METEORITE ACCUMULATIONS ON MARS. P. A. Bland[1] and T. B. Smith[2], [1]Department of Mineralogy, Natural History Museum, Cromwell Road, London SW7 5BD, U.K., email: phib@nhm.ac.uk, [2]Department of Physics, The Open University, Milton keynes, MK7 6AA, U.K., email: t.b.smith@open.ac.uk

Introduction: Meteorites are found at the Earth's surface because our atmosphere decelerates material from high cosmic velocities to comparatively low impact speeds. In a few arid areas, where chemical weathering is reduced, these samples accumulate over time: stony meteorites in Antarctica have been recovered with terrestrial ages of 2-3 x 10^6 yr [1,2]. Although its atmosphere is much less dense, these factors may also apply to Mars. Previous work has modelled the seismic effects of large impacts on Mars, and their flux at Mars' surface [3], and estimates exists for the contribution of fine-grained meteoritic material (60-1200 µm) to the Martian soil [4], however, the survivability of intermediate meteorite-sized fragments has not been evaluated.

We identify a narrow range of small masses which should impact Mars at survivable speeds. Using published estimates of weathering rates on Mars, we estimate the accumulation of samples at Mars surface.

Background: Defining a maximum survivable impact velocity for small meteorites is problematic. There have been numerous studies dealing with hypervelocity impact, but the focus has been on effects in the target rock, rather than the impactor. The few relevant studies available [5,6] have found that stainless steel projectiles fired at 1.4 km s^{-1} which encountered mostly fines during impact were intact, with a fused/sugary blob of "regolith" welded or sintered to the part of the sphere that made first contact with the target [5]. At 2 km s^{-1} the projectile sometimes fractured during impact, but the pieces were still recognisable. Unpublished work [6] suggests that speeds up to 1.6 km s^{-1} may be survivable for a chondrite, although fracturing may well occur. In this study, we take this speed as an approximate upper limit of survivability for stony meteorites.

The model: Initially, we seek to determine whether it is possible for meteoritic material to reach Mars' surface with speeds less than ca. 1.5 - 2 km s^{-1}. In this model the distribution of masses and speeds of incoming meteoroids are taken to be independent. The normalised distribution of meteoroid atmospheric entry speeds at Mars has been estimated [3,4], and has mean speed of 10.2 km s^{-1}.

We take a similar approach to that of Davis [3], with similar assumptions. We assume: that there is no fragmentation in flight; that an incoming meteoroid is decelerated in proportion to the product of the square of its speed and its cross sectional area; that at the speeds considered, gravity may be ignored; and that as the meteoroid penetrates deeper into the atmosphere it loses mass by ablation at a rate proportional to the product of atmospheric density, cross sectional area, and the third power of its speed. In addition to this, a third equation defines the exponential fall-off with height of atmospheric density.

In this model the rate of mass loss is proportional to the ablation factor, s , which can be expected [3] to take values between 0.01-0.04 s^2 km^{-2}, the higher value corresponding to a more rapid loss rate.

The qualitative results of our calculations appear to be robust under sensible variations of the parameters, showing that an appreciable proportion of meteorites in a narrow range of entry masses (approximately 20-50 grams) can be expected to impact Mars at speeds low enough to be survivable. This is indicated in Fig. 1. In each case, the left set corresponds to the choice s = 0.01 and the right-hand set to s = 0.04. The curves within each set correspond to arrival speeds for meteorites on the ground larger than m_{min} (10 grams or 20 grams) of 1.2 (only seen for m_{min} = 10 grams), and 1.4, 1.6, 1.8, 2.0, and 2.2 km s^{-1}.

The accumulation at Mars: Camera network studies [7] have estimated the flux of material entering the Earth's atmosphere as $\log N = -0.689 \log m + 3.76$ where N is the number of meteorites per year having masses greater than m grams incident on an area 10^6 km^2. Due to its proximity to the Asteroid Belt, this flux may be a factor of 2.6 higher at Mars [8], so we can estimate that ca. 878 meteorites of 20-50 grams (ie. in the mass range of interest) per 10^6 km^{-2} yr^{-1} enter Mars atmosphere. From our analysis, we infer that at least 10% of this material impacts the surface at slower than 1.6 km s^{-1} with a mass greater than 10 grams, and as a crude first approximation, we assume that all this material survives (possibly as discrete fragments). Thus, we can estimate for Mars that ca. 90 meteorites greater than 10 grams (but less than 50 grams) land per 10^6 km^2 yr^{-1} (for samples m_{min} = 10 grams with impact speeds < 1.2 km s^{-1} this number will be approximately 10-20 meteorites in the same area). On Earth, taking into account the weathering decay rate for meteorites in a hot desert [9], the current terrestrial flux produces a steady-state meteorite population density on the ground of ca. 2-3 samples larger than 10 grams per km^2 in a typical hot desert accumulation site [9]. In attempting to constrain the concentration of meteorites on Mars, we need to estimate a weathering decay rate there.

The rate of oxidation of Fe^{2+} ions in equatorial melt-waters in contact with the Martian atmosphere is estimated at 0.4-3.0 x 10^{-3} ppm Fe yr^{-1}, depending on pH [10]. This compares to values of approximately 0.1-1.5 ppm Fe yr^{-1} for the production of Fe^{3+} ions in the weathering of meteorite finds from Antarctica [11], and 10-20 ppm Fe yr^{-1} for the production of Fe^{3+} ions in the weathering of meteorites found in hot desert regions [9]. Thus, the rate of chemical weathering in the equatorial region of Mars may be approximately 3 orders of magnitude slower than weathering in polar regions on Earth, with chemical weathering of meteorites on Mars occurring on a 10^9 year timescale, rather than the 10^5 to 10^6 year timescale observed in terrestrial polar regions.

Given that erosive physical weathering may also be quite minor [12], we may thus expect ca. 10^4 meteorites of mass greater than 10 grams per km^2 (if 1.2 km s^{-1} proved to be a more reasonable upper speed limit on survivability, then the number of samples at the surface would be nearer to 10^3 meteorites of mass greater than 10 grams per km^2), with possibly an excess of iron meteorites due to their greater strength.

Conclusions: Although this estimate may have an error of at least 1 order of magnitude, it indicates that substantial meteorite accumulations should be preserved on Mars. It also indicates that, contrary to the preliminary findings of Viking (which analysed fine grained Martian soil) and some subsequent studies [13], organic material from meteorites may be present in Mars' soil, but as large discrete fragments rather than micrometeorites. Intact carbonaceous chondrites might be expected to partially shield their organic components from degradation by UV, where organic material in a micrometeorite soil component would be rapidly degraded [13].

Our analysis suggests that a narrow mass range of meteoritic material may impact the surface of Mars at survivable speeds. Given the expected low physical and chemical weathering rates, stony meteorites that might have a maximum terrestrial lifetime of ca. 2 million years may be preserved in the Martian environment for billions of years. Not only would this give rise to appreciable meteorite accumulations, it would provide information about the variation in meteoroid flux in the inner solar system over the last billion years. It may also preserve samples that are now rare or absent in the Main Belt, such as mantle material from differentiated asteroids comminuted to small sizes by repeated collisions [14].

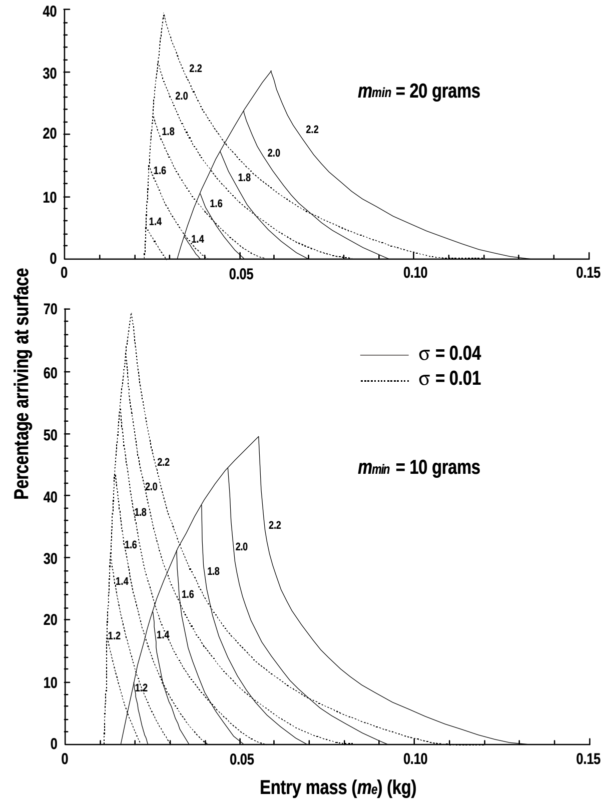

FIGURE 1. Proportion of meteoroids of mass m_e at the top of Mars atmosphere, arriving at Mars surface with mass > m_{min} below a given impact speed, for different ablation factors (σ). The proportion arriving at impact speeds of 1.2, 1.4, 1.6, 1.8, 2.0 and 2.2 km s^{-1} is shown, with m_{min} = 10 grams and = 20 grams.

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