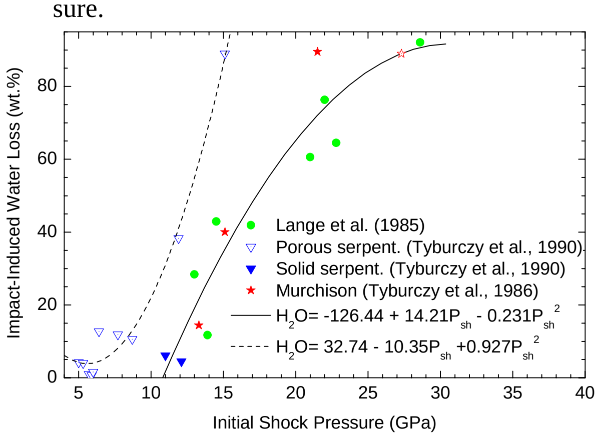
INVESTIGATING THE IMPACT EVOLUTION OF HYDRATED ASTEROIDS. A. S. Rivkin[1] E. Pierazzo[2], [1]Massachusetts Institute of Technology (Cambridge MA 02139, USA; asrivkin@mit.edu); [2]Planetary Science Institute (1700 E. Ft. Lowell Rd., Suite 106, Tucson AZ 85719, USA; betty@psi.edu).

Introduction: The volatile inventory of asteroids is of great interest for the origin of volatiles on all terrestrial planets. Water- and OH-bearing minerals are seen at the surfaces of some asteroids, and in many carbonaceous chondrites, but not all bodies where they may have been expected (e.g., Mathilde and the martian satellites). Some of these bodies may have lost their surface volatiles through low-velocity collisions which could have heated up and destroyed relatively fragile hydrated minerals without producing significant melting of the asteroid.

We are testing this hypothesis through hydrocode simulations to investigate the shock dehydration in low-velocity impacts from which we can extract the relative proportions of dehydrated and still-hydrated material in the impact ejecta.

Volatiles in Asteroids: It has been known for a quarter-century that water and/or hydroxyl (OH) is present on the surfaces of some asteroids in the form of clays and/or salts [1,2,3,4]. It has been known for even longer that clays, salts, and other remnants of aqueous alteration are present in carbonaceous chondrite meteorites [5,6,7]. However, while water-bearing minerals have been detected, it is currently unknown to what extent the surface mineralogy of an asteroid reflects the interior mineralogy. Asteroid mineral fractionation is typically characterized as a thermally driven internal process, but surface fractionation may also be driven externally by impact. Characterizing that fractionation, and the fate of the lost water, is essential for understanding the role asteroids have played in the delivery of volatiles to planetary surfaces during the evolution of the Solar System.

Figure 1: Shock dehydration of serpentine and Murchison samples, as function of the initial shock pressure.



Serpentine is generally considered a good analogue of asteroidal material. The composition of serpentine closely resemble phyllosilicates found in carbonaceous chondritic material [8]. The use of serpentine to represent asteroidal material is justified also by the close agreement of dehydration experiments of Murchison samples [10] with analogous nonporous serpentine experiments [11,12], as shown in Fig. 1. Recent shock experiment studies on serpentine carried out at JSC for this project [9] have not provided conclusive information on sample shock-dehydration. Thus, at present we must rely on results of older studies.

Shock devolatilization experiments for serpentine [11,10,12], have been done using different laboratory techniques (gas or solid recovery method) for measuring devolatilization. Tyburczy et al. [12] have shown that these techniques yield consistent results. Tyburczy et al. [10,12] concludes that initial (Hugoniot) shock pressure is a better parameter to use for determination of shock dehydration, instead of the maximum peak reverberated pressure generally obtained in laboratory experiments. This choice is justified by the utilization of shock entropy calculations in general theoretical models of the impact-induced devolatilization process [13]: Virtually the entire entropy increase of a sample during shock recovery experiments occurs during the first shock, the reverberations being nearly isentropic. By interpolating the experimental data with a second order curve (Fig. 1), we have determined shock levels for various degrees of devolatilization, which are indicated in Table 1. These are the values we use for reference in the hydrocode simulations.

Impact simulations: We use the 3D hydrocode SOVA [14], coupled to the ANEOS equation of state [15] to carry out simulations of an asteroid 2 km in diameter impacting at 45° (most probable angle of impact) an asteroid 200 km in diameter (g=0.07 m/s^2). Impact speeds investigated so far are 1, 3, and 5 km/s (a 10 km/s run was also performed for testing purposes). The original ANEOS equation of state for serpentine [16] has been updated to take advantage of new features in ANEOS, which allow us to improve on the model liquid-vapor phase transition. The introduction of the molecular cluster treatment in ANEOS [17] allows for biatomic molecules in the gas phase, a major improvement over the old atomic gas approach in ANEOS. Combined with the introduction of the Lennard-Jones cold potential for the description of the pressure at the absolute zero temperature, it allows for more realistic descriptions of the liquid/vapor phase change, and of the vapor phase in general.

Results: Figure 2 shows the target region subject to various dehydration shock levels for the impact velocities modeled. The simulations indicate that only the very surface layers of the target experience complete dehydration. At the highest impact velocity, 5 km/s, his dehydration extends over a region roughly equal to the projectile footprint at a depth of at most 250 meters. Very little melting occurs at such low impact velocity. For the lower impact velocities, 3 and 1 km/s, this region is much smaller both in extension and depth. Most of this material will be excavated by the impact and will blanket the region surrounding the crater, leaving behind a cavity where material is, at most, only partially dehydrated.

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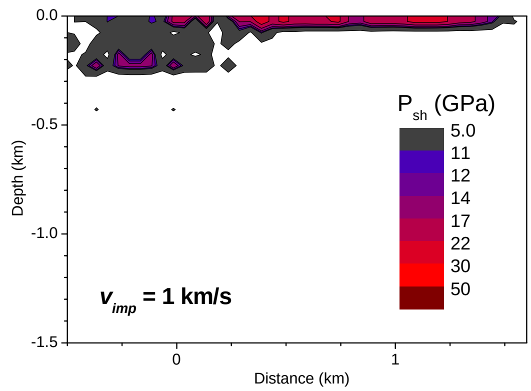
References: [1] Lebofsky L.A. (1978) *MNRAS*, *182*, 17-21. [2] Jones T.D. et al. (1990) *Icarus*, *88*, 172-192 [3] Rivkin A.S. et a. (1995) *Icarus*, *117*, 90-100. [4] Rivkin A.S. et al. (2000) *Icarus*, *145*, 351-368. [5] DuFresne E.R., Anders E. (1962) *GCA*, *26*, 1084-1114 [6] Kerridge J.F. and Bunch T.E. (1979) In *Asteroids* (Gehrels Ed.) 745-764 (Univ. of Arizona Press). [7] Rubin A.E. (1996) *MAPS*, *32*, 231-247 [8] Zolenksy M. and McSween H.Y. (1988) In (Kerrdige-Matthews Eds.) *Meteorites and the Early Solar System*, 114-143 (Univ. of Arizona Press). [9] Rivkin A.S. et al. (2003) *LPSC*, *34*, Abst. #1716. [10] Tyburczy J.A. et al. (1986) *EPSL*, *80*, 201-207. [11] Lange M.A. et al. (1985) *GCA*, *49*, 1715-1726. [12] Tyburczy J.A. et al. (1990) *EPSL*, *98*, 245-260. [13] Ahrens T.J. and O'Keefe J.D. (1972) *The Moon*, *4*, 214-249. [14] Shuvalov V.V. (1999) Shock Waves, 9, 381-390. [15] Thompson S.L. and Lauson H.S. (1972) SC-RR-61 0714, Sandia Nat. Labs. [16] Brookshaw L. (1998) Working Paper Series SC-MC-9813, (Univ. of Southern Queensland, Queensland, Australia). [17] Melosh H.J. (2000) LPSC, 31, Abst. #1903.

Table 1: Impact-induced water loss as a function of initial shock pressure based on interpolation (solid curve, Fig. 1) of available experimental data for serpentine and a carbonaceous chondrite (Murchison).

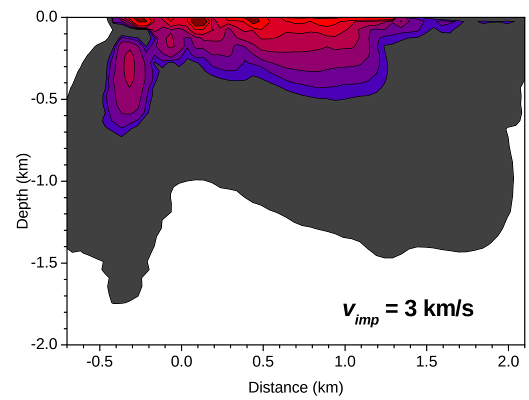
Shock Pressure (GPa)	Shock-induced water loss (wt.%)
11	0 (incipient)
12	10
13.7	25
17	50
22	75
30	100

Figure 2: Dehydration shock levels (in GPa; see Table 1)for an asteroid 2 km in diameter impacting at 45 ° a 200km-diameter asteroids with various impact velocities.

a) v=1 km/s



b) v=3 km/s



c) v=5 km/s