No. 136 TERRESTRIAL, LUNAR AND INTERPLANETARY ROCK FRAGMENTATION (SYNOPSIS)*

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ABSTRACT

Table 1 presents collected data on mass distributions of fragmented rocks. Mass distributions are typically power-law functions with exponent *b*; the *b*-values (slopes on log-log plots) increase as the samples are exposed to greater grinding and crushing or greater energy expenditure per particle. Plots of mass distributions can be used to interpret terrestrial and extraterrestrial rock samples.

Rocks fragmented under different conditions have significantly different mass distributions. This fact has been widely treated, both as a problem of theoretical physics (Gilvarry, 1961) and as a geological and industrial tool (Krumbein and Pettijohn, 1938; Krumbein and Tisdel, 1940; Pettijohn, 1957). It has also been applied to meteoritics (Hawkins, 1960) and to the moon (Hartmann, 1965; Jaffe, *et al.* 1966; Rennilson, *et al.*, 1966; Shoemaker, *et al.*, 1968; Meloy and O'Keefe, 1968; and others). The purpose of this paper is to re-analyze some of the older data and present some new experiments in an effort to investigate the properties of the lunar surface, asteroids, and meteorites.

One problem in this field is that the theoretical parameters and the way of expressing the data vary widely; mass distributions may be plotted as incremental histograms, cumulative mass of particles smaller than x, and cumulative mass of particles larger than x, etc. I have attempted to present the data homogeneously below.

It is well-known that rocks fragment according to a power law mass distribution

$$N = Cm^{-b}$$

where $N =$ cumulative no. fragments of mass $> m$
$b =$ negative slope in a $\log N - \log m$ plot
$C =$ constant 1)

The slope b is found to be variable, depending on the conditions of fragmentation. For example, rocks subjected to a single fragmenting blow break with relatively low b values, typically 0.5 – 0.7. Upon grinding, sizes become more uniform and the slope steepens to 1 and even greater values under certain conditions.

The full paper discusses theoretically the conversion from this law into other forms that have been used in the literature; examples of these are incremental logarithmic distributions, incremental linear distributions, cumulative distributions of mass smaller than m, and distributions of size instead of mass.

A number of experimental data are given in the full paper. Various rock samples were experimen-

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Fig. 1 Rock debris scattered by the 1924 steam blast explosion of Halemaumau crater, Volcanoes National Park, Hawaii. In the foreground is a secondary impact crater of roughly two meters diameter. Photographed in 1968 by the author.

tally fragmented or observed in the field in a naturally fragmented state. An example of the latter case is shown in Fig. 1. This strewn boulder field was created during the 1924 steam blast eruption of Kilauea Volcano, Hawaii. In the foreground of Fig. 1 is a secondary impact crater. Some of these craters had fragmented projectiles associated with them. Fig. 2 shows the mass distribution of fragments of such a shattered projectile and Fig. 3 shows the mass distribution of the strewn boulders that were blown out by the violent steam blast. The shattered rock has a b-value of 0.68 while the blast debris has a value of 0.92.

This illustrates the general principal that rocks subjected to "simple fragmentation" have b-values close to ⅔, while any tendency toward "multiple fragmentation" or regrinding processes increases the b-value. The Kilauea debris, for example, were probably subjected to violent grinding and multiple collisions during their ascent in the vent of the volcano.

Table 1, from the full paper, summarizes the data gathered and shows a gradual increase in the b-value with increasing violence or regrinding in the fragmentation process.

Table 2 shows a selective comparison of terrestrial and extraterrestrial samples, from which cer-

TABLE I

TERRESTRIAL FRAGMENT SAMPLES

SAMPLE DESCRIPTION	b	EST. PE	CHARACTERISTIC PARTICLE SIZE (CM)
Singly fractured basalt blocks	0.60	0.04	1.0
Artificially crushed quartz	0.63	0.04	0.05
Fragments near a secondary impact crater[a]	0.64	0.04	8.0
Gravel in a dry wash[a]	0.67	0.05	3.0
Multiply fractured basalt blocks	0.67	0.06	1.0
Fragments near a secondary impact crater[a]	0.68	0.02	5.0
Disaggregated gneiss	0.71	0.06	0.1
Disaggregated granite	0.74	0.06	0.02
5 Disintegrated igneous boulders (avg.)	0.79	0.05	0.05
Disintegrated igneous glacial boulder	0.80	0.05	0.05
2 Sandy clays	0.87	0.05	0.05
Detritus from weathered gneiss	0.89	0.05	0.05
Ejecta from hypervelocity impacts	0.9	0.1	0.3?
Ejecta from steam blast explosion[a] (Halemaumau)	0.92	0.02	5.0
12 Terrace sands and gravels	0.94	0.06	0.02
Glacial till	0.96	0.03	0.05
Tuff	1.03	0.05	0.1
Sand from 2 washes	1.11	0.09	0.1
Ash and pumice (Valley of Ten Thousand Smokes)	1.18	0.1	0.8
Ejecta from hypervelocity impacts	1.2	0.2?	10^4

[a] Surface, not volume, distributions; uncorrected. "Gravel in a dry wash" requires an additive correction of about 0.2. The other values represent debris on a pre-existing surface and must be nearly correct.

TABLE II

SELECTED TERRESTRIAL AND EXTRATERRESTRIAL OBSERVATIONS

TERRESTRIAL SAMPLES		EXTRATERRESTRIAL SAMPLES			
DESCRIPTION	b[a]	DESCRIPTION	PARTICLE SIZE (CM)	MEASURED b	CORRECTED b[a]
Singly fractured basalt blocks	0.60	Debris broken by landing, Surv. V	0.1–10	0.54	0.6
Artificially crushed quartz	0.63	Telescopic asteroid	10^7	—	0.6
Multiply fractured basalt blocks	0.67				
Debris near secondary impact craters	0.7	Debris near 13-m crater, Surv. III	7–200	0.50	0.7
		Field debris near Luna 9	1–20	0.54	0.7
Disintegrated igneous boulders	0.79	Field debris near Tycho, Surv. VII	0.1–50	0.61	0.8
Disintegrated glacial boulder	0.80	Larger rocks near Surveyor III	4–50	0.63	0.8
Detritus from weathered gneiss	0.89	Meteorites	1–100	—	0.8
Ejecta from steam blast explosion	0.9	Field debris near Surveyor I	0.1–500	0.70	0.9
		Fine debris near Surveyor I	0.5–8	0.78	0.9
Ejecta from hypervelocity impacts	1.0	Field debris near Surveyor III	0.1–50	0.82	1.0
		Field debris near Surveyor VI	0.1–7	0.83	1.0
Ash and pumice	1.18	Field debris near Surveyor V	0.1–4	0.87	1.1

[a] Surface values have been corrected. For debris scattered upon a pre-existing surface the correction is not more than +0.1; for mixed debris the correction is +0.2.

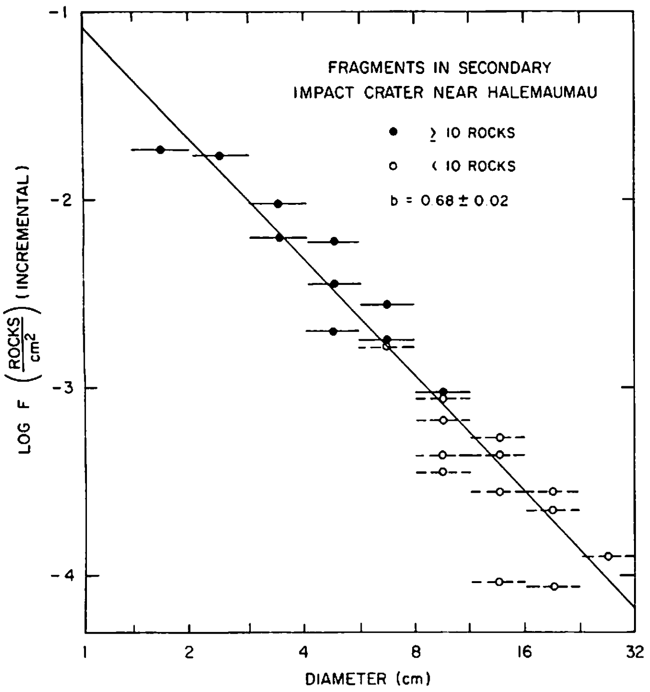

Fig. 2 Diameter spectrum of projectile fragments exposed in a two-meter secondary impact crater, based on several independent surface counts.

tain conclusions are drawn regarding the history of the latter lunar surface material disturbed by Surveyors is broken in a way characteristic of low-energy, mechanical fragmentation, as expected. Debris around decameter-scale lunar craters with strewn rock-fields also exhibits this property, supporting the contention that many of these craters are secondary impact sites produced by low-velocity projectiles. Millimeter-scale debris on the lunar maria show evidence of extensive regrinding, probably due to repeated primary and secondary impacts. Such debris near Tycho (Surveyor VII) appears not to have been so extensively ground; evidently this is a result of Tycho's low age. Telescopic asteroids have *b*-values characteristic of simple fragmentation, probably a result of breakup by attenuated shock waves in sporadic collisions. Meteorites, on the other hand, are apparently debris from repeated and or hypervelocity impacts.

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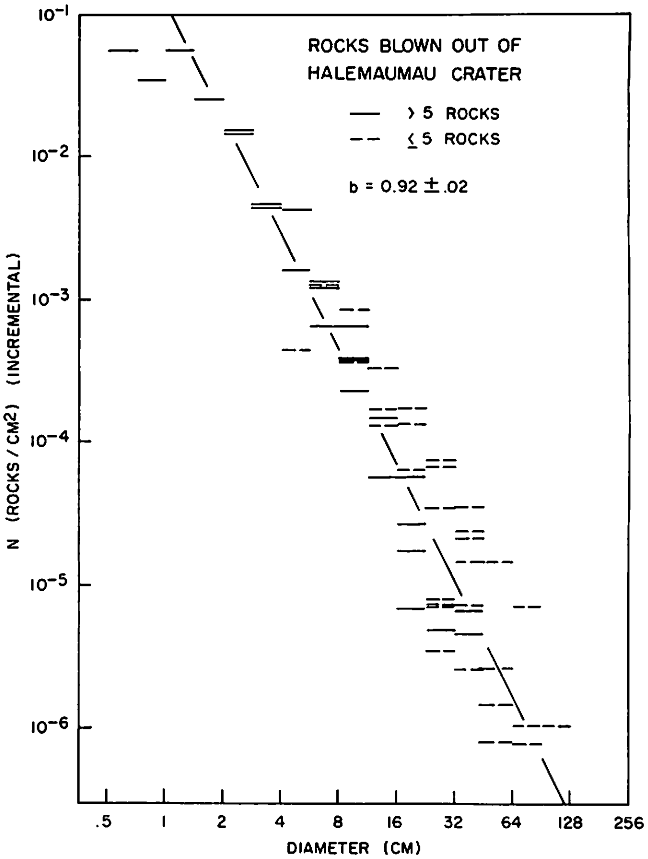

Fig. 3 Diameter spectrum from several independent surface counts of debris scattered by 1924 steam blast explosion of Halemaumau crater.

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