Lab 2 : Impact Crater Counting

Objective

Making the assumption that the cratering rate on the Moon, as measured by the Apollo missions, is typical of the cratering rate for the entire inner Solar System, you will extend the measurements of the lunar crater density (where we know the actual ages of the surfaces) to the surface of Mars and Earth. In doing so, we will estimate the ages of two specific regions on Mars and compare/contrast those ages with a specific area on the Earth.

Introduction

The geologic record of past events on Earth is jumbled, disconnected and incomplete. Tectonics and our planets atmospheric processes are mostly responsible for this fact. What our planet looked like, what conditions existed early on in its geologic history are therefore concepts that seem hazy and ill-defined at best. Erosion, deposition and tectonic shuffling have erased much of the evidence about what occurred early on in the Earth geologic history. Fortuitously, conditions on other planets and satellites have enabled a much clearer and complete record of the Solar Systems (SS) early history to be preserved and provide us with a baseline for unraveling our own planets geological record. Because geologic and atmospheric conditions vary widely across the SS bodies, we have an understanding of how the geologic history of the objects differed and how the physical attributes of each body influenced their evolution to become the objects we see today.

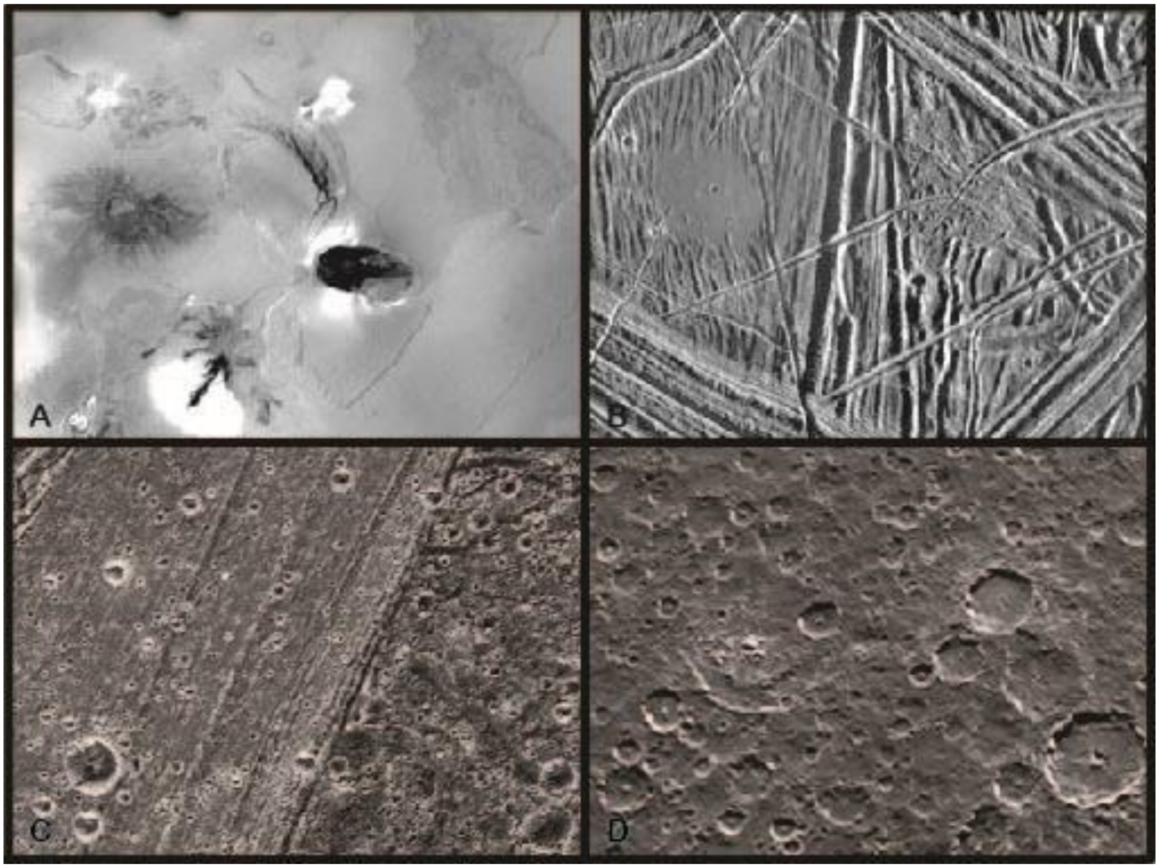
Cratering

In the dawn of the formation of our Sun and its surrounding bodies, the region we know today as the Solar System was a very different place. The conditions in this region during that time were chaotic, violent and unimaginably hazardous. Debris of all sizes, shapes and compositions orbited the early Sun forming a *protoplanetary disc*. Collisions of all sizes, velocities and energies were not just frequent, they were the norm. Because of these chaotic conditions, impact craters dominate the landforms found on most of the solid-surface bodies in our SS. On objects lacking atmospheres and dynamic surface processes, the impacts ranged in size from the minute to the colossal and were well preserved. Today, the accumulation of impact craters on these surfaces provides us with a comprehensive record of the changing conditions over the lifespan of our SS. The number of craters on a surface increases with the length of time that surface has been exposed to space without being modified by other geologic processes. The frequency of larger impacts has decreased over that same time period as more and more material was accreted into larger and fewer objects. These rather simple ideas are the basis for a very powerful tool, called crater counting, that planetary scientists use to unravel the history of a planetary surface.

The basic idea is that an old planetary surface will have more, and proportionally larger, impact craters than a younger surface (Figure 1). Shortly after the formation of the major SS bodies from the protoplanetary disc we see today, a period known as the Late Heavy Bombardment occurred between ~4.1 – 3.8bya. This period was the culmination of the accretional process. As the last few large objects were accreted by the larger planets and moons of the SS, their impacts upon these surviving objects produced the largest and oldest impact craters we see on their surfaces today. By combining the frequency and size of the craters together for a given area, we can begin to get an accurate picture of the age of that surface. Because some planets and/or moons have the physical conditions necessary to preserve surficial features over long periods of geologic time we find a more complete record of the conditions and events that modified these surfaces from very early in our SS's geologic history to today. It turns out we have an excellent control sample population for crater counting very close to us here on Earth; the Moon.

Activity 1. Galilean moons of Jupiter

Below are images of the surfaces of the four Galilean Satellites. The four large, Galilean Satellites of Jupiter offer an excellent example of how cratering and resurfacing can modify planetary surfaces. Images were acquired by the Galileo spacecraft and are courtesy of NASA/JPL.



a) Using the simple concepts of cratering rate and size through time, rank the four surfaces above in descending order of age. Briefly explain what processes modified each surface and how they affected your rankings.

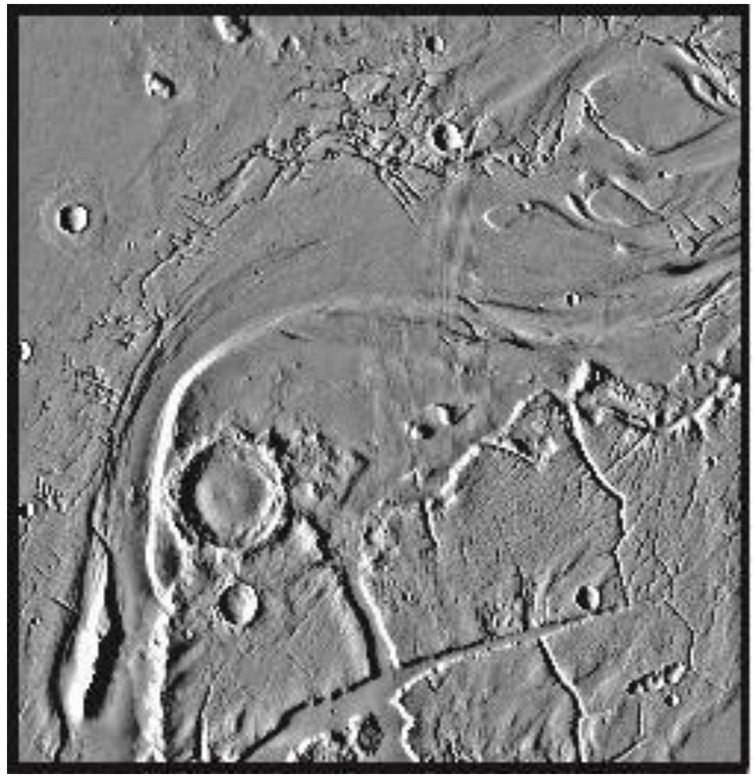
b) Can you identify the satellite in each image? Explain why the satellites have different surface ages.

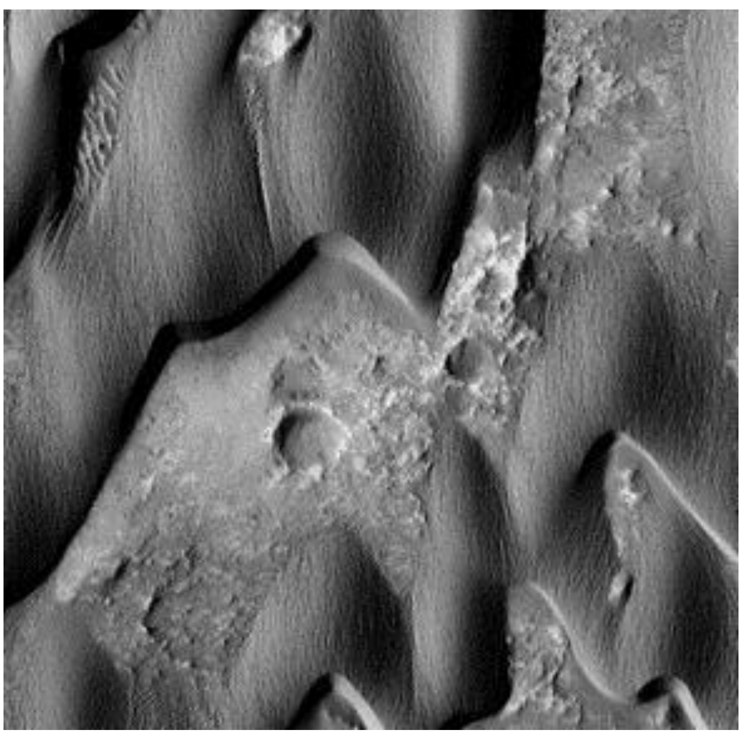
c) Can you see older/younger surfaces within each image? If so, outline or define one or two on each image.

Activity 2: Resurfacing

The modification of a planetary surface is known as "resurfacing". Several geologic processes can resurface a portion of a planet or moon, essentially "wiping the slate clean" and producing a newer, unmodified surface. Both erosional and depositional processes do this quite efficiently (Figures 2, 3 & 4).

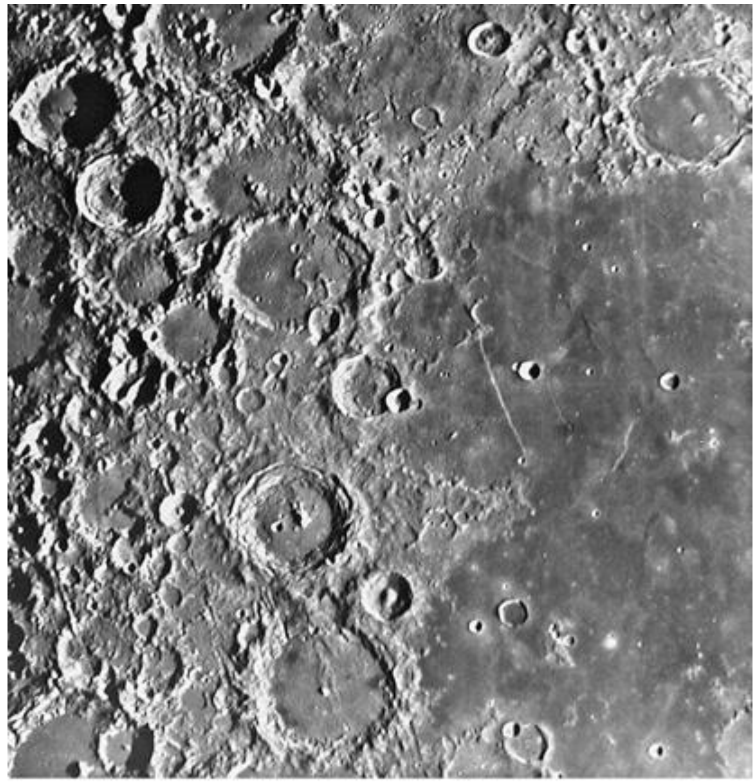
a) Examine this shaded relief image of an area on Mars (image courtesy of the USGS/NASA) and on it delineate at least two areas that suggest crustal material of different ages. Label them numerically on the image from youngest to oldest. What geologic process/processes might be responsible for the alteration of this area?





b) Examine this high resolution image of Mars. The largest crater is about 2 km across. Why are there so few craters in this image? What process is responsible for this lack of impact features? How might the modification of this surface be different from the one in Figure 2?

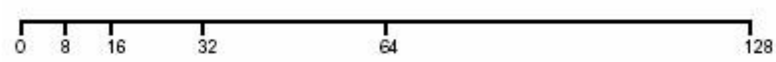
c) This image is of a portion of the Moon. There are two main types of lunar crust scientists use to separate these surfaces, what are they called and delineate and label them on the image. What geologic processes do you think are responsible for these different surfaces?



Activity 3: Crater Counting

Crater density counts are a standard method of determining the relative age of a planetary surface. In this exercise you will count craters and use their densities to determine the ages of two surface regions of Mars.

On each of the images at the end of this assignment are 5 white bars that represent 128, 64, 32, 16 and 8 km lengths. Use these bars to create a scale bar that is divided into several different size ranges (0-8 km, 8-16 km, 16-32 km, etc.). It should look like this:



Now use your scale bar (NOT the one just above) to determine how many craters are in each size range. You may not be able to use all the different size ranges. There may be no craters in some of the larger ranges or too many craters in the smallest ranges. There will also be a limit to the smallest craters you can positively identify, so use common sense in your counting of the smaller ones. Try to fill in as many of the size ranges as you can with as many craters as you can positively identify. Record the numbers in the Crater Density Table.

The data for the crater density of the Apollo sites was determined over 1,000,000 km^2. The total area of the images you are using is shown at the bottom of the image. Using the numbers from the table and the formula below, determine how many craters of each size range are found in 1,000,000 km^2. Record this number in the table.

Number of craters per 1,000,000 km^2 = Number of craters × (1,000,000 km^2 / (Image size) km^2)

Plot your data points from the table on the Crater Density Graph. Put your points on the graph in the **middle** of your size range. For example, if you had 200 craters in the 0-8 km size range, you should put your point at the intersection of 200 on the y-axis, and 4 on the x-axis. (Note: the y-axis of this graph has a logarithmic scale.

Determine the age of your surface. Once you have your points plotted, draw a best-fit straight line through the points, as best you can. Your line should be parallel to the age lines on the graph. The line you have drawn represents the average age of the cratered surface you have been examining and defines that age where it meets the right-hand y-axis. Estimate the age by interpolating the age given by the line you have drawn with the age lines already on the graph.

What is the surface age of the martian northern hemisphere area?
What is the surface age of the martian southern hemisphere area?

Crater counting questions:

a) How accurate do you believe your estimate of the age of the surfaces are – for each surface, what are the oldest and youngest ages that fit your data? Be quantitative (e.g. ± 1 billion years).

b) What do you believe was your greatest source(s) of uncertainty in determining the ages? (Please be as specific and as quantitative as possible)

c) Based on your data, do you think you could tell the difference two surfaces 100 million years apart in age? Why or why not?

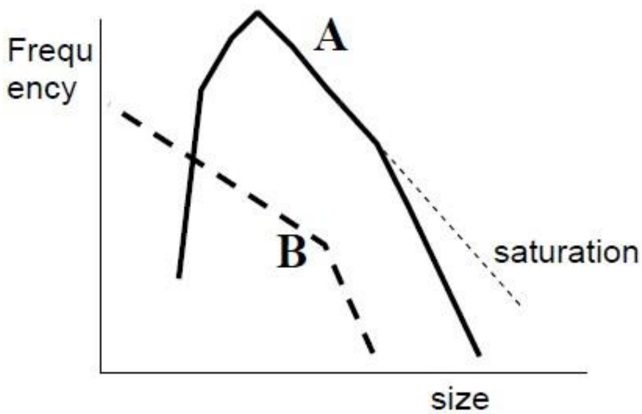
d) Describe one way that you could increase the accuracy of your age determination.

e) Consider these two facts: (a) The Earth has been hit by as many impactors as the Moon and Mars. (b) The state of Virginia has a total land area of about 110,000 km^2. Calculate how many 5-km-sized craters have been formed in Virginia over the last 4 billion years. (Show your work.)

f) Currently the state of Virginia has **zero** 5 km impact craters. Come up with 2 or 3 good explanations for what you believe happened to them.

g) What is the saturation equilibrium? Does this apply to either of the surfaces you counted/dated?

Activity 4: This figure shows two hypothetical crater size-frequency distributions (A and B) for two different planetary surfaces. The crater saturation line curve is also indicated.



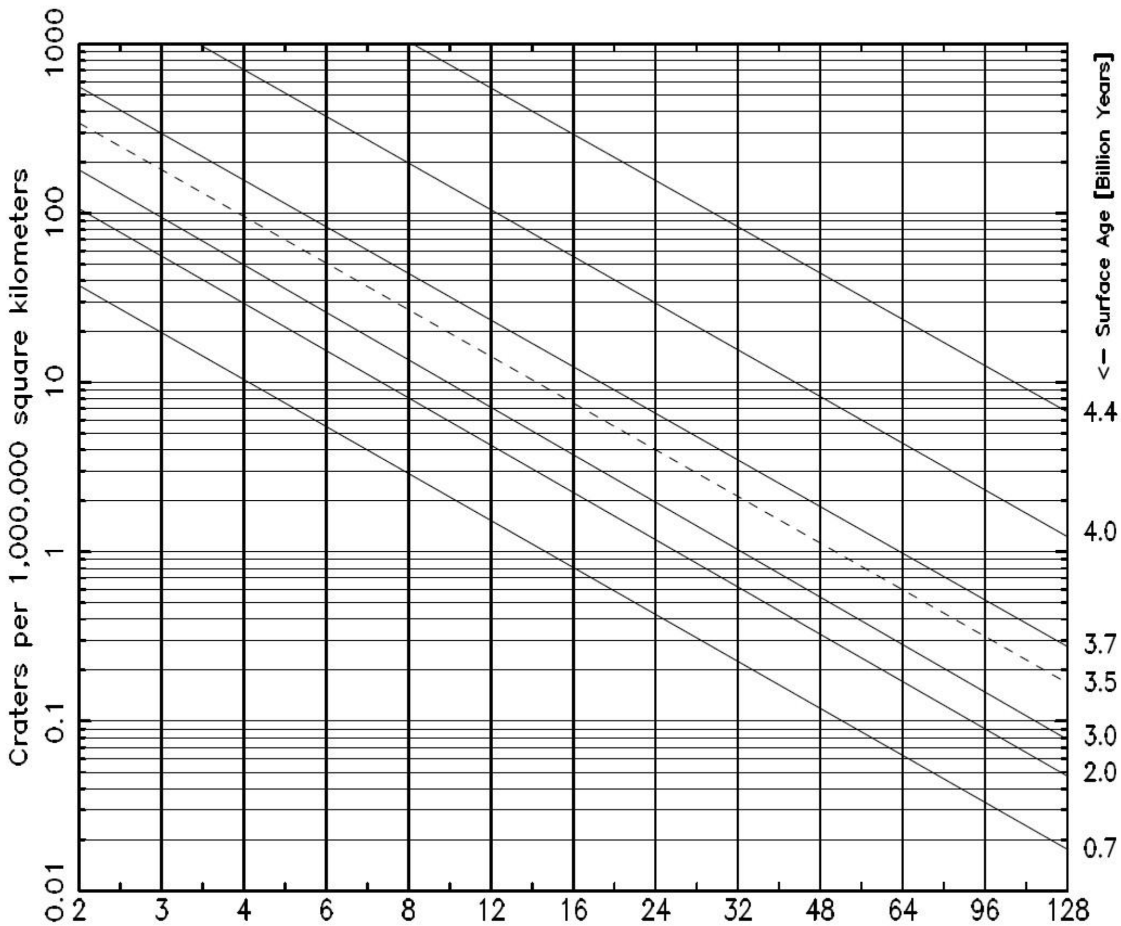
a) Which surface is older and why?

b) Give 2 possible explanations for the deficit in small craters seen for population A.

c) Large craters on B were probably produced by the same population of impactors which produced large craters on A. Do you think the small craters on B were produced by the same population?

d) Say that one of A or B is from an inner solar system body, and one is from an outer solar system body. Without any other information, which would you guess is which, and why?

Martian Crater Density Data Table				
	Northern Hemisphere		Southern Hemisphere	
Crater Size Range (km)	**Number of craters in image**	**Number of craters in 1,000,000km^2**	**Number of craters in image**	**Number of craters in 1,000,000km^2**
<8				
8-16				
16-32				
32-64				
64-128				



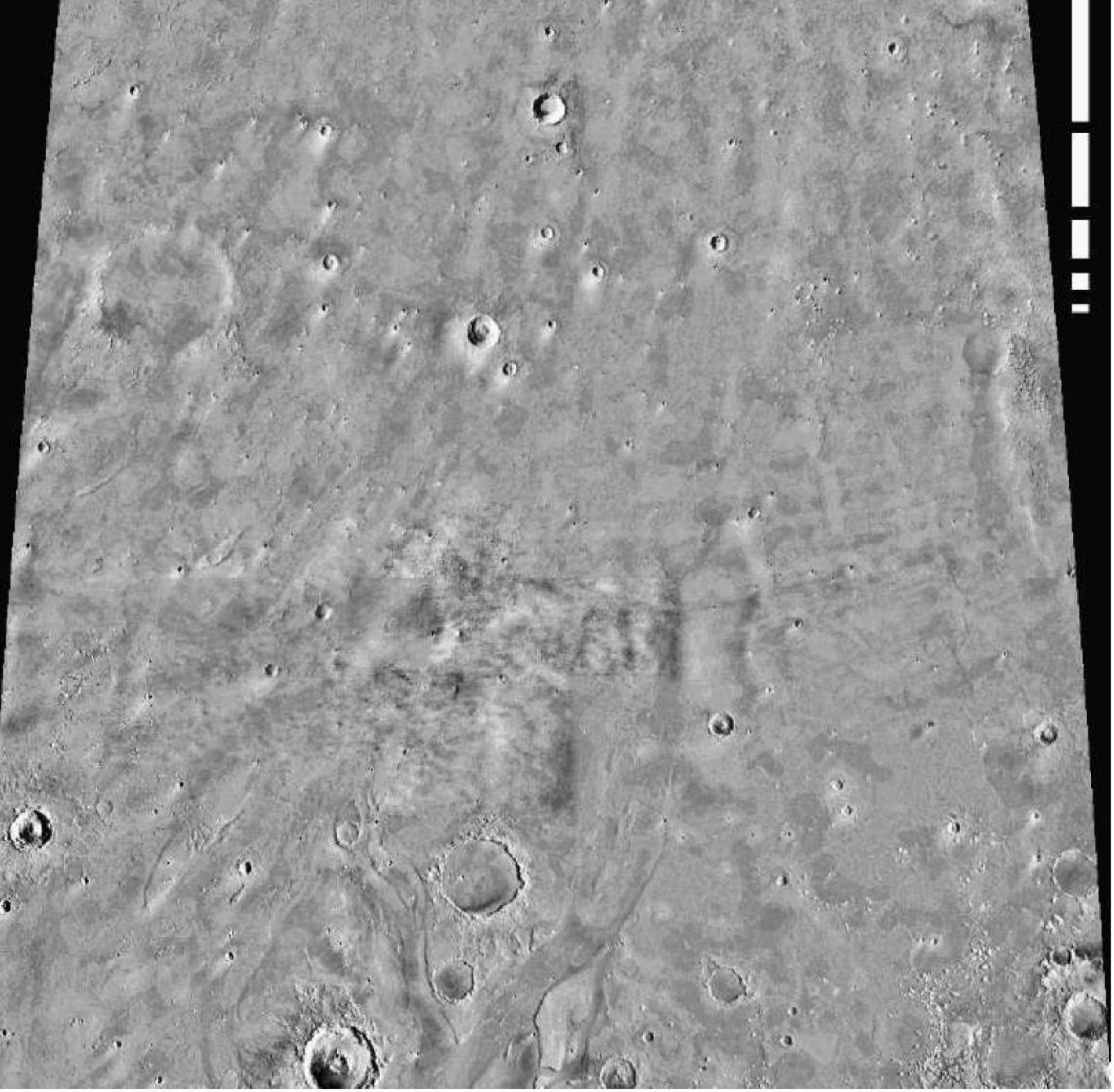
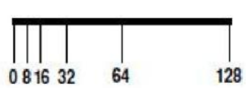


Image Scale



Martian Northern Hemisphere - Image Size = 812,250 km^2

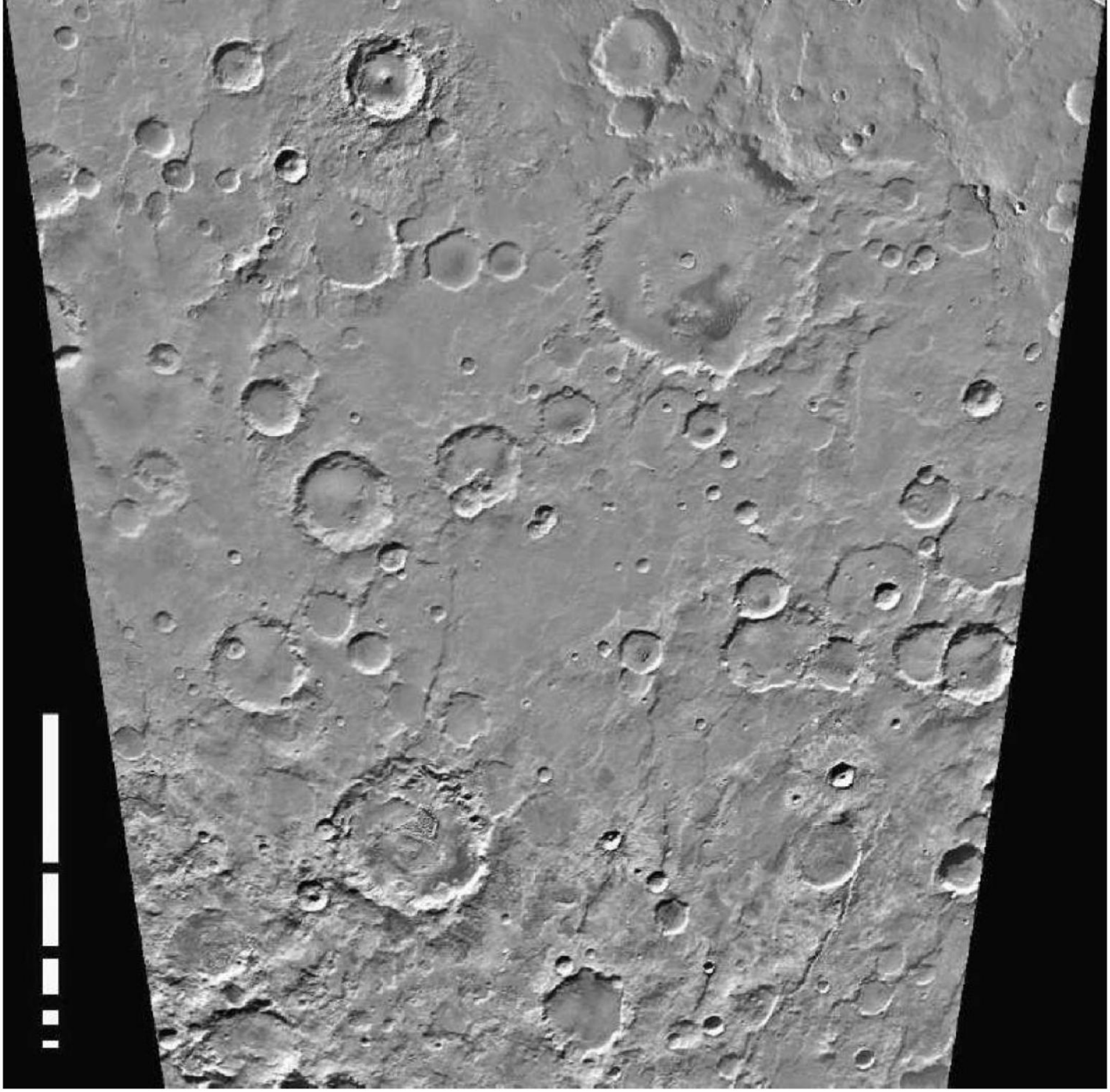


Image Scale 0 8 16 32 64 128

Martian Southern Hemisphere - Image Size = 774,250 km^2