THE RECENT ATMOSPHERIC HISTORY OF MARS DERIVED FROM SMALL CRATERS OBSERVED BY MSL.

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Introduction: The obliquity of Mars has undergone semi-periodic, quasi-chaotic fluctuations throughout the planet's history that have subsequently resulted in atmospheric density fluctuations [1], [2]. Periods of high obliquity expose the poles to longer amounts of sunlight and shorter amounts at low obliquity. The exposure of the Martian poles allows for greater sublimation of the reservoir of CO_2 ice contributing more CO_2 to the atmosphere. During periods of higher obliquity, the increase contribution of CO_2 increases the atmospheric pressure of Mars and alters the interaction of projectiles encountering the atmosphere which form the smallest craters on Mars. Small craters are a geologic reflection of the atmospheric density [2]. The distribution of the smallest craters on a surface can determine if there have been atmospheric fluctuations over the lifespan of small craters. We are reporting here our improvements to the data since the work of Hoffman et al. [3].

Methods: The objective of this study was to identify and measure all crater candidates near the rover. The primary method for identifying craters was OnSight, an augmented reality of the traverse constructed with images from the mission. OnSight is compatible with a Hololens and has a web-based version. Being able to see the traverse with a 3D headset proved to be the most useful tool to find small craters of D < 1 m. After a crater was identified, it was measured with the ruler tool in OnSight. Candidates that were harder to distinguish as craters we also analyzed in Midnight Mars, a program that collects anaglyphs of images from the mission. If the crater appeared to be a circular, bowl-shaped depression, it was considered to be a more favorable crater candidate. If a crater was still questionable, Analyst Notebook, another tool to review data from the mission, was used to draw topographical profiles of craters to see if there was a circular depression. If a candidate was still questionable after these methods were implemented, it was not included.

Crater Mechanics: Objects that encounter planetary atmospheres undergo some degree of deceleration, ablation, and possibly fragmentation as they travel to the planet's surface [4], [5]. Smaller objects that result in D < 5 m primary impact craters are greatly influenced by deceleration and ablation but are not likely to fragment which would result in a primary impact cluster [5], [6]. Most small objects are slowed down through energy loss to the atmosphere to speeds below hypervelocity or ablate completely before the projectile can impact the surface [5]. Despite the fact that most small primary projectiles vaporize completely or are decelerated below hypervelocity, there are still objects that survive and form the smallest hypervelocity primary craters. Atmospheric affects are dependent on whether it is an iron or stony meteorite. Fragmentation of small primary projectiles is not likely to occur because smaller impactors are more homogenous, contain less fracturing, and have a greater bulk strength [5]. For present day Martian atmospheric conditions, the smallest primary crater theorized to be able to form is D = 25 cm [5], [7], [8].

Crater Catalog: Over the first 2119 sols, a total of 156 craters were found along the traverse using the rover's imaging capabilities. Of the 156 total craters, 126 were D < 5 m, 26 were D < 1 m, and 5 were D < 0.5 m. The smallest crater measured was D = 0.33 m.

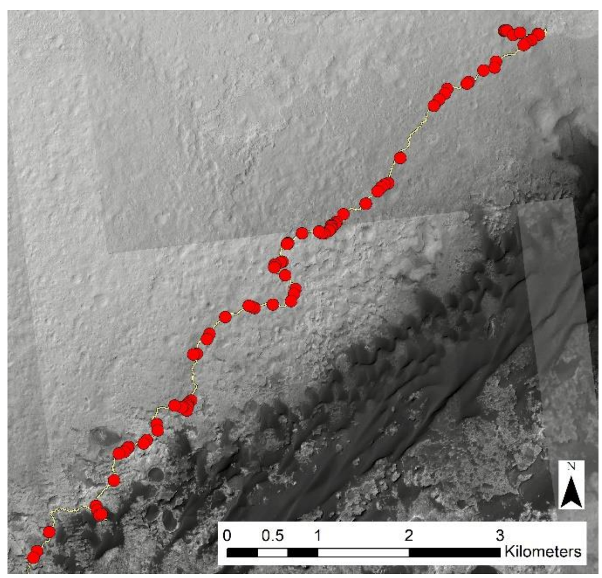

Figure 1. Location of craters found across the traverse for the first 1700 sols.

After a thorough review of the traverse, there were still candidates that were too hard to distinguish as craters, usually because they were heavily eroded or there was limited imagery. The catalog is also considered to consist of primary craters and not secondary craters, or craters that formed from ejecta from other impacts on the surface. The craters of this catalog are mostly circular and assumed to be young enough so that if they were secondaries, there could still be evidence of rays from the primary crater [9], [10]. There is still ongoing debate in the literature on how secondary craters influence crater statistics, especially with small diameter craters [9], [11]. Any craters that were suspected of being secondaries were not included, however it is still difficult to distinguish distant secondaries from primary impacts.

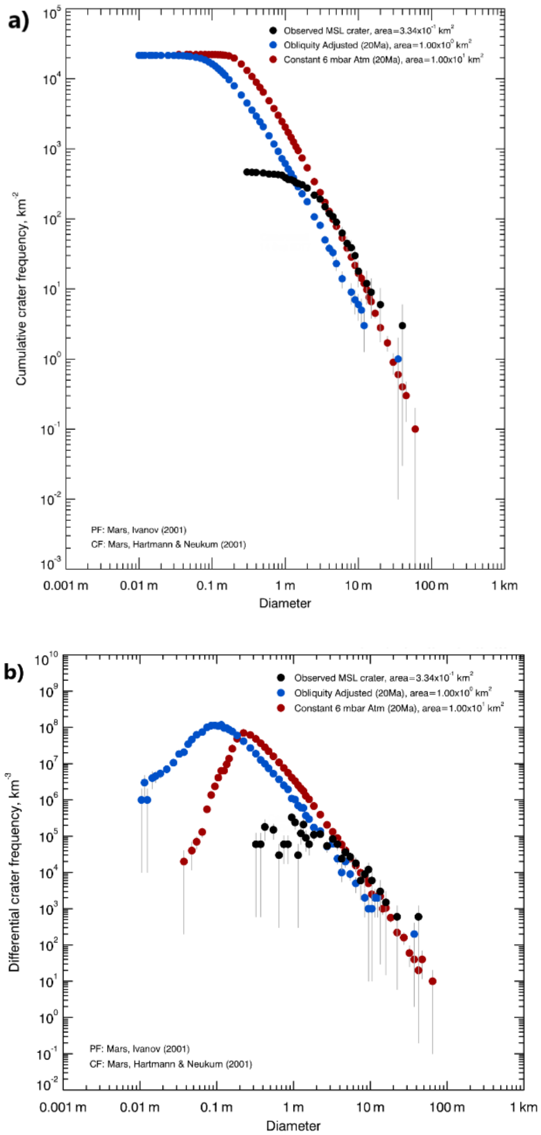

Figure 2. **a)** The cumulative crater frequency of the craters observed by MSL (black) over an area of 334,029 m^2 compared with simulations of a 6 mbar average Martian atmosphere propagated for 20 Ma (red) and of a Martian atmosphere varying in pressure with obliquity over 20 Ma (blue) [Williams et al., (2018)]. **b)** The differential crater frequency of the craters identified along the traverse compared with the same simulations. The turnover of crater frequency occurs at D = 0.93 m and the smallest craters appear to fall off similar to the obliquity adjusted scenario. Plots from Craterstats 2 [13].

Atmospheric Fluctuations: If the atmosphere of Mars has experienced a change in density over the lifetime of the smallest craters, then that fluctuation should be reflected in the crater frequency distribution [2], [12]. According to Laskar et al., (2004), the obliquity of Mars was at angles closer to 40 degrees as recently as 5 million years ago. This could allow for atmospheric pressures of 100 mbar. The crater statistics of this study were compared to simulated statistics from Williams et al., (2018) which sought to understand how the recent obliquity fluctuations and subsequent atmospheric fluctuations effected the crater size frequency distribution.

Erosion Rates: The crater catalog can only provide insight into the atmospheric history of Mars as long as the smallest craters can survive at the surface. Current estimates predict that centimeter-sized craters can survive for 20 million years [14]. There is still work to be done to understand how erosion rates effect the crater counts. The more gentle turnover of crater diameter distributions at D = 0.93 m from the differential crater size distribution could be affected by eroded craters not being counted. It is also possible that the texture of the terrain is influencing the amount of small observable craters. The target density these impactors are encountering is changing even along the traverse. Craters may be harder to identify when there are numerous rock fragments present due to erosion, or when the rocks are comparable or larger than the impactors, the impact energy might contribute to fragmenting the rock rather than forming craters. An increase rock abundance might cause the suppression of small crater formation [15].

Conclusions: There have be 156 craters observed by MSL over the first 2119 sols. The size frequency distribution illustrates that there are fewer than predicted small submeter diameter craters for the current Martian atmospheric conditions. However, the crater catalog maybe influenced by erosion of craters and the specific characteristic of the target terrain. It is still plausible that the data support a denser Martian atmosphere over the last 5 to 20 million years.

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