HYPOVELOCITY IMPACTS IN THE ASTEROID BELT;

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The mean impact speed in the asteroid belt is roughly 5 km/s. Coincidentally, that is also roughly the speed of sound in iron-nickel meteorites and in basalt [1,2]. The speed of sound in ordinary chondrites is about 3.5 km/s [3]. Because of this, other things being equal, a higher percentage of impacts into chondritic parent bodies will generate shock waves than impacts into metallic or basaltic bodies. Without a shock wave, much less material may be vaporized and lost to space [4]. Similarly, impacts involving metallic or basaltic impactors may be less likely to disrupt and vaporize the impactor, perhaps resulting in preferential retention of these materials over chondritic material on the asteroidal surface.

To investigate the frequency of "hypovelocity" (slower than the speed of sound in a material) impacts with members of the C, S and M classes, we have calculated probability distributions of impact velocities between the 682 asteroids with $D > 50$ km (a representative sample of asteroids in the main belt) and 21 asteroids of various classes using the technique of Bottke et al. (1994) [5]. We find that peak impact speeds can vary by 2–3 km/s from asteroid to asteroid, and because these speeds are close to the speed of sound in iron-nickel, basalt and ordinary chondrite, these relatively small changes can give rise to large differences in percentage of hypovelocity impacts from asteroid to asteroid. We also find that for a given target, C, S and M-class impactors all have very similar impact speed distributions. Because of these factors, it seems clear that discussions of impact-generated "space weathering" should take not just asteroid size into account, but also compositions and orbits.

Table 1 presents the asteroids studied, with their spectral class and radius. v_{50} is the median impact speed with other main belt asteroids. The parameters $P_{5.5}$ and $P_{3.5}$ are the percentage of impacts occurring at speeds *slower* than 5.5 and 3.5 km/s, respectively. These two speeds are roughly the seismic velocities of iron meteorites (and basalts, coincidentally) and ordinary chondrites, respectively [1-3] These percentages are computed using a sample of all asteroids larger than 50 km, and assuming the distribution of orbits for these asteroids is the same as the distribution of smaller asteroids. Because all asteroids larger than 50 km have almost certainly been found, we feel this is a reasonable assumption. In addition to using a sample of all asteroids, we separately used samples of all C, S and M asteroids larger than 50 km. Because 27% of asteroids larger than 50 km are unclassified in the Tholen taxonomy, however, these analyses are inevitably uncertain.

From Table 1, several things are apparent: First, there is a wide variation in $P_{3.5}$, ranging from 2% for 25 Phocaea to 40% for 24 Themis. This suggests that impact energies vary significantly on asteroids, with any corresponding "impact weathering" processes varying similarly in efficiency. For many of these asteroids $P_{3.5}$ is near 25-30, suggesting that a quarter to a third of all impacts into chondritic targets are *not* in the hypervelocity regime. The value of $P_{5.5}$ is, of course, higher than $P_{3.5}$. For basaltic or metallic asteroids, half or more impacts typically are not in the hypervelocity regime, such as 64% for 4 Vesta, and 80% for 16 Psyche. Even here, however, there is variation between asteroids such as with 216 Kleopatra (35%) and 75 Eurydike (39%) compared to Psyche.

Along with situations where no shock wave is generated in the target, there are situations where no shock wave is generated in the impactor. For impacts on the Earth and Mars, we are accustomed to assuming that impactors are vaporized. However, the lowest possible impact speeds onto the Earth and Mars are still high enough to generate a shock wave in a large impactor and usually vaporize it [4]. Table 1 shows that in a significant number of cases shocks may be generated in a chondritic target, but not in a metallic or basaltic impactor. For instance, if 1 Ceres is chondritic, 67% of impacts by metallic or basaltic impactors are hypovelocity as far as the impactor is concerned, while only 27% are hypovelocity with regard to Ceres or a chondritic impactor. This suggests that more metal from a typical metallic impactor is retained than chondritic material is retained from a chondritic impactor. If true, this could be a reason ordinary chondrite parent bodies in the main belt may have surfaces that don't spectrally look like ordinary chondrites.

References: [1] Carmichael R. S. ed. (1982) *Handbook of Physical Properties of Rocks*, CRC Press, Iowa City. [2] Gorshkov E. S. et al. (1972) *Modern Geology* **3**, 105–106. [3] Wood J. A. (1963) in *The Moon, Meteorites and Comets*, University of Chicago Press, Chicago. [4] Melosh H. J. (1989) *Impact Cratering: A Geologic Process*, Oxford University Press, New York. [5] Bottke W. F. et al. (1994) *Icarus* **107**, 255–268.

Hypovelocity Impacts: Rivkin and Bottke

Asteroid	Spectral Class	Diameter	v_{50}	$P_{5.5}$	$P_{3.5}$
1 Ceres	G	933 km	4.6 km/s	67	27
3 Juno	S	262 km	6.4	35	8
4 Vesta	V	545 km	4.6	64	29
6 Hebe	S	186 km	6.4	33	9
7 Iris	S	222 km	5.2	55	16
10 Hygiea	C	430 km	3.8	82	37
11 Parthenope	S	155 km	4.1	74	36
13 Egeria	G	244 km	6.2	34	11
16 Psyche	M	247 km	4.0	80	35
24 Themis	C	249 km	3.8	85	40
25 Phocaea	S	72 km	8.2	13	2
32 Pomona	S	92 km	3.9	76	37
44 Nysa	E	69 km	4.4	69	33
55 Pandora	M/W?	185 km	4.4	70	28
67 Asia	S	59 km	4.8	61	23
75 Eurydike	M	99 km	6.1	39	8
80 Sappho	S	83 km	5.4	52	17
92 Undina	W	184 km	4.3	73	33
201 Penelope	W	144 km	4.7	66	24
216 Kleopatra	M	100 km	6.4	35	8
584 Semiramis	S	53 km	5.9	42	12

Table 1: Percentage of hypovelocity (subsonic) impacts for 21 asteroids: v_{50} is the median impact speed, $P_{5.5}$ is the percentage of impacts occuring at speeds slower than 5.5 km/s (the speed of sound in iron meteorites). $P_{3.5}$ is the percentage of impacts occuring at speeds slower than 3.5 km/s (the speed of sound in ordinary chondrite). There is a wide range of values in both P columns, showing the wide diversity in impact energies available to different asteroids.

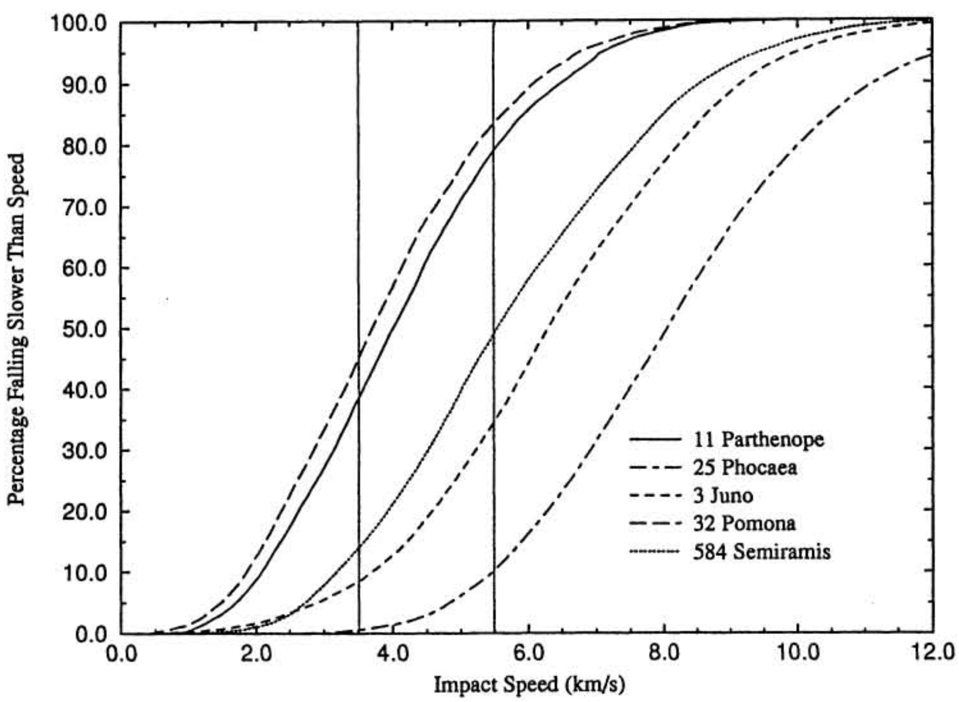

Figure 1: Impact speeds of M-class projectiles into S-class asteroid targets: Lines are drawn at 3.5 and 5.5 km/s. While some S asteroids like 32 Pomona experience no shock at all from a third or more of these impacts, others like 25 Phocaea experience shock from more than 90 % or more of these impacts. In addition, metallic impactors do not experience shock in over 75% of cases for Pomona, but only 10% for Phocaea.