DISRUPTION OF POROUS PUMICE TARGETS: IMPLICATIONS FOR CRATERING ON 253 MATHILDE.
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Introduction: We previously determined that it requires roughly twice as much impactor energy to disrupt an ordinary chondrite meteorite as a non-porous terrestrial basalt of the same mass [1]. We attributed the "strength" of these chondritic meteorites, the most common type of meteorites that fall to Earth and likely samples of the most common asteroid type in the inner half of the main belt, to their ~10% porosity. Some asteroids have densities, measured by orbital perturbations of other asteroids or close encounters with spacecraft, significantly lower than the minerals out of which they are composed, as inferred from reflection spectroscopy. The bulk density of the C-type asteroid 253 Mathilde was estimated at ~1.3 gm/cc from the NEAR spacecraft flyby [2]. Thus the porosities of some asteroids are significantly higher than the 10% of the ordinary chondrite meteorite targets we disrupted.

We performed disruption experiments on four hydrous CM2 meteorites, but they are also only moderately porous. The largest CM2 meteorite, Murchison, has a porosity of ~22% [3]. But higher porosities have been reported for CI1 meteorites and Tagish Lake. A 47 gram sample of the Orgueil CI1 meteorite has a bulk density of 1.58 gm/cc, and a bulk porosity of 35% [3]. Tagish Lake has a bulk density of ~1.5 gm/cc, suggesting a slightly higher porosity for Tagish Lake than Orgueil [4]. But the scarcity of the CI1 and Tagish Lake meteorites has, thus far, precluded impact disruption experiments on these very porous asteroid fragments.

Some investigators suggest that the extreme porosity of CI1 and Tagish Lake meteorites explains their rarity among falls and finds because these meteorites break into numerous small fragments due to the air pressure experienced during atmospheric deceleration, not surviving as large samples that reach the ground [4]. However, "weakness" for highly-porous meteorites results from a lack of shear and compressional strength, and does not directly correspond to the dynamic strength parameter (Q^*_D) used in disruption modeling of asteroids. Porous targets are more resistant to collisional disruption, requiring a higher specific impactor energy to produce the same effect seen on a more compact target [5]. The high porosity of some asteroids may significantly affect their response to collisions.

Disruption of Extremely Porous Targets: Housen et al. [6] demonstrated that hypervelocity impacts into porous powder targets can produce large, overlapping craters like the ones seen on Mathilde in images taken during the NEAR flyby. They performed impact experiments shooting polyethelene cylinders at ~1.9 km/sec into an ~60% porosity mixture of quartz sand, perlite, fly ash, and water. While these powder targets may simulate the regolith of an asteroid, the large craters on Mathilde are likely to have penetrated deeply into the underlying solid material. We have extended this work, impacting four highly-porous rock targets. The targets were hung in the chamber of the Ames Vertical Gun Range (AVGR) and impacted by Al-spheres shot at the center of each target. We shot three pumice targets, 292 gm, 100 gm, and 93 gm, each having a density of ~0.9 gm/cc, using 1/8th inch Al projectiles fired at ~4.5 km/sec. In addition, we shot a 58 gm pumice target twice, using $1/16^{th}$ inch Al projectiles shot at ~4.5 km/sec. The results are summarized in Table 1.

In our prior disruption experiments using projectiles of the same specific impact energy on non-porous 300 gram basalt or anhydrous meteorite targets the result was catastrophic disruption with the largest fragment being <60% of the target mass [1]. In the case of the 292 gm pumice target and the two impacts into the 58 gm pumice target there was no disruption at all. The projectile produced a "cratering" event rather than a disruption. In the 292 gm target the resulting crater had an unusual, roughly cylindrical, shape with an ~2 cm diameter, about 6 times the projectile diameter and about $1/5^{th}$ the diameter of the target. But it was unusually deep, with a depth to diameter ratio of >1.6. There was very little ejecta, since the mass of the target after impact was 285 gm, 97.6% of its initial value. The cylindrical volume excavated by the projectile contained about 9 grams of material prior to impact, but the total mass loss was only 7 grams. The deep crater coupled with the minimal mass loss suggests that the projectile penetrated into the pumice target, compressing some of the pumice target along its path, until all the energy of the projectile dissipated, rather than disrupting the target. We impacted the 58 g, pumice target twice with a smaller $1/16^{th}$ inch projecttile shot at ~4.5 km/s. These impacts produced overlapping 0.8 cm diameter craters having a depth of 1.1 cm, a depth to diameter ratio of 1.4. Only a small amount of dust ejecta was produced, with the target having a mass of 57 gm after the two impacts. Our impacts of porous, open-pore foam produced a similar result [7].

Table 1: Disruption Conditions and Results

Shot #	Target	Target Mass, M_T	Projectile Type	Projectile Mass	Projectile Speed	Largest Fragment Mass, M_L	M_L/M_T
090221	pumice	292 g	1/8-in Al	0.0450 g	4.99 km/s	285 g	0.976
090233	pumice	100 g	1/8-in Al	0.0450 g	4.86 km/s	30 g	0.300
100611	pumice	93 g	1/8-in Al	0.0450 g	4.61 km/s	34 g	0.166
100609	pumice	58 g	1/16-in Al	0.0063 g	~4.5 km/s*	57 g	0.983
100610	pumice	57 g	1/16-in Al	0.0063 g	~4.5 km/s*	57 g	1.00
011006	anhyd. basalt	231 g	1/8-in Al	0.0453 g	4.55 km/s	141 g	0.610

*Speed was not measured for these projectiles.

The impact into the 100 and the 93 gram targets did produce disruptions, with the largest fragment having a mass of ~30 grams and ~34 grams respectively. But, prior impacts into less porous ~100 gram targets produced much smaller fragments.

Implications for Cratering on High Porosity Asteroids: NEAR spacecraft images of the carbonaceous asteroid Mathilde showed five large (>20 km diameter) craters on the sunlit side of the 66X48X44 km asteroid [2]. This high density of large craters would be impossible to produce in a compact, non-porous target, so Veverka et al. [2] suggested the poor transmission of shock in this highly-porous target allowed production of large, sometimes overlapping craters.

Q^*_D for Pumice Targets: The "strength" or "threshold collisional specific energy," which is the energy required to disrupt the target such that the largest fragment has 50% of the mass of the target (a parameter called Q^*_D), is frequently used in modeling the effects of impacts on asteroids. Q^*_D is derived from the best fit to the power-law plot of the relative mass of the largest fragment (M_L/M_T) versus impactor specific energy [8]. Since no two natural targets have exactly the same shape and distribution of flaws, and no two projectiles ever hit the target in exactly the same spot, the results from several disruption experiments, conducted under similar conditions, must be averaged to provide a reliable result, especially for Q^*_D determination which relies critically on a single measurement, the mass of the largest fragment produced in each disruption.

Since all the pumice disruption results plot to the right of the orduinary chondrite disruption field in Figure 1, the pumice is stronger, i.e., Q^*_D is larger, than the 1419 J/kg we previously reported for the ordinary chondrites. Although more measurements on pumice targets are required to determine Q^*_D, the present data suggests Q^*_D is >2000 for these pumice targets.

Conclusions: Impact experiments into highly porous pumice targets demonstrate that under the same conditions that produce disruption of non-porous targets the impactor can produce a crater-like hole, with very little ejecta. This process is likely to explain the large, overlapping craters on the low density asteroid Mathilde.

Our prior results demonstrate that both the anhydrous meteorites and the hydrous carbonaceous meteorites that we disrupted have properties not completely mimicked by the terrestrial analog materials we used in our initial experiments. Disruption experiments on highly porous meteorite targets, such as Tagish Lake or Orgueil are essential to the understanding of impact processes on their porous asteroid parent bodies.

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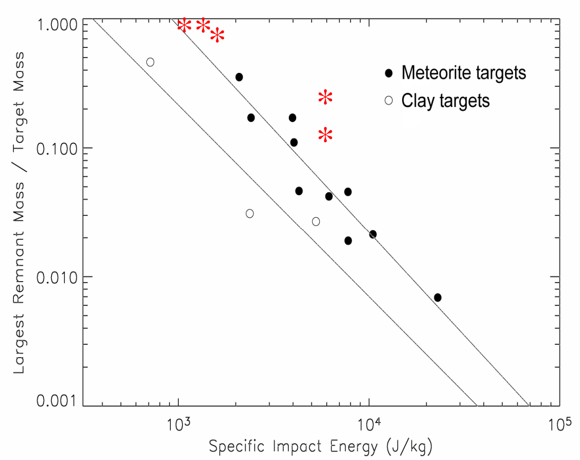

Figure 1: M_L/M_T vs. Specific Impact Energy for the 5 pumice distruptions (*) compared to our prior measurements for 10 chondritic meteorites and 3 clay targets disrupted under similar conditions.