THE ORIGIN OF SAND AND DUST ON MARS: EVIDENCE FROM THE INSIGHT LANDING SITE. M. Golombek[1], C. Charalambous[2], W. T. Pike[2], and R. Sullivan[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2]Department of Electrical and Electronic Engineering, Imperial College, London, [3]CCAPS, Cornell University, Ithaca, New York.

Introduction: On Earth, the production of sand size grains (0.06-2 mm diameter) is dominated by chemical and physical weathering processes in which many minerals transform to clay-sized grains, leaving resistant sand-sized quartz grains [1]. Once formed, quartz sand grains become rounded during transport, but otherwise undergo little substantial further size reduction.

On Mars, sand is dominated by basaltic particles and primary igneous minerals [2,3,4]. The presence of these primary igneous minerals, including olivine, which is particularly susceptible to aqueous alteration, indicates that the production of sand on Mars is primarily due to physical processes. Golombek et al. [5] argued that sand on Mars can be produced by repeated fragmentation from impact and eolian activity based on the size-frequency distribution of measured rocks, sand and dust. This abstract provides further evidence for this origin from observations by the InSight lander and argues that Mars dust can be produced by the rounding and chipping of sand grains during saltation.

Clues from the InSight and Spirit Landing Sites: These two landing sites appear to have produced relatively thick (3-10 m) regolith layers composed mostly of sand on top of Late Amazonian-Hesperian basalt flows dominantly by impact and eolian processes [6,7].

Geologic investigations by the InSight lander show the surface has been formed by impact, mass wasting and eolian processes [7]. Orbital and surface measurements of thermal inertia (~200 J m^{-2} K^{-1} $s^{-1/2}$) indicate a surface composed of dominantly unconsolidated, fine sand (~0.17 mm) with few rocks (<5%) [7,8], consistent with observed slow shallow seismic velocities [9]. The onset diameter of rocky ejecta craters and observations of nearby Hephaestus Fossae show a relatively fine-grained impact generated regolith 3-10 m thick that overlies coarse breccia and bedrock [8,10,11]. Orbital mapping shows lobate flows and inflation plateaus consistent with the bedrock being a stack of basalt flows ~300 m thick [11]. Eolian bedforms are limited to the interior and continuous ejecta blankets of fresh rocky ejecta craters, suggesting the wind rapidly mobilizes the sand size fraction soon after impact, filling the craters.

At the Gusev cratered plains, investigated by Spirit, rocks are dark, fine-grained basalts with a ~10 m thick impact-generated regolith developed over basalt flows [6]. Ubiquitous shallow, soil-filled, circular depressions, called hollows, are impact craters filled with sand. Observed deflation of the surface 5–25 cm [6] is equal to that required to fill the hollows suggesting that the sand was produced by impact and filled the craters via saltation [12].

Sand Characteristics: Microscopic images of sand on Mars generally show that the larger grains that can be resolved are rounded to sub-rounded and equant and have been rounded by eolian saltation [13]. Sullivan et al. [14] argues that as grain size falls below 0.8 mm, the probability of saltation increases, with kinetic energy during saltation collisions contributing to grain size attrition. Collisional attrition is likely to be less efficient once grain size reaches around 0.125 mm, because greatly reduced grain mass reduces kinetic energy available during collisions, and grains become increasingly susceptible to suspension during strong wind events. Sullivan et al. [15] argues that this process leads to poorly sorted deposits dominated by fine sand (<0.125 mm). This scenario suggests that eolian activity plays an important role in the size and shape of sand that makes up most of soils of Mars.

Fragmentation: Recent work shows that under repeated fracture events (in this case, dominantly impacts), fragmentation results in a particle size distribution described as a negative binomial (NB) function [16]. Two parameters govern the fragmentation processes and the evolution of the particle size.

The first, the maturity index quantifies the number of fragmentation events experienced by the particle population, in this case set by the number of meteorite impacts at the landing site. For a maturity index of 1, the NB reduces to the well-known power-law relationship for the size distribution from a single fragmentation event expected from fractal analysis [17]. The average regolith gradation with depth and the particle size distribution can then be determined from the cratering production function and the age of the surface.

To derive a particle-size distribution of the martian regolith we use: orbital and surface rock counts of the InSight landing site, which are similar to those of the Phoenix and Spirit landing site [7]; microscopic image measurements of sand at the Spirit and Curiosity landing sites [3,4,13]; and optical and atomic force microscope data <0.2 mm from the Phoenix landing site down to 100 nm [18]. These data were converted to a cumulative fractional mass (CFM) versus diameter distribution [5]. An NB fragmentation prediction based on the Hesperian cratering record matches the particle size-frequency distribution for diameters of 10 m to 0.6 mm (coarse sand) (Figure 1).

Below around 0.2–0.5 mm the particle-size distribution transitions from the NB statistics predicted by fragmentation theory to one controlled by Poissonian statistics (Figure 1). This would be expected for a mature population, saturated by undergoing randomly repeated, but substantially weak impacts. The maturity index abruptly increases from <4 for the larger diameters to >100 for the smaller diameters, and the probability of fragmentation drops to ~0 for the smaller diameters. In other words, the grain population experiences multiple collisions with a very small probability of successful fragmentation. This provides a surge in the multiplicity effect inherent in the fragmentation theory, in contrast to highly energetic and efficient fragmentation events by meteorite impacts. An NB fragmentation model of this type fits the particle size distribution below 0.2-0.5 mm (Figure 1). The CFM distribution and model prediction was also converted to a particle size frequency distribution, which yields a unimodal peak in particles from 0.1-0.2 mm, in agreement with thermal inertia measurements and the observed population of sand at the landing sites [3,4, 8,13].

Production of Mars Dust: Impact fragmented particles are angular and experiments confirm that chipping the corners of particles will occur during saltation impact on both Earth [19] and Mars [20]. On Earth, saltation chipping of quart sand in the Sahara is a major producer of dust aerosols [21]. We argue that the same chipping processes during saltation are responsible for the fine dust on Mars. Mars dust is fine grained (<10 μm), mildly chemically altered basaltic weathering products [22,23,24] that is dominantly produced by physical processes.

Summary: The transition in processes producing particles above and below 0.2–0.5 mm predicted from fragmentation theory is in general agreement with the observations and numerical modeling of Sullivan et al. [14,15] in which particles <0.8 mm have high kinetic energy during saltation that reduces particle size to around 0.125 mm where their reduced size decreases their susceptibility to further attrition by the wind. Fragmentation theory predicts that meteorite impact can efficiently produce sand size particles down to around 0.6 mm and that eolian activity is responsible for the subsequent reduction in particles down to around 0.125 mm. Further rounding of particles occurs via chipping during saltation impacts. These chipped particles forms the fine grained dust on Mars. The end state of these processes is a size-frequency distribution with a rounded to sub-rounded, unimodal peak in particle size from 0.1-0.2 mm and fine-grained dust from corner chipping of the sand in agreement with observations. These results suggest that the global surface layer of sand and dust size particles on Mars is produced dominantly by impact and eolian processes.

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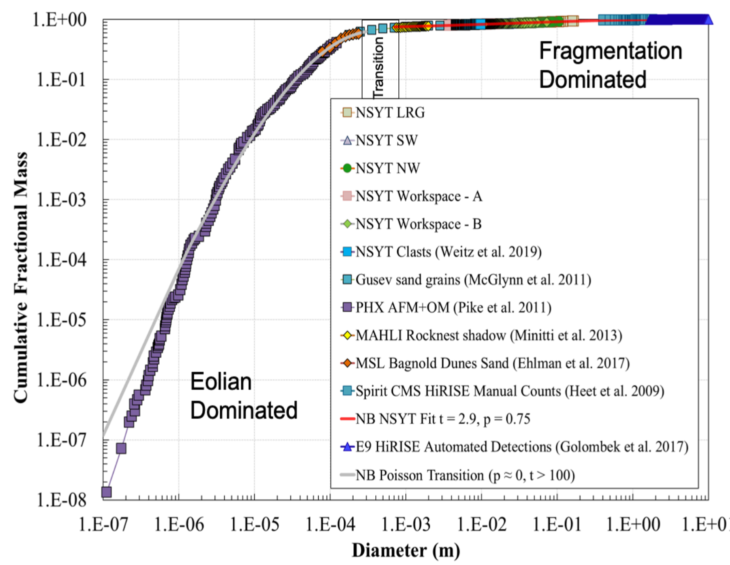

Figure 1: Cumulative fractional mass versus diameter distribution over 8 orders of magnitude and NB fragmentation models. Sand size particles are from Spirit and Gale landing sites [3,4,13], particles <0.2 mm are from Phoenix [18], and rock distributions are from surface and orbital measurement of InSight and other landing sites (sources [3,4,13,25,26], unnamed from [7]). Note the transition in the fragmentation curves between impact dominated processes above 0.2-0.5 mm and eolian dominated processes below.