CHASMA BOREALE ON MARS: THE CRATERING RECORD.

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In its history, Mars has undergone various periods of impacts from space objects causing numerous primary craters as well as from secondary material ejected off the primary impact site i.e. secondary craters. These craters have been either modified or completely wiped out in the North and South Polar layered deposits due to resurfacing events. A Chasma is an equivalent of a canyon on other planets and moons. The largest example of a feature interpreted by some authors to have been formed by outflow of melt water on the north polar caps of Mars is the Chasma Boreale. Records of craters formed within the Chasma and adjacent regions can provide a useful insight into their origins and timescales of formation. In order to create these records, visual images from the THEMIS instrument aboard the Mars Odyssey spacecraft and MOC instrument aboard the Mars Global Surveyor (MGS) are being used. These data sets are complemented with MOLA (also aboard MGS) relief maps for both regions. An unusually high number of craters were found at the head of Chasma Boreale. In contrast, there is a unit free of all craters in the middle, followed by more cratering at the mouth of the Chasma. This has indicated a varied and dynamic history of resurfacing events and raises questions on the validity of the current theories behind its formation. This study should help complement current work on the nature of the Chasmas [*Fishbaugh et al*. 2001] as well as provide insight into their unusual locations and extent within the Polar Layered Deposits. It is also an objective of this investigation to attempt to place the Chasmas more precisely into the resurfacing history of the Polar Layered Deposits on Mars.

1. INTRODUCTION

Layered sediment and ice cores are used by geologists to read the record of Earth's history and past climate. The Martian north and south polar regions are similarly covered by large areas of layered deposits which consist of a mixture of ice and dust. Since their discovery, it is widely believed that the Polar Layered Deposits (PLD) have recorded climate variations over the past 10 to 100 million years [*Murray et al.,* 1972*; Cutts et al.,* 1976*; Howard et al.,*1982*; Plaut et al.,*1988*; Thomas et al.,*1992]. The PLD are sedimentary deposits that are thought to be composed of water ice and varying amounts of wind-blown dust and are typically characterized by spiral troughs cutting through the layered terrain on each pole (Figure 1).

There are a number of interesting comparative features apparent in imagery of both the North and South PLD on Mars. One such example of features interpreted by some researchers to have been formed by outflow of melt water is Chasma Boreale in the North and Chasma Australe in the south. 'Chasma' is a word used in planetary geology to refer to a long, narrow, steep sided canyon on other planets and moons. Chasma Boreale cuts deep into the interior of the North polar cap and is in contrast to the typical spiraling troughs that mark the boundary of the NPLD (Figure 1). Research by *Fishbaugh and Head* [2001] reveals evidence of subsurface melt water flowing downstream due to a general downward sloping relief from the head of the Chasma to its mouth, which led to water-induced erosion and lowering of the North polar ice to form the current depression. While it has also been acknowledged that katabatic winds and aeolian processes have played a major role in the modification of this feature, [*Howard,* 2000] there has been no attempt to scrutinize the timescales involved in these various surface modification processes. This work, hence, uses cratering records in the region to provide insight into the relative ages of various units within Chasma Boreale and in doing so provide the reader with ample evidence to judge the validity of current theories for themselves.

(a) (b)

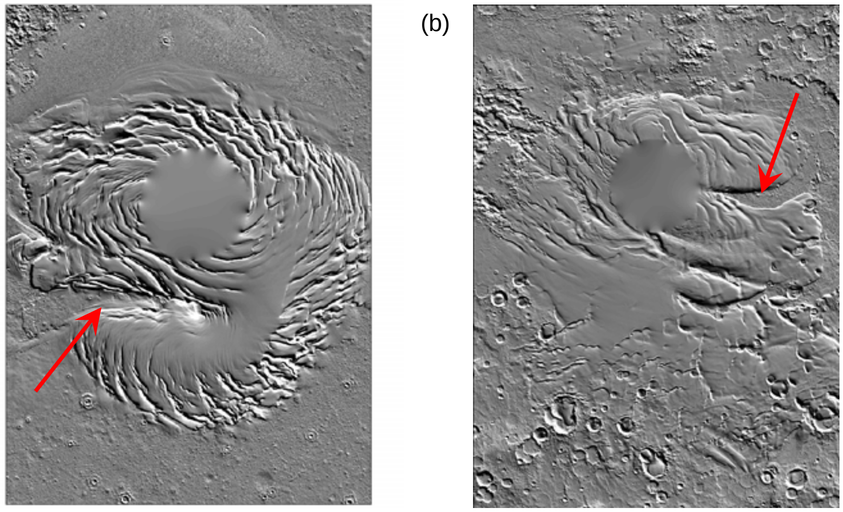


Figure 1. (a) The Martian North Polar Layered Deposits (NPLD). Arrow points to Chasma Boreale.
(b) The Martian South Polar Layered Deposits (SPLD). Arrow points to Chasma Australe.

Because of the unavailability of rock or soil samples from the Martian surface, statistics of impact crater populations remain the only method for dating regions and estimating the rate of resurfacing processes. Martian crater morphology is extremely similar to that of the Moon and Mercury. Small craters (< 10-15 km in diameter) show simple, bowl-shaped depressions with raised rims as well as a blanket of ejected material around the crater. Craters on Mars also appear to experience more erosion or other degradation than those on the Moon and Mercury. This is believed to be the combined result of a dynamic atmosphere (i.e., more intensive aeolian processes), more active volcanism throughout the history of the planet, and more weathering due to processes associated with the possible existence of water. Hence, the overlying resurfaced terrain has a younger surface age (after modification) compared to an older region which has not undergone surface modification and still has its crater morphology retained and evident.

2. DATA SOURCES AND METHODOLOGY

The cratering record for PLD's was previously estimated using the Viking orbiter images and from selected Mariner 9 images [*Herkenhoff and Plaut, 2000*] in both the North and South PLD's. The inferred surface age of the SPLD (about 10Ma) is two orders of magnitude greater than the surface age of the NPLD (about 100ka).

To estimate the age of Chasma Boreale within the NPLD, a search for craters using two instruments aboard the Mars Global Surveyor (MGS) spacecraft in orbit since 1997 was carried out. The first of these, Mars Orbiter Laser Altimeter (MOLA) provides shaded relief maps of the surface using laser technology onboard, whilst the Mars Orbiter Camera (MOC) provides visual images. However, during this study, a large number of craters were also detected using newly available images from the visible imager of the Thermal Emission and Imaging System (THEMIS) instrument aboard the Mars Odyssey 2001 spacecraft.

Initially, MOLA topography maps were used to identify various units of differing relief within the Chasma. 5 units were separately mapped out and color coded (Figure 2b). Analyzing this alongside the unmapped region (Figure 2a), the two partially circular depressions at the head of Chasma Boreale were mapped separately as the blue and red regions. The unusually smooth stretch of material that appears similar in texture to the surrounding NPLD was mapped as the orange region. Finally, the lobate deposit at the mouth of the Chasma that extends into the surrounding lowlands is distinguished by a 300m high scarp that defined the green region. An obvious difference in roughness of surface terrain is evident between the yellow/green boundary that initially provided justification in mapping them separately.

With a resolution of approximately 30m/pixel, MOLA shaded relief maps expose remarkable detail (Figure 1) and have been used widely in recent cratering studies [e.g. *Koutnik et al.,* 2002]. However, due to the regional constraints of this investigation, only the higher resolution MOC narrow angle (NA) images (resolve 1.4m/pixel) and THEMIS visible images (resolve 19m/pixel) were initially used to identify craters larger than 100 meters in diameter. The newly available THEMIS and MOC/NA data sets allowed complete coverage of all units mapped without having to resort to MOLA for crater identification.

Craters were defined as "likely" or "possible", consistent with the classification of *Plaut et al.* [1988] and *Koutnik et al.* [2002] in their studies of craters on the SPLD. Similar to their work, craters identified on MOC/NA and THEMIS/VIS were validated as "likely" only if they satisfied the following criteria: (1) appeared roughly circular on the imagery, (2) appeared bowl shaped, and (3) were located within the sample study area. In most cases, because of the high resolution of the data set used, evidence of raised rims and/or ejecta blankets was used as further evidence of likely classification. Also because of the high effective resolution of images, 279 of the 310 craters identified within the entire region provided enough visual evidence to be classified as likely.

Craters have traditionally been classified into primary and secondary craters. A primary crater is formed from a hypervelocity impact originating from space and has distinct morphology; including circular, raised rims and bowl shapes. Many have evidence of ejecta blankets and in some cases, a distribution of a secondary crater field surrounding the primary impact site. Secondary craters on the other hand are thought to be derived from debris of primary craters once material has been ejected away from the primary impact site, a view supported by *Wilhelms et al.* [1978].

Hartmann [1999] developed a system of dating Martian surfaces using isochrons on a log plot of crater density vs. crater diameter. An isochron represents the age of a surface and this is found by statistics of craters of different diameters over a certain area. The *Hartmann* [1999] isochron has a primary branch and a secondary branch to represent primary and secondary crater production. The primary branch has slope of -1.80 and the secondary branch has a slope of -3.82 (Figure 3b). His methodology involves plotting isochrons in conjunction with incremental (as opposed to cumulative) crater size-frequency data. The objective in this method is to obtain an isochron that most closely fits the incremental data set and hence derive an approximate age for the surface concerned. The crater data for each of the mapped units were plotted onto Hartmann isochrons in a similar way to obtain relative age differences between them.

The Appendix shows a spreadsheet of data used to group craters into diameter bins that differed by a factor of $\sqrt{2}$. The number density of craters (N/km^2) that fell within each bin was plotted against the upper value of the diameter bin in order to obtain an incremental plot and compare with *Hartmann* [1999] isochrons. Y error bars on the plots were obtained by assuming a counting error of $\pm \sqrt{(\text{number density})}$.

In an effort to obtain information about the morphologies of craters, depths and rim heights were measured using MOLA profiles for craters greater than 500m in diameter. Depth to diameter ratios of craters provides important information on the 'freshness' of a crater. A higher depth to diameter ratio indicates a fresher crater which can shed light on the age of the impact surface as well as resurfacing events.

3. RESULTS AND ANALYSIS

Figure 2b shows a map of crater densities in the 5 distinct units within Chasma Boreale. Each colored spot represents a crater and sizes of spots are proportional to measured crater diameters. From the plot it is evident that the blue and red regions at the head of the Chasma, though comparatively smallest in area have the highest crater densities. Counting from blue to green (right to left), the number of craters detected were 114, 72, 1, 33 and 90. From this plot alone, we can confirm that the crater counts complemented boundaries of the initial units traced out as separate and distinct. Each region will hence be examined separately in this paper.

(a)

(b)

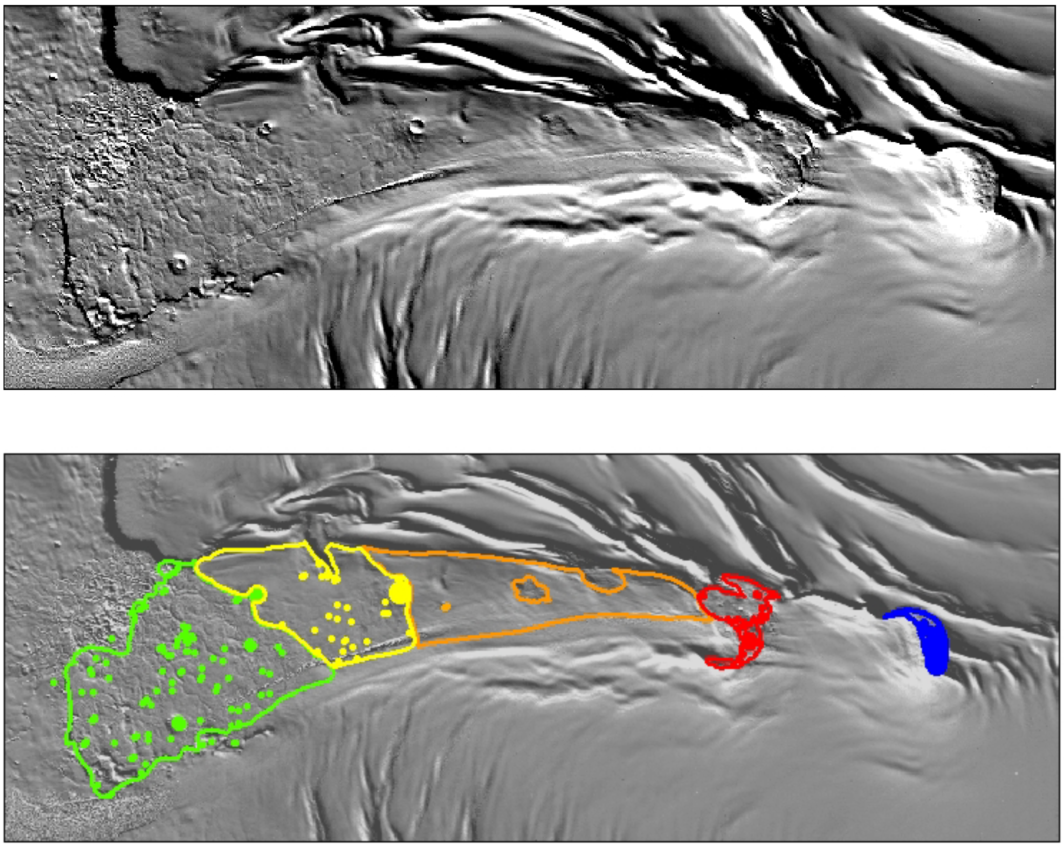
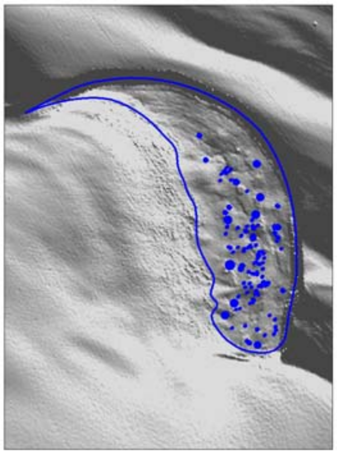


Figure 2. (a) MOLA shaded relief map of Chasma Boreale without 5 units mapped onto it. (b) Chasma Boreale with 5 distinct mapped units of differing surface terrain.

3.1 BLUE REGION

(a)



(b)

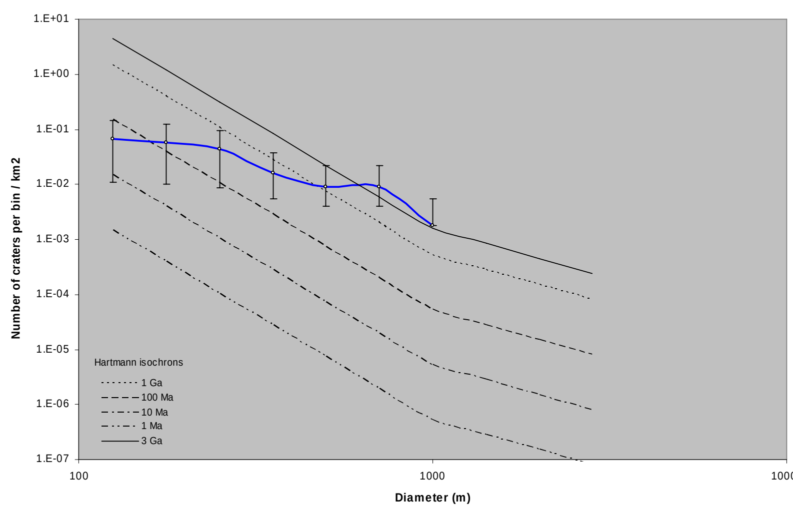
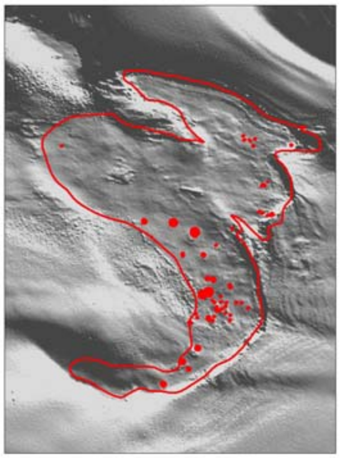


Figure 3. (a) Craters identified within the blue region at the head of the Chasma.
(b) Impact crater population for craters >100m compared to the *Hartmann* [1999] production model isochrons.

The blue region in Figure 3a represents the circular depression within the NPLD that marks the interior end of Chasma Boreale. A total of 114 likely and possible craters were detected within an area of 560 km^2 mapped as the blue boundary. Thus, a crater density of approximately 20.54 caters every 100 km^2 marks this region as the most densely populated of the 5 units. An incremental plot of the data in comparison to Hartmann isochrons (Figure 3b) provides further analysis of the comparative age. In spite of the error bars, the plot does not fit any one isochron and cuts right through the 3Ga, 1Ga and 100Ma isochrons. Although the plot is within the reaches of the older isochrons, a specific age cannot be determined. One possible explanation for this misalignment is that the smaller craters (<500m) have undergone some form of diameter dependent resurfacing which tended to wipe out a larger number of craters within the smaller diameter range than within the larger, hence, a reduced count of smaller craters and a reduction in the slope of the plotted line. A high crater density implies a much older surface revealed within this depression which may have been protected from severe resurfacing typical of the rest of the NPLD. If the outflow of meltwater downstream thought to have been responsible for the formation of the Chasma did in fact occur during the history of the Chasma, it may have had very little or no effect on the modification or indeed total obliteration of small craters within this region. On the other hand if this unit, that defines the core of the Chasma, was once buried by similar processes that dominate resurfacing of the rest of the NPLD, then some other process later in its history may have caused the unit and its craters to be exhumed.

3.2 RED REGION

(a)



(b)

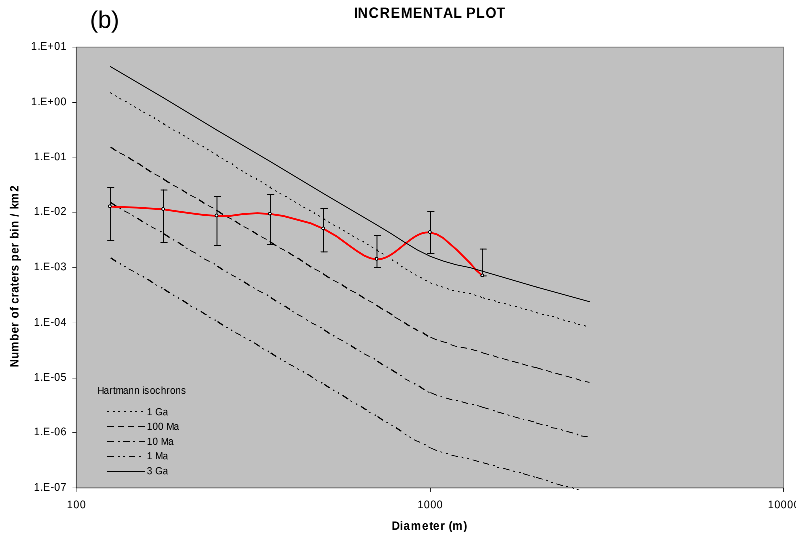


Figure 4. (a) Craters identified within the red unit in Chasma Boreale.
(b) Impact crater population for craters >100m compared to the *Hartmann* [1999] production model isochrons.

Moving outward from the interior core Chasma Boreale, we come across another generally circular depression within the NPLD that is similar to the blue unit but appears smoother in MOLA data and is larger in area – 1400 km^2. It is this red unit (Figure 4a) that marks the beginning to the lengthy depression that identifies most of the Chasma (orange, yellow and green units). Crater counts greater than 100m in diameter amounted to 72 within the red unit, however, crater density per unit area here is 5.36 craters every 100 km^2. Although this is roughly four times less than the blue unit, it is still quite a large number in comparison to the remaining units discussed later. The incremental plot in comparison to Hartmann isochrons reveals a further discrepancy in that the isochrons spanned by the plot now covers an even larger range of 10Ma to 3Ga in spite of error bars (Figure 4b). This provides further evidence of diameter dependent resurfacing if not similar to, then comparatively more than the adjacent blue region i.e. there are fewer small craters in the red region than the blue. A smaller crater density and smoother surface in close proximity to the largely resurfaced orange unit provides evidence of greater resurfacing over the red unit compared to the blue, hence, the red unit is relatively younger than the blue. Similarities with the blue region lie in the fact that both have a high crater density and both have been exposed out from the rest of the NPLD. Perhaps the most striking similarity is that both units appear in MOLA data as large semicircular depressions at the head of the Chasma. Craters within the red unit, just as in the blue unit may have been protected from resurfacing processes, or they may have been simply exhumed after being previously resurfaced.

3.3 ORANGE REGION

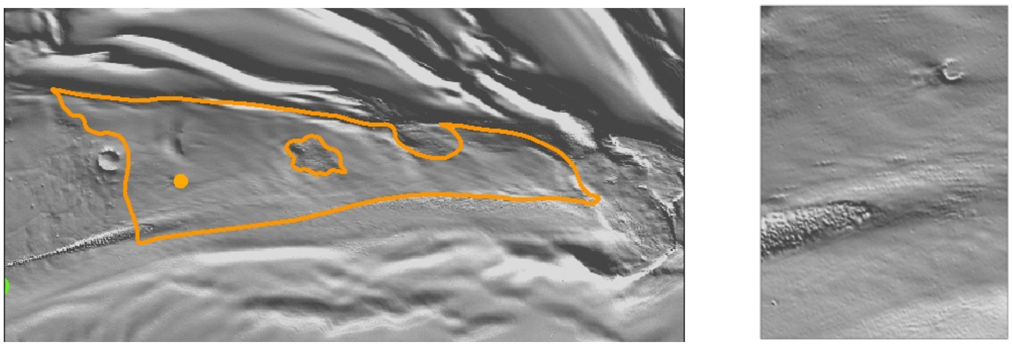


Figure 5. (a) Smooth orange unit within Chasma Boreale.
(b) MOLA relief map of single crater identified within the orange unit in Chasma Boreale.
MOLA relief map of partially resurfaced dune field at the bottom left of the unit.

The smooth stretch of material that appears similar to the rest of the NPLD but that is not as thick and falls within a depression has been mapped as a single orange unit in this study (Figure 5a). THEMIS/VIS and MOC/NA data reveal only one crater 2300m in diameter marked by a spot on Figure 5a. This crater is large enough to be clearly seen in MOLA relief map (Figure 5b, top right) and has been clearly modified by a material and process that caused resurfacing of the entire unit. The stretch of material at the bottom left of Figure 5a reveals a dune field that falls in the yellow unit discussed below. However, as it stretches into the orange unit, it has also evidently been resurfaced by the same process (Figure 5b, bottom left). This evidence points to a recent resurfacing process perhaps similar to processes that formed the surrounding NPLD may have occurred to produce a fresher unit atop an older underlying surface. Furthermore, the partial obliteration of the crater's rim and the envelope of material that covers the dune field suggest that the resurfacing process involved the flow of material in a direction from East to West rather than deposition processes that tend to retain crater rims. Hence a destructive (as opposed to constructive) sedimentary process has led to the eradication of smaller craters from the unit.

Because of the unavailability of cratering records within this unit, an incremental plot analysis in comparison to *Hartmann* [2000] isochrons could not be made. We can thus use the observed lack of craters to place an upper bound on the age of the surface as described by *Herkenhoff and Plautt* [2000]. Since the youngest age we dealt with in producing the isochrons was 1Ma, statistics used to plot the isochron imply that for a 1Ma old surface there should be 0.003467 craters for every km^2 in area on the surface.
Hence, for the orange unit (of area $7070km^2$), one crater>100m should be produced every 42,400 yrs. Considering Poisson statistics, a surface is younger than three times the average impact interval at the 95% confidence level. The probability of no impact events resulting in craters larger than 100m occurring during time interval t is

$$P\,(0,t,\tau) = e^{-t/\tau},$$

where τ is the average recurrence interval. When $t = 3\,\tau$, P = 5%. Thus, the maximum age of the unit at the 95% confidence level is 127.2ka (42.4x3).

3.4 YELLOW REGION

(a) (b)

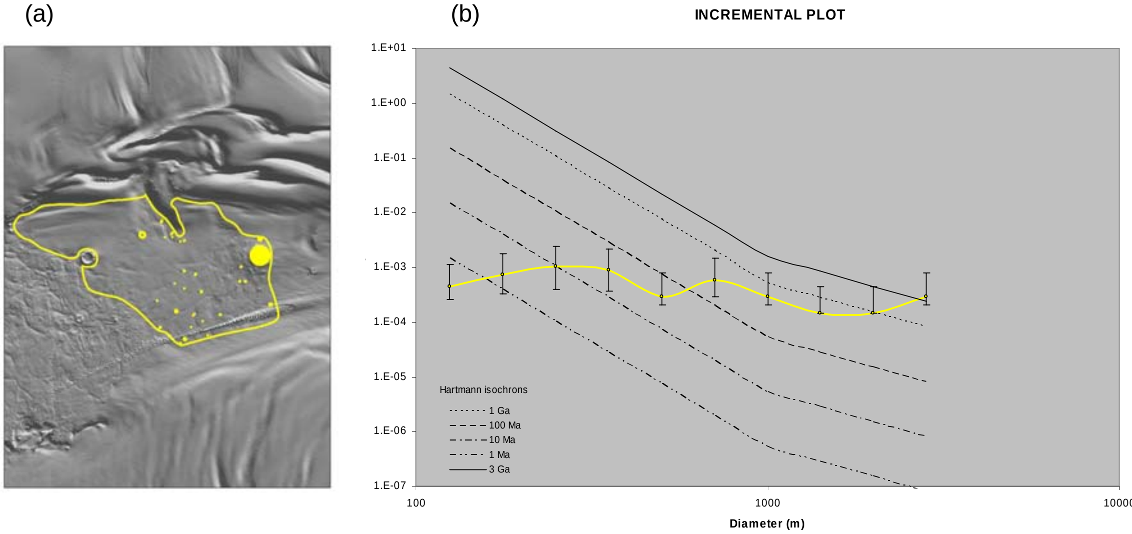


Figure 6. (a) Craters identified within the yellow unit in Chasma Boreale.
(b) Impact crater population for craters >100m compared to the *Hartmann* [1999] production model isochrons.

Figure 6a shows the yellow unit; a slightly more uneven surface that follows immediately after the boundary of the young orange unit and is bounded by the dune field stretch mentioned earlier at the bottom and an even more rugged surface to the left (green unit). Parts of the upper areas of this unit seem much smoother and similar in surface topography to the orange unit and in fact it is these regions of the yellow unit that show lack of craters. A total of 33 likely and possible craters >100m in diameter appeared in THEMIS and MOC data, representing a crater density of 0.44 craters per 100km^2 of the unit. A younger range of isochrons have been spanned by the incremental plot of the crater data ranging from hundreds of million years to just 1Ma. A flat plot indicates that the number of craters per bin size is approximately constant, and it also indicates that the plot does not follow an upward sloping isochron as expected because of resurfacing events that have severely wiped out smaller craters but retained larger ones. The presence of an exposed dune field might suggest aeolian processes that may have played some part in crater obliteration during the history of the unit. As discussed in the following section, certain parts of the yellow unit may be considered part of the green unit due to similar crater density; however, a conspicuous boundary visible in MOLA topography justified their separation.

3.5 GREEN REGION

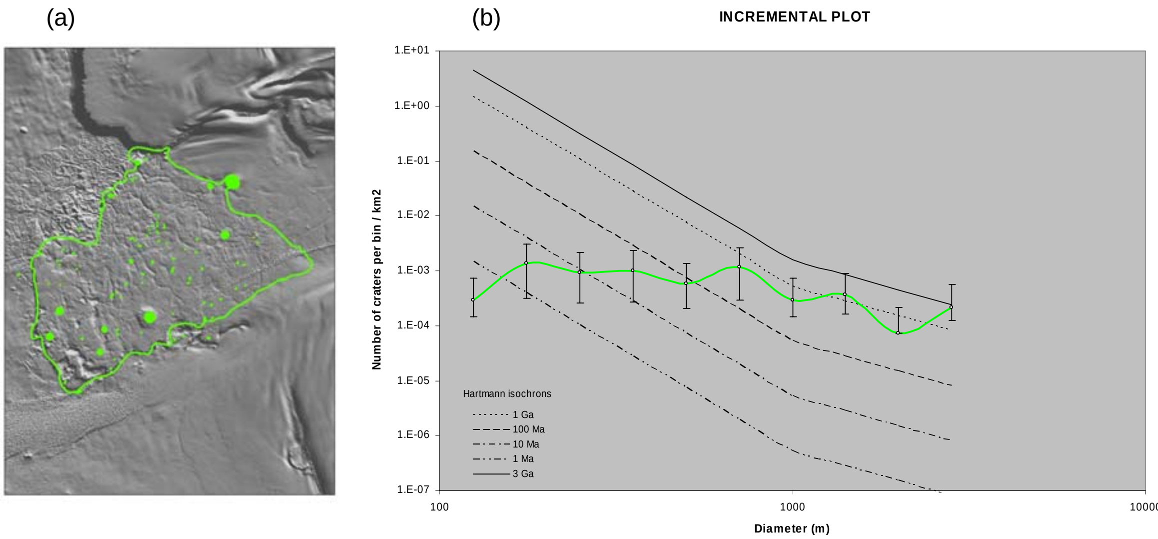


Figure 7. (a) Craters identified within the green unit in Chasma Boreale.
(b) Impact crater population for craters >100m compared to the *Hartmann* [1999] production model isochrons.

At the very end of Chasma Boreale what appears to be a lobate deposit of material that seems to have flowed out of the Chasma and deposited at its mouth, and bounded by a 300m scarp is found [*Fishbaugh and Head*, 2001]. This scarp and the difference in surface terrain at the yellow-green boundary mentioned earlier define the green unit (Figure 7a). This feature forms part of the evidence for an outflow of meltwater, originally proposed by *Clifford* [1987] and *Benito et al*. [1997] leading to cataclysmic flooding and subsequent formation of the Chasma. Covering an area of 13,800km^2, the green unit is the largest of the five mapped units in figure 2a. With a well spread out distribution of 90 craters, a value of 0.44 craters per 100km^2 is derived. This is quite similar to the 0.66/100km^2 found in the yellow unit which may lead one to argue that they are in fact part of the same unit. The incremental plot of craters in the green unit (Figure 7b) covers the same range of isochrons as in the yellow and shows evidence of similar diameter dependent resurfacing leading to modification, if not obliteration of smaller craters.

4. DISCUSSION

From crater counts alone, it is possible to infer relative ages of the various mapped units based on the hypothesis that an older surface will have more craters exposed than a recently resurfaced unit. Hence, the blue unit (20.54 craters/100km2) at the head of Chasma Boreale is oldest followed by the red, green, yellow and orange units in chronological order. This reasoning is confirmed in the incremental plot showing all units mapped out together for comparison (Figure 8).

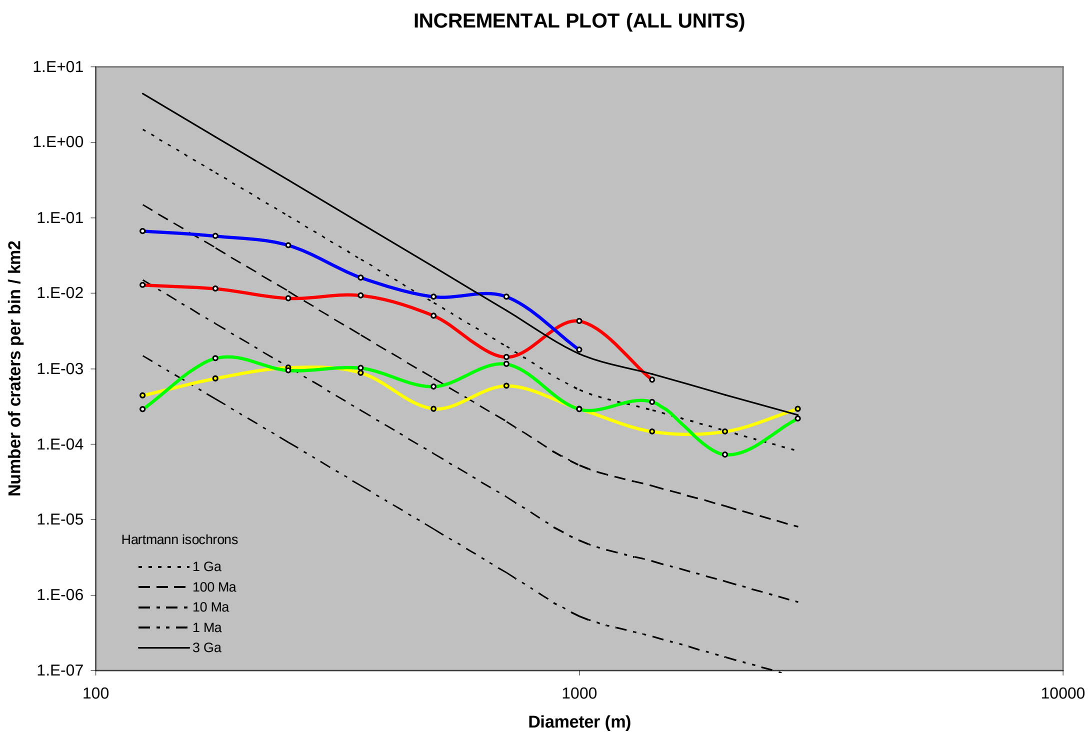


Figure 8. Incremental log plot of crater density vs. diameter for all units showing Hartmann (1999) isochrons for ages 1Ma to 3Ga.

The blue plot can be seen higher up on the 'isochron ladder' compared to the red, hence confirming the old age of its surface. The green plot has 7 of its 10 plotting points either marginally higher or at the same level as the yellow plot. This may lead one to argue that the yellow and green areas represent more or less the same unit, however the unconformity in surface terrain at the yellow/green boundary mentioned earlier was the initial criterion used in mapping individual units.

As mentioned earlier during the initial assessment of each unit, all regions seem to exhibit some form of resurfacing due to a reduction in gradients of plots at smaller diameters – hence, diameter dependent resurfacing. The oldest units (blue and red) also seem to have undergone some form of resurfacing, though not as significant as in yellow and green.

Finally, MOLA profiles were used to measure depths and rim heights of all craters greater than 500m in diameter in order to better understand these results. The plot in figure 9 shows the importance of depth/diameter ratios in this analysis. A higher depth/diameter ratio is evident in many craters within the green unit compared to the yellow unit, thus indicating the existence of fresher craters there. Both red and blue units had no craters greater than 1000m in diameter leading to a limited data set, however comparing the few found in each of them, the blue unit appears to have fresher craters.

Presuming various resurfacing periods defining the Chasma, a resurfaced crater would tend to be filled and hence reduce in depth. This would be indicative of a new surface overlying an older one. Taking an example of the single crater found in the orange unit (Figure 5b), we can note that resurfacing of the orange unit (that occurred ~127,000 yrs ago) infilled the crater and reduced its depth. This is in contrast to a crater which is found on an older underlying surface that would be deeper due to not having been resurfaced by a similar process. Hence, depth/diameter ratio in this context would mean that an older surface would have deeper, fresher craters of the same diameter than a recently resurfaced one. Keeping this in mind, data from figure 9 would show that the green unit is older than the yellow unit and that the blue is older than the red, again, consistent with our previous analysis.

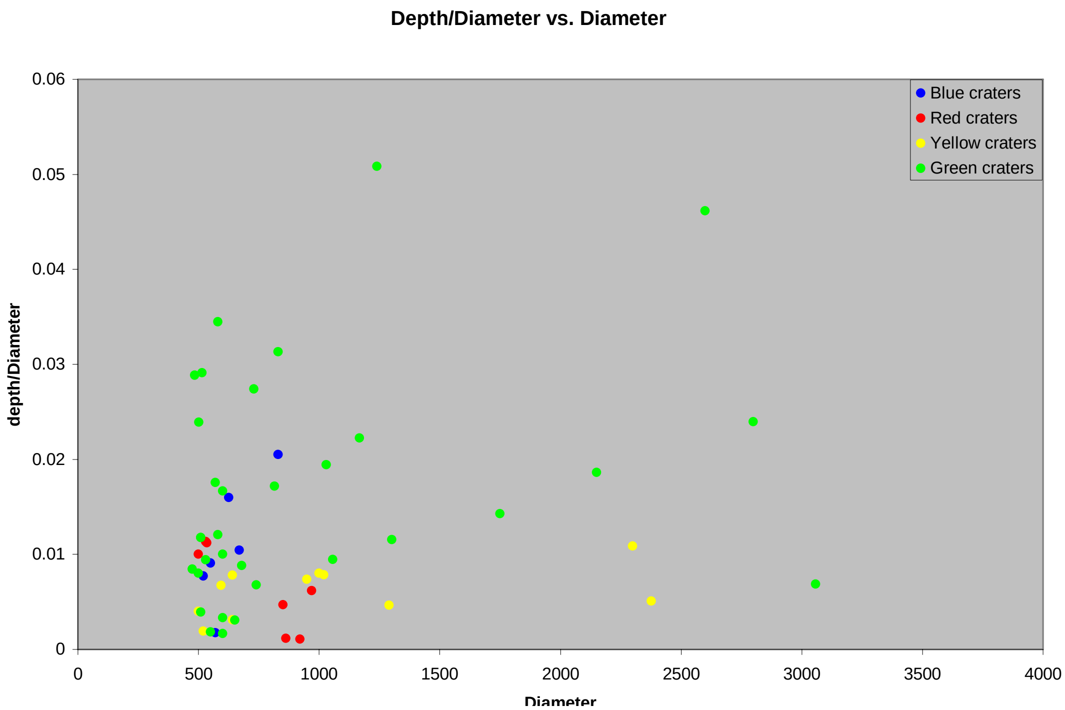


Figure 9. Plot of depth/diameter ratio vs. diameter for all craters >500m in the mapped units. The depth/diameter ratio is a measure of the 'freshness' of a crater.

Recent work done on the climatic history of the North polar region suggests that water saturated sediments covered the entire Northern plains at the beginning of the Amazonian period [*Tanaka*, 2005]. Compaction and freezing of these sediments may led to sedimentary volcanism and the erosion and redistribution of these may have formed the base of much of the NPLD known as the Scandia region. In his paper, *Tanaka* marks our green unit as a kilometer high scarp part of an eroded margin of Scandia materials west of Chasma Boreale. In such a scenario, the lobe of sediment that forms the green unit would have originated from volcanic origin rather than cataclysmic flooding. However, the red and blue units, also plotted in his paper are identified as Scandia material similar in age to our green unit. This is inconsistent with the crater counts and relative ages of these various units obtained using our incremental log plots in Figure 8.

5. CONCLUSIONS

The cataclysmic downstream flow of meltwater that broke out from within and below the cap proposed by *Clifford* [1987] and *Benito et al.* [1997] and later supported by *Fishbaugh and Head* [2001] does not fully conform with these findings. The blue and red units boast an unusually large number of craters (even smaller than 100m in diameter) to have been the only source of the meltwater. The varied crater density across the length of Chasma Boreale suggests that at least three independent resurfacing events may have occurred during its history. The apparent similarity between the boundaries of the red and blue units as well as their high crater densities may suggest that they were exposed to the same resurfacing event that covered their surfaces just as the surrounding NPLD, but were later exhumed. However, there still lies the possibility that both units were instead protected from severe resurfacing that created the NPLD around them.

The yellow and green units on the other hand may also have been affected by another resurfacing event that wiped out smaller craters further along the Chasma. The freckled nature of the green unit suggests that it was exposed to the same event that eradicated/modified craters. The lower crater density in the yellow and green units compared to the blue and red could be indicative of a separate and independent resurfacing event later in the history of the Chasma after the modification of red and blue unit craters.

Finally, the orange unit has clearly been resurfaced most recently as indicated by virtually no crater count. The single infilled crater that appears on the orange unit actually originates from an older surface below the current unit. Hence a third sedimentary process, possibly erosional rather than depositional in nature erased all craters from the unit.

Another hypothesis equally weighty in lieu of the possibility of 3 separate resurfacing events is that there may have been (and still is) only one sedimentary process that originates in the orange unit and is working outward, thus infilling craters as it moves further afield. This would be consistent with the fact that each unit appears more heavily cratered with deeper craters as we move away from the orange unit. The cause of such a process would be open to argument based on further work done in the region.

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APPENDIX

BLUE REGION						
bins (km)		upper limit (m)	N	N/km2	upper N	lower N
0.088388	0.125	125	37	0.066071	0.076934	0.055209353
0.125	0.176777	176.7766953	32	0.057143	0.067244	0.047041332
0.176777	0.25	250	24	0.042857	0.051605	0.034108965
0.25	0.353553	353.5533906	9	0.016071	0.021429	0.010714286
0.353553	0.5	500	5	0.008929	0.012922	0.004935593
0.5	0.707107	707.1067812	5	0.008929	0.012922	0.004935593
0.707107	1	1000	1	0.001786	0.003571	0
RED REGION						
bins (km)		upper limit (m)	N	N/km2	upper N	lower N
0.088388	0.125	125	18	0.012857	0.015888	0.009826685
0.125	0.176777	176.7766953	16	0.011429	0.014286	0.008571429
0.176777	0.25	250	12	0.008571	0.011046	0.00609707
0.25	0.353553	353.5533906	13	0.009286	0.011861	0.006710321
0.353553	0.5	500	7	0.005	0.00689	0.003110178
0.5	0.707107	707.1067812	2	0.001429	0.002439	0.000418419
0.707107	1	1000	6	0.004286	0.006035	0.002536079
1	1.414214	1414.213562	1	0.000714	0.001429	0
YELLOW REGION						
bins (km)		upper limit (m)	N	N/km2	upper N	lower N
0.088388	0.125	125	3	0.000441	0.000696	0.000186463
0.125	0.176777	176.7766953	5	0.000735	0.001064	0.000406461
0.176777	0.25	250	7	0.001029	0.001418	0.000640331
0.25	0.353553	353.5533906	6	0.000882	0.001243	0.000522134
0.353553	0.5	500	2	0.000294	0.000502	8.61451E-05
0.5	0.707107	707.1067812	4	0.000588	0.000882	0.000294118
0.707107	1	1000	2	0.000294	0.000502	8.61451E-05
1	1.414214	1414.213562	1	0.000147	0.000294	0
1.414214	2	2000	1	0.000147	0.000294	0
2	2.828427	2828.427125	2	0.000294	0.000502	8.61451E-05
GREEN REGION						
bins (km)		upper limit (m)	N	N/km2	upper N	lower N
0.088388	0.125	125	4	0.00029	0.000435	0.000144928
0.125	0.176777	176.7766953	19	0.001377	0.001693	0.001060949
0.176777	0.25	250	13	0.000942	0.001203	0.000680757
0.25	0.353553	353.5533906	14	0.001014	0.001286	0.000743358
0.353553	0.5	500	8	0.00058	0.000785	0.000374752
0.5	0.707107	707.1067812	16	0.001159	0.001449	0.000869565
0.707107	1	1000	4	0.00029	0.000435	0.000144928
1	1.414214	1414.213562	5	0.000362	0.000524	0.000200285
1.414214	2	2000	1	7.25E-05	0.000145	0
2	2.828427	2828.427125	3	0.000217	0.000343	9.18804E-05