Mars Surface Dating

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Introduction

It is very difficult to know the exact age of a planet's surface when we have never visited it. In order to know how a planet formed and what processes have occurred on the surface, it is important to have some ideas about how old different surfaces are. There are many ways one can estimate the age of a planet's surface, but some techniques are more accurate than others. The most accurate way to age a planet's surface is impractical to use for Mars – Mars would have to be visited and samples taken in order to perform radioactive dating. This method is not a viable option (because of time, money, etc.) and we must therefore employ other, more practical, methods. For this project, the Martian surface age was dated using a crater counting and sizing procedure.

The approach that we used takes advantage of data previously gathered from the Moon, a surface that we have accurate dating of already. The Moon has been visited and studied extensively because it is the closest neighbor to Earth in the Solar System and it is by far the easiest to reach. Samples have been collected from the lunar surface and radioactive dating has been performed on those samples in order to get an accurate representation of the Moon's age. The Moon cratering data were adapted to the Martian surface in order to provide a fairly accurate Martian cratering diagram. In order to adjust the lunar data, Mars' size and location were taken into account. For instance, since Mars is a lot larger and more massive that the Moon, it has stronger gravitational force and therefore is able to pull in more debris. Also, since Mars is closer to the asteroid belt, it is more likely that it would have a higher frequency of impacts. Even though the data needs to be adjusted to account for the aforementioned reasons, the adaptation is not a significant one because the Moon and Mars have similar shapes and compositions.

There is a relationship between surface age and crater size/frequency which was determined when the Moon was visited and analyzed. An isochron is a line on the diagram, marked out by a crater size and frequency, which specifies an age. Older surfaces have more craters because the surface has been exposed for a longer period of time, making it vulnerable to more impacts. The isochrons were then calculated to represent surface age on the lunar surface and adjusted to the Martian surface[1]. This technique is known to be particularly accurate when performed correctly and the following project will take advantage of its simplicity.

[1] (Hartmann and Neukum, 2001)

Data

Images for studying Mars surface cratering were obtained from the Mars Global Surveyor (MGS) mission[2]. Launched in 1996, MGS has been orbiting Mars and taking high-resolution photographs of the Martian surface since 1997 using the onboard Mars Orbiter Camera (MOC). These photographs have been digitally catalogued by Malin Space Science Systems (MSSS) in an effort to promote research efforts. Images for this project were obtained from the MSSS catalog of MOC images, located on the internet[3].

The high-resolution images were selected from the MOC image gallery by the authors based on their level of detail, interesting features, and an understanding of the difficulty of manually counting and measuring individual crater features. With the knowledge that the counting process would be difficult, we exercised caution in selecting images: an image with too many confusing surface features would lead to large errors and might not be completed in the time allotted for this research. Attempts were also made to choose images that were located in interesting regions of Mars' surface and were taken when the solar incidence angle was reasonable to permit undistorted views of surface effects. The only true requirement for image choice was that the images had both a narrow-angle image and a context image available for study.

Table 1 shows the MOC images used by each student researcher:

Table 1: Mars Orbiter Camera Images and Internet Addresses

Researcher	**Mars Region**	**Narrow Image**	**Context Image**	**Internet Location (http://www.msss.com/moc_gallery/…)**
Brookman	MC28	R22-00877	R22-00878	r22_s04/images/R22/R2200877.html
	MC16	R22-00474	R22-00475	r22_s04/images/R22/R2200474.html
Brown	MC26	R14-00473	R14-00474	r10_r15/images/R14/R1400473.html
	MC20	R22-00678	R22-00679	r22_s04/images/R22/R2200678.html
	MC28	R22-00997	R22-00998	r22_s04/images/R22/R2200997.html
Fields	MC18	S01-00245	S01-00246	r22_s04/images/S01/S0100245.html
	MC24	R22-00549	R22-00550	r22_s04/images/R22/R2200549.html
	MC21	S02-00235	S02-00236	r22_s04/images/S02/S0200235.html
Koch	MC25	R05-00643	R05-00644	r03_r09/images/R05/R0500643.html

Each image had its own set of important characteristics, including a scale for the width of individual pixels (to relate pixel size to actual surface size), a real-world image width and height (in km), and latitude and longitude in Martian coordinates. The scale was useful in determining the actual size of craters, while the real-world width and height were useful in determining the area captured by each image. The latitude and longitude were helpful in learning more about the area from which the image originates, so that other surface phenomena could be considered in age determination.

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2 (Jet Propulsion Laboratory, <http://www.jpl.nasa.gov/news/fact_sheets/mgs.pdf>)
2 (Malin Space Systems, <http://www.msss.com/moc_gallery>)

Table 2 shows the latitude and longitude of the image locations, pixel scale, and actual image width and height.

Table 2: Image location, pixel scale, and image dimensions

Image	Center Location Coordinates	Pixel Scale (m)	Actual Dimensions (km)
R22-00877	278.76° W, 34.51° S	5.84	2.99 × 23.60
R22-00878	278.33° W, 34.53° S	245.28	119.02 × 118.86
R22-00474	135.17° W, 28.30° S	4.42	2.83 × 25.67
R22-00475	134.76° W, 28.33° S	247.43	119.99 ×118.83
R14-00473	7.18° W, 36.39° S	5.89	3.02 × 53.09
R14-00474	6.72° W, 36.42° S	247.46	120.10 × 117.19
R22-00678	317.48° W, 20.41° S	4.30	2.75 × 41.92
R22-00679	317.11° W, 20.45° S	237.28	114.99 × 132.28
R22-00997	246.33° W, 35.10° S	5.84	2.99 × 28.90
R22-00998	245.89° W, 35.13° S	245.36	119.06 × 118.82
S01-00245	85.69° W, 19.82° S	2.85	2.92 × 13.15
S01-00246	85.31° W, 19.85° S	237.47	115.06 × 132.34
R22-00549	144.77° W, 46.25° S	4.38	2.95 × 16.48
R22-00550	144.25° W, 46.26° S	245.21	119.14 × 118.42
S02-00235	275.22° W, 15.43° S	5.93	3.03 × 19.06
S02-00236	274.84° W, 15.46° S	248.99	120.62 × 119.05
R05-00643	76.14° W, 35.39° S	5.83	2.99 × 92.01
R05-00644	75.70° W, 35.43° S	244.81	118.80 × 118.79

Analysis

The craters in each camera image were measured using digital image manipulation software. The software chosen had a pixel measurement tool for counting pixels between two selected locations.

To maintain consistency among researchers and limit error due to pixel resolution, a few rules were followed while measuring craters:

1. If the crater is less than 5 pixels in size, do not include it.
2. If the crater is less than 15 pixels across, measure horizontally or vertically instead of at an angle with respect to pixels. If the crater is larger than 15 pixels across, measuring at an angle is acceptable.
3. If the crater is elongated or oblong, measure the shortest distance between opposite "sides." Determine this shortest distance by superimposing a circle over the central part of the crater.
4. If the crater has a terraced rim, measure the outer edge.
5. If the crater is less than halfway shown in the narrow-angle image, do not include it. This can be verified by superimposing a circle over the crater shape.

With these rules under consideration and the measurements collected for each crater, we measured, catalogued, and counted craters of all shapes and sizes.

After we measured all the craters in pixels, we converted these numbers into kilometers using the conversion factor supplied with the image.

The resulting diameters were then converted into log base 2. We solved for X in the natural logarithm of $D=2^{x,}$ which resulted in the following relation:

$$X = \frac{\ln(D)}{\ln(2)}$$

Because of the typical crater sizes in our images, X was between -6 and 6.

These crater diameters were then sorted into bins. For example, one bin was $2^{-3} \geq D^{x} > 2^{-2}$ with our X being the exponent. One bin was created for each integer increase in power of 2. The crater sizes that were converted into log base 2 were placed within their appropriate bins and the number of craters in each bin was summed up. On average, the bins with the most craters were the smaller size craters bins. We also found the average size of the diameter of the craters in each bin.

The final calculation was the total number of craters per bin over the total area of the image. The total area was found for the image by multiplying the scaled image width by the scaled image height.

We used standard error propagation techniques to calculate the error in our results. The error in n is the standard deviation for n, with n being the number of craters per area. In other words,

$$\sigma(n) = \frac{\sqrt{N}}{A}$$

with σ being the error, N being the number of craters per bin, and A being the total area of the image. For each bin we calculated n ± σ (n). The points that were plotted were log(n) with the upper and lower error limits as follows:

$$\log(n + \frac{\sqrt{N}}{A}) \text{ and } \log(n - \frac{\sqrt{N}}{A})$$

Therefore, for each bin, we calculated three numbers. This allowed for us to visualize the certainty of points along the isochron.

Results

Brookman: R22-00877 (near Hellas Basin)

The narrow-angle image designated R22-00877 and its corresponding context image were taken in the area of the Hellas Basin, on the northeastern edge. The image appears to be part of a water flow region.

Several data points were generated relating crater diameter to the number of craters per area. By nature of the images, the smallest craters were challenging to count and catalog, so their associated data does not fit as well onto the isochrons as data for larger craters. For this reason, it is likely that not all of the smallest craters were accounted for, which resulted in an age that is younger than expected. In order to avoid distortion of results, the leftmost data point in this isochron fitting is ignored when making an age determination. Figure 1 shows the narrow-angle image, Figure 2 shows the context image, and Figure 3 shows the isochron fitting.

Figure 1: Narrow Angle Image R22-00877

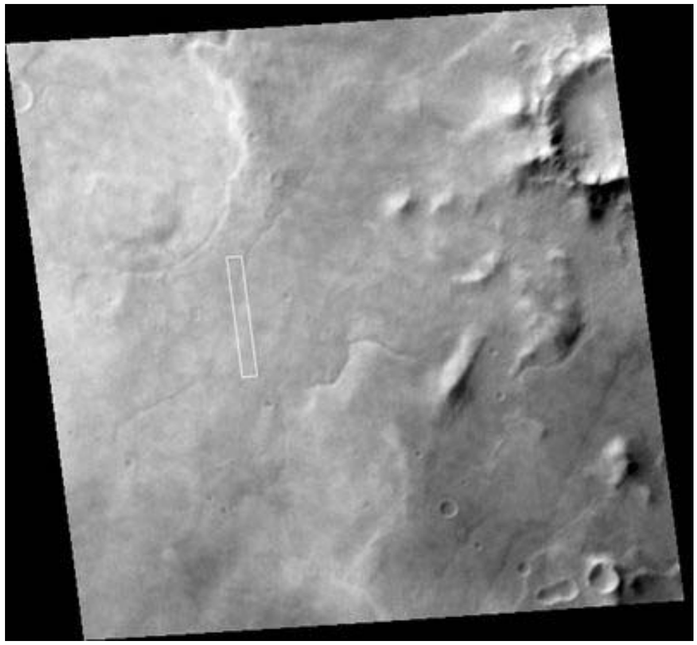

Figure 2: Context Image R22-00878

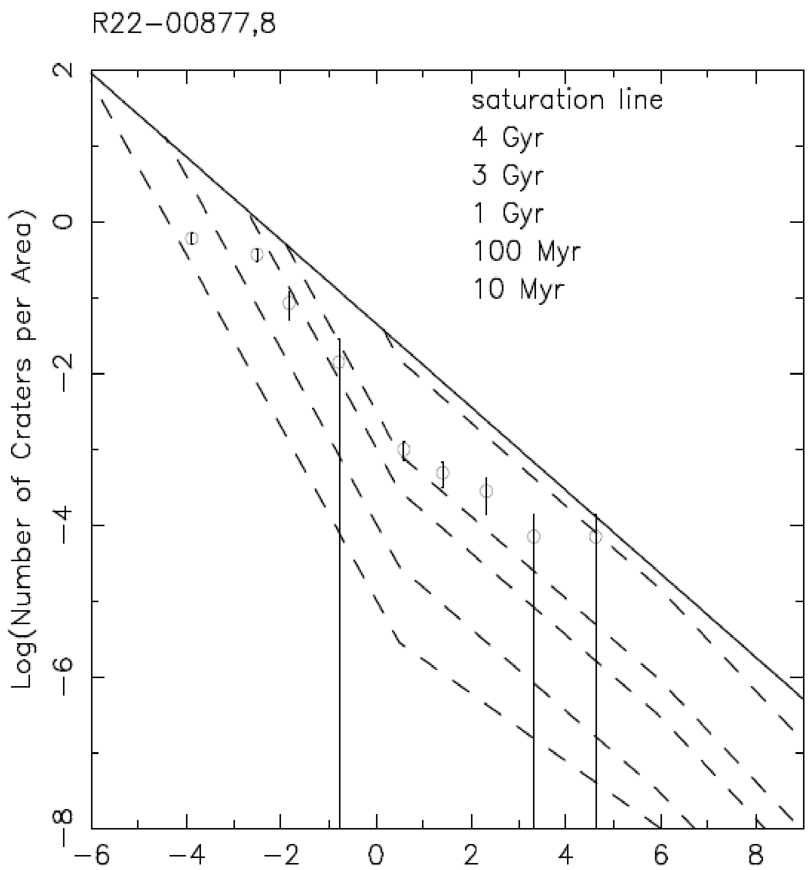

Figure 3: Isochron Fitting for R22-00877,8

Based on the remaining data, an average age determination can be made that puts the age of the surface at approximately 2 billion years old. There are three points that follow the 1 billion year isochron and a few more that better follow the 3 billion year isochron. Interestingly, the younger data points were from the narrow-angle image, while the older data points were from the context image.

Full understanding of the age determination requires study of the processes going on around the image location. The images designated R22-00877 and R22-00878 were obtained near the northeastern region of the Hellas Basin. Study of maps from Google's Mars exploration webpage[4] reveal that the context image is actually right on the "shoreline" of the Hellas Basin. This could indicate the influence of liquid flow and erosion as water entered the basin.

Figure 4 shows the region from which the images came, right at the shoreline of the Hellas Basin. The images came from roughly in the center of the image, which has been colorized to show elevation (more blue indicates lower altitude):

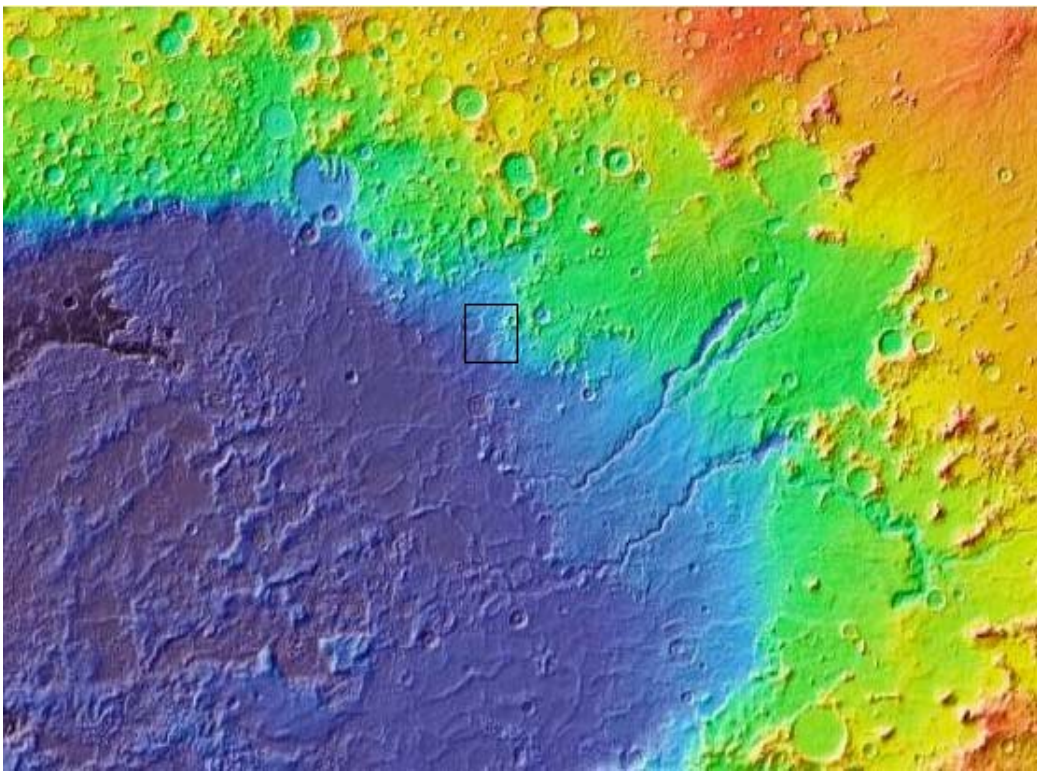

Figure 4: Google Mars Image, Location of Images R22-00877 and R22-00878

The location can explain why the narrow-angle image shows a younger age and the context image reveals an older age. The narrow-angle image shows only a few small craters, and no significantly large ones. Water flow may have washed away the older small craters. This flow would not have washed away the larger craters. This makes the narrow-angle image show a younger age, as it only has a few small craters that have

[4] (Google Mars, <http://www.google.com/mars/>)

formed since the surface was last washed over by water. The context image shows older surface because the largest craters were not wiped away. Essentially this is an area that is 3 billion years old, but there are regions of activity as recent as 1 billion years ago. This is consistent with the consensus by researchers that water last flowed on Mars about 3.5 billion years ago. The surface may have been cleared on a large scale when the water flowed, but in more recent history, small craters have affected the surface.

Brookman: R22-00474 (near Arsia Mons)

The narrow-angle image designated R22-00474 and its corresponding context image were taken in the vicinity of the volcano Arsia Mons. The images were obtained near the southwestern slope of the volcano region, where there are obvious effects from lava flow.

The isochron determination is not as clear-cut, but this can be explained by studying the surrounding region. As in other images, the leftmost data point does not perfectly fit the age determination, due to our inability to accurately count every tiny crater. Therefore, the age determination is based on the remaining four data points. Figure 5 shows the narrow-angle image, Figure 6 shows the context image, and Figure 7 shows the isochron fitting.

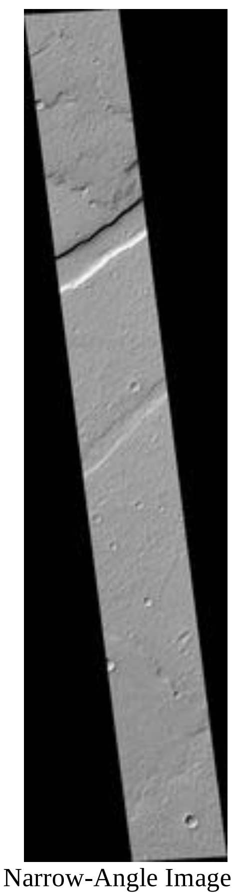

Figure 5: Narrow-Angle Image R22-00474

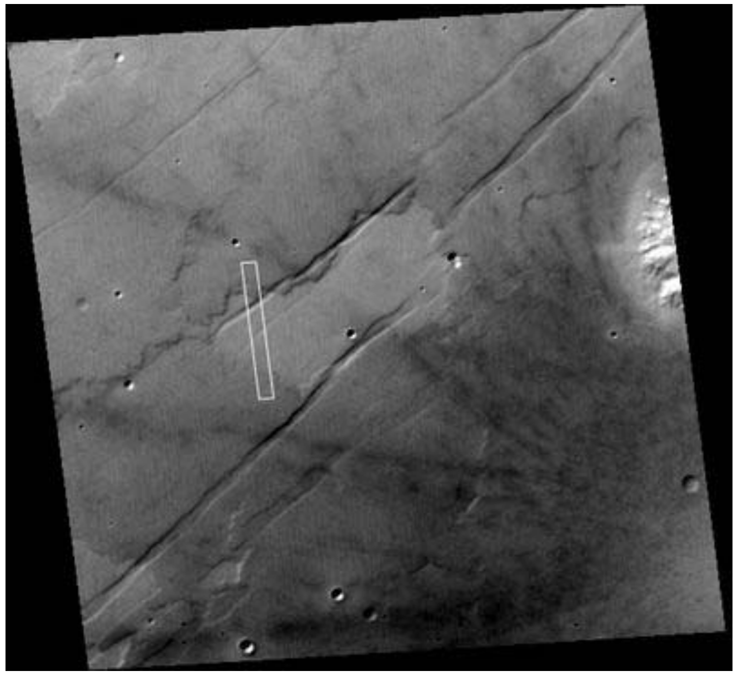

Figure 6: Context Image R22-00475

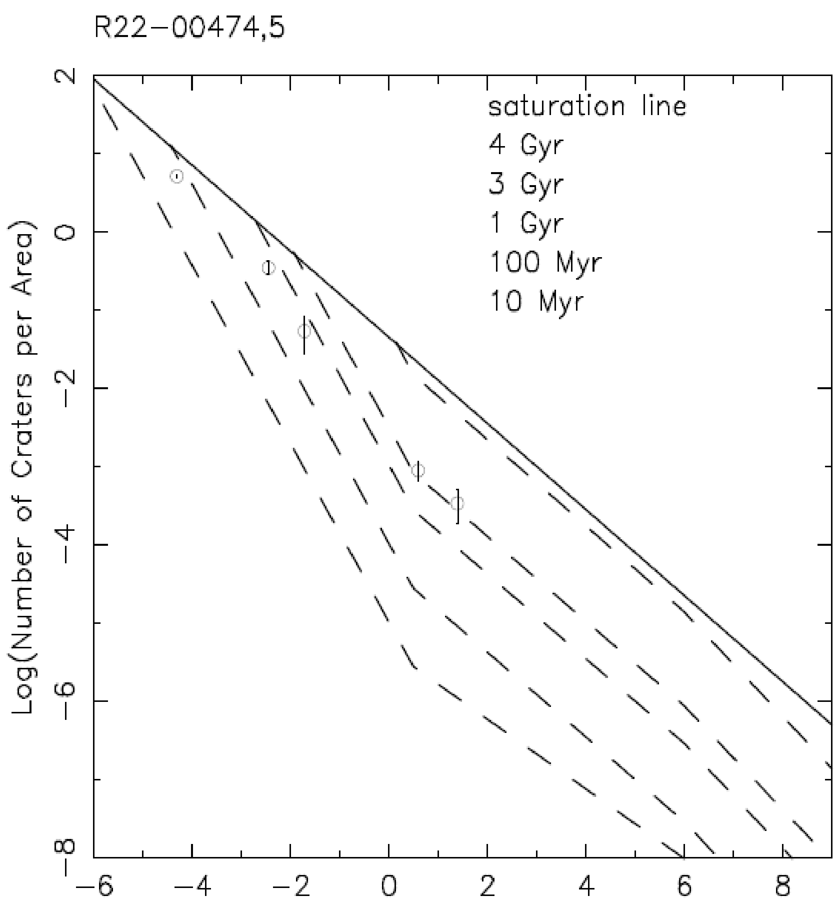

Figure 7: Isochron Fitting for R22-00474,5

Based on the four rightmost points on the isochron fitting, the age can be determined as being between 1 and 3 billion years old. A visual inspection can provide an average age of roughly 2 billion years. The narrow-angle image shows an age of 1 billion years, while the context image reveals an age of about 3 billion years. This age discrepancy is due to the phenomena occurring around the area of the images. These images were from the region Daedalia Planitia, and from studying Google's maps of the region, it is apparent that this is in the middle of an ancient lava flow from Arsia Mons and the surrounding volcanoes. Figure 8 shows the colorized image of the region:

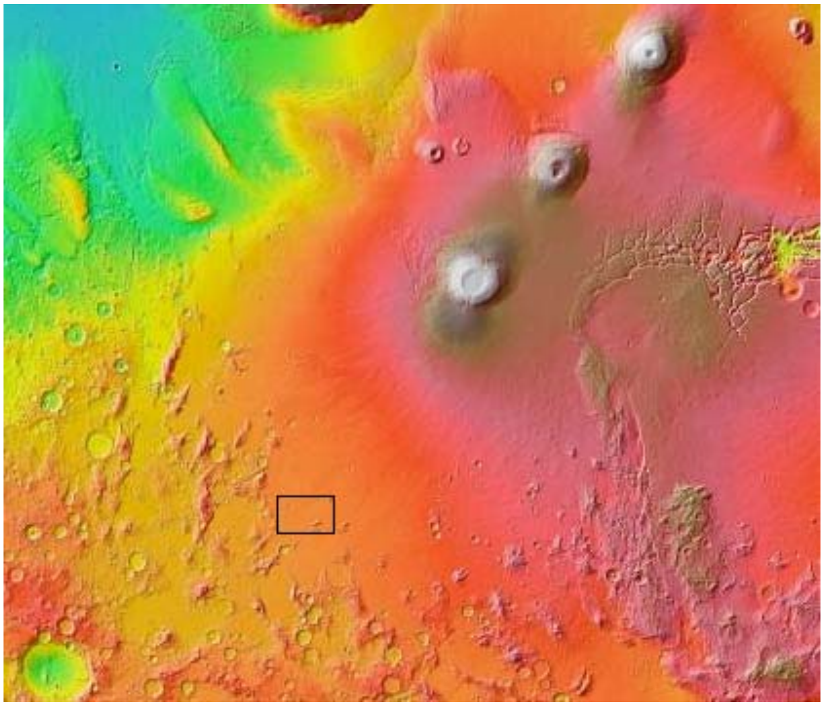

Figure 8: Google Mars Image, Location of Images R22-00474 and R22-00475

Because the area is situated in the region of lava flows, it is easy to see that only the largest and deepest craters could remain after a volcanic eruption or lava outflow. This creates the situation where the context image only has the largest craters, as the smaller ones were either filled in or erased by lava flow. The narrow-angle image contains many smaller craters that have been created since the lava flow occurred. This explains the age problem. The general area is about 3 billion years old, but in smaller regions within, there are spots of more recent resurfacing, as recent as 1 billion years ago. This is consistent with Mars geology researchers, who agree that volcanic activity was common until about 100 million years ago. This supports the thought that volcanic activity was a factor in resurfacing this area.

Brown: R14-00473 (near Argyre Basin)

This image was taken of an area to the Northeast of the Argyre Basin on the Martian surface (7.18°W, 36.39°S). The Argyre Basin is the second largest basin on Mars next to the Hellas Basin. The narrow-angle image (Figure 10) had some very well defined craters, as well as some indistinct ones. The wide-angle context image (Figure 9) showed a few medium-large craters as well as a possible valley or riverbed.

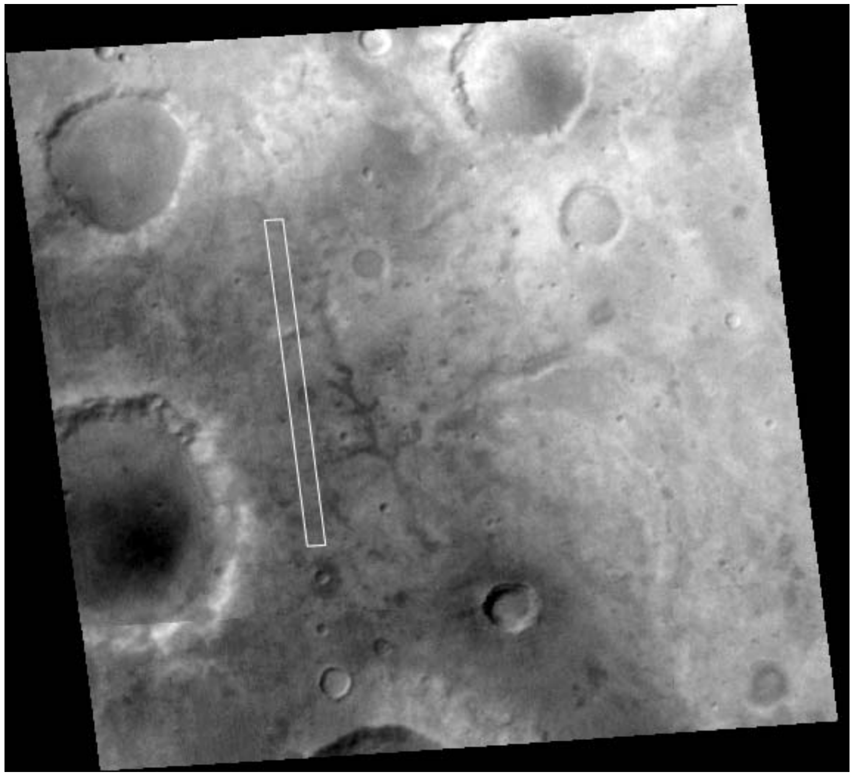

Figure 9

The only unusual data point on the isochron for this image (Figure 11) is the second to largest crater point (second from the right, below). This data point was out-of-line with the ones smaller than it; the point itself was close to the saturation line and the error bar only extended over the 4 billion year isochron. This does not fit well with the other data points.

Figure 10

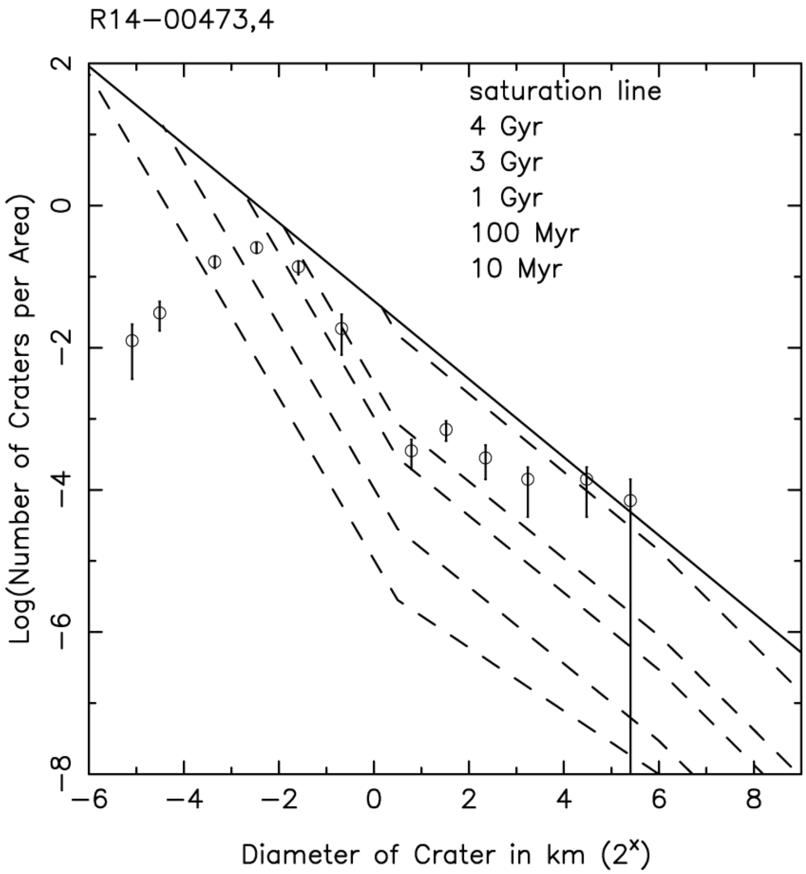

Figure 11: Isochron Plot for Image R14-00473,4

The data points for this image indicate that the surface is roughly 3.3 billion years old. This age was obtained after disregarding the craters smaller than 2^{-2} km, as it was believed that these counts were artificially low due to measuring difficulty. Taking error into account, the numbers of each size of crater seem to line up fairly well just above the 3 billion age line, especially the larger craters from the context image.

As seen on the elevation map from Google Mars (Figure 12), this area is located between two low-lying areas, which means that water may have at some point been flowing between them and over the surface. The best estimates of when water was last on Mars are about 3.5 billion years ago which matches with the age of this surface if in fact there was water flowing over it at one point. Google Mars provides more evidence for liquid water in the area. Figure 13 shows a crater just north of the wide-angle image in infrared. The crater appears to have its north side collapsed, possibly through water buildup and subsequent drainage.

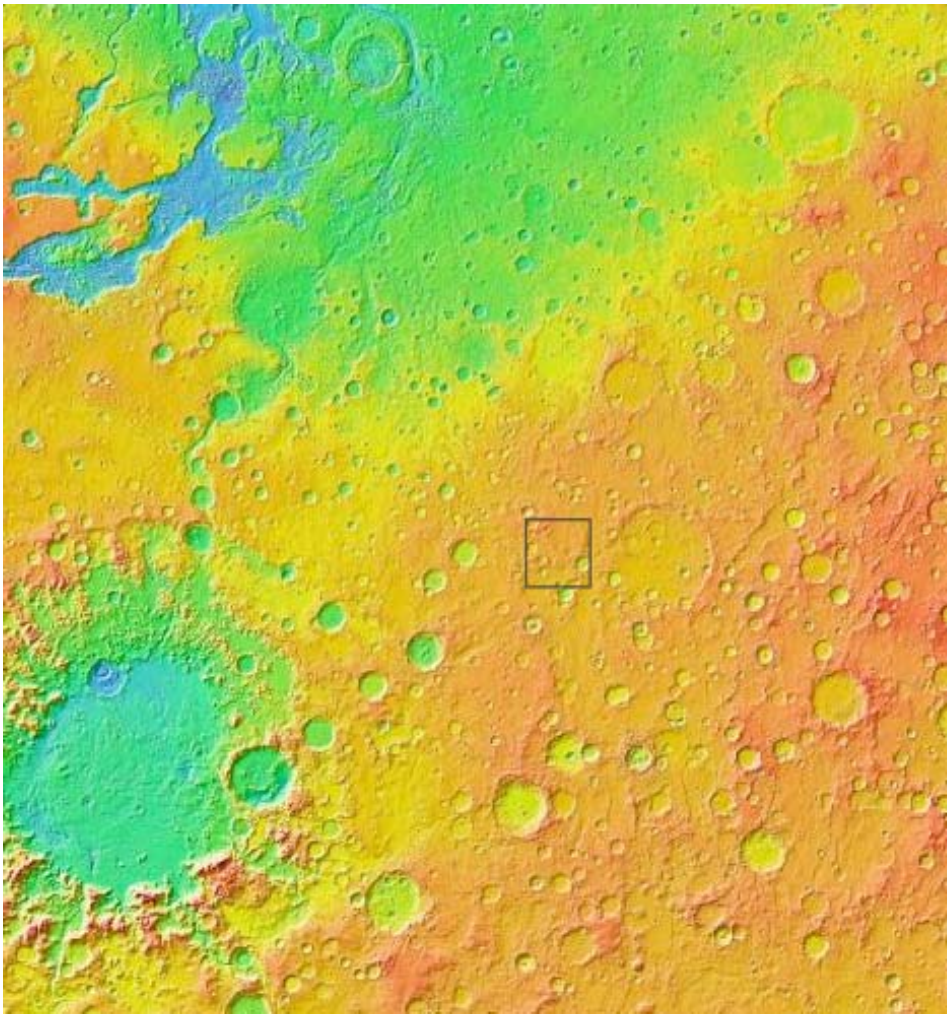
Figure 12: rectangle denotes approximate wide-angle context image area

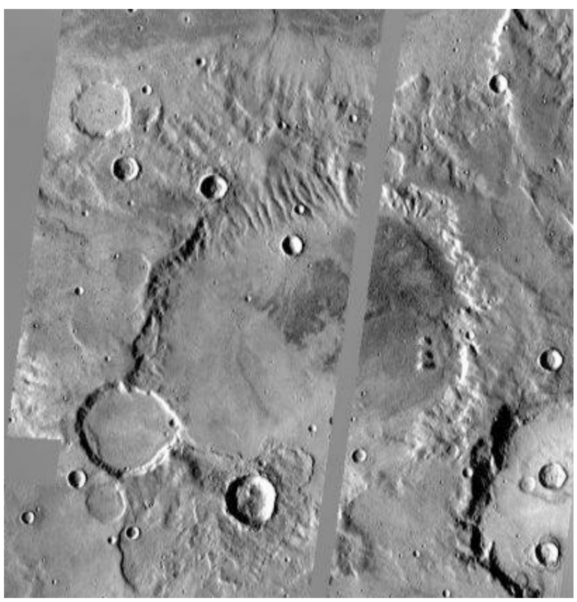
Figure 13

Brown: R22-00678 (near Hellas Basin)

The area covered by this image is located to the Northwest of the Hellas Basin in Mars's southern hemisphere (317.48°W, 20.41°S). The narrow-angle image (excerpt, Figure 14) shows many sand dunes, which made crater identification difficult. The wide-angle context image (Figure 15) has many large craters, suggesting an older surface. The craters in the wide-angle image are not particularly well-defined, suggesting some wind erosion which is supported by the sand dunes in the narrow-angle image.

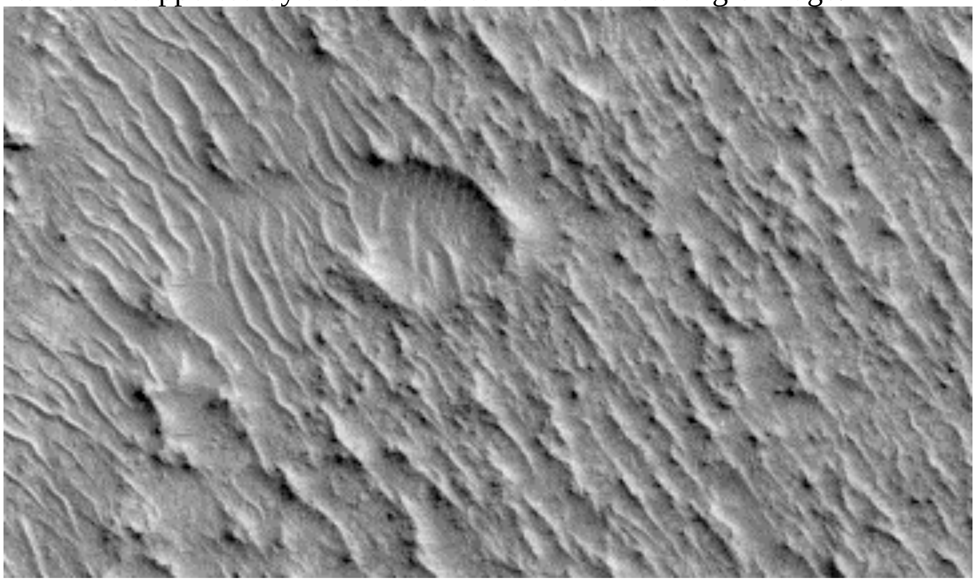

Figure 14: narrow-angle image R22-00678

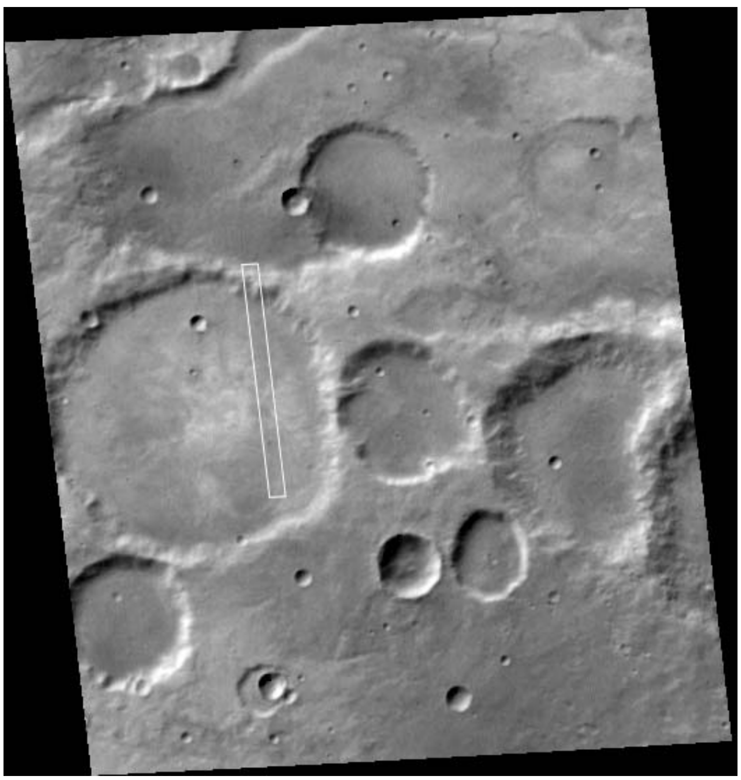

Figure 15: Wide-angle Image R22-00679

This image had some unusual data points with the larger craters (Figure 16). The largest three data points (the three rightmost points below) deviate from the slope of the isochrons, although they are linearly aligned with each other. Also, the smaller craters measured in the narrow-angle image seem to be low, even factoring in the turnover. This is likely due to crater erosion.

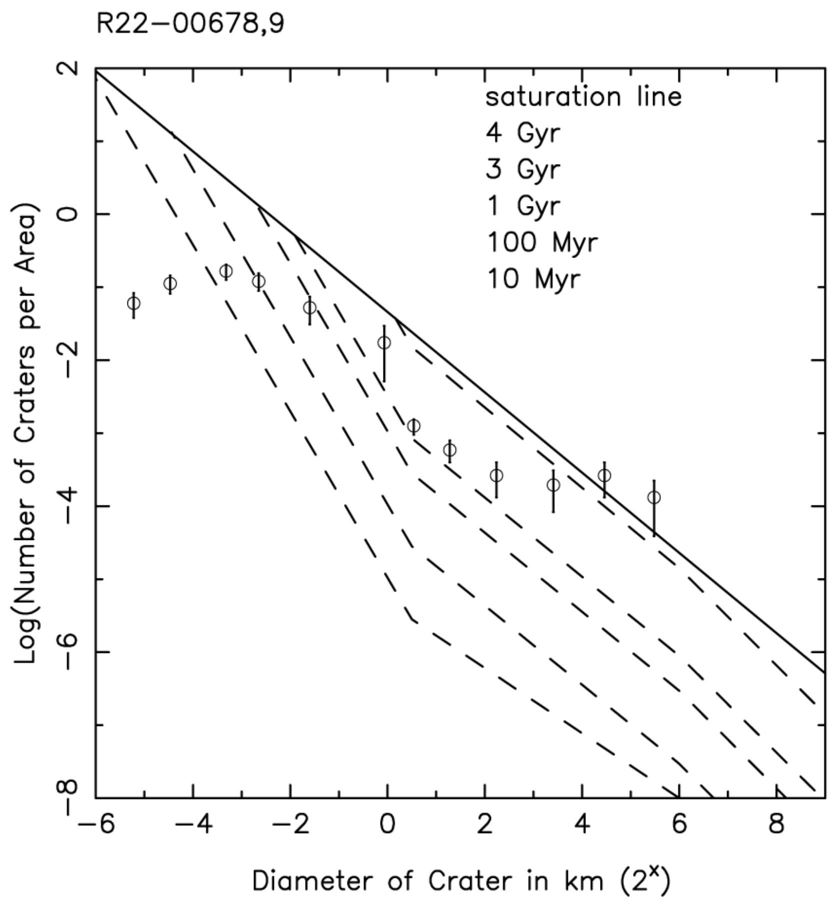

Figure 16: Isochron Plot for Image R22-00678,9

This area of Mars is around 3.2 billion years old. The smaller crater size counts from the context image line up just above the 3 billion year line. Most of the narrow-angle image is of a crater floor, so results from the floor of the crater and the area around this crater could be different. The crater floor would be as old as the crater, but the area around this large crater would be older, presumably. So while the context image might indicate an age around 3.2 billion years, the narrow-angle image might very well be younger.

The age determined by the context image is within expectation. The age derived from the narrow-angle image is affected by the great amount of sand dunes in the image. This would indicate that the surface is being resurfaced by wind, and low crater counts would indicate this is so, even though the data points do not line up on a particular isochron. From the elevation map on Google Mars (Figure 17), we know that the area is high in elevation, right on the rim of the Hellas Basin. This would support the idea of wind erosion in the area, as higher elevations tend to experience more wind than lower elevations. Wind is the likely cause of both the sand dunes from the narrow-angle image as well as the crater erosion visible in the wide-angle context image.

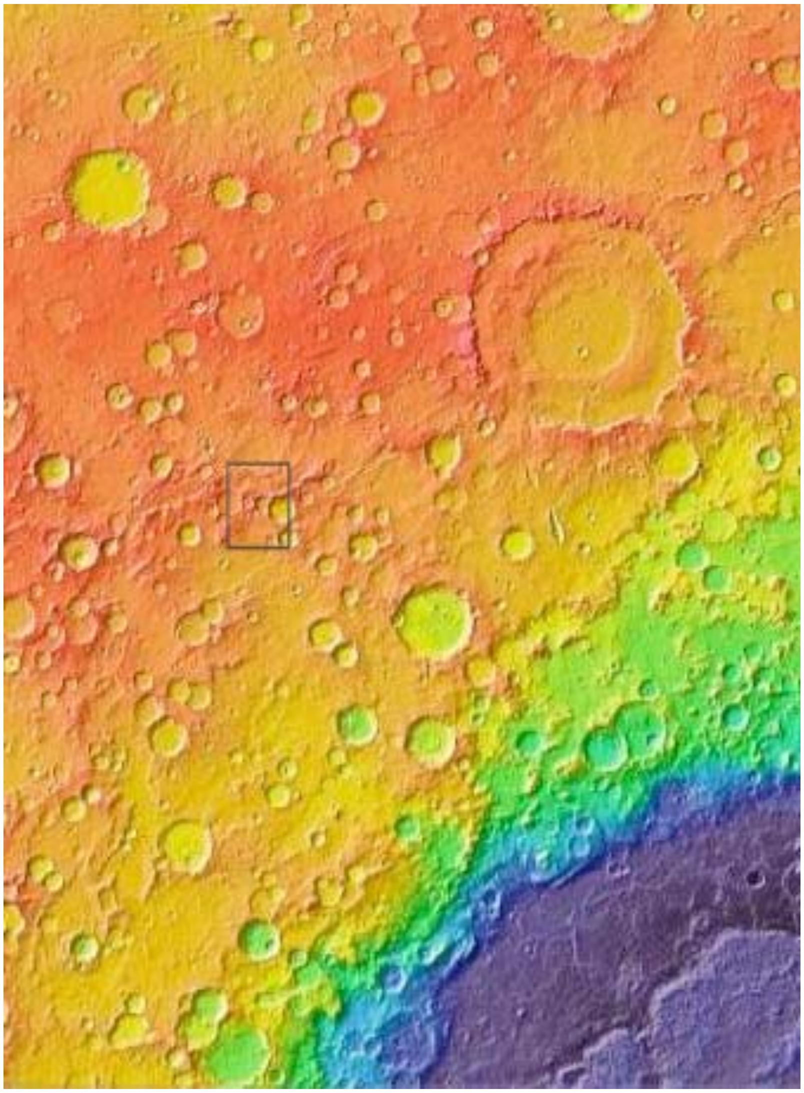

Figure 17: rectangle denotes approximate wide-angle context image area

Brown: R22-00997 (near Hellas Basin)

This area is East of the Hellas Basin (246.33°W, 35.10°S). The narrow-angle image (Figure 18) has few distinct craters, but has many well-worn ones. The wide-angle context image (Figure 19) shows few large craters but a few flat-bottomed medium craters. The craters have the appearance of once being filled in with water or lava which formed a flat crater bottom.

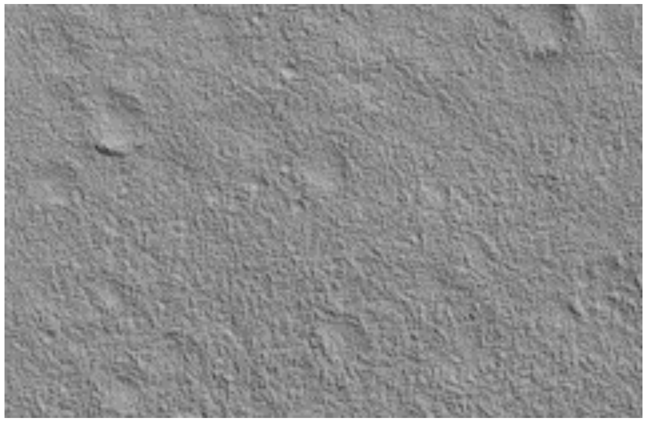

Figure 18: narrow-angle image R22-00997

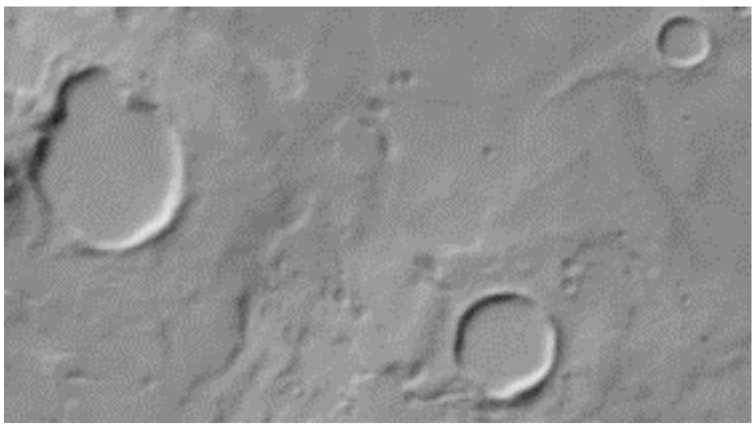

Figure 19: wide-angle image R22-00998

The data from this image (Figure 20) have no real outlying points, although four of the points were plotted with a single crater so the error is large. The smaller craters from the context image seem to line up well with the isochrons, but the craters from the narrow-angle image do not.

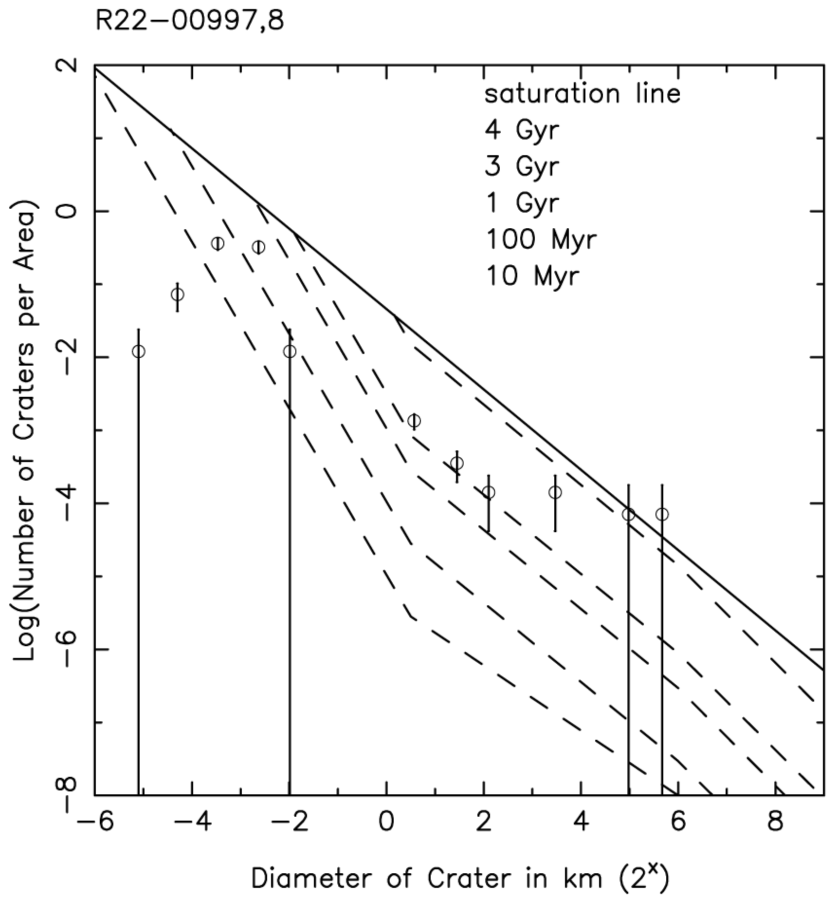

Figure 20: Isochron plot for Image R22-00997,8

The age of this surface is approximately 3.1 billion years. The craters from the context image agree on this age, and the smaller craters on the plot are not that far off from where one would expect them to be. Measurement limitations and error are relatively high in this image because the surface appeared "soft" – the craters were not well defined and it was difficult to tell the difference between a highly eroded crater and one that had eroded fully (See Figure 18 above). Therefore, the surface may be younger than the age presented above. The indistinct nature of the craters from the narrow-angle image may indicate the type of rock in the area, as it may be pyroclastic ash deposits from a volcano.

This area of Mars is Southeast of Tyrrhena Patera, a medium-sized volcano. Figure 21 shows the Google Mars elevation map of the area. Lava or pyroclastic deposits are likely the cause of the "filled-in" appearance of the craters in the wide-angle context image. The context image has telltale signs of lava or pyroclastic flow presence, including filled-in craters and slight flow marks. Volcanic activity could also be the cause of the appearance of the craters in the narrow-angle image.

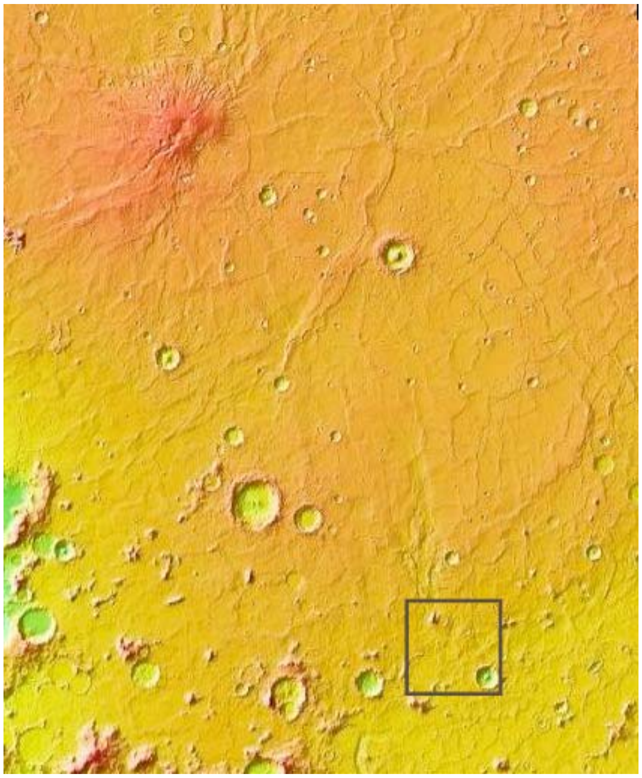

Figure 21: rectangle denotes approximate wide-angle context image area

Fields: S01-00245 (Coprates)

Image S01-00245,6 is located at 19.7°S 85.5°W and is named "crater with rayed ejecta" on the *Malin Space Science Systems* website. The region from which this image was taken can be seen below in figure 22:

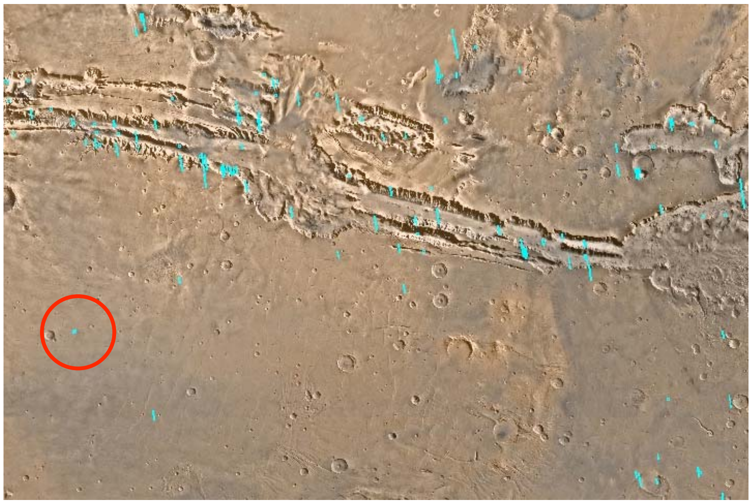

Figure 22: MOC Narrow-Angle Image Gallery: Mars Chart 18: Coprates

Figure 23, below, is an elevation map which gives more insight into the surface's surrounding area:

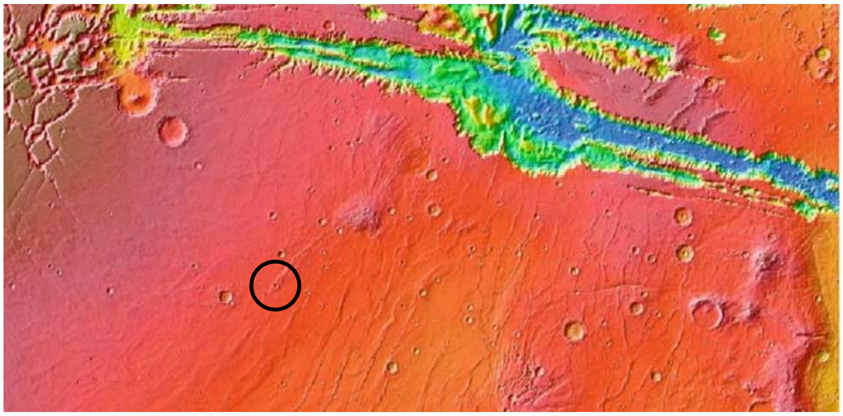

Figure 23: Image S01-00245,6 elevation map from Google Mars

These maps show that Image S01-00245,6 resides just south of the Valles Marineris. The actual image's surface lies on a slightly elevated ridge and has a few large distinct craters surrounding it. This region looks as though there has been some sort of water erosion because of the wrinkles in the surface. These wrinkles could have also been caused by some sort of tectonics or volcanic activity, but it is more likely that they were caused by flowing water. From afar, the surface appears have minimal cratering, which leads me to believe that the water erosion happened recently.

Figure 24 shows a closer view of the region in which Image S01-00245,6 resides. As predicted above, this image confirms that there could have been some water erosion in this area. The surface looks smooth and the wrinkles look as though they were caused by water flow. If not water flow, the wrinkles could have been caused by the Tharsis Bulge, which is located near this surface.

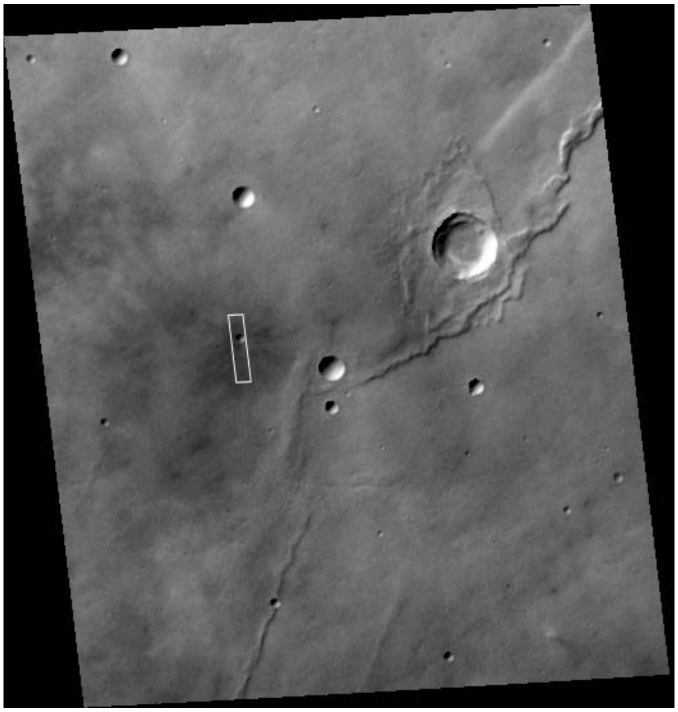

Figure 24: MOC red wide-angle context image S01-00246

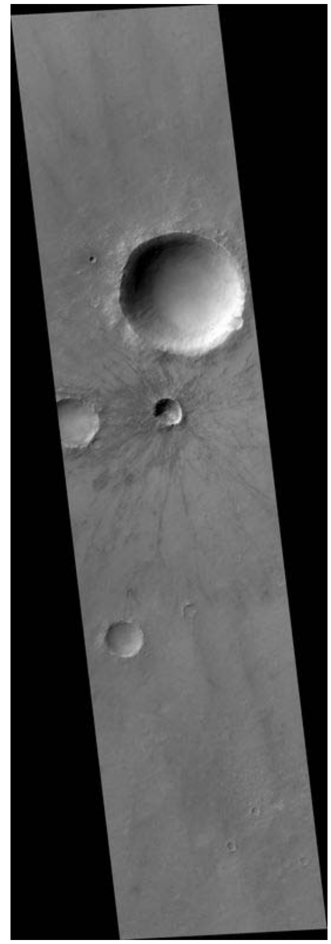

Figure 25: MOC narrow-angle image S01-00245

Figure 25 is narrow-angle image in which craters were counted and cataloged. This close-up view of the area in question provides further evidence for a younger, water eroded surface. The craters have very distinct rays of ejecta which were most likely caused by when the surface was wet and the ejecta would have "sploshed" out further than usual. Also, if the surface was dryer than right under the surface, the "wet" underneath could have contributed to the color differences in the crater bottoms and the surrounding ejecta.

After all the craters were analyzed and counted, an isochron plot was produced. This plot estimates the age of this area to be about 100 million years old. This is relatively young for a Martian surface, but it is reasonable if the water erosion theory or tectonic activity is taken into account.

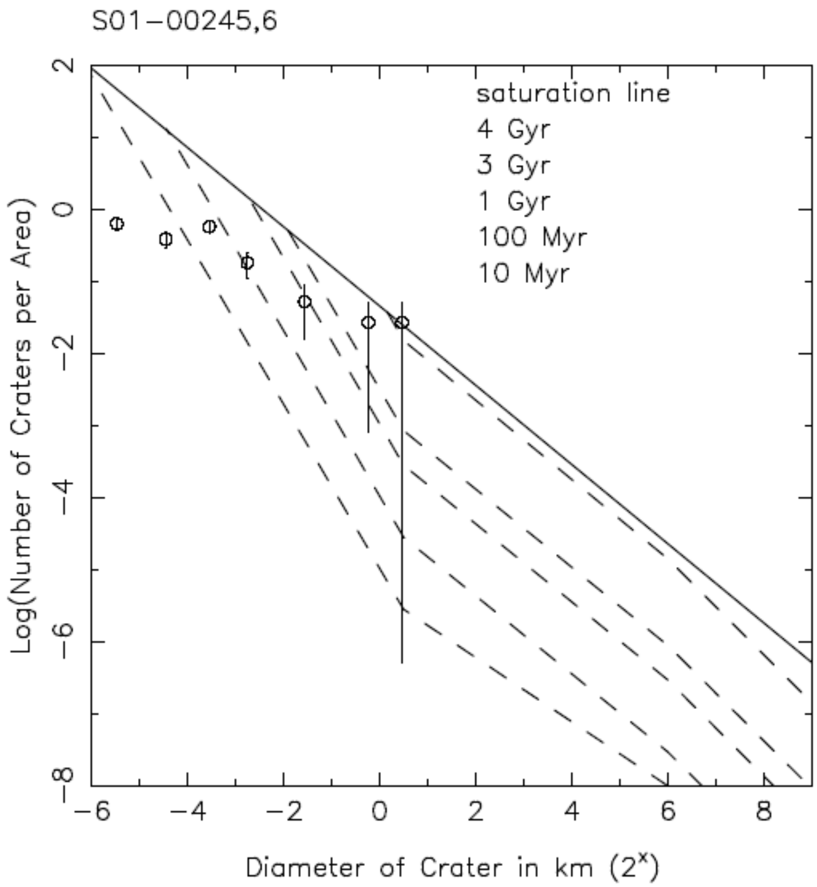

Figure 26: Isochron plot for Image S01-00245,6

There appears to be a "turn-over" point in the data above before the 2^{-2} diameter mark. This can be accounted for in the inability to accurately count and measure the smallest craters in the narrow-angled image. This is why the two left-most points were disregarded in the plot. Following similar reasoning, there is a "knee" for craters above the 2^{0}; this is where the narrow-angle image and context image counting collide. This knee is compensated for with the error bars and none of the points were disregarded.

Fields: R22-00549 (near Phaetontis)

Image R22-00549,50 is located at 46.2°S, 144.6°W. The image is named "crater wall" on the *Malin Space Science Systems* website. The region from which this image was taken can be seen below in figure 1:

Figure 27: MOC Narrow-Angle Image Gallery: Mars Chart 24: Phaethontis

Figure 28, below, is an elevation map which gives more insight into the images surrounding area:

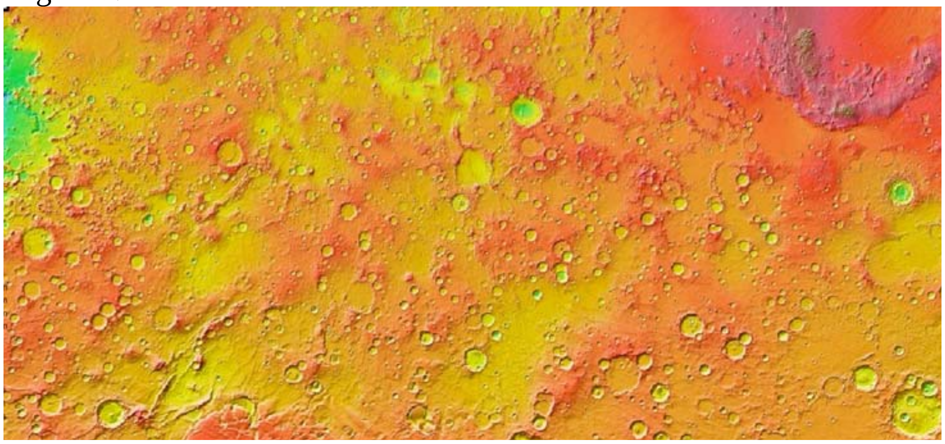

Figure 28: Image R22-00549,50 elevation map from Google Mars

These maps show that image 27 resides in a heavily cratered portion of the Martian surface. There does not seem to be any drastic changes in elevation around the location of the image, but it does look as though there are slight depressions in the area; this is most likely caused by an older surface which has seen little erosion and resurfacing except for the addition of more craters over the years. The depressions could just be old, large craters which are now covered up by newer craters.

Figures 29 and 30 are the images that were analyzed for their crater content. Figure 29 is the context image in which figure 30 resides.

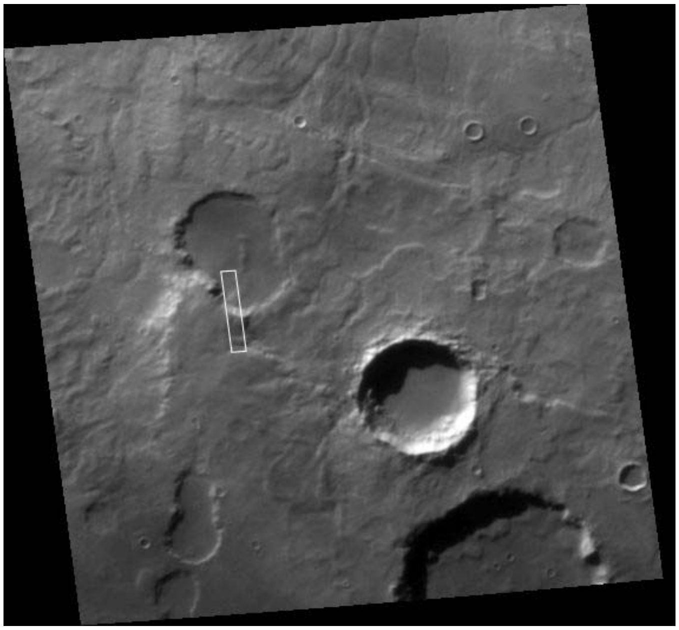

Figure 29: MOC red wide-angle context image R22-00550

Figure 30: MOC narrow-angle image R22-00549

From the context image, it looks as though the surface was covered by a lava flow at one point in time. This area is just south of the four large volcanoes so it makes sense that this surface could have been affected by the flow of a past eruption. The depth of the craters provides further evidence for this; the visible craters are very deep into the surface which means that the surface was somewhat malleable when the impacts occurred. The crater depth could also be attributed to a lack of wind erosion, which would cause the craters to not fill up with surrounding dust.

The narrow-angled image is positioned on the rim of a crater. It looks like there has been minimal recent erosion, but there has definitely been some wind erosion in the past. This can be seen on the floor of the large crater in the form of sand dunes. Also, the rippled terrain on the bottom of the image suggests lava flow.

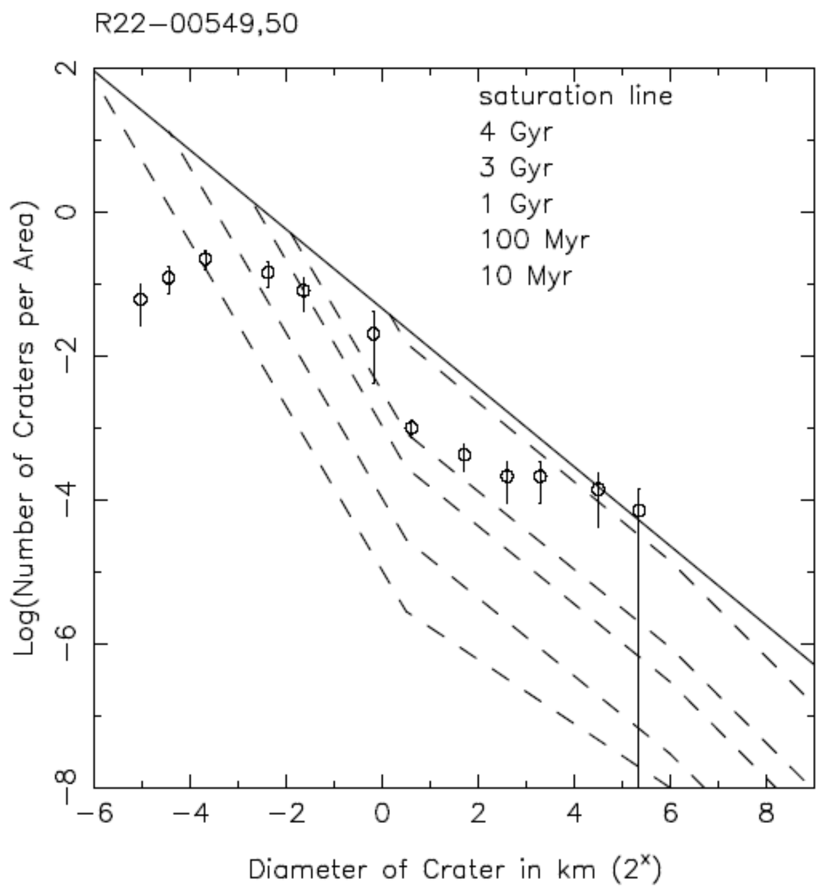

Figure 31: Isochron plot for image R22-00549,50

This section of the Martian surface looks to be about 3 billion years old. Most of the data point or error bars line up with this isochron if the turn-over points, the three left-most points, are disregarded (as explained above). This age makes sense because the surrounding area is heavily cratered and it seems that there has not been any recent erosion except for the occasional wind erosion.

Fields: S02-00235 (near Iapygia)

Image S02-00235,6 is located at 15.8°S, 275.1°W. The image is named “survey walls of crater” on the *Malin Space Science Systems* website. The region from which this image was taken can be seen below in figure 32:

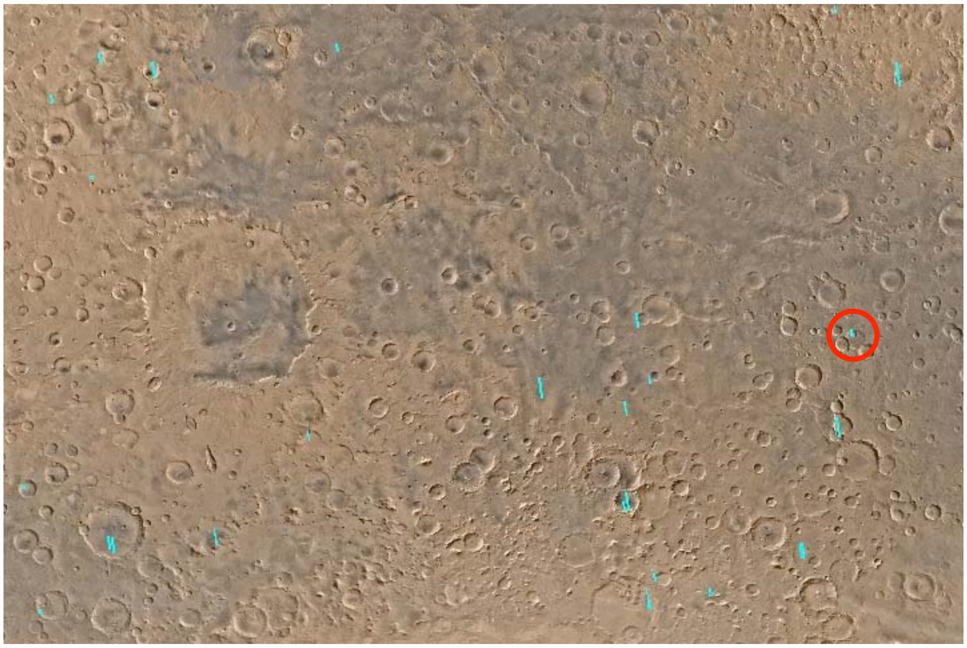

Figure 32: MOC Narrow-Angle Image Gallery: Mars Chart 21: Iapygia

Figure 33, below, is an elevation map which gives more insight into the images surrounding area:

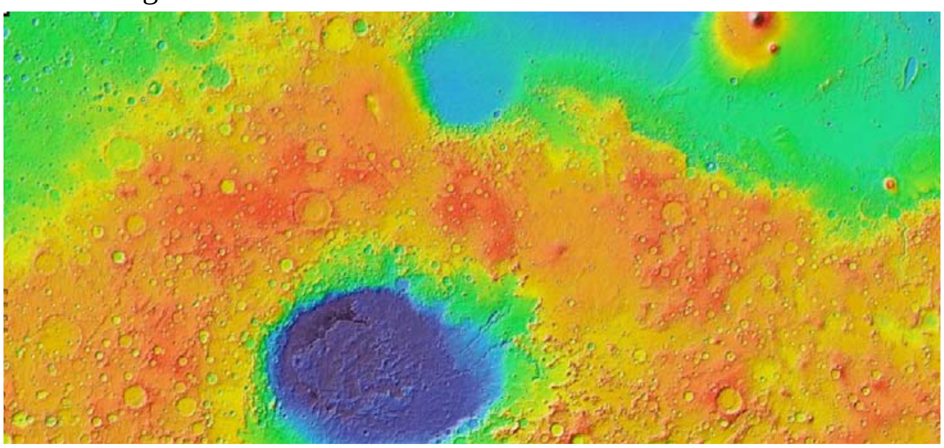

Figure 33: Image S02-00235,6 elevation map from Google Mars

This area of the Martian surface is heavily cratered. This usually means that the surface is older. There does not appear to be signs of large-scale erosion because all of the craters are formed well and intact.

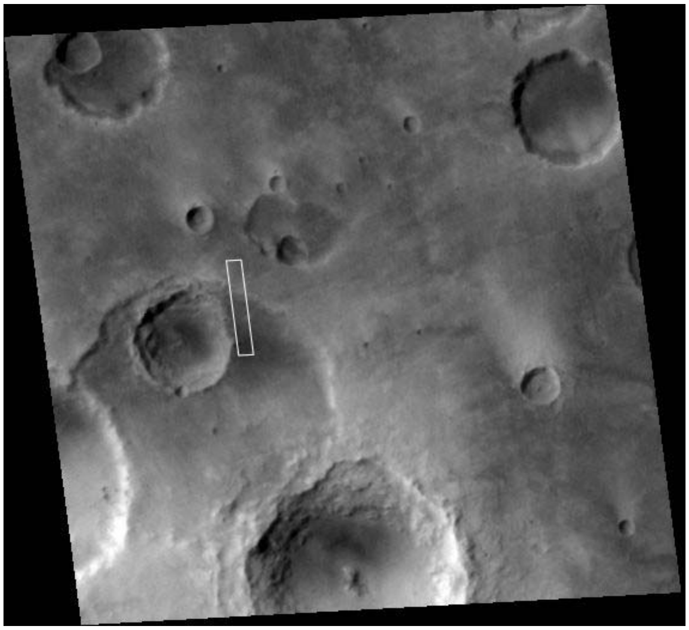

Figure 34: MOC red wide-angle context image S02-00236

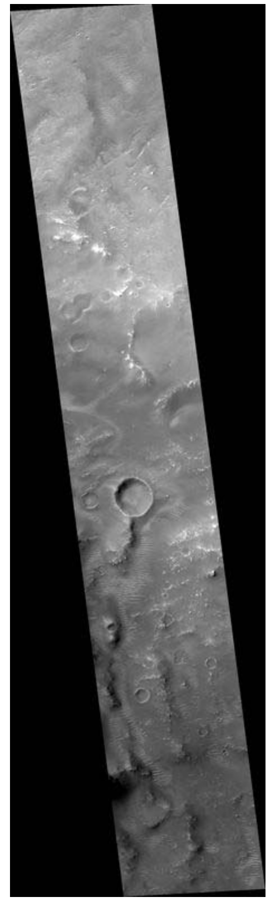

Figure 34: MOC narrow-angle image S02-00235

In looking at the context and narrow-angled images, it is apparent that this Martian surface is rather old. There are many overlapping craters which stresses this point. Also, it looks as though there was some sort of lava flow before the craters were made. The surface is smooth, but in a way that hints at the solidifying of lava. Seeing as though the evident craters were formed after the lava flow, the lava must have solidified before the impacts.

It also looks as thought there could have been some wind erosion on this surface. A lot of the craters in the context image look covered up slightly because they are not very deep. Also, it looks as thought some large older craters have been completely erased because slight depressions are still evident.

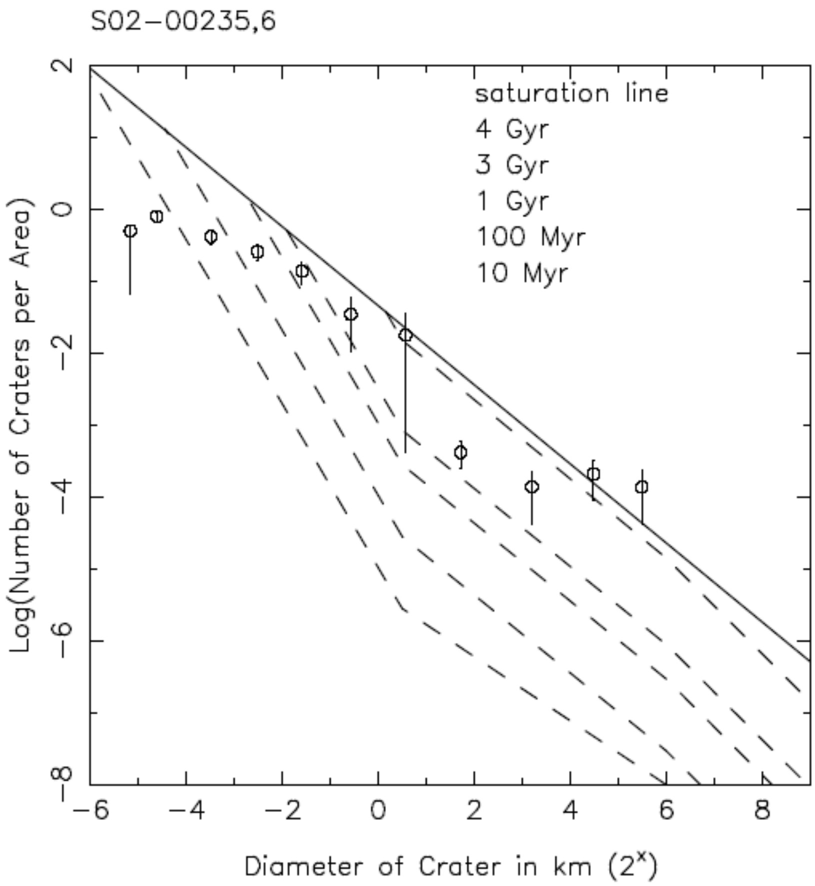

Figure 35: Isochron plot for Image S02-00235,6

From the data supplied in figure 35, the surface in question looks to be about 3 billion years old. This is consistent with the predictions made by looking at the surrounding surface. The four left-most data points were neglected in this case, but if they were to be included, they would show that the narrow-angled surface could possibly be younger than 3 billion years old. Because there were few craters in this area, the data in figure 15 does not follow one isochron, but the data and error bars fall closest to around 3 billion years.

Koch: R05-00643 (near Thaumasia)

Image R05-00643 can be found in MC 25, as designated from standard Mars maps by U.S. geological survey. The area is more commonly known as Thaumasia. (Figure 36) The exact location of the image is 35.39°S and 76.14°W. It is identified as the "Cross Valley East of the Coracis Fossae." The region is south east of the Tharsis bulge. There is a circular depression with a ridge around it, with the image located on the outer south east side of the ridge. (Figure 37)

A fossa is a long, narrow, shallow depression; the fossa in question is 50 km wide and 747 km long and is a possible rift structure formed between 3.5 and 3.9 Gyr b.p. This is mostly due to plate tectonics, most notably from the creation of the surrounding volcanoes on the Tharsis Bulge. The image is therefore lying within a crack, in order for it to be fossa, and is atop of the ridge. (Figure 37) The altitude of the region is 6 km which is higher than the surrounding circular depression, which is at 2km. The circular depression is most likely younger due to the resurfacing from the nearby volcanoes, but the ridge is at a higher altitude and therefore has not been recently resurfaced by flowing lava.

The context image shows definite rift structures smoothed over by lava flow from a long time ago. We know that this last resurfacing was in the distant past due to the total number of the craters atop of the ridge. (Figure 38) The smaller craters are younger because they are more easily resurfaced by the above processes as well as simple processes such as wind. (Figure 38) The overall surface is much older and is dated at approximately 3.3 billion years old as seen from the data plotted on the isochron chart. (Figure 41)

On the isochron, the first three data points were neglected because they made up the turnover caused by incomplete crater counting, or the spot where that data points move more toward the left than upward. Also, the last three points on the right were not as heavily weighted because the error bar on these was very large. There was a slight knee in the isochron which was caused by the turnover point of the context image. Aging the data after taking in all these considerations identifies this area of Mars to be 3.3 billion years old.

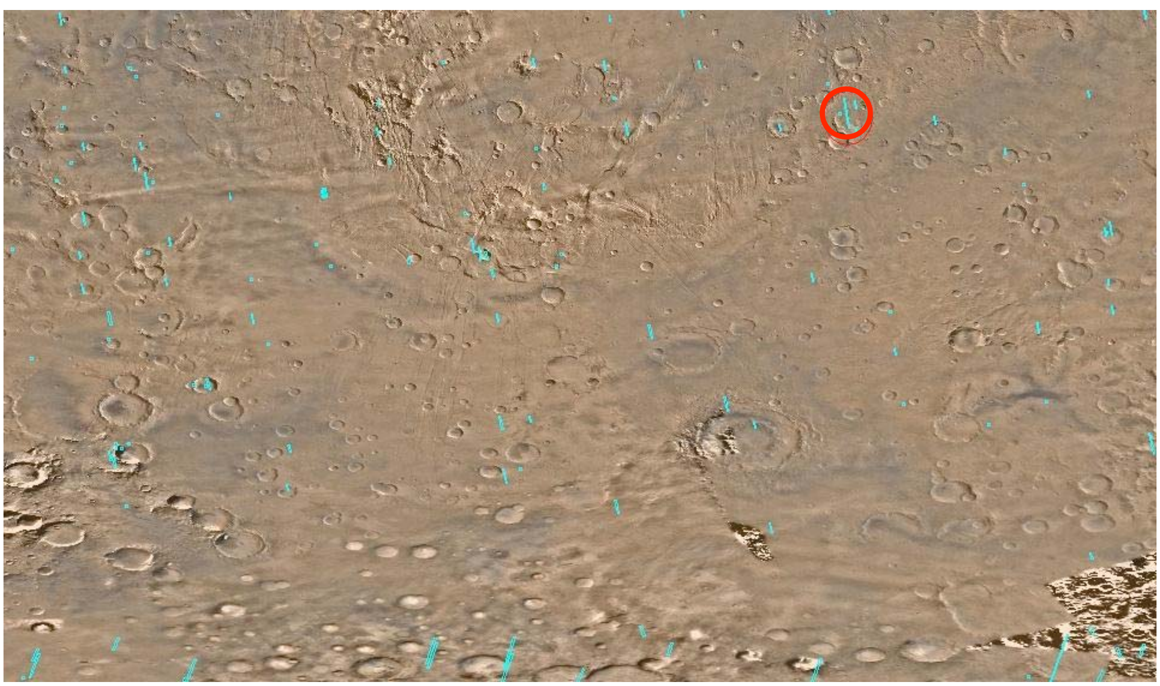

Figure 36: Image MC 25, Thaumasia

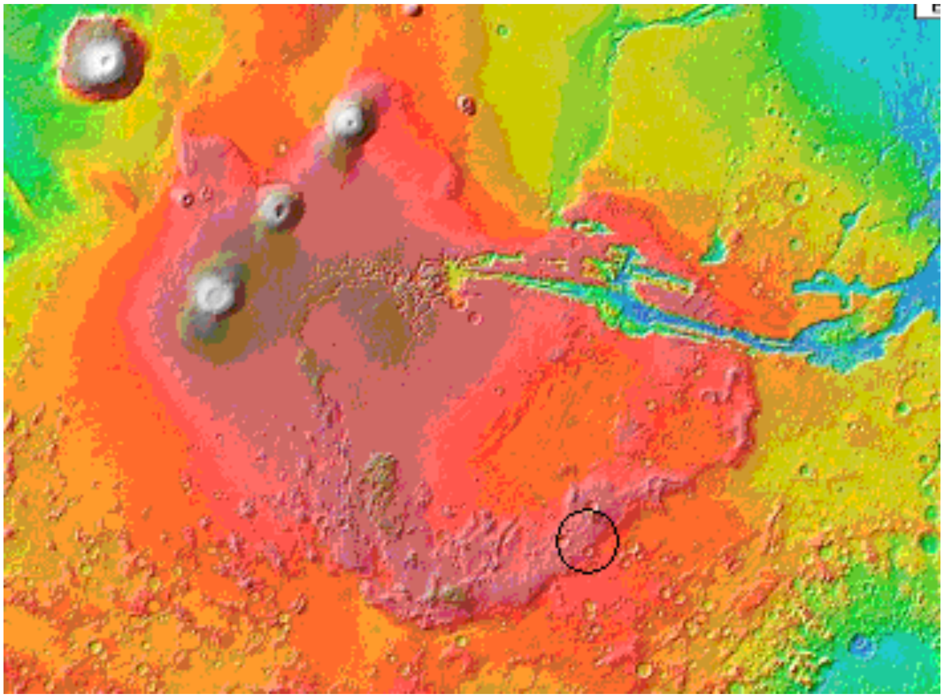

Figure 37: Elevation of area surrounding image R05-00644 as provided by Google Mars

Figure 38: Close-up of elevation around image R05-00644 as provided by Google Mars

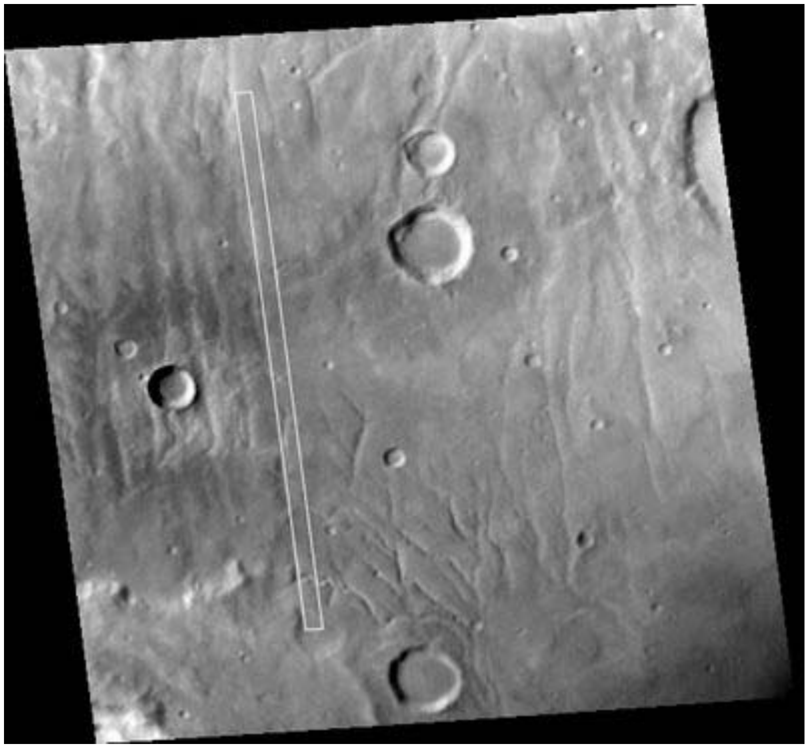
Figure 39: Image R05-00644: wide angle context area of narrow image R05-00643

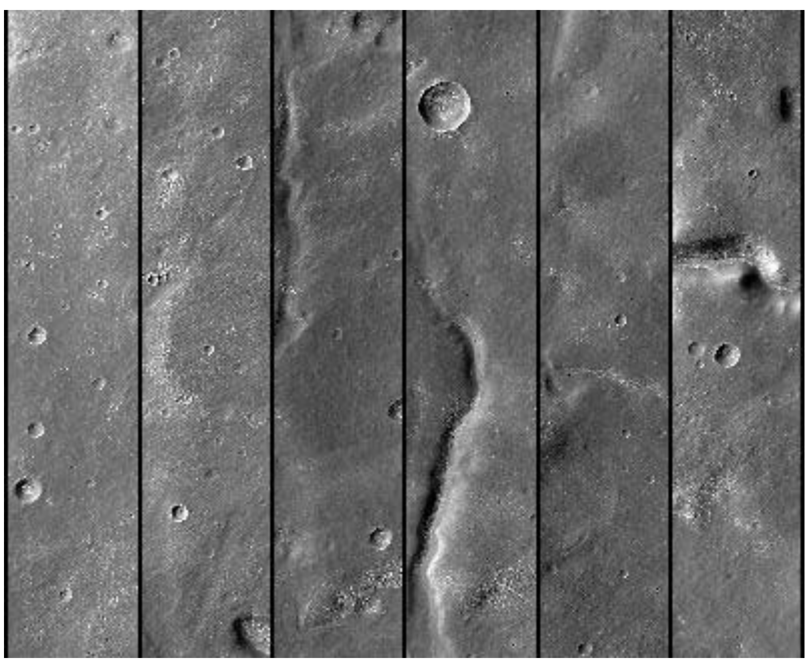
Figure 40: Narrow angle image of R05-00643

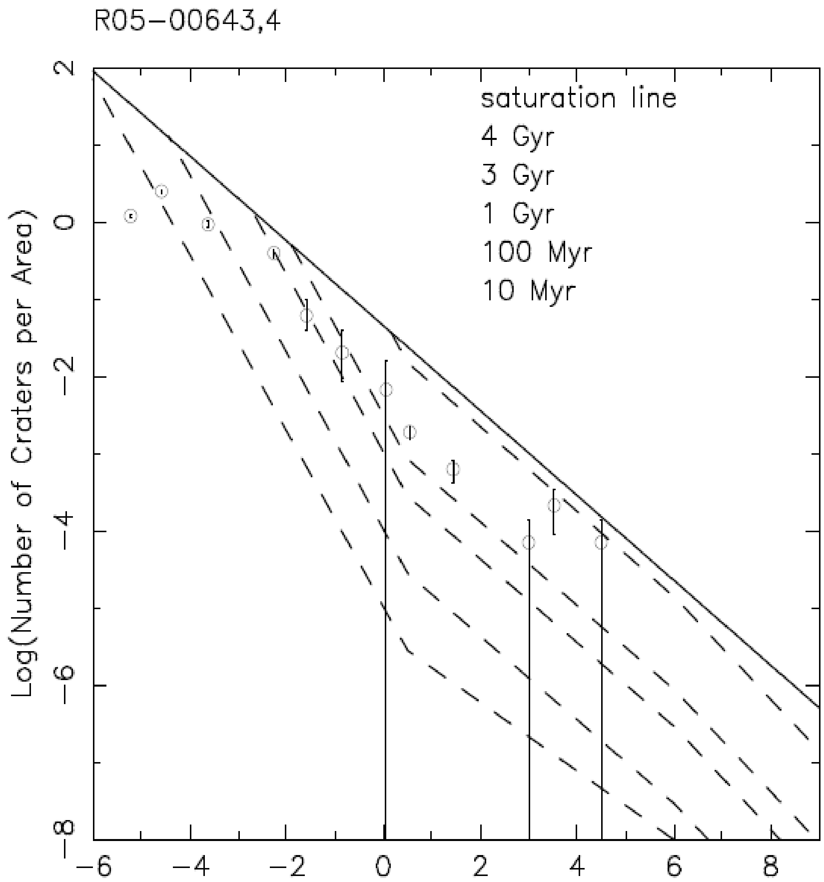

Figure 41: Isochron from images R05-00643 and R05-00644

Conclusion

The goal of this project was to determine the age of selected surfaces of Mars. We obtained MOC narrow-angle images from MGS managed by Malin Space Science Systems and analyzed these for crater size and number. We analyzed the data to determine how many craters of each size were found in each image, plotted the data on established Mars isochrons, and used the results to determine the age of each surface.

Table 3: Conclusion Table

Narrow Image	Notable Features	Determined Age
R22-00877	Water erosion	2 Gyr
R22-00474	Lava flows	2 Gyr
R14-00473	Between low-lying areas	3.3 Gyr
R22-00678	Sand dunes in narrow-angle image	3.2 Gyr
R22-00997	Well-worn craters, washed-out look	3.1 Gyr
S01-00245	Splosh craters, water erosion	100 Myr
R22-00549	Lava flows, wind erosion	3 Gyr
S02-00235	Old lava flows, overlapping craters	3 Gyr
R05-00643	Circular depression with ridge, fossae	3.3 Gyr

While the measurement and analysis went smoothly overall, the difficulty we had was mostly due to two factors. First, the smallest craters in the images could not be resolved. This was due to the resolution of the images, which was not high enough to detect craters smaller than roughly 25 meters in diameter, or about 5 pixels wide in each image. Second, some land forms, in particular sand dunes, can make crater detection difficult. Erosion also dulls craters, possibly lowering the number detected, particularly with smaller craters which may become too indistinct to detect. The angle of the Sun when each picture was taken was also a factor in our measurements. While we tried to choose images with favorable solar incidence angles, having a more favorable angle might outline some craters or other surface features we missed.

Generally we found two ages for each surface. This was due to the fact that we were using two images for each surface. Generally the narrow-angle image and the wide-angle context image would provide two ages, which is to be expected given that from each image we gathered distinct data sets. We plotted the data points from both images on the same isochron, and the points would align in two distinct sets, one for each image. While this made dating the surface more difficult, it is to be expected considering the images we had available.

The analysis procedure could be improved by gaining access to higher resolution images. While the images we analyzed were some of the highest resolution available today, better images will be taken in the future, and analyzing those will allow us to identify smaller craters with greater accuracy. Also, having a better picture of a region would help differentiate between craters and other landforms such as sand dunes. Another improvement would be gaining access to infrared images of the surface. Having images of a different wavelength of light might help differentiate features or recognize craters among the hills, sand dunes, and other land features.

If we were to continue with the project, the next logical step would be to analyze images from areas near the areas we have already analyzed. By doing so, we can compare the new results with those already obtained. This will allow us to verify the age of the area or with differing results would tell us to study the area more closely to determine a correct age. Alternatively, we could examine areas with well established ages and see if our results match those ages. As an accuracy check, we could have 2 or more researchers analyze the same area to make sure our methods were as close as possible. It should be noted, however, that we established rules to make sure that each researcher performed the same judgments on all the craters they saw. When a researcher came across a difficult crater to analyze it was brought to the group's attention and the team determined how to handle the situation by examining the crater as a group.

References

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