ANALYSES OF ROCK SIZE-FREQUENCY DISTRIBUTIONS AND MORPHOMETRY OF MODIFIED HAWAIIAN LAVA FLOWS: IMPLICATIONS FOR FUTURE MARTIAN LANDING SITES.

Robert A. Craddock[1], *Matthew Golombek*[2], *and Alan D. Howard*[3]; [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington, DC 20560, craddock@ceps.nasm.edu; [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; [3]Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903.

Introduction: Determining the rock size-frequency distribution for any given location on the martian surface is difficult. However, in order to properly assess the potential hazards associated with large rocks within future landing sites such analyses are important. While size-frequency distributions of rocks emplaced by a variety of geologic processes on the Earth have the general shape of an exponential curve, there is a great deal of variability in exactly where the largest sized particle falls [1]. For example, previous studies of rocky locations on the Earth, such as basalts emplaced by catastrophic flood deposits, in situ weathering, and as part of an alluvial fan, have large particle sizes that range from a few tens of centimeters to several meters [1]. An additional physical element that may be useful for evaluating the geology of the site once the spacecraft has successfully landed is rock morphometry [2]. Such information could provide us with the quantitative ability to reliably separate a rock deposited by fluvial processes from one deposited by impact cratering or any other type of geologic process. These types of measurements could prove invaluable when selecting samples for return to Earth.

In preparation for selecting future Mars landing sites and to aid in assessing the local geologic environments of these sites once we have landed, we have analyzed a number of basaltic lava flows in Hawaii that have been modified by a variety of geologic processes. The Hawaiian islands are particularly well suited for such a study because of the fairly ubiquitous geochemistry of the rocks [e.g., 3], the wide range of rock ages (recent to 1.84 million years old within the study areas [4,5,6]), and the diversity of microclimates [e.g., 7].

Geologic Setting: By far the dominant geologic process modifying lava flows on Hawaii is chemical weathering, and the stages of this form of degradation can be observed from one island to the next. Usually within a few decades, lava flows near Kilauea on the Big Island show signs of oxidation on the upper glassy layer (HP1, MU1). Flows that are subsequently buried are weathered by chemical processes resulting from groundwater flow. This process eventually rounds the edges off blocks comprising individual flow units, resulting in core stones that are frequently concentrated in gullies when processes such as overgrazing (observed in western Molokai) allow the supporting matrix to be removed (MR1). Also observed on the summit of Haleakala were flows that appear to have been modified predominately by frost shattering. Such mechanical weathering may have been restricted to glacial periods in the Pleistocene (MS1-4).

The Kau Desert is dominated by aggradational processes. Periodic phreatic eruptions of Kilauea caldera have emplaced the Keanakakoi tephra, which is >5 m thick in places [8]. Although the Kau Desert receives ~130-30 cm of rainfall annually, the high permeability of the tephra and high evaporation rates support only occasional overland flows. Partially buried or exhumed lava flows are oxidized, but typically only the upper glassy layer has been removed (KD1). Other geologic processes that we observed with potential martian application include rocks deposited by Kilauea phreatic eruptions (PE1-4), which may be analogous to impact cratering, rocks emplaced by overland flow (POP1-2), and rocks modified by wave action.

Size-Frequency Distributions: Not unsurprisingly, plots of the cumulative fractional area versus diameter (Figure 1) show the same general exponential shape as discussed in [1], which appears to be governed by fracture and fragmentation theory [9,10]. Similarly, plots of the cumulative number versus diameter (Figure 2) show the same general trends as presented in [1]; however, the Hawaiian sites presented here have a great deal more variation in behavior than those observed previously. For example, Figure 1 shows surfaces with 100% rock coverage to those with <1%. Figure 2 shows sites with up to 1000 rocks/m^2 to those with only 1 rocks/m^2. By comparison, previous data presented in [1] show a variation of 1-10 rocks/m^2. Interestingly, the Hawaiian variations in rock distribution occurs predominantly at rock diameters <0.6 m, which is smaller than the extremely rocky locations surveyed in [1]. Of particular note are the cumulative area curves (Figure 1) measured for rocks emplaced by Kilauea phreatic eruptions (PE1-5). Generally with increasing distances from the caldera the total rock abundance decreases while the largest particle size increases. This may indicate a change in how the particles were deposited (suspension versus ballistic emplacement). Arguably such deposits are analogous to impact ejecta and suggest that rock populations measured on Mars may be related to the distance to the crater rim. This idea is supported by work on rock counts around lunar impact craters [11]. In general, the diversity observed in Hawaii suggests that it might be possible to determine the “fingerprints” of processes affecting rock distributions.

Particle Shape Analyses: Sphericity is related to the three principal axes of symmetry and can be used to estimate the relative distance a particle travels [12]. Angularity describes the variations in corners, edges and faces on the particle and is typically more useful for environmental interpretations [13]. While most of these data were presented previously [2], we have increased the number of measurements and investigated additional locations. Plots of these data (Figure 3) show several trends: (A) Rocks generated from chemical weathering of the upper glassy layer (HP1, MU1, KD1; various crossed symbols) result in rocks with both a low sphericity and angularity. These morphometric characteristics are maintained regardless of age or amount of degradation. (B) Rocks at the summit of Haleakala, Maui (MS1-4; half-filled squares) were eroded through frost shattering. Because this process tends to calve off the outer portion of the exposed outcrops by exploiting grain/grain boundaries, the resulting rocks have some of the lowest angularities observed. (C) The polygonal fractures that exist in pahoehoe flows result from contraction as the flow cools. Resulting rocks (hatches) form when the cooled flow is disrupted usually by undercutting (e.g., gulleying, EKDF). These rocks showed no other signs of weathering. (D) Chemical weathering (MR1; half-filled diamonds), specifically spheroidal weathering, is an important degradational process affecting most Hawaiian lava flows at lower elevations (i.e., less than ~2,000 m). (E) Rocks formed near beaches generally assume a "flat" shape and have the high angularity. These physical characteristics resulting from wave action are apparent from rocks examined near Kepuhi Bay, Molokai (cross). (F) Also shown for comparison are basaltic rocks deposited in the Ephrata Fan during the catastrophic flooding of Pleistocene Lake Missoula (opened square) as well as values determined in [14] for the Viking landing sites (solid square).

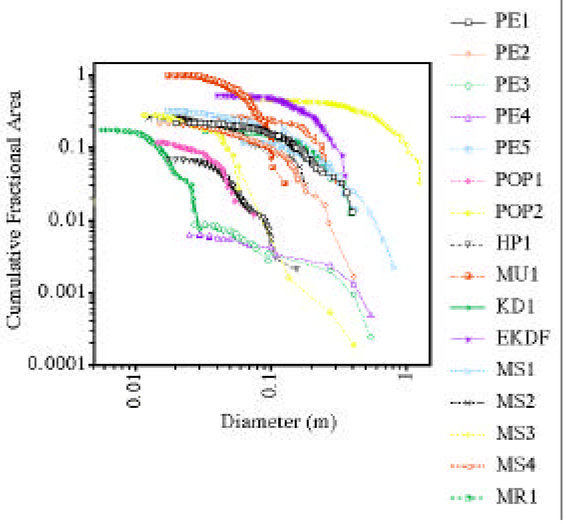

Figure 1. Cumulative fraction of surface area covered by rocks emplaced by a variety of geologic processes on Hawaii. Abbreviations are discussed in the text. POP1 & 2 refer to rocks deposited in a playa outwash plain in the Kau Desert.

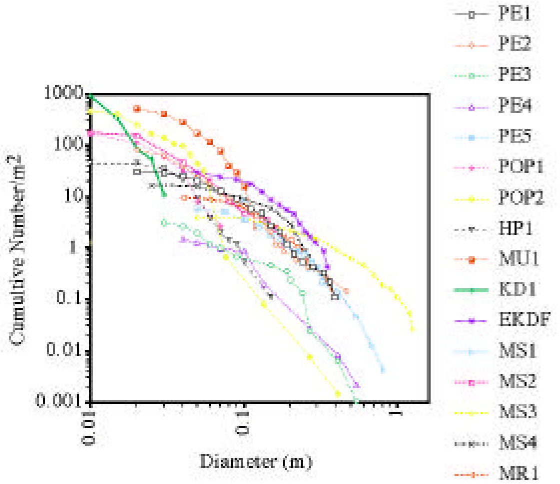

Figure 2. Cumulative number of rocks versus diameter for rocks emplaced by a variety of geologic processes on Hawaii.

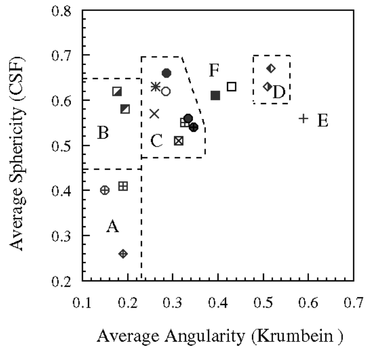

Figure 3. Angularity versus sphericity for basaltic rocks >64 mm in diameter. Data fields are described in the text.

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