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MICROCRATERS ON LUNAR ROCKS, D. A. Morrison, D. S. McKay, NASA-MSC, Houston, Texas 77058, H. Moore, U.S.G.S., Menlo Park, California 94025, D. Bogard, G. Heiken, NASA-MSC, Houston, Texas 77058

Microcrater population distributions have been determined on part or all of the surfaces of ten lunar rocks from Apollo 12 and 14. Lunar surface orientations of three rocks not documented by surface photography were determined by microcrater distribution studies.

Flux Rates: A current estimate of the influx of meteoroids is expressed by two equations (1):

$$\emptyset_1 = 10^{-14.37}\ m^{-1.21}\ (10^{-6} \leq m \leq 10^{0}\ \text{gms})$$

$$\emptyset_2 = 10^{-14.34}\ m^{(1.58\ -\ 0.63\ \log_{10} m)}\ (10^{-12} \leq m \leq 10^{-6}\ \text{gms})$$

where $\emptyset_1$ and $\emptyset_2$ are numbers of impacts/meter^2/sec/2π steradians and m is the particle mass in grams. A second estimate is provided by Whipple, Curve B (2) expressed as:

$$\emptyset_3 = 10^{-13.80}\ m^{-1.0}$$

These estimates bracket calculated flux using the particle track age of Fleischer et al (3) and the crater counts of Horz et al (4) for the glass surface on rock 12017G which indicates a flux of approximately $10^{-7.4}$ particles/meters^2/sec of mass 10^{-6} grams and larger. Particle density is taken as 0.44 gms/cc - in keeping with Whipple's density estimates.

We set a lower limit of the influx of meteoroids on the lunar surface with crater population and exposure age data from rock 14301. This flux predicts a minimum infall of approximately $10^{-8.8}$ particles/meters^2/sec of mass 10^{-6} gms for particles with a density of 0.44 gms/cc. The rate is a minimum because the exposure age of 6.5×10^5 years is based upon an Al^{26} measurement which does not distinguish between direct exposure of the rock and burial of a few mm. The true flux, therefore, could be higher but not lower. The data from 14301 is in fair agreement with the flux suggested by crater counts of Bloch et al (5) and particle track ages of Crozaz et al (6) for one surface of rock 12063. For the other surface of 12063, the flux obtained may be a minimum because it may be in a steady-state and therefore record fewer events than the number actually occurring. Both fluxes are less than that obtained from rock 12017G and the current estimates of flux by a factor of about 10 at a mass of 10^{-6} gms. Fluxes extrapolated to 1 gram particle sizes using the equations for $\emptyset_1$ and $\emptyset_3$ are higher than those obtained by Lathom et al (7) for that mass.

Mass Distribution: Crater size frequency and mass distributions have been determined primarily by optical methods which are unreliable for small craters on rock surfaces (3). To extend the crater size-frequency distribution below optical resolution an exterior chip of breccia 12073 was examined using a Scanning Electron

Microscope (SEM). A 40X mosiac of 44.22 mm^2 of the surface showed a total of 74 craters. The crater size distribution curve has a relatively constant slope of -1.9 down to a size of about 50 microns (pit diameter) where it levels out rapidly. The smallest crater measured has a central pit diameter of 15 microns corresponding to a mass of $10^{-10.6}$ gms.

The glassy liners of many of the 74 craters detected by the scan were examined for superposed microcraters. None were found that could be identified unambiguously as microcraters produced by hypervelocity impact. A further search was made of smooth crystal faces on the rock surface and a total of 37 faces with an aggregate area of 0.59 mm^2 were scanned at magnifications ranging from 500-2000X. No craters larger than the crater resolution limit of 5 microns were seen. Although an area this small is not ideal statistically, it sets an upper limit of 1 crater per 0.59 mm^2, or about 170 craters per cm^2, larger than 5 microns on this steady state breccia surface. This limit agrees with a projection of the distribution curve for the larger craters to a size of 5 microns. The upper limit of 170 craters/cm^2 larger than 5 microns is less than that obtained by Bloch et al (5).

Because the mass distribution obtained by the scanning microscope on a breccia surface is in disagreement with those obtained by other workers (5) on glass surfaces, we have made a preliminary scan of a glass chip from the surface of rock 15015. This scan showed a higher percentage of craters per unit area of less than 5 microns diameter, but it also indicated that a wide variety of impact-like features occur, some of which could be attributed to low velocity, possibly secondary particles whereas others may represent vesicles. We conclude that there is a lack of criterion for distinguishing primary microcraters from features of similar morphology, and that crater counts of glass surfaces may result in unusually high numbers of microcraters of less than 10 microns diameter per unit area if all crater-like forms are considered to be primary impact craters. Until unambiguous criteria can be established, only craters in crystalline surfaces should be used in determining flux of micron size particles. This is particularly true in the case of spherules.

The Steady State: Ideally, the cumulative frequency distribution of craters on rock surfaces becomes independent of time when surfaces reach a steady-state. Our understanding of the steady-state surface for a rock is unclear at this time. The youngest dated rock surface (12017G, 9×10^3 years) yields a flux rate and frequency distribution which is in reasonable agreement with current estimates of the crater production frequency for the moon. Older rock surfaces ($>10^6$ years) have fewer craters than expected by a factor of at least 1/5. This decrease may be the result of 1) approaching or attaining the steady state, 2) a decrease in crater production with time, i.e. the present flux rate is higher than the recent past, 3) the orientation of the rock on the lunar surface, 4) partial covering of rock by fines, or 5) any combination of these.

Because there are only two data points for flux rates, the flux of micrometeorites is not known with certainty, and the time required to attain the steady state remains somewhat speculative. We assume that all cratered surfaces which are well-rounded are in the steady state, because most or all of the original surface has been removed. By this criterion, most of the rock surfaces examined have steady-state microcrater populations. Optically determined crater-size distribution curves for such surfaces exhibit the general characteristics described by Horz et al (4). However, some rocks have steady-state populations considerably in excess of the 10% saturation value of Gault. Such large populations (e.g. 124 craters/cm^2 larger than 75 microns

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central pit diameter on a surface of 14306) occur on surfaces which have spall diameter to central pit diameter ratios of 3.4/1.

Exposure Age: Studies of craters on several rocks indicate that an estimate of surface residence time may be obtained by combining crater populations with flux rates. We calculate that 14053 was exposed for approximately 1.1×10^6 years assuming 1) the crater population has not been severely biased by an approach to the steady state and 2) the crater population of 14306 is the steady-state. We also calculate a surface exposure of 1.2×10^6 years for rock 14311 with the same assumption concerning steady state. These estimates can be tested. In both cases the rocks are not rounded but do show some signs of wear. Flux rate and crater distribution data indicate that rock 14313 had a five-stage surface history with a surface exposure time 23×10^6 years or larger. The rock assumed five distinct positions on the surface of greater than 10×10^6, approximately 2.5×10^6, and 1×10^6, collectively and greater than 10×10^6, and greater than 1×10^6 years duration successively.

1. Soberman, R. K., 1971, The terrestrial influx of small meteoric particles, Reviews of Geophysics and Space Physics, p. 239.
2. Whipple, F. L., 1963, On meteoroids and penetration, J. Astrophys. Res., 68, p. 4929-4939.
3. Fleischer, R. L., Hart, H. R., Comstock, G. M., Evwaraye, A. O., 1971, The particle track record of the Ocean of Storms, Proceedings of the Second Lunar Science Conference, Vol. 3, p. 2559-2568.
4. Horz, F., Hartung, J. B., Gault, D. E., Micrometeorite craters on lunar rock surfaces, Lunar Science Institute Contribution No. 09.
5. Bloch, M. R., Fechtig, H., Gentner, W., Neukum, G., Schneider, E., 1971, Meteorite impact craters, crater simulations, and the meteoroid flux in the early solar system, Proceedings of the Second Lunar Science Conference, Vol. 3, p. 2639-2652.
6. Crozaz, G., Walker, R., Woolum, D., 1971, Nuclear track studies of dynamic surface processes on the moon and the constancy of solar activity, Proceedings of the Second Lunar Science Conference, Vol. 3, p. 2543-2558.
7. Lathom, G. U. Ewing, M., Press, F., Sutton, G., Dormon, J., Nokamura, Y., Toksoz, N., Duennebir, F., Tommlein, D., 1971, Passive Seismic Experiment, Apollo 14 Preliminary Science Report, NASA SP-272, p. 133.