AN EMPIRICALLY DERIVED -2 POWER LAW CUMULATIVE PRISTINE CRATER PRODUCTION FUNCTION FOR MARS BASED ON UPDATED CRATER MORPHOLOGY AND GEOLOGIC MAPPING DATA.

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Introduction. Crater densities have been instrumental in determining ages of surfaces on Mars and other cratered planetary bodies. Fundamental to this technique is the cumulative bombardment of the surface by projectiles supplied from the population of Mars-crossing asteroids and comets. Diameters of craters are a function of impact energy determined by the velocity and mass of the projectiles [e.g., 1].

Accumulation of craters over time eventually results in a statistically defined crater size-frequency production function (CPF), generally expressed as a simple power law or polynomial function. The CPF is poorly constrained statistically at larger diameters due to fewer craters in the population. It also becomes difficult to assess at sub-kilometer diameters, because smaller craters are more readily obliterated by resurfacing and may include overwhelming numbers of secondary craters [2, 3]. Furthermore, geologic processes complicate the picture by resurfacing areas of the planet through burial, degradation, and erosion. Determining the CPF empirically requires an extensive surface that formed in a narrow window of time relative to the cratering rate, for which older craters were highly obscured while younger, superposed craters appear mostly un-obscured. The latter requirement necessitates careful morphologic examination of every crater and an understanding of the geologic unit on which the crater is observed.

Based on these requirements, geologic mapping of the northern plains of Mars [3] has identified a nearly ideal surface to establish the planet's pristine CPF—the Vastitas Borealis (VB) interior unit. We introduced this investigation last year at Mars Crater Consortium 7 [4] and have updated our study with new assessments of crater preservation states, fine-tuning of crater locations and of unit-contact mapping, and inclusion of additional geologic units and areas for comparison.

Data and Methods. Our geologic mapping [5-6] and crater database [7], which includes all craters ≥5 km in diameter, are based on the MOLA DEM and Viking, THEMIS, and MOC images. A crater preservation state (PS) is assigned to each crater and ranges from 0 to 7 in increments of 0.5, where 0 values represent the most degraded craters and 7 the most "pristine", based on topography, geomorphology, and thermophysical properties [7]. A PS≥4 indicates a crater is surrounded by a recognizable ejecta morphology and usually is interpreted to superpose the immediately adjacent geologic unit. All craters in our study are assigned a PS value.

Crater data were compiled for several geologic units that display a range of resurfacing characteristics (Table 1). The VB units cover much of the northern plains and appear to be sedimentary deposits and perhaps other materials reworked by various periglacial and soft-sediment processes at the beginning of the Amazonian [5-6]. While the VB interior unit (ABv$_i$) covers the overwhelming majority of the northern plains, the VB marginal unit (ABv$_m$) skirts the interior unit along the margins of the northern plains and around the Acidalia Mensa inlier of ancient terrain. The interior unit may be pervasively reworked by mud volcanism and similar processes, whereas ABv$_m$ is partly reworked by deformation and perhaps local mass flows [5-6]. The Alba Patera unit (HTa) consists of lava flows on the northern flank of Alba Patera. The Utopia Planitia 1 unit (HBu$_1$) includes mass-wasted plains deposits below the highland/lowland boundary at Protonilus Mensae. The Tinjar Valles units (AEt) consist of debris flows, fluvial deposits, and possible volcanic flows in Utopia Planitia. The crater unit (AHc) that comprises Lyot crater (~200 km diameter) consists of rim, interior, and ejecta deposits.

Results. A summary of crater counts is shown in Table 1. We use N(5) and N(16) crater densities to define the CPF power-law slope, which coincide with data used by [8] to define Martian epoch boundaries.

Table 1. Crater densities and mean cumulative size-frequency power-law slope in the 5 to 16 km diameter range for selected map units [3].

Unit[a]	Area[b]	N(5)[c]	N(16)[c]	Slope[d]
ABv$_i$ (p)	11.51	72.1±2.5	6.9±0.8	-2.01±0.13
ABv$_i$ (t)	11.51	88.6±2.8	11.3±1.0	-1.77±0.11
ABv$_i$ (b, p)	2.51	67.4±5.2	9.2±1.9	-1.71±0.26
ABv$_i$ (b, t)	2.51	83.8±5.8	14.4±2.4	-1.51±0.22
ABv$_m$ (p)	1.94	57.7±5.5	7.7±2.0	-1.73±0.33
ABv$_m$ (t)	1.94	120.1±7.9	31.9±4.1	-1.14±0.17
HTa (p)	0.93	75.1±9.0	9.7±3.2	-1.76±0.45
HTa (t)	0.93	111±11	20.4±4.7	-1.45±0.31
HBu$_1$ (p)	0.71	78.0±10.5	11.3±4.0	-1.66±0.48
HBu$_1$ (t)	0.71	189±16	41.1±7.6	-1.31±0.25
AEt (p)	1.39	61.9±6.7	8.6±2.5	-1.69±0.38
AEt (t)	1.39	76.3±7.4	8.6±2.5	-1.87±0.38
AHc (p)	0.67	47.6±8.4	10.4±3.9	-1.31±0.54
AHc (t)	0.67	90.7±11.6	43.1±8.0	-0.64±0.26

[a]See text for unit descriptions; p = pristine, t = total, b = craters within ~150 km of unit ABv$_m$. [b]Units of 10^6 km^2. [c]N(X)=no. craters ≥ X km diameter per 10^6 km^2. [d]Power-law fit for N(5)/N(16); slope error based on N(5) and N(16) errors.

We determine a -2 power law for the VB interior unit (-2.01), slightly higher than for the whole of the VB units combined (-1.96) [4]. The interior unit generally demonstrates intense, pervasive obliteration of older craters as indicated by the moderate increases in crater density when values for total craters are compared with pristine ones only. We also find that the marginal unit has a lower N(5) but comparable N(16) relative to the interior unit for pristine craters, indicating that the units may have had the same formational age, but that moderate resurfacing of the marginal unit continued, destroying 20% of the craters in the 5 to 16 km diameter range and resulting in a -1.73 slope. Degraded craters are much more abundant in the VB marginal unit than in the interior unit, suggesting that the processes that formed the marginal unit were less effective at destroying older craters. We also determined the density of craters in the VB interior unit within ~150 km of the contact with the marginal unit (Table 1); this too shows a lower slope of -1.71 in which pristine craters >16 km appear somewhat more preserved.

The Alba Patera (HTa) and Utopia Planitia 1 (HBu$_1$) units have power-law slopes of -1.76 and -1.66, respectively, for pristine craters and lower slopes for total craters. These distributions may indicate preferential obscuration of smaller craters due to gradual burial by lava flows and mass-wasted debris.

The Tinjar units (AEt) have a total crater power-law slope near -2 and display no poorly preserved, ejectaless craters >16 km in diameter. However, we do observe that many of the larger craters display ejecta but are actually embayed by the Tinjar units. These units apparently were so thin that they only destroyed the ejecta of craters <16 km in diameter on the underlying VB interior unit. This may be a case in which the -2 slope is essentially preserved in the total population due to a lack of burial of ejecta for >16 km craters and only partial burial of ~20% of the 5 to 16 km diameter craters. Heavily degraded craters on the underlying unit apparently were mostly rimless or nearly rimless (<10-20 m high rims) such that they were completely buried by the Tinjar units, which were probably tens of meters thick.

Lyot crater ejecta have the lowest slope (-1.31) for pristine craters and an even lower slope (-0.64) for total craters. Because the unit was not buried by later geologic activity, the obliteration of superposed craters is likely related to their rapid degradation, which suggests that the superposed crater forms and materials were highly friable.

Implications for the Martian CPF. Results for the form of the CPF range significantly for intermediate range craters on Mars (Table 1). Generally, prior to this study, power-law slopes have been <-2, except for Tanaka's Hesperian and Amazonian distributions for 1 to 5 km diameter craters [8]. We propose that a -2 power-law also applies to the 5-16 km diameter range for the Amazonian based on the current study. The generally lower power-law slopes in other studies that address the Martian CPF indicate that the vast majority of surfaces on Mars suffer from obliteration effects for craters <16 km in diameter. This includes Amazonian and Hesperian lava-flow fields and other plains materials that likely have long, complex emplacement and/or resurfacing histories. Noachian surfaces tend to be rugged because of cratering effects and materials, and our analysis of crater distributions within the boundary of Lyot crater material indicates that obliteration of smaller craters may be particularly enhanced on ejecta. Thus, Noachian surfaces are unlikely to display a pristine CPF. However, at larger diameters, the Neukum CPF steepens to ~-2.5 and the Hartmann CPF to -2.2 [1]. Frey [9] finds a slope of -2 for combined large craters and quasi-circular depressions inferred to be craters >25 km in diameter; the high power-law slope at these larger diameters might be related to saturation [10], to a different production population [e.g., 11], or extension of the intermediate-diameter power law determined herein to populations that include older, larger craters.

Table 2. Power-law slopes of intermediate-range crater diameters for proposed Martian CPFs..

Reference	Diam. range (km)	Power-law slope
Hartmann [12][a]	1-32	-1.72
Neukum [12][b]	6-14	~-1.1
Tanaka [8][c]	1-5	-2
Tanaka [8][d]	5-16	-1.79
Tanaka [8][e]	5-16	-1.19
This study	5-16	-2.01±0.13

[a] Slope value derived in [1]. [b] Slope value measured from Fig. 7 in [1]. [c] For Amazonian and Hesperian surfaces. [d] For the Noachian/Hesperian boundary. [e] For the Middle and Late Noachian.

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