Introduction

Named after the Roman God of War, Mars is the fourth planet from the Sun and the seventh largest in our Solar System. Throughout Mars' geological history, four dominant forces have shaped the landscape of the planet: volcanism, impactors, and fluvial and Aeolian erosion.

Although Mars does not currently have an active hydrological cycle, the origin and fate of its water is still uncertain, although a large amount of research is currently devoted to fluvial erosion of Mars. Water cannot currently exist on Mars' surface, as the atmosphere is too thin and it is unsustainable. Millions of years in the past though, liquid water either flowed from the surface, or seeped from underground deposits to create small gullies, dendritic channels, and fan-like deltas.[1]

Currently, perhaps the greatest force of erosion is Aeolian, or wind. These powerful winds sandblast rocks, create huge sandstorms and tornado-like cyclones, and sometimes even trigger planet-wide dust storms. These dust particles are typically one-millionth of a meter, and due to the thin atmosphere, can travel ten times faster than those on Earth. The global temperature differences on Mars perpetuate these wind storms, as local ground heating produces a spinning column of warm gas that sweeps up dust and creates dust devils. This Aeolian erosion has significantly shaped the Martian landscape, and will continue to long into the future.[2]

In addition to fluvial and Aeolian erosion, volcanism was, and perhaps still is, a major geological force on Mars. Especially in the northern hemisphere, volcanoes and volcanic plains dominate the surface and have covered up craters and other older geological formations. Mars' volcanism has persisted for the majority of its 4.6 billion year history, and perhaps is still an active force today. Due to the concentration of volcanoes in the northern hemisphere (the product of a difference in crustal composition between the hemispheres), the north has far fewer craters than the south.[3] For our present study, the universal force of impactors is of prime importance. The Martian surface is dominated by craters, each widely varying in age. [4]

The number of craters is the important factor, not necessarily size. Older regions have far more craters, while younger regions have much fewer. Fewer craters total, regardless of size, means a younger surface. The more craters counted ensures a greater degree of accuracy when determining the age of a surface. As there is a clear correlation between number of craters and surface age, scientists use isochron graphs to plot this relationship. These impact-crater isochrons are defined by William Hartman as "size distributions of impact craters on undisturbed Martian surfaces of specified ages." By counting craters on the planet's surface, one can estimate the age of the surface, and thus clarify the nature of Mars' geological processes.[5]

While all of this information helps explain the Martian geological processes and the current shape of the Martian surface, one must still wonder: "Why does it matter?" Foremost, studying other planets, especially terrestrial planets similar to Earth, helps one to better understand physics and the laws of nature which govern our planet. The study of Mars can also help us understand how changes in the atmosphere can lead to catastrophic effects on the surface below. As Earth is currently undergoing significant climate change, an understanding of terrestrial atmospheres is of prime importance. Furthermore, as human beings have always

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[1] Lang, Cambridge Guide to the Solar System, 235-6

[2] Ibid, 245

[3] Ibid, 255-57

[4] Neil McBride and Iain Gilmour, *An Introduction to the Solar System*, (Cambridge: 2003)

[5] William K. Hartman, Isochron refinement and the chronology of Mars, 294-96

sought to learn and understand more, the study of Mars provides us with more information to better understand our Solar System and the fate of terrestrial planets. Lastly, Mars' impact history could be very similar to Earth's, but easier to study because of less geological processes and erosion. There is a lot of learn about our own planet from Mars.

Data

The images analyzed were collected from Malin Space Science Systems Inc, which has over 212,000 images from the Mars Global Surveyor (MGS). The Mars Global Surveyor was the first successful U.S. mission launched to Mars since the Viking mission in 1976. "Mars Global Surveyor arrived at Mars on September 11, 1997, and has contributed a multitude of findings, including signs of past, persistent water such as an ancient delta and currently active water features in the gullies of canyon walls"[6]. After nearly a decade of discovery, MGS went silent in November, 2006. MGS used three instruments; a narrow angle camera that obtained grayscale high resolution images (typically 1.5 to 12 m per pixel) and red and blue wide angle cameras for context (240 m per pixel) and daily global imaging (7.5 km per pixel)[7]. During this study, six images were selected and their pertinent data are below.

Image Name (Tom)	Pixel Ratio m/pixel	Latitude and Longitude	Area km²
M0306704/Image 1	5.77	2.10°N 240.07°W	114.46
M1104164/Image 2	3	23.97°N 263.85°W	23.283
M1600778/Image 3	4.52	26.47°N 226.69°W	56.6
(Dustin)			
M0306584/Image 1	6.16	41.34N 73.91W	253.94
M0306582/Image 2	1.52	32.55N 72.51W	15.24
(Philip)			
R1402904/Image 1	4.7	19.06°N 72.30°W	67.186

Analysis

The procedure used to count craters was to zoom into the image at 400X using GIMP. GIMP is freely distributed photo editing software. Then, we measured the diameter of the craters in pixels. Pixel measurements were converted into km by multiplying the pixel ratio by the pixel diameter of the crater. We then choose multiple average pixel ranges, increasing in size, for each image, these were called bins. For example, an average bin could range from five pixels wide to six pixels wide and would represent a single point on the isochron of the image.

To follow published isochrons we calculated the crater diameters in powers of 2, which was done by dividing the log(size in km) by log(2). The number of craters per area was found by dividing the amount of craters by the area of the image. Center points on the isochron were calculated by calculating the log(# of craters per bin/area). Positive error bars were calculated by taking the log(# per area + (√(# of crater per bin)/area), and negative error bars were calculated

[6] Mars Global Surveyor
[7] Malin Space Science Systems

by taking the log(# per area - (√(# of crater per bin)/area). √(# of crater per bin) was used as the uncertainty because we assume impactors hit the surface of Mars randomly and didn't prefer to hit any specific location.

Results

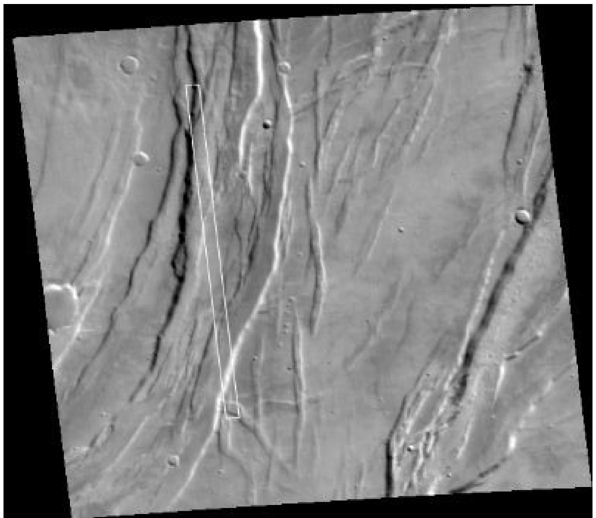
(Dustin) M0306584/Image 1

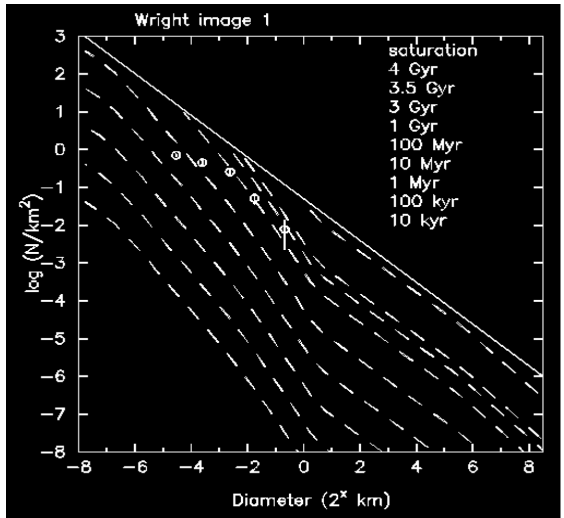
The region in this image lies north-east of Tempe Terra. A noteworthy feature of this region is abundant tectonic activity. A series of rifts and jagged terrain is visible in the context image. These formations are described on the Mars Global Surveyor website as "graben/horst terrain." A graben is a long ditch formed between two faults. A horst is an elevated strip of land between two grabens. These formations occur on Earth at a divergent plate boundary, such as the mid-Atlantic ridge, so we suspect that some form of tectonic activity has occurred in this region.

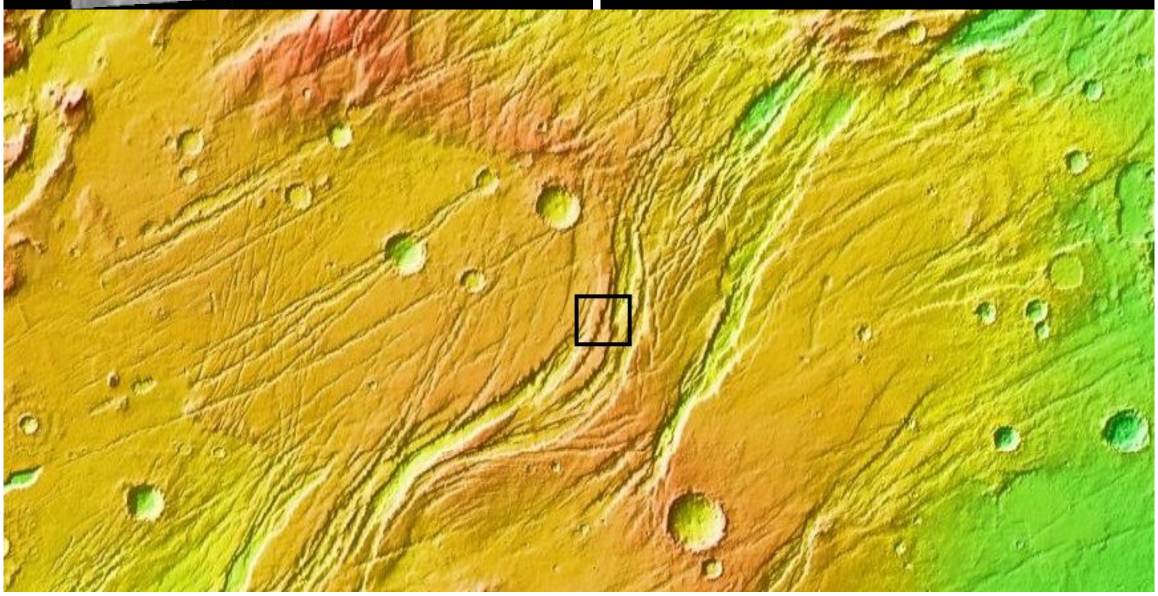
Careful analysis estimates that the age of this region is approximately 1 billion years, plus or minus 100 million years. The three data points on the isochron plot corresponding to the largest craters in the image closely match this estimate. The two data points corresponding to the smaller craters fall short of the estimate, however. The discrepancy can likely be attributed to landslides and volcanism that may have altered the ages of the surfaces, as there is evidence of both in the image. Smooth surfaces in the bottom of rifts are less cratered than their surroundings, and their smoothness is characteristic of lava flow. Rough terrain near the base of cliffs is also present, which strongly suggests the presence of landslides.

Close-up of the image, showing detailed features.

The estimated age of 1 billion years is supported by features of the image. When the region was tectonically active, rifting destroyed craters and formed a younger surface layer. Thus, the craters that exist on this surface were not formed until after the rifting ended. This suggests that the tectonic activity in this region ceased around 1 billion years ago.

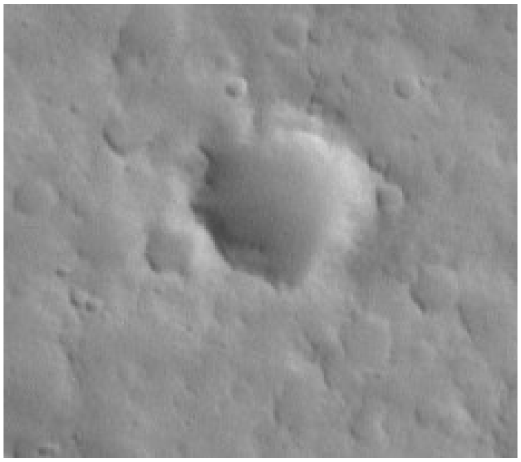


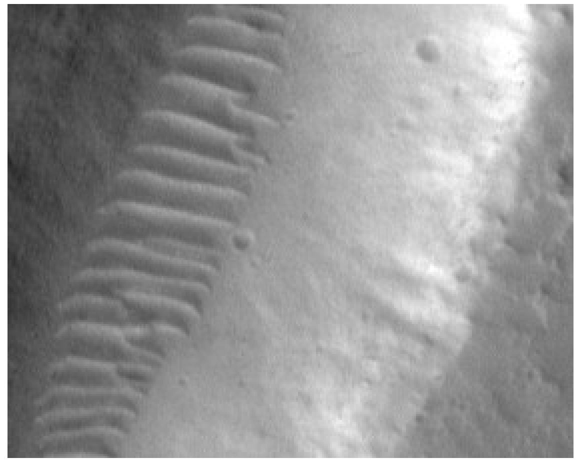




(Dustin) M0306582/Image 2

The region in this image is located near Tempe Terra. While not obvious in the context image, it’s clear from looking at the high-resolution image that this region is visually saturated with craters. Many of the craters are faded thanks to large scale wind activity. This wind has formed broad dunes, giving some insight into the intensity of the wind.

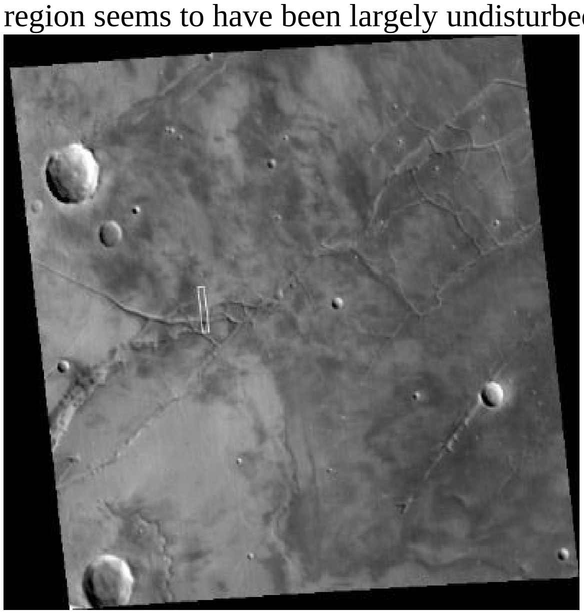


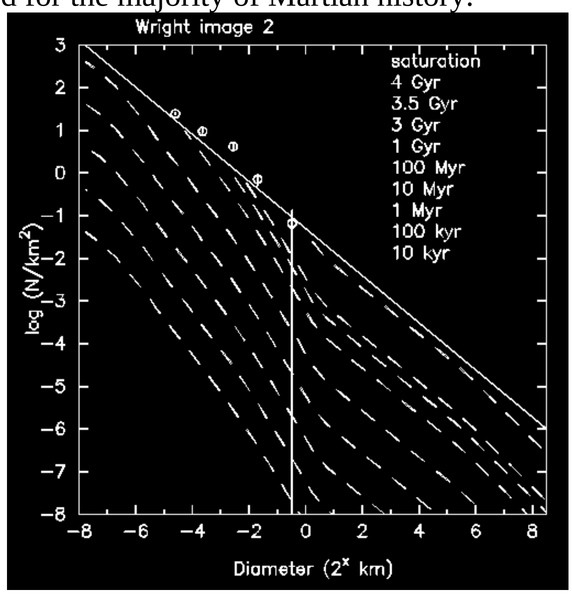


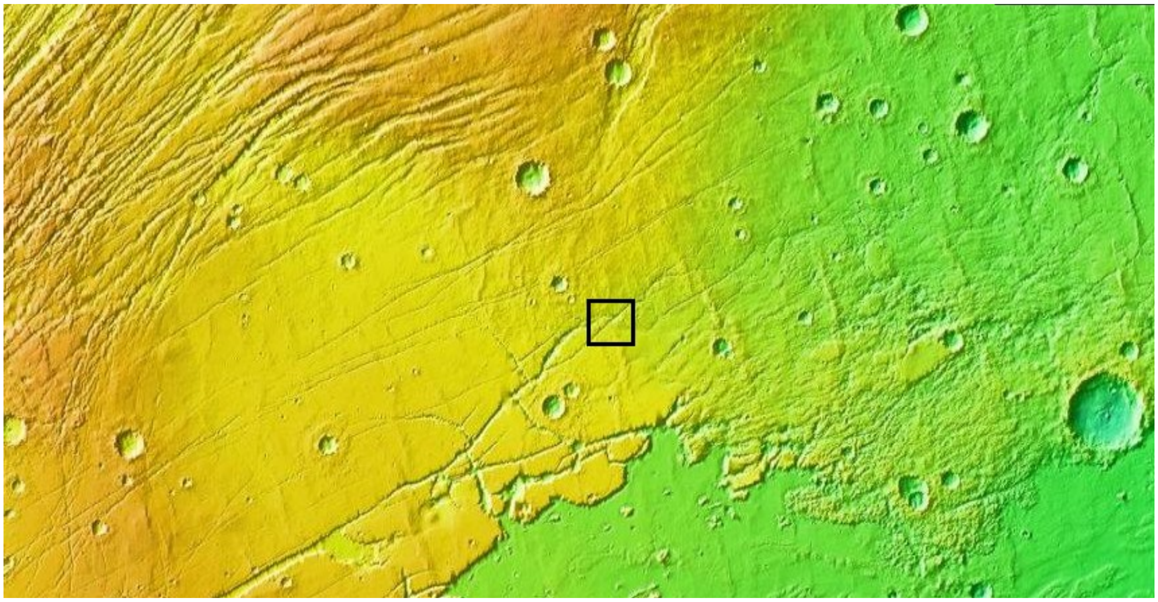
The image is saturated with craters. It also has evidence of wind.

We estimated the age for this region to be at least 4 billion years. Points on the isochron plot are above and beyond the saturation line, which only goes back as far as 4 billion years. The sheer number of craters present in the image confirms the age estimate. It's possible the cratering on this surface dates back to the late heavy bombardment period.

The age of 4 billion years appears valid because of the high crater density on the surface. It looks as though no process has erased the craters in the majority this region. While there is evidence of wind in the image, it is not strong enough to fully erase craters of the size measured in this project (3 pixels and above). Being part of the highlands and away from volcanism, this region seems to have been largely undisturbed for the majority of Martian history.

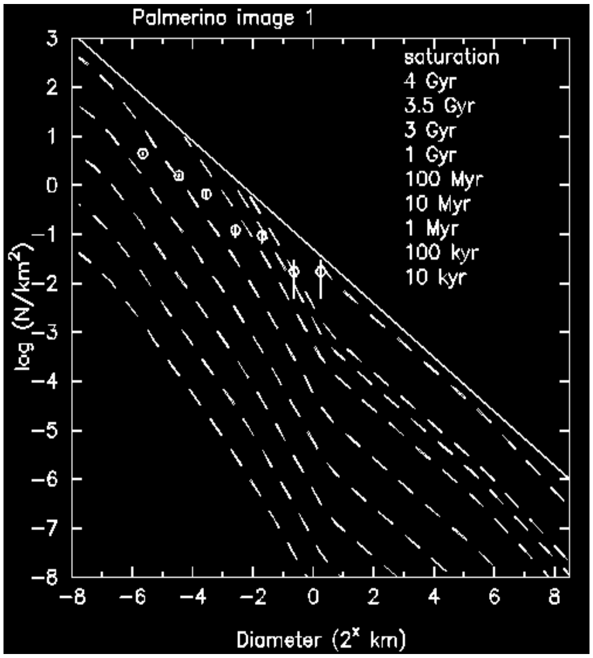


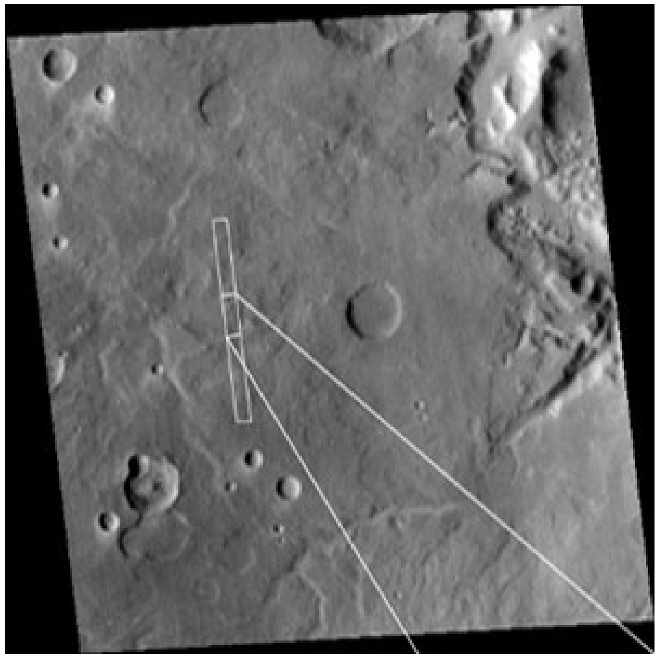


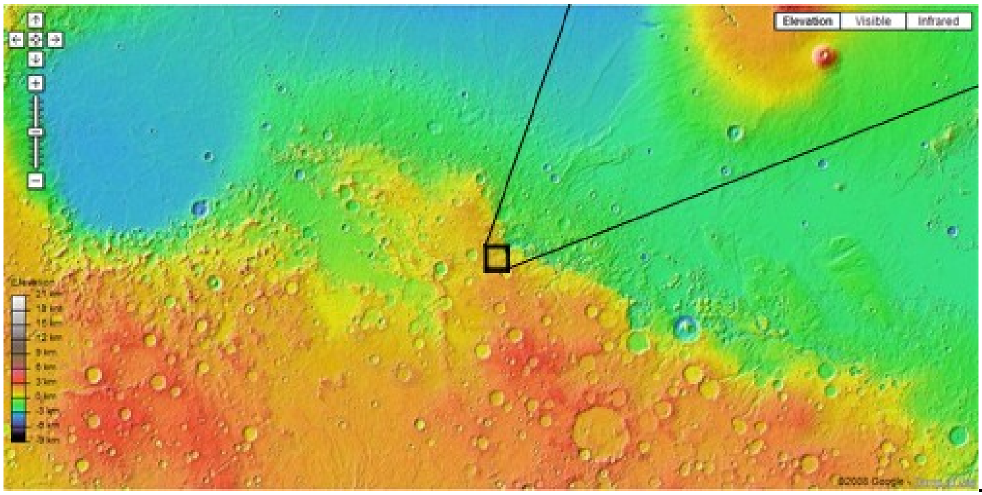


(Tom) M0306704/Image 1

This image is located very close to the equator with an elevation of about 1km. We would estimate the age of the image to be 1.75±0.5 billion years old. The isochron shows the smaller diameter craters leveling off. This would give the impression of a younger surface; however, we believe this tendency is due to counting error and some distortion due to erosion. It is difficult to count all the smallest craters because of the time restrictions of the project, and evidence of wind erosion is present on the image. One would expect a slightly older age than directly translated from the isochron because of the location of the image. The image is located in the Martian highlands. By looking at a much larger image of this area we can see that there are relatively more craters here than in the lowlands, this means that the highlands should be relatively older than the lowlands.

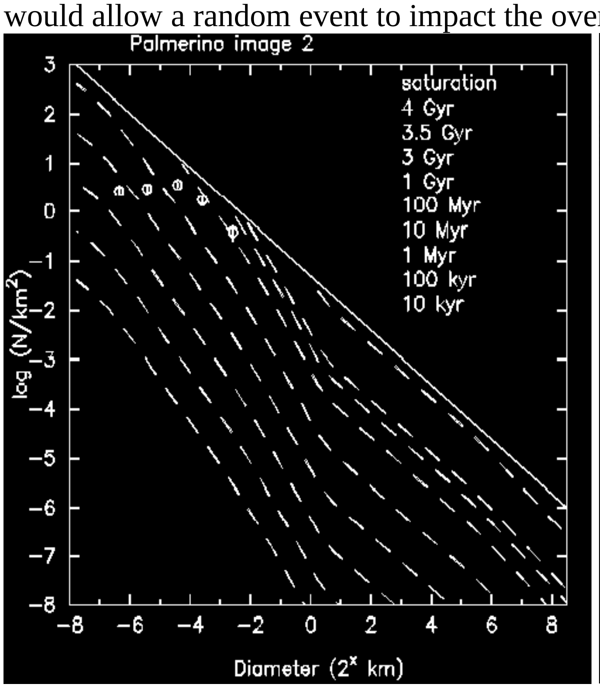


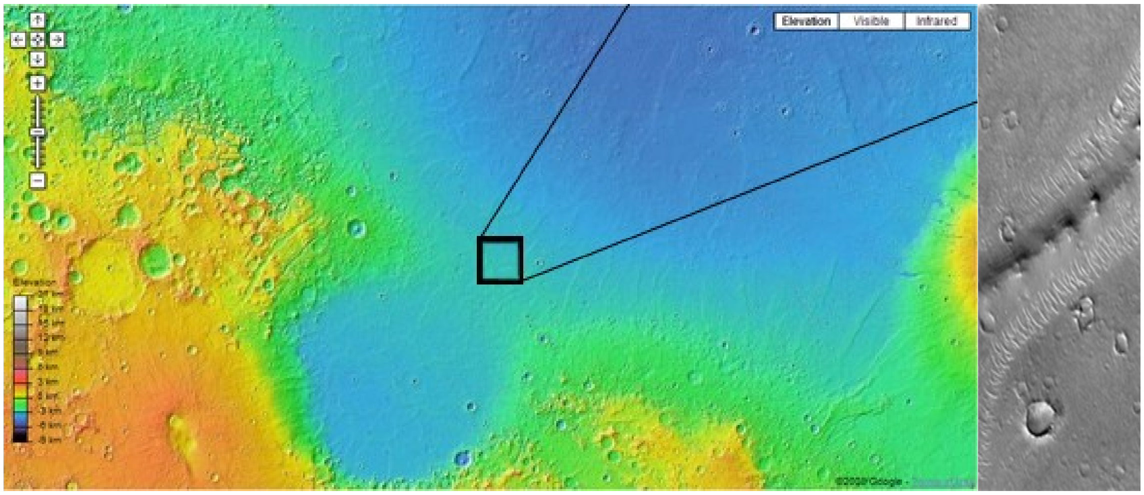




(Tom) M1104164/Image 2

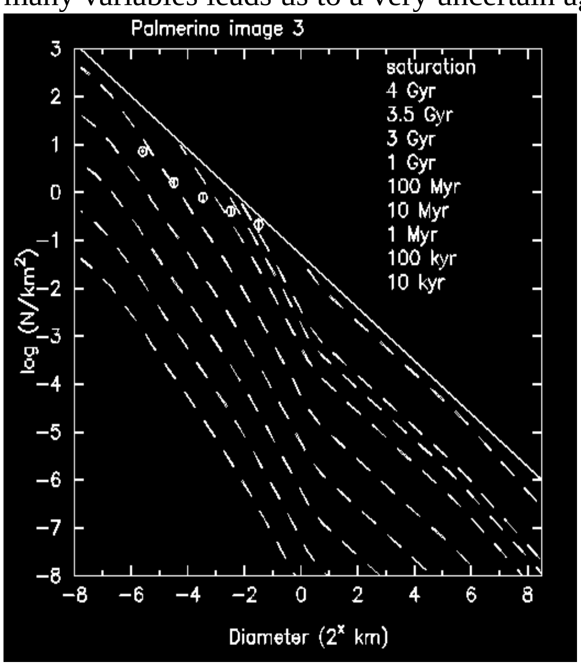
This image is located in the Martian lowlands and in the northern hemisphere with an elevation of about -3km. We would estimate the age of this image to be 0.5±0.2 billion years old. The isochron shows the smaller diameter craters leveling off much more than usual; this gives the impression of a much younger surface. We believe that the smaller diameter craters (about 9 meters in diameter and smaller) could have been erased fairly easily by Martian winds. We found evidence of wind in the image near a ridge; sand dunes had formed at the base of the ridge. Only about half of this image was analyzed, restricting the sample size and area. The smaller area would allow a random event to impact the overall data relatively more than a larger area.

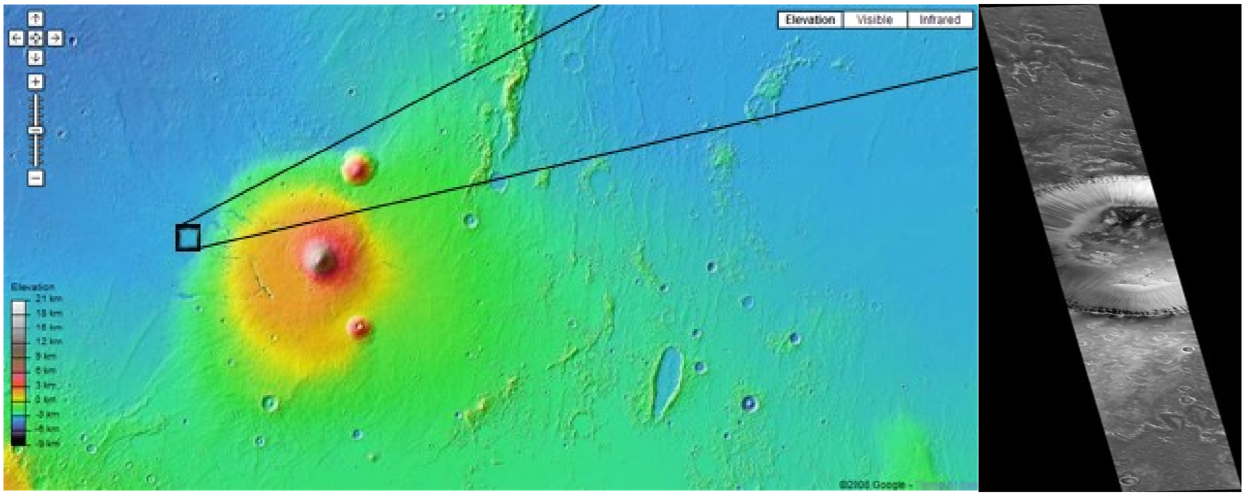




(Tom) M1600778/Image 3

This image is located in the Martian lowlands, in the northern hemisphere, and west of the Tharsis Bulge. The elevation is about -4km and we would estimate the age to be 0.5±0.45 billion years old. The isochron is completely downward sloping; this gives the impression of a very consistent age. However, we believe that the large number of small craters might be because of debris from the large impact in the center of the image, since the largest density of small craters is directly south of that impact. There is also evidence of wind in this image; with many sand dunes at the bottom of craters and even on the surrounding area. The presence of so many variables leads us to a very uncertain age measurement.





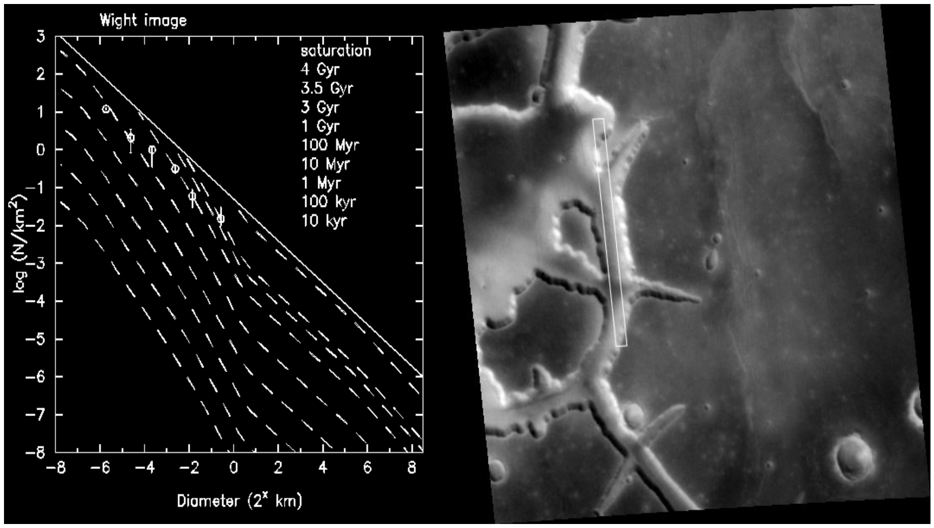
(Philip) R1402904/Image 1

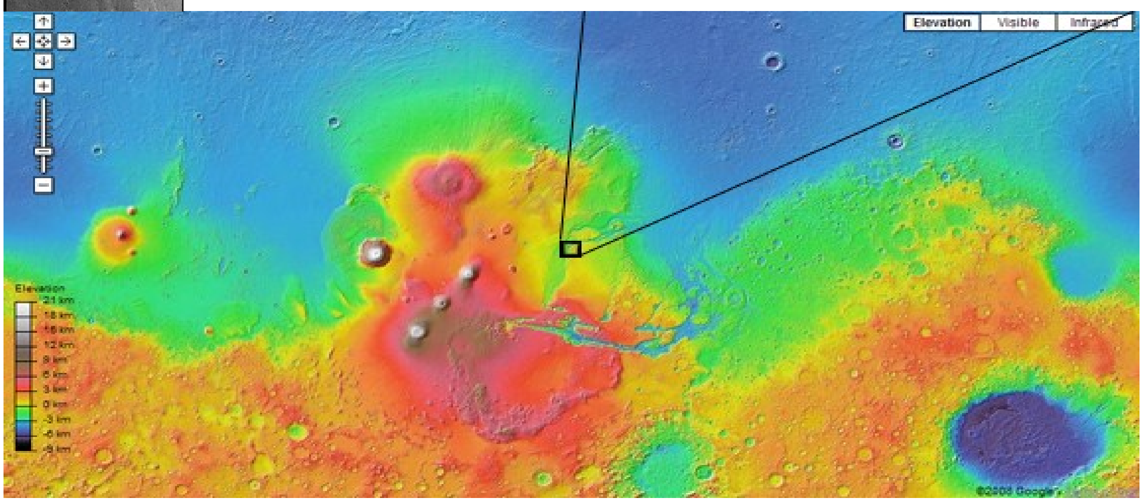
Two environmental conditions are primarily responsible for the age distribution of my craters on the isochron graph. Fluvial erosion in the form of large floods and effusive volcanic activity (less viscous, less silicate-based materials, thinner; results in seeping out of lava, rather than explosion) significantly shaped the Martian landscape and created a “younger” surface layer.[8] The large variance in age between these two environmental events significantly explains the then wide age distribution of craters, from 100 million years to 3.5 billion years. The average age of the craters, and thus the surface region, in this sample was roughly 1 billion years, plus or minus 100 million years.[9]

The majority of the surface can be explained by effusive volcanic activity and lava flows which dominated the Kasei Valles system between 90 million and 1.6 billion years ago. These less viscous flood lavas were in many ways typical of terrestrial volcanism, and explain the relatively young age of the surface.[10] The significant gap between my two points located at 1 billion years and my oldest plot of 3.5 billion years is explained by gigantic flood events and fluvial activity. It is essential to understand that surface ages are calculated due to the lack of craters, not by studying the craters themselves.

The Kasei Valles system is the largest outflow channel systems on all of Mars, the result of massive discharges of water from an active hydrological system. These floods date from between 3 billion to 3.8 billion years ago. The source of the water is the Kasei Valles is thought to be a long open-ended depression, 175km wide and 100 km long, known as the Echus Chasma. The multiple floods that carved the valleys of the Kasei system confirm a gradual formation history.[11]

[8] Mars Express Images the Kasei Valles Outflow Channel System
[9] Chapman
[10] Outflow Channel in Kasei Valles
[11] Chapman





Conclusion

The only way to determine exact ages of the surfaces on Mars is to perform radiometric dating of Martian rocks. Since that can’t be done in a timely or inexpensive fashion, statistical analysis of cratering is our best method of approximating the ages of Martian surfaces. By knowing their approximate ages, we have a means of drawing conclusions about recent geologic activity on Mars.

Our six images share various geologic features in common. The most abundant feature is dunes formed by wind. Other prevalent features include volcanism, tectonic activity, landslides, and collapse pits. They differ, however, in the size and abundance of these features.

Map of image locations:

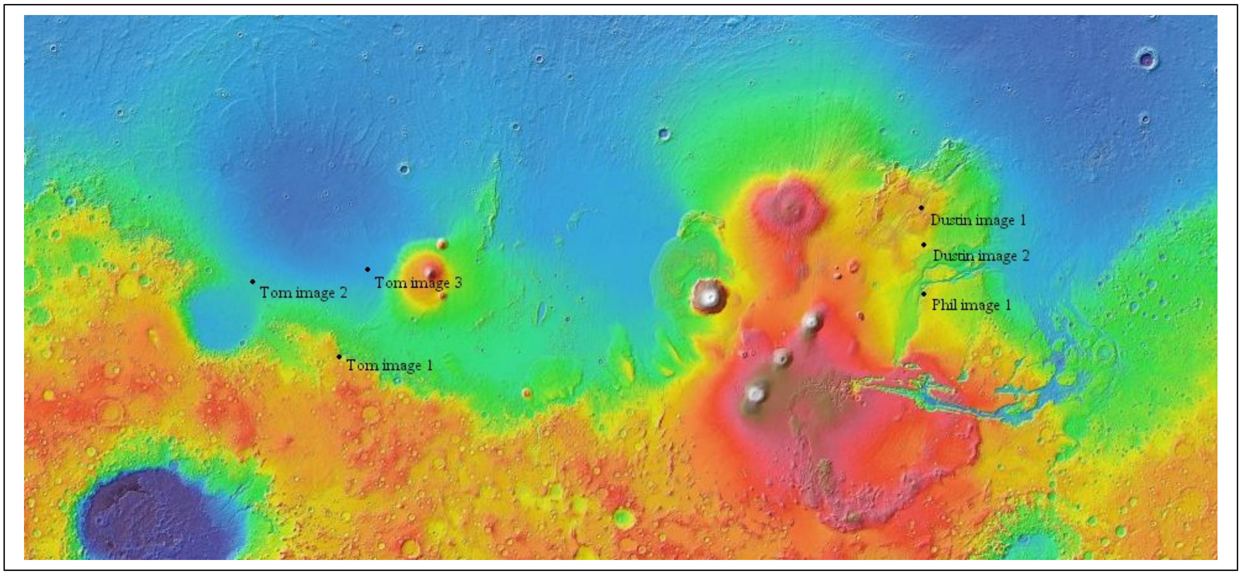


Table of ages:

Image Name	Age	Error +/-
	(million years)	(million years)
(Tom)		
M0306704/Image 1	1,750	500
M1104164/Image 2	500	200
M1600778/Image 3	500	450
(Dustin)		
M0306584/Image 1	1,000	100
M0306582/Image 2	4,000	500
(Philip)		
R1402904/Image 1	1,000	500

This project was not without its complications. The main problem was an inconsistency between the isochron plots and calculated points on the plot. A large part of the discrepancy is attributed to random variation in crater formation, which can be expected for this kind of analysis. Two regions of the same age may not have equal crater density, simply because cratering is a random process. Additionally, some other factors are influencing data points corresponding to small craters, making them consistently fall below the age estimates outlined by larger craters. We suspect that this is a result of Martian geologic activity, including wind, landslides, and other erosive activity, which destroys smaller craters but only marginally impacts larger craters.

The error associated with randomness in cratering can never be completely removed, but it is possible to mitigate it. Using multiple images from nearby regions and averaging their ages would reduce this random error, thus leading to more accurate age estimates. Likewise, it may be possible to mitigate human error. One way to do this is if after an image is analyzed, a second person briefly checks the image and confirms all identified craters to ensure that none have been missed. Doing so would reduce the uncertainty in the analysis, leading to more accurate age estimates. Both of these solutions would improve the accuracy of the results, but they also require more time and manpower. When repeating this project in the future, using a larger group of people would be ideal in the interest of more accurate results.

Sources:

Chapman, M G., G Neukum, S C. Werner, and S Van Gasselt. "ECHUS CHASMA AND KASEI VALLES, MARS: NEW DATA AND GEOLOGIC INTERPRETATIONS." Lunar and Planetary Science (2007).

Lang, Cambridge Guide to the Solar System

"Mars Express Images the Kasei Valles Outflow Channel System." Mars Daily 01 Sept. 2006. 15 Apr. 2008 <http://www.marsdaily.com>.

"Mars Global Surveyor." 08 Apr. 2008. NASA. 26 Apr. 2008 <http://mars.jpl.nasa.gov>.

"Mars Global Surveyor (MGS)." Malin Space Science Systems. 26 Apr. 2008 <http://www.msss.com>.

Neil McBride and Iain Gilmour, *An Introduction to the Solar System*, (Cambridge: 2003)

"Outflow Channel in Kasei Valles." Mars Odyssey Mission. 15 Apr. 2008 <http://themis.asu.edu>.

William K. Hartman, Isochron refinement and the chronology of Mars, 294-96