MARS STUDENT IMAGING PROJECT
ASU MARS EDUCATION PROGRAM

Name ________________________

Date ________________________

Earth / Mars Comparisons and Introduction to MSIP and THEMIS Images

1. The Mars Student Imaging Project is sometimes called _____________________ for short.

2. The Science Process involves:
   a. Idea / Topic / ______________________
   b. Experiment Design / ______________________
   c. Competition (for use of the ______________________ camera)
   d. Selection / Acceptance
   e. Reformatting how you will answer your ______________________
   f. ______________________ Analysis, and Interpretations
   g. Write-up (Science Report or ______________________)
   h. ______________________ Work

3. The name of the spacecraft the camera is on is the _____________________ spacecraft.

4. The name of the camera student scientists can use is _____________________.

5. MSIP students can use the _____________________ imaging system.

6. The _____________________ topography map uses color to show the different elevations on Mars. The colors blue and purple indicate _____________________ elevations and the colors red and white indicate _____________________ elevations.

7. Earth and Mars are alike in that they both: (list your observations):

8. Earth and Mars are different in that they: (list your observations):

9. The actual surface of Earth and Mars are alike in that they both have _____________________ and _____________________.

10. In looking at the globe of Mars, list at least 3 features or observations:
    a.
    b.
    c.

For the rest of the slides, take notes on the information and observations of topics and features discussed that are found on both Earth and Mars and are seen in THEMIS visible images.

General Topic: Mountains, Volcanoes and Volcanic Features

Earth	Mars	THEMIS Images

General Topic: Canyons and Canyon Features

Earth	Mars	THEMIS Images

General Topic: Aeolian (Wind Related) Features

Earth	Mars	THEMIS Images

General Topic: Craters and Crater Features

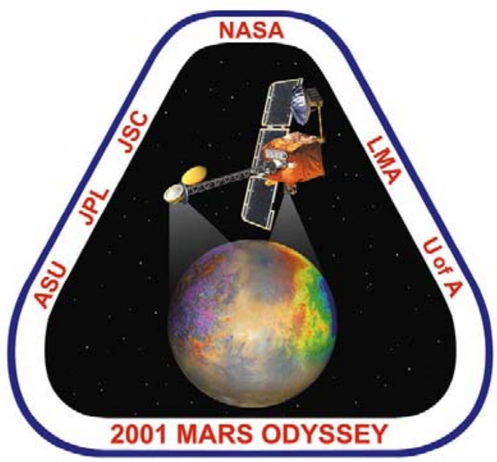
Earth	Mars	THEMIS Images

General Topic: Water Related Features

Earth	Mars	THEMIS Images

MARS STUDENT IMAGING PROJECT

Resource Manual



Mars Education Program
Jet Propulsion Laboratory
Arizona State University

Version 2.00

The Mars Student Imaging Project

Written and Developed by:

Keith Watt, M.A., M.S.
Assistant Director
ASU Mars Education Program

Image Processing Curriculum by:
Sara Watt, M.S.
ASU Mars Education Program

Editing by:

Paige Valderrama, M.A.
Assistant Director
ASU Mars Education Program

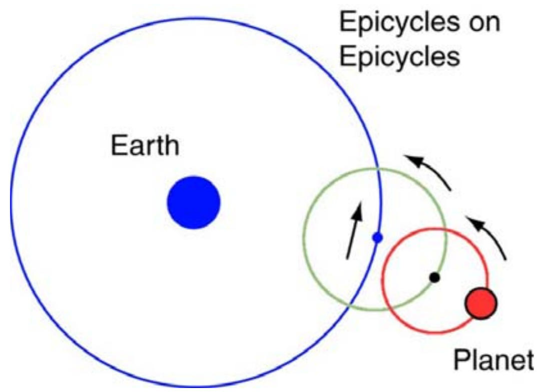
Sheri Klug, M.S.
Director
ASU Mars Education Program

Chapter 1: Mars in Society and Culture

Mars has always played a significant role in human society. The early Greeks noted that unlike the other planets, Mars sometimes seemed to reverse its direction across the sky. This "contrary" motion suggested disorder and anarchy to the Greeks, which, along with its reddish color, led them to name the planet after Ares, their god of war. The Romans later changed the planet's name to that of their god of war, Mars, and the name has remained ever since.

In the Beginning

Science and our view of the world change only when we are presented with some observation we can't explain. Early Greek scientist-philosophers believed that Earth was at the center of the Universe and all other celestial bodies revolved around it. Eudoxus, a mathematician who lived in the fourth century B.C., was one of the first people to propose this theory. Eudoxus' version of the theory was elegantly simple: God is perfect, the only perfect forms are circles, therefore the Sun and planets must move in circles around the Earth. Claudius Ptolemy, a Greek scholar who lived in Alexandria, Egypt, around 140 AD noted that there were some problems



The Ptolemaic Universe
Credit: University of Tennessee

with the theory, however. Careful observations showed that the planets did not quite move in perfect circles. Faced with an observation that couldn't be explained with current theories, Ptolemy modified Eudoxus' theory and replaced his simple circles with a complicated system of "epicycles", circles that interlock like gears in a complex machine. Ptolemy's theory could describe and predict the motions of the planets with an accuracy never before achieved. For almost 1,400 years, until the 16th century, Ptolemy's theory was considered to be the only correct theory of the Universe. The theory was endorsed by the Catholic Church, which declared any other explanation for the planets' motions to be heresy and punishable by death.

Ptolemy's theory only had one problem: it was wrong. One hundred years after Eudoxus, the astronomer Aristarchus watched the shadow of the Earth sweep across the surface of the Moon during a lunar eclipse. His observations showed that the Sun had to be much larger than the Earth, and he felt that it was not likely that a large

Sun would rotate around the smaller Earth. He proposed instead that the Earth revolves around the Sun. He was condemned for heresy because of his theory and all of his writings were rounded up and destroyed. The only reason we know anything about Aristarchus at all is because he is mentioned in the writings of the great mathematician Archimedes. No other scientist was willing to risk the wrath of the Church by mentioning the astronomer's work. In 1543, nearly 2,000 years later, however, Aristarchus' theory was taken up by Polish doctor, lawyer, and part-time astronomer Nicolaus Copernicus. Copernicus' careful observations could not be explained by Ptolemy's theory. Only if the Sun were at the center of the Solar System could his data make sense. Once again, because of new observations, new science and a new worldview was born.

The New Scientists

Mars played a major role in the controversy. Even Copernicus' theory could not explain the strange motions of Mars. In 1600 Tycho Brahe had undertaken the careful study of Mars' orbit. Tycho was perhaps the greatest observational astronomer the world has ever known. We can make more accurate observations today only because we have more accurate instruments. Tycho was world famous, a rock star of science who toured the palaces of kings and other nobility all over Europe. Tycho had given his student, a German mathematician named Johannes Kepler, the task of creating a mathematical description of Mars' orbit. Tycho, however, was very protective of his data, as are many scientists today. He would throw out an observation over dinner in casual conversation, which Kepler would frantically scrawl down in a notebook that he kept under the table. When Tycho finally died several years later, Kepler broke into Tycho's safe and stole all of his data. Tycho's family demanded the documents be returned, and Kepler did so – but only after he had made exact copies of all of the precious data. Kepler, like most of his fellow scientists, felt certain that the planets traveled in perfect circles. After years of struggling with Tycho's observations of Mars, however, he finally reached the inescapable conclusion that all the work done before him was wrong: the planets move in ellipses, not circles. In addition, he discovered two other laws of planetary motion that he published in 1609. Thanks to Mars, we now understand not only its motion, but the motion of the entire Solar System as well.

Johannes Kepler (1571-1630)
Credit: University of St Andrews, Scotland

In 1634, Kepler published a book called *The Dream*, in which he described a fanciful flight from the Earth to the

Moon. It was one of the first works of science fiction. Science fiction books have spurred generations of people to wonder about the stars and the planets that travel through the heavens. By the end of the 19th century, however, improved telescopes showed that the Moon was a barren, desolate place, a place where no life could possibly exist. Mars, however, was still a fuzzy disk in even the best telescopes. Science fiction authors, scientists, and the imaginations of the general public turned away from the Moon and looked instead to the Red Planet. In 1877, Italian astronomer Giovanni Schiaparelli observed a series of lines that seemed to cross most of the surface of Mars. In his notes, he called these lines *canali*, an Italian word that means "channels". American amateur astronomer Percival Lowell, however, translated the word as "canals", a very similar meaning, but one that has very different implications: "canals" implies intelligence. Lowell believed that Schiaparelli had discovered the engineering works of a dying Martian society desperately trying to bring water from the Martian icecaps to the equatorial lands. Lowell was so excited by the discovery that he had a state-of-the-art observatory built in Flagstaff, AZ, specifically to study Mars. His writings ignited the imagination of generations of people around the world, including great science fiction authors such as Edgar Rice Burroughs (the *Barsoom* series of 11 novels), Ray Bradbury (*The Martian Chronicles*), and H.G. Wells (*The War of the Worlds*). Wells' work was made even more popular when Orson Welles (no relation to H.G. Wells) and his *Mercury Theater on the Air* performed the most famous radio play in American history. To celebrate Halloween of 1938, Welles adapted *The War of Worlds*, a tale of a Martian invasion of the Earth, into a radio broadcast. Story events were presented as "news broadcasts" reporting New York City in flames and unstoppable aliens destroying everything in their paths. Millions of people, who tuned in to the play late, thought the broadcasts were real and fled their homes in terror of the "invasion". Most had taken to the streets in panic and never heard the play's end and Welles' wish for them to have a happy Halloween. NBC issued a public apology the next day; Welles became one of Hollywood's most successful actors. Mars, and the possibility of life there, was so firmly ingrained in the minds of the public that no one questioned that the events of that night might not have actually been real. Mars has always had this power over us.

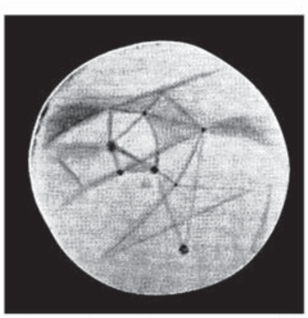
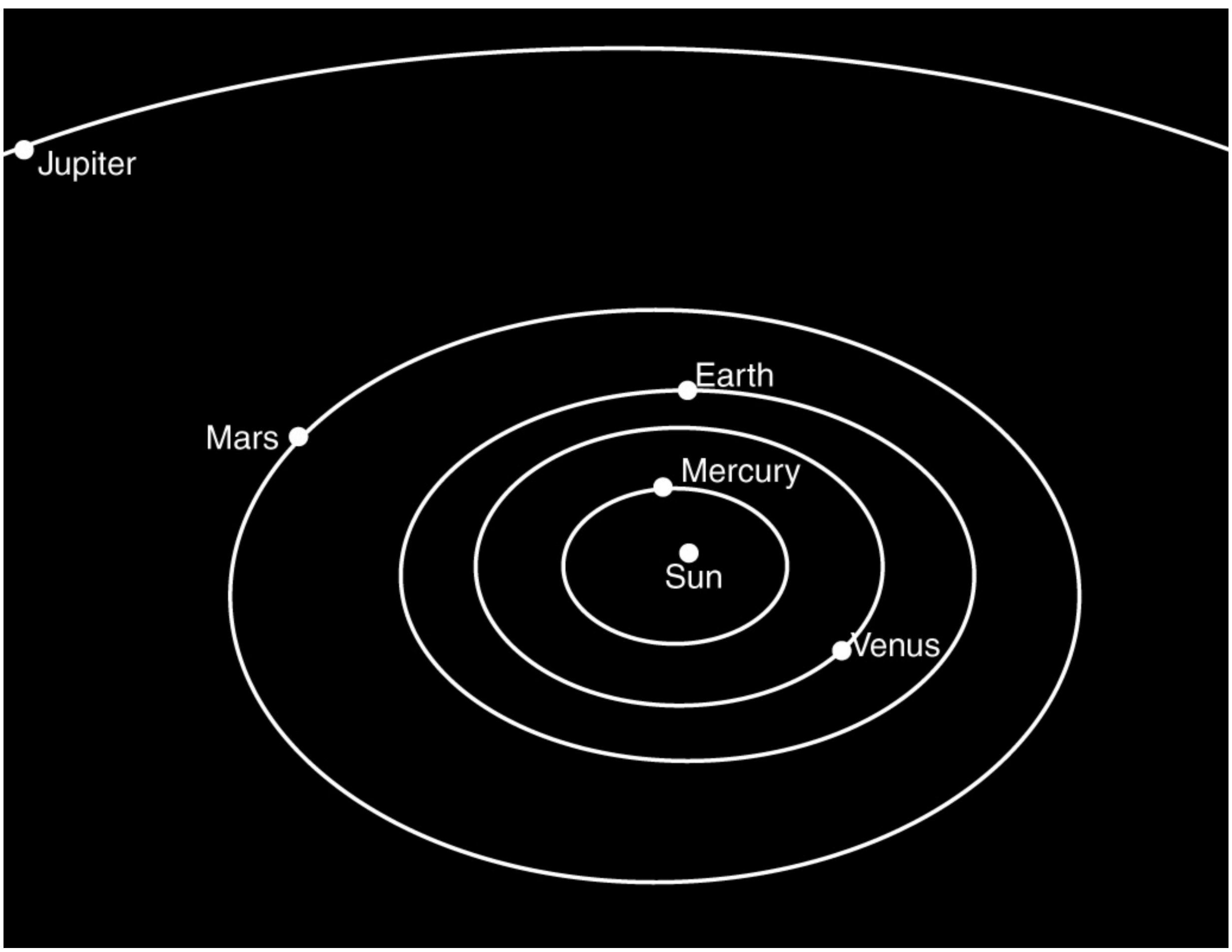


FIG. I. NOV. 14. LONG. CENT. 114° SEEING 4 TO 8. DIAM. 17".9

Lowell's drawing of Mars
Credit: The Wanderer Project

Today scientists know that Mars in its current form probably cannot support life as we know it. Spacecraft sent to

Mars have found no trace of Lowell's "canals" or of his dying civilization. But was Mars always as it is now? Data returned from our Mars spacecraft show us that it almost certainly was not. At some time in the past, Mars was much warmer and wetter than it is today. What happened to Mars? Did it once have life? Where did all the water on Mars go? Could Earth also change as Mars has? These are just a few of the questions scientists hope to answer, important questions that you will also help to answer as you begin your exploration in the *Mars Student Imaging Project*.



The Inner Solar System

Credit: Keith Watt

Chapter 2: Mars Exploration Background

As mentioned in Chapter 1, Mars has attracted the attention and imaginations of observers for thousands of years. The first serious observations of the Martian surface were conducted by Schiaparelli in 1877, whose work was expanded upon by Lowell in 1890. Until the dawn of the space age in the early 1960's, telescopic observations were the only way we could study Mars. Even the best telescopes, however, must still look up through the Earth's atmosphere in order to see out into space. It's a lot like trying to watch clouds from the bottom of a swimming pool: the objects are there, but they are fuzzy, wavering, and hard to make out. If we want to conduct serious observations of another planet, we need to go there.

The Mars Race

On October 4, 1957, the Soviet Union launched *Sputnik 1*, the first man-made object into space. In doing so, they did more than launch a spacecraft, they launched a race that would ultimately end with the United States landing a total of 12 astronauts on the surface of the Moon. While many people are familiar with the Moon Race, not many people realize that there was a "Mars Race" as well. In 1960, the Soviet Union attempted to launch two robotic space probes to Mars. Both exploded at launch. In 1962, however, they successfully launched their *Mars 1* probe and put it on course for the Red Planet. All seemed to be going well until the spacecraft was about halfway to Mars. Suddenly, all contact with the probe was lost. No one has ever determined what happened to the probe, but its loss gave the American team another chance to be the first to Mars.

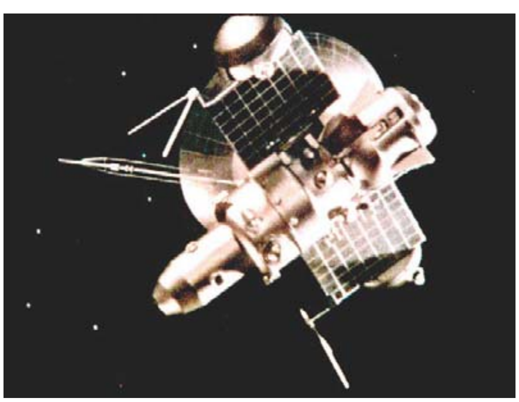
Sputnik
Credit: NASA

Thrilled with the success of *Mariner 2,* the first unmanned mission to Venus, NASA began its program of Mars exploration, hoping to be the first country to explore Mars as well. Approximately every two years the planets are in just the right position for an Earth-Mars trip that requires the least amount of fuel. In 1964, NASA prepared to launch *Mariner 3* and *Mari-*

Mariner 4
Credit: NASA/JPL

ner 4 to Mars. During the launch of *Mariner 3*, the spacecraft's protective launch shroud collapsed, destroying the spacecraft. With only three weeks remaining in the low-fuel launch window, NASA engineers scrambled to get *Mariner 4* ready to take the place of its sister spacecraft. On November 28, 1964, *Mariner 4* launched successfully and put onto the path to Mars. The Soviet Union was not far behind, however. Two days later, on November 30, they launched *Zond 2* and put it on course to Mars as well. There was now a literal race to the Red Planet. Two spacecraft were headed to Mars. Which would get there first?

The race stayed close for the first months of the trip, but just as *Zond 2* reached the point near where *Mars 1* vanished, it too lost all communications. NASA engineers joked about a "Great Galactic Ghoul" that ate Mars spacecraft. They stopped laughing when *Mariner 4* began having communications difficulties in the same area. Unlike *Zond 2*, however, *Mariner 4* resolved its difficulties and sailed on to Mars. On July 15, 1965, *Mariner 4* became the first spacecraft to visit Mars. The spacecraft returned 21 images that revealed the dry, cratered surface of Mars. Dreams of a garden planet were laid to rest forever, but the data showed that Mars was a fascinating planet in its own right.

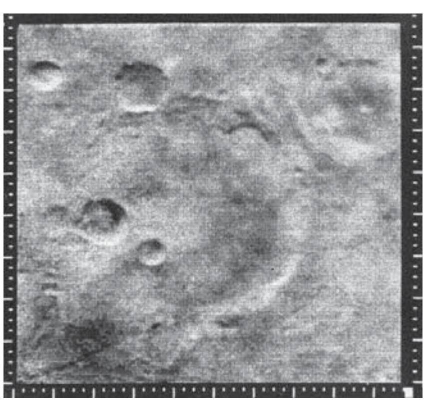


Zond
Credit: Lunar and Planetary Institute

Missions to Mars continued with *Mariner 6* and *Mariner 7* in 1969, both performing flyby missions similar to *Mariner 4*. *Mariner 6* performed flawlessly, but *Mariner 7,* during its mission, suddenly lost contact with Earth. Engineers were afraid the "ghoul" had returned, but they managed to re-establish contact and determined that a battery on board had exploded during the pass behind the planet. The controllers instructed *Mariner 7* to shut down its damaged systems and continue the mission. The two spacecraft together returned 58 pictures of the Martian surface taken from a distance half as far from the planet as *Mariner 4*. The images, and particularly those from *Mariner 7*'s flight over the Martian polar caps, once again changed the way we view Mars. *Mariner 7* carried an infrared spectrometer on board that was able to analyze the composition of the ice. The spacecraft discovered that the south polar cap of Mars is not water ice at all, but is instead composed almost entirely of frozen carbon dioxide, or "dry ice".

Mariner 9

NASA engineers quickly realized that in order to carefully study a planet, you have to not only go there, you have to *stay*. What was needed was a spacecraft that would travel to Mars and place itself in orbit around the planet. The United States was not alone in this assessment. The Soviet Union designed three spacecraft that would travel to Mars during the next launch window. In 1971 they were to join the American *Mariner 8* and *Mariner 9* probes on the long journey to the Red Planet. The Soviets, however, were attempting to leapfrog the United States: each of their spacecraft contained not only an orbiter, but also a lander designed to descend and send back the first pictures from the surface of Mars. The American *Mariner 8* spacecraft died when the second stage of its Atlas-Centaur booster rocket failed to ignite. The Soviet *Cosmos 419* made it into space, but never left Earth orbit because the ignition timer for its last stage had been mistakenly set for 1.5 years rather than 1.5 hours after launch. The fleet of spacecraft headed to Mars had been reduced from five to three in just a few weeks.



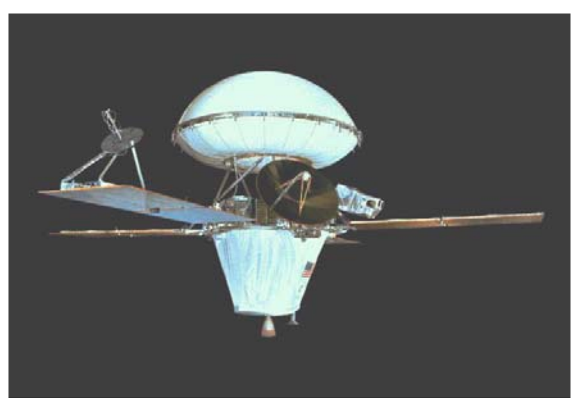
Mariner image of cratered area on Mars
Credit: NASA

The three remaining craft, the Soviet *Mars 2* and *Mars 3* and the American *Mariner 9*, were all launched in May of 1971. Once again, the race to Mars was on. The race was won by *Mariner 9*, which was on a slightly faster course than its Soviet counterparts. On November 14, 1971, *Mariner 9* became the first artificial satellite of another planet. *Mars 2* arrived two weeks later and *Mars 3* shortly after that. Unfortunately, when the three spacecraft arrived at Mars, there was nothing much to see. In September of 1971 a dust storm, visible from Earth, began which eventually covered the entire planet. Nothing of this scale had ever been observed on any planetary body. The Soviet *Mars 2* dispatched its lander anyway, as it programmed to do, but the lander crashed on the surface, sending back no data. *Mars 3*'s lander faired a bit better, sending back a few seconds of data before it was blown over and destroyed by the raging Martian winds. Still, the Soviet Union had become the first nation to land a spacecraft on another planet – even if it didn't do much once it got there. The Soviet orbiters snapped featureless pictures of the dust-enshrouded planet until their batteries died. Nothing could be seen through the dust on any of the images. *Mariner 9*, however, had been designed with an onboard computer that could be reprogrammed from Earth. NASA controllers instructed the spacecraft to shut itself down and conserve power until the storm passed. By December of 1971, the storm was over and NASA woke up the sleeping spacecraft, which returned the highest resolution pictures of Mars that had ever been obtained.

Once again, new observations completely changed everything we thought we once knew. Observations of Mars by previous spacecraft had led us to believe the surface of Mars was a cratered, dead landscape, not much different from Mercury or the Moon. All of those spacecraft, however, had flown past only the southern hemisphere of Mars. The *northern* hemisphere of Mars is made up of smooth plains and lava basins, totally unlike the cratered south. *Mariner 9* also solved the mystery of the "seasonal variations" Mars seems to display. These dark areas on the surface seem to change location with the seasons and were thought to be indications of plant life growing during the warmer Martian summers. *Mariner 9* found that the dark areas were just huge areas of dark rock exposed when the bright red Martian dust was blown away by surface winds. As the seasons changed, so did the direction of the winds, uncovering new dark regions. The three previous *Mariner* spacecraft sent to Mars had shown no indication of volcanic activity. *Mariner 9* discovered Olympus Mons, the largest volcano in the Solar System, and the three Tharsis Montes volcanoes, each larger than any volcano on Earth. The spacecraft also discovered Valles Marineris, the largest canyon system in the Solar System, formed when some cataclysmic event caused the crust of Mars to bulge so much it cracked. The canyon is so huge, if placed on the Earth it would extend from San Francisco to Washington, D.C. The entire Grand Canyon would fit in one of its side canyons. Most significantly, *Mariner 9* discovered long channels that look unmistakably like dry riverbeds – indicating that Mars may have once had liquid water. These and other wonders were returned to Earth in the 7,329 images sent back to Earth during the course of *Mariner 9*'s year-long mission. The spacecraft ran out of fuel on October 27, 1972, and went forever silent.

The *Viking* Missions

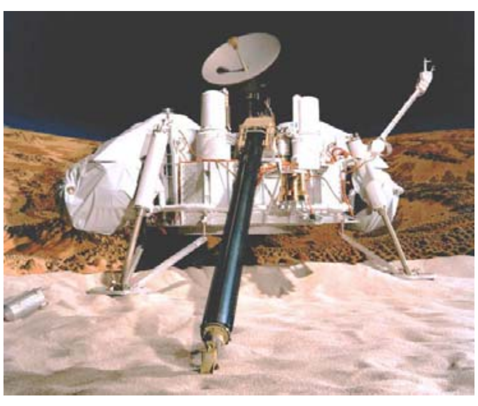
NASA missed the next launch window in 1973 because it was preparing for an even more ambitious mission: a large-scale lander that would carry a



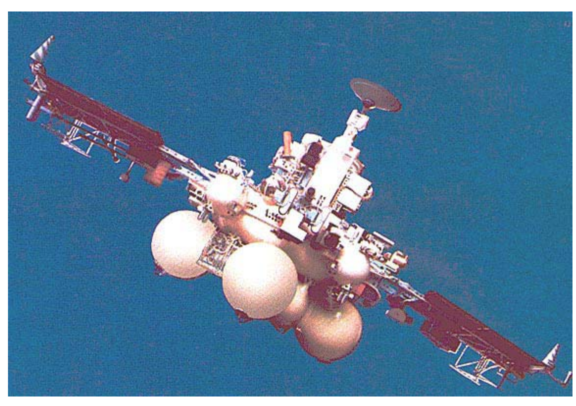
Viking orbiter
Credit: NASA/JPL

complete laboratory to the surface of Mars. The Soviet Union was not idle, however, using the 1973 launch opportunity to send four spacecraft to the Red Planet. None were successful. By 1975, the American *Viking 1* and *Viking 2* spacecraft were launched and headed to Mars. Like their Soviet counterparts, each *Viking* spacecraft carried both an orbiter and a lander. The landers carried no less than 14 different experiments, most of which were designed to detect life on the surface. The trouble was that no two scientists agreed upon a *definition* of life, much less the means to test for it. Both landers touched down safely, *Viking 1* on July 20, 1976, and *Viking 2* on September 3, 1976. The landers immediately began the tests for life that were finally worked out as the best that could be done. The experiments initially caused great excitement when they indicated they might have actually found biological activity in the Martian soil. Later analysis of the results, however, indicated that the excitement was misplaced. Today, most scientists believe that the *Viking* experiments did not in fact detect life on Mars. The question still remains, however: even if there is no life on Mars now, did life ever exist there in its past? The question is still unanswered.

With the end of the Apollo lunar program, NASA's shrinking budget forced it to concentrate on the Shuttle Transportation System, better known as the Space Shuttle. As a result no American spacecraft visited Mars for nearly twenty years. The Soviet Union (which would simply become Russia the following year) launched *Phobos 1* and *2* in 1988 to study the moons of Mars, but the "Great Galactic Ghoul" struck once again: *Phobos 1* was lost en route to Mars just one month after launch. *Phobos 2* arrived near Mars and managed to perform, among other things, important studies of the solar wind near Mars before a computer failure caused controllers to lose contact with the spacecraft just before reaching its destination. Neither mission was counted as a success.



Viking lander
Credit: NASA

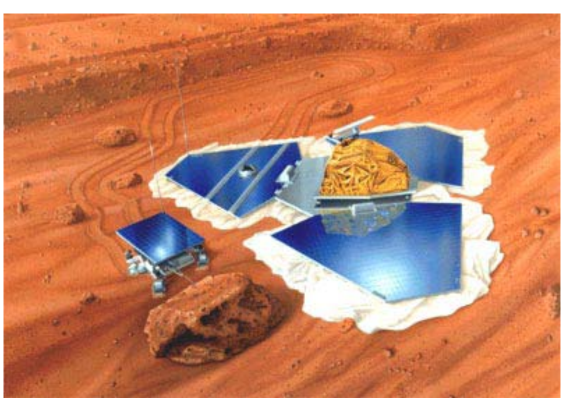


Mockup of Phobos
Credit: High Energy Astrophysics Science Archive Research Center

In 1992, the United States decided to return to the Red Planet and renew its studies of this fascinating world. As with the Russian spacecraft, *Mars Observer* lost contact with Earth a year later just as it was about to enter orbit around Mars. The *Mars Observer* mission cost nearly one billion dollars. It would be the last of the "old-style" planetary explorers.

Faster, Better, Cheaper

Under the leadership of its new administrator, industrialist Dan Goldin, NASA decided to try a new approach dubbed "faster, better, cheaper". The idea was to use many, smaller spacecraft, instead of one huge expensive spacecraft. In this way, the loss of one craft would not doom an entire exploratory mission. The first in this series of "Discovery missions" was *Mars Pathfinder*. In contrast to the billion-dollar *Mars Observer* mission, *Pathfinder* was designed, built and launched for only 250 million dollars, one-fourth the cost of *Observer*. Like *Viking*, *Pathfinder* included a lander, but it also included something never before attempted: an independent rover, named *Sojourner*, capable of traveling up to ten meters (32 feet) away from the lander. The mission tested a number of new technologies. Instead of using a *Viking*-style retrorocket, the *Pathfinder* lander was encased in four large six-chambered air bags. Upon entering the Martian atmosphere, the lander parachuted most of the way to the surface, then deployed and inflated its air bags for landing. The spacecraft bounced 15 to 20 times, sometimes as high as 50 feet. The landing went exactly as planned. On July 4, 1997, *Pathfinder* opened its landing petals, and began its science mission while sending the *Sojourner* rover on its way. The mission was a complete success. The lander returned over 16,500 images, some in 3D. The rover returned over 550 images but, more importantly, sent back over 15 chemical analyses of rocks and soil, as well as data on Martian winds and weather. On September 27, 1997, the *Pathfinder* lander, now called Sagan Memorial Station, failed to answer a routine status check. Controllers tried for several months to reach the silent craft, but finally gave up on March 10, 1998, officially ending one of the most successful Mars missions in history.



Pathfinder Lander and Rover

Credit: NASA/JPL

Although launched a month earlier than *Mars Pathfinder*, an orbiter called *Mars Global Surveyor* actually arrived at Mars after *Pathfinder*. *Mars Global Surveyor* was designed to use a technique called "aerobraking", in which the spacecraft dips into the Martian atmosphere to slow down and place itself in Mars orbit. Aerobraking is a delicate maneuver. If the spacecraft enters too low into the atmosphere, it will burn up. The spacecraft spent almost a year and half slowly modifying its orbit around Mars until it was in a nearly circular polar orbit. This orbit would allow *Global Surveyor* to image virtually the entire planet during the course of its two-year science mission, which began in March of 1999. Like *Pathfinder*, *Global Surveyor* has been a phenomenal success, returning more data about the Martian surface and atmosphere than all previous Mars missions combined. The spacecraft carried not only a camera (the Mars Orbiter Camera, or MOC), it also carried an infrared spectrometer (the Thermal Emission Spectrometer, or TES) designed to search for minerals and measure the temperature of Mars, as well a laser altimeter (the Mars Orbiter Laser Altimeter, or MOLA) which provided the first accurate measurement of the topography – terrain heights – of Mars. The spacecraft completed its primary mapping mission on January 31, 2001, but was in such good health, mission managers decided to extend the mission and to continue gathering data. It was fortunate that they did so, as on June 15, 2001, *Global Surveyor* scientists detected the beginnings of what would become the largest global dust storm since the *Mariner 9* mission almost exactly thirty years prior.

Flush from the successes of *Mars Pathfinder* and *Global Surveyor*, NASA commissioned two more spacecraft for the 1998-99 launch window. *Mars Climate Orbiter* was to function as a Martian weather satellite and as a communications relay satellite for the other craft, *Mars Polar Lander*. *Polar Lander* was to land near the south polar ice cap of Mars and dig under the surface in search of water ice. It also carried two "penetrators", called *Deep Space 2* (*Deep Space 1* was a probe designed to study comets using an experimental ion propulsion unit). Unfortunately,

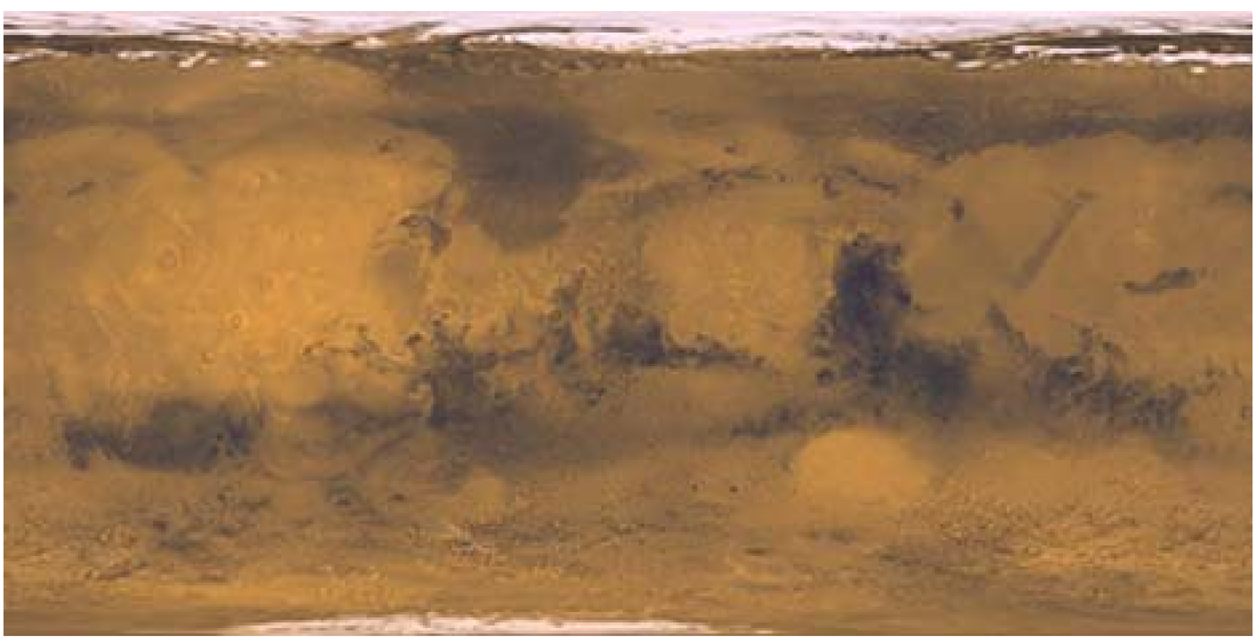
Mars Global Surveyor

Credit: NASA/JPL

Mars Polar Lander

Credit: NASA/JPL

Climate Orbiter suffered from human-caused failure, similar to that which struck the Soviet *Cosmos 419* in 1971. Navigation parameters were fed to the spacecraft in English units, when the program was designed to use metric units. The spacecraft disappeared behind Mars on September 23, 1999, and never reappeared. The fate of *Polar Lander* is still unknown. The spacecraft seemed to be functioning normally as it entered the Martian atmosphere, but no signal from the surface was ever received. Theories include that *Polar Lander* burned up on entry, crashed into the surface, or perhaps it simply landed in rough terrain and was unable to point its antenna at Earth. This last theory is particularly ironic: the spacecraft could have been completely healthy, it just needed someone to kick it back upright. Strangely, though, nothing was heard from the *Deep Space 2* penetrators either, even though they were deployed early in *Polar Lander*'s descent. We may never know what happened to *Mars Polar Lander* – at least not until we are able to go there and look at the crash site ourselves.



Mars Global Surface Map

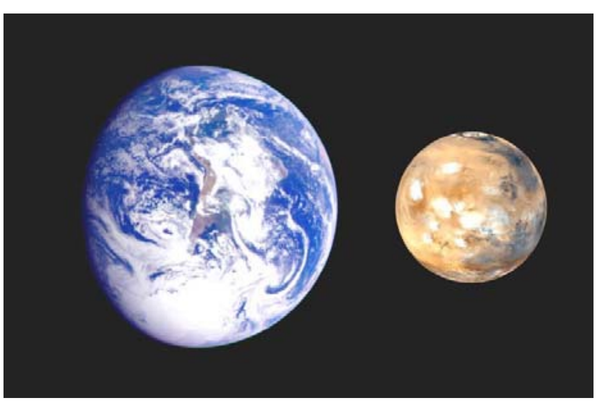
Credit: NASA

Chapter 3: Mars in the Solar System

Mars is a world of puzzles. It is both very similar to and very different from our own Earth. Mars is the fourth planet from the Sun and orbits at a distance one and a half times that of Earth's orbit. As a result, Mars receives much less light and heat from the Sun than the Earth does, so it is much colder. Also, unlike the Earth, Mars has a very thin low-pressure atmosphere which is unable to retain what heat it does receive. Because of the temperatures and pressures on the Martian surface today, water cannot exist in liquid form. Mars today is therefore a dry, frozen desert.

Similarities and Differences

Mars is similar to Earth in a number of important ways. It has an axial tilt of 23.98 degrees, very similiar to Earth's 23.44 degrees. Mars therefore has seasons, just like Earth, with cold winters and warmer summers. Mars' rotation period, its "day", is 24 hours, 37 minutes, again almost exactly the same as Earth's. Like Earth, Mars has ice caps at both poles. It has clouds, winds, weather, dust storms, volcanoes, and channels. For many years, Venus was considered the "twin" of Earth. Unlike Mars, Venus is very similar in size and mass as Earth and therefore has very similar gravity. But Venus is a hothouse, with temperatures soaring to hundreds of degrees centigrade and atmospheric pressures high enough to crush our toughest metals like tin cans. Mars, on the other hand, could one day conceivably be changed to be more like Earth through advanced engineering known as "terraforming". In many respects, Mars is a much more hospitable environment than Venus, making it an obvious target for our imaginations.



Earth/Mars Comparison
Credit: NASA/JPL

But Mars is very different from Earth as well. Surface temperatures on Mars range from hundreds of degrees centigrade below zero in the winter to nearly freezing (0º C) in the summer. Because Earth's orbit is nearly circular, our seasons are virtually the same in both hemispheres. Mars travels in a more elliptical orbit around the Sun than does the other planets, so it is 20% closer to the Sun during southern summer than it is in northern summer. This results in very long, relatively warm southern summers and very long, cold northern winters. Mars has an atmospheric pressure less than seven-tenths of one percent of Earth's, far too low to sustain most forms of life as we know it. The southern ice cap is made mostly of frozen carbon dioxide ("dry ice"), not water. Much of the surface of Mars is covered with craters much like the Moon. All of these differences make Mars a world unto itself, rather than a "twin" of Earth or another planet.

The northern and southern hemispheres of Mars are very different. In general, the south is very heavily cratered, while the north is made up mainly of smooth dark plains. There are many exceptions to this general rule, for example, Hellas Planitia (*planitia* are smooth, low plains or basins) lies in the southern hemisphere and, at 3 km below "datum", is the deepest basin on Mars. The word "datum" is used rather than "sea level", because, obviously, Mars currently has no seas! The datum is defined as the altitude at which the atmospheric pressure is 6.1 millibars (6.1 thousandths of the sea level pressure on Earth). The planet isn't spherical either. There is a very large bulge in the crust located at around 113º west longitude. This region, called the Tharsis Bulge, is home to the largest volcanoes on Mars – and in the entire Solar System. The southern hemisphere reveals the ancient cratering record of impacts early in the Solar System's history. On Earth, this record has been virtually erased by the effects of volcanoes, wind, and water. Planets such as Mercury died young, ceasing geological activity not long after the period of major impacts. Mars, however, was geologically active for most of the life of the Solar System – the great volcano Olympus Mons was probably active just thirty million years ago – so has examples of young terrain in the north right alongside the ancient cratered terrain in the south. In many ways, Mars uniquely records the history of the Solar System in its surface features.

Polar Caps

The polar caps of Mars change dramatically over the course of a Martian year (which is almost two Earth years). During each hemisphere's winter, carbon dioxide freezes out of the atmosphere at the poles to form "dry ice". This dry ice causes the polar cap in that hemisphere to grow by a substantial amount. As much as one-third of the atmosphere of Mars freezes into dry ice at each pole during winter in its hemisphere. Changes of this magnitude in the atmospheric pressure of the Earth would signal that a storm of

Mars South Polar Cap, Summer 2000

Credit: Malin Space Science Systems

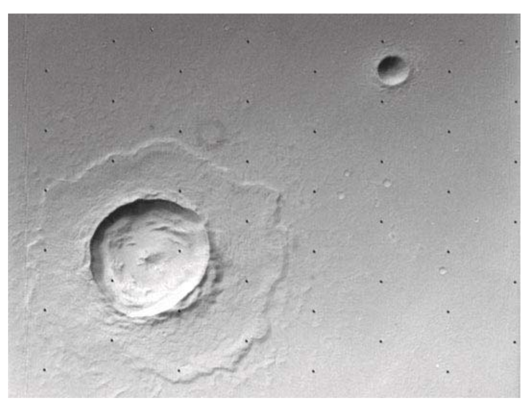
unprecedented power was forming, but on Mars it is just a part of the yearly cycle. In the summer, the temperature rises above the vapor point of carbon dioxide and therefore the dry ice sublimates back into the atmosphere. The polar cap then begins to shrink, though there is always some ice left at the poles. The two poles are not the same, however. The ice that remains at the north pole during the northern hemisphere's summer is mostly water ice, while the residual ice at the south pole is still mostly carbon dioxide ice. Scientists assume that there is water ice buried below the dry ice at the south pole. *Mars Polar Lander* was intended to resolve this particular question once and for all (but unfortunately did not).

Craters

As with Earth and the Moon, Mars was bombarded with debris left over from the formation of the Solar System. The craters left behind have many of the same properties as those on the Moon: a nearly circular raised rim, steep walls, and a smooth floor. If the debris hit with enough energy to liquefy the surface at impact, a central peak often formed in the center of the crater floor. Ejecta, material blasted into the air from the impact, fell in a blanket that extends outward from the crater. Unlike the Moon, however, ejecta blankets on Mars do not have a perfectly circular form. Many craters have irregular ejecta blankets that seem to indicate that some of the ejecta flowed across the surface outside of the crater rather than simply falling straight back to the surface. Craters of this type are called rampart craters because the ejecta is made up of sheets that have distinct outer ridges, or ramparts.

Another unique type of crater on Mars is the pedestal crater. This type of crater is found largely in the northern hemisphere. Craters of this type seem to sit upon a raised pedestal of ejecta. Some of these craters also show ridges like rampart craters, but in other cases the ridges have been eroded away by wind. In some cases the pedestal crater looks to be situated atop a flat, raised plateau which rises above the surrounding terrain.

Any of these types, including the more "standard" lunar-type crater can be made into an incomplete circle by lava flows covering part of the rim. These flooded craters are particularly common near the Tharsis Montes volcanoes.



Belz Crater, Chryse Planitia, Mars

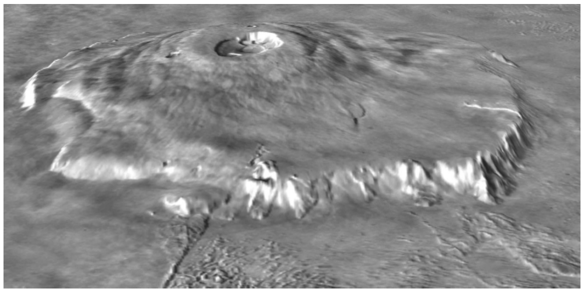
Credit: NASA

Wind Features

Although Mars has a very low atmospheric pressure, the surface winds are very fast. Wind effects are responsible for many of the features that are seen on Mars today. Sand dunes, very similar to those seen on Earth, are abundant in the northern hemisphere. These dunes form in broad lines that run perpendicular to the wind direction. By tracking these dunes, we gain some idea of how the Martian winds flow over time. The wind is also responsible for eroding the Martian landscape, often in strange and bizarre shapes. The wind is strong enough to blow the red dust away to expose darker-colored rock below, an effect which, as mentioned in Chapter 2, once convinced scientists that Mars was covered with vegetation.

Volcanoes

Mars has the largest volcanoes in the Solar System. One theory why this is true is that Mars seems to have a much thicker crust than Earth, and so it doesn't have floating, moving crustal plates. Instead of lots of comparatively small eruptions, as occurs with volcanoes on Earth, the pressure on Mars built up into major eruptions that always occurred in the same places – the weak points in Mars' stable crust. One of the most significant features influencing the development of volcanoes, however, is the Tharsis Montes bulge. The bulge is the site of Olympus Mons, the largest volcano in the Solar System, as well as the three Tharsis Montes volcanoes, each larger than any volcano on Earth. Olympus Mons is 22 km (13.75 miles) high and 550 km (343.75 miles) in diameter. If placed on the surface of the Earth, it would be two and a half times the height of the tallest mountain on Earth (Mt. Everest at 8.85 km or 5.5 miles) and would cover almost the entire state of Arizona! Numerous other volcanoes dot the region as well. These volcanoes were almost certainly formed from lava upwelling through vents in the fractures created by the bulge. No one really knows what formed the bulge. A number of theories have been proposed, but none have yet been proven. Mars has no magnetic field to speak of, so it probably has no molten, liquid core as the Earth does. Some rocks, however, do show "frozen-in" magnetic field lines, which could be evidence that Mars had a strong magnetic field – and therefore a liquid core – in the past. What happened to the core to cause it to solidify? What formed the Tharsis bulge? These are some of the puzzles that Mars presents to us today.

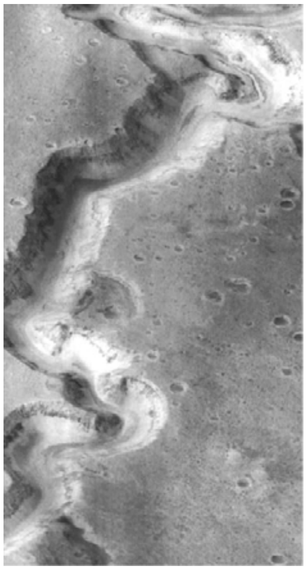


Olympus Mons

Credit: Goddard Space Flight Center

Canyons

Canyons exist in many places on Mars, but none are as famous as Valles Marineris ("The Valley of the Mariners", named for the American probes sent to Mars). The largest canyon in the Solar System, Valles Marineris is even visible from Earth. The canyon is not actually a single canyon, but is instead a system of interconnecting canyons. Valles Marineris varies in depth, but reaches a maximum over 7 km (4.37 miles). Individual canyons are as much as 200 km (125 miles) wide. The central section of Valles Marineris is made up of three nearly parallel canyons, having a total width of over 700 km (437.5 miles) and nearly 2,400 km (1,500 miles) in length. The total length of the Valles Marineris system is over 4,000 km (2,500 miles). The canyon is divided into three general parts. In addition to the central section, to the west, near the Tharsis Montes, is an extremely complex system of interlocking canyons called Noctis Labyrinthus. The eastern end of the canyon is a region of chaotic terrain that could be the result of huge floods flowing out of the canyon after it was formed. Unlike most canyons on Earth, Valles Marineris was not formed by flowing water. The canyon is another effect of the Tharsis bulge. One theory is that it was formed by a literal ripping apart of the Martian crust during the event that caused the Tharsis bulge. Another theory proposes that the canyon was formed when magma underneath it was drawn out in the eruptions of the Tharsis Montes. Once again, we have many puzzles, but very few answers.



Nanedi Vallis

Credit: Malin Space Science Systems

Central Valles Marineris

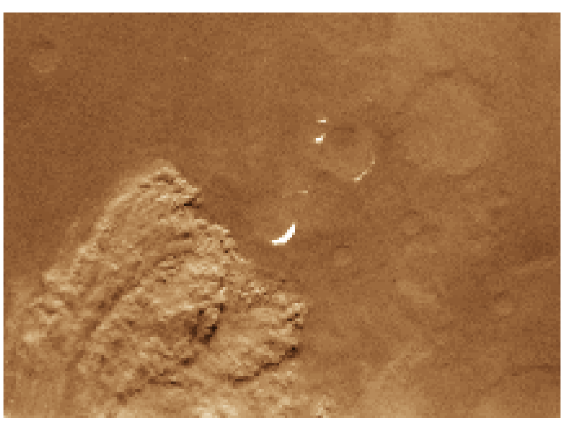
Credit: NASA

Channels

As mentioned previously, Mars today cannot have liquid water present on its surface. We have ample evidence, however, that Mars did at one time have water flowing across its surface. Much of this evidence is in the form of channels that appear to be the result of water runoff and outflows from flooding. We know some channels were formed by flooding that resulted when large impact craters were formed on the surface. The force of the impact melted the permafrost (a layer of ice that scientists think lies frozen beneath the Martian surface) and caused the resulting water to flow violently away from the crater. This water eventually refroze or evaporated into the atmosphere. In addition to water-created channels, channels could also have been formed by flowing lava. Channels formed by water and channels formed by lava have very different appearances. The characteristics of the channel (its walls, its floors, whether or not it has tributaries, etc.) also tell us something about how much water was present and how fast it was flowing. The questions of what happened to the water on Mars and what the surface of Mars was like when water flowed across it are the central questions facing Mars scientists today. Our experience on Earth has been that where there is water, there is life. Is the same thing true on Mars?

Atmosphere

The atmosphere of Mars is very thin, but Mars still has weather! The atmosphere is composed of about 95% carbon dioxide, 2.5% nitrogen, and 1.5% argon. The remaining 1% is mostly oxygen, carbon monoxide, and water vapor. We believe that much of the water on Mars is frozen at the poles and under the ground in a layer called "permafrost", but some of it actually exists as ice-crystal clouds that float in the atmosphere. These clouds don't look like the fluffy cumulus clouds we see here on Earth, but they can resemble the thin, wispy cirrus clouds we often see high in our atmosphere. Where different air masses come together, cyclones can form on Mars, just as they do on Earth. The most striking features of the Martian atmosphere, however, are the dust storms, which can grow strong enough to cover the entire planet. In addition to the dust storm of 1971, which blocked *Mariner 9*'s view of the planet, in 1977 the *Viking* orbiters observed no fewer than 25 major dust storms, two of which grew to global proportions. In 2001, the *Mars Global Surveyor* spacecraft was fortunate to witness the formation and growth of the largest dust storm since the 1971 storm. We have learned a great deal about how the surface of Mars and its atmosphere interact as a result of seasonal heating. This is information that we can use here on Earth as we try to understand our weather and its interactions with the surface.



Local Dust Storm on the Surface of Mars

Credit: NASA

Chapter 4: The *2001 Mars Odyssey* Spacecraft

(Note: Much of this material was taken from official NASA sources. The author gratefully acknowledges their assistance!)

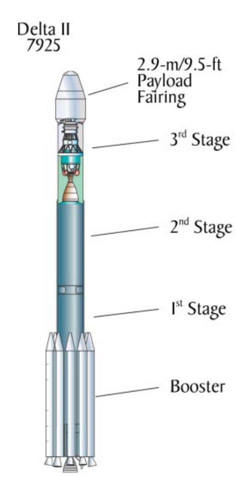
2001 Mars Odyssey is an orbiting spacecraft designed to determine the composition of the planet's surface, to detect water and shallow buried ice, and to study the radiation environment near Mars. The mission will last for at least two Martian years, or almost four Earth years.

Overview

The surface of Mars has long been thought to consist of a mixture of rock, soil and icy material. However, the exact composition of these materials is largely unknown. *Odyssey* will collect infrared and visible images that will be used to identify the minerals present in the soil and rocks on the surface to study small-scale geologic processes and landing site characteristics. By measuring the amount of hydrogen in the upper meter of soil across the whole planet, the spacecraft will help us understand how much water may be available for future exploration. The spacecraft will additionally give us clues about the planet's climate history. Furthermore, the orbiter will collect data on the radiation environment to help assess potential risks to any future human explorers. Finally, the spacecraft can act as a communications relay for future Mars landers.

Launch and Interplanetary Cruise Injection

Odyssey's mission to Mars began at 11:02 a.m. Eastern time on April 7, 2001, as the spacecraft roared into space onboard a Delta II rocket launched from Space Launch Complex 17A at Cape Canaveral Air Station, Florida. Sixty-six seconds after liftoff, the first six solid rocket strap-ons were discarded. The remaining strap-on rocket boosters were then ignited, and when their fuel was expended, were jettisoned. About 4 minutes, 23 seconds after liftoff, the first stage, the lower section of the Delta II booster, stopped firing and was discarded eight seconds later. About six seconds after that, the engine for the second stage (the middle section of the Delta II booster) was ignited. The fairing, or nose-cone enclosure of the launch vehicle, was discarded 4 minutes, 42 seconds after liftoff. The second-stage burn ended about 10 minutes after liftoff.



The Delta II rocket
Credit: Boeing

At this point, the vehicle was in a low-Earth orbit at an altitude of 195 kilometers (120 miles). The vehicle coasted for several minutes, and once it was at the correct point in its orbit, the second stage was restarted for a brief second burn. For stability, small rockets then fired to spin the third stage on a turntable attached to the second stage. The third stage separated and ignited its motor, sending the spacecraft out of Earth orbit. After the final burn, the third stage and the attached spacecraft were despun so that the spacecraft could be separated and placed into its proper cruise orientation. This was accomplished by a set of weights that were reeled out from the side of the spinning vehicle on flexible lines, much as spinning ice skaters slow themselves by extending their arms. Approximately 30 minutes after liftoff, the spacecraft separated from the Delta's third stage, and the remaining spin was removed using the orbiter's onboard thrusters. The solar array was deployed so that the Deep Space Network could acquire the signal from the spacecraft. At 11:55 a.m. Eastern time, flight controllers at NASA's Jet Propulsion Laboratory received the first signal from the spacecraft through the Deep Space Network (DSN) station in Canberra, Australia, indicating that all was well aboard the orbiter.

DSN antenna in Goldstone, CA
Credit: InterPlanetary Network and Information Systems Directorate

Interplanetary Cruise
The interplanetary cruise phase is the period of travel from the Earth to Mars and lasts about 200 days. It begins with the first contact with DSN after launch and extends until seven days prior to arriving at Mars. Primary activities during the cruise include check-out of the spacecraft in its cruise configuration, check-out and monitoring of the spacecraft and the science instruments, and navigation activities necessary to determine and correct *Odyssey*'s flight path to Mars.

Odyssey's flight path to Mars is called a Type 1 trajectory, which takes the spacecraft less than 180 degrees around the Sun. During the first two months of cruise, only the Deep Space Network station in Canberra was capable of viewing the spacecraft. Late in May, California's Goldstone station was able to view *Odyssey*, and by early June, the Madrid station was also able to track the spacecraft. The project also added the use of a tracking station in Santiago, Chile, to fill in tracking coverage early in the mission.

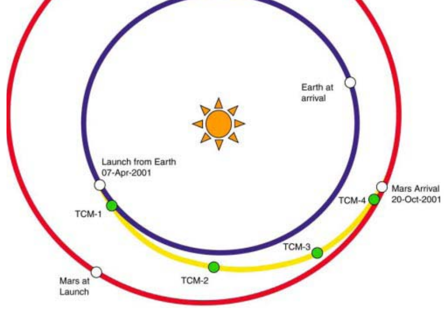
The orbiter transmits to Earth using its medium-gain antenna and receives commands on its low-gain antenna during the early portion of its flight. About 30 days after launch, the orbiter was commanded to receive and transmit through its high-gain antenna. Cruise command sequences are generated and uplinked approximately once every four weeks during one of the regularly scheduled Deep Space Network passes.

The spacecraft determines its orientation in space chiefly via a star camera and a device called an inertial measurement unit. The spacecraft flies with its medium- or high-gain antenna pointed toward the Earth at all times, while keeping the solar panels pointed toward the Sun. The spacecraft's orientation is controlled by reaction wheels (devices with spinning wheels similar to gyroscopes). These devices are occasionally "desaturated," meaning that their momentum is unloaded by firing the spacecraft's thrusters.

During interplanetary cruise, *Odyssey* was scheduled to fire its thrusters a total of five times to adjust its flight path. The first of these trajectory correction maneuvers (TCM) was scheduled for eight days after launch, and it corrected launch injection errors and adjusted the Mars arrival aim point. It was followed by a second maneuver 90 days after launch.

The remaining three trajectory correction maneuvers were used to direct the spacecraft to the proper aim point for insertion into Mars orbit. These maneuvers were scheduled at 40 days before arrival (September 14), seven days before arrival (October 17) and seven hours before arrival (October 24). The spacecraft communicated with Deep Space Network antennas continuously for 24 hours around all of the trajectory correction maneuvers. Maneuvers were conducted in a "turn-and-burn" mode, in which the spacecraft turned to the desired burn attitude and fired the thrusters. It was not Earth-pointed during the thruster firing, so no communication was expected in this short but critical time period.

Science instruments were powered on, tested and calibrated during cruise. The Thermal Emission Imaging System (THEMIS) took a picture of the Earth/Moon system about 12 days after launch confirming that THEMIS was operating normally. Star calibration imaging was performed 45 days after launch. Two calibration periods for the gamma ray spectrometer were conducted during cruise. Each of the



2001 Orbiter Interplanetary Trajectory
Credit: NASA/JPL

spectrometer's three sensors could be operated during the calibration periods depending upon spacecraft power capabilities. The Mars Radiation Environment Experiment (MARIE) was designed to collect radiation data constantly during cruise to help determine what the radiation environment is throughout the journey to Mars.

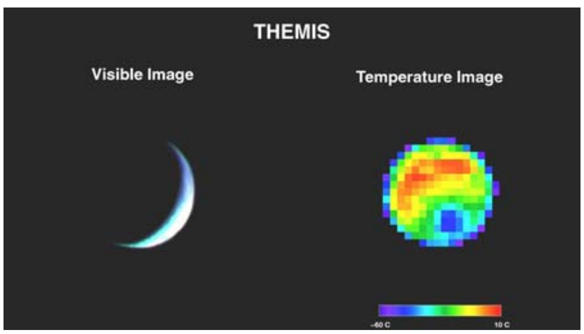


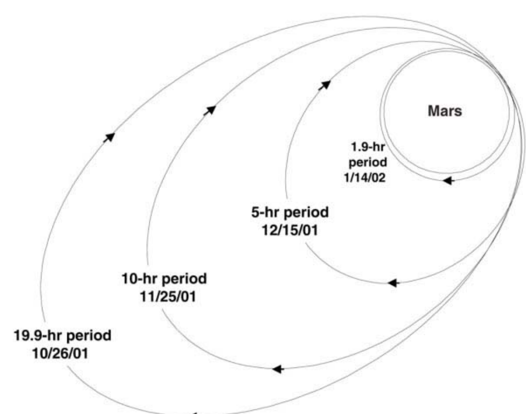
Image of Earth taken by THEMIS
Credit: Arizona State University

Mars Orbit Insertion (MOI) and Aerobraking

Odyssey arrived at Mars on October 24, 2001 Universal Time (October 23 in the United States). As it neared its closest point to the planet over the northern hemisphere, the spacecraft fired its 640-newton main engine for 20 minutes, 19 seconds to allow itself to be captured into an elliptical, or looping, orbit around Mars. After capture, *Odyssey* looped around the planet every 18.5 hours.

Aerobraking is the transition from the initial elliptical orbit to the two-hour circular science orbit. It is a technique that slows the spacecraft down by using frictional drag as it flies through the upper part of the planet's atmosphere. During each of its long, elliptical loops around Mars, the orbiter passed through the upper layers of the atmosphere each time it made its closest approach to the planet. Friction from the atmosphere on the spacecraft and its wing-like solar array caused the spacecraft to lose some of its momentum during each close approach, known as "a drag pass." As the spacecraft slowed during each close approach, the orbit gradually lowered and circularized.

Following aerobraking walk-out, the final stage of the aerobraking process, the orbiter was in an elliptical orbit with a periapsis (closest point) near a 120 kilometer (75 mile) altitude and an apoapsis (furthest point) near the desired 400 kilometer (249 mile) altitude. Periapsis was near the equator. A maneuver to raise the periapsis was performed to achieve the final 400 kilometer (249 mile) circular science orbit. The transition from aerobraking



Predicted Aerobraking orbits
Credit: NASA/JPL

to the beginning of the science orbit required about one week. The high-gain antenna was deployed during this time and the spacecraft and science instruments were checked out.

Mapping Orbit and Communications Relay Phases

The science mission began in February of 2002. The primary science phase will last for 917 Earth days. The science orbit inclination is 93.1 degrees or almost perpendicular to the Martian equator. This is a nearly polar (90 degree inclination) orbit, but the actual poles themselves will not directly pass under the spacecraft. The orbit period will be just under two hours. Successive ground tracks (areas that pass underneath the spacecraft) are separated in longitude by approximately 29.5 degrees and the entire ground track nearly repeats every two sols, or Martian days of 24 hours, 37 minutes.

During the science phase, THEMIS will take multi-spectral thermal-infrared images to make a global map of the minerals on the Martian surface, and will also acquire visible images with a resolution of about 18 meters (59 feet). The Gamma Ray Spectrometer (GRS) will take global measurements during all Martian seasons. The Mars Radiation Environment Experiment (MARIE) will be operated throughout the science phase to collect data on the planet's radiation environment. Opportunities for science collection will be assigned depending on when conditions are most favorable for specific instruments.

The relay phase begins at the end of the primary science mission in approximately two to five years. During this phase, the orbiter will provide communication support for U.S. and international landers and rovers.

Thermal Emission Imaging System (THEMIS)

By looking at the visible and infrared parts of the electromagnetic spectrum, THEMIS will determine the distribution of minerals on the surface of Mars and help understand how the mineralogy of the planet relates to the landforms. During the Martian day, the sun heats the surface. Surface minerals radiate this heat back to space in characteristic ways that can be identified and mapped by THEMIS. At night, since THEMIS maps heat, the imager will search for active thermal spots and may discover "hot springs" on Mars.

In the infrared spectrum, the instrument uses nine spectral bands to help detect minerals within the Martian terrain. These spectral bands, similar to ranges of colors, serve as spectral "fingerprints" of

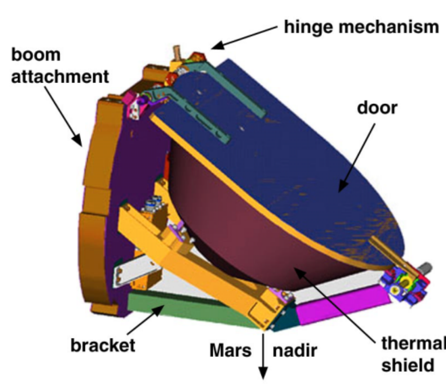
Thermal Emission Imaging System
Credit: Raytheon Santa Barbara Remote Sensing

particular types of geological materials. Minerals, such as carbonates, silicates, hydroxides, sulfates, hydrothermal silica, oxides and phosphates, all show up as different colors in the infrared spectrum. This multi-spectral method allows researchers to detect, in particular, the presence of minerals that form in water and to understand those minerals in their proper geological context.

Using visible imaging in five spectral bands, the instrument will also take 20-meter (65.6-feet) resolution measurements of the surface to determine the geological record of past liquid environments. More than 15,000 images — each 18x18 kilometers (11x11 miles) — will be acquired for Martian surface studies. These more detailed data sets will be used in conjunction with mineral maps to identify potential landing sites for future Mars missions. The part of the imaging system that takes pictures in the visible light will be able to show objects about the size of a house. This resolution will help fill in the gap between large-scale geological images from the Viking orbiters in the 1970s and the very high-resolution images from the currently orbiting Mars Global Surveyor. The THEMIS investigation is led by Arizona State University in Tempe, AZ.

Gamma Ray Spectrometer (GRS)
The Gamma Ray Spectrometer will measure the abundance and distribution of about 20 primary elements of the periodic table, including silicon, oxygen, iron, magnesium, potassium, aluminum, calcium, sulfur, and carbon. Knowing what elements are at or near the surface will give detailed information about how Mars has changed over time. To determine the elemental makeup of the Martian surface, the experiment uses a gamma ray spectrometer and two neutron detectors. When exposed to cosmic rays (charged particles in space that come from the stars, including our Sun), chemical elements in soils and rocks emit uniquely identifiable signatures of energy in the form of gamma rays. The Gamma Ray Spectrometer looks at these signatures, or energies, coming from the elements present in the Martian soil.

By measuring gamma rays coming from the Martian surface, it is possible to calculate how abundant various elements are and how they are distributed around the planet's surface. Gamma rays, emitted from atomic nuclei, show up as sharp emission lines on the instrument's spectrum. While the energy represented in these emissions determines which elements are



Gamma Ray Spectrometer
Credit: University of Arizona

present, the intensity of the spectrum reveals the elements' concentrations.

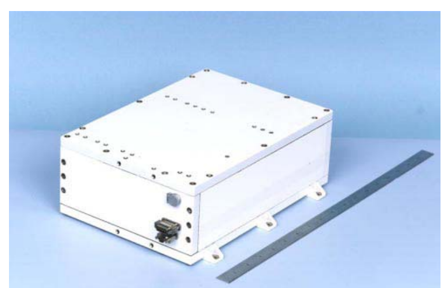
By measuring neutrons, it is possible to calculate the abundance of hydrogen on Mars, thus inferring the presence of water. The neutron detectors are sensitive to concentrations of hydrogen in the upper meter of the surface. Like a virtual shovel "digging into" the surface, the spectrometer will allow scientists to peer into this shallow subsurface of Mars and measure the amount of hydrogen that exists there. Since hydrogen is most likely present in the form of water ice, the spectrometer will be able to measure directly the amount of permanent ground ice and how it changes with the seasons. GRS is led by the University of Arizona in Tucson, AZ.

Mars Radiation Environment Experiment (MARIE)

Led by NASA's Johnson Space Center in Houston, TX, this science investigation is designed to characterize aspects of the radiation environment both on the way to Mars and in the Martian orbit. Since space radiation presents an extreme hazard to crews of interplanetary missions, the experiment will attempt to predict anticipated radiation doses that would be experienced by future astronauts and help determine possible effects of radiation in the Martian environment on human beings.

Space radiation comes from cosmic rays emitted by our local star, the Sun, and from stars beyond our solar system as well. Space radiation can trigger cancer and cause damage to the central nervous system. Similar instruments are flown on the Space Shuttles and on the International Space Station (ISS), but none have ever flown outside of Earth's protective magnetosphere, which blocks much of this radiation from reaching the surface of our planet.

A spectrometer inside the MARIE instrument will measure the energy from these sources. As the spacecraft orbits Mars, the spectrometer sweeps through the sky and measures the radiation field. The instrument, with a 68-degree field of view, is designed to collect data continuously during *Odyssey*'s cruise from Earth to Mars and while in Martian orbit.



Mars Radiation Environment Experiment

Credit: NASA/Johnson Space Center

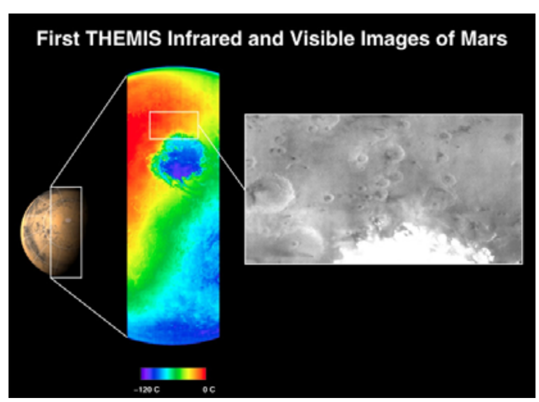
Chapter 5: An Introduction to THEMIS

Of the three instruments on board *2001 Mars Odyssey*, the one you will be using is the Thermal Emission Imaging System (THEMIS, pronounced *THEE-mis*). THEMIS is the second in a series of ASU instruments which are planned for the exploration of Mars. The first, the Thermal Emission Spectrometer, or TES, flew aboard *Mars Global Surveyor*. The third, a smaller version of TES called, appropriately enough, "Mini-TES", will fly aboard the *Mars Exploration Rovers* (MER) in 2003. All use similar principles to explore the Red Planet.

Seeing the Invisible

THEMIS is actually composed of two instruments, a thermal infrared (IR) camera and a visual (VIS) camera. You experience infrared radiation every day as heat! Each color that we see in a rainbow actually corresponds to a specific wavelength or frequency. Red light has a very long wavelength, while blue light has a very short wavelength. Infrared light has wavelengths even longer than red light – it's a color "redder than red", a color so red your eye can't even see it! The range of all wavelengths, which includes the colors that your eye can see, is called the electromagnetic spectrum. The part of the electromagnetic spectrum that your eye can see is actually a very tiny slice called the visible spectrum. The part of the spectrum that we call infrared ranges from the edge of the visible spectrum to the start of the radio portion of the spectrum. Yes, radio is nothing more than light! It's just a color of light so far beyond red that your eye can't perceive it. Within the visible spectrum there is actually an infinite number of colors, not just the seven we usually give names to. The same is true of the infrared part of the spectrum. The THEMIS IR camera has detectors sensitive to nine different wavelengths, or "colors", of infrared light. Minerals on and just below the surface of Mars receive heat from the Sun and re-radiate that heat back into space. The re-radiated heat – infrared light – contains the "signature", composed of specific infrared "colors", that allow THEMIS to detect different minerals. By making maps of the different colors received by the THEMIS IR camera, we can map the minerals on the surface of Mars from orbit.

Both the THEMIS IR and VIS cameras



First THEMIS image
Credit: Arizona State University

are high-resolution. This means that they can see small details on the surface of the planet. Each "pixel", or dot that makes up the image, on the IR camera represents an area of 100 meters (328 feet) on each side. Thus, a football field imaged by THEMIS would take up just a bit more than one "dot" in the image. The VIS camera, on the other hand, can resolve features as small as 18 meters (65.6 feet) on a side. The VIS camera could therefore see things as small as a house – which would appear as a single "dot" in the VIS image. Each VIS image is of a relatively small area, about 18 x 18 km (11 x 11 miles), roughly the size of a small town. The combination of resolution and image size makes the VIS camera an excellent mapping tool. The *Mars Student Imaging Project* will use the VIS camera.

Mission Planning

Flying a spacecraft to Mars cannot be accomplished without a large staff to support it. In the case of *Odyssey*, the spacecraft itself is managed by Lockeed Martin Astronautics (LMA) in Denver , CO, under contract to NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA. *Odyssey* carries three science instruments on board, each of which is controlled by a separate team. Each team has its own needs for the spacecraft, and these often conflict with other teams or with the needs of the LMA engineers. Within each instrument team are several science teams, each with different priorities for observations. In addition, orbital factors such as the position of the Sun or Mars' moons must be taken into account. The mission planner is responsible for looking at the needs of all of these groups and trying to please everyone! In reality this is often an impossible task, but the mission planner tries very hard to make it all fit together.

The Principle Investigator for THEMIS is Dr. Philip Christensen. Dr. Christensen is responsible for the overall management of the THEMIS project and has the ultimate responsibility for the instrument. Dr. Christensen decides what percentage of observations available will be assigned to which science teams. That information is given to THEMIS Mission Planner Kelly Bender along with the requests for observations from the different science teams. Ms. Bender takes these requests and schedules them as best as possible so that Dr. Christensen's percentages are met and as many of the science teams' observations are made as possible. She must also consider the needs of the two other instruments on board *Odyssey*, as well as the needs of the spacecraft engineers at LMA regarding the positioning of the spacecraft. It is not an easy task!

Once the mission planner has scheduled all the observation requests for the upcoming two-week period, she writes a small program that transmits the commands to JPL. JPL "packages" the commands in a format that the spacecraft can read directly, then passes that information on to LMA in Denver. LMA checks to make sure there are no commands that will harm the spacecraft or other instruments, then passes the commands to the Deep Space Network (DSN), a system of communication dishes spread around the world that maintain communication with *Odyssey*. DSN then transmits the commands to the spacecraft, which, if all was done correctly, carries out its new instructions. Once the observations are complete, *Odyssey* transmits its data back to DSN on Earth and back through the pipeline to the mission planner. At this point, THEMIS Data Archivist Kim Murray processes the data into a form that is usable by the science teams and hands the new images over to them. In addition to the two-week lead time required for planning purposes, once the commands are sent from ASU it can take as much as a day before they travel through the communications pipeline and reach *Odyssey*. The observations can usually be taken in a day, and the results are available on the third day, if all goes well. Sometimes problems with the spacecraft or with the weather on Mars can delay observations for as much as a week or more. Exploring another planet is never a routine job!

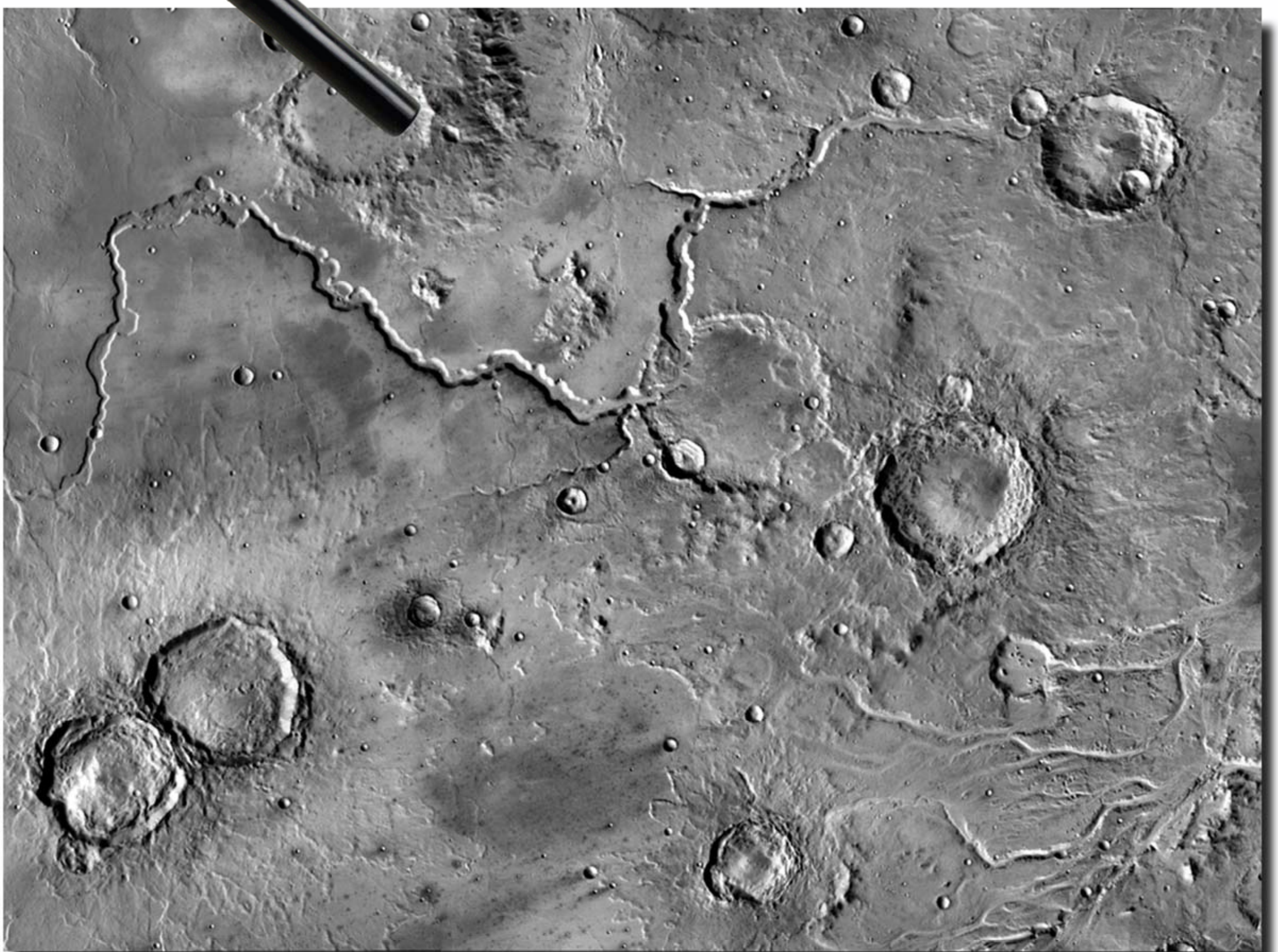
Teachers:
It is important that you as the students' MSIP teacher have a general understanding of the spacecraft and its mission, capabilities, and constraints, as this will help you guide your students to choose the most appropriate questions for their research.

Arizona State University

National Aeronautics and Space Administration

Mars Uncovered

Revealing the Geologic History Through Mapping



An inquiry-based, critical thinking lesson about interpreting the geologic history of regions on Mars

STUDENT GUIDE

Student Worksheet I

Initial Observations and Strategies

Name(s) ______________________________

Date _________________________________

Look at the Thermal Emission Imaging System (THEMIS) Daytime Infrared (IR) image mosaic your teacher has given you. You will be investigating this image throughout this activity looking for clues about the geologic history of this region. Areas where no THEMIS data has been acquired yet are seen as vertical black lines on the image.

1. What is the name of your region on Mars: ______________________________________

2. What are the two main geologic features seen in your image? Explain the process of how these features form.

   A. Geologic Feature: ______________________________

      Formation:

   B. Geologic Feature: ______________________________

      Formation:

3. List two pairs of geologic features (two craters, or a crater and a channel) that you feel you can determine which you feel is younger or older. Briefly describe where those features are located on your image mosaic (NW part of image, center of image, etc.):

   A. Two Features:____________________________ Location:____________________

      Younger Feature:____________________________________

      Older Feature:______________________________________

   B. Two Features:____________________________ Location:____________________

      Younger Feature:____________________________________

      Older Feature:______________________________________

4. Describe two strategies (methods) you used to determine which features are younger/older.

   A.

   B.

Mars Uncovered

Revealing the Geologic History Through Mapping

OBJECTIVE:
Make a simple geologic feature map of a region on the surface of Mars and using relative age dating techniques interpret its geologic history.

BACKGROUND INFORMATION:
Planetary scientists create maps of Mars in order to generate an interpretation of the geologic history of a particular region. These geologic feature maps show present day features and evidence of past events that have modified or changed a region. Scientists investigate these maps and look for clues to determine what geologic events have occurred. They do this by making observations of the surface features. Clues scientists use as part of their investigation are called relative age dating techniques. These techniques help infer a sequence of events that shaped a planetary surface. Exact dates can not be determined, but you can reconstruct a history to determine what event may have occurred before or after another. By determining the relative ages of features, the geologic history of a region can be inferred. On Earth, maps can be made by using photographs taken from airplanes or Earth-orbiting satellites. On Mars, maps can be made by using photographs (images) taken from orbiting spacecraft.

There are many images available of Mars. Over the past 30 years, NASA has sent landers, rovers and orbiters to image the martian surface. Cameras on orbiting spacecraft have taken numerous images from above the surface. Images taken of specific areas can be put together like a puzzle to create what is called a mosaic. Mosaics allow you to look at a large region of Mars. This allows scientists to map that region, analyze it, and interpret the geologic history.

This activity will put you in the role of a scientist. You will use mosaics created by images taken with the Thermal Emission Imaging System (THEMIS). This camera system is onboard the Mars Odyssey spacecraft. THEMIS has taken thousands of images of Mars that are available on the Internet (http://themis.asu.edu).

THEMIS (pictured on the left) is a two-in-one camera system:

- Visible Imaging System:
  - Shows the morphology or shape of the surface
- Infrared Imaging System:
  - Can tell us the temperature of the surface (daytime and nighttime)
  - Provides information about what materials on the surface are made of
  - Daytime infrared images can also show the morphology or shape of the surface in much the same way visible images do.

This activity will use daytime infrared image mosaics created by THEMIS. Although the infrared mosaics can provide information on both the morphology (the shape of the surface) as well as the temperature of the surface, for this activity, you will focus on the morphology of each region. This will allow you identify features such as craters and channels. As you go through the process of mapping a region it is important for you to be able to:

- Distinguish between preserved, modified and destroyed craters
- Understand different relative age dating principles

These are both considered relative age dating techniques that will allow you to better interpret the geologic history (a sequence of events that made a surface look the way it does today) of a region.

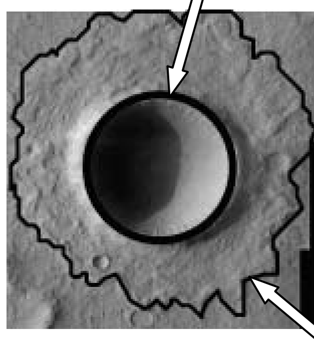
Mars Uncovered

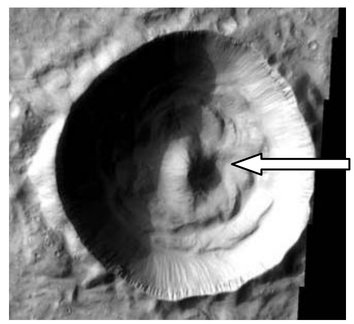
Crater Classifications

We can classify impact craters into three general categories based on their appearance. These three categories or classifications can help us understand the history (or relative age) of the crater. We can not identify the exact age of a crater on Mars, but the relative ages of different craters help us determine if one crater is older relative to another.

I. Preserved Craters:

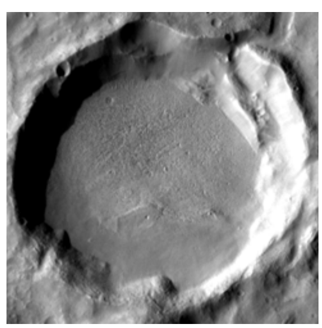
- Near perfect craters
- Raised rims
- Look new
- Can sometimes see ejecta blanket or central peak
- Young crater

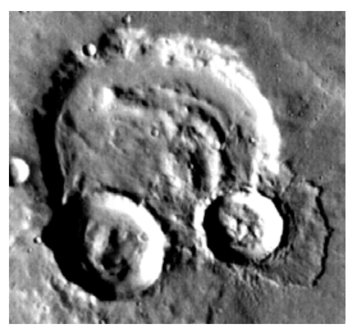




II. Modified Craters:

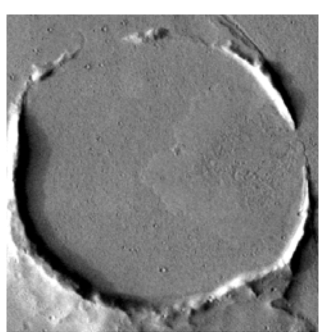
- Craters that have been changed or modified by:
    - o Erosion (wind, water or lava)
    - o Other impacts
- Sometimes crater ejecta is visible but looks eroded
- Crater may have smooth floor (partially filled in with material or sediment)
- Middle-aged craters

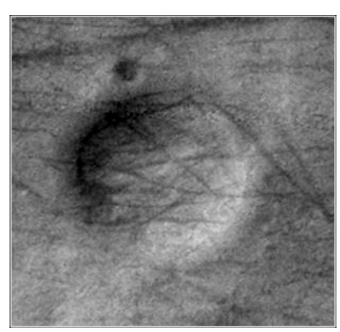




III. Destroyed Craters:

- Look very worn away
- Rims are broken
- Have been severely changed or modified
- Crater has been filled in almost completely by sediment
- Very old craters





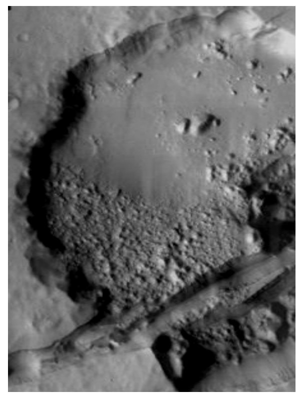
Mars Uncovered

Relative Age Dating Principles

Scientists use two basic relative age dating principles (rules) that can be used to help determine the relative age of craters or other features on a surface. They are as follows:

I. Cross-Cutting Relationships:

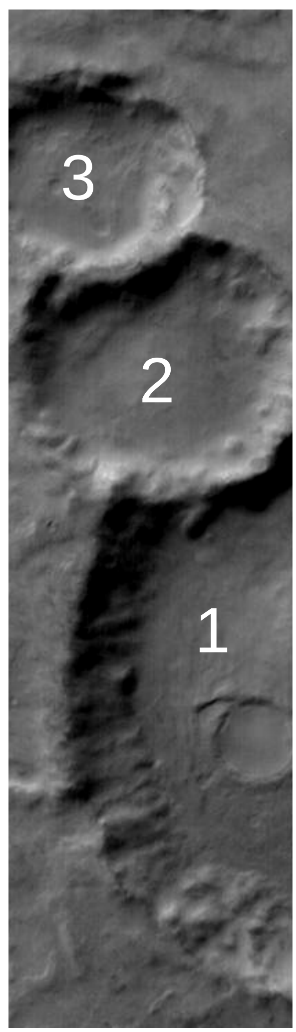
- A crater (or any other feature) can be cut by another feature.
- The feature cut is older than the feature that cut it.



Crater shown here is older than the fracture (crack) that cut through it.

II. Principle of Superposition

- When one feature is on top of another feature, the feature on top is younger.
- The feature on the bottom is the oldest feature.



Crater #1 is on the bottom of the two other craters and is therefore, the oldest.

Crater #2 is on top of crater #1 so it is younger than crater #1.

Crater #3 is on top of crater #2 so it is the youngest of all.

Student Worksheet II

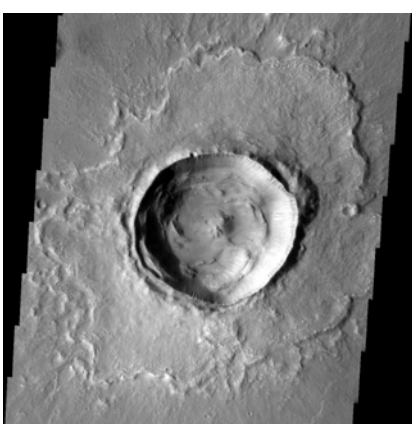
Classifying Craters

Name(s) ________________________________

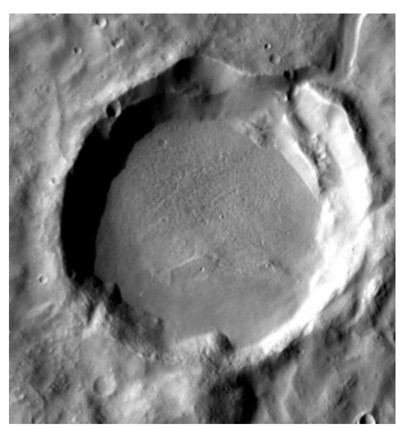
Date __________________________________

Based on the *Crater Classification* information sheet, classify the craters at the bottom of the page. Be sure to explain your reasoning for each classification.

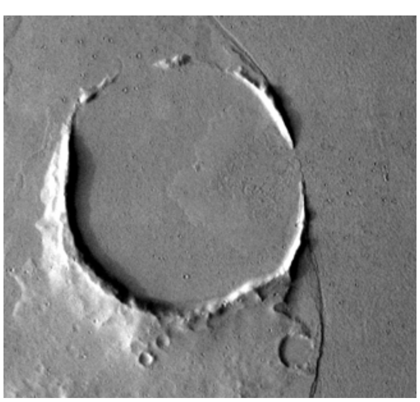
CRATER IMAGE	CRATER CLASSIFICATION: Preserved, Modified or Destroyed	REASONS
Crater A		
Crater B		
Crater C		
Crater D		



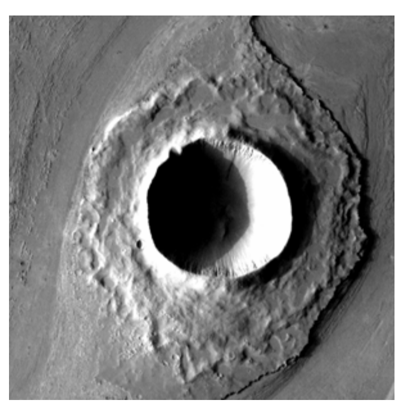
Crater A



Crater B



Crater C



Crater D

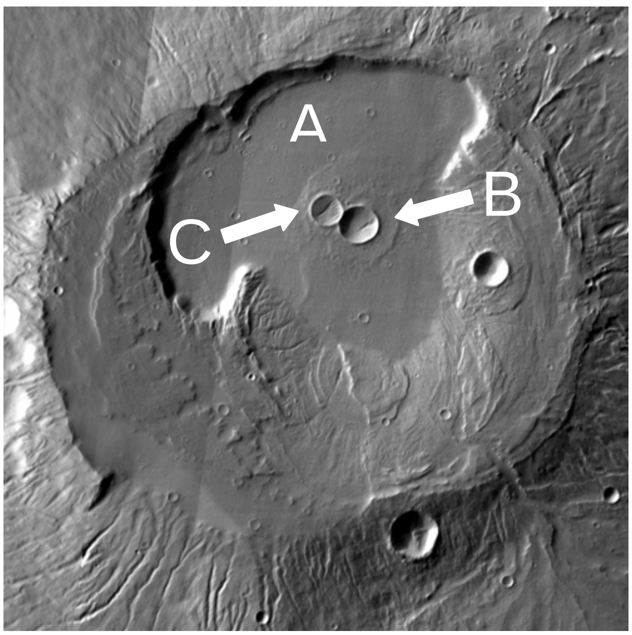
Student Worksheet III

Relative Age Dating Principles

Name(s) ________________________________

Date __________________________________

Based on the two relative age dating principles (cross-cutting relationships and superposition), write your interpretation of the relative ages of the features in the following images:



Oldest Crater: ________

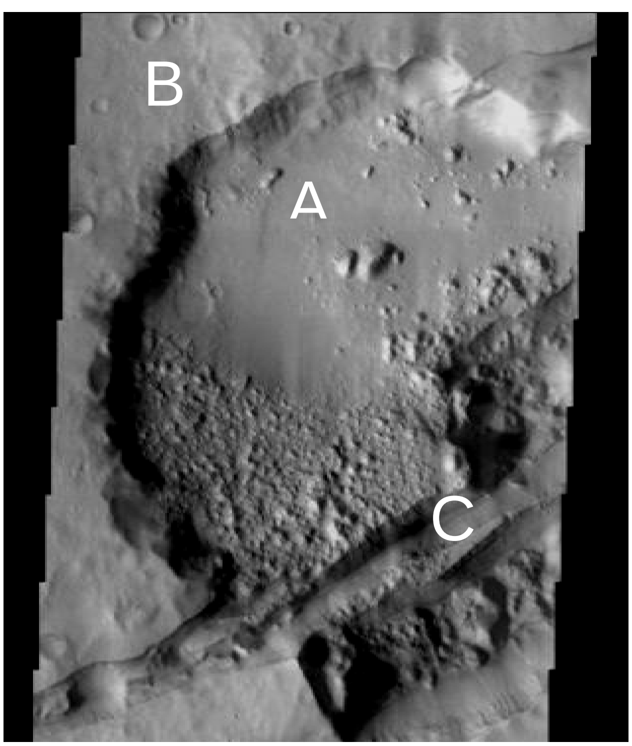
Younger Crater: ________

Youngest Crater: ________

Please explain your answers:

Which principle(s) did you use to choose your answer?

____



Oldest Feature: ________

Younger Feature: ________

Youngest Feature: ________

Please explain your answers:

Which principle(s) did you use to choose your answer?

____

Student Worksheet IV

Creating a Surface Feature Map

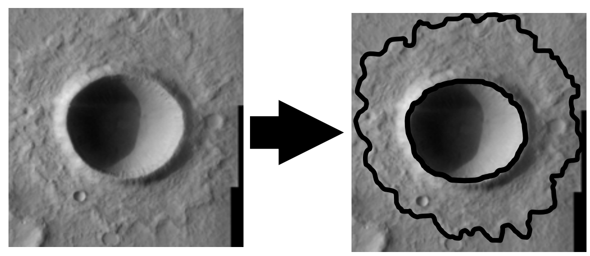
Now you know how to classify craters and are familiar with relative age dating principles. You can now create a feature map of your region of Mars that will help you interpret the geologic history.

In order to create your feature map, you will need to put a piece of transparency paper over your THEMIS mosaic image. Using paper clips, secure the THEMIS image and your paper together.

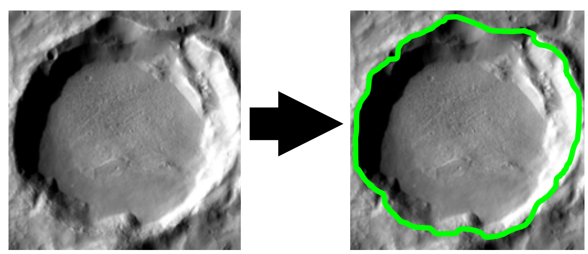
Using your observations and erasable markers, identify the features listed below to create your map. Keep in mind that some features may be too small to map. Use your best judgment to decide what may be too small to map and in determining how to the outline or color features. Outline or color the features as indicated below.

Feature | **Colored Feature**

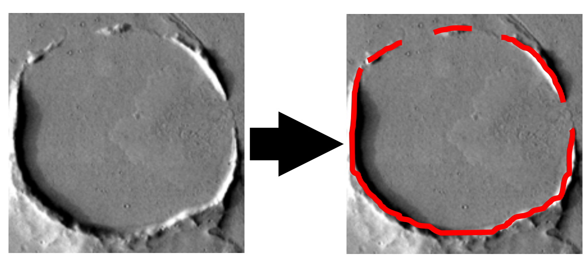
1. **Preserved Craters**: Carefully outline the rims and ejecta (if visible) of all preserved craters in **BLACK.**



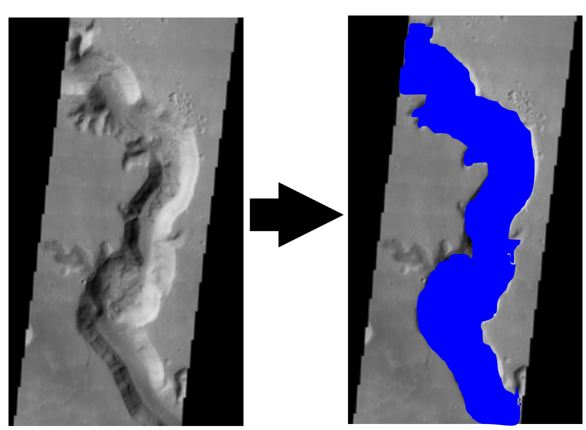
2. **Modified Craters**: Carefully outline the uneven, or eroded rims and ejecta (if visible) of the modified craters in **GREEN.**



3. **Destroyed Craters**: Carefully outline the very eroded crater rims in **RED.**



4. **Channels:** Color (not outline) all channels in **BLUE.**



Student Worksheet V

Interpreting the Geologic History

Name(s) ________________________________

Date ___________________________________

Once you have made your feature map, you are now able to answer some questions and interpret the geologic history of your region. Be sure to name the age dating technique you used for each answer.

REGION NAME: ______________________________________

1. Which is older – the channel(s) (blue) or the destroyed (red) craters? How do you know?

2. Which is older – the channel(s) (blue) or the modified (green) craters? How do you know?

3. Which is older – the channel(s) (blue) or preserved (black) craters? How do you know?

4. Which are older – most large craters or smaller craters? How do you know? Why do you think this is?

5. Which features are oldest, youngest, and of medium age?

STUDENT WORKSHEET V
Interpreting the Geologic History
(cont'd)

6. Scientists don't always agree, but they try to convince each other with logical reasons for their interpretations. Discuss and defend your answers to questions #1 through #5 with another group that is studying the **same region**. Change any of your answers to questions #1 through #5 if you feel it is necessary. Fill out the table below after your discussion.

Question #	Did you agree or disagree with the other groups answer	Did you change your answer (yes or no AND why) (Be specific and use 'geologic reasons')
1		
2		
3		
4		
5		

7. Write your interpretation of the geologic history (the sequence of events that made this area look the way it does today) of this region of Mars. You can use this sample starting sentence or create your own. Use additional paper as necessary.

In the __________________________ region of Mars, there was a lot of geologic activity that modified the surface. First, what happened was…..

Student Worksheet VI

Initial Strategies and Future Investigations

Name(s) ___________________________________

Date ______________________________________

1. Look back at question #4 from *Student Worksheet I*. List each of your initial strategies in the first column provided below. In column two, indicate if you feel it was a valid scientific strategy (method) to use. Use the knowledge you acquired after completing the lesson to make this decision. In the third column, state the common scientific name (if one exists) for the strategy you listed (crater classification or one of the relative age dating principles). If you feel your strategy is valid but there is no name for that strategy, create a name for that strategy that you feel is appropriate. If you feel the scientific strategy is not valid, leave the last column blank.

Initial Strategy Used	**Valid Scientific Strategy (Yes or No)**	**Common Scientific Name (if applicable)**

2. After creating, observing and interpreting your feature map, list at least two questions you have about channels or craters on Mars and how would you go about investigating each question?

Question about craters or channels on Mars	**How would go about investigating your question?**
1.	
2.	

NOTES

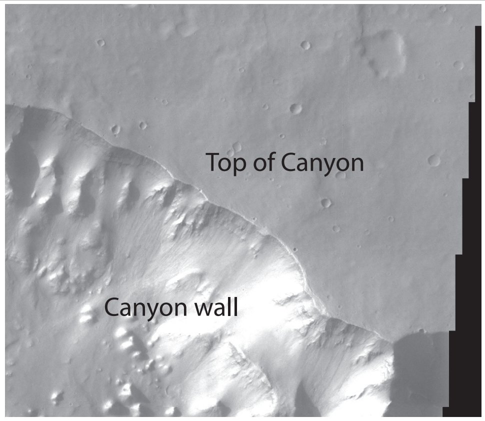
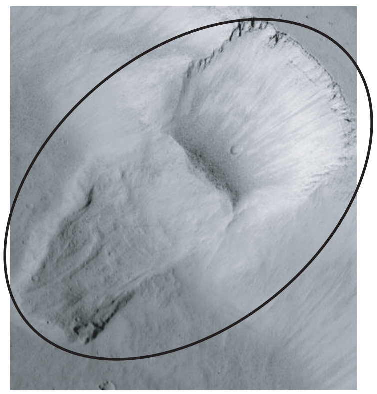
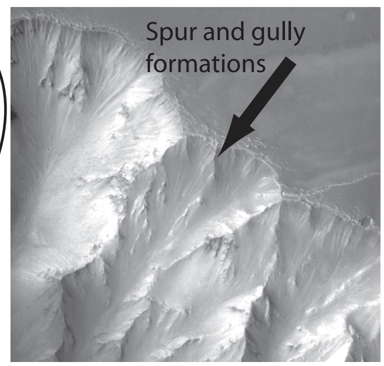
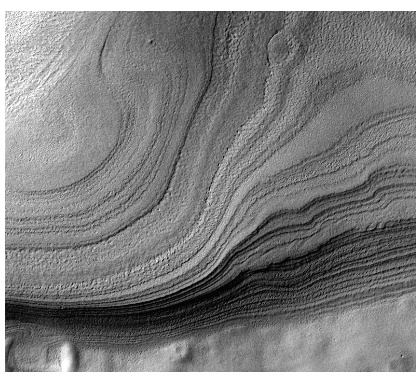
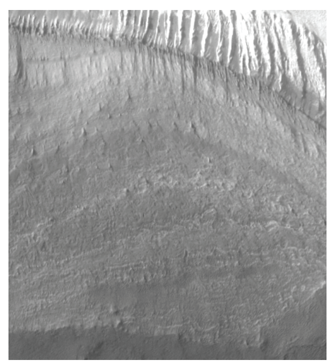
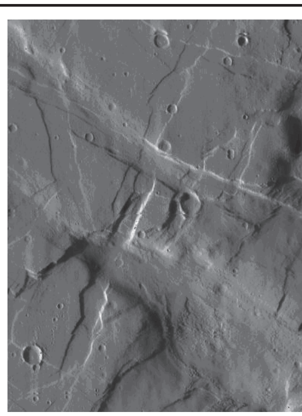
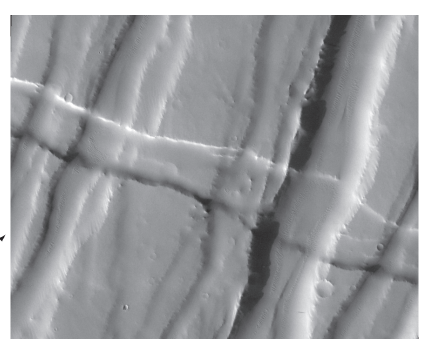
Mars Uncovered

Revealing the Geologic History Through Mapping

http://marsed.asu.edu
http://msip.asu.edu

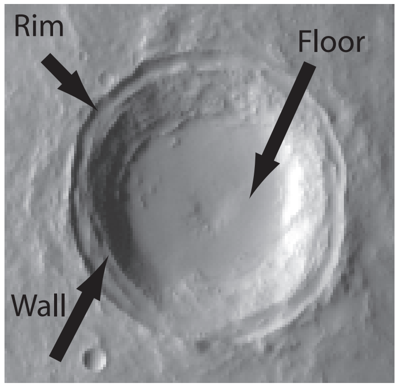
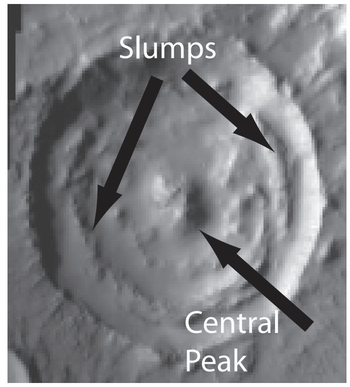
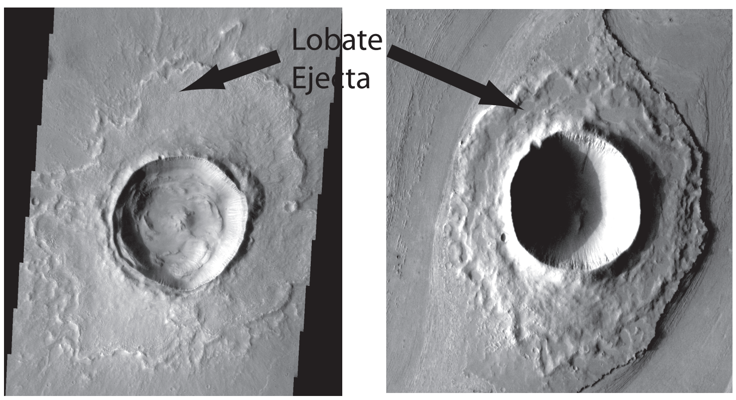
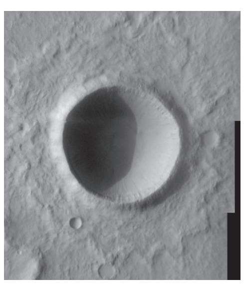
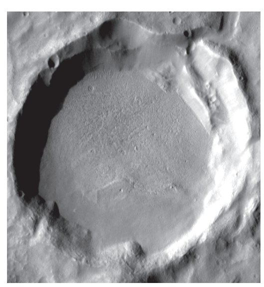
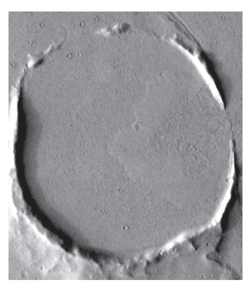
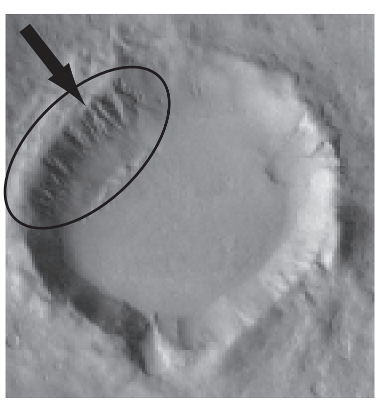
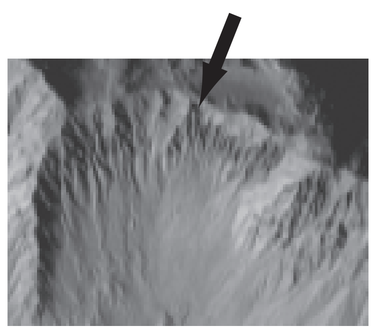
FEATURE IDENTIFICATION CHART

Features Often Associated with Canyons

Feature	An Example of this Feature	Description of Feature
Canyons		-Identified by a steep drop in elevation, similar to what we see with canyons on Earth -Canyon walls often show material that has fallen or slid down slope -Top of canyon is generally flat and smooth
Landslides	 	-Material that has fallen or slid down a steep slope -Landslide material piles up at the bottom of slope -Often seen on steep canyon walls -Spur and gully formations are landslides that look similar to gullies that can be seen on crater walls
Layers	 	-Layers of material can be seen in different areas of Mars, including canyon walls -May be formed by stacks of lava flows, ash from volcanoes, dust, or by sediments deposited in water
Fractures/Faults	 	-The result of a break in the surface -Thought to be a result of weaknesses in the crust -Generally straight features that scar the surface -Often run parallel in areas where multiple fractures occur

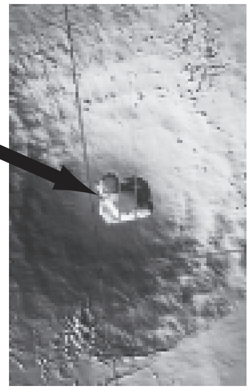
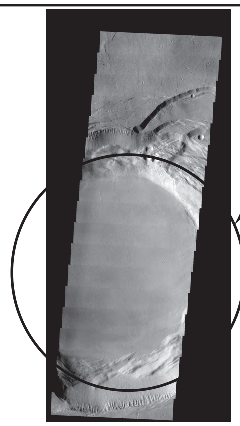
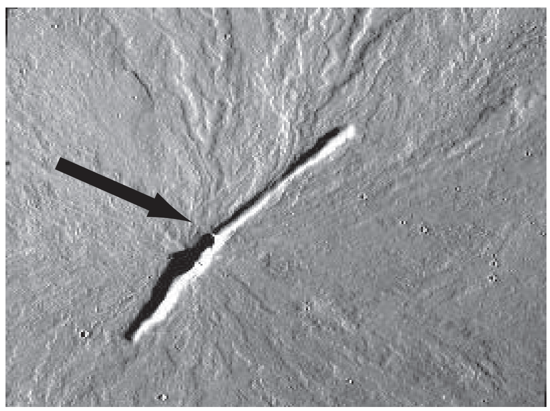
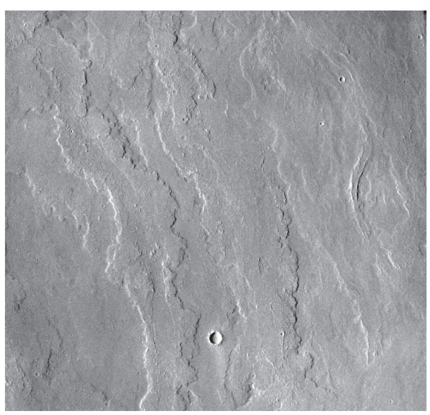
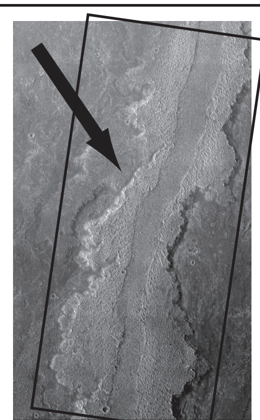
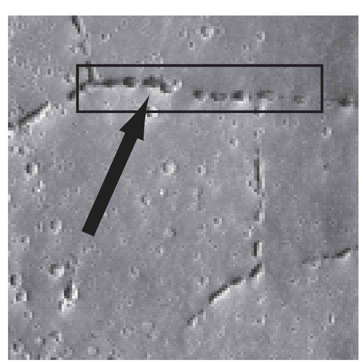
FEATURE IDENTIFICATION CHART

Features Often Associated with Craters

Feature	An Example of this Feature	Description of Feature
Crater	 	-Formed by meteorites striking the surface -Circular in shape -Have a rim, floor, and walls -Some have central peaks -Material can slump down to the bottom of the crater
Rampart Crater		-Have a special ejecta called lobate -Lobate ejecta looks like it flowed away from the crater (as if you dropped a ball into mud) -Are associated with liquid water or ice being below the surface at impact
Crater Classifications: Preserved Modified Destroyed	Preserved  Modified  Destroyed 	**Preserved Craters:** -Near perfect craters -Raised rims; look new **Modified Craters:** -Older craters -Changed by erosion or other impacts **Destroyed Craters:** -Very old -Look very worn away
Gullies	 	-Often found on crater walls or other slopes -Appear to be very young -Possibly associated with: 1. Past liquid water 2. Areas once covered with snow

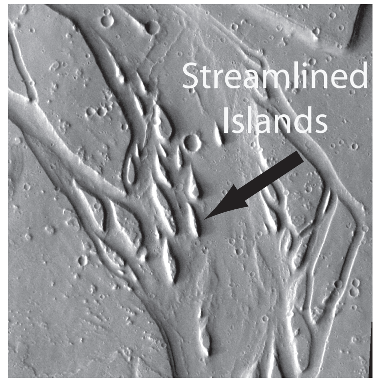
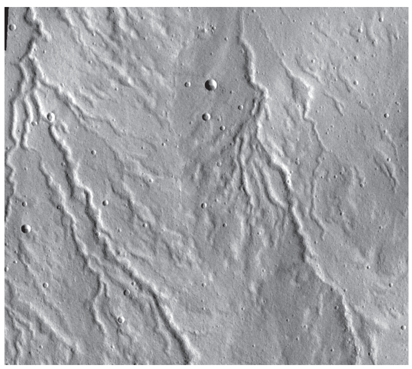
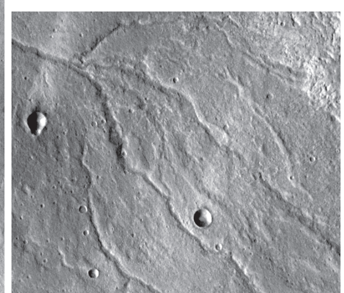
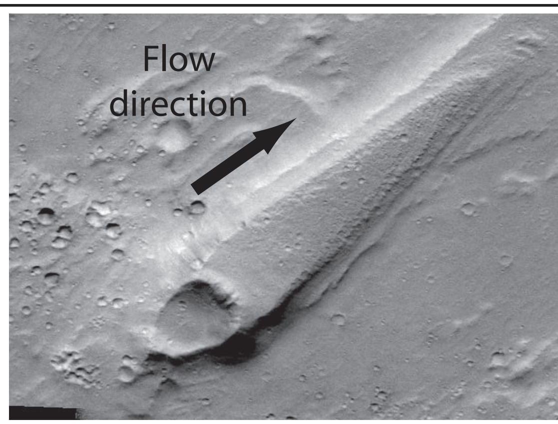
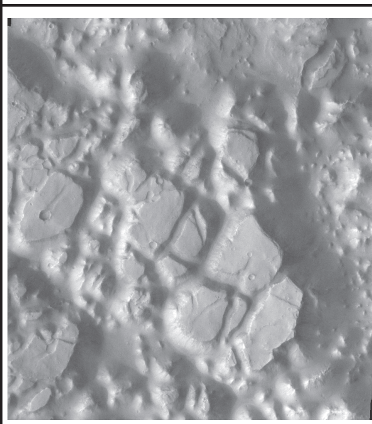
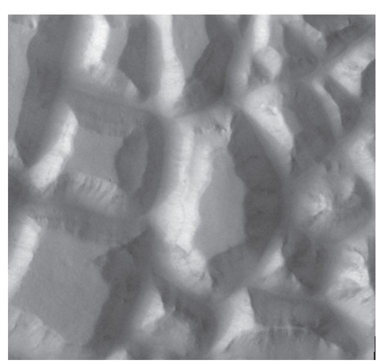
FEATURE IDENTIFICATION CHART

Features Often Associated with Volcanoes

Feature	An Example of this Feature	Description of Feature
Caldera	 	-A circular depression generally at the summit of a volcano -Considered a collapsed feature (magma comes up through a chamber and once the chamber is empty, collapse can occur) -Sometimes called a central vent
Fissures		-Cracks that are found sometimes on the sides of volcanoes -Lava flows can be seen trailing away from these cracks, indicating a fissure eruption
Lava Flows	 	-Formed by the eruption and flow of lava from a volcano -Flows can look "wavy" or “fingery” -You can often identify multiple lava flows in an image -Flows are raised features
Collapsed Lava Tubes	 	-Look similar to channels -Lava once flowed under ground through a “tunnel” and once the tunnel is empty these features often collapse -Some aren’t completely collapsed and look like a chain of small craters

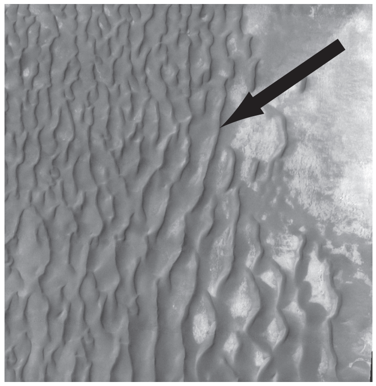
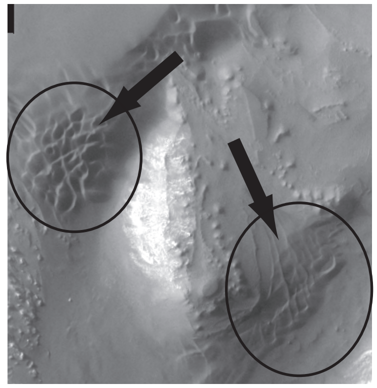
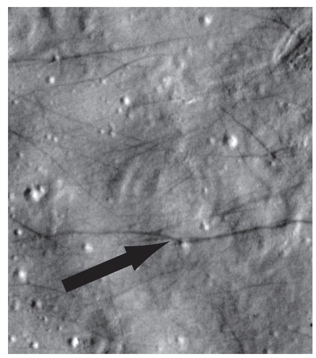
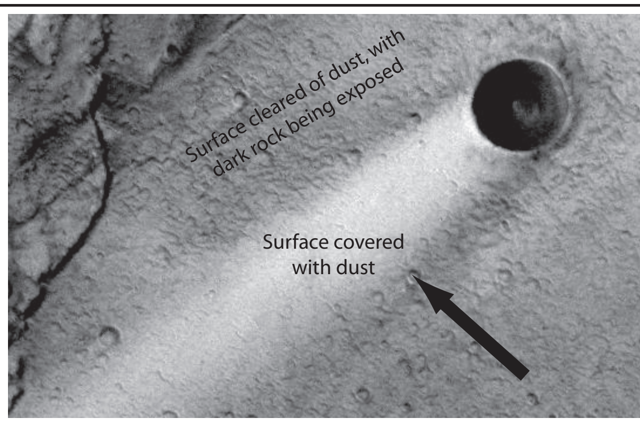
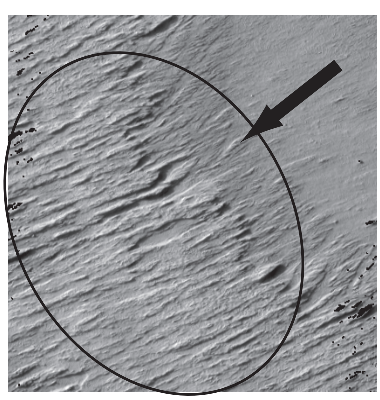
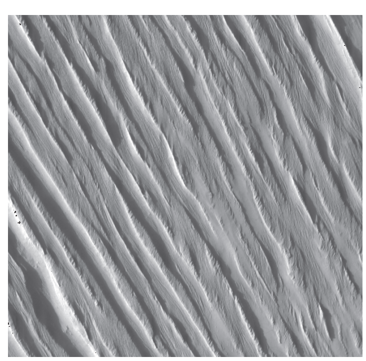
FEATURE IDENTIFICATION CHART

Features Often Associated with Water-Related (Fluvial) Processes

Feature	An Example of this Feature	Description of Feature
Channels	 	-Large channels are thought to have formed by a catastrophic flow of water -Seem to form curvy “river-like” features -May have streamlined islands
Valley Networks	 	-Small channels -Generally formed by flow of water in the past -May have numerous branches that start small and feed into larger branches
Streamlined Islands		-Thought to be associated with the past flow of water around a feature, such as a crater -Often found in large channels where large amounts of water flowed -Indicate flow direction -Also called teardrop islands
Chaotic Terrain	 	-Often found at the head or start of large channels -Thought to be areas where water burst out from the ground causing a chaotic collapse of the surface -Can look like jumbled terrain

FEATURE IDENTIFICATION CHART

Features Often Associated with Wind-Related (Aeolian) Processes

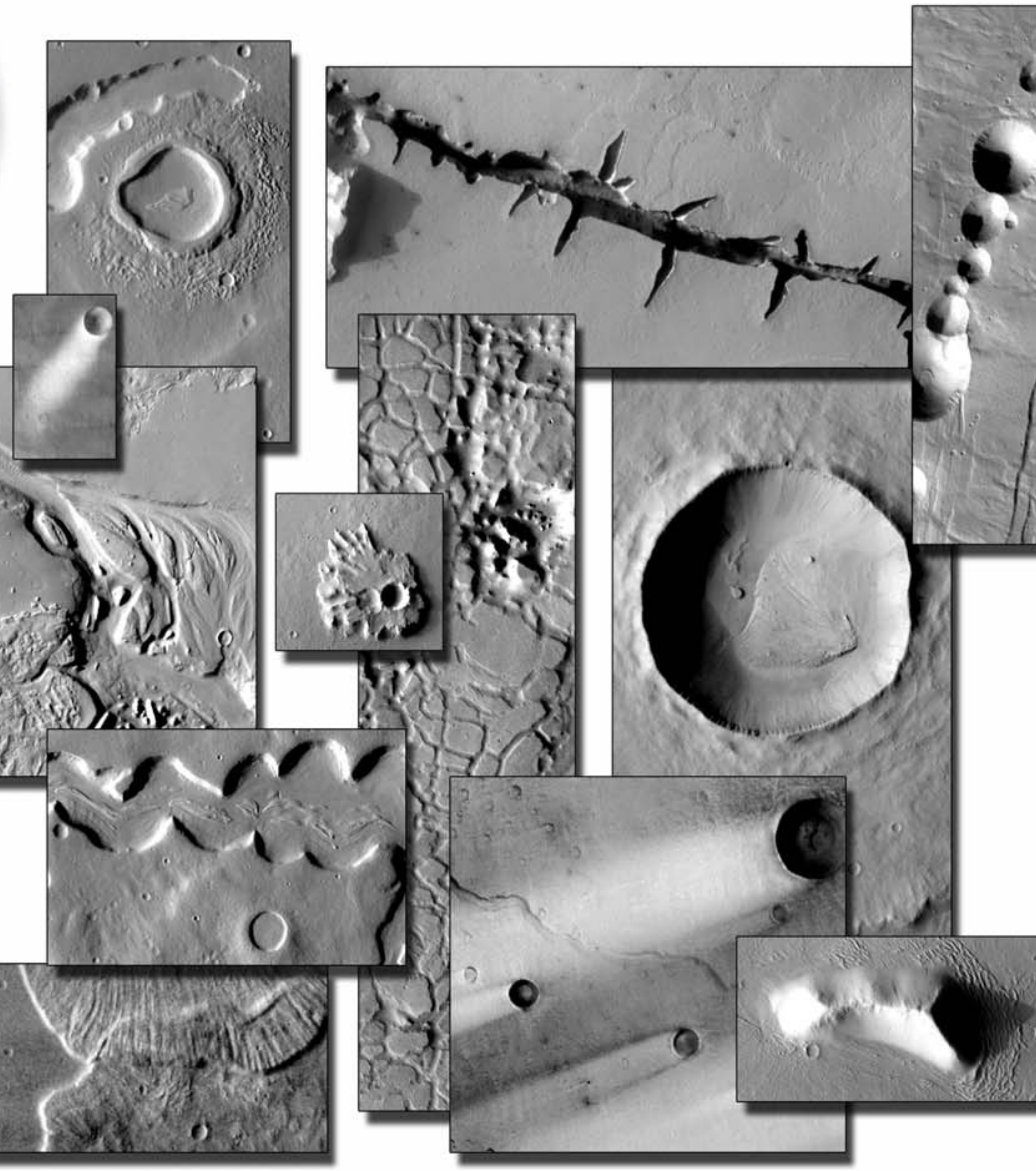
Feature	An Example of this Feature	Description of Feature
Sand Dunes	 	-Can form in many areas -Often seen in the bottom of craters or channels -Generally darker than the surrounding terrain -Can range in size and shape -Look like ripples of material
Dust Devil Tracks	 	-Left by dust devils (mini-tornadoes) moving through an area -Dust devils pick up dust uncovering the darker surface underneath -Darker tracks are newer -Lighter tracks tend to be older, as they could have been recovered by some dust
Wind Streaks		-Can be light or dark -Are often seen behind craters -Can give you an idea of wind direction
Yardangs	 	-Formed by sand-sized particles being blown against a surface wearing it away -Have a uniform direction -Are linear features -Found on surfaces that erode easily

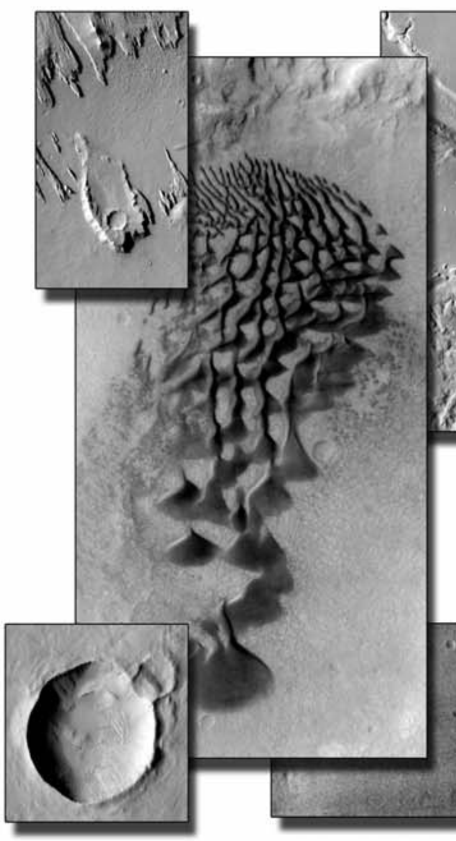
Arizona State University

National Aeronautics and Space Administration

Question Mars

An Introduction to the Process of Science





An inquiry-based, critical thinking lesson as an introduction to the process of science.

STUDENT GUIDE

Question Mars

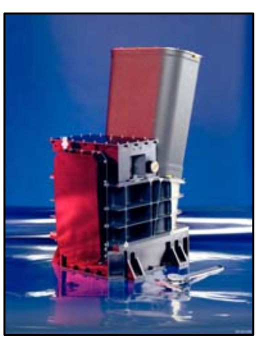
An Introduction to the Process of Science

Objective: Create a question about Mars that can be answered using images taken from orbit.

Student Introduction:
All science begins with a question. That is the foundation of this activity. The beginnings of the process of science, or what some people refer to as the “scientific method”, that we learn in our classrooms start from questions we create based on our curiosity. Professional scientists have questions about Mars they want to answer, and so will you as you start to investigate images from our neighboring planet. As you go through the process of science as it relates to this activity, it is important for you to:

- Think about what you are curious about related to Mars and create general questions
- Evaluate your questions making sure you have appropriate tools to answer those questions
- Realize that science is most often conducted in small bits and pieces. It’s understandable to have “big picture” questions, but scientists (and you) need a specific focus/question of study. This will contribute to a greater understanding about Mars through detailed research.

There are many images available of Mars. Over the past 30 years, NASA has sent landers, rovers and orbiters to image the surface of Mars. This activity will focus on images that have been taken from orbit. The Mars Odyssey spacecraft has been orbiting Mars since 2001. One of the tools it uses to take images of Mars is the Thermal Emission Imaging System (THEMIS). THEMIS has taken thousands of images of Mars that are available on the Internet (http://themis.asu.edu).



THEMIS (pictured on the left) is a two-in-one camera system:

- Visible Imaging System:
  - Shows the morphology or shape of the surface
- Infrared Imaging System:
  - Can tell us the temperature of the surface (daytime and nighttime)
  - Provides information about what materials on the surface are made of
  - Daytime infrared images also show the morphology or shape of the surface in much the same way visible images do.

As you gather observations, you should try to focus on and examine visible images. If you do decide to examine infrared images, just be sure to focus on the shapes (morphology) of the surface features you see.

All science begins with a question and continues with observations and the development of possible hypotheses based on your initial observations. Keep in mind that it is a natural part of science to refine or even change your question as you research. The process of science continues with designing an experiment of how to answer that question and test your hypotheses. For this activity, the focus is on coming up with a question to research using the THEMIS camera as your primary tool or data set. This is not necessarily an easy task, but through making observations and looking for patterns, it should be fun!

Student Worksheet I

Establishing a Research Topic

Name(s) ________________________________

Date ___________________________________

1. Within your group, brainstorm four general topics that can be studied about Mars:

______________________ ______________________

______________________ ______________________

2. After a class discussion, list six major categories of topics the class can choose to study about Mars:

______________________ ______________________

______________________ ______________________

______________________ ______________________

3. List the topic your group will research: ______________________________

Brainstorming Questions

List five questions you are curious about based on your topic and how it may relate to Mars:

Question 1: ____

____

Question 2: ____

____

Question 3: ____

____

Question 4: ____

____

Question 5: ____

____

Student Worksheet II

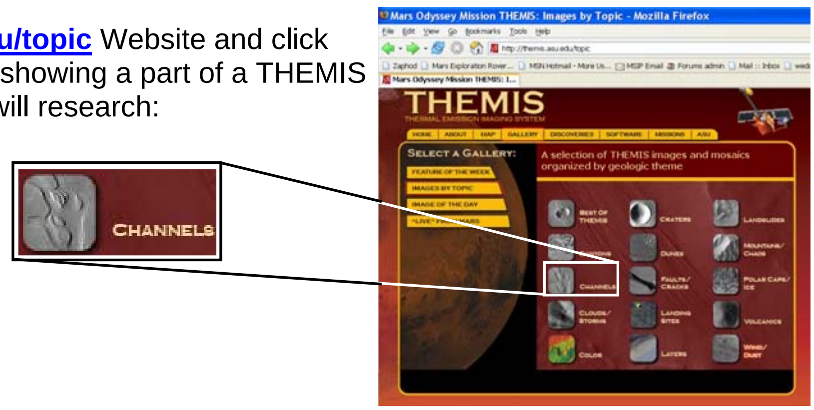
Making Observations of THEMIS Images

Name(s) ________________________________

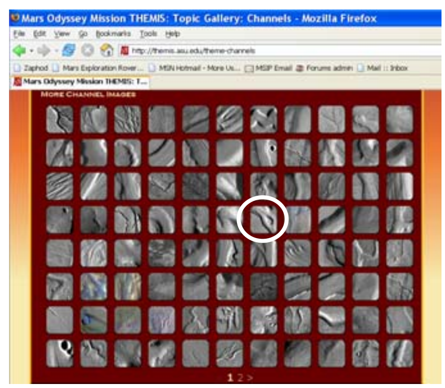
Date __________________________________

This activity will focus on images that have been taken from orbit by the Thermal Emission Imaging System (THEMIS) onboard the Mars Odyssey spacecraft. These images of Mars show great detail of many of the geologic features seen on the surface of Mars from orbit. In this exercise, you will look at THEMIS images and log specific information about each image you observe. Here's what to do:

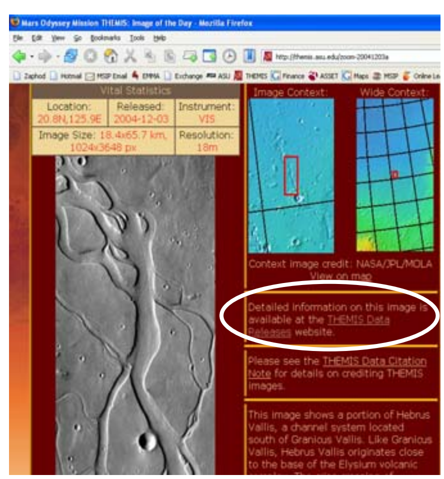
1. Go to the http://themis.asu.edu/topic Website and click on the thumbnail (small square showing a part of a THEMIS image) of the topic your group will research:



2. Click on any of the thumbnails to see a THEMIS image of Mars related to your topic:
   - There are six large thumbnails at the top of the page.
   - Below the top six thumbnails are more thumbnails of additional images.
   - There are generally multiple pages of image thumbnails to choose from.



3. Click on a thumbnail to see a specific THEMIS image, context images showing the area where the image is located on Mars, and general information about the image.
   - You can get an enlarged view of the THEMIS or context images by clicking on the image.
   - To get the Image Identification Number click on the THEMIS Data Releases link.
     - This will open a new window showing the Image ID # and image information
     - Images that are not yet released will not have this link.



STUDENT WORKSHEET II (continued)

4. Log the information on the observation tables. Make observations of a minimum of 4 images. The more images you can observe, the more easily you can look for patterns. Log the following:

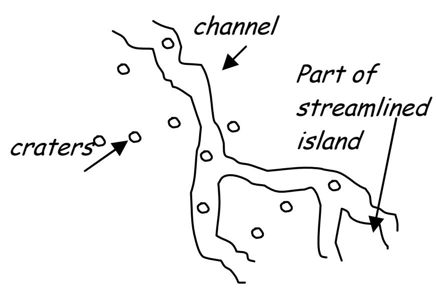
    a. Surface/Geologic Feature(s) Observed: Name the **specific** surface/geologic features you find interesting in each image. Look for patterns or for the same surface/geologic features in multiple images. Be sure to include those same features in your table multiple times. This will help you remember how a particular feature looks the same (or different) in multiple images – very valuable information! To help you correctly name surface/geologic features, use the **Feature Identification Charts**.

    b. Image ID Number: If the image has the THEMIS Data Releases link, click on it to find the image identification number. If not, write the title of this image and/or the page, column, and row number to possibly relocate it.

    c. Sketch the Feature(s): Make a sketch or drawing of the portion of the THEMIS image that shows the feature(s) you are observing. Do not sketch the entire image.

    d. Specific Observations of Feature(s): Write down specific observations of the feature(s) you sketched. Consider patterns you may look for with these features in other images.

Here's an example of how you can fill out the observation table:

Surface/Geologic Feature(s) Observed & Image ID #	Sketch of Surface/Geologic Feature(s)	Specific Observations of Surface/Geologic Feature(s)
Channel with craters **Image ID #:** V11030007		*-Channel does not seem very wide* *-Can see streamlined islands* *-Small craters both on the outside and inside of channel* *-All craters in image seem to be about the same size*

Student Worksheet II

Making Observations of THEMIS Images

Surface/Geologic Feature(s) Observed & Image ID #	Sketch of Surface/Geologic Feature(s)	Specific Observations of Surface/Geologic Feature(s)
Image ID #:		
Image ID #:		
Image ID #:		
Image ID #:		

Student Worksheet II

Making Observations of THEMIS Images

Surface/Geologic Feature(s) Observed & Image ID #	Sketch of Surface/Geologic Feature(s)	Specific Observations of Surface/Geologic Feature(s)
Image ID #:		
Image ID #:		
Image ID #:		
Image ID #:		

Student Worksheet III

Question Development – Refining Questions

Name(s) ___________________________________

Date _____________________________________

After making your observations of the different surface/geologic features, you should now have a better idea of what types of questions can be answered using THEMIS images. Keep in mind that ALL questions are good questions! Anything you are curious about is a valid question! For any science experiment, however, your question should be answerable by using the tools you have available. Your primary tool is the THEMIS camera.

Create three new questions that focus on specific geologic feature(s) you have observed. Important points to think about are:

- Focus on Identified Surface/Geologic Features: Look at your *THEMIS Observation Tables*. Choose a **feature or combination of features** (sand dunes, lava flows, lava tubes, etc.) you were able to identify in one or more THEMIS image as the focus of your question. You must be able to answer your question by looking at images.
- Try to focus on **size(s)** or **shape(s)** or **where a feature may form**.
- Key Question Words: Here are some suggested key words/phrases you may consider using:
  - Is there a relationship between __________________ and __________________?
  - What is the size range of ____?
  - Where do ___________________ occur on or around ______________________?

Here are two examples:

Example 1: Name of Surface Feature: Lava tubes

Sample Question: How wide are different lava tubes on Mars?

Example 2: Name of Surface Feature: Dunes and craters

Sample Question: Is there a relationship between crater size and evidence of sand dunes?

Create your new questions below:

Name of Surface Feature(s):_________________________________

Question 1: ____

____

Name of Surface Feature(s):_________________________________

Question 2: ____

____

Name of Surface Feature(s):_________________________________

Question 3: ____

____

STUDENT WORKSHEET IV

Experiment Design and Hypothesis Development

Name(s) ________________________________

Date ____________________________________

For this exercise you will focus on one particular question that you refined in the last exercise. You will create a plan (an experiment design) of how you would go about answering that question using THEMIS images. Additionally, you will develop a set of working hypotheses (possible answers to your question) and consider how you would go about testing those hypotheses.

Science Question:____

____

1. What specific feature(s) do you need to have in a THEMIS image to answer this question?

2. What regions of Mars would you go to in order to find images that would help you answer this question? (You can either name regions or Mars or describe what type of regions you would look for.)

3. How many images of Mars do you think would be necessary to realistically and sufficiently answer your question?

1 5 - 10 20 - 40 60 - 80 100+

Please explain:

4. Do you need to make any measurements to answer your question? If yes, what measurements need to be made?

Student Worksheet IV (continued)

5. Based on your current observations, list up to two possible outcomes to the answer to your question? (These will become your two working hypotheses.) Include what observations you have already made that lead you to formulate each hypothesis.

Hypothesis A:

Current observations that support this hypothesis:

Hypothesis B:

Current observations that support this hypothesis:

6. In science, experiments need to be designed so they are repeatable. This allows others to conduct the experiment following the same step-by-step procedure to get the same results. Let's pretend that you actually gathered the data from questions #1-4 in this section in order to answer your science question and test your hypotheses. Would that be enough information to have your experiment be repeatable? If yes, please explain. If no, what other information might you need to obtain to make your experiment repeatable by any scientist?

Student Worksheet V

Experiment Design – Refining Your Experiment

Name(s) ___________________________________

Date ______________________________________

1. When designing an experiment to answer a question, you need to be able to describe, in as much detail as possible, the step-by-step plan of how you would go about answering your question and/or testing your working hypotheses. To do this, think about specific information (including details from the previous questions) you would need to record from each image you observe, and what steps you would take to obtain data towards answering your question. It is important to think about why each step would be important in your process.

Here's how you may consider starting your list of steps:

1. First I would go to the http://themis.asu.edu *topic page** website to find images I could make observations of that pertain to my question and hypotheses. For my project I would look at images relating to ________________________ (*list what topic/feature you are focusing on)*. (*Think about whether you would use the topic page or the map tool.)

2. For each image I observe, I would write down the **Image Identification number** (the V#) so that I (or other scientists) could reexamine those images at any time.

3. For each image I observe, I would also write down whether it had the specific feature/s in the image that I am looking for. Even if the image does not have the feature that I am looking for, that still would be valuable data. The specific feature/s I would be looking for are: ____ *(list the specific geologic features you are looking for).*

4. Next I would record the **latitude/longitude** of each image to look for any patterns in the observations I make and also to be able to plot that information on a map.

Continue this list or start a new list that describes how you would go about gathering data to test your hypotheses and help answer your question. (Use additional paper as necessary.)

2. How will conducting each step of your test ensure that you have a complete and unbiased data set?

NOTES

Question Mars

An Introduction to the Process of Science

http://marsed.asu.edu

http://msip.asu.edu

MARS STUDENT IMAGING PROJECT

Graphing Information and Data Analysis

This activity is designed to help you organize data collected in order to graph and analyze it. The data table provided in this example is a sample only. Many data tables put together by students may have more data than what is shown on this sample table.

Goal of Activity: After completing this activity you will be able to:

- Use Excel to input any data you collect
- Use Excel to select and graph any pair of data you collect
- Make observations of data you graphed
- Make interpretations from your observations

Graphing Information and Data Analysis

Presenting the information or data you gather from your images can be done several different ways. Having your information in a data table is extremely important. This will allow you to have an organized view of your data. This can also help you decide what to graph. Additionally, it will help you analyze your data. For this exercise, you will be asked to look at some sample data taken of channels. For this example, a channel's width and depth have been determined. This information, along with other important information is presented in a data table. You could leave the information in the data table and make observations, but it is important to illustrate your data in a way that is easy for you to analyze it.

Below is a data table that shows channel data from five THEMIS images. The THEMIS Image ID's are not real. Follow the instructions to graph this data:

	A	B	C	D	E
1	**THEMIS Image ID**	**Longitude (E)**	**Latitude (N)**	**Channel Width (meters)**	**Channel Depth (meters)**
2	V11111111	288.2	17.1	720	43
3	V22222222	177.6	-17.3	16952	926
4	V33333333	136	26.6	3626	301
5	V44444444	41.6	11.5	12836	658
6	V55555555	106.5	-41.4	4291	661

1. Open Excel by clicking on the green Excel icon on the desktop. ( )

2. Choose a new Excel workbook.

3. Type in the data from the table above into your new Excel workbook. Make sure to enter the data from columns A through E from the white boxes only.

4. Click and drag your mouse over all the cells below **columns D** and **E**, including their titles ("Channel Width" and "Channel Depth").

5. Choose **Insert ▶ Chart.**

6. Choose a **XY (Scatter)** chart in the left-hand menu and click **Next**.

MARS STUDENT IMAGING PROJECT

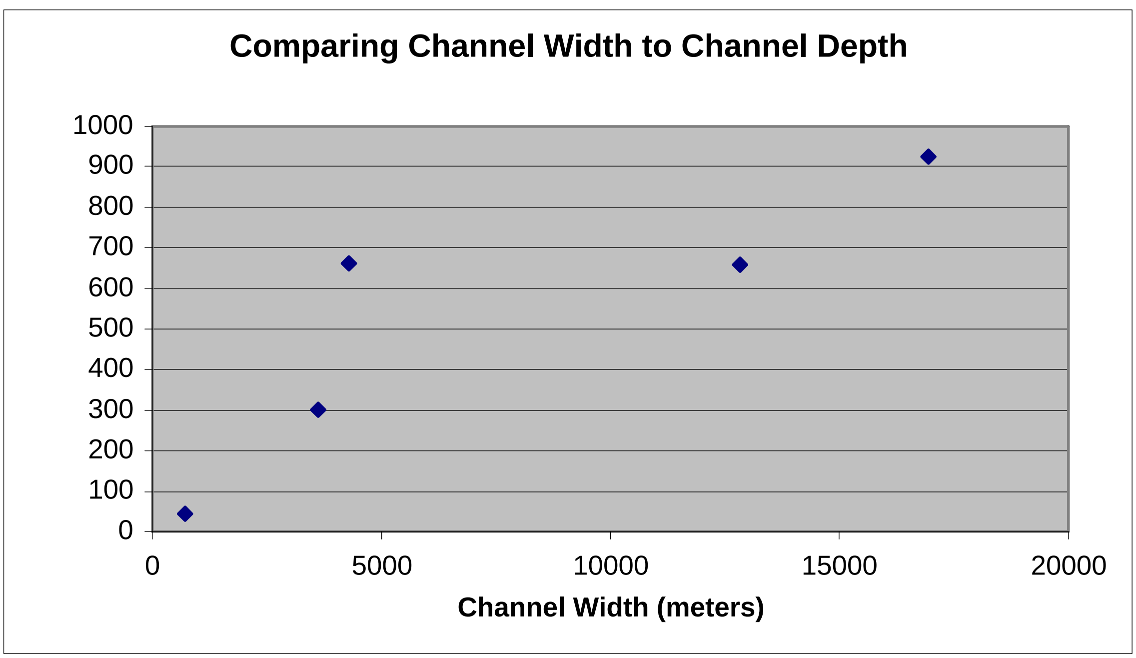
Graphing Information and Data Analysis (cont.)

7. Make sure your chart looks alright in the preview box. Then click **Next**.

8. In the Chart Options dialog box click on the *Titles* tab and enter a title for your chart. Then enter the titles for each X and Y axes in the "Value" boxes. For example, the "Channel Width (meters)" would be the X-axis title. Also, be sure to include the correct channel dimension for your Y-axis.

9. Under the *Legend* tab, uncheck **Show Legends**, then click **Next.**

10. Choose to place your chart "as new sheet" and click **Finish**. Your chart should look similar to the one below.



Graphing Information and Data Analysis (cont.)

Now that you have graphed channel width versus channel depth from the data table, it's important to determine what these data mean scientifically. This can be done in two important steps: 1) making **observations** of your data, and 2) using these observations to make **interpretations**.

Observations are made by looking at data and explaining their general characteristics, including any patterns or trends. For example: This graph shows that channels with greater widths are generally be deeper.

Interpretations are made by taking observations and explaining what they may mean scientifically. For example, an interpretation of why wider channels tend to be deeper, could be that wider channels were formed by greater amounts of water. Channels that *don't* follow this trend may indicate that there are other processes at work on Mars that need to be considered.

Make one observation of your own of the channel data in the graph:

____

____

Make one interpretation of your own of what your observation may mean:

____

____

For your science project and question, list two specific pairs of information you could graph, including what the graph could tell you about these data. (For the above example it was channel width versus channel depth. This told us if there was a relationship between the width and depth of channels - which there was.)

1. ___________________________versus___________________________

   Can tell you____

   ____

2. ___________________________versus___________________________

   Can tell you____

   ____

Graphing Information and Data Analysis (cont.)

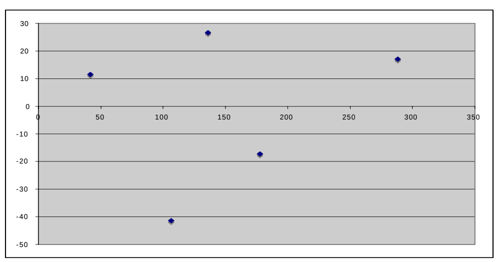
It may also be helpful when analyzing your data to plot the latitudes and longitudes of your THEMIS images on a map of Mars which will give you a different type of graph! One reason for doing this is to see where your channels (or whatever feature you are studying) are located on the planet, including where they are in relation to each other. You could also see other geologic features present in the region that may have a relationship to the channels you observed. These types of relationships are difficult to see in a data table!

1. To see the table of data you entered in the previous activity, click on the “Sheet” tab at the bottom of your screen. Then click and drag your mouse over all the cells below columns B and C, including their titles (“Longitude” and “Latitude”).

2. Choose **Insert ▶ Chart**.

3. Choose a **XY (Scatter)** chart in the left-hand menu and click **Next**.

4. In the preview box, your graph should look like the example below:



   Then click **Next**.

5. In the next **Chart Options** dialog box, do the following:
   a. Under the *Titles* tab, enter a title for this chart (it should not be “Latitude (N)”) and label the X- and Y-axes. Note, the X-axis is Longitude (East), and the Y-axis is Latitude (North).
   b. Under the *Gridlines* tab, uncheck all grid line boxes.
   c. Under the *Legend* tab, uncheck “Show Legend”.
   d. Then click **Next**.

6. In the **Chart Location** dialog box, choose to place your chart "as new sheet" and click **Finish**.

Graphing Information and Data Analysis (cont.)

7. You're almost there! Now you will need to set up your graph to look like a map of Mars.

   a. For the lines of latitude (the Y-axis), put the mouse directly over the Y-axis and double-click. Then click on the *Scale* tab and enter the following in the Value (Y) axis scale boxes:
      - Minimum: -90
      - Maximum: 90
      - Major Unit: 30
      - Minor Unit: leave as is
      - Value (X) axis Crosses at: -90
      - Make sure that all boxes are <u>unchecked</u>.
      - Then click **Ok**.

   b. For the lines of longitude (the X-axis), double click on it also, and enter the following in the Value (X) axis scale boxes:
      - Minimum: 0
      - Maximum: 360
      - Major Unit: 90
      - Minor Unit: leave as is
      - Make sure that all boxes are <u>unchecked</u>.
      - Then click **Ok**.

   c. Look at the structure of your graph and check to see that the latitude and longitude data from your table are correctly displayed in the graph. The longitude should range from 0 to 360 degrees East, and the latitude should range from -90 to 90 North.

8. Now, for the final step, to add the color MOLA background map of Mars to your graph.

   a. Double-click on the gray area in your graph to open the **Format Plot Area** box.

   b. Underneath the "Fill" category, click on the **Color** drop down menu and then "Fill Effects". Note: if you are using a PC computer, click on the **Fill Effects** button.

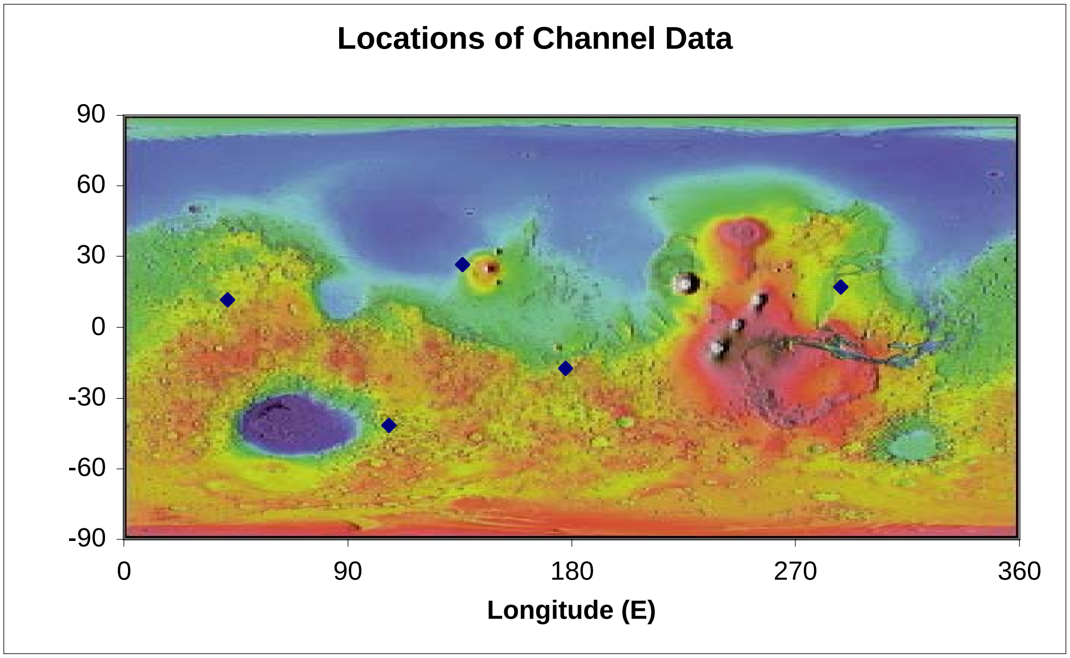
   c. Go to the *Picture* tab. Then click on the **Select Picture** button.

   d. Go to the desktop and click on the file "MOLA_Map_of_Mars.jpg" file. Click **OK** or **Insert**.

   e. Click **OK** on the **Fill Effects** window, and **OK** on the **Format Plot Area** window.

Graphing Information and Data Analysis (cont.)

9. Your map of Mars should be underneath your data! Your map may be stretched to high. To adjust the shape of your map, click and drag the black square at the top or bottom center of the plot area. You may want to change the color and size of your location points. Double click on the points to make changes. Your map should be complete as in the example below:



Now that you have plotted channel data on a map of Mars, make one observation of these data from the graph:

____

____

Make one scientific interpretation of this observation:

____

____

MARS STUDENT IMAGING PROJECT
ASU MARS EDUCATION PROGRAM

MSIP Proposal Outline

I. Introduction

The purpose of the introduction section is to introduce your project and science question. It should include the following information:

- What is your science question?
  (This question should have a specific focus and you should be able to answer it by analyzing THEMIS images.)

- Why is this question important and interesting?

- List any hypotheses you may have of what the answer(s) might be to your science question.
  (You may not formulate any hypotheses until you have done some background research.)

II. Background

The purpose of the background section is to provide background information about the specific features you are studying. Any facts you mention should be followed by the source where you found that information. For example: *Mars has the largest volcanoes in the Solar System. One theory why this is true is that Mars seems to have a much thicker crust than Earth, and so it doesn't have floating, moving crustal plates (MSIP Resource Manual, p.16).* It is important to cite your sources as it gives readers a way to verify your information.

A few suggested resources you can use as you conduct your research are:

-MSIP Resource Manual:	http://msip.asu.edu/curriculum.html
-Feature ID Charts:	http://marsed.asu.edu/upload/FeatureIDCharts.pdf
-THEMIS website:	http://themis.asu.edu

The background section should include the following information:

- List definitions, specific knowledge, and hypotheses from other scientists about your geologic feature(s) on Mars as it relates to your science question. (cite your information)

- Show what your features **look like** on Mars in selected images, sketches, or pictures.

Note: Along with the images, sketches or pictures, you should include some written information. The information may include the following details:

- How this may be used as a "control" for your experiment – an exemplary example of what you are studying.
- Defining characteristics of your feature(s) that you will look for in other images.
- It would be EXCELLENT to include an actual THEMIS image or a cropped portion of a THEMIS image that illustrates the feature(s) you are studying for your project.

(Don't forget to cite the source of any and every image you include!).

- Show **how** your features are thought to form (the geologic process) on Mars in a sketch or image.

- If the features you are studying are found on Earth, how are they thought to be formed?

- During your preliminary background research of looking at THEMIS visible images, you may consider plotting points on a map of Mars that represent the location of each image you observe. If you do this, think about:

  -What geographic regions did you observe these features on Mars?

  For example, "*During our preliminary research, as we have looked at THEMIS images on the http://themis.asu.edu website and plotted them on a map, we have noticed that most of the images of ________ seem to be found...(you would explain what you are noticing).*

  Note: It is very important to:
  - Keep a log of all images you make observations
  - One of the most important pieces of information to note down is the image identification number (the V#). This will allow you to re-examine these images at a later time by going to the http://themis-data.asu.edu website.
  - Observations of these images serve as data points that will help you draw your conclusions and help you answer your question.
  - You should continue to gather observations of many images throughout your research.
  - The more observations you make, the better you can draw your conclusions.

III. Experiment Design

The purpose of the experiment design section is to show how you plan to design your experiment in order to allow other scientists to repeat it. This section includes the step-by-step process detailing exactly what you will do to collect your data to answer your science question.

This section can include the following:
(Note: Some of this information may not apply to all projects):

- What specific spacecraft and camera will you use to collect data for your research?

- What specific geologic features will you focus on for your study and why?

- What geographic regions, if any, will you focus on for your study? (For example, certain latitude bands, certain regions (northern or southern hemisphere), etc.). Note: It is not recommended to focus on one specific geographic location on Mars.

- What website(s) will you use to gather your data and how will you use it (them)? Be specific.

- How many THEMIS images will you need to gather in order to answer your science question?

- As part of your experiment design, list the specific information you plan to record in a table from each image you observe, and why?

  For example:
  - **Image identification # (V#)**: This will allow us and other scientists to reexamine the images we observed to check our data.
  - **Latitude and longitude:** This will allow us to map where each image we examine is located
  - **Specific feature(s) (***You would name the specific features here)*: We will look for ________ and _________ as those directly relate to our science question
  - **Other??**

  List what you will record from each image here:

- What measurements you will make, if any. Please include why and how you will make those measurements.

IV. Analysis Plan

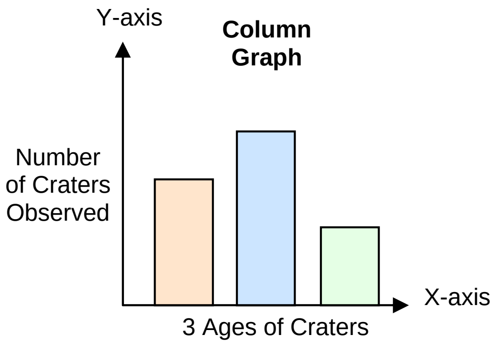
The purpose of the analysis plan section is to plan how to list and display your data in order to analyze it. This section may include:

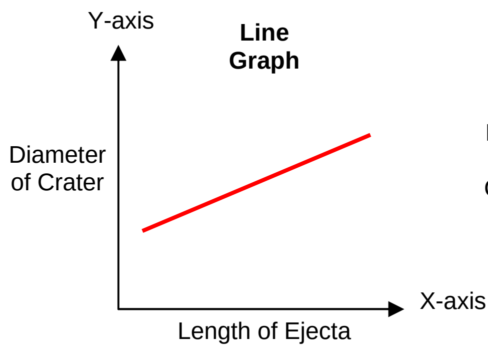
- **TABLE:** Specific information (Image ID#, latitude, longitude, specific feature(s), measurements, etc.) you will record from each image you observe. [For your proposal, you should include the table outline you will use to display your information]

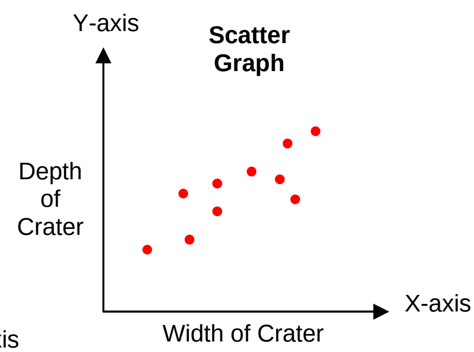
Image ID (V #)	Lat. (N)	Long. (E)			
EXAMPLE					

What will your table look like?

- **GRAPHS**: What specific pairs of information will you graph (including what type of graph you may use: bar, line, scatter, etc.; see examples shown below) and what will each graph tell you?







List the pairs of information you plan to graph:

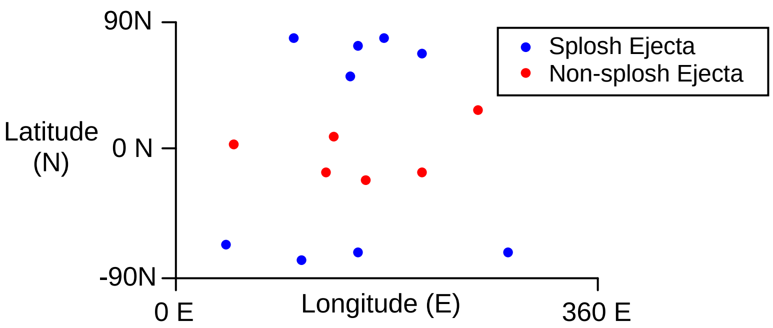
_________________________________ versus _________________________________

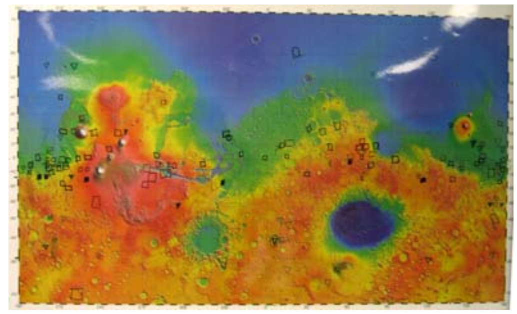
_________________________________ versus _________________________________

_________________________________ versus _________________________________

What types of graphs will you create?

- **MAP**: Will you plot your data on a map? (2 examples below) If so, please explain why. How will you do this and what will this show you. **[A MOLA map is available at the following website, half-way down the page: http://msip.asu.edu/curriculum.html]**.





MOLA map with plotted dust devil data

Will you plot your images on a map? If yes, please explain why? (What will this show you?)

- **OTHER**: Is there any other way you will display your results (Annotated images, etc.?)

V. Conclusion

The purpose of the conclusion section is to summarize what your team is proposing to do. It should:

- Restate your science question.

- Restate your hypotheses (if you had any).

- Restate why it is important to answer your question and why your proposal should be accepted for your team to use the THEMIS visible camera.

VI. References

The purpose of the references section is to support all sources of information used to create your science proposal. It includes:

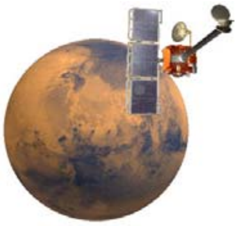
- A list of books, websites, people and equipment used to obtain information for your proposal.
- www.apastyle.org is helpful

Note: Do not list sources that did not provide information you included in your proposal. Each reference you list in this section should be cited within your proposal. For example:

<u>Within your proposal</u>: (MSIP Resource Manuel, p. 16)

<u>In your reference section:</u>

Watt, K. (2002). *Mars Student Imaging Project: Resource Manuel*. Retrieved June 29, 2006, (the date you downloaded) from Arizona State University, Mars Student Imaging Project Web site: http://msip.asu.edu/curriculum.html.



Data Analysis

For each graph, think about what the data is showing you (your observations). Based on these observations, think about what you can imply about what those observations mean (interpretations).

I. Type of Graph: ________________________________

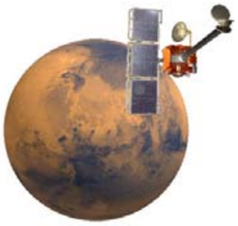
Graph of ______________________ versus ______________________

Observations	Interpretations

II. Type of Graph: ________________________________

Graph of ______________________ versus ______________________

Observations	Interpretations



Data Analysis cont'd

III. Type of Graph: ________________________________

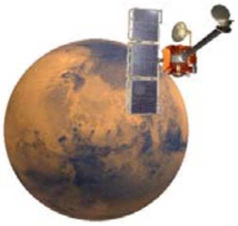
Graph of ____________________ versus ____________________

Observations	Interpretations

IV. Type of Graph: ________________________________

Graph of ____________________ versus ____________________

Observations	Interpretations



Data Analysis cont'd

V. Type of Graph: ________________________________

Graph of ______________________ versus ______________________

Observations	Interpretations

VI. Type of Graph: ________________________________

Graph of ______________________ versus ______________________

Observations	Interpretations

MSIP Final Report Outline

I. Introduction

The purpose of the introduction section is to introduce your project and science question. It should include the following information:

- What is your science question?
- Why is this question important and interesting?
- List any hypotheses you may have had of what the answer(s) might be to your science question.

II. Background

The purpose of the background section is to provide background information about the specific features you are studying. Any facts you mention should be followed by the source where you found that information. For example: *Mars has the largest volcano in the solar system (Watt, MSIP Resource Manual).* It is important to cite your sources as it gives readers a way to verify your information.

The background section should include the following information:

- List definitions, specific knowledge, and hypotheses from other scientists about your geologic feature(s) on Mars as it relates to your science question.
- Show what your features **look like** on Mars in selected images, sketches, or pictures.

- Show **how** your features are thought to form (the geologic process) on Mars in a sketch or image.

- If the features you are studying are found on Earth, how are they thought to be formed?

*Remember to cite (reference) any facts and images you include in your background information (where did that information come from) and include those sources in your bibliography.

III. Methods

The purpose of the methods section is to allow other scientists to repeat your experiment and to show the reliability of your data. The methods section includes the step-by-step process detailing exactly what you did to collect your data.

This section can include the following:
(Note: Some of this information may not apply to all projects):

- What specific spacecraft and camera did you use to collect data for your research?

- What geographic region(s) and/or geologic features did you focus on during the process of collecting your data?

- What website(s) did you use to gather your data and <u>how</u> did you use it (them)? Be specific as to how you used the web site.

- List the specific type of information you planned to record from each image you observed, and why?

- What measurements did you obtain, how and why?

IV. Data

The purpose of the data section is to list and display the data you collected. It does not include interpretations of those data.

This section may include:

- How many THEMIS images did you collect?

- Show good examples of the features you observed and/or measured from the data you collected.

- Display your data (attach any and all information you put together for this section:
  - SHOW YOUR DATA TABLE
  - SHOW YOUR GRAPHS
  - SHOW YOUR DATA ON A MAP OF MARS

V. Discussion

The purpose of the discussion section is to show the data you collected and discuss and explain the meaning of your data as it relates to your science question. It should include the following information:

- ATTACH A CLEAN COPY OF YOUR DATA ANALYSIS SHEETS THAT DISCUSS EACH DATA TABLE, GRAPH OR MAP THAT YOU INCLUDED ABOVE.

- Discuss the potential errors with the data you collected
    - Could there be inaccuracies? If so, please explain.

    - Could there be misinterpretations? If so, please explain.

VI. Conclusions

The purpose of the conclusion section is to summarize and conclude your science project. It should include the following information:

- Restate and <u>answer</u> your science question based on your interpretations from the discussion section.

- Restate and <u>support or refute</u> any hypotheses based on your interpretations from the discussion section.

- What future work could be done to expand your research project?

- Who can you acknowledge for helping you complete your science project?

VI. References

The purpose of the references section is to support all sources of information used to create your science report. It includes:

- A list of books, websites, people and equipment used to obtain your information.
- www.apastyle.org is a useful Internet resource for appropriately referencing your resources.

MARS STUDENT IMAGING PROJECT
ASU MARS EDUCATION PROGRAM

MSIP Team Results Outline Form

I. <u>General Information:</u>
School Name:

Teacher Name:

Grade Level:

City:

State:

Country:

II. Science Question:

III. Main Results: (3 major points)

1)

2)

3)

IV. Extra Comments: (3 student quotes)

1)

2)

3)

II. Pictures:

A) Team Image – a digital picture of your team (optional)

If you would like the team picture to be put online, we would also need to have Image Release forms for each student in the picture. Image Release forms are available at:
http://marsed.asu.edu/upload/MarsEd_ImageReleaseFormv2.pdf

B) THEMIS Image – the image ID # of a THEMIS image that best displays the focus of your research.

C) Extra Image – an additional digital image of your students working (optional)

Other Information: If this information is available electronically, it would be extremely helpful for use to post some of this on-line.

-Electronic copy of archived final report
-Link to school related MSIP website (if one exists)