SIZE-FREQUENCY DISTRIBUTIONS OF ROCKS ON MARS

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Predicting the size-frequency distribution of rocks at different locations on Mars is difficult owing to the limited data set (ground truth from only two sites at the surface) and yet is critical for determining potential hazards for future Mars landers. In this abstract, we review rock frequency data at the two Viking landing sites and a variety of sites on the Earth with special reference to larger rocks that could be hazardous to a lander, describe the data in terms of simple mathematical expressions, and provide a means of extrapolating the data to any location on Mars from relationships between the rock frequency curves and remote sensing data.

We used rock lengths, widths and heights carefully measured from stereo Viking landing images by H. Moore and co-workers [1] consisting of a total of over 400 rocks in areas of ~84 m^2 at the Viking 1 and 2 sites (VL 1, VL 2). The rock data plotted in either cumulative number per square meter or cumulative area versus diameter have similar shapes at both Viking sites, displaying a convex up curved shape on log-log plots that can be fit well with simple exponential functions. Included in Figure 1 is an estimate of >0.8 m diameter rocks in the far field (160 m diameter area) surrounding VL 1 (outcrops at VL 1 are not included as they are not hazards to landing). The rock data do not appear linear on log-log plots (both near and far fields), so that power-law functions (commonly used to fit crater size-frequency data) overestimate the frequency and fractional area covered by both large diameter and small diameter rocks (Fig. 1).

Similar shaped size-frequency distributions of rocks are found at a wide variety of rocky surfaces on the Earth (Fig. 1). Data collected by Malin [2] for Icelandic catastrophic outflow deposits, Antarctic dry valley wall talus, and Hawaiian volcanic ejecta, as well as data we have collected from Mars Hill, an abandoned and washed alluvial fan in Death Valley, a presently active alluvial fan on the eastern side of the Avawatz Mountains in the Mojave Desert, two eroded and mass wasted volcanic surfaces (basalt and tuff breccia) in the eastern Mojave Desert (Goldstone), and catastrophic outflow deposits of the proximal Ephrata fan in Washington state, all show curved convex up size-frequency rock distributions on a log-log plot. Data from these sites have all been fit reasonably well with simple exponential functions, which describe both the precipitous drop off in rocks with large diameters as well as the relative decrease in cumulative number or area of rocks at small diameters.

The VL 2 site is believed to be ejecta from the nearby crater Mie [3], whereas VL 1 is believed to be a partially covered and eroded lava flow surface, possibly with some local crater ejecta and flood deposits [4]. As a result, they appear to have formed by very different geologic processes, yet the shape of the rock size-frequency distributions at both sites are the same. In addition, sites on the Earth described above formed from a variety of geologic processes, yet the rock size-frequency distributions are all similarly shaped. All sites show a precipitous fall off in number or fractional area of rocks at large diameters, which may have something to do with the dearth of large coherent blocks of material (typically fractured into small blocks) and the inability of geologic processes to transport such large blocks without breaking them into smaller pieces.

The consistency of the size-frequency rock distributions found on the Earth and the two Viking landing sites suggests that similar shaped rock size-frequency distributions are applicable to other areas on Mars. A combined fit to both VL cumulative fractional area of rocks versus diameter data was made with a general exponential function of the form $F_k(D) = k \exp\{-q(k) D\}$, in which $F_k(D)$ is the cumulative fractional area covered by rocks of a given diameter or larger, k is the total area covered by rocks at the site, and $q(k) = (1.79 + 0.152/k)$. Simple linear height versus diameter relationships, $H = (0.25 + 1.4 k) D$ were also derived from H/D ratios of ~3/8 and ~1/2 at VL 1 and 2, respectively, which suggest that rockier areas on Mars have higher standing rocks than less rocky areas. Height was then substituted into the general exponential function derived for diameter, which yielded $F_k(H) = k \exp\{-p(k) H\}$ with $p(k) = (1.79 + 0.152/k)/\{0.25 + 1.4 k\}$, which describes the cumulative fractional area of rocks versus height for any given total rock coverage.

Viking thermal inertia measurements and models developed by Christensen [5] have been used to estimate the fractional surface area covered by high thermal inertia rocks greater than about 10 cm diameter versus smaller particles, such as sand and dust, with low thermal inertia for 1° latitude by 1° longitude remotely sensed areas on Mars. Because the cumulative fractional area covered by rocks of 10 cm diameter and larger is fairly close to the total rock coverage, it can be used as the pre-exponential constant k in the general fit to the VL rock data to describe the cumulative fractional area versus diameter or height at any location on Mars. This calculation is conceptually equivalent to Christensen and Malin's [6] suggestion that rock abundances on Mars reflect the thickness of mantling fine material. In this simple model, the maximum rock abundances (~30%) occur in areas with no mantling sand or dust, and less rocky areas (down to 2%) are mantled by progressively greater thicknesses of dust (up to 1 m thick). The exponential curves in Figure 1 show these distributions in terms of cumulative area versus diameter for any value of rock abundance and the equations derived above show the decrease in H/D for less rocky areas.

Results indicate that most of Mars is rather benign with regard to hazards from landing on large rocks. Roughly 50% of Mars has rocks covering only 8% or less of its exposed surface [5]. For total rock coverage of 8% analogous to VL 1 without the outcrops, about 1% of the surface is covered by 20 cm or higher rocks. A surface covered with 12% rocks has only 1% of its surface area covered by rocks higher than 35 cm, so that a lander designed to clear 35 cm rocks could be sent to 75% of Mars with a low probability of landing on a hazardous rock. The Mars Pathfinder lander air bag system is designed to accommodate landing on 0.5 m high boulders. Such a landing system could land on a surface covered by about 20% rocks, similar to VL 2, with a percent or two of the surface covered by rocks of 0.5 m or higher. Surfaces with 20% or fewer rocks account for over 90% of the surface of Mars, so that such a landing system could be sent to all but the rockiest 10% of Mars with a low probability of landing on a ≥0.5 m high rock. The Ares Vallis landing site selected for Mars Pathfinder has total rock abundances of ~20% [7], indicating a low probability of landing on potentially hazardous rocks.

References: [1] Moore & Keller, 1990, NASA Tech. Mem. 4210, 160 & 1991, NASA Tech. Mem. 4300, 533. [2] Malin, 1989, NASA Tech. Mem. 4130, 363. [3] Mutch et al., 1977, JGR 82, 4452. [4] Binder et al., 1977, JGR 82, 4439. [5] Christensen, 1986, Icarus 68, 217. [6] Christensen & Malin, 1993, LPSC XXIV, 285. [7] Golombek et al., 1995, LPSC XXVI, 481.

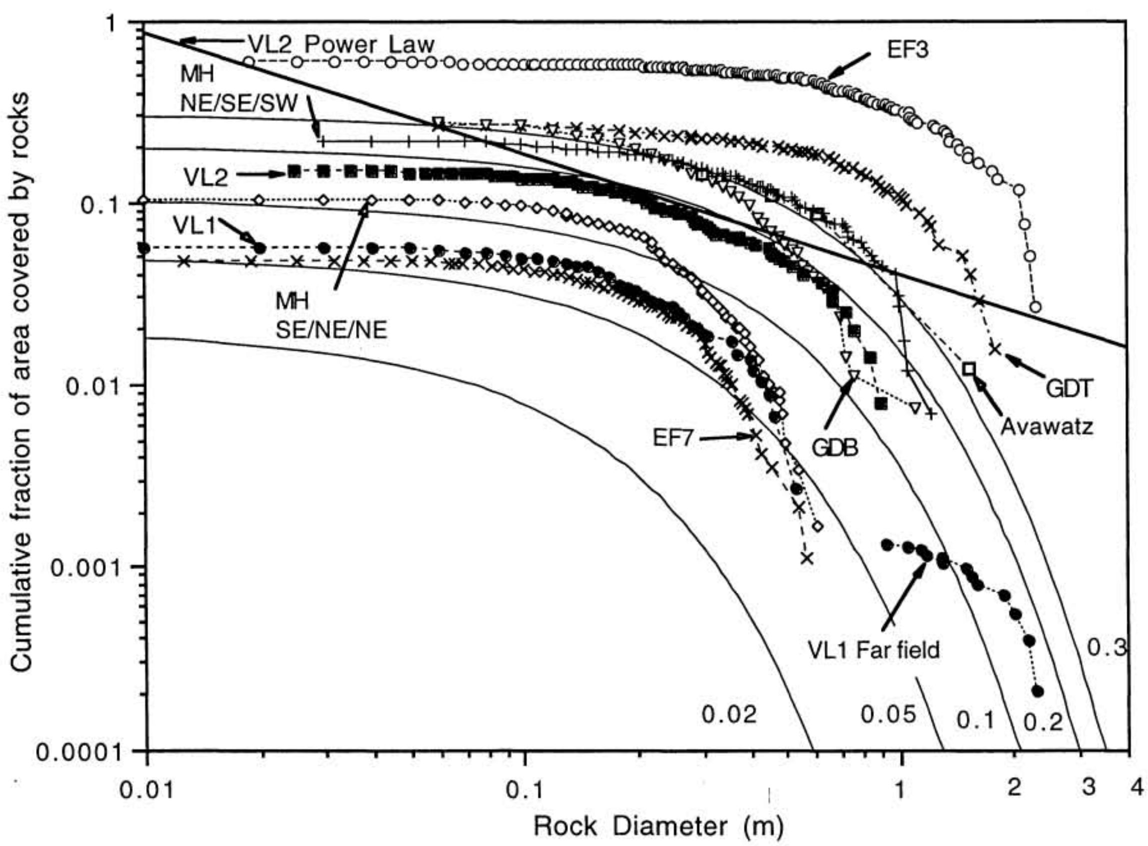

Figure 1. Cumulative fractional area covered by rocks versus diameter for rocks at VL 1 and 2, Mars Hill (MH), Ephrata fan (EF), Goldstone (basalt, GDB and tuff, GDT) and Avawatz. Power law distribution suggested for VL 2 rocks greater than 0.1 m diameter [1] also shown. Solid curves marked 0.02-0.3 are the rock distributions predicted for various rock abundances (2%-30%) on Mars derived from a combined exponential fit to VL 1 and 2.