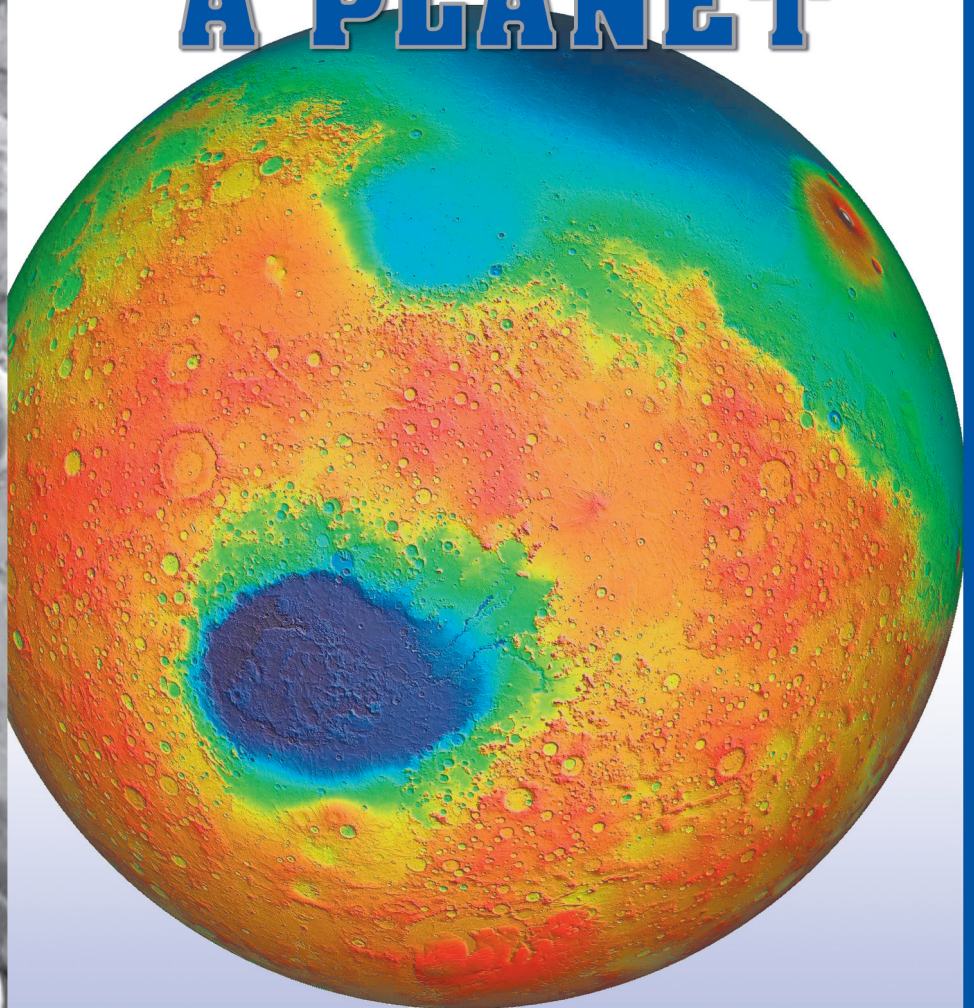
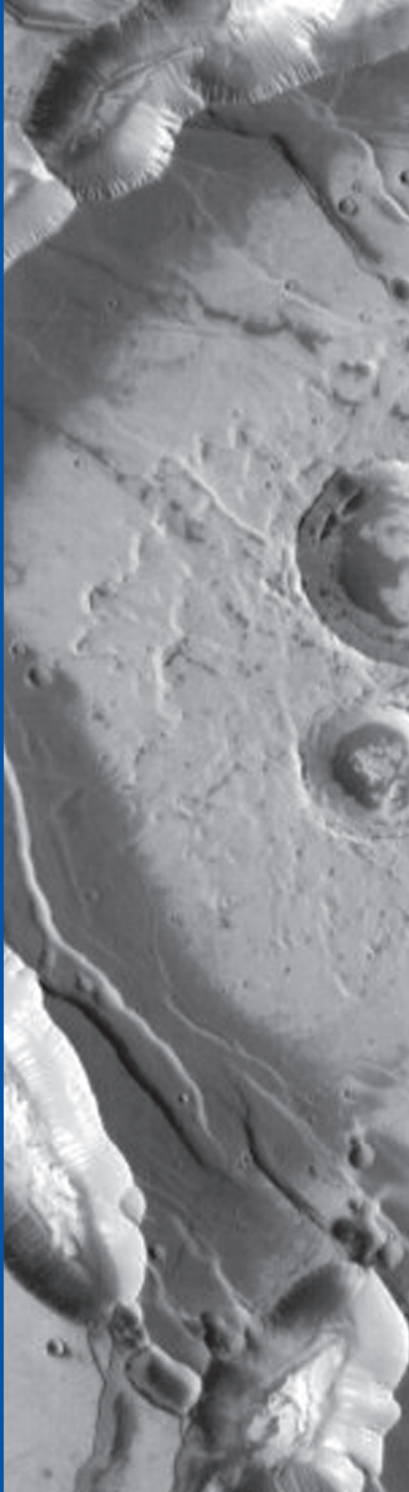


# MARS EXPLORATION

Student Data Teams



# MAPPING THE SURFACE OF A PLANET



Written and Developed by:

**Keith Watt,**  
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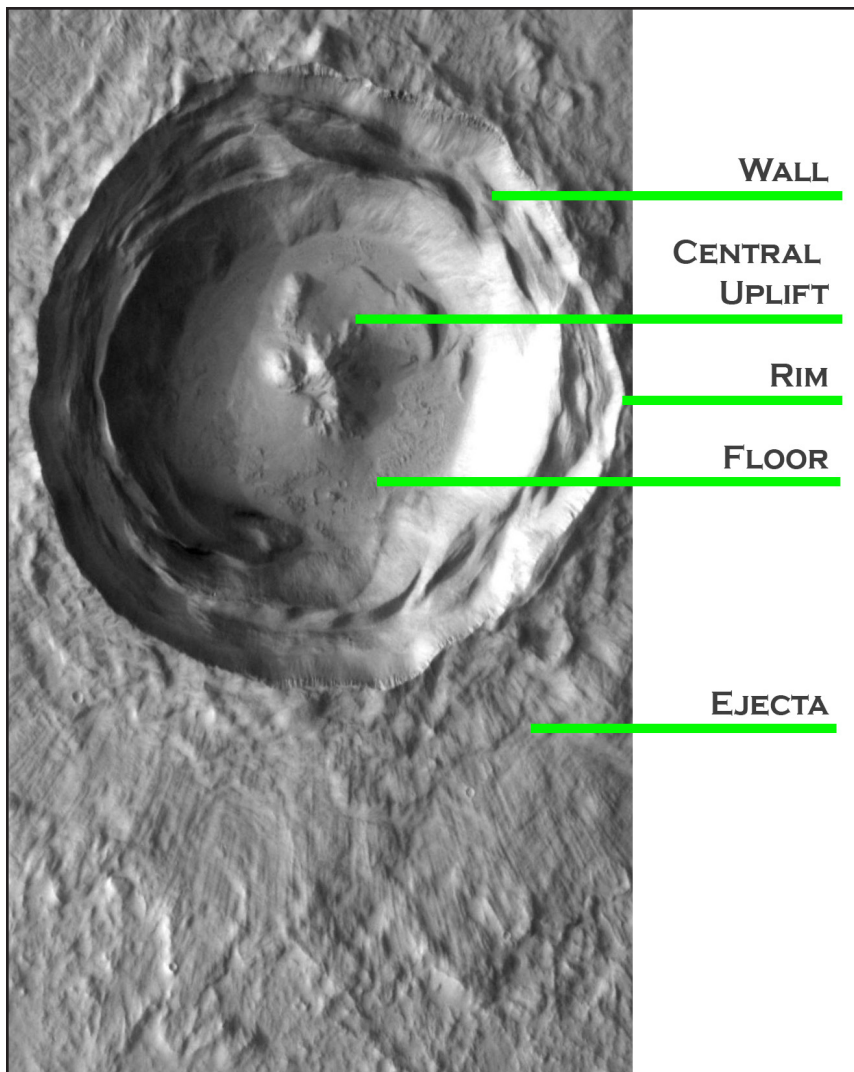
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## Identifying Surface Features

The National Aeronautics and Space Administration (NASA) has been returning pictures of Mars back to Earth since 1965, when the *Mariner 4* spacecraft flew past Mars and sent back twenty-one images. Science and technology have progressed greatly since the early mission days. The *Mars Global Surveyor* spacecraft has sent back over 100,000 pictures of the Martian surface. These pictures have helped scientists determine what types of geological activity have occurred to make the planet appear as it does today. Impact craters, volcanoes, layering, and river beds look much the same on Mars as they do on Earth. Scientists can, therefore, use Earth's features as a comparison for Mars. In these activities you are a mission scientist trying to figure out what is happening on the surface of Mars. Geological features on Mars are easy to identify if you know what you are looking for. The following is a description of some of the most common geological features on Mars. Becoming familiar with these features will assist you in completing the activities that follow.

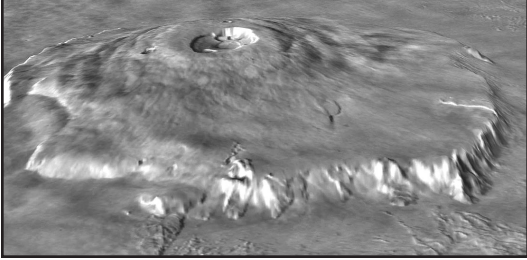


### Impact Craters

**Impact craters** on Mars, the Moon, or any other planetary body are formed when meteorites slam into its surface displacing rock and soil, creating a bowl-shaped hole or crater. Impact craters on Mars vary in size from less than 1 km (0.6 miles) to 2,100 km (1,300 miles) in diameter. An impact crater usually has five parts, although not all of these parts are visible in all craters. The picture at right is of a crater in a region called Arabia Terra on Mars.

It is typical of craters found not only on Mars, but on the Earth and Moon as well. The raised area around the edge of the crater is called the **rim**, and is material that was thrown upward by the violence of the impact that created the crater. Some of the material that was in the crater was thrown high into the air and landed outside the crater in a blanket called **ejecta**. One type of ejecta is long, outward-pointing streaks called **rays**. These rays are particularly visible on the Moon. The **walls** of the crater slope down to the **floor**, which is often remarkably flat. If the impact was violent enough to melt the rock which

became the floor of the crater, a **central uplift** or peak will often form. You can see this for yourself by adding drops to a glass of water. As each drop hits the water's surface, a crater will form complete with a central uplift. Try it!



## Volcanoes

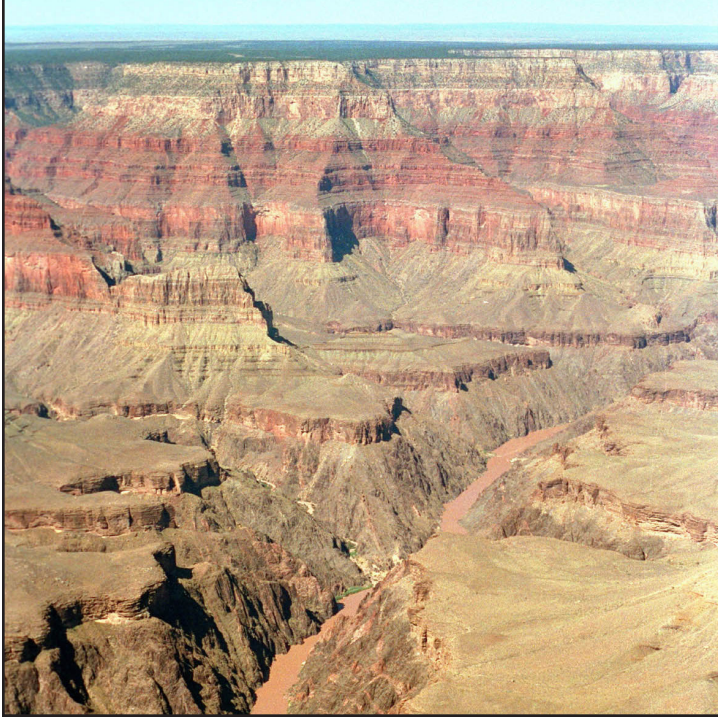
On both Earth and Mars, volcanoes are hills or mountains made from built-up layers of **lava** (hot, molten rock) ejected from cracks or **vents** in the planet's crust. At the top of the volcano is a roughly circular depression. This depression is called a **caldera** if it is larger than one mile (0.6 km) in diameter or, confusingly enough, a **crater** if it is smaller than one mile (0.6 km) in diameter.

There are five major types of volcanoes. **Shield volcanoes** are domes much wider than they are high (shaped like a shield) and have very low slopes. They are formed from hot, freely-flowing lava (usually silica-poor basalt). The largest volcano on Earth is a shield volcano called **Mauna Loa**, which rises over 9 km (5.4 miles) from its base on the sea floor. The largest volcano in the Solar System, **Olympus Mons** on Mars, is a shield-like volcano. Olympus Mons is almost 27 km (17 miles) high and its base is almost 700 km (430 miles) across!



If the lava from a volcano is made up mostly of silica, it will flow more sluggishly. This lava doesn't flow very far from the vent, but instead gets heaped up into a bulbous "plug", giving this type of volcano the name **plug dome**. This type of volcano is usually small, rising not more than a few thousand meters above the surface. **Spatter cones** are of a similar size, but are formed from gas-charged lava fountains that spew lava high into the air. **Cinder cones** are formed from volcanic ash and coarse materials exploding from the vent. The most famous cinder cone appeared in a Mexican farmer's cornfield in 1943. The cinder cone erupted for nine years and reached a height of over 400 meters (1300 feet)!

The last type of volcano, and the most common on the Earth, is the **composite volcano**. This type of volcano is actually a blend of the other types, sometimes having quiet eruptions and sometimes having violent explosive eruptions. Mount St. Helens, which last erupted on May 18, 1980, is an example of this type of volcano.



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## Stratification

The Earth's crust has experienced many changes over its four and a half billion year history. The crust is made up of many layers of rock, one laid on top of the other in a process called layering or **stratification**.

These rock layers, or strata, tell us much about the history of the Earth and how it has changed over time. The strata form a geological timeline that we can use to date significant changes in the Earth's crust. Wherever this timeline is exposed, we can easily read off the history of that area. One spectacular place where we can see the strata that make up the Earth's crust is in the Grand Canyon. The canyon was formed over many millions of years as the Colorado River slowly wore through the surface rock and carved deeper and deeper channels. As the river dug deeper, more and more layers of rock were exposed, revealing more and more about the geological history of this region.

Canyons also exist on Mars, some possibly cut by a moving fluid such as water or lava. The largest canyon on Mars is **Valles Marineris**, which is over 10 km (6 miles) deep and 4,000 km (2,500 miles) long. If placed on the Earth, it would stretch across the entire United States! The entire Grand Canyon would fit in one of its side canyons. Unlike the Grand Canyon, however, Valles Marineris was not cut by a river. Instead, it was formed when some event caused the Martian crust to bulge so that it pulled apart. Regardless of whether a canyon was formed by flowing water or by a separating crust, the strata revealed tell us the same story of the planet's history. Using cameras aboard spacecraft orbiting Mars, scientists have found evidence of layered terrain. Could these layers tell us how Mars has changed over time? This is one of the questions scientists hope to answer by studying the strata found on Mars.



Image credit: NASA/JPL/Arizona State University



## River Beds

Rivers on Earth form when running water carves channels into the land as rainwater flows from higher to lower elevations. On Mars, no liquid water can exist today because of its cold surface temperatures and low atmospheric pressure, so no water can flow to carve channels. NASA spacecraft instruments, however, have found many examples of long, snake-like formations that resemble dry river beds similar to those

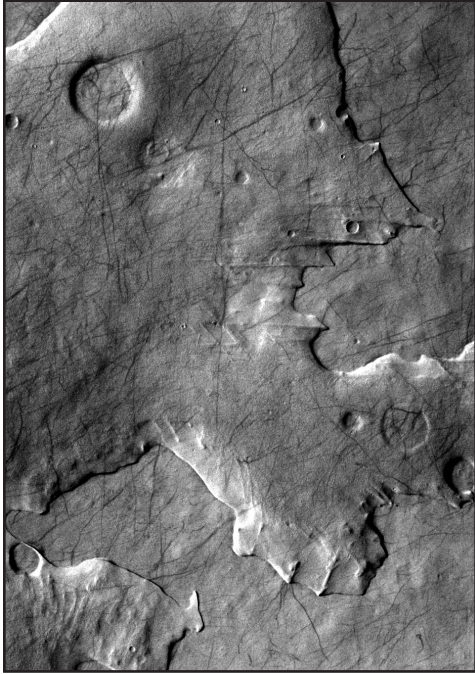
found on Earth. At the eastern end of Valles Marineris is a complex system of outflow channels that drain into the plain called Chryse Planitia. These channels were thought to have formed when hundreds of cubic kilometers of water suddenly flooded the surface, carving each channel in just a few weeks. It was as if all of the water in the Great Lakes were suddenly drained into the Gulf of Mexico in just two weeks. There are many features on Mars, such as Nanedi Vallis, shown below, that indicate that at one time the planet may have been much warmer and wetter than it is today. So where did all the water go? Water on Mars today can exist only as ice or as water vapor. Scientists theorize that much of Mars' water is locked up as ground ice deep beneath the surface. This layer of frozen ice and rock, called permafrost, may be several kilometers thick. Even after much of the water on Mars froze, scientists believe that periodically large impacts may have melted the permafrost and temporarily allowed water to flow on Mars again. Not for long though! This water would eventually either refreeze or turn to vapor and escape into the atmosphere. The water in the Martian atmosphere is visible today as wispy ice clouds that float over the surface. If Mars was warmer and wetter in the distant past than it is today, what happened to cause this change? Could the same change happen to Earth? These are questions that scientists are attempting to answer by using data returned by spacecraft sent to Mars.



Think of the most beautiful and interesting place you have ever seen. Are there mountains, lakes, volcanoes, rivers, or rocks there? Do you have any idea how these geological features were formed? Determining how these and other geological features formed and how they influence their surroundings is the job of geologists. With geological knowledge gathered from the Earth's surface, geologists can determine what is happening on other planets. Once you have learned to identify geological features on the Earth or on Mars, the next question you should ask is: How were these features formed? Which features were formed first and are therefore older? Which features were formed later and therefore are younger? The process of answering these questions is called determining the surface history of the planet. In order to make this determination, geologists use three basic rules, or principles, when trying to figure out an area's geological history. You must learn these principles so that you can determine the history of the areas of Mars you will study in the activities that follow.

# Determining Surface History

Image credit: NASA/JPL/Arizona State University



## The Principle of Superposition

The first principle which is used in determining the surface history of an area is called the Principle of Superposition. This principle describes the order in which rocks are placed above one another. You know from our discussion of stratification that rocks in the Earth's crust are laid down in layers, one on top of the other. The Principle of Superposition states that strata located at the bottom of an undisturbed stack of rocks are older than the layers at the top of the stack. If you think about it, this makes sense. No natural force would have peeled back layers of older rock and then laid down a layer of younger rock in between. The only place the younger rock could be laid down is on top of the older layers. The picture to the right is of an area on Mars and shows an excellent example of strata. Which layers in this picture are the oldest? Which are the youngest? On Earth, by examining the different minerals and fossils that appear in the different layers, geologists can estimate when the rock layers were laid down. In this way we discover a timeline of Earth's geological history preserved in the exposed layers of rock. In areas where the layering is not exposed, geologists drill into the ground and remove long tubes of rock called core samples. These core samples

reveal the layering of rock beds in exactly the same way.



Image credit: Ramon Arrowsmith/Arizona State University/USGS

## The Principle of Cross-Cutting Relationships

The second principle geologists use in determining the surface history of an area is called the Principle of Cross-Cutting Relationships. This principle states that rocks or geological features such as canyons, rivers, or cracks in rocks, may be cut by other rocks or by other geological features. This picture in the Grand Canyon shows rocks that have been cut over millions of years by the Colorado River. The river slowly wore its way down through the layers of rock to produce the deep canyon feature we see today. Because the rocks were cut by the river, they must be older than

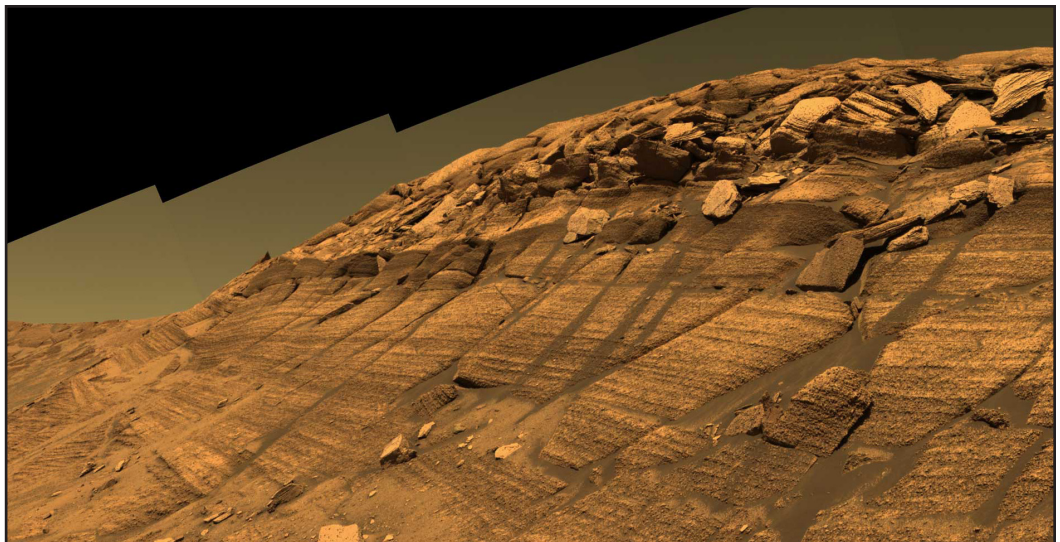
the river. The canyon itself, the "cut" in the rocks, was created by the river carving its way through the rocks. Therefore, the rocks are the oldest feature, followed by the river, and then the canyon "cut". These kinds of relationships help geologists determine the age of different geological features on the surface. This process will reveal a lot about the surface history of a region!



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### The Principle of Horizontal Bedding

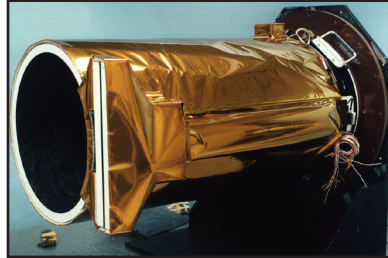
The final principle used by geologists that we will study here is called the Principle of Horizontal Bedding. This principle states that rocks that are deposited by water, such as limestone, or rocks that are deposited by wind, such as sandstone, are deposited in nearly horizontal layers. If the layers are no longer horizontal, they must have been bent or folded after they were originally laid down. The picture to the left is of folded bedding in a rock unit near California. What forces could have caused these layers to bend? California lies upon a fault, or a moving fracture between two huge plates of the Earth's crust. These continental plates are moving very slowly, and over millions of years the rock layers begin to buckle. Take a telephone directory and hold it by its edges. Look at the end of the book and notice that the pages start out horizontal. Now watch the pages as you move your hands together. They bend! This is the same effect that is happening as the continental plates apply force to the rock layers, so they bend as well.



Burns Cliff, Mars  
Image credit: NASA/JPL/Arizona State University



## ACTIVITY I



Now is your chance to apply what you've learned to actual images of the Martian surface. The image included with this activity was taken by the **Mars Orbiter Camera (MOC)**, one of the three instruments aboard the **Mars Global Surveyor (MGS)** spacecraft. MGS was launched November 7, 1996, and arrived at the Red Planet on September 12, 1997. The spacecraft completed

its primary mission on January 31, 2001, but was still in good health so controllers decided to extend its mission. The goal of this activity and the ones that follow is to give you practice analyzing actual data sets from Mars in order to determine the surface history of the planet. You will need to be able to recognize the various geological features and apply the three principles we studied to determine the ages of those features. Once you have the ages of all the features, you will develop hypotheses of how those features were formed.

**For this activity use:**

- (1) **Activity One Image.pdf**
- (2) **Activity One Context\_v105.pdf**

### Features Near Olympus Mons (MOC2-102)

1. The image has been overlaid with a grid that has been marked in kilometers so that you can record the positions of features you identify.
  - a) What is the width of the area shown on the image? \_\_\_\_\_ km
  - b) What is the length of the area shown on the image? \_\_\_\_\_ km
2. Examine the long, winding feature that extends from the bottom left to the top right of the image. Is it raised above the surface or is it carved into the surface? What is your hypothesis?  
\_\_\_\_\_
3. In order to answer question 2, you actually need more information: the Sun is illuminating the picture from the right. Your teacher will perform a demonstration which will show you where the shadow appears when features are illuminated from different sides. Now look at the circular feature just above and to the right of the center of the image. If the Sun is shining from the right side of this feature, is it a volcano or an impact crater? \_\_\_\_\_

For this image, if the shadow is on the right side of a feature, is that feature raised or lowered? \_\_\_\_\_  
If the shadow is on the left side, is that feature raised or lowered? \_\_\_\_\_

4. Olympus Mons, the largest volcano in the Solar System, produced the lava flows that you see in the upper left corner of the image. Which feature is older, the lava flows or the long winding feature that extends across the image?

**ACTIVITY I**

**Features Near Olympus Mons (MOC2-102) - Data Log**

Feature	Grid Coordinates	Age Rank	Notes

5. Complete the Data Log above, identifying as many features (such as craters, canyons, riverbeds, and volcanoes) in the image as you can recognize. Record the grid coordinates of each feature on the Log so that you can find them later. After you have identified these features, use the three principles you learned previously to rank the features from oldest to youngest. Be sure to explain your reasoning in the “Notes” column! Finally, in the space below “tell the story” of what has happened to form the features shown in this image in your own words.

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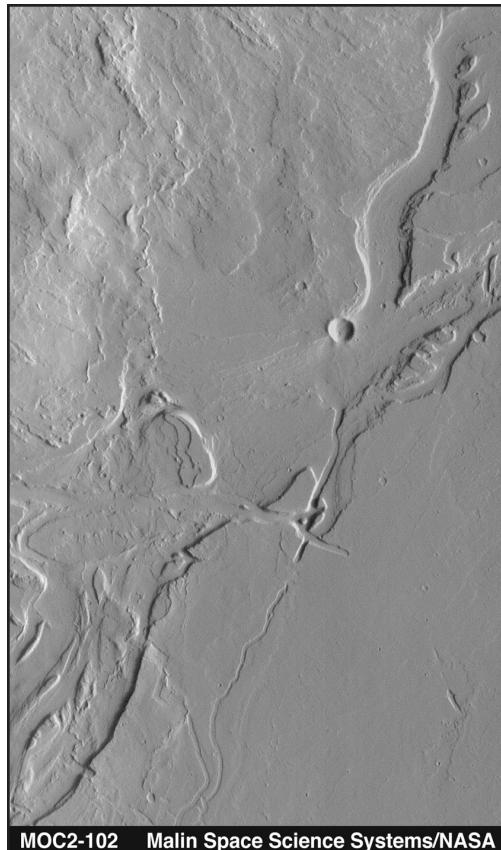
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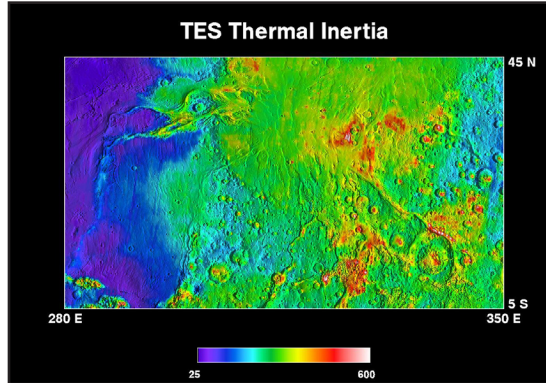
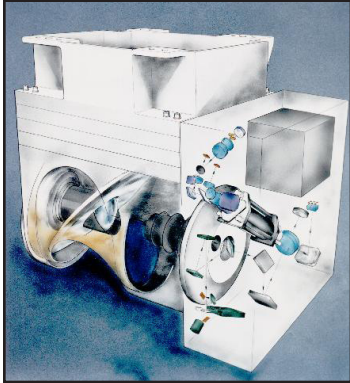
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## ACTIVITY 2



The second instrument aboard the Mars Global Surveyor spacecraft is the Thermal Emission Spectrometer (TES). The purpose of TES is to measure thermal infrared (IR) energy that is emitted from Mars. We often perceive thermal IR energy as heat. Just like visible light, thermal IR energy exists in many different “colors” or wavelengths. These “colors” however, are so red that your

eye can’t perceive them. TES has a special instrument which can not only see these wavelengths, but it can also measure how much of each wavelength is present. The instrument is also capable of measuring the total amount of energy reflected from the surface of Mars. Material with a high albedo is shiny and bright because it reflects a great deal of light, while material with a low albedo does not reflect much light and appears dark. You will use TES’s measurement of the albedo of the Tharsis Province to learn more about the unique geology of this region.

**For this activity use:**

(1) **Activity Two Image.pdf**

### Albedo of the Tharsis Province

- Examine the scale printed below the TES image. This scale shows the percentage of visible and IR light received from the Sun that is being reflected from the surface of Mars.
  - What is the minimum percentage of visible and IR light that is reflected in the image? \_\_\_\_\_
  - If you were looking at this area through a telescope, would it appear light or dark? \_\_\_\_\_
  - What is the maximum percentage of visible and IR light that is reflected in the image? \_\_\_\_\_
  - If you were looking at this area through a telescope, would it appear light or dark? \_\_\_\_\_
  - Approximately what percentage is represented by a dark green color? \_\_\_\_\_
- Find the three volcanoes of the Tharsis Montes region. The volcano located on the lower left is called Arsia Mons, the volcano in the middle is Pavonis Mons, and the volcano located to the upper right is Ascraeus Mons.
  - Which of these volcanoes has the highest albedo? \_\_\_\_\_
  - Which of these volcanoes has the lowest albedo? \_\_\_\_\_

## ACTIVITY 2

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3. The large volcano northwest of (to the left and above) the Tharsis Montes is Olympus Mons, the largest volcano in the Solar System. Notice that there is a region of very bright material on the northwest face of the volcano. This bright material is actually not on the surface, it is water-ice clouds in the atmosphere.

a) Which side of Olympus Mons is the material on? \_\_\_\_\_

b) Now look at the Tharsis Montes. Which side is the material on here?  
\_\_\_\_\_

c) Why do you think the material is only found on one side of the volcanoes?  
\_\_\_\_\_  
\_\_\_\_\_

d) What does this tell you about the winds on Mars?  
\_\_\_\_\_  
\_\_\_\_\_

4. Look at the filmy white feature stretching northeast from Pavonis Mons and lying southeast of Ascraeus Mons. This feature is Valles Marineris, the largest canyon in the Solar System. The canyon is marked by material that is similar in albedo to the material on the northwest side of the Tharsis Montes.

a) What do you think this material might be? \_\_\_\_\_

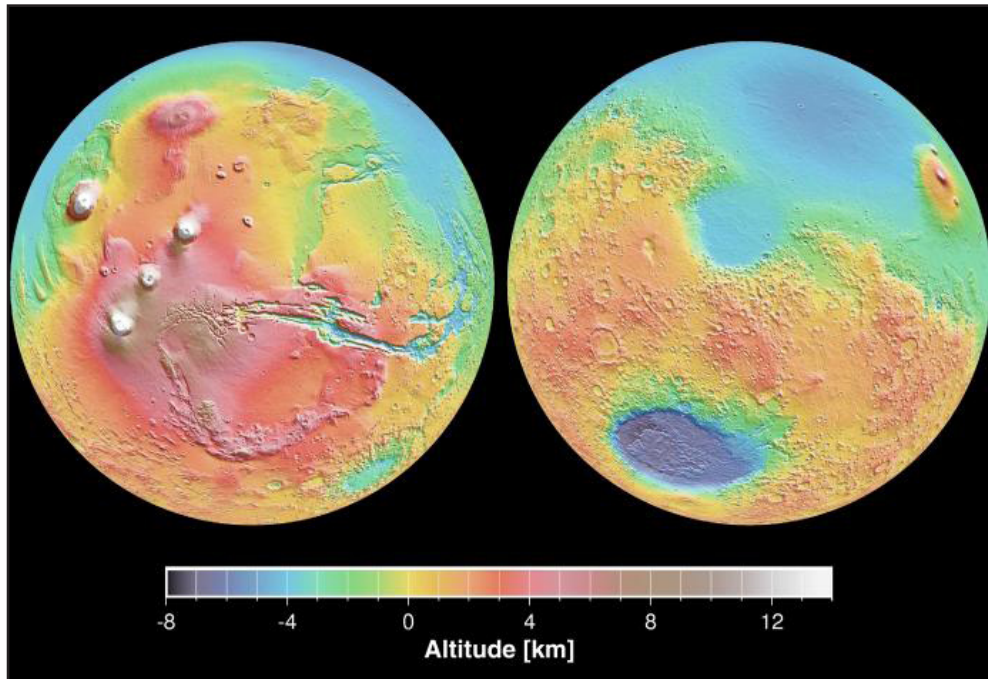
b) Why do think this material would collect in the canyon?  
\_\_\_\_\_  
\_\_\_\_\_

5. Look at the red-colored region near the north pole of Mars (the black circular area here is just the area where Mars Global Surveyor could not collect data).

a) Is this region bright or dark? \_\_\_\_\_

b) Why do you think the region appears this way (bright or dark)?  
\_\_\_\_\_  
\_\_\_\_\_

## ACTIVITY 3



The third major instrument on board the Mars Global Surveyor spacecraft is the Mars Orbiter Laser Altimeter (MOLA). This instrument, controlled from NASA's Goddard Space Flight Center in Greenbelt, Maryland, transmits infrared laser pulses towards Mars. These pulses bounce off the Martian surface and the instrument measures the time it takes to receive the return pulse. Because light (and an infrared laser pulse) always travels at the same speed, the instrument can measure the distance from the spacecraft to the surface with a great deal of accuracy. The image you will use in this activity shows the topography or heights, of the region surrounding the three Tharsis Montes volcanoes. This image is not a photograph! A computer generated this image by assigning colors to represent different heights above or below the datum, or "sea level" on Mars. The color scale below the image will allow you to determine the heights of the features.

**For this activity use:**

(1) [Activity Three Image.pdf](#)

### Topography of the Tharsis Montes Region

- The grid on this image is marked in degrees of latitude and longitude. The Martian equator runs directly through the middle of the image at 0 degrees latitude. One degree of latitude or longitude in this region is about 59 km.
  - What is the width (in degrees) of the image? \_\_\_\_\_ deg
  - What is the length (in degrees) of the image? \_\_\_\_\_ deg

## ACTIVITY 3

2. Notice the three volcanoes that cross the image from bottom left to top right.
  - a) How tall (in meters) are these features above the datum? \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ m
  - b) How wide (in degrees) are the volcano bases? \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ deg
  - c) Multiply each of your three answers in part b by 59 km/degree to find out the width (in km) of each base. \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_ km
3. Based on your reading and your results from question 2, what type of volcano do you think the Tharsis Montes are? Why?  
\_\_\_\_\_
4. Based on what you know about this type of volcano, what type of rock might the interior of Mars be made of (basalt or silica-rich rocks)? Why?  
\_\_\_\_\_

### Topography of the Tharsis Montes Region - Data Log

Feature	Grid Coordinates	Age Rank	Notes

5. Complete the Data Log above, identifying as many features in the image as you can recognize. Record the grid coordinates of each feature on the Log so that you can find them later. Using the color key below the image, estimate the height of each feature. After you have identified these features, use the three principles you learned previously to rank the features from oldest to youngest. Finally, in the space below “tell the story” in your own words of what happened to form the features seen in the image.

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## Keywords

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**Albedo:** ratio of the amount of electromagnetic energy reflected by a surface to the amount of energy incident upon it

**Caldera:** A large depression at the top of a volcano, caused by collapse or explosion of a volcano. Typically larger than one mile in diameter (0.6 km).

**Chryse Planitia:** A smooth circular plain in the northern equatorial region of Mars close to the Tharsis region. It is 1600 km in diameter and with a floor 2.5 km below the average planetary surface altitude, and is thought to be an ancient impact basin.

**Cinder cones:** A volcanic cone, formed from volcanic ash and coarse materials exploding from the vent.

**Composite volcano:** (also called a Stratovolcano) is a tall, conical mountain (volcano) composed of both hardened lava and volcanic ash. The shape of these volcanoes is characteristically steep in profile because lava flows that formed them were highly viscous, and so cooled and hardened before spreading very far.

**Continental plates:** Huge mobile sections of the Earth's crust

**Datum:** a fixed or established point of reference, usually with a fixed elevation.

**Fault:** A moving fracture between two huge plates on the Earth's crust.

**Impact crater:** A circular depression on a surface, usually referring to a planet, moon, asteroid, or other celestial body, caused by a collision of a smaller body (meteorite) with the surface.

Associated with impact craters:

- **Rim:** The raised area around the edge of the crater that was created by the violence of the impact that created the crater.
- **Ejecta:** Material that was thrown high into the air and landed outside the crater in a blanket-like shape.
- **Rays:** A type of ejecta that consist of long, pointing streaks.
- **Walls:** The sides of the crater
- **Floor:** The bottom of the crater
- **Central uplift:** If the impact was violent enough to melt the rock which became the floor of the crater, then a peak will form at the center of the crater. For example, when a rock is thrown into a pond or lake, the splash of water will have a central peak associated with the impact.

## Keywords

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**Lava:** Hot molten rock, often associated with a volcano.

**Mariner 4 (1964-1965):** The spacecraft flew past Mars on July 14, 1965, collecting the first close-up photographs of another planet. The pictures, played back from a small tape recorder over a long period, showed lunar-type impact craters (just beginning to be photographed at close range from the Moon), some of them touched with frost in the chill Martian evening. The Mariner 4 spacecraft was not expected to survive much longer than the eight months to its Mars flyby encounter, but actually lasted about three years in solar orbit, continuing long-term studies of the solar wind environment and making coordinated measurements with Mariner 5, a sister ship launched to Venus in 1967.

**Mars Global Surveyor (MGS—1997-present):** Launched November 7, 1996, Mars Global Surveyor became the first successful mission to the red planet in two decades. After a year and a half spent trimming its orbit from a looping ellipse to a circular track around the planet, the spacecraft began its prime mapping mission in March 1999. It has continued to observe the planet from a low-altitude, nearly polar orbit ever since.

**Mars Orbiter Camera (MOC):** This camera (onboard the Mars Global Surveyor) produces a daily wide-angle image of Mars similar to weather photographs of the Earth. In addition, the narrow-angle lens with image motion compensation captures images of objects as small as 0.5 meters (1.7 feet) across. One dramatic example from the spacecraft's Mars Orbiter Camera shows wheel tracks of NASA's Mars Exploration Rover Spirit and the rover itself.

**Mars Orbiter Laser Altimeter (MOLA):** This experiment measures the height of Martian surface features like mountains and depths of valleys.

**Mauna Loa:** Located on the big island of Hawaii, this volcano is the largest shield volcano on Earth. It rises over 5.4 miles (9 km) from its base on the sea floor.

**Olympus Mons:** The largest volcano in the solar system. This shield volcano is almost 17 miles (27 km) high and its base is almost 430 miles (700 km) across.

**Permafrost:** a layer of soil at varying depths below the surface in which the temperature has remained below freezing continuously from a few to several thousands of years

**Principle of Cross-cutting Relationships:** Rocks or geological features such as canyons, rivers or cracks in rocks, may be cut by other rocks or by other geological features.

**Principle of Horizontal Bedding:** Rocks that are deposited by water, such as limestone, or rocks that are deposited by wind, such as sandstone, are deposited in nearly horizontal layers.

**Principle of Superposition:** Strata located at the bottom of an undisturbed stack of rocks are older than the layers at the top of the stack.



## Keywords

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**Plug dome:** The steep-sided, rounded mound formed when viscous (mostly silica) lava wells up into a volcanic crater and is too stiff to flow away. It piles up as a dome-shaped mass, often completely filling the vent from which it emerged.

**Shield Volcano:** A gently sloping volcano in the shape of a flattened dome, built almost exclusively of lava flows.

**Spatter cones:** A steep-sided volcanic cone, formed from gas-charged lava fountains that spew lava high into the air.

**Strata:** Rock layers

**Stratification:** Many layers of rock, one laid on top of the other in a process called layering.

**Thermal Emission Spectrometer (TES):** This instrument (onboard the Mars Global Surveyor) studies the atmosphere and maps the mineral composition of the surface by analyzing infrared radiation, scanning for heat emitted from the surface of Mars

**Topography:** precise detailed study of the surface features of a region

**Valles Marineris:** (Latin for Mariner Valley, named after the Mariner 9 Mars orbiter of 1971-72 which discovered it.) is a vast canyon system that runs along the Martian equator just east of the Tharsis region. Valles Marineris is 4000 km (2500 mi) long and reaches depths of up to 7 km (4 mi) and widths of up to 200 km (125 mi).

**Vent:** A fissure in the earth's crust (or in the surface of some other planet) through which molten lava and gases erupt

**Volcanic Crater:** A depression at the top of a volcano, caused by a collapse or explosion of a volcano. Typically smaller than one mile in diameter (0.6 km).

**Wavelength:** Light waves come in many sizes. The size of a wave is measured as its wavelength, which is the distance between any two corresponding points on successive waves, usually peak-to-peak or trough-to-trough. The wavelengths of the light we can see range from 400 to 700 billionths of a meter. Instruments found on spacecraft such as the Mars Global Surveyor can measure infrared light which is just beyond the visible region humans can see.