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Mars Cratering

Crater count isochrons of Arsia and Pavonis Mons

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Imagery of Arsia and Pavonis Mons taken by Mars Global Surveyor was analyzed using the crater count isochron method, which entails calculating the crater densities of craters of varying sizes and comparing against isochrons for known ages. Calculations for Arsia Mons yielded a surface age of 500 million years, whereas Pavonis Mons had a surface age of only 100 million years. The result for Pavonis Mons yields evidence for recent volcanism. It is not known whether the volcanoes are of significantly different ages, or if one simply erupted more recently than the other.

Introduction

In this paper we present a rough age estimate of the last eruption/surface activity for two of the three Tharsis volcanoes, Arsia Mons and Pavonis Mons, calculated using isochron charts by William K. Hartmann (Hartmann, 1999). Finding the ages of these surfaces on Mars is important because it helps to narrow down the time in which Mars was most recently volcanically active. Since the invention of the telescope, scientists have long argued whether Mars was a vibrant or a dead world. Now, we know it to be mostly dead, but it shows evidence of recent volcanism that indicate it may still have some life left after all. Heating from current or recent volcanism may have affected the presence of liquid water, and water is, we think, the key to life. Knowing the current geological status of Mars is especially important if humanity is ever to consider colonizing it.

The isochron charts we used map a set of relationships between crater sizes along one axis and crater density along the other, both in logarithmic scale. The upper limit on the isochron chart is the saturation line, which represents the point at which each additional newly created crater would, on average, destroy another crater. As one gets further away from the saturation line on the graph, one sees isochron lines in characteristic shapes mapping out a relationship between crater size and density that represent younger surface ages. Each isochron represents a correlation between crater size and crater density for a specific surface age.

The isochron charts are calibrated against experimental radiometric dating data from samples returned by NASA's manned lunar missions. Hartmann's isochron charts for use on Mars have been adjusted to account for Mars' increased gravity, lack of a large neighborhood companion, and farther distance in the solar system, where the asteroid/comet size distribution is different. We used the most recent version of Hartmann's isochrons, which are additionally calibrated to account for large impactors that split up in Mars' atmosphere to yield many smaller impacts, as well as secondary craters formed by impacts from ejecta created by primary impacts.

To use an isochron chart to find an approximate surface age, one must count up the number of craters of varying sizes on a photograph, calculate the density by dividing into the total area, plot the points on the isochron graph and connect them with a line, and interpolate between the two nearest isochron lines to find an age.

The Tharsis region of Mars is located along the equator near the western terminus of the Valles Marineris. It is a large upland formed by mostly volcanic processes. The Tharsis Bulge, part of the overall Tharsis region, contains some of the solar system's largest volcanoes, including the highest one, Olympus Mons. To the southeast of Olympus Mons lay the three Tharsis Montes in a northeast-to-southwest orientation. From top to bottom they are Ascraeus Mons, Pavonis Mons, and Arsia Mons. We focused on the latter two in this paper.

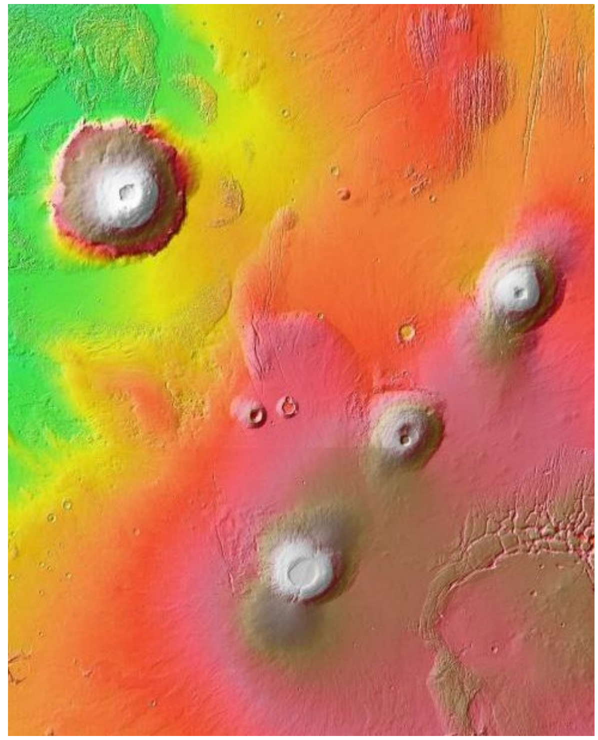


Figure 1: Olympus Mons and the Tharsis Montes. Image credit NASA / JPL.

Previous studies using crater counts have indicated that the calderas on the Tharsis Montes are about 40 to 100 million years old, indicating recent volcanism (Helgason, 2001). The actual bulk of the volcanoes is expected to be much older, but they have erupted relatively recently and mostly repaved their calderas and parts of their flanks.

We examined two images each of Pavonis Mons and Arsia Mons. The images were taken using the Mars Orbiter Camera on the spacecraft Mars Global Surveyor. We included images that showed both the calderas of the volcanoes and their flanks, so we could calculate separate ages for each in case eruption had, for example, more recently repaved the calderas than the flanks.

Qualitative analysis of images of the Tharsis Montes reveals significant recent volcanic features that have not yet been repaved by erosion or impact cratering. In particular, lava tubes (some collapsed), subsidences, pit chains, and flank landslides are all evident in these images. These features may have affected the analysis because some of the volcanic features, particularly circular subsidences from collapsed lava tubes, look nearly indistinguishable from eroded craters.

Data

We examined four separate images of Mars taken by the Mars Orbiter Camera, one of the scientific instruments aboard the Mars Global Surveyor spacecraft. The images had pixel resolutions ranging from 1.52m to 8.52m. Two of the images were of Arsia Mons; one was centered in the caldera and the other was on its flank. The other two images were of Pavonis Mons; one focused entirely on the caldera, and the second included parts of both the caldera and the flank.

Table 1: Image acquisition and data parameters.

Image ID	Date	Image Dimensions	Coordinates	Scaled Pixel Size	Region Size	Local True Solar Time
		(px)		(m)	(km)	(dec. hours)
M10-03730	1999-12-31	336 x 8,704	120.48°W 9.46°S	8.52	2.86 x 77.71	13.75
R15-01602	2004-03-17	512 x 12,160	120.72°W 10.87°S	5.97	3.05 x 72.30	13.72
R13-04204	2004-01-27	1,024 x 13,056	113.03°W 0.31°N	1.52	1.56 x 19.33	13.46
E10-01691	2001-11-11	512 x 16,256	113.02°W 0.86°N	6.08	3.11 x 96.29	13.81

Images M10-03730 and R15-01602 are of Arsia Mons. Images R13-04204 and E10-01691 are of Pavonis Mons.

Analysis

The data collection was carried out by counting the number of craters of varying sizes on each image. A total of four images were counted, with each image examined by two separate people and the results compared. The craters were sorted into different categories based on their diameters. The category cut-offs were based on successive powers of two. For example, one category of craters could contain craters ranging from 2^5 – 2^6 (32 - 64) meters in diameter. The smallest category was decided by the smallest size crater that could be distinguished base on the pixel scale of the image. The largest category was decided by the largest crater found in the image. The counting and sorting of craters is the first, and most time consuming, step towards determining the age of the surface of the image.

After these craters were counted and sorted, the area of the images was calculated by determining the length and width of the images in pixels. By using the pixel scale that was given for each image in the MOC gallery, we were able to calculate the area encompassed by each image by simply multiplying the length and the width of the image. Using the total number of craters counted (N) and the area of the image (A), the crater density (n) was calculated (n = N/A). The error for this crater density was then calculated by dividing the square root of the number of craters by the area (error = sqrt(N)/A). This error was then added to and subtracted from the calculated crater density to determine the error bars for the measurement. These figures were calculated for each crater size category.

These limits and the originally calculated density were then converted to a logarithmic scale. The reason for this is that the isochrons are plotted on logarithmic axes in order for them to appear as straight lines, since they are power functions. This makes them easier to evaluate. Additionally, they are plotted on logarithmic axes for the pragmatic reason of being a better way to display the exponential data. The y-axis is plotted according to a logarithm in base 10, while the x-axis is plotted according to a logarithm in base 2. When the data are plotted in such a manner, they can easily be matched up with the straight line isochrons in order to make an estimate for the age of the surface in the image.

Results

Arsia Mons

Two images of Arsia Mons were analyzed. The first image was of the caldera floor. The second image was of the flank of the volcano. The analysis of these images followed the procedure described in the previous section with one exception: For the $2^6 – 2^7$ craters in the second image, only a smaller sub-area of the image was counted. This is because there were shadows in some areas of the image, making it impossible to distinguish all of the small craters. The brightest area of the image was selected and the density was calculated solely based on that smaller area. The data collected are recorded in the table below.

Table 2: Crater count data for the images of Arsia Mons.

Diameter	N	A	n	σ (n)	Log(n)	log(n+ σ)	Log(n- σ)
Caldera							
Ben's counts							
2^5.5	166	12.341	13.4505	1.04396	1.1287	1.1612	1.0936
2^6.5	232	212.29	1.09282	0.07174	0.0385	0.0661	0.0090
2^7.5	7	212.29	0.03297	0.01246	-1.4818	-1.3426	-1.6880
Paul's counts							
2^5.5	154	12.341	12.4781	1.00552	1.0961	1.1298	1.0596
2^6.5	235	212.29	1.10695	0.07221	0.0441	0.0715	0.0148
2^7.5	7	212.29	0.03297	0.01246	-1.4818	-1.3426	-1.6880
Flank							
Ben's counts							
2^6.5	251	191.53	1.31048	0.08271	0.1174	0.1440	0.0891
2^7.5	50	191.53	0.26105	0.03691	-0.5832	-0.5258	-0.6494
2^8.5	11	191.53	0.05743	0.01731	-1.2408	-1.1264	-1.3966
2^9.5	4	191.53	0.02088	0.01044	-1.6801	-1.5040	-1.9812
2^10.5	2	191.53	0.01044	0.00738	-1.9812	-1.7489	-2.5145
2^11.5	3	191.53	0.01566	0.00904	-1.8051	-1.6071	-2.1791
Paul's counts							
2^6.5	234	191.53	1.22172	0.07986	0.0869	0.1144	0.0576
2^7.5	45	191.53	0.23494	0.03502	-0.6290	-0.5686	-0.6991
2^8.5	10	191.53	0.05221	0.01651	-1.2822	-1.1629	-1.4473
2^9.5	5	191.53	0.02610	0.01167	-1.5832	-1.4227	-1.8407
2^10.5	2	191.53	0.01044	0.00738	-1.9812	-1.7489	-2.5145
2^11.5	3	191.53	0.01566	0.00904	-1.8051	-1.6071	-2.1791

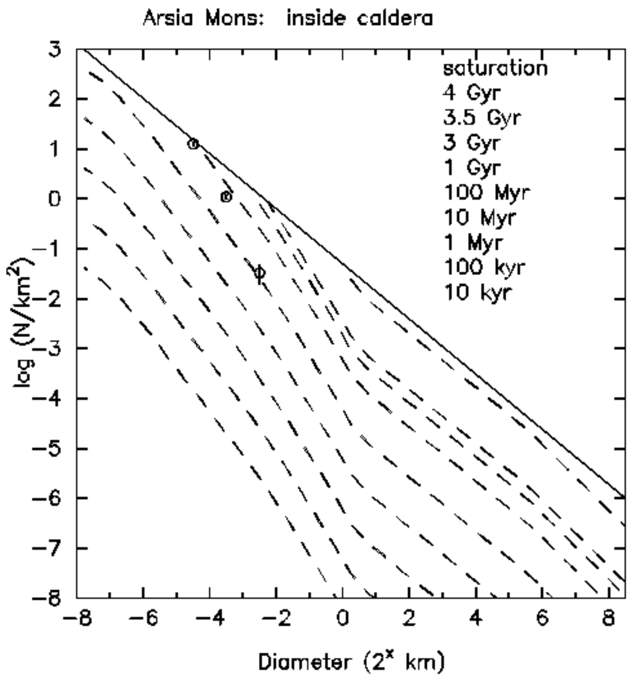


Figure 2: Isochron chart for Arsia Mons, caldera.

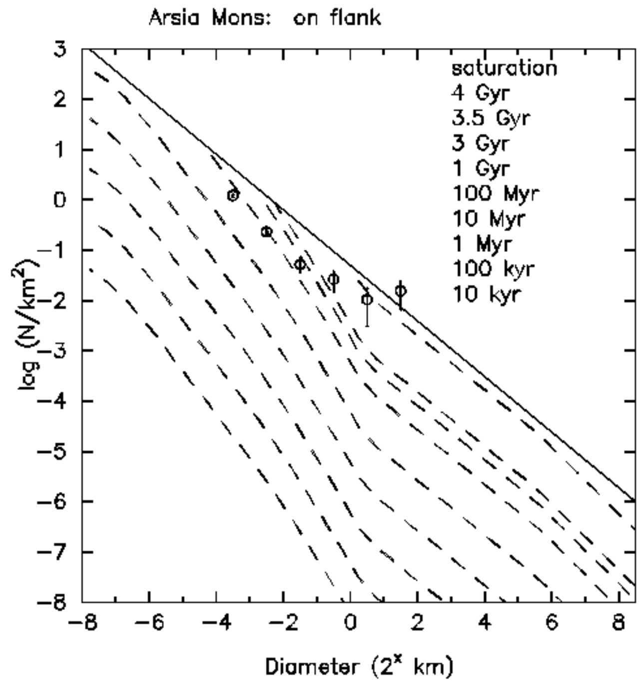


Figure 3: Isochron chart for Arsia Mons, flank.

The data points were plotted along the isochron chart, yielding very different ages for the inside and outside of the volcano. The data points suggest that the inside of Arsia Mons is around 500 million years old, while the outside of the volcano is around one billion years old. The outside was expected to be older than the inside of the volcano, so the results are not surprising. However, there still were some abnormal trends in the data that need some explaining.

First of all, there were a large number of large craters on the flank. A suggested explanation for this issue is that some of the "craters" that were counted are actually collapsed lava tubes. The large craters were located on the flank of the volcano, placed precariously on the surface of a system of lava tubes. It is not a farfetched idea that a lava tube could collapse in an almost circular manner, appearing to be a crater from far away. This would explain the unusually high count of large craters. Also, based on the ages determined, the number of small craters

Figure 4: The smaller sub-area from image M10-03730 that was counted for the smallest crater size. Image credit MGS MOC.

was too low on the outside and too high on the inside. For the outside of the volcano, erosion could have been a factor. Over the years, erosion can easily make small craters disappear, accounting for the low count of craters outside of the caldera. However, on the inside of the caldera, the count was higher than expected. This could be the result of using a small sampling area to represent the entire area. If the sample's density was higher than normal, then the density will appear to be higher for the entire image.

Pavonis Mons

Two images of Pavonis Mons were studied. There was one variation from the aforementioned procedure. Since the inside of the caldera was in both images studied, the crater counts for inside the caldera were combined. This changed the way in which the error was calculated for these crater counts. The error for each individual image was calculated using the previous formula (error = sqrt(N)/A). The error for the combined image was calculated by taking the square root of the sum of the squares of each individual error (total error = sqrt($(error1)^2 + (error2)^2$)). The data for the inside of the volcano in both images is recorded in the table below.

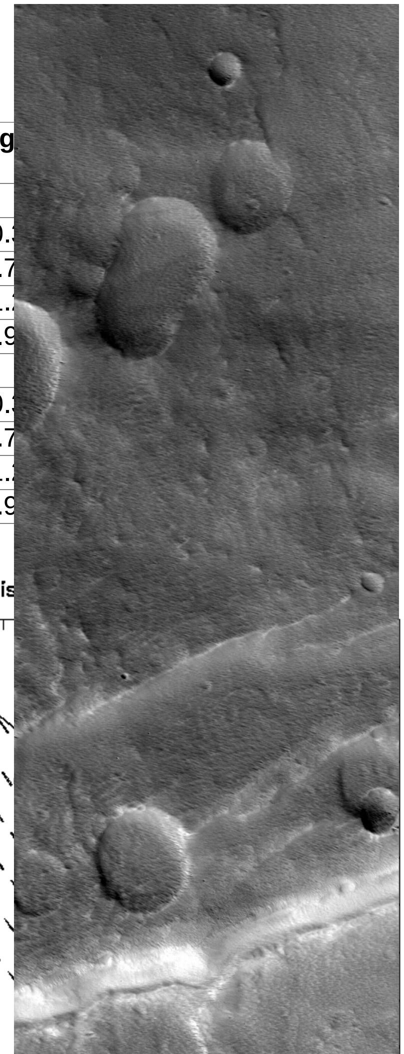
Table 3: Crater count data for the caldera of Pavonis Mons.

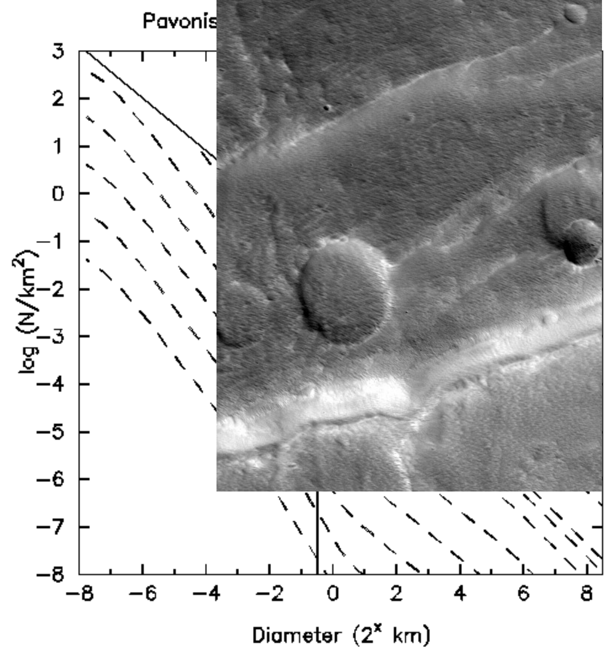
Bin	N1	A1	N2	A2	N	A	n	σ(n)	log(n)	log(n+σ)	log(n-σ)
Ben's counts											
2^5.5	22	19.983	0	0	22	19.983	1.100918	0.234716	0.138707	0.417525	-0.20723
2^6.5	6	19.983	24	81.6	30	101.63	0.295178	0.136473	-1.76034	-1.21206	-2.65558
2^7.5	1	19.983	5	81.6	6	101.63	0.059036	0.057045	-4.08227	-3.1068	-8.97275
Paul's counts											
2^5.5	20	19.983	0	0	20	19.983	1.000834	0.223793	0.001203	0.292343	-0.36394
2^6.5	5	19.983	23	81.6	28	101.63	0.2755	0.126376	-1.85988	-1.31518	-2.74542
2^7.5	1	19.983	5	81.6	6	101.63	0.059036	0.057045	-4.08227	-3.1068	-8.97275

The outside of this volcano was also studied, and the procedure for counting and calculating the error was carried out as stated in the analysis. The data for the craters on the outside of Pavonis Mons are listed in the following table:

Table 4: Crater count data for the flank of Pavonis Mons.

Bin	N	A	n	σ(n)	log(n)	log
Ben's counts						
2^6.5	70	173.6344	0.403146	0.048185	-0.3945	-0.
2^7.5	27	173.6344	0.155499	0.029926	-0.8082	-0.7
2^8.5	7	173.6344	0.040315	0.015237	-1.3945	-1.
2^9.5	1	173.6344	0.005759	0.005759	-2.2396	-1.9
Paul's counts						
2^6.5	67	173.6344	0.385868	0.047141	-0.4135	-0.
2^7.5	29	173.6344	0.167018	0.031014	-0.7772	-0.7
2^8.5	7	173.6344	0.040315	0.015237	-1.3945	-1.
2^9.5	1	173.6344	0.005759	0.005759	-2.2396	-1.9





The combined results for the caldera on Pavonis Mons yields a surface age of 100 million years. The data points are well-grouped along the 100 million year isochron line. The results for the flank of Pavonis Mons, however, yield a surface age of 1 billion years. This age is more difficult to estimate than that of the flank, because the error bars are very large on the largest sized crater bin. Also, the smaller craters tail off and approach the isochron line of 100 million years. However, it is more likely

Figure 5: Isochron chart for Pavonis Mons, caldera. **Figure 6:** Isochron chart for Pavonis Mons, flank.

that wind erosion smoothed away the smaller craters over time than that there were significantly more large impacts than one would expect for a young surface age. Wind erosion rates are affected by mountainous terrain, whereas cratering rates are not.

Some of the larger crater counts were imprecise due to ambiguities over whether certain circular features were craters or collapsed features associated with lava tubes. It may be impossible to definitively classify these features sort of examining the rock first hand and looking for tell-tale fracture planes that are only produced by impacts.

Pavonis Mons' caldera appears to be significantly younger than Arsia Mons, both from analysis of our data and a simple qualitative inspection of the images: Arsia Mons is much more highly cratered. The flank ages are roughly similar. It is impossible to determine from our data whether Arsia Mons is actually significantly older than Pavonis Mons, or if it just has not experienced volcanic activity as recently. We can conclude that Pavonis Mons has experienced volcanic activity more recently, but we cannot say if the bulk of the volcano itself is significantly younger.

Figure 7: Ambiguous features on the flank of Pavonis Mons. Are these craters or subsidences created by collapsed lava tubes? Image credit MGS MOC.

Conclusions

The results of this study show that both volcanoes' calderas are younger than their flanks. This was to be expected. However, the interesting result of this study is the evidence of recent volcanism on Mars. 100 million years is recent in contrast to Mars' age of about 4.4 billion years. A striking result of this study is that Pavonis Mons' caldera appears to be much younger than the caldera of Arsia Mons. Pavonis Mons' caldera is around 100 million years old, while Arsia's is around the 500 million year mark.

If these ages are somewhat accurate, then Pavonis Mons holds some promise for active volcanism. Since, it appears to have been active in the past 100 million years; it is still a possibility that it has not fallen completely dormant. Also, with the idea of volcanism being a current force on Mars' surface comes the promise of water. If there is indeed active volcanism on the surface of Mars, conditions could be warm enough to have liquid water on Mars. More studies have to be conducted to determine the current status of volcanism on Mars.

References

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