CATASTROPHIC DISRUPTION OF HYDRATED TARGETS: Implications for the Hydrated Asteroids and for the Production of Interplanetary Dust Particles

G. J. Flynn

Dept. of Physics, SUNY-Plattsburgh

and

D. D. Durda

Southwest Research Institute, Boulder, CO

Asteroid Reflection Spectra

- Asteroids are classified on the basis of their reflection spectra, and their surface mineralogy is inferred by comparing these spectra to minerals.

Class	Albedo	Spectrum	Mineralogy
C	low	flat to slightly reddish	hydrated silicates + carbon, organics
D	low	featureless slightly red at short λ very red at λ >5500 Å	carbon organic-rich silicates?
P	low	featureless flat intermediate between C and D	carbon organic-rich silicates?
M	moderate	featureless flat	metal trace silicates?
S	moderate	absorption feature shortward of 7000 Å	metal + olivine + pyroxene

Carbonaceous Asteroids

- The outer half of the main-belt is dominated by asteroids that are classified as C-, P-, or D-type, based on their reflection spectra.
- These low-albedo asteroids are believed to be the parent bodies of the carbonaceous chondrite meteorites.
- Surveys indicate that these carbonaceous asteroids constitute more than 50% of the asteroids in the main-belt.

The carbonaceous asteroid Mathilde (photographed by the NEAR spacecraft).

Hydrated Asteroids

- A significant fraction of the carbonaceous chondrite meteorites are hydrated.
- Some of the C-, P-, and D-type asteroids show evidence for hydration in their reflection spectra.
- Thus, ***a significant fraction of the targets for cratering and collisional disruption in the outer half of the main-belt are likely to be hydrated.***
- Nonetheless, most disruption experiments on natural rock targets have concentrated on anhydrous rocks, such as basalts.

The Tagish Lake meteorite has a matrix dominated by hydrated silicate minerals (NASA JSC photograph).

Disruption Experiments on Hydrated Targets – Prior Work

- Tomeoka et al. [*Nature*, 2003] impacted a small target of the hydrated carbonaceous meteorite Murchison and compared the results to the disruption of Allende, an anhydrous carbonaceous meteorite.
- They found that Murchison disrupted far more easily than anhydrous meteorite targets.
- Tomeoka et al. [*Nature*, 2003] suggested that, since both hydrated and anhydrous asteroids are equally likely to experience collisions, the ease of disruption of hydrated targets might result in ***the hydrated asteroids contributing far more dust to the Zodiacal Cloud than would be expected based on their abundance in the main belt.***

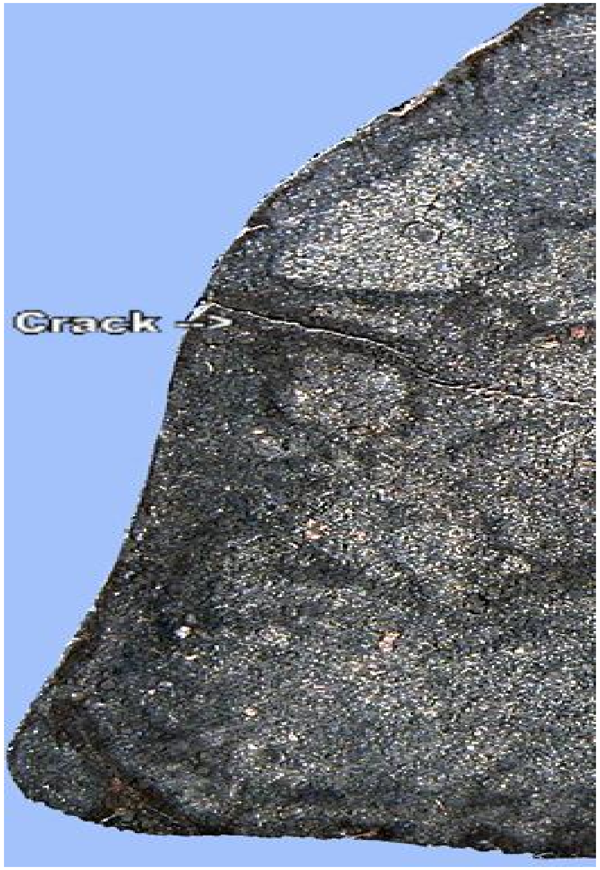
Disruption Experiments on Hydrated Targets – This Work

- We have begun a series of impact experiments on hydrated targets – both terrestrial rocks and meteorites – to compare their response to disruption with the results we have previously reported on anhydrous terrestrial basalt [Durda and Flynn, *Icarus*, 1999] and anhydrous meteorite [Flynn and Durda, *Planetary and Space Science,* 2004] targets.
- For comparison with the anhydrous, basaltic targets we previously disrupted, we prepared targets of "greenstone" -- a basaltic rock in which the olivine and peridotite that made up the fresh rock have been metamorphosed by high pressure and warm fluids into green minerals including epidote, actinolite or chlorite.

Greenstone Targets

- The greenstone appeared to be moderately fractured, which may affect its response to collisions.
- However most meteorites, including the hydrated carbonaceous meteorites, have significant porosity [see Flynn, Moore and Klöck, *Icarus,* 1999], and the most common type of porosity in meteorites is cracks.
- Thus, the pre-existing fractures in our greenstone targets may make it an appropriate analog material.
- We impacted three "greenstone" targets, weighing 83 grams, 229 grams, and 492 grams, spanning the range of anhydrous basalt target masses previously disrupted.

- **A crack is easily visible in this polished surface of the carbonaceous meteorite Kainsaz.**



Disruption Conditions and Results

- In each case, the projectile was a 1/8th inch diameter Al sphere fired at ~5 km/sec using the NASA Ames Vertical Gun Range (AVGR).
- This speed is comparable to the mean collision velocity in the main belt, and is intended to simulate asteroid-asteroid collisions.

High-speed video of target disruption at AVGR.

Table 1

Shot #	Target	Mass of Target (M_T)	Projectile Type	Projectile Mass	Projectile Speed	Mass of Largest Fragment (M_L)	ML/M
030802	greenstone	83 g	1/8-in Al	0.0455 g	4.42-5.35 km/s	2.2 g	0.025
030805	greenstone	229 g	1/8-in Al	0.0453 g	4.86-4.93 km/s	7.1 g	0.03
030810	greenstone	492 g	1/8-in Al	0.0452 g	3.93-3.95 km/s.	227 g	0.46
011006	anhyd. basalt	231 g	1/8-in Al		4.55 km/s	141 g	0.61

Collisional Destruction

- The extent of the destruction in a collision is frequently characterized by the ratio of the mass of the largest fragment produced in the collision (M_L) to the mass of the target (M_T).
- This parameter, M_L/M_T, is 1 for a perfect rebound in which the target emerges unaltered. An M_L/M_T value of 0.5 is generally taken as the boundary between cratering events and catastrophic disruption [see Fujiwara et al., in *Asteroids II*, 1989].
- Thus M_L/M_T ranges from 0.5 to 1 for cratering events, and M_L/M_T <0.5 for catastrophic disruption.
- Each of the three greenstone targets suffered a catastrophic disruption, with the mass of the largest fragment being less than 50% of the target mass (see Table 1).

Comparison with Basalt Destruction

- One of our previous shots into an anhydrous, porphyritic olivine basalt (Shot 011016) almost exactly mimicked the impact conditions experienced by one of the greenstone targets (Shot 030805).
- The mass of the olivine basalt target was 231 grams compared to 229 grams for the greenstone target.
- Both targets were struck by 1/8-inch diameter Al projectiles.
- The projectile speed was 4.55 km/sec for the olivine basalt target and ~4.9 km/sec for the greenstone target.
- Thus, the kinetic energy of the projectile was approximately 20% higher for the greenstone target.

- The results in Table 1 show that the greenstone target was much more severely disrupted than the olivine basalt target.
- The largest fragment from the olivine basalt disruption was 141 grams, and the collision was not quite catastrophic, since the mass of the largest fragment was ~0.6 times the mass of the target.
- The greenstone disruption was super-catastrophic, with the largest fragment having a mass only ~0.03 that of the target.
- The factor of 20 difference in the mass of the largest fragment cannot be explained by the ~20% difference in kinetic energy of the projectile.
- This result suggests that disruption of a hydrated target produces significantly more small debris than disruption of an anhydrous target under the same conditions (although we note this greenstone target contained more fractures than the basalt target).

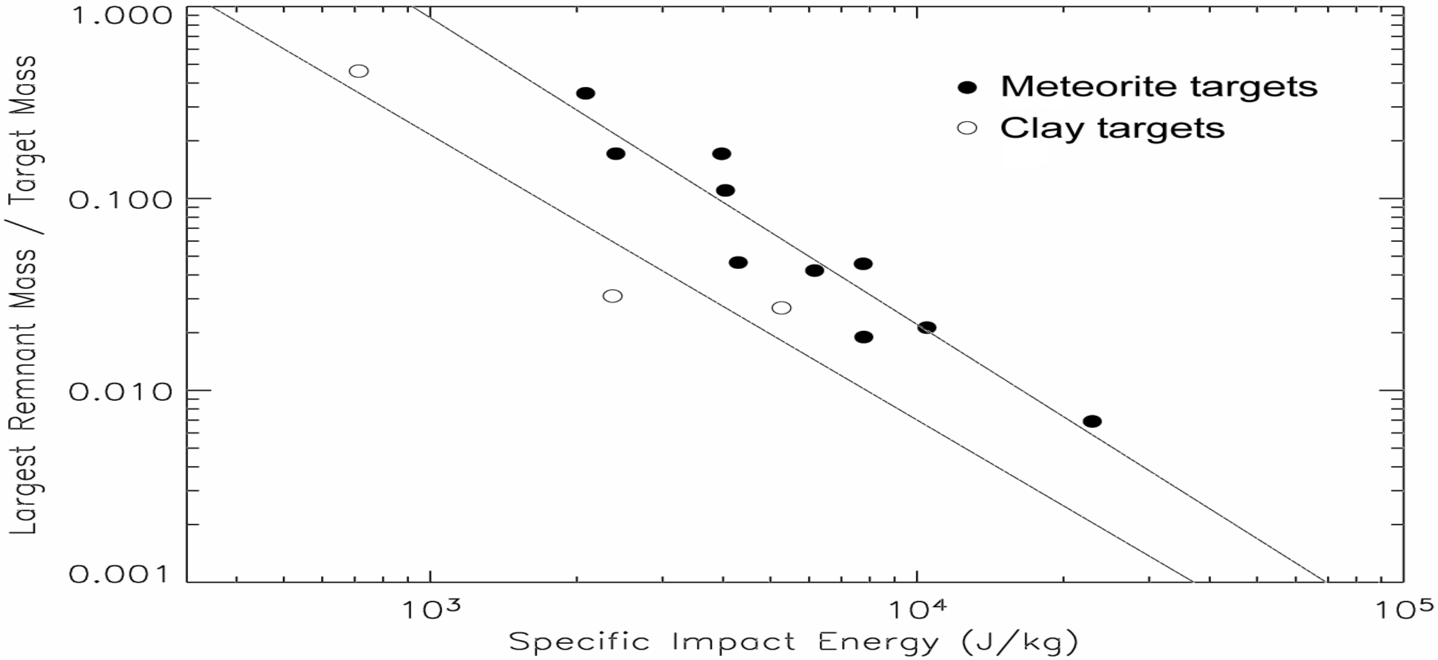
Size Frequency Distribution of Debris

- We recovered all of the debris from the disruptions of both the greenstone target (Shot 030805) and the anhydrous olivine basalt target (Shot 011016) from the floor of the AVGR.
- While we have not yet determined the size-frequency distribution of the debris from the greenstone target, a visual comparison of the debris indicates that most of the mass from the disruption of the anhydrous olivine basalt is in rock fragments while the majority of the mass from the disruption of the greenstone target is in fine material and dust.
- This result is consistent with the observations of Tomeoka et al. [*Nature*, 2003] that ***hydrated targets produce more dust-size fragments than anhydrous targets under the same impact conditions.***

Q^*_D Value for Targets

- Plots of M_L/M_T versus the "specific impact energy" (i.e., the impact kinetic energy per unit target mass) generally show a power-law trend in laboratory impact experiments on many terrestrial materials.
- The energy required disrupt the target material such that the largest fragment has 50% of the mass of the target (a parameter called Q^*_D) can be derived from the slope of this power-law (as discussed by Fujiwara et al. [in *Asteroids II*, 1989]).
- Our hypervelocity impacts into 10 anhydrous meteorite targets, previously reported in Flynn and Durda [*Planetary & Space Science*, 2004], show this power law trend (see Figure 1).

Figure 1



- The ratio of the largest fragment mass to the target mass versus the specific impact energy is plotted for 10 anhydrous chondritic meteorites [from Flynn & Durda, *Planetary and Space Science*, 2004] and the 3 greenstone samples disrupted in this work.
- The greenstone data is plotted as open circles while the meteorite data is plotted as filled circles.

Q^*_D for Hydrated Targets

- A plot of M_L/M_T versus the specific impact energy for the disruption of the 3 greenstone targets is also shown in Figure 1.
- A least-squares fit to the anhydrous meteorite data yields a value of 1419 J/kg for the threshold collisional specific energy (Q^*_D) for the anhydrous meteorites.
- The least squares fit to the greenstone data yields a value of only 567 J/kg.
- These preliminary results indicate that, at the size scale of ~200 gram targets employed in this study, ***disruption of the greenstone targets requires significantly less specific energy than is required to disrupt the anhydrous meteorites.***

Conclusions

- Our preliminary data on three hydrated targets suggests the disruption of hydrated targets requires less specific energy than disruption of anhydrous targets.
- The collisional specific energy (Q^*_D) for the greenstone targets is only 567 J/kg, compared to Fujiwara et al.'s [in *Asteroids II*, 1989] values of Q^*_D ~700 to 800 J/kg for laboratory experiments on glass, basalt, and granodiorite, and 1419 J/kg for anhydrous meteorites [Flynn and Durda, *Planetary and Space Science*, 2004].
- The disruption of hydrated targets produces a significantly higher mass of dust-size particles than we obtained from an anhydrous target disrupted under similar conditions, consistent with results of Tomeoka et al. [*Nature*, 2003].
- Further experiments on hydrated targets, including disruption experiments on hydrated meteorites, like Murchison, are required to develop an understanding of the response of hydrated asteroids to collisions and to assess the rate of dust production from these asteroids.