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ABSTRACT

This booklet gives a history of human observations of Mars, including observations made from U.S. unmanned spacecraft. Also included is a discussion, "Encountering a New World: How to Explore a Planet," which contains classroom discussion questions and four classroom activities. The classroom activities include: (1) How to explore a planet; (2) Geography and mission planning; (3) Magnetic Material in the soil; and (4) a close look at Valles Marineris which includes a map of the Valles Marineris Canyon System in comparison with the United States. (MKR)

Educational Brief

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Topic: Planetary Science

THE EXPLORATION OF MARS

Mars, fourth planet from the Sun, has been known to astronomers since ancient times. It is one of the five "naked-eye" planets—visible from Earth without the aid of a telescope. Before the first astronomical telescope was invented by Galileo Galilei in the early 1600s, these five planets intrigued stargazers with their unusual motions and changes in brightness against the seemingly fixed backdrop of stars. Mars was known by the red color it exhibits during its brightest periods, and was aptly named "Ares" by the Greeks, after their god of war. When the Romans conquered Greece, they gave the planet their name for the god of war, Mars. The planet's presence and changes had also been cataloged by Babylonian stargazers as long ago as 1700 B.C., and were no doubt known to the ancient Chinese and Egyptian astrologers as well.

Until Galileo's time, the heavens were studied by astronomers and astrologers alike, each trying to decipher the meaning of the celestial motions. With the advent of telescopic astronomy, the planets were seen to have individual form and substance. Mars, due to its proximity and location just beyond Earth's orbit, was particularly revealing. By the end of the 19th century, the noted American astronomer Percival Lowell and others had seen polar ice caps advancing and receding on Mars, suggesting seasonal change. Lowell also thought he saw straight lines resembling terrestrial canals on Mars, and thus advanced the notion that there was or may have been a martian civilization attempting to marshal the planet's water.

Mars Exploration: The Missions

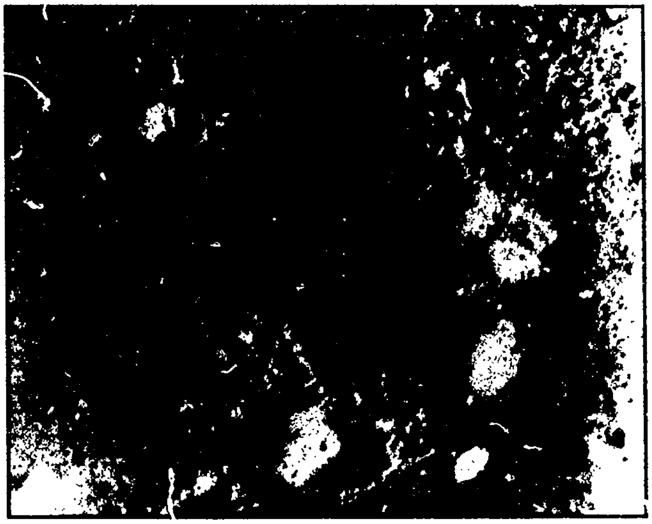
Year of Launch	Mission*	Results
1964	Mariner 4 (U.S. Flyby)	Pictures (22) of desolate, cratered southern hemisphere. No signs of life, but frost on crater rims apparent. Nearest approach 9.844 kilometers.
1969	Mariner 6 (U.S. Flyby)	Pictures (201, with Mariner 7) of equatorial region. Measured planetary diameter, surface composition and atmospheric pressure, and temperature. Nearest approach 3.412 kilometers.
1969	Mariner 7 (U.S. Flyby)	Pictures (201, with Mariner 6) of southern hemisphere and south polar ice cap. Measured planetary diameter, surface composition and atmospheric pressure, and temperature. Nearest approach 3.425 kilometers.
1971	Mariner 9 (U.S. Flyby)	Pictures (7000) of global dust storm, and subsequently, global surface features. Mapped 85% of planet's surface, providing high-resolution images of major features including the Tharsis volcanoes and the huge equatorial rift valley later named Valles Marineris. First images of martian moons Phobos and Deimos. First planetary orbiter.
1975	Viking 1 (U.S. Orbiter/Lander)	Global imaging (26,000 pictures). Atmospheric and surface weather data. Soil analysis yields no signs of life. Lander operates for 6.5 years.
1975	Viking 2 (U.S. Orbiter/Lander)	Global imaging (26,000 pictures). Atmospheric and surface weather data. Seismology hampered by wind effects, but may have detected a small "marsquake." Soil analysis yields no signs of life. Lander operates for 3.5 years.
1992	Mars Observer (U.S. Orbital Survey)	Global imaging and multispectral mapping of surface and atmosphere. Monitors all parameters for 1 Martian year (687 Earth days) from 365-kilometer polar orbit. Will determine if Mars has a magnetic field, and will monitor important surface/atmosphere interactions.
1996	MESUR Pathfinder (Proposed U.S./International Lander)	Mars Environmental Survey. Pathfinder will provide proof-of-concept for subsequent MESUR Network. One lander will provide brief scientific data.
1999-2003	MESUR Network (Proposed U.S./International Lander Network)	Network will have as many as 16 landers monitoring surface and atmospheric properties and dynamics. Strong international contribution. Multiple launches with several landers on each.

*U.S. only. Russians have had five missions that reached or approached Mars, but none achieved their scientific goals.

Although the theme of a martian civilization in hydrological distress has persisted in the popular imagination, the dawn of the space age has profoundly changed the course of scientific interest in Mars. Starting early in this century, astronomers using newly developed instruments began to make accurate observations of the Mars surface environment. These measurements indicated that Mars is a cold, dry place with a very thin atmosphere, dominated by carbon dioxide.

In 1960, the Soviet Union began launching space missions toward Venus and Mars, with the U.S. following suit in 1962. These early planetary missions, equipped with television cameras and probes, met with little success. It wasn't until the U.S. **Mariner 4** mission, launched in November 1964, that a terrestrial spacecraft flew by Mars and sent back pictures. People hoping for signs of civilization were disappointed to see in these pictures a desolate, cratered surface much like the Moon. There were no signs of any canals, but some of the 22 photos sent back appeared to show water ice in the form of frost on the rims of some craters. The promise of Mars as a habitat was diminished, but not entirely

*Developed by the Solar System Exploration Division,
NASA Headquarters.*



Frost-Filled Craters (Mariner 7)

put to rest. For the next few years, the Nation's attention turned toward lunar studies and the manned space program as NASA geared up for the Apollo missions to the Moon.

Five years after Mariner 4, in 1969, NASA's **Mariner 6 and 7** missions flew by the Red Planet, returning pictures of the equatorial region and southern hemisphere. Mariner 6's view of the equatorial region showed fewer craters than Mariner 4 had seen in the south, but among them was a chain of gigantic craters, including one more than 483 kilometers in diameter. Again, frost was seen on the rims of some craters. Mariner 7 concentrated on the heavily cratered southern hemisphere, where it found evidence of large volcanoes as well. This was exciting news. Our understanding of volcanic processes is extensive, because we have so many on Earth. The martian volcanoes, therefore, represented a way to "read" the geologic history and processes of the Red Planet. But pictures were not all Mariners 6 and 7 had to offer. Remote sensing had progressed in the years since Mariner 4, partially as a result of NASA's drive to characterize the Moon in preparation for the Apollo landings. Mariners 6 and 7 were equipped with sophisticated instruments that measured the martian diameter, surface temperature, atmospheric pressure, and composition. Measurements taken by these instruments confirmed, for example, that Mars' surface atmospheric pressure is about .7 percent of Earth's, and that the atmosphere is mostly carbon dioxide.

The excitement at the success of the scientific data-gathering and transmission by Mariners 6 and 7 fueled expectations for **Mariner 9**. This spacecraft, launched in 1971, was more than twice the size of its predecessors and carried new instruments, including infrared and ultraviolet spectrometers for surface and atmospheric composition studies. Mariner 9 was also the first U.S. orbiter-type planetary spacecraft, designed not just to fly past a planet, but to stay in orbit around it for an extended period, mapping the surface with its instruments. At the very time Mariner 9 arrived in Mars orbit, a planet-wide dust storm was raging, obscuring the surface almost completely. Had this been a flyby mission, it would have been nearly for naught. But instead, scientists got a chance to observe the progress and conclusion of a major surface/atmosphere interaction crucial to understanding the planet. Mariner 9 went on to exceed mission expectations by mapping about 85 percent of the Red Planet's surface. It sent back more than 7,000 spectacular pictures revealing plains, huge volcanoes, and an equatorial rift valley stretching the equivalent of the distance from New York to Los Angeles. Mariner 9 also showed us wide regions eroded by what must have been flowing water sometime in the planet's past.

Volcano on Tharsis Ridge (Mariner 9)

The Mars revealed to us by Mariner 9 was our first close-up global view of the planet. There were many surprises. In diameter, Mars is about half the size of Earth, yet its most notable surface features are more massive than anything we have seen on Earth. Mariner 9 showed us the Tharsis Ridge, a bulge so large that it has deformed the sphericity of the planet. Several enormous volcanoes, the Tharsis Montes, sit atop the ridge. The huge equatorial canyon, Valles Marineris, extends away from the Tharsis Ridge and may be related to it. Great flood channels extend from collapsed terrain associated with this canyon. Also unexpected was the strong dissimilarity of the northern and southern hemispheres of the planet. The northern hemisphere is primarily low-lying volcanic plains, while the southern hemisphere (which is all the early Mariners saw) is heavily cratered highlands, much older than the north. These highlands bear the scars of water flow, which seems to have occurred well after much of the cratering, judging by the erosion of old craters by the flow.

Mariner 9 also provided us with our first close-up views of the martian moons, Phobos and Deimos. These small, irregularly shaped bodies appear to be asteroids captured by martian gravity. Mariner 9's spectrometers provided us with information about the Red Planet's atmospheric composition, which is 95 percent carbon dioxide, with smaller amounts of nitrogen and argon, and traces of many other molecules, including oxygen, carbon monoxide, and water. The argon was of particular interest because comparisons of the abundances of different isotopes of argon in the atmosphere suggest that the martian atmospheric pressure was once much higher than it is today. Higher atmospheric pressure would have better enabled liquid water to exist on the surface of the planet. An infrared radiometer on Mariner 9 also measured surface temperature, which varies regionally and seasonally on Mars from about +20 to -120 °C.

Equipped with a global view of Mars, NASA and the science community spent the early 1970s designing a mission to address the emerging questions With new evidence that water once flowed on Mars, there was a renewed interest in looking for signs of biological activity in the soil. And now that we had a synoptic view of the planet, why not get some "ground truth" by landing some cameras to look around? From these seeds arose the Viking mission of 1975. Viking consisted of two spacecraft, each including an orbiter and lander. The landers would be small soil-testing and meteorological laboratories and would include cameras. The orbiters would perform remote-sensing observations, including high-resolution imaging of areas of interest, particularly near the polar caps and in regions of apparent past water flow.

Martian Horizon (Viking Orbiter 1)

The Viking mission achieved spectacular success. Launched in the summer of 1975 and arriving in the summer of 1976, both orbiters and landers did their jobs, sending back a wealth of data that are still being assimilated. Each lander included a weather station, a seismometer for detecting "marsquakes," small soil-analysis facilities, and a TV camera. The orbiters, in addition to high-resolution photographic mapping, mapped surface temperature and atmospheric composition, with particular attention to water content in the atmosphere. The soil analyses carried out by the landers searched extensively for signs of terrestrial-type life forms or at least the molecular precursors to life. No conclusive evidence was found, even under rocks where the soil was protected from incoming radiation. The weather stations monitored average winds of about 15 mph and recorded persistent sub-freezing temperatures. The lander cameras showed us the pinkish color of the surface, probably resulting from oxidation of iron in the soils. The cameras also revealed frost cycles that are probably related to water vapor transportation in dust storms. The landers also weathered some martian dust storms that raged across the northern plains.

The Viking orbiters provided detailed maps of the surface, showing us, at resolutions greatly improved since Mariner, impact crater ejecta distributions, water-flow features on a massive as well as local scale, and, at particularly high resolution, layered terrain in the polar regions. Each of these features has led to new theories and new questions about the history of Mars:

- The crater ejecta distribution patterns suggest to scientists that some of the ejecta may have been waterlogged at the time of impact, but we need actual sample analyses to be sure.
- The water-flow features suggest massive flooding, but the flood channels empty mysteriously—there are none of the deltas or alluvial-plain features typically produced by terrestrial rivers. This, too, requires further research, including soil- and rock-sample analyses and higher resolution imaging.
- The layered terrain in the polar regions suggests that there have been periodic climate changes on Mars, perhaps similar to the waxing and waning of ice ages on Earth. But when did the martian changes occur, and what were their natures? If we learn when the martian climate changes took place, and what happened during each age, we can compare these data with what we know about Earth to determine whether both planets experienced simultaneous or related orbital fluctuations.

We can also learn more about changes in the martian climate over time to help us construct a better model of surface/atmosphere interactions and their relation to volcanism, impact events, and perhaps, orbital changes. Such modeling is crucial to our understanding of terrestrial planetary processes as we strive to understand the history and future of our own planet.

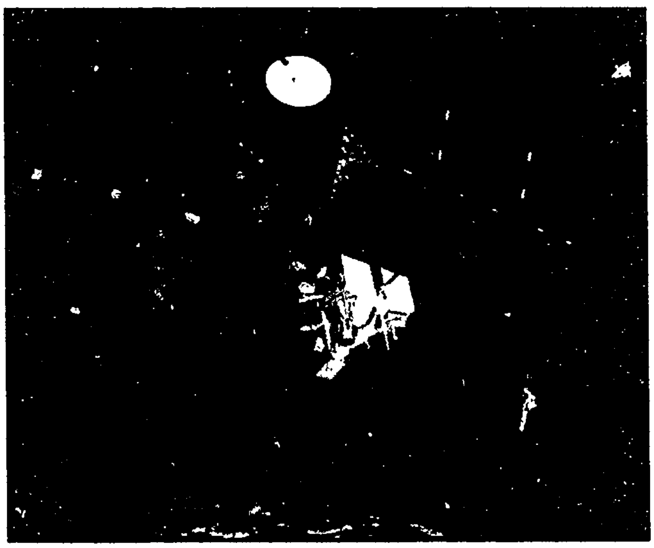
The Viking mission sent back years' worth of data, much of which are still being analyzed. This is the nature of orbiter-lander missions. The data volume from an orbiter is huge, literally global in scale, and the lander lifetimes were quite long (the Viking 2 lander operated for 3.5 years and the Viking 1, 6.5 years).

Viking ended the first era of space-based Mars exploration. In the years since then, NASA and the planetary science community

Water Ice on Mars (Viking Lander 2)

have been poring over the data from the first era, not only to learn what the data have to say, but to determine what needs further or closer study. The emerging field of comparative planetology has helped provide an overarching structure to these interim years. As we learn more about Earth and other planets, Venus in particular, we have a better idea of what questions to ask about Mars. From this ferment in the late 1970s and early 1980s came the design of the first mission of the second era of Mars exploration: Mars Observer.

The **Mars Observer** spacecraft, launched September 25, 1992, takes advantage of tremendous advances in spacecraft and instrument technology. It is a very sophisticated, relatively lightweight spacecraft whose design is based on a combination of proven communication and meteorological satellite technologies. Mars Observer's instruments will study martian surface and atmospheric properties, climate, magnetic field, and gravity.



An Artist's Concept of the Mars Observer Spacecraft

A *Gamma-Ray Spectrometer* will determine surface composition of the Red Planet, and will measure variations in the seasonal polar cap thickness and the atmospheric column density. The *Mars Observer Camera* will produce a daily wide-angle ("weather map") image of the entire planet, as well as narrow-angle (high-resolution) images of objects of interest as small as 3 meters across. The *Thermal-Emission Spectrometer* will contribute to the mapping of surface minerals and rocks, and will help locate and characterize ices on the surface and ice and dust particles in clouds. A device called the *Pressure-Modulator Infrared Radiometer* will map the thermal structure, dust content and distribution, water vapor, and other properties of the martian atmosphere in three dimensions. A *Laser Altimeter* will provide detailed topographic data for analysis of local terrain as well as global mapping. A *Magnetometer* will determine the nature of the planet's magnetic field, and an associated electron reflectometer will characterize the interaction of the magnetic field with the solar wind. The radio signal from Mars Observer will be analyzed for gravitational effects as it passes through the limb of the planet, helping to build, over the nearly 2 Earth years of the mission, a global data base of martian gravity. And, in a touch that may be a harbinger of things to come, Mars Observer will carry a data relay for a Russian lander (Mars '94) that will be in operation during Mars Observer's mission lifetime.

Mars Observer was designed in direct response to the pressing questions of planetary science peculiar to Mars. These include questions about climate change, interior structure, surface composition, atmospheric processes, and the presence of water. The answers to each of these questions will bear directly on our understanding of Earth and the other terrestrial planets. Mars Observer is also an essential step toward the future exploration of Mars, whether we explore the planet with robot spacecraft in the next few years or with human presence in the next century. Mars Observer will provide a more detailed global "road map" of Mars, its surface, and its atmosphere. It will also provide a necessary data base for getting missions to the surface and for planning what to do when they get there. As an immediate step in this process, data from Mars Observer and previous missions will be used to assist the Russians in their selection of reasonably safe and scientifically important landing sites for their Mars '94 landed stations. Mars Observer data will also be important to the selection of future U.S. landing sites.

The planned Mars Environmental Survey mission, or **MESUR**, will undertake the next phase of U.S. Mars exploration after Mars Observer. The **MESUR Pathfinder** mission has been proposed by NASA to emplace one short-lived lander on Mars to test the lander concept and technology. The lander may be equipped with a "microrover" to move instruments or sample-gathering equipment for investigations at locations of interest near the lander. MESUR Pathfinder is proposed for launch in 1996, and will help pave the way for any Mars exploration that follows. One possible follow-up would be a more extensive set of landers called **MESUR Network**. The Network would be established by means of a series of launches, each carrying perhaps three or four landers, to build up the Network over time. The landers would study local soil composition and atmospheric properties, as well as monitor meteorology and seismology. NASA planners are now discussing the program with the international space community to determine how to best use the technical and scientific resources available.

On-site martian soil and rock analysis will be of great value to science and to further exploration goals. To follow and build on such analysis, NASA is considering a **Mars Sample Return** mission to bring martian soil and rock samples back to Earth for comprehensive analysis in terrestrial laboratories. Lander laboratories, designed to do their work on-site, must be designed to look for specific properties of interest in the samples in order to maximize science return while minimizing launch weight. Samples returned to Earth laboratories, however, can be analyzed in a greater variety of ways, and serendipitous or unexpected findings can be followed through to the end of our best analytical ability. A Mars Sample Return mission will enable terrestrial scientists to bring their full genius to bear on samples returned to Earth. This will not only better prepare us for the potential hazards the Mars environment might present to human visitors, it will also help determine where to go on the Red Planet, and what to do when we get there.

Encountering a New World: How to Explore a Planet

Mars is one of the first planets to be studied scientifically using spacecraft. In the 1960s, at the dawn of the Space Age, rocket technology was still new, so we sent spacecraft to the places in the solar system most easily reached — to the Moon and the inner planets, Mercury, Venus, and Mars. Our early interest in Mars was also propelled by the intriguing glimpses of the planet we'd gotten with Earth-bound telescopes. The scientific study of Mars since then provides an example of a strategy of discovery for strange and distant objects. NASA's strategy for exploring planets (or any celestial bodies) was developed and refined in the process of learning about the Moon and Mars in particular.

The NASA strategy for the scientific study of any celestial body has three phases. These phases are, in order of performance, *reconnaissance*, *surveillance*, and *in-depth study*. Each of the three phases has its own types of observations, and each phase builds on the discoveries of the previous phase.

Reconnaissance means to observe an object intently for a short period, and then report the results of your observation. Planetary reconnaissance is usually performed by what are called "flyby" missions. In a flyby mission, a spacecraft makes one pass by a planet, radios back its data, and then continues off into space. Reconnaissance missions give us our first close-up look at a body, and allow us to compare the close-up view with Earth-based observations. We look for gross geological features, cratering, general atmospheric composition, and gravity effects on the spacecraft, which reveal the planet's mass. Flyby missions address questions such as, What is the planet made of? What are the large features of its surface? What is its atmosphere like? Are there craters? Volcanoes? How many? What is the planet's mass? The results of addressing these questions set the stage for the next phase of exploration.

Surveillance means to observe an object intently for a long period of time, recording all observable characteristics and activities during that time. Surveillance usually implies setting up a site from which to observe. Planetary surveillance is usually performed by orbiting spacecraft. An orbiter is sent to the planet on a very precise course that will cause it to be captured and held in orbit by the planet's gravity for some extended period of time. While in orbit, the spacecraft will point its instruments at the planet and record great volumes of information over a wide area and for an extended period of time. Orbiters typically orbit in a north-south axis over the planet's poles, so the planet in essence turns beneath the spacecraft and the instruments can view a different strip of the planet on each orbit, eventually viewing the same spot more than once, to see if anything changed since the last look. Orbiters also let you check out anything interesting you spotted during reconnaissance, answering questions such as, Was that a volcano or an impact crater? Was that frost or sand? Why does this region look different from the rest of the planet? The repeat views of the same area help address the question: Is there any ongoing volcanic, geological, or atmospheric activity?

The orbiters that we launch today are very sophisticated. Some include probes that are dropped through the planet's atmosphere to detect and measure local atmospheric components and pressure. Today's orbiter instruments can also study everything from complex atmospheric composition to soil, rock, and ice types on the surface. This information is not only of great scientific value, it is important to help prepare for the next phase.

In-Depth Study is the final phase of data-gathering, when you, or your robots, land on the planet and explore relatively small areas of the surface in great detail, like the Apollo missions to the Moon and the Viking missions to Mars. The instruments and mission for in-depth study are specifically designed to target things you found worthy of inquiry from the previous phases. In-depth study can include landers with weather stations, soil analyzers, devices to bring samples back to Earth, and rovers to bring a set of instruments to locations remote from the lander. In-depth study also can include landing humans on the body, as the Apollo mission did on the Moon (humans are by far the smartest and most capable landers!).

Because in-depth study missions can explore only small areas, site selection is a very important element of this phase. All of the data from the previous missions must be analyzed to determine a safe and scientifically fruitful spot to land. In-depth study addresses questions such as, Are there microorganisms in the soil? What are the rocks made of? How old are they? How does the surface wind speed change during the days and weeks? What are typical daily temperature swings in this region? Are there temblors (quakes)? How often? How strong? For Mars, future in-depth study will be carried out first by robots, and then by humans.

Questions for Discussion

1. Based on the history of Mars exploration presented in this Brief, which Mars missions fall into which of the three strategic phases?
2. Has Mars exploration followed the three-phase sequence in precise order? If not, what seems out of order, and why do you think it was done that way? Was there an important question to be answered right away? What was it?
3. What scientific questions about Mars were addressed in the reconnaissance missions? What questions were raised or left unanswered by these missions?
4. What questions were addressed in the surveillance missions? What questions were raised by these missions?
5. What do we know about Mars, its surface, its atmosphere, and its geological history?
6. What kinds of studies are to be carried out by future Mars missions? What do we expect to learn, and why is it important?

Activity 1: How to Explore a Planet

This exercise will involve the students in a three-phase program of observation of an object of interest. Although we encounter much of the world around us in a free and unconstrained manner, using all of our senses and our mobility to grasp all at once, the exploration of new and distant worlds involves a series of carefully planned steps. This exercise will show how such steps take place, and how you have to think a little differently in the process.

Teachers should be creative in selecting or manufacturing an object — to serve as the planet — that will reward observation at each phase. Ideally, the object will have some characteristics not evident from a distance, but which become clearer as you get closer. The exercise would also benefit from an object that has something surprising on the back side. The object could be outside the classroom, if it is visible from a classroom window. In an urban environment, this could be a building across the street. If there is a parking lot or playground visible from the classroom, the teacher might want to place an object of interest out there before the class. If the object is to be in the classroom, the teacher might consider something rewarding multisensory inspection, like a strange fruit, or a fragrant onion dyed with food coloring, perhaps studded with cloves on the back side. The object could also be dynamic, like something that is melting, evaporating, or boiling. Imaginative construction of a multisensory object will be the most rewarding. If the object is familiar, then the teacher might ask the students to imagine they are from another planet and have no idea about human civilization, but are learning as they go. The teacher might consider the possibility of running the observation program in a darkened classroom, with a flashlight used for each observation. Or, if a flash-equipped Polaroid camera is available, use it as the data-gathering tool for the reconnaissance and surveillance phases, followed by data (photo) interpretation sessions. Some geometry could be brought in to determine object size, etc.

Once the "planet" is in place, the program of observation can begin. It might help to get the class involved by devising a working name for the planet at this stage, and to see if the class wants to revise the name after each stage of observation. The class should then divide up into four groups: the mission planners, the mission controllers, the spacecraft, and the mission scientists. For each phase:

1. The **mission scientists** look at the existing data and decide what observations of the planet should be made, remembering the limits of each mission type (flyby, orbiter, orbiter/probe, lander). The scientists should also discuss the meaning of the data they seek. For example, Is this planet likely to be similar to Earth, in which case we can compare it with Earth and thereby better understand our home planet? Or is it apparently very different from Earth, in which case we may be able to learn more about the solar system as a whole, and how and when various things formed in it, and what they're made of?

The scientists then report the mission's observation requirements to the mission planners. This meeting should also produce a name for the mission.

For example, each of the reconnaissance flights could be called Quicklook-1, Quicklook-2, etc.

2. The **mission planners** then decide among themselves what set of spacecraft will be needed for the type of mission, and, with the teacher sitting in as an adviser, what the spacecraft's observing tasks will be. The planners then report the selection and observing task to the spacecraft group.

3. The mission planners will then meet with the **mission controllers** and turn the spacecraft over to the controllers.

4. The controllers then decide upon the order of flight, the launch site, and a way to get the data back from space. The controllers then brief the **spacecraft**, telling each its name, what it is to do, and in what order.

5. Each spacecraft will then be launched, fly its mission, record its observations, and return them to the mission controllers, as instructed.

6. The mission controllers then give the returned data to the mission scientists. The mission scientists are in charge of making sense out of the data and figuring out what should be done in the next phase. They then formally report the exciting science results to the group at large. Then each other group formally reports to the rest about how the mission went, and makes recommendations for improvements. The mission scientists then discuss the next phase, basing it on what has been learned and what is still unknown.

Reconnaissance: The first step is to simulate Earth-bound observation. From the maximum viewing distance, the whole class should record their observations of the planet in all five senses, even those where there are no data (sound and smell, for example) or data are not yet obtainable (feel). Most of the data at this point will be visual, and will include shape, color, surface texture, position, etc. Students should also write any questions they might have about the planet, including recommending further observations that they might expect to be rewarding.

Next, the mission should begin, as described in the six steps above. The spacecraft should execute a flyby mission as instructed (quickly walking past the planet on one side only). The students should pay attention to what new information is available from this perspective, and report as instructed by the controllers.

Surveillance. The spacecraft should now be permitted to walk around (orbit) the planet at a distance chosen to provide new information. Again, they should observe and report as instructed by the controllers.

In-Depth Study. Here the spacecraft can approach, orbit, and then fully encounter the planet in all five senses. Actions should be performed exactly in accordance with the instructions of the controllers, remembering that the spacecraft are robotic. They then report back their data to the controllers as instructed.

The entire class should engage in the final data analysis, discussing everyone's observations and perhaps coming up with a new name for the object. The entire class can then decide what should be done in the future.

Activity Questions

1. It is rare that we encounter an object with no idea at all what to make of it. What prior knowledge did you use in your encounter with the planet?

2. Astronomers' early, fuzzy observations of Mars led to some exotic ideas about what might be on the Red Planet. Was there any point in your encounter with your "planet" when you realized earlier observations had been misleading?

3. The spacecraft in this exercise acted as robots, doing only and exactly what they were told. What advantage would there be to having human beings in the place of robots during the in-depth study phase? What disadvantages? Would you like to go to Mars? Why or why not?

Activity 2: Geography and Mission Planning

The following chart includes the martian latitudes and longitudes of locations that were considered possible landing sites for the Viking spacecraft.

Latitude	Longitude
1. 22° N	48° W (Viking 1 landed near here)
2. 20° N	108° E
3. 44° N	10° W
4. 46° N	110° W
5. 46° N	150° E (Viking 2 landed near here)
6. 7° S	43° W
7. 5° S	5° W

1. If MASA (Martian Aeronautics and Space Administration) sent spacecraft to land at the same latitudes and longitudes on Earth as NASA considered on Mars, where would each spacecraft land? What hazards would be encountered? What would happen to the spacecraft? What would the spacecraft see? Would it detect water? Life? Intelligence?

2. If you were working for MASA, which sites would you pick for a landing on Earth? Why? For each site, identify the hazards that your spacecraft lander would have to survive. What would you expect to find?

3. Examine some pictures of the Earth from space and discuss the hazards for the spacecraft lander once it reaches Earth. What would one expect to find at each location?

Source: Mars: The Viking Discoveries (EP-146, October 1977) by B.M. French

Activity 3: Magnetic Material in the Soil

One instrument carried by the Viking landers was very simple: a magnet. Its job was to determine whether there were any magnetic materials, such as iron metal or iron oxides, in the martian soil. Magnetic material was detected, and from its magnetic properties it was identified as an iron oxide called maghemite.

For this activity, make a synthetic "martian soil" by mixing about 5 percent of magnetic material (crushed magnetite, Fe_3O_4, or iron metal filings) with clean white sand. Using a large bar- or horseshoe magnet wrapped in paper or plastic film (so that you can easily remove the magnetic material that adheres to it), try various methods of collecting the magnetic material from the soil; e.g., scraping the magnet through the soil, pouring the soil over the magnet, or spreading out the soil in a thin layer and passing the magnet over it.

Examine the collected material with a hand lens or a low-power microscope. How much white nonmagnetic sand was collected with the dark magnetic material?

Prepare a soil sample that contains a known weight of magnetic material. Try various collection methods and weigh the amount of magnetic material collected in each way. Calculate the efficiency of each method; i.e., the weight collected divided by the weight originally present. Discuss why some collection methods do not approach 100 percent efficiency.

Make up several soil samples with varying amounts of magnetic material; e.g., 1, 5, 10, and 25 percent. Process each sample with the most efficient collection method, and weigh the amount of magnetic material collected. Calculate the total amount of magnetic material present, knowing that (amount present) = (amount collected)/(efficiency). Repeat the experiment a few times. How reproducible are your results? How accurate are they?

Substitute a different magnetic material (iron metal filings for magnetite or vice versa) and repeat the experiments. Does the efficiency of the collecting methods change? Why?

Source: Mars: The Viking Discoveries (EP-146, October 1977) by B.M. French

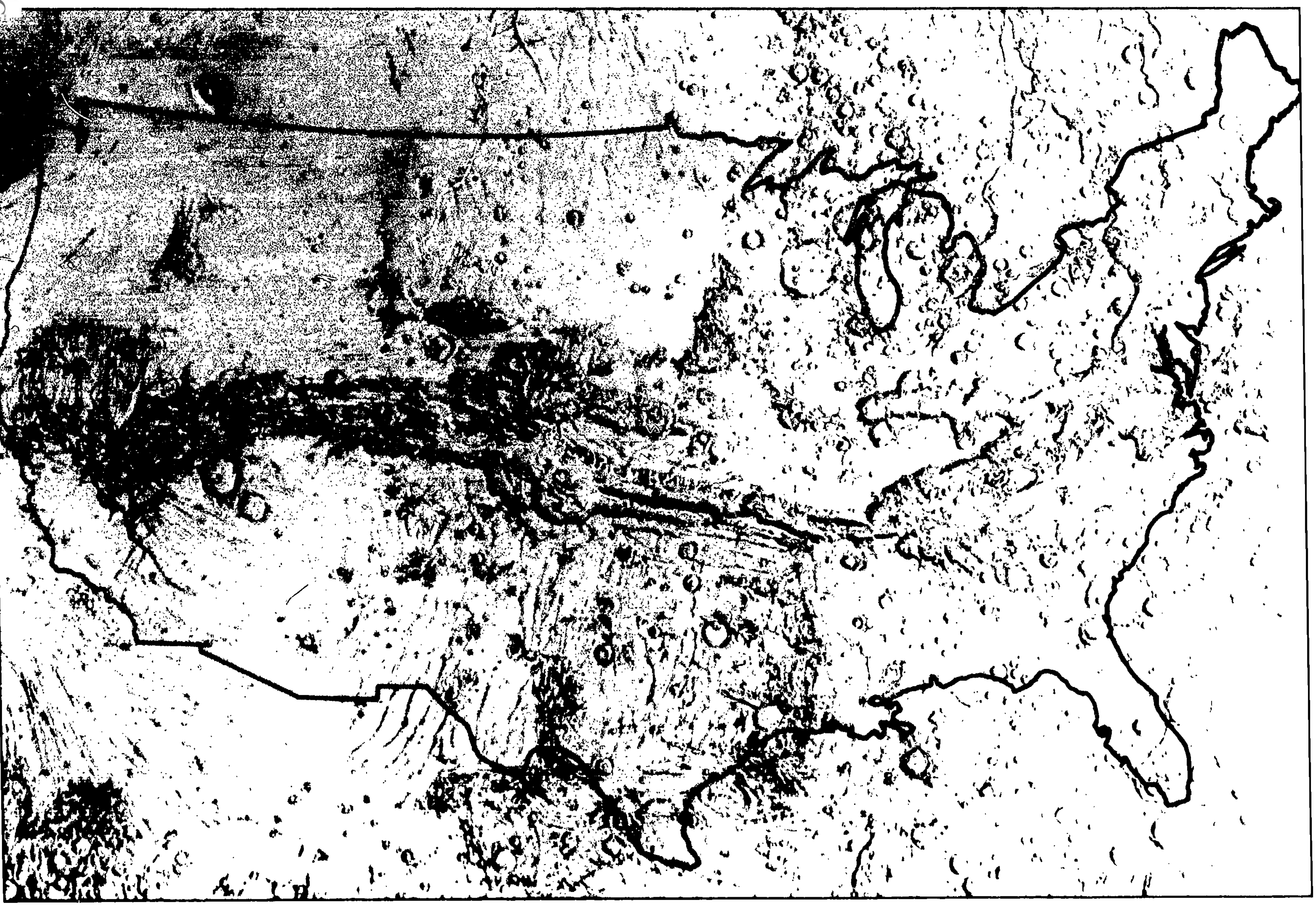
Activity 4: A Close Look at Valles Marineris

Named after the Mariner 9 spacecraft that discovered it, Valles Marineris is a huge canyon system on Mars. It extends to the east from the Tharsis Ridge (an area of enormous volcanoes). The canyon system is over 4,000 kilometers long. Its depth ranges from 2 kilometers to 7 kilometers in the central section. At its widest point, the chasm is more than 600 kilometers wide.

Valles Marineris was formed largely by faulting, in a sequence of geological events that was probably related to the formation of the Tharsis volcanic region to the west. However, other processes were clearly involved in the development of this complex canyon system. There is evidence of subsidence as well as faulting in the western part of the canyon system. Some of the deep, branching, side valleys (comparable in size to our own Grand Canyon) appear to have been created by water erosion. The water source was probably seeping groundwater rather than rainfall.

Layered sediments toward the eastern end of the canyon system must have been formed under water. This suggests that some of the seeping groundwater was trapped in lakes, which subsequently broke through to extend the canyon eastward and ultimately flooded the plains beyond the canyon system.

The illustration on the following page demonstrates the huge extent of the Valles Marineris canyon system by comparing it with the United States, at the same scale.



The Valles Marineris Canyon System in Comparison with the United States