ON THE MASS DISTRIBUTION OF METEORITES AND THEIR INFLUX RATE

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The problem of calculating the mass distribution of meteorites and their influx rate can be resolved into three sections; (a) the flux of meteorites hitting the surface of the Earth must be calculated (b) the mass distribution of these meteorites must be assessed, care being taken to include the effect of fragmentation in the atmosphere and (c) atmospheric ablation, which is a function of mass, velocity, composition and zenith angle must be taken into account. The final result will give the meteoritic influx to the Earth's upper atmosphere and its mass distribution.

Brown (1960) estimated that the observed meteorite fall rate was 0.32 falls $y^{-1}(10^6\ km^2)^{-1}$. By considering specific high population areas of the Earth, Brown (1961) revised this rate upwards to 1.09 falls $y^{-1}(10^6\ km^2)^{-1}$. Millard (1963) in a detailed study of recovery efficiency raised this figure to 15 falls $y^{-1}(10^6\ km^2)^{-1}$. Both authors assumed that the actual meteorite fall rate was not dependent on the season. To compensate for the fact that the observed rate peaks around June and minimises around December they increased the values given above by 50%. Both authors assumed that the fall rate was independent of time of day. To compensate for the fact that the observed rate peaks at 1500 h and minimises at 0300 h they increased the above values by a further factor of 2. A more reasonable assumption, that the meteorite fall rate follows the meteoroid influx rate would change the latter factor to 4. We are left with:

	observed fall rate $y^{-1}(10^6\ km^2)^{-1}$	actual fall rate	actual fall rate using x 4 diurnal factor	falls $y^{-1}\oplus^{-1}$
Brown 1960	0.32	0.96	1.92	980
Brown 1961	1.09	3.27	6.54	3300
Millard 1963	15	45	90	46000

Figures in the last column predict that 120, 400 and 5600 hit the British Isles in the last 200 years. 20 falls were recovered and taking the middle figure as the most reasonable this indicates that about 19 out of 20 are overlooked.

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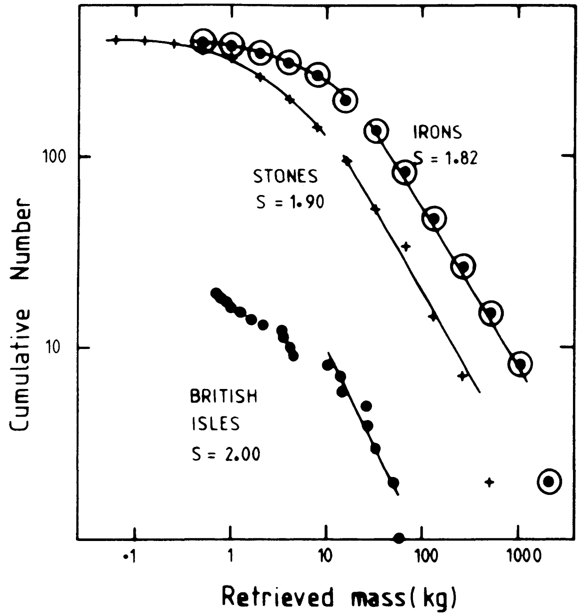

Fig. 1 The cumulative number, N, as a function of retrieved mass, M_e, for iron falls and finds, for stone falls and for all the meteorites retrieved in the British Isles. The gradients of the high mass linear portions are (1–s) where s is the mass distribution index.

The mass distribution of meteorites is shown in Fig. 1. M_e is the mass of meteoritic material retrieved from each fall or find site. On average this represents about 30% of the mass actually hitting the ground although it varies wildly around this value. Brown concluded that the linear trends in the high mass region of Fig. 1 (which to my mind are far from impressive) extend over a much larger range, the deviation at lower masses resulting from excessive atmospheric attrition, and a lower probability of sighting and recovering.

The cumulative flux curves shown in Fig. 2 are produced by taking the following factors into account. Falls divide into 6.6% iron, 1.9% stoney irons and 91.5% stones. Of the 416 stone falls plotted in Fig. 1, 93 have masses greater than 16 kg. Taking the middle line of the above table as the most reasonable one it can be concluded that 675 of the 3300 falls hitting the Earth each year are stones of mass greater than 16 kg. The mass distribution of stones is given in Fig. 1. Thus the flux of stoney meteorites to the surface of the Earth each year, ϕ_S, having retrieved masses greater than M_e kg is given by

$$\log_{10} \phi_S = 3.91 - 0.90 \log_{10} M_e \quad (1)$$

A similar calculation for irons gives

$$\log_{10} \phi_I = 3.11 - 0.82 \log_{10} M_e \quad (2)$$

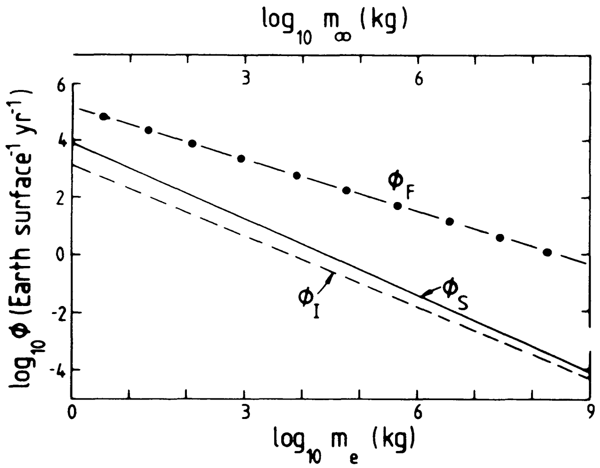

Fig. 2 The cumulative fluxes of meteoritic bodies to the Earth. ϕ_I and ϕ_s are the cumulative numbers of irons and stones having retrieved mass on the Earth's surface greater than M_e. ϕ_F is the cumulative number of fireball producing meteoroids having masses greater than M_∞ above the atmosphere.

The mass range for both these is about $16 < M_e < 1000$ kg. Leaping momentarily to the top of the atmosphere the Prairie network fireball data (McCrosky 1968) gives

$$\log_{10} \phi_F = 5.18 - 0.61 \log_{10} M_\infty \tag{3}$$

where ϕ_F is the number of fireball-producing meteoroids hitting the upper atmosphere of the Earth each year having masses greater than M_∞ kg. The observation range of these data is $1 < M_\infty < 1000$ kg. Plots of equations (1), (2) and (3) are shown in Fig. 2. One way of interpreting Fig. 2 is to consider the 100 heaviest bodies to hit the Earth each year. These have individual masses greater than about 10^5 kg just outside the atmosphere but only masses greater than about 10^2 kg when they reach the Earth's surface. This gives a crude indication that the ablation ratio, M_∞/M_e, is about 1000. Needless to say, if we take the Millard (1963) values the flux increases by x 14, the log ϕ values in equations (1) and (2) increase by 1.14 and the ablation ratio drops to about 60.

ReVelle (1976) has produced an ablation model for meteorite entry into the atmosphere and has plotted a series of curves showing how the ratio between the initial and final mass of a bronzite meteorite incident at an entry angle of 45° varies as a function of mass and heliocentric velocity. Typical values of M_∞/M_e are given in the table below.

Initial mass (kg) / Velocity (km s^{-1})	10^{-1}	10^3	10^7
11.2	3	1.6	1.6
20	10	28	200
35	600	1.3×10^4	10^9
68.94	5×10^{10}	10^{12}	10^{14}

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It is obvious from this table that the Earth's atmosphere acts as an extremely efficient velocity filter in the mass range considered. Only the low velocity meteoroids stand any chance of getting through. (The trend must change at higher mass as is evidenced by the fact that

$$\log_{10} \phi_c = - 11.85 - 2 \log_{10} D$$

where ϕ_c is the production rate ($km^{-2}\ y^{-1}$) on land of craters with diameters greater than D km (see Grieve et al. 1979)). Also the variability of M_∞/M_e as a function of mass indicates that the mass distribution indices of the meteorites recovered from the ground (1.90 for stones and 1.82 for irons) bears scant relationship to the mass distribution of the causative bodies when they are above the atmosphere. For example if M_∞/M_e decreases as a function of M (as it does for a 11.2 km s^{-1} incident velocity) the mass distribution index of the incident bodies is smaller than that of the retrieved meteorites. The fact that the mass distribution index of the fireball meteoroids is about 1.61 supports this supposition. If, as is the case for 20 km s^{-1}, M_∞/M_e increases as a function of mass the mass distribution of the incident bodies is greater than that of the retrieved meteorites. As there is no simple power relationship between M_∞ and M_e (see ReVelle 1976) a constant mass distribution index for the incident bodies will result in a variable index (as a function of mass) for the retrieved meteorites. The unimpressive linearity of the high mass regions of Fig. 1 supports this conclusion.

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DISCUSSION

Cook: The atmosphere acts as a filter, admitting as meteorites those bodies below crater producing size (10^7-10^8 kg, Hughes) which approach the Earth in orbits of low eccentricity and low inclination.

Lokanadham: The mass distribution index for meteorites seems to be the same as that for sporadic meteors. Is this to be expected?
Hughes: No. They seem to me to be completely unrelated physically.

ReVelle: In comparing the Prairie Network fireball data with the distribution of recovered meteorites, I assume that you used the photometric mass of Ceplecha and McCrosky (1976). I contend that this mass value is an increasingly poor approximation of the "true" pre-atmospheric mass for progressively larger bodies, due partly to fragmentation, to the uncertainty in luminous efficiency, and other factors.
Hughes: I agree that there are problems here. The photometric mass is probably too small, but I don't think it is out by more than a factor of 10.