radius of the Earth, showing the results for calcite, serpentine, and Murchison. The results for Murchison indicate that devolatilization could have begun when the Earth's radius was only 18% its present value. During this early phase, it is likely that water was released preferentially to the other major volatile components (graphite, hydrocarbons, and sulfur) (4). Thus, preferential burial of carbon (as hydrocarbons or graphite) would have occurred during early phases of accretion.

Conclusions. Shock recovery experiments on the carbonaceous chondrite Murchison indicate that for a given impact velocity, water loss is nearly twice as efficient as total volatile loss. The impact-induced water loss is nearly identical to impact-induced water loss from serpentine. Volatiles were probably driven off accreting material by shock quite early in the growth of the Earth, when the Earth's radius was as low as 15% of its present value. In these early stages of growth, the preferential devolatilization of hydrous phases over carbon- and sulfur-containing phases would have created an early atmosphere dominated by water. Conversely, the volatile budget of the solid portion of the proto-Earth would have been dominated by carbon and sulfur.

Acknowledgments. Supported under NASA Grant NGL-05-002-105. We are grateful to the Center for Meteorite Studies, Arizona State University for samples, and George Rossman, Samuel Epstein and Edward Stolper for advice. We appreciate the use of laboratory facilities operated by George Rossman.

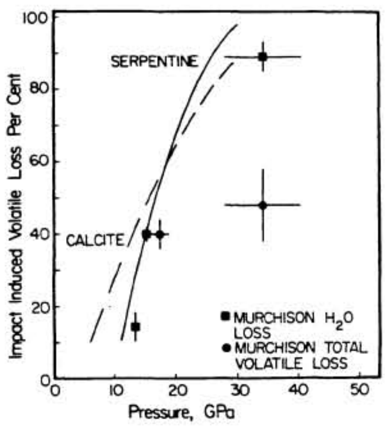

Fig. 1
TJA85019SFD

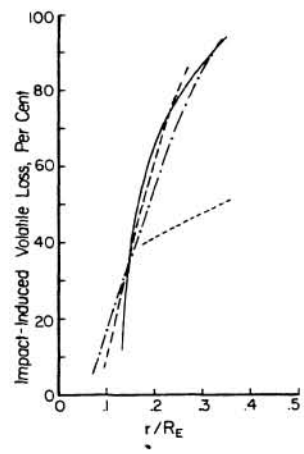

Fig. 2
TJA85020SFD

Figure 1. Shock-induced volatile loss as a function of initial shock pressure for Murchison (this study), calcite (5) and serpentine (4). Solid line is H_2O loss from serpentine, dashed line is CO_2 loss from calcite. Squares are H_2O loss from Murchison, circles are total volatile loss from Murchison.

Figure 2. Impact-induced volatile loss as a function of fractional Earth radius. Solid line, H_2O loss from Murchison; dotted line, total volatile loss from Murchison; dashed line, H_2O loss from serpentine (4); dash-dot line, CO_2 loss from calcite (5).

Table 1. Experimental Results

Shot #	Projectile velocity, km/sec	Initial shock pressure, GPa	Total volatile loss, %	H_2O loss, %
1	2.5±.4	34.1±6.2	48±10	89±3
2	1.4±.1	17.3±1.4	40±3	--
3	1.08±.03	13.3±.4	--	14±4
4	1.21±.02	15.1±.3	--	40±4

References: (1) Frisch, B. and T. J. Ahrens (1983). Shock-induced volatile loss from a carbonaceous chondrite and planetary accretion, *Lunar Planet. Sci. Conf. XV*, 274-275. (2) Arrhenius, G., B. R. De, and H. Alfven (1974). Origin of the ocean. In *The Sea* (E. D. Goldberg, Ed.), pp. 839-861. Wiley, New York. (3) Benlow, A. and T. J. Meadows (1977). The formation of the atmospheres of the terrestrial planets by impact. *Astrophys. Space Sci. 46*, pp. 293-300. Fanale, F. P. (1971) A case for catastrophic early degassing of the earth. *Chemical Geology, 8*, 79-105. (4) Lange, M. A. and T. J. Ahrens (1982a). The evolution of an impact-generated atmosphere. *Icarus, 51*, pp. 96-120. (5) Lange, M. A. and T. J. Ahrens, (1982b). Impact induced dehydration of serpentine and the evolution of planetary atmospheres. *Proc. Lunar Planet. Sci. Conf. 13th, Part I, J. Geophys. Res. 87*, pp. A451-A456. (6) Lange, M. A. and T. J. Ahrens (1984). Shock-induced CO_2 loss from $CaCO_3$: Implications for early planetary atmospheres, in press. (7) Rice, M. H., R. G. McQueen, and J. M. Walsh (1958). Compression of solids by strong shock waves, *Solid State Physics, 6*, 1-63. (8) Marsh, S. P. (Ed.) (1980). *LASL Shock Hugoniot Data*, Univ. of Calif. Press, Berkeley, p. 327. (9) Fuchs, L. H., E. Olsen, K. J. Jensen (1973). Mineralogy, crystal chemistry and composition of the Murchison (C2) meteorite. *Smithsonian Contrib. Earth Sci. 10*, pp. 1-39. (10) Stöffler, D. (1971). Deformation and transformation of rock-forming minerals by natural experimental shock processes. *Fortschr. Miner., 49*, 50-113.