Dating Approximation and Analysis of Select Mars Surface Features

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Introduction

Our objective for this project was to select images of specific locations on Mars and date the ages of the surfaces. The images used were obtained from the gallery of Mars Global Surveyor’s Mars Orbiter Camera, which has taken upwards of 212,000 detailed photographs of the planet’s surface since its launch in 1996. Once locations were selected, they were cross referenced using the Google Mars geographical information system, a Java-based program developed by the Mars Spaceflight Facility at Arizona State University. This software combines images from three different Mars orbiters into a single image with options for visual, infrared, and elevation maps of the terrain.

The most accurate means of finding the ages of these surfaces would be through radiometric dating of the minerals and compounds of the ground. However, since traveling to Mars in person to collect soil samples is not yet a possibility, we have to use other methods. From our knowledge of the solar system, its history, and findings from lunar studies, we know that relationships exist between crater sizes, crater density (number of craters in a given area) and surface age. Generally, more heavily cratered surfaces are older, having been exposed for a longer period of time, allowing more debris the opportunity to impact. Newer surfaces, having been changed over time by various geological processes (water flows, wind erosion, etc.), will have fewer craters.

This can be visually represented by an isochron plot. This plot of crater density and frequency contains static isochron lines, which denote certain time periods of the past. Once our images were selected and craters counted, they were plotted on the graph and compared to the isochron lines, giving us an estimate of the surface age. Our plots had lines representing ten million years ago, 100 million years ago, one billion years ago, three billion years ago, and four billion years ago. These lines have a downward slope, which takes into account that smaller objects impact more frequently than larger ones. The estimation from this plot, combined with what we are able to deduce from the images themselves, such as evidence of water flow or erosion, allows us to not only estimate the surface age, but also hypothesize as to what we believe may have caused the different features visible in the images.

Data

The Mars Global Surveyor (MGS) mission was developed by Malin Space Science Systems (MSSS) and was launched on November 7th 1996. The MGS mission was a follow up to the Mars Observer which was lost in August 1993. MSSS provided the spare Mars Observer Camera (MOC) for use in this mission. The current contract includes “observation planning, development of the commands to send to the spacecraft for the camera, retrieving and processing the data returned from the camera by the spacecraft, and analyzing and archiving the data. More than [212,000] images have been taken, processed, and archived since September 1997.” (http://www.msss.com/msss.html) In our research, we chose images from this large set to analyze. The MOC Gallery can be found at: http://www.msss.com/moc_gallery/

The following are explanations of some of the characteristics of images followed by the images themselves:

1. Scaled pixel width: This is the size in meters of a single pixel in the image.
2. Pixel aspect ratio: The ratio of the number of pixels in the image’s height to the number of pixels in the image’s width. A ratio becomes more acceptable as it gets closer to 1.
3. Scaled image width: This is the width of the whole image in kilometers.
4. Scaled image height: This is the height of the whole image in kilometers.
5. Incidence Angle: The angle at which the Sun is in relation to the surface.

Image Characteristics:

Image name	Longitude (°)	Latitude (°)	Incidence Angle (°)	Aspect Ratio	Scaled Pixel Width (m)	Scaled Image Width (km)	Scaled Image Height (km)
E13-00436	346.11° W	43.48° N	60.41°	0.88	4.91 m	3.30 km	26.59 km
S09-00771	262.86° W	19.40° N	53.24°	0.93	4.74 m	3.18 km	10.71 km
S08-00984	115.49° W	24.52° N	58.30°	1.38	3.18 m	3.25 km	33.71 km
R19-00241	200.25° W	7.00° N	35.54°	1.11	1.49 m	3.04 km	6.55 km
M02-02310	70.64° W	26.62° N	39.33°	1.95	9.03 m	3.03 km	108.16 km
M02-01125	71.61° W	26.31° N	38.31°	0.98	12.03 m	3.07 km	94.68 km
S09-02300	13.29° W	32.25° N	27.05°	0.98	3.01 m	3.09 km	16.70 km
S06-00101	250.93° W	8.12° N	43.24°	0.99	6.02 m	3.08 km	72.15 km

Each of us involved in this research was instructed to choose two images which we found interesting. The following are reasons why the analyzed images were chosen.

S08-00984:

Ryan chose this image because of the interesting flow features and gorges. He wished to see that if these features were caused by water, how long ago the water was on the surface.

R19-00241:

Ryan chose this image because of the extremely high resolution. He also was interested in what may have caused the central area to collapse. Another thing which attracted him to this region was the amount of uniformity of the land surrounding it.

M02-02310:

Jon picked this image because he was looking for some sort of image with flow features. This image looks like there is flow from the higher elevation above. The flow seems to be a mystery. He is not sure what could have caused it but thinks it may be a crater impact melting ice and the land rising to move the water or some sort of lava flow.

M02-01125:

Jon chose this image because he wanted to see if he could age the image M02-02310 better with two images in the same area. The images are of the same feature and fairly close to each other.

E13-00436:

The context image (Figure II) is what Leanne found the most intriguing, because there appeared to be some sort of canyon formation (the "fretted terrain"), not the typical water flow features or dunes caused by wind erosion. She was curious to find the age of the surface of these features and try to understand more about how they formed.

S09-00771:

Leanne chose this image because of the fact that it is just craters. There are no other outside influences that would have changed the surface, and this seemed to be a very rare occurrence, especially in the northern hemisphere. She thought it would be interesting to date this specific surface, and see if it matched up with the time the original Martian surface would have formed.

S09-02300

David found this terrain interesting due to the interesting pattern of dunes and cliff faces in the narrow angle image (Figure XXV). The context image (Figure XXVI) looks fairly even, and the narrow angle seemed out of place in the area. Another thing which David liked was the crater overlap in the top of the context image.

S06-00101

David liked the overlapping crater feature in his previous image, so he sought another image with a similar feature. This context image (Figure XXX) is a great example of a large impact crater with a smaller, younger one on its edge. David liked the features and chose to date the floor of the crater.

Google Mars:

Google Mars is an effort by Google to map the entire surface of Mars in three different ways (Elevation, Visible, and Infrared). After choosing our images using MSSS, we used the following formula to find our coordinates in Google Mars' terms.

Google Mars uses a -180 to +180 degree scale for its longitude, so to use the latitude and longitude from MGS we must do the following:

0° to **180**° W in MGS ➔ **0**° to **-180**° in Google Mars
180° W to **360**° W in MGS ➔ **180**° to **0**° in Google Mars

Once we were locked in on our images, we used Google Mars to identify features around our context images on maps different than could be seen in the MOC gallery, such as elevation and infrared maps. Noting the different elevations and detail of certain features aided in the analysis of all of our images.

Analysis

Analyzing the data is always one of the most crucial steps in an experiment. It is important to use the correct formulas so that the data can be used to its maximum potential. Understanding what the information represents individually and as a whole is also important because without an understanding of the data, the experiment would be a complete waste.

All of the images' craters were counted as carefully as time allowed. Ryan, Jon, and David used a version of *Adobe Photoshop* to count the craters on their images while Leanne used *Gimp* as an alternative program. We each used a tool that allowed us to make rings of a certain pixel size. The range from one pixel size to another defined a bin, and any craters that fit between these two rings were classified as being in that bin. It was decided to use the sequence 2^n meters, where n existed in natural numbers; that is, starting at 1 and hitting every integer greater than that as their bin sizes; therefore, the first bin would have bin would have bin 2-4 meters, the second would be 4-8 meters, the third would be 8-16 meters, etc.

The images each possessed a scaled pixel width given in meters/pixel. Therefore, in order to calculate the bin sizes in pixels, each bin was divided by the scaled pixel width, leaving pixels as the unit. This allowed the categorizing of craters into their appropriate bins. However, a 5-pixel minimum was designated to count a crater. This was established to ensure that we were able to make accurate counts since the scaled pixel width on many of the images would not be able to clearly define craters of such small sizes.

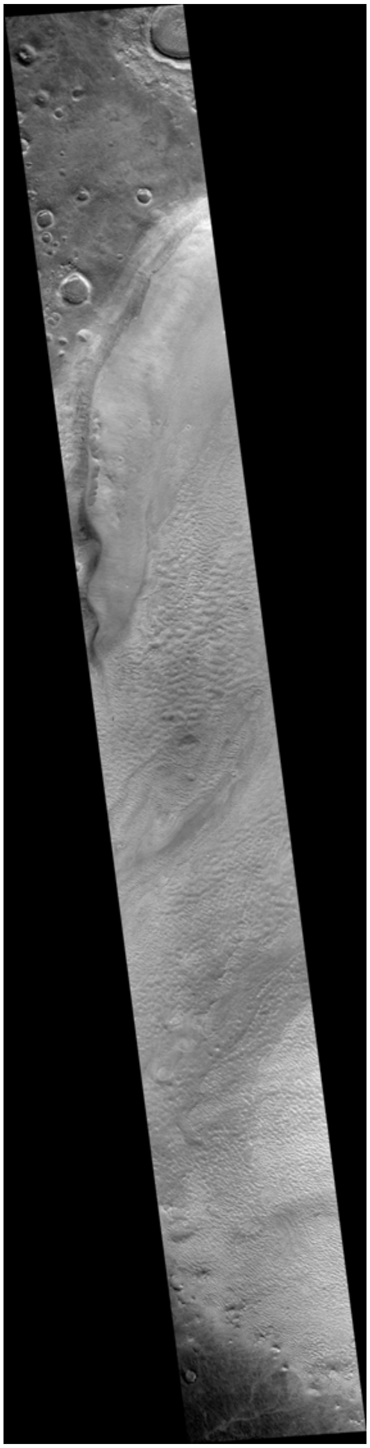
The images' information also gave a scaled image width and scaled image height, given in km for each image, so the area of each image was simply the product of these two numbers. However, some images were only partially counted; therefore, some of us had to estimate the percentage of the image that was actually counted and multiply that by the area of the whole image. The area was calculated so everybody could determine the crater density of the image according to each bin, to find the age of the image, and to plot the data points on the isochron plot.

We also needed to calculate the midpoint of the size of the bins in km so we could plot them on the isochron plot; adding the bins minimum and maximum size, and dividing by 2 accomplished this goal. We also had to calculate the base 10 log of the crater density of the image for each bin. All the counts for each bin were taken and divided by the area of their images. The log of this number was taken so that it could be plotted on the isochron plot. Calculating 2^X, where x represented the midpoints of each bin in kilometers, was also necessary to take advantage of the linearity of the system when in the form of a power law.

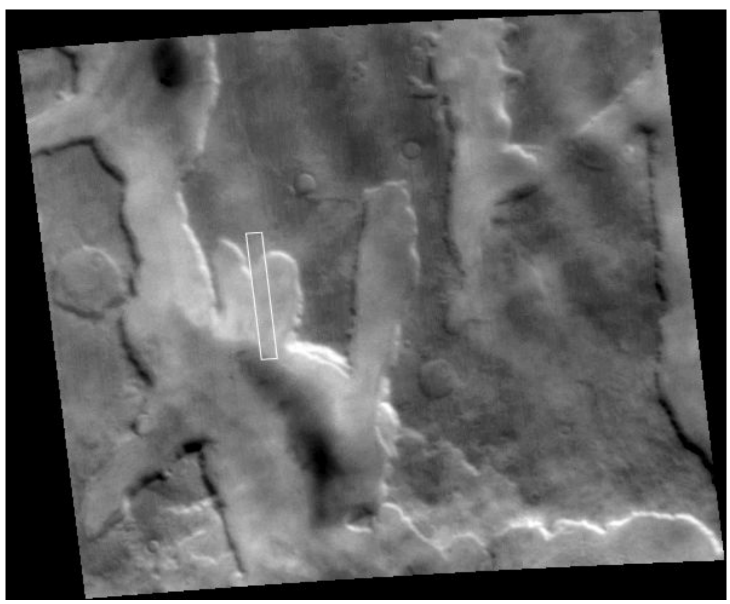
Next, we had to calculate the error that is always present when doing research and computations. In order to calculate the error present from counting inconsistencies, a triangular algorithm was used. The Pythagorean Theorem states that A^2 + B^2 = C^2. This holds true for what we set out to accomplish. Two of us counted each image to get a more accurate count for the images. In order to calculate the error between each other's counts, we had to calculate the average between the two and then subtract the counts of the person's image; this represented A. B represented the square root of the counts of the person's image. This number is based on the Poisson distribution and is used to consider the fact that impacts are random. Taking these into account, each of these values were squared as the Pythagorean equation suggests and then added them together, this gave C^2. Taking the square root of this number provided C, giving the appropriate error in the number of counts. However, the total error was the target, which includes the area over which this count error occurs; therefore, by dividing the calculated error by the area of the image, the total error of the system was successfully determined. Now, since all the ages were plotted onto the isochron plot as log(N/A), it was appropriate that we do the same with the errors. Consequently, since error works in both directions, the total errors were added and subtracted from the density of each image. The logs of these new numbers were then taken to obtain the total error in terms of a logarithmic function. This error calculation is how we arrived at the error bars that are now plotted on the isochron plots.

<u>Results</u>

Image E1300436 (Analysis by Leanne)



Links:
MOC Gallery:
http://www.msss.com/moc_gallery/e13_e18/images/E13/E1300436.html

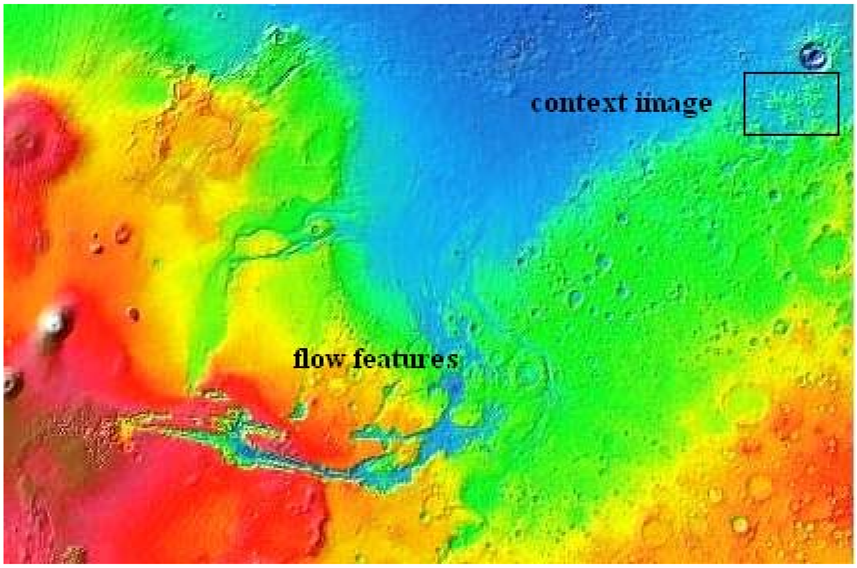


Narrow-Angle (Fig. I)

Context (Fig. II)

Estimated Age: 50 Million Years old

The context image shows a region of Mars of fretted terrain known as Deuteronilus Mensae, which consists of canyon-like features. When counting craters in the narrow angle image, only those which are inside of the canyon were taken into account.

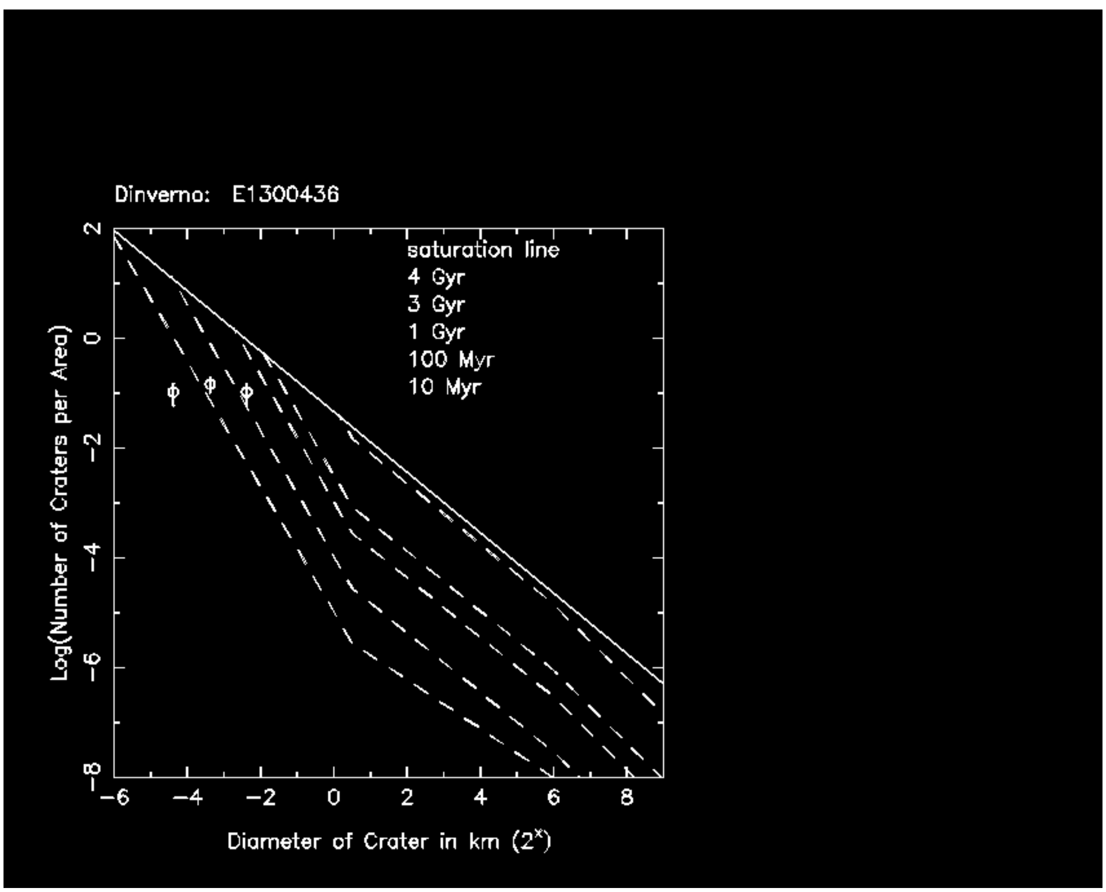


Google Mars Elevation Map (Fig. III)

To the south of this surface is higher terrain, with what appears to be water flow features leading to the area surrounding Deuteronilus Mensae (this is evident in Fig. III). However, the specific area does not exhibit these flow characteristics, making it more difficult to determine what geological process could have left such a landscape. One possibility is that the ground at this area was a combination of hard and soft rock, then water flowed in and eroded away the softer areas but left the hard rock behind; this could explain the unusual topography. The fact that there were so few craters supports this idea, because any craters in the soft rock would have been more vulnerable to erosion. The presence of only a few craters leads to the estimation that this surface is very new, approximately 50 million years old (see Fig. IV). The accuracy of this estimation could have been thrown off due to the fact that the craters found only fell into three different bins. Had there been more bins to use the age estimation would have been more accurate. The three points on the graph also appear horizontal, rather than following the downward slope of the given isochrons. This is perhaps because smaller craters were preferentially eroded; possibly due to the previously mentioned water flow, or wind erosion which appears evident in the canyon floor. This could have brought the smaller crater count down, and since there were only three points, made the horizontal orientation on the plot. Again, had there been more bins we probably would have seen a downward slope to the points.

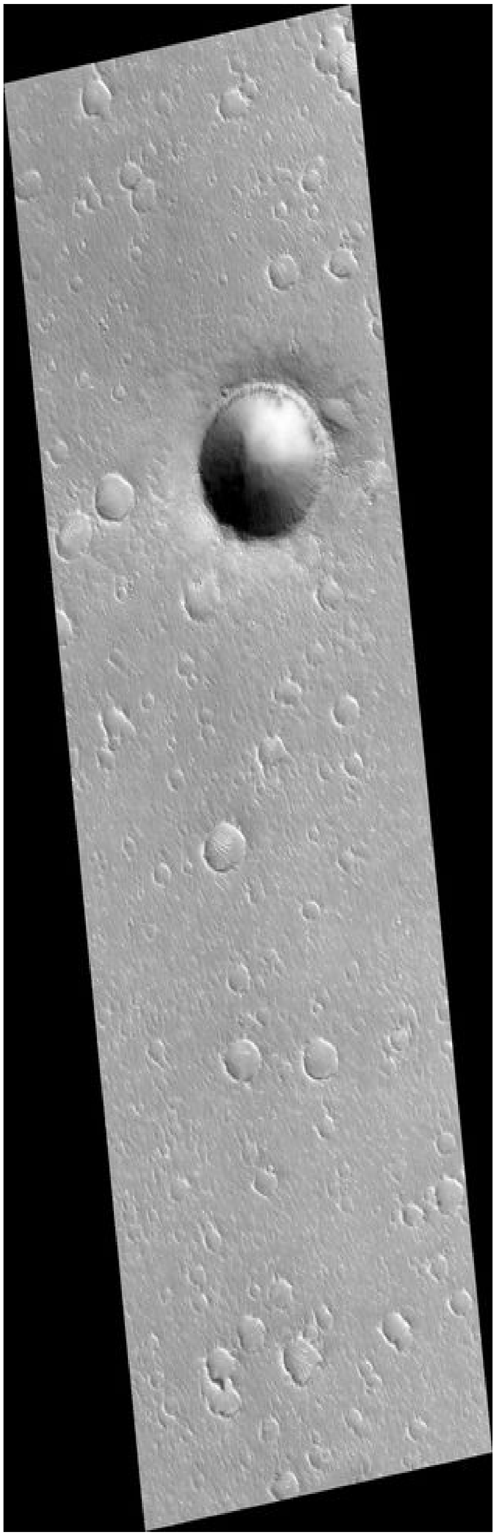
Crater-counting data:	
Range in km	**number of craters**
.032 - .064	7
.064 - .128	10
.128 - .256	7

(Table I)



Plotted Isocron (Fig. IV)

Image S0900771 (Analysis by Leanne)

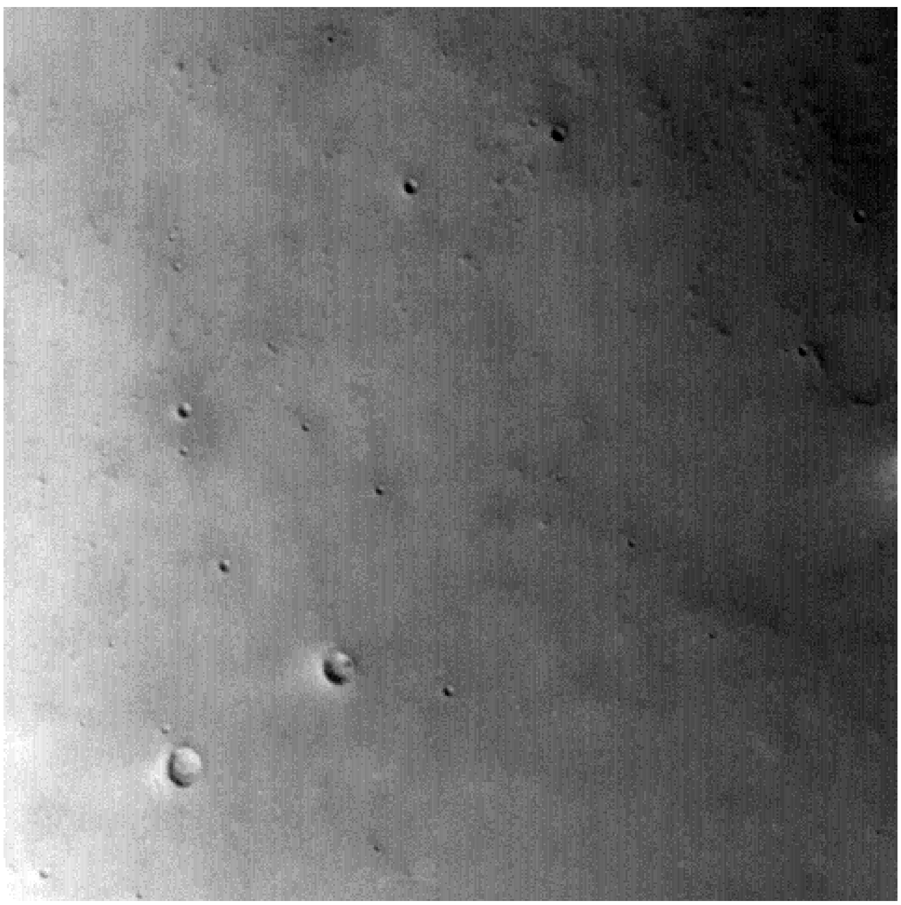


Narrow Angle Image (Fig. V)

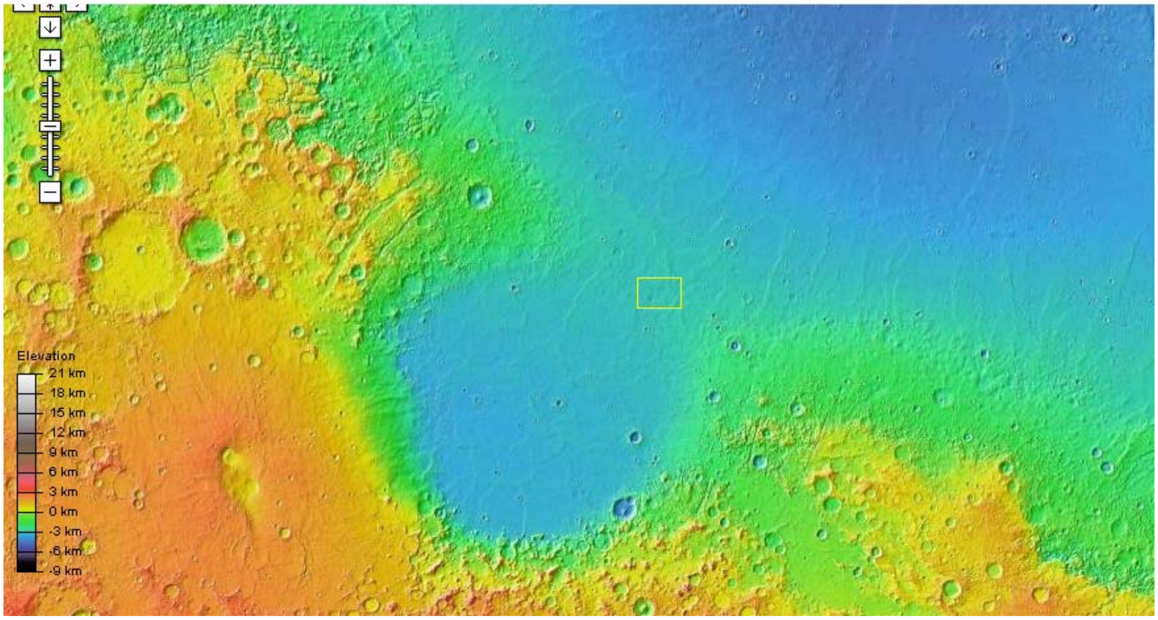
Links:
MOC Gallery:
http://www.msss.com/moc_gallery/s05_s10/images/S09/S0900771.html

Estimated Age: 4 Billion years + / Saturation Point

This image shows a surface in the Northern Hemisphere, an area that usually exhibits evidence of different geological processes such as water and wind erosion. What is interesting about this surface is how unaffected it is, leading to an estimation, even prior to crater counting, that it is one of the oldest of the surfaces we have looked at for this project. The isochron plot supports this idea, with the points appearing very close to the saturation line, or just after the period of the Great Bombardment, when the planets were being hit by debris extremely frequently, more than four billion years ago. The final two bins, being below the four billion year line, can be explained by the fact that large craters are rare in general, and it is not unexpected for this count to be lower.



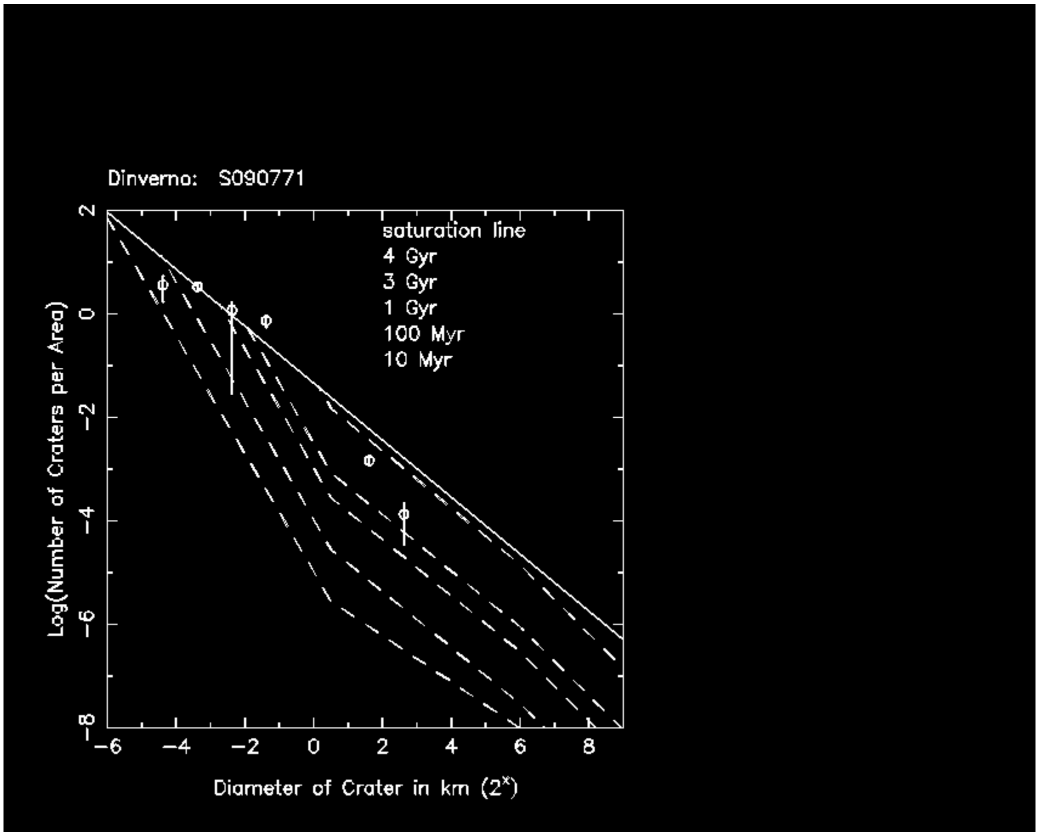
Context Image (Fig. VI)



Google Mars Elevation Map (Fig. VII)

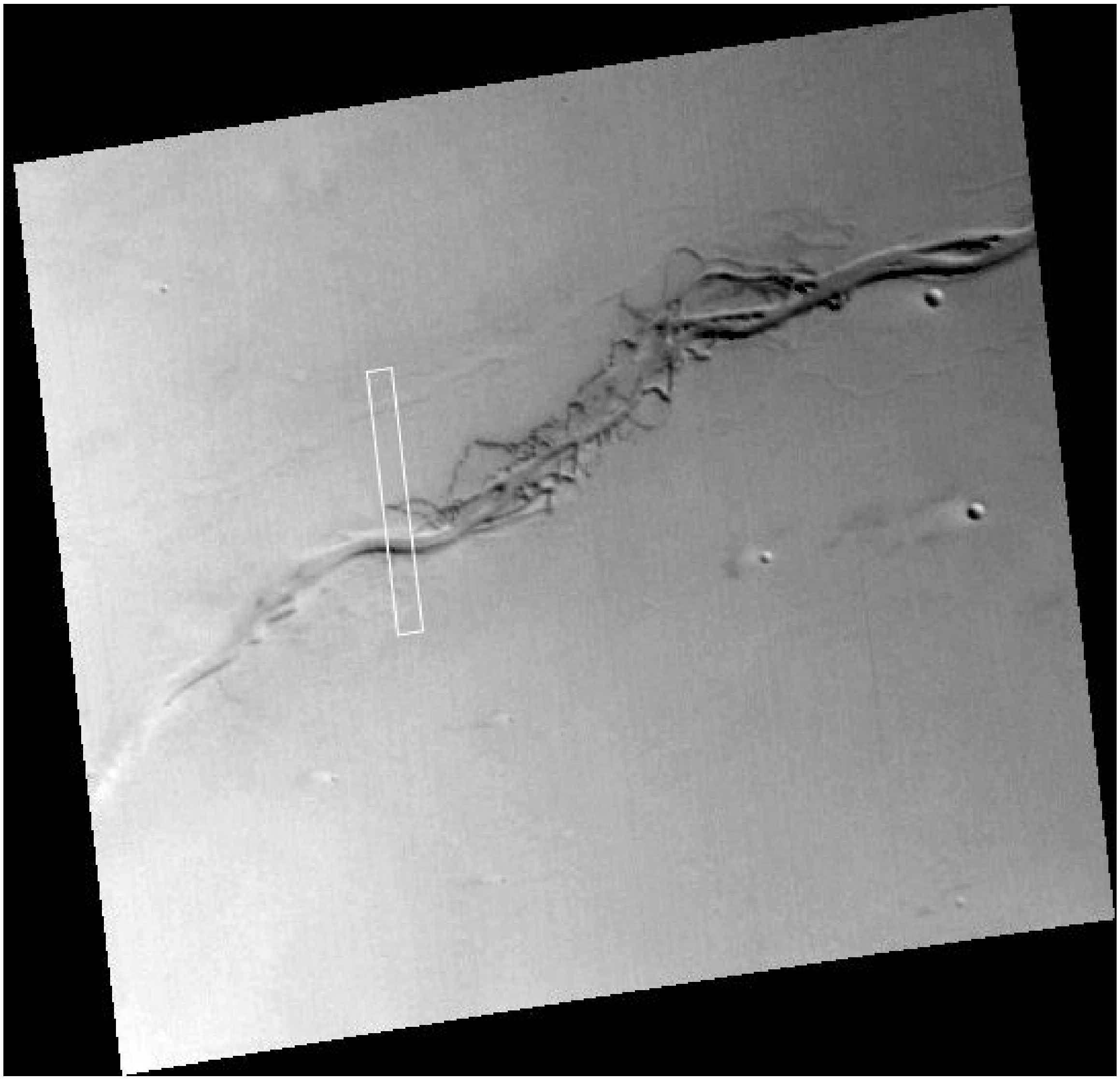
Crater-counting data:	
Range in km	**number of craters**
.032 - .064	124
064 - .128	112
.128 - .256	40
.256 - .512	25
.512 – 1.024	0
1.024 – 2.018	0
2.018 – 4.036	22
4.036 – 8.072	2

(Table II)

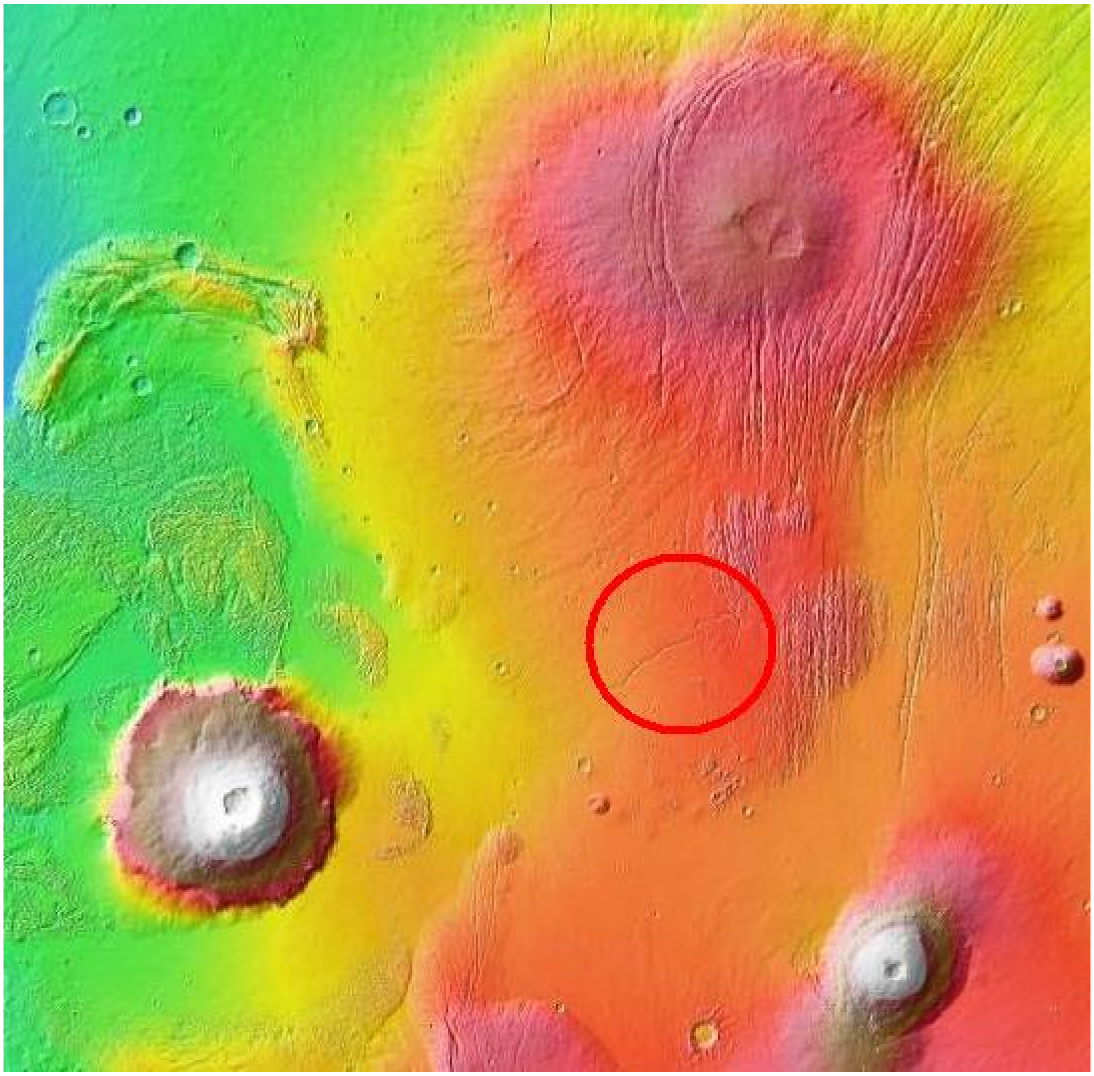


Plotted Isochron (Fig. VIII)

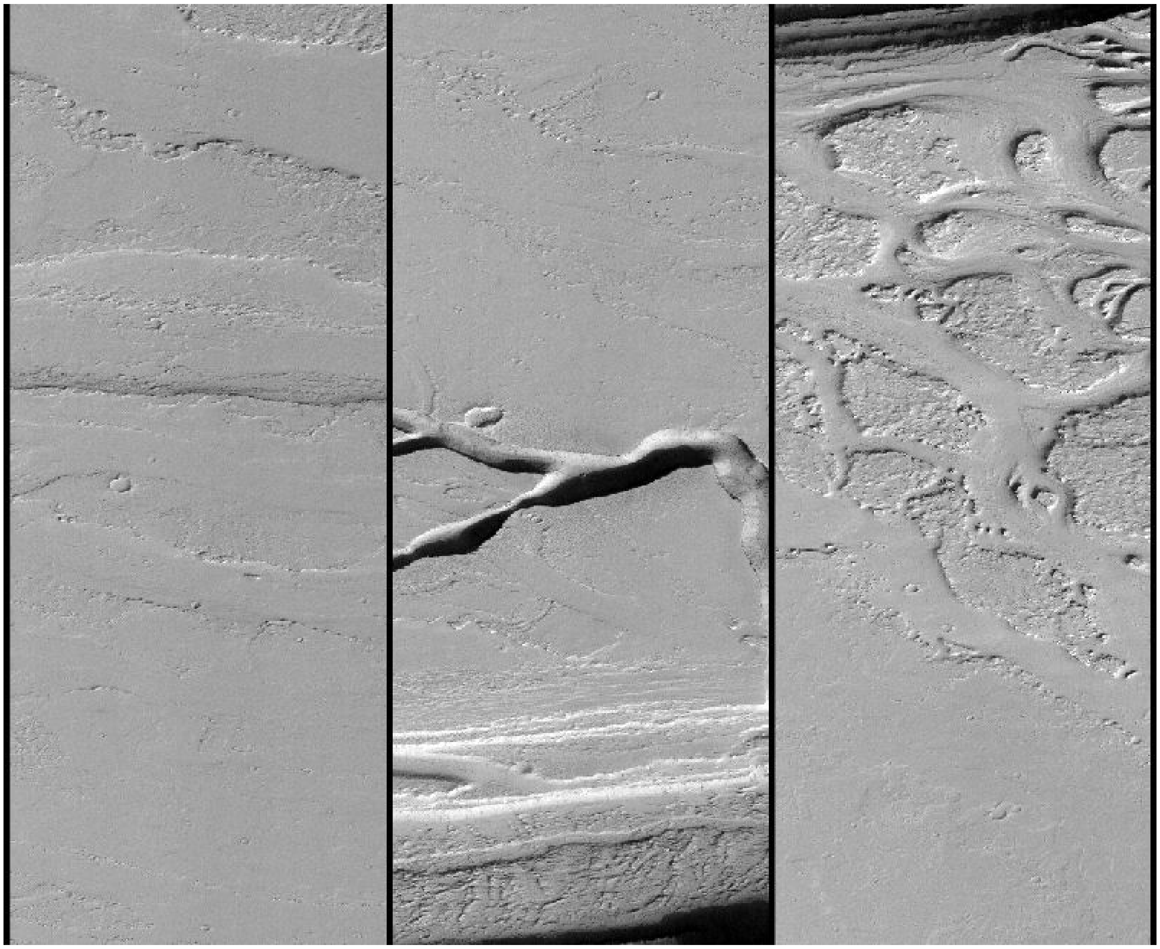
Image S0800984 (Analysis by Ryan)



Context Image (Fig. IX)



Google Mars Elevation Map (Fig X)



Narrow Angle (Fig. XI)

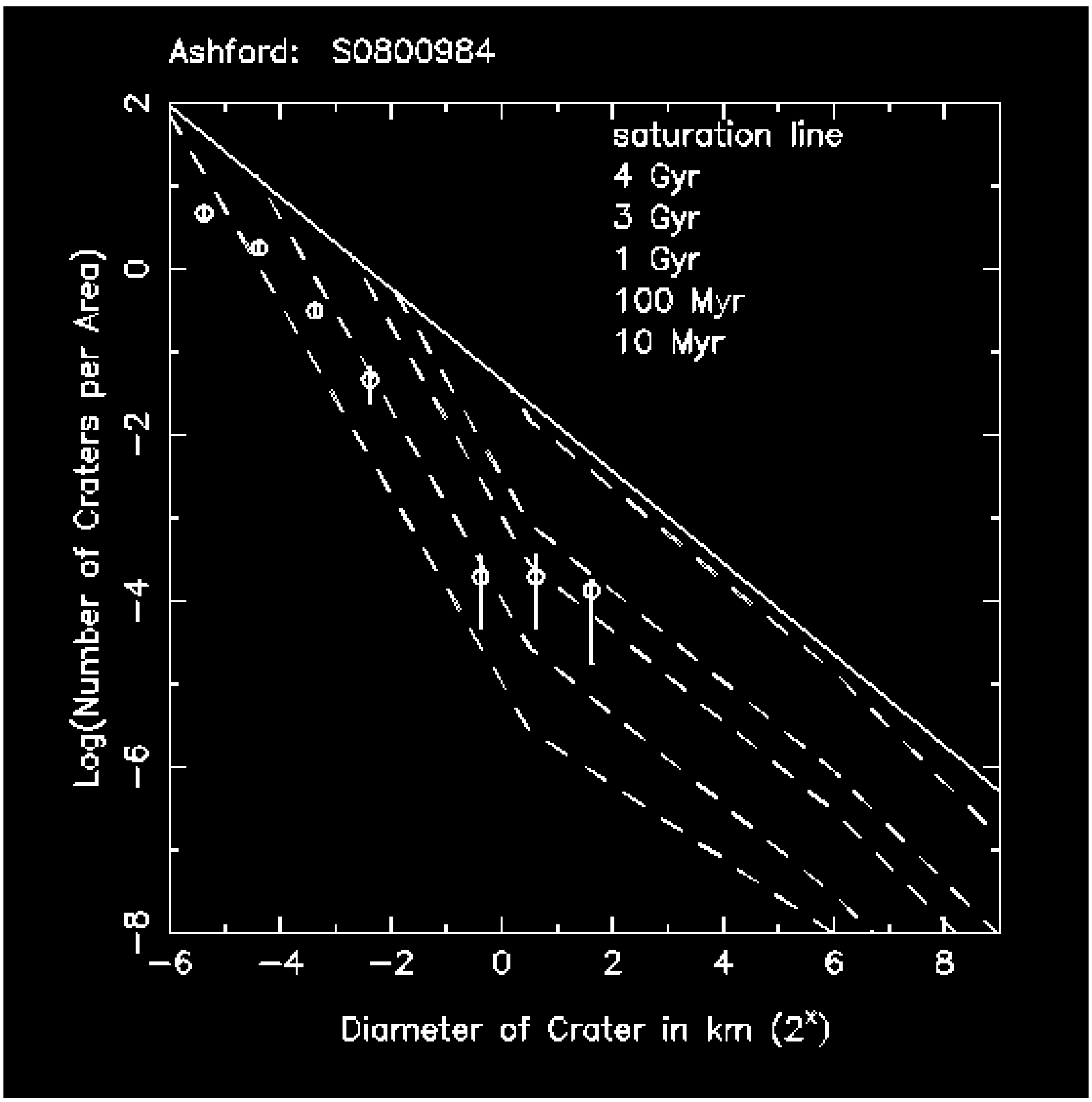
Image Context:

This image is of a long river-like feature beginning to the south of a very wide volcano by the name of Alba Patera which is to the northeast of Olympus Mons. It seems to begin near some higher elevation compression features to the south of Alba Patera, probably caused long ago by tectonic activity in the area. From its start, the feature proceeds towards Olympus Mons' base, but ends well before reaching it. This feature's context image and its surrounding area, seen using Google Mars, gives the hint that this feature is caused by water erosion. The land is very uniform, though sloping down from right to left. The features in the provided images may have originally formed if subsurface ice melted when the vertical compression ridges were forming.

CRATER COUNTING DATA:

Diameter of Craters(km)	Number of craters
0.016 - 0.032	508
0.032 - 0.064	195
0.064 - 0.128	35
0.128 - 0.256	5
0.256 - 0.512	0
0.512 - 1.024	3
1.024 - 2.048	3
2.048 - 4.096	2

Table III

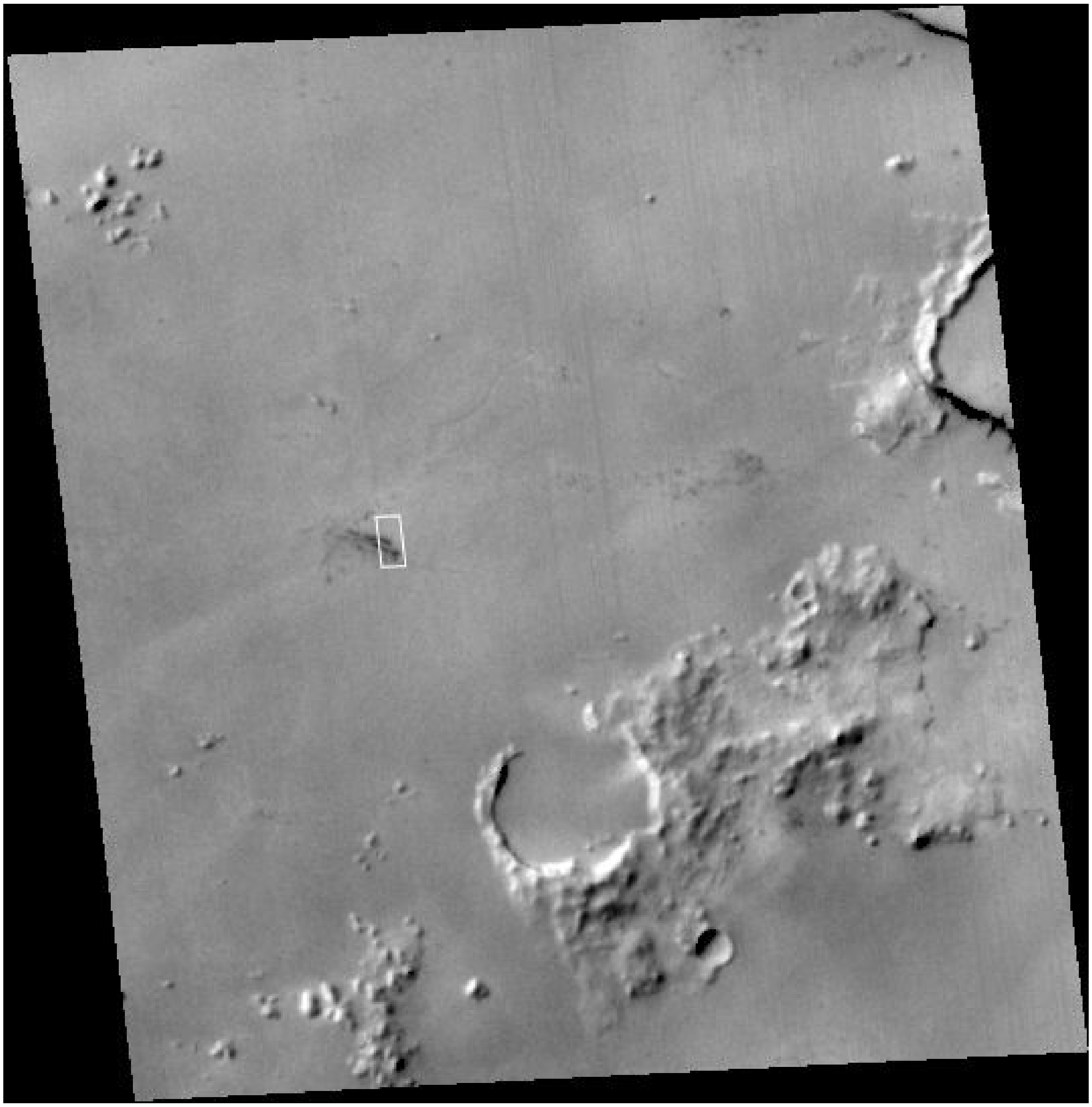


Isochron (Fig. XII)

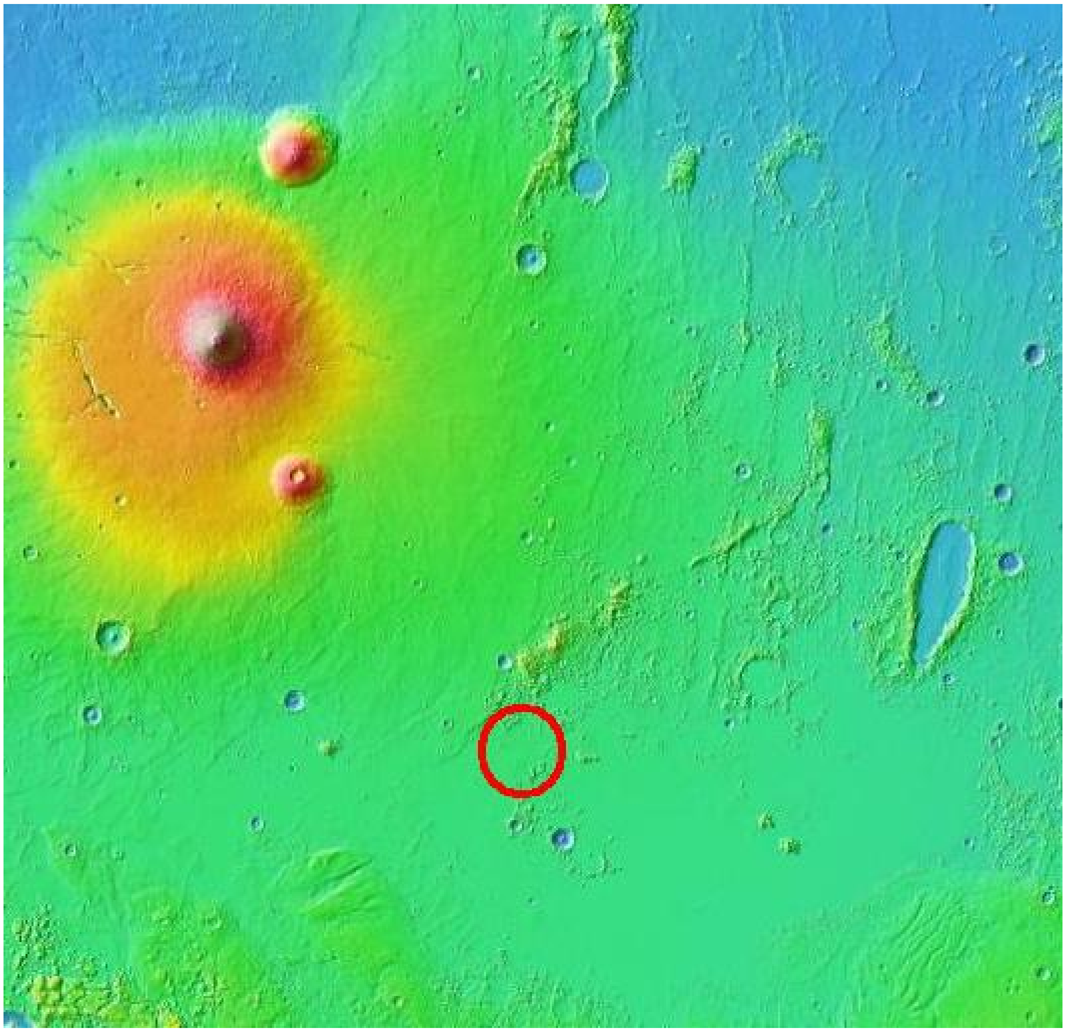
Estimated Age : 70 Million Years Old

Upon analyzing the features of the narrow angle image, I noticed many features which appeared to imply erosion due to both flows and wind. You can see in Figure XI that above and below the chasm are what appear to be channels carved out across the surface. Upon further inspection of these channels, I noticed the effect of wind upon the surface making it much more regular, and probably eroding a lot of the smallest craters. Also this erosion destroyed some features, it also helps us see below the surface slightly. And due to this I did not notice any features which would have dated much different than the rest of the image. Though erosion should be considered in the age estimation I felt that because of the fairly good line of the second through fourth points on the isochron that this count may have been a little low. The three points on the right side of the plot represent the largest craters seen, and are not as reliable because of the small sample size in the images. So, I based my decision mainly around the second, third and fourth points plotted. Their error is small, and there is less of a chance of being eroded away. And since they lie approximately between 30-100 million years, counting the top of the error bar of the fourth point, I used the third point as an estimation of the surface's age, which would make it 70 million years old. Because of the uniform nature of the erosion in this image, I would have to say that this age seems very reasonable. This age is extremely young and may imply some sort of warming of this region of the planet, or at least recent activity there. Further study of the general area's features will have to be made.

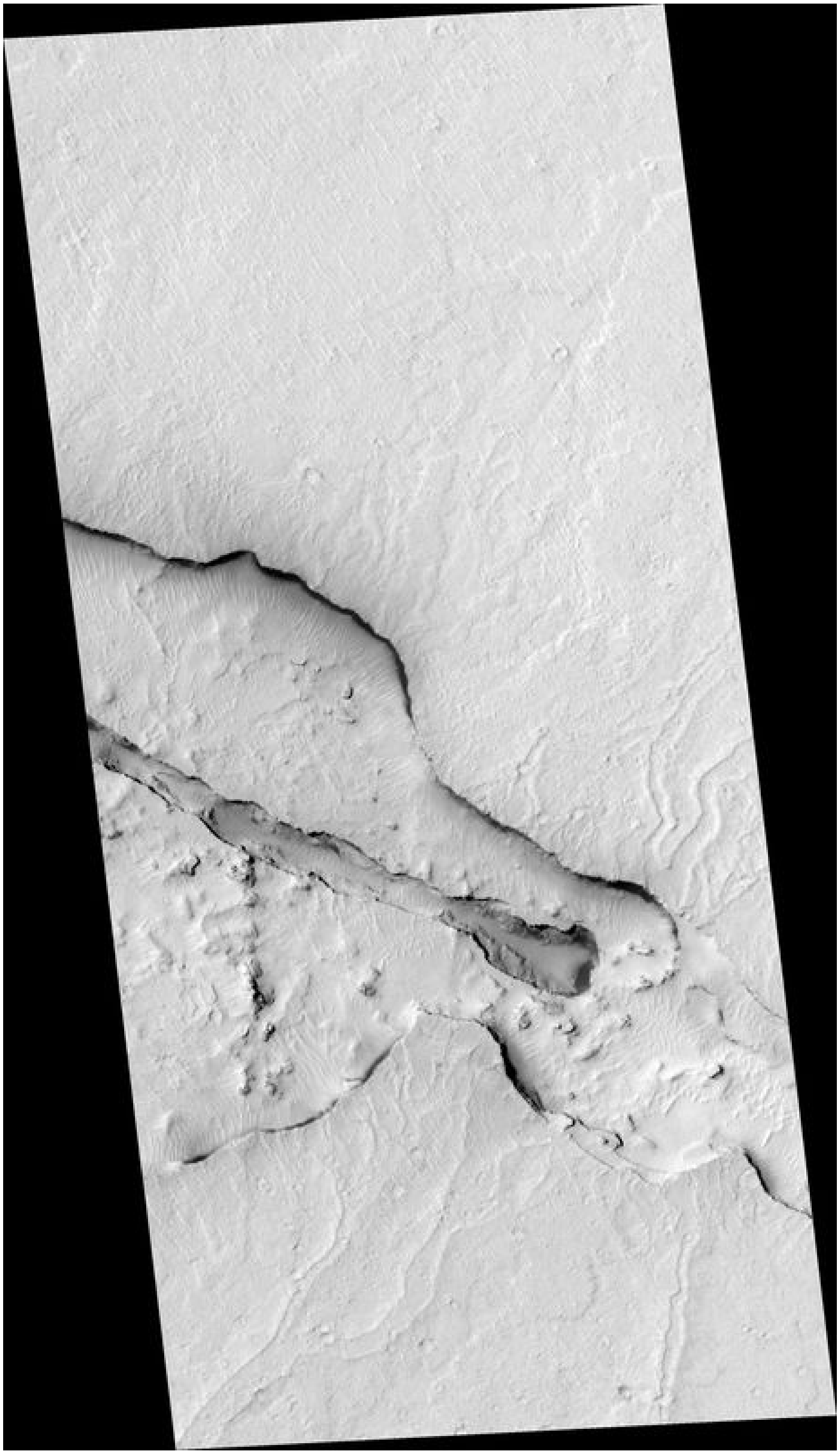
Image R1900241 (Analysis by Ryan)



Context Image (Fig. XIII)



Google Mars Elevation Map (Fig. XIV)



Narrow Angle (Fig. XV)

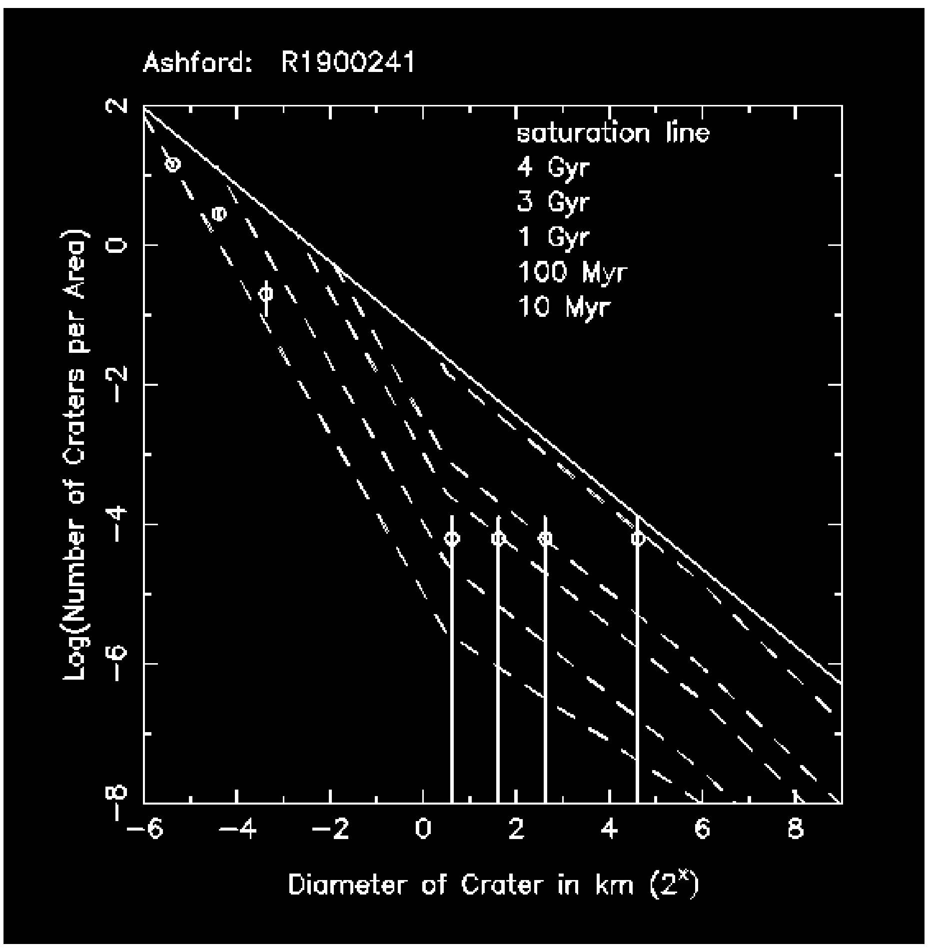
Image Context:

This image is to the west of the Valles Marineris and to the northeast of the Hellas Basin. It lies in a lower elevation region to the southeast of the volcano Elysium Mons. The area is very flat and uniform and has very few notable features. In the context image, and the surrounding area, we can see many features which appear to be covered up or filled in by some kind of flow or high winds, or a mix of both. Upon first inspection the surface reminded me of the maria that we see on the Moon. It could be an old area which was covered with water and the bottom of it evened out over time. Because it is so near a volcano it may be possible that some sort of lava flow resulted in the uniformity of the land and partial filling-in of craters, though there are not any noticeable lava flow features to make this a definitive answer. The narrow angle image depicts a flat area with a large land collapse feature in the center. The land surrounding the collapse has a lot of dunes and effects of wind erosion all over. However there are also shallow channels surrounding the collapsed feature. As previously mentioned, the surrounding area appears to have the effects of some sort of flow. These shallow channels help reinforce this uniform flow observation of the surrounding land. It may be possible that the channels are due to currents at the bottom of any body of water which may have been here. I am not positive why the center may have collapsed but it may have been related to subsurface ice melting, for reasons currently unknown, which would create a void for the surface to fall into. There are few hints which give a definite answer about the feature's origins. Nevertheless it is an interesting feature.

CRATER COUNTING DATA:

Diameter of Craters(km)	Number of craters
0.008 - 0.016	414
0.016 - 0.032	291
0.032 - 0.064	56
0.064 - 0.128	4
0.128 - 0.256	0
0.256 - 0.512	0
0.512 - 1.024	0
1.024 - 2.048	1
2.048 - 4.096	1
4.096 - 8.192	1
8.192 - 16.384	0
16.384 - 32.768	1

(Table IV)

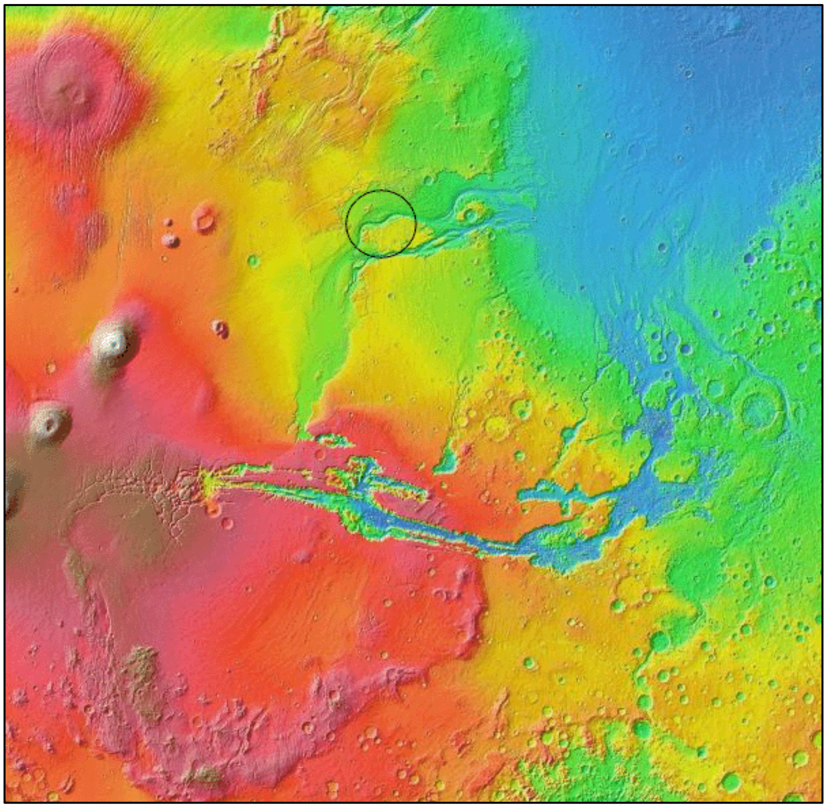


Plotted Isochron (Fig. XVI)

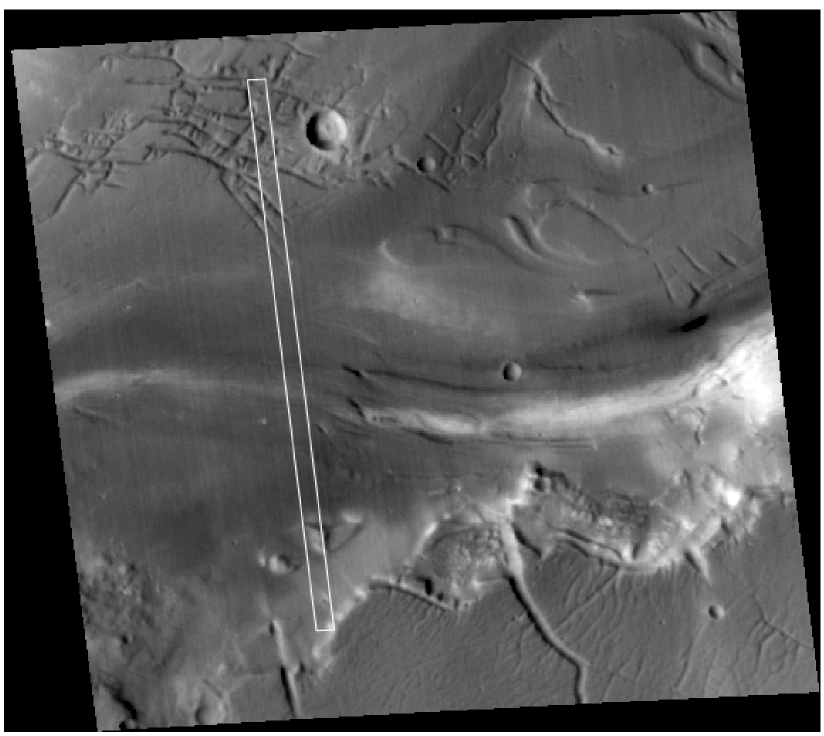
Estimated Age: 40 Million Years Old

There are a lot of dunes in this image. This means there has been some sort of wind erosion here. Even with this expected erosion, there are still many small craters visible. It is also important to note that because this image has a smaller pixel width smaller features are much easier to see, meaning a little higher accuracy in the crater counting. So, looking at the isochron we see a fairly good line following at the 40 to 70 million years range. If we use at the line between the second and third point, I feel that 40 million years is a more accurate estimate. The four points to the right are within this estimate as well. Only one crater was in each of those bins so anything within the error bars is acceptable. We can probably say that there is only one age for this image because the only different feature is the large collapse feature in the center of the image, and even here the crater spacing is almost evenly spread out. So, in the end, the isochron plot gives a pretty good look into the age of the surface.

Image M02-01125 (Analysis by Jon)



Google Mars Elevation Map (Fig. XVII)

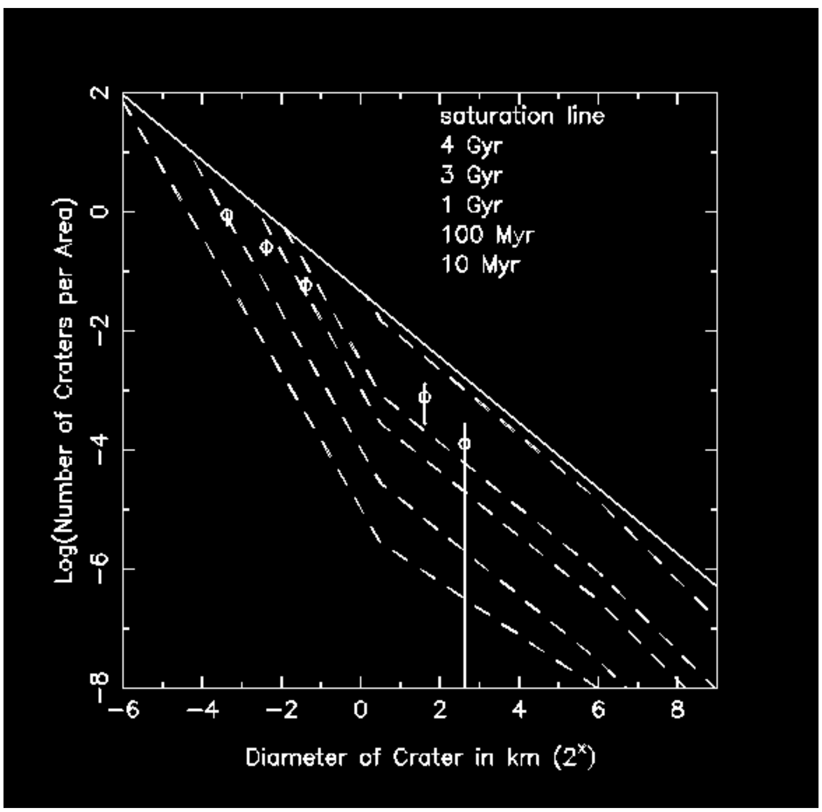


Context Image (Fig. XVIII)

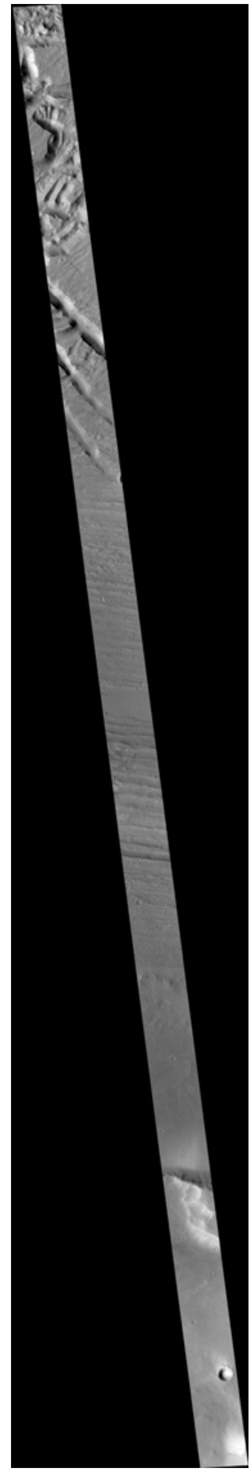
Estimated Age: 525 Million Years Old

Crater Counts for Images M02-01125 / M02-01126 (Table V)

Diameter of Crater (km)	**Number of Craters**
.064 - .128	152
.128 - .256	44
.256 - .512	10
.512 – 1.024	0
1.024 – 2.048	0
2.048 – 4.096	6
4.096 – 8.129	1

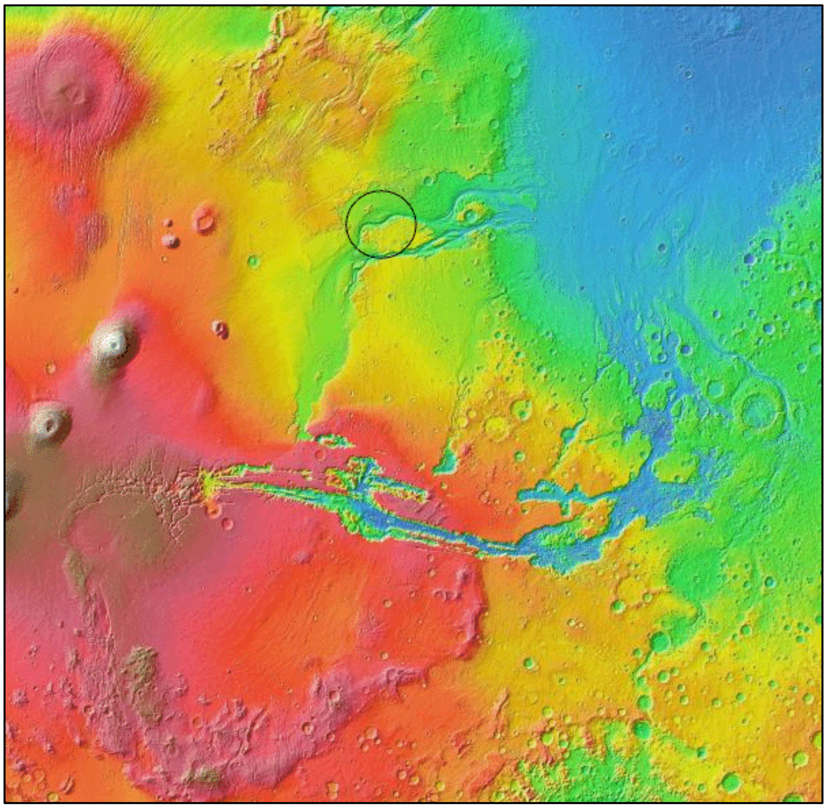


Plotted Isochron M02-01125/M02-01126 (Fig. XX)

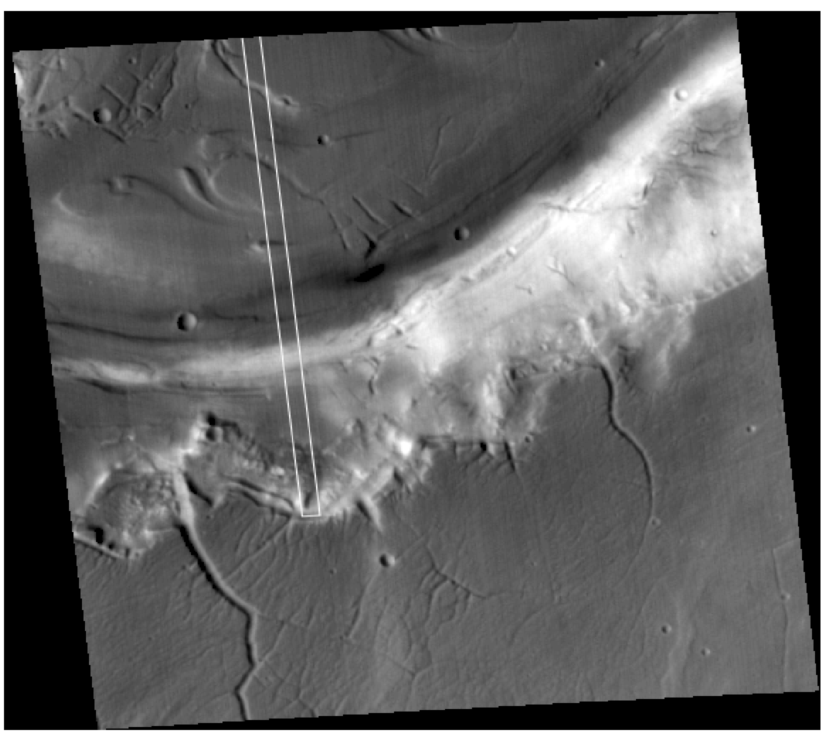


Narrow Angle M02-01125
(Fig. XIX)

Image M02-02310 (Analysis by Jon)



Google Mars Elevation Map (Fig. XXI)



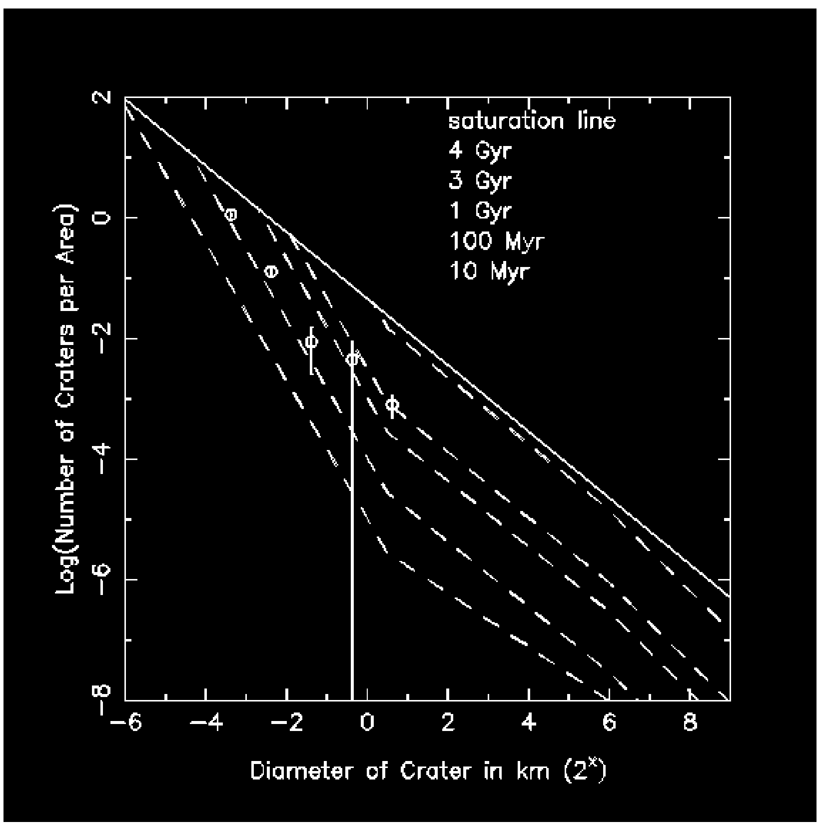
Context Image (Fig. XXII)

Estimated Age: 525 Million Years Old

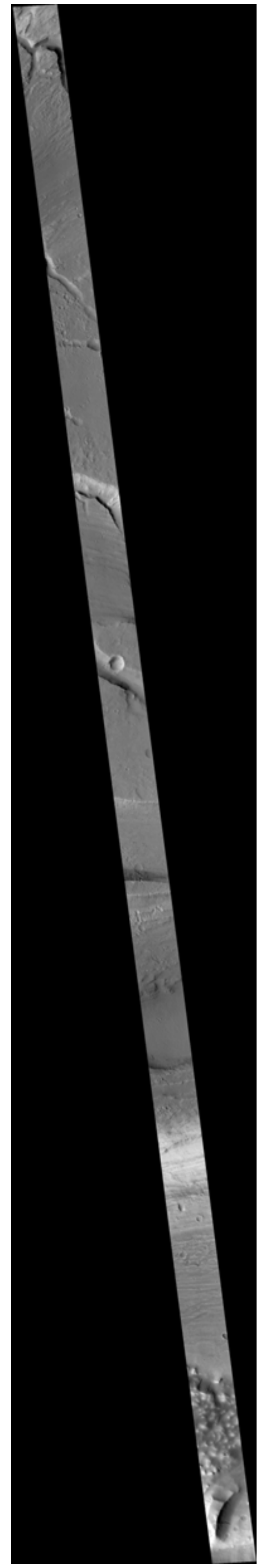
Crater Counts

Diameter of Crater (km)	**Number of Craters**
.064 - .128	255
.128 - .256	29
.256 - .512	2
.512 – 1.024	1
1.024 – 2.048	8
2.048 – 4.096	0

(Table VI)



Plotted Isochron (Fig. XXIV)



Narrow Angle
(Fig. XXIII)

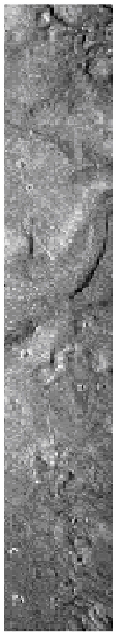
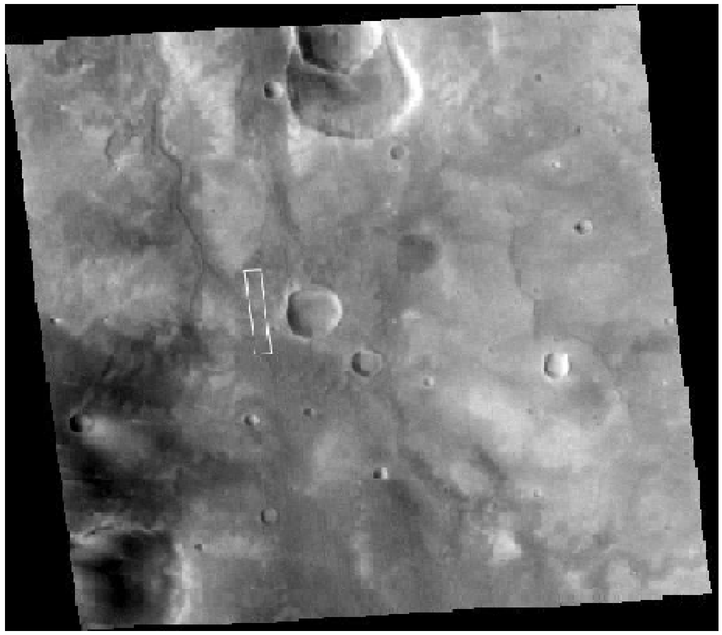
The Kasei Vallis (Images I – IV) was dated using isochron plots: a logarithmic plot of the diameters of the craters set into bins vs. the log of the crater density or number of craters per area. Only craters within the feature itself (Kasei Vallis) were counted and the two ages from the isochrons were averaged in order to yield a more accurate age of Kasei Vallis. The first isochron, for images M02-01125 and M02-01126 (XVII, XVIII respectively), was interpreted to portray an age of 750 million years old. The largest diameter bin only contained one point and, as a result, had very substantial error yielding an upper limit of 3.5 billion years. The second largest diameter bin also had a relatively large deviation, ranging from just over 3 billion years to approximately 3.7 billion years. The three smallest bins average to an age of 700 to 800 million years with very small standard deviations. As the largest diameter bins contained few points and had larger margins of error, the average age was weighted in favor of the three smallest diameter bins.

For the second set of images, images M02-02310 and M02-02311(XXI, XXII respectively), the isochron exhibits a slightly younger age. The largest diameter bin falls very closely to the age of 3 billion years but also contains a small sample size and little comparison as its neighboring bin has a very significant error. The three smallest diameter bins display almost the same exact age and have very small deviations. For this reason, the age was approximated using almost solely these three points. These three points all fall right above the 100 million years old line and so the age was approximated at 300 million years old. When these two ages are averaged, the age of the Kasei Vallis is estimated to be 525 million years old.

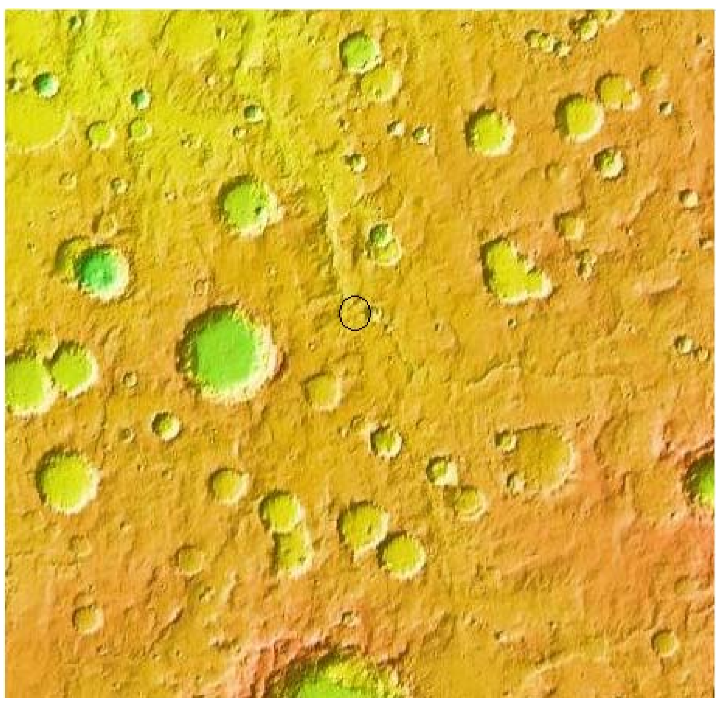
Mars formed 4.6 billion years ago, making the estimated age of Kasei Vallis relatively young. It appears from the image and surrounding territory that the Kasei Vallis was carved out of land by some sort of flow, be it lava or water. The flow travels from a higher elevation in the southwest to a lower elevation in the northeast. The flow could have been a result of three different geological activities: 1) a volcanic eruption could have flowed down the elevation carving out the Kasei Vallis or 2) tectonic activity could have elevated the land causing a large runoff of a body of water (i.e. lake), or 3) heat from a volcano or impact could have melted a large sum of ice in the higher altitude and it flowed down to a lower altitude. If this were the case, then either liquid water and/or volcanic activity would have to be present. And the estimated age falls within a period of time in which Mars could have had liquid water / volcanic activity.

Looking at the context image from Google Mars, it can be seen that there is an area of high elevation to the southwest of the Vallis Kasei. It is not clear exactly where the flow that forms Vallis Kasei comes from but there are several features at its start that could have formed it: volcanoes, high elevation, and an impact crater. The volcanoes could have erupted with low-viscosity lava and carved out the Vallis Kasei. Another possibility is that the tectonics of the region could have shifted, causing the land to the southwest to rise. If this land housed water, this shift would have caused the water to flow down the elevation, carving the Vallis Kasei as it flowed to lower altitudes. A third possibility is that an impactor collided with the area of high elevation, either melting a large sum of ice or shifting a large amount of water, causing a massive flow to carve the Vallis Kasei.

Image S09-02300 (Analysis by David)

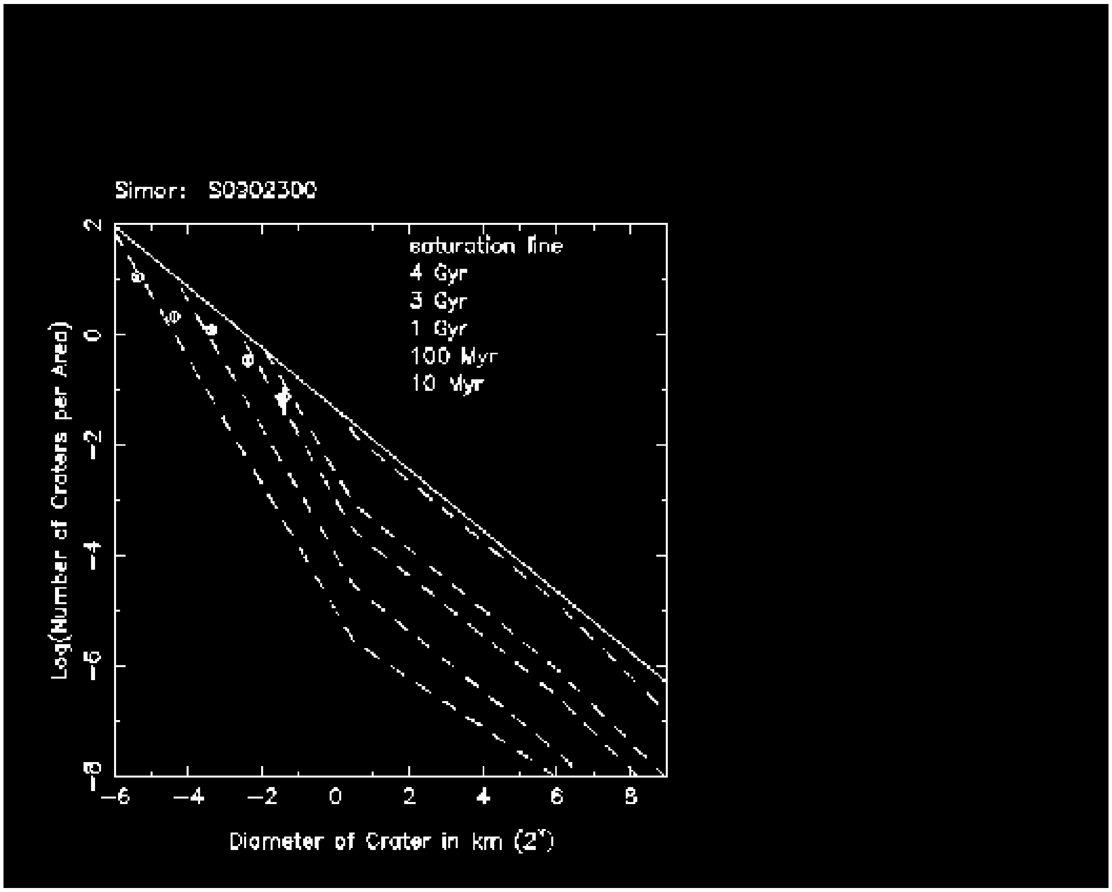



Narrow Angle Image [Left] (Fig. XXV) ;   Context Image (Fig. XXVI)



Google Mars Elevation Map (Fig. XXVII)

These images are located northeast of Argyre Planitia and southeast of the landing site of the Mars 6 Lander that the USSR sent to Mars. This is a low altitude terrain, around 1 or 2 kilometers above sea level, which is surrounded by even lower altitude terrains. The surrounding area has many craters and what appear to be cracks or remnants of rivers. These rivers or cracks could have helped erase craters from the surface, thereby distorting the surfaces age to appear younger. The approximate coordinates of these images on Google Mars are –32 degrees latitude and –13 degrees longitude.



Plotted Isochron (Fig. XXVIII)

Estimated Age: 500 Million Years Old

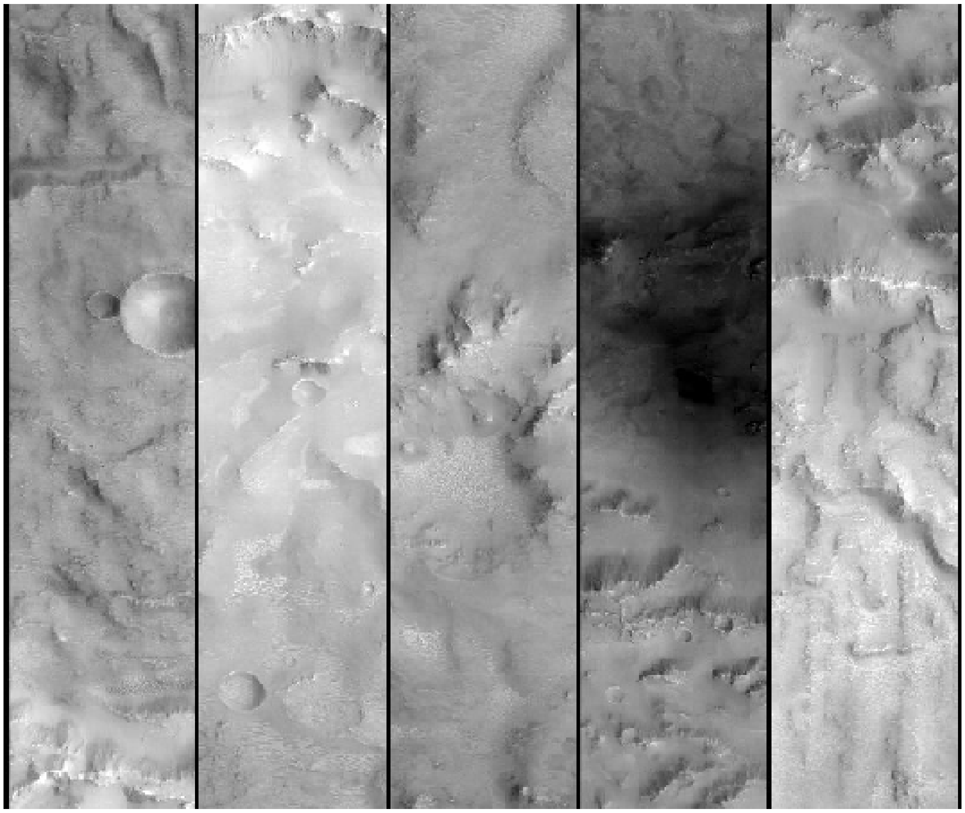
All of the points on Figure XXVIII were equally used in the dating of this surface. The error bars on all of the data points aren't large enough to cause concern over the age differences. Overall, I estimated this surface to be roughly 500 million years old.

Crater Counts

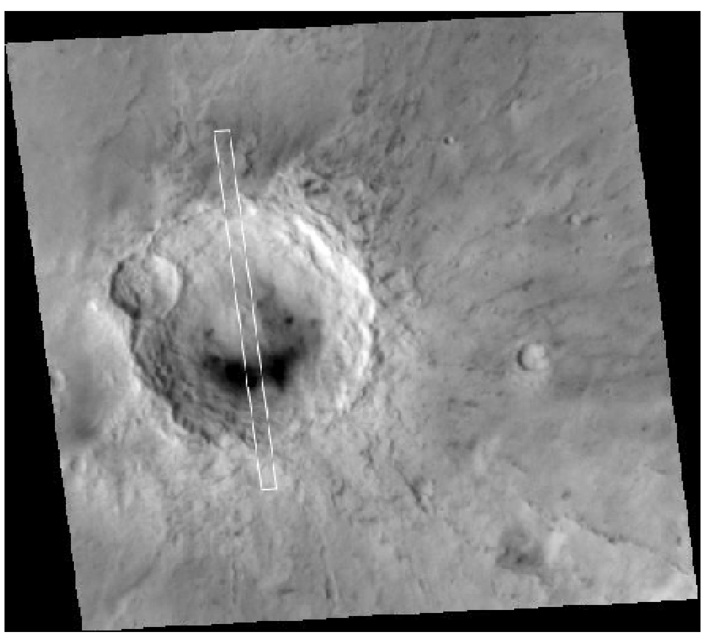
Kilometers	Craters
.016 to .032	587
.032 to .064	111
.064 to .128	65
.128 to .256	18
.256 to .512	4

(Table VII)

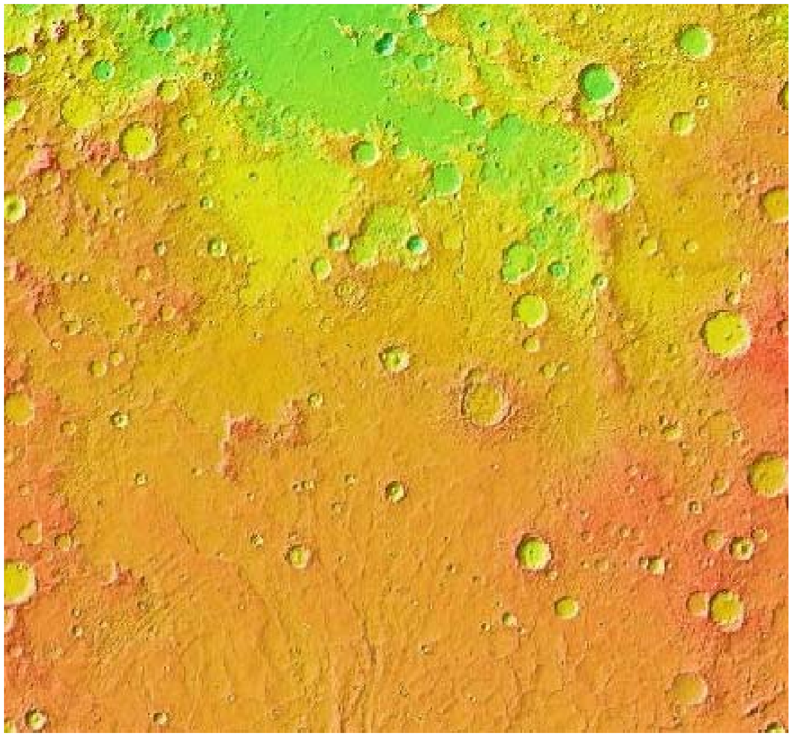
Image S06-00101 (Analysis by David)



Narrow Angle (Fig. XXIX)

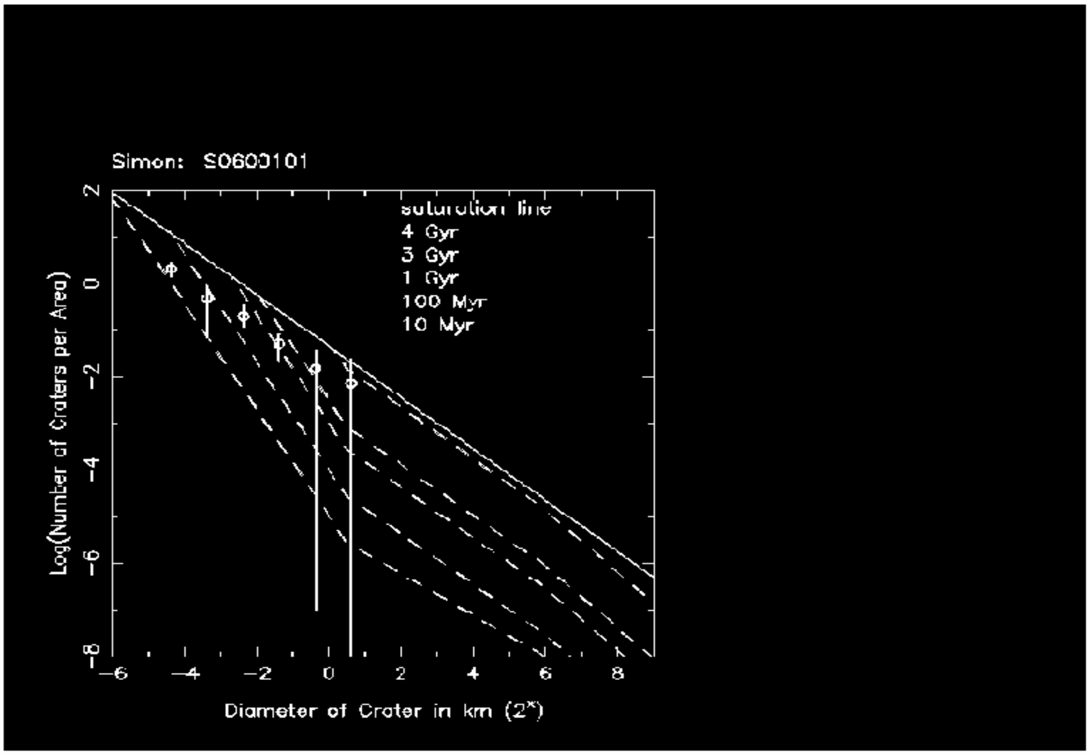


Context Image (Fig. XXX)



Google Mars Elevation Map (Fig. XXXI)

This surface is located northeast of an extremely low altitude region, which is east of Argyre Planitia. The surface is roughly 3 km in altitude itself and is surrounded by relatively flat terrain. Slightly north of the image is a stretch of land that looks like it could have been an inlet to what used to be a body of water; this could explain the smooth land around the crater under examination.



Plotted Isochron (Fig XXXII)

Estimated Age: 400 Million Years Old

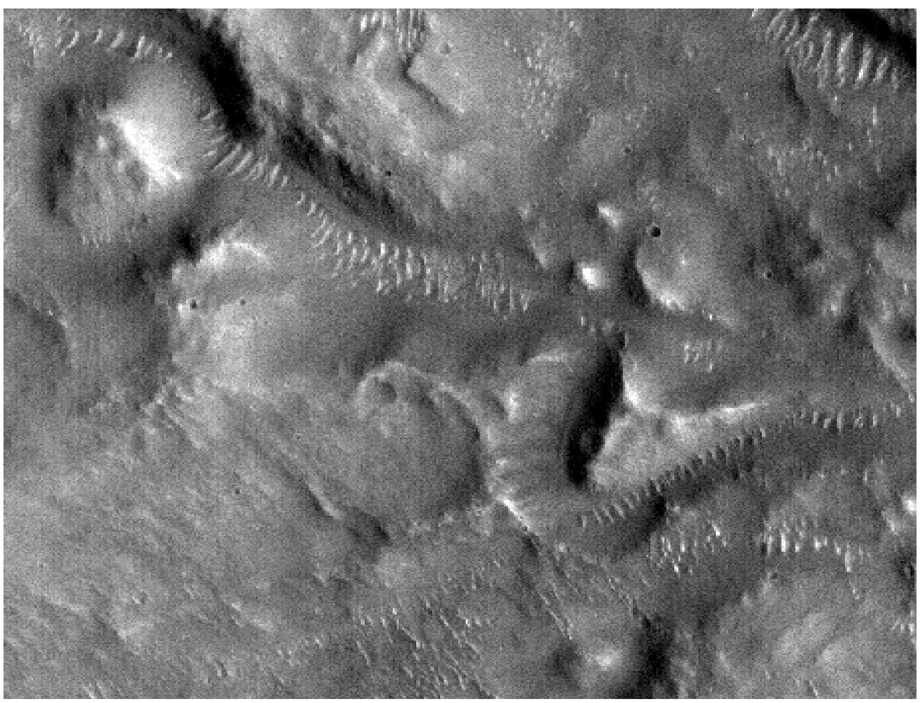
It is clear that the ages of these surfaces are very similar because their data points are very close to each other. However, this image is younger than the first because the last two data points cannot be heavily weighted due to the size of the error bars. The overall age of this image is roughly 400 million years old.

Crater Counts

Kilometers	Craters
.032 to .064	285
.064 to .128	67
.128 to .256	27
.256 to .512	7
.512 to 1.024	2
1.024 to 2.048	1

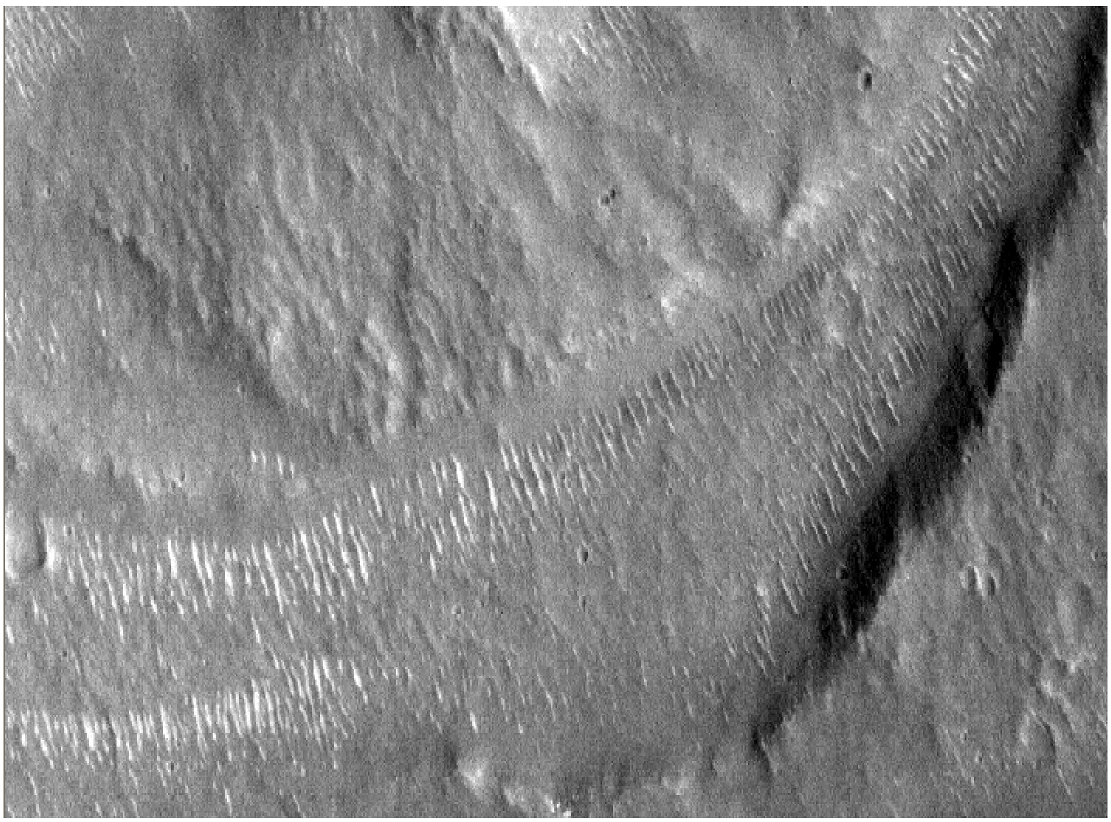
(Table VIII)

Smaller craters are obviously the easiest and fastest to erode away; therefore, the smaller diameter bins will indicate a younger age than the larger diameter bins because relatively fewer craters will be seen. However, since the bins were limited to a 5-pixel minimum, it is unlikely that the numbers would be affected drastically enough to warrant concern for the images in question. This is due to the fact that for the images the group chose, a 5-pixel width crater would still take a long time to erode away. The larger bins are actually more difficult to date because there are so few craters in them; the age of the craters could span vast amounts of time. In image S09-02300 (Figure XXV) there were enough craters to get a rough idea of how old they are; however, in image S06-00101 (Figure XXIX) there was an insufficient amount of craters in the last 2 bins, as shown in Table VIII, allowing for a large margin of error. This caused their error bars to extend down through all age classes. Therefore, the age of the surface in image S06-00101 is much more uncertain than that of the surface in image S09-02300.



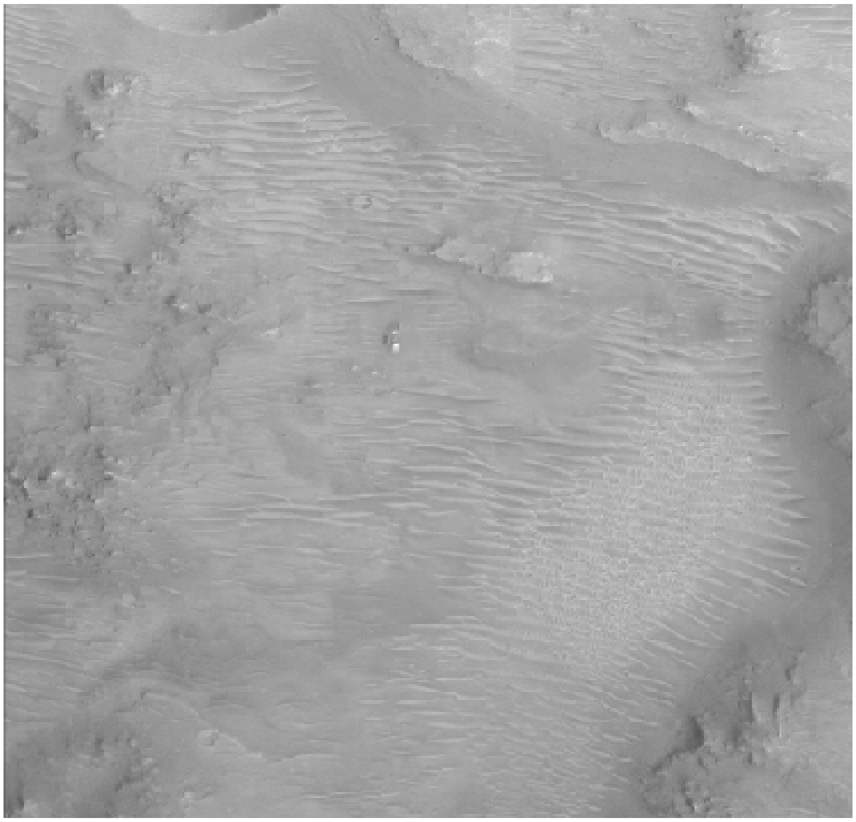
Detail (Fig. XXXIII)

Observations of images S09-2300 and S06-00101, examples are above and below, have led to the conclusion that wind has been, and still is, a major contributor to the erosion of many craters in these images. In Fig. XXXIII, wind erosion is shown at the top of the image where there are streaks of dunes that span long distances across the image. These dunes were no doubt caused by heavy winds piling sand and other materials together.



Detail (Fig. XXXIV)

Slightly farther down this image as shown in Fig XXXIV, there is a small valley that is riddled with more dunes, characteristic of high winds. Many craters also have portions missing from their rims that look as if they were just stripped away.



Detail (Fig. XXXV)

Image S06-00101 also has evidence of wind erosion. The middle of the crater is covered in dunes just like those in image S09-02300. However, the edge of the crater becomes smooth and placid with few ripples in them, with the occasional rock surface sticking out. This might be caused by the steep slope of the craters rim so, as wind blew against it, the disturbed sand and materials would slide down the slope towards the center of the crater. This action is also replicated as a crater settles soon after forming.

Conclusion

Counting craters on a planetary surface can be used to calculate an approximate age of that surface due to the consistency of the frequency and size of impact catering within the solar system. Crater counts plotted on isochrons have resulted in the approximate ages for the surface features of Mars shown below:

Image Number	Name of Structure	Estimated Age (in millions of years)
E13-00436	Junction of Aprons at Deuteronilus Mensae	50
S09-00771	Not Available	4000
S08-00984	Landforms of Olympia Fossae Region	70
R19-00241	Troughs and flows near R03-00830 and E01-00866 in Cerberus Region	40
M02-0012/M02-02310	Entire width of Northern Vallis Kasei	525
S09-02300	Samara Valles near 32.2 S, 13.1 W	500
S06-00101	Survey walls of craters centered at 8.1 S, 250.7 W	400

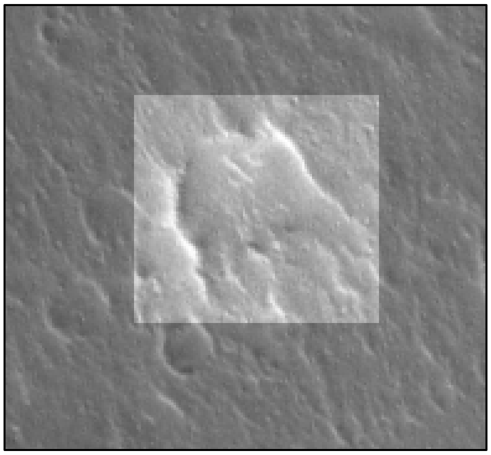
(Table IX)

Error has been minimized as much as possible but can still cause large discrepancies in age. These large discrepancies can be separated into difficulties in measurements and difficulties in analysis.

Difficulties in measurement are those that directly relate to error in counting the number of craters per image per bin. These errors result in a younger or older bin age by misrepresenting the actual number of craters per bin. The more these errors are reduced, the closer the isochron will be to the actual age of the surface / feature. One of the more minor considerations is the technology used, taking into account both the collection and analysis of the images. When collecting, the resolution of the image collected will limit the number of craters able to be resolved. The resolution of the monitor used to count the number of craters is also a limitation as is the contrast ratio of the monitor. For all three of the above mentioned difficulties in measurement, the worse the technology, the fewer the number of craters counted, the younger the age, and vice versa. A slight shift in where the bin starts and ends can also lead to a change in the estimated age. This is because as the diameter of the crater decreases, the number of craters in a given bin increases exponentially. Slight shifts in the bin crater size could result in an exponential increase or decrease in the number of craters in the bin and; hence, a very large change in the estimated age of that bin.

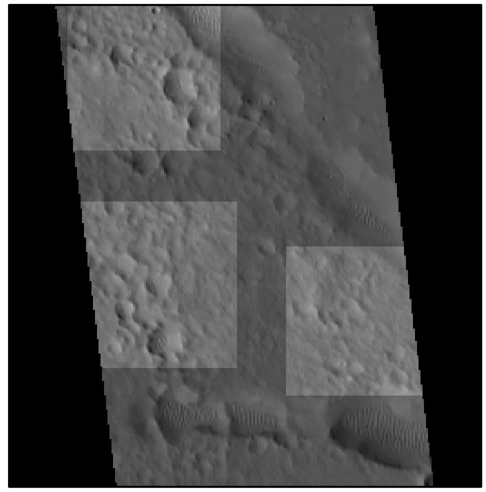
The largest difficulty in the measurement was not the technology but rather determining what was actually a crater as opposed to a circular mountain range or sand dune, or a partially eroded crater. Due to the limited resolution of the images, it was difficult to determine whether the feature was a crater or some other surface feature for the smaller diameter craters. Some of these crater-like features are actually circular mountain ranges or sand dunes. To make the measurement even more difficult, craters of all sizes have been partially eroded, making them look less like craters and more like circular mountain ranges or sand dunes. Examples of each are shown below:

Circular Mountain Range:



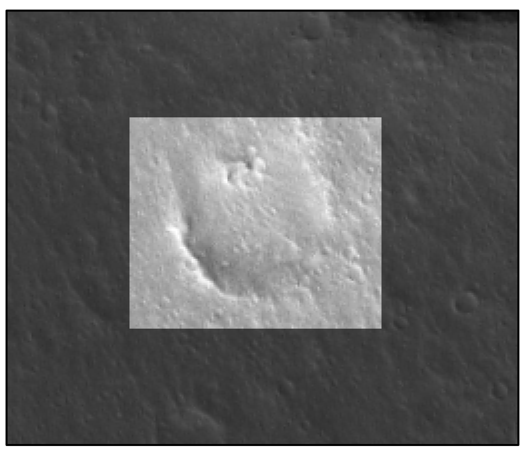
(Fig. XXXVI)

Craters Mixed with Sand Dunes:



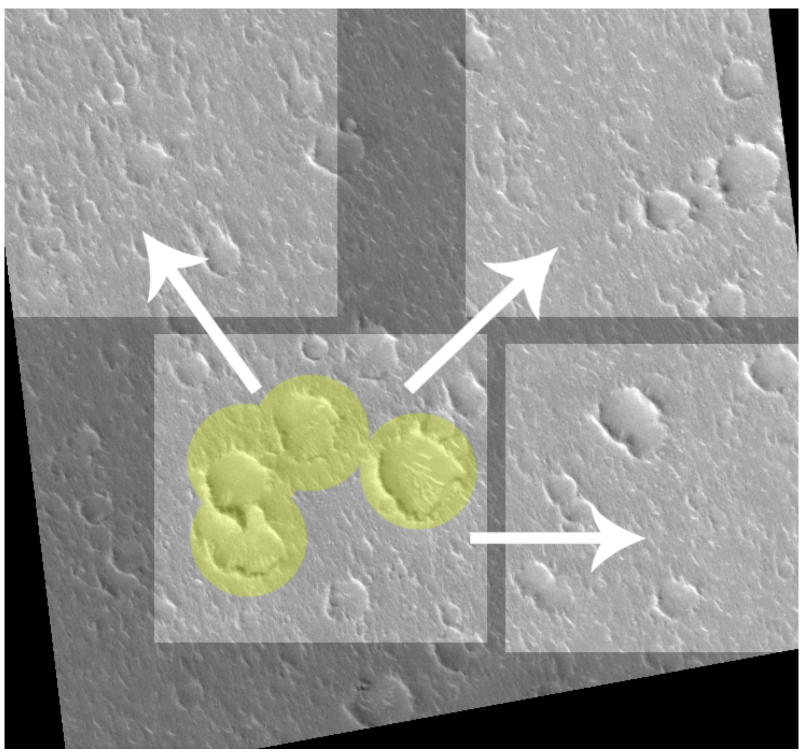
(Fig. XXXVII)

Partially Eroded Crater:



(Fig. XXXVIII)

Difficulties in analysis are those errors not directly related to counting the number of craters that can result in a younger or older age due to calculation error or inherent errors of the technique used. As the calculations were double-checked, human calculation error has been made minimal and will have a negligible effect. This negates error that comes from rounding differences and simple calculation error. The largest analysis error is in the technique itself. The locations are only a small sample and, as a result, the larger diameter bins are very inaccurate. Working with an image just north, south, east, or west of the actual image used could show as many as five or six times the amount of craters in a given bin. This drastically alters the calculated age and also results in huge standard deviations. This effect is shown in the images below:



(Fig. XXXIX)

Figure Descriptions