

THE SPACECRAFT DETERMINED MICROMETEOROID FLUX AND ITS APPLICATION TO PROBLEMS IN LUNAR RESEARCH. H. Zook, NASA Johnson Space Center, Houston, TX 77058.

It was noted early in the Lunar Sample Analysis Program that the flux of meteoroids derived from spacecraft measurements was about an order of magnitude higher than the meteoroid flux obtained from lunar rock data (1). The "lunar flux" was derived by dividing an observed areal density of microcraters by a lunar surface "exposure age" obtained from solar flare track measurements. However the uncertainties in determining meteoroid masses from both spacecraft and lunar data appeared large enough so that, within the parametric uncertainties, the differently determined meteoroid fluxes might well be in agreement (2). Most authors (e.g., 3, 4) seemed to prefer the lower fluxes derived from lunar rock data.

It will now be demonstrated that the "high" flux is the correct one. The primary source of data are the spacecraft window data which are especially suitable for comparison with the lunar meteoroid impact data. One need only compare impact pits of a certain size on the windows with those of the same size on lunar rocks. The different kinds of glass involved should require only small corrections. The main problems arise in correcting the spacecraft data for "gravitational" (including spacecraft orbital velocity derived) flux increases from Moon to Earth and in shielding by the Earth, the Moon, and spacecraft structures.

The meteoroid fluxes so derived are shown in Table 1. The gravitational increase factor is obtained by comparing the Lunar Orbiter 1 through 5 data with near-Earth data obtained with identical sensors (or nearly so) on the Explorer 16 and 23 satellites. The gravitational increase factor chosen from this data is 2.7. The Gemini and Apollo window data were reduced by Cour-Palais (5) assuming a gravitational increase factor of 1.9, for those missions which were near-Earth. Thus a slight reduction of his flux should be made at the Moon. However, the statistically somewhat more important Skylab data gives a flux of $0.016/(\text{cm}^2\text{-yr})$ for meteoroids producing $20 \mu\text{m}$ diameter and larger pits at the Moon.

There is evidence (6) that loosely bound dust is shielding exposed rock surfaces from impacts by meteoroids in the sub-micrometer range. There is, therefore, reason for concern that such shielding might greatly reduce the number of impact pits in the $20 \mu\text{m}$ range. Such shielding by dust, if occurring, does not appear to be significant, however. The ratios of the number of $20 \mu\text{m}$ diameter pits to the number of $100 \mu\text{m}$ diameter pits on lunar rocks 12054, 15205, and 60015 were 12.5, 4, and 5, respectively. Of the 27 impact pits with pit diameters larger than $20 \mu\text{m}$ observed on all the spacecraft windows, 4 had pit diameters larger than $100 \mu\text{m}$ (7) for a ratio of ~ 7 for $N(\geq 20 \mu\text{m})/N(\geq 100 \mu\text{m})$. Variations in the lunar data are very likely due to the statistical uncertainty of the number of $100 \mu\text{m}$ pits for 15205, the possibly incomplete microscopic data at the $20 \mu\text{m}$ size level for 60015, and the difficulty of matching together counts taken at different magnifications on 12054. The evidence, indeed, is that there is negligible suppression, due to dust, of $20 \mu\text{m}$ diameter pits relative to $100 \mu\text{m}$ diameter pits on these rocks.

Spacecraft observations can now be directly applied to lunar data to give us absolute, present-day, erosion and glass production rates on lunar rocks. A fit to a variety of lunar rock impact pit data is given by Fechtig et al. (2) and, when normalized to the flux of $20 \mu\text{m}$ in diameter and larger pits suggested here ($0.015/\text{cm}^2 \text{ yr}$), gives

$$f = \begin{cases} 3 \times 10^{-5} D_p^{-1} & D_p \leq 0.02 \text{ cm} \\ 1.29 \times 10^{-9} D_p^{-3.57} & D_p \geq 0.02 \text{ cm} \end{cases}$$

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where D_p is pit diameter in cm and f is cumulative flux in number/cm² yr. Assuming that a crater volume (pit plus spall) can be modelled by a cone of depth $D_p/2$ and of diameter $4D_p$, the above flux gives an erosion rate of 1.7 mm/10⁶ yr. This is in the range given earlier by Gault et al. (1) and also corresponds closely to the "high" flux of Hörz et al. (3). A glass production rate is similarly derived where the initial glass volume produced in a pit is assumed given by a hemisphere of diameter D_p and depth $D_p/2$ (a small fraction of this - perhaps 10% to 20% - will be vapor). The derived glass production rate is 6.4×10^{-8} g/(cm²-yr). Pits larger than about 100 μ m appear to be only the remnant bottom of an assumed original hemispherical pit. Therefore it is felt that the effective pit diameter should probably be increased by about 25%. This gives a factor of 2 more glass produced. At a density of 3 g/cm³ the glass production rate from pristine lunar rocks is about 0.04 cubic cm per cm² of surface area per 10⁶ yr. This rate of glass production is 14 times greater than suggested by Gault et al. (1), but is in the range suggested by Zook (8). It should also be possible to model agglutinate production in the lunar soil if the flux and size of meteoroids larger than about one centimeter in diameter can be correctly estimated.

Finally, the meteoroid flux given in this abstract has other important consequences. If the areal densities of 20 μ m and larger impact pits on rocks 12054, 15205, and 60015 are divided by the present production rate of 0.015 pits/(cm² yr), lunar surface exposure ages for these rocks are obtained that are about 6 times younger than the solar flare ages reported for these rocks (9). These results appear to imply one of the following consequences: (a) The meteoroid flux has changed in time and was much less $\sim 10^4$ yr. ago, (b) the present assumed solar flare track production rate is wrong and should be about 6 times greater, (c) the solar flare track production rate has varied with time with large increases from 10^4 to $\sim 3 \times 10^4$ yr. ago, or (d) some combination of above. These alternatives will be discussed more fully later.

References:

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Table 1. Meteoroid Impact Rates Obtained from Various Spacecraft

Spacecraft	Cell thickness or pit diameter	Punctures or impacts	Rate (no./cm ² -yr)	Shielding correction ⁽¹⁾	Unshielded rate (no./cm ² -yr)	Ratio to Lunar Orbiter	Rate at ⁽²⁾ Moon (no./cm ² -yr)
Lunar Orbiters ⁽³⁾ 1 thru 5	25 μm (Be-Cu)	22	0.00584	0.12	0.0066		0.0066
Explorer 16	25 μm (Be-Cu)	44	0.0123	0.252	0.0164	2.49	0.0061
Explorer 23	25 μm (Stainless steel)	50	0.0139	0.279	0.0192	2.92	0.0071
Explorer 16	50 μm (Be-Cu)	11	0.0063	0.252	0.0084		0.0031
Explorer 23	50 μm (Stainless steel)	74	0.0079	0.279	0.0110		0.0041
Genini and Apollo windows	≥20 μm (fused silica)	9					0.015 ⁽⁴⁾
Skylab command Module windows	≥20 μm (fused silica)	18	0.027 ⁽⁵⁾	0.345	0.0417		0.016
HEOS II	"sporadics"	2	0.024	~0	0.024		0.024

(1) Obtained by assuming the spacecraft is in circular orbit at an altitude given by its semi-major axis and evaluating shielding by the Earth or the Moon, respectively.

(2) The "Rate at Moon" is obtained by dividing the near-Earth rate by 2.7. This "gravitational increase" factor is obtained by comparing Explorer data with Lunar Orbiter data.

(3) Lunar Orbiter and Explorer 16 and 23 data from refs. (10) and (11).

(4) Reduced to unshielded lunar conditions by Cour-Palais (1974).

(5) Cour-Palais, B.G. (personal communication).