

WELCOME TO THE MARS EDUCATION PROGRAM



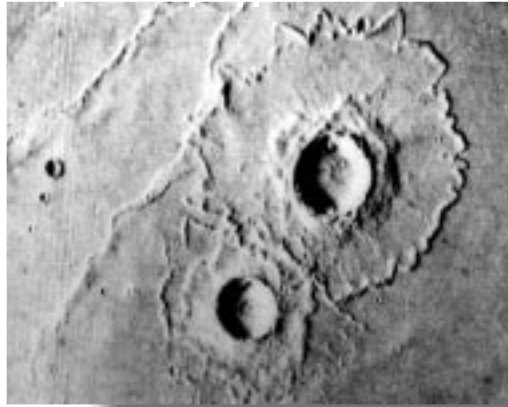
Over the next ten years, NASA is sending ten spacecraft to investigate Mars. To take advantage of this historic set of explorations, NASA's Mars Exploration Program has created a series of curriculum modules to connect students to the excitement and learning potential of these missions. The Mars Exploration Program will help you:

- engage your students in hands-on, inquiry-based learning,
- involve students in questions central to current Mars exploration,
- teach engineering concepts, and physical, Earth and life science in a relevant way,
- provide a context for learning about both Mars and Earth,
- address student misconceptions, and
- prepare students for using live data and images from Mars.

The module series was developed and field tested by a team of educators and scientists to make sure that it is both scientifically accurate and educationally powerful. Each module contains a set of activities that relate to an over-arching theme. The activities are sequenced so students can progress from introductory experiences to more advanced investigations and deeper understandings. The teacher handbook and correlated student materials enable you and your students to do the activities regardless of your previous knowledge about Mars and planetary exploration.



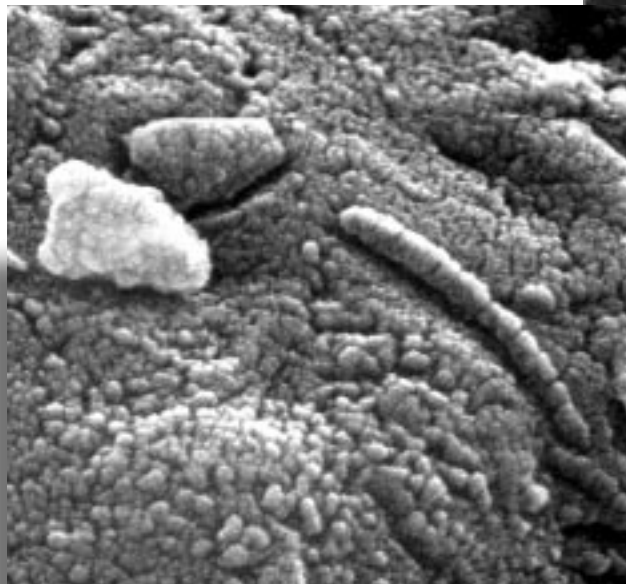
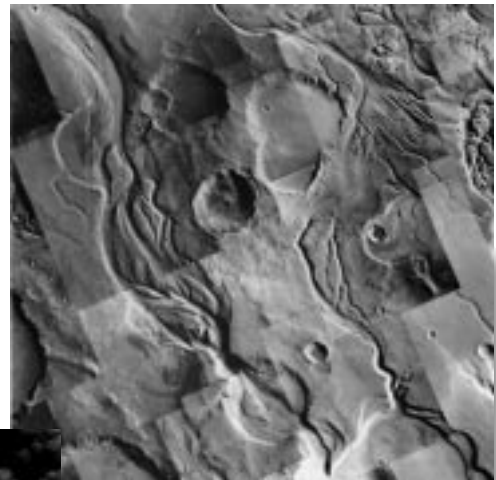
MARS IS A FASCINATING PLANET



What do the “mudflows” around this crater suggest about the sub-surface?

Craters can be used to study sub-surface ice and water on Mars.

Could water have flowed freely on a planet that today is dry and frozen?
Channels can be used to study the way water flowed on Mars.



Was ancient Mars teeming with early life?

The controversial Martian “microfossil” can be used to evaluate the possibility of life on Mars.

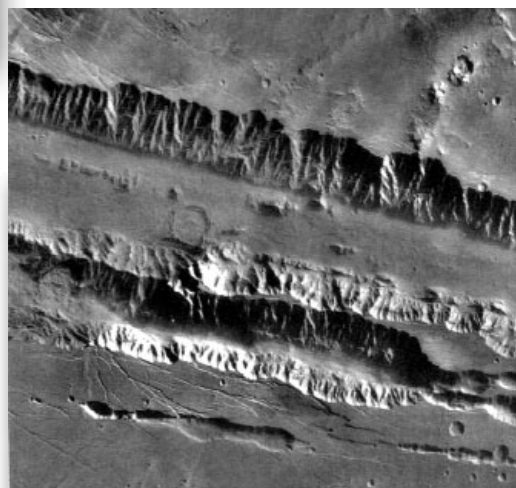


How can such a small planet have the solar system's largest mountain?

Martian volcanoes can be used to investigate the presence or absence of plate tectonics.

How could a single crack go halfway around a planet?

Martian canyons can be used to study processes that alter a planet's surface.



Where does a dust storm that covers an entire planet originate?

Dust storms can be used to study the circulation of the Martian atmosphere.

WHAT'S DISTINCTIVE ABOUT THIS MODULE SERIES?



Brings Science Topics to Life in an Engaging, Relevant Way

Students not only learn a lot about Mars, Earth science, astronomy, chemistry, biology, physics, engineering and geography, but they also develop and hone their science thinking skills such as designing experiments, devising models, analyzing data, developing, refining and revising hypotheses, and applying their understanding to real-world situations.

Provides Multiple Paths to Investigate a Topic

In the module activities, students use experimentation, modeling, Mars-Earth comparisons and image analysis to amass evidence to support their ideas.



Promotes Student Ownership of the Investigative Process

Because the mastery of fundamental science concepts is dramatically enhanced when students feel a high degree of ownership for their work, the activities are structured so that students can own the intellectual process going on in the classroom.

Builds a Foundation for Understanding Live Data from Mars

Over the Internet, NASA will provide the public with images and data from the Mars missions on a weekly basis. Never before has material from a planetary mission been made available in near-real time. This opens a new chapter in the way students can participate in on-going research. Providing students meaningful background experiences is a central element of the Mars Exploration Program. Consequently, the modules prepare students to analyze images, understand NASA's key research questions, know the capabilities of the instruments on the spacecraft and recognize Mars' planetary features. Given such a foundation, students can contribute meaningfully to our understanding of the planet.

Gives Students a Stake in the Missions

Mars exploration is at its beginning. The competing explanations within the scientific community and the gaps in the existing evidence leave plenty of room for students to develop their own hypotheses. Students can use evidence from their own investigations to take positions on a particular question, debate the alternate hypotheses and refine their own thinking about Mars.



Helps Transform Science Education

Mars is not only the focus of on-going scientific investigations, it also offers a wonderful opportunity to improve science education. The letter at the end of the preface from the Program Educator for the Mars Exploration and Education Program describes how the module series contributes to this effort.

Implements the National Science Education Standards

The content and skills in the module series relate closely to national, state and local curriculum standards. The series can help schools implement these standards in a creative, innovative and multi-faceted program. In particular, students will learn:

- fundamental concepts of Earth and space science
- skills of inquiry and investigation
- how to base arguments on evidence
- how to discuss alternate hypotheses
- how to gather information using computers and telecommunications

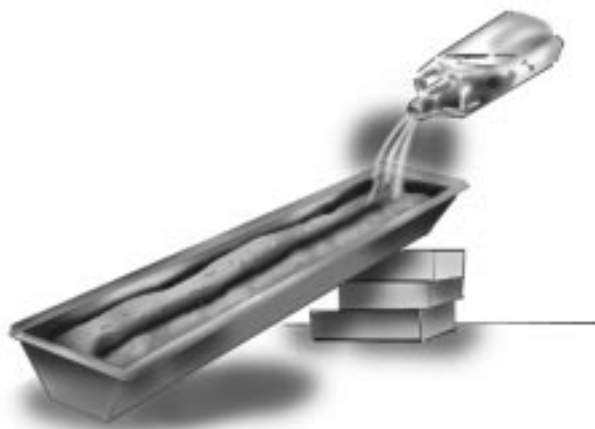
The modules develop such skills and understanding by responding to many of the National Science Education Standards' recommendations for science teaching, professional development, assessment and content.



THE THREE KINDS OF ACTIVITIES IN THE MODULES

Each activity is designed around a question that is examined through four different investigative paths - experimentation, modeling, Mars-Earth comparisons, and image and data analysis. Each path sheds light on a different aspect of the question. Students piece together the evidence to develop hypotheses, to debate and refine their thinking, and to address their misconceptions.

• Conducting Classroom Experiments and Creating Models



Students conduct hands-on experiments that generate data and model processes that occur on Earth or Mars. These inquiry-based experiences build understanding and lay the conceptual and experiential base for other activities.

• Making Mars/Earth Comparisons

Mars-Earth comparisons help students bridge the gap from a local, familiar environment on Earth to distant Mars.



Earth Image: Grand Canyon

Mars Image: Valles Marineris





•Using Real Data and Images from Mars

Students use data and high-quality images from previous Mars missions.* After NASA's missions arrive at Mars, students can use the Internet to obtain the latest data and images, enabling them to experience the excitement of scientific exploration and discovery as it happens.

* Student Image Sets

The student image sets are the only printed student material for each module. They provide you and your students with a set of maps and photos of the surface of Mars. The activities are based on these images, and students use them to provide clues as they pursue their investigations. We recommend that you get one set for each group of two or three students. This enables each student to examine the images closely and supports dialogue about the images.

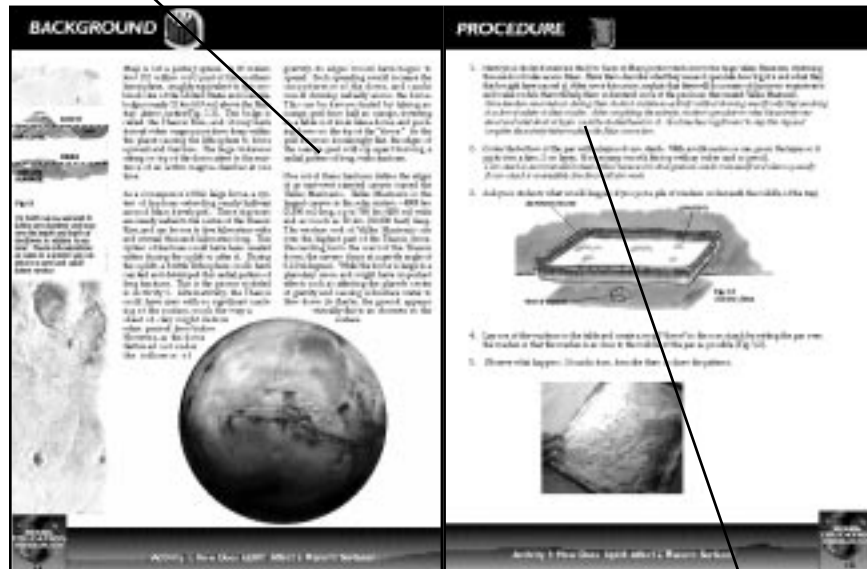


HOW IS THE TEACHER HANDBOOK ORGANIZED?

Each module is written as a Teacher Handbook which gives the module a conceptual and pedagogical structure while still providing teachers the flexibility to tailor the activities to the needs of their classes. The Teacher Handbook prepares teachers to conduct classes around core questions, and it outlines investigations that explore those questions.

Background

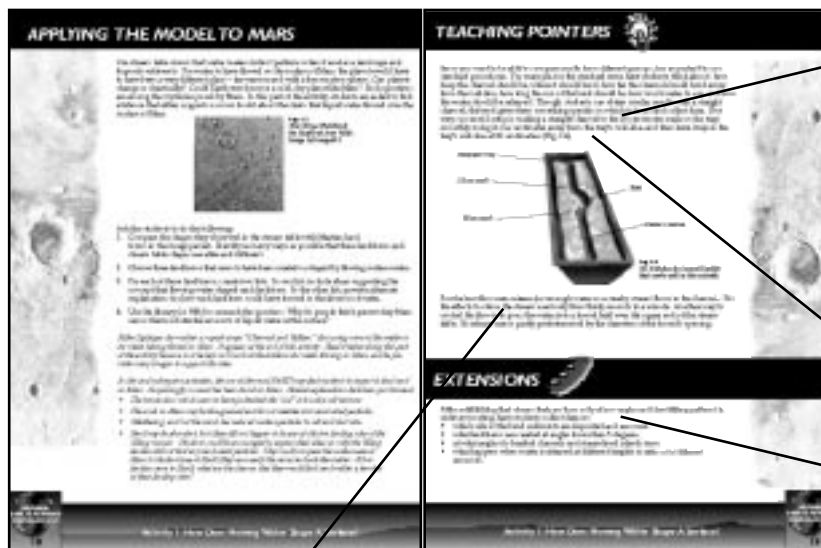
Thorough, easy to understand background information enables teachers to understand the key concepts in an activity.



Learning Activities

Clear, detailed activity procedures (with reproducible student sheets, when required) facilitates planning and classroom implementation.





Teaching Pointers

The pointers, classroom management strategies, discussion suggestions, extensions and answers to the questions listed here assist teachers in conducting hands-on, inquiry-based activities.

Assessment Suggestions

Each module provides teachers several options for assessing students including preassessment questions, question sets, case studies and suggestions for alternate ways of exhibiting student understanding.

Technology /Internet Recommendations

Computers can give students access to a rich set of related support materials, and the modules tell you about particularly applicable Web sites, CD-ROM's and videos and about how to get the live images and data from Mars. However, you still can use these modules without the use of any classroom technology.

Case Studies

Each module has a particular story to tell, and each activity in a module provides a part of that story. A case study gives students the opportunity to piece together that module's story by applying and integrating the key concepts introduced in a module. Case studies help students synthesize their learning and can be used as an assessment tool.



HOW DO I GET STARTED?

Selecting Among the Modules

Getting Started is a comprehensive introduction to studying Mars in the classroom and is recommended as the first module. It contains investigations that showcase how the series uses inquiry-based learning, image analysis, models, and experiments to develop students' understanding of Mars and the solar system. If your students have a solid understanding of the solar system, or if you want to study a particular topic or question, you could also start with another module.



Finding Out What is in a Module

To understand how the activities examine the question around which a module is organized, read the “Overview of the Module Activities and Science Themes” section. Each activity is described, and you will learn about the conceptual sequence and the culminating project.



Finding Out What is in an Activity

To understand each activity in greater detail (including material and time requirements), read the “At a Glance” page at the beginning of each activity.

Materials

Turn to the “Materials Used in This Module” section at the end of the module. The activity procedures call for the use of these materials. As much as possible, the activities use readily available materials, but occasionally, specific maps, posters or videos will greatly enhance a lesson. In such cases, all ordering information is provided. If budget or time constraints make obtaining these materials difficult, read about their use in the activity description and judge for yourself which items are especially important for conducting the activity with your students. **AT A MINIMUM, ORDER THE STUDENT IMAGE SETS. ONE IMAGE SET FOR EVERY TWO STUDENTS IS RECOMMENDED.**





Mars Education Program

Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena, CA 91109

An open letter from Dr. Meredith Olson, the Mars Program Educator for the Mars Exploration Education and Public Outreach Program.

Dear Colleague,

The ultimate goal of NASA's Mars Exploration Program is to use the adventure of going to Mars as a tool for the improvement of science education. We are at a moment in history when we have both the unprecedented Mars exploratory missions and tremendous interest in the improvement of science instruction. Both will unfold over the coming decade. The Mars Exploration Program provides a high-profile way to tap the excitement of planetary exploration and to promote teaching for scientific understanding.

Our goal is not just to teach about Mars. Our goal is to teach habits of mind. Very often the modules do not start with investigating Mars, but bring Mars science and engineering in at appropriate times when students are primed to make discoveries. We seek to promote the habits of mind that underlie science literacy, science reasoning and engineering ingenuity. The questions that underlie our task include how do we:

- engage their interest and ingenuity?
- inspire confidence and joy in their own reasoning abilities?
- teach without telling?
- help students develop habits of mind as they make meaning of Mars data?

We believe that a scientifically literate society is built from exposure to carefully crafted lessons that reveal students' misconceptions and which engage them in activities that help them reconstruct their understandings.

Educational research points out the severe limitations of communicating real understanding through lectures. The only time lectures communicate effectively is when one already understands the underlying concepts! One cannot internalize what one has not experienced. How can you explain a blizzard to someone who has never experienced snow? Consequently, as we develop lessons, we are guided by four questions:

1. What is the opening question of the lesson?
2. What series of experiences highlight patterns among seemingly unrelated events so students discover a concept?
3. How do we structure investigations to assure student ownership?
4. Which Mars topic best relates to the concept just learned?





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1. Each activity starts with an introductory question

These questions a) attract students' attention and generate interest in the topic; b) challenge students to confront the extent to which they do or do not understand a concept; and, c) confront the contradictions between their assumptions and actual physical phenomena.

2. The activities follow a carefully considered sequence

Lesson activities contain concrete materials for students to manipulate. Handling real materials allows students to notice similarities and contrast attributes. It is important for students to experience several activities, one after another, so they discover subtle comparisons. Student interest is aroused by class debate over attributes they have detected from these experiences. By experiencing a concept in different activity settings, students are more likely to form connections among ideas and build a web of relationships by which these concepts acquire meaning.

3. Lab activities and data treatment become personal ventures for students

It is important that students feel they own the intellectual process going on in the classroom. For example, as they implement an activity designed in class discussion, they must figure out the details of how to set up their own equipment to perform procedures. They must measure and record data while watching the event happen. The public sharing of data provides regular feedback and prompts frequent reflection about a student's predictions, method, conclusions and accuracy. Disagreement in results can be a springboard for discussions that empower students to craft revised experiments. The mastery of fundamental science concepts is greatly enhanced and made meaningful when students feel a high degree of ownership for their work.

4. Students generalize their understandings of science to Mars

After students have gained understandings about specific concepts, presenting them with an image of a unique Martian feature or an engineering device produces exclamations of awe and excitement. Students are energized by their own powers of deduction as they generalize their understandings of fundamental science concepts to Mars and planetary science. For example, students find watching planetary rovers navigate remote sites more engaging after attempting to create their own rover. People are generally more interested in and appreciative of the devices of others when they have already tried to do the task independently.

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Misconceptions

Students bring every-day common-sense misconceptions with them to the classroom. Left unexamined, new information will be forgotten in favor of these prior tenaciously held impressions.

Experiences

A sequence of juxtaposed experiences provides the opportunity for students to discover patterns in data gathered from seemingly unlike activities.

Data Collection

Rather than having committees doing separate projects, teams of students do the same lab. Class discussion reporting data from each lab provides enough replication of the procedure to create a scattergram graph. Rather than "teacher-tell" methods, the scattergram of data they have each personally experienced convinces students of the reliability of the findings.

Transfer

After students have gained understanding and strategies for thinking about specific concepts, presenting them with a unique feature of Mars or a space engineering device produces exclamations of awe and excitement.



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The Mars Exploration Program's module series offers experiences that students enjoy and which promote their understanding of fundamental science concepts. Such lessons can transform the "severe, terminal boredom" often exhibited by science students into an appreciation and excitement over the exploration of Mars. The Mars module series promotes understanding about Mars and aspires to transform science education in the United States.

Thank you for becoming involved in this important work.

Dr. Meredith Olson
Mars Program Educator

Dr. Meredith Olson is the Mars Program Educator for the Mars Exploration and Education Program. Based on her expertise and experience as a science teacher, she has a strong voice in shaping the educational philosophy and learning activities in the Mars Education modules. She is the Middle School Chairman and Science Education Specialist at the Seattle Country Day School, in Seattle, Washington.





Activity 2: What Do These Images Show?

Purpose

To introduce students to Mars by having them examine images from the Image Set.

Overview

Working in small groups, students examine images of Mars, discuss the features in each image and speculate about what might have caused them. Students share their interpretations in a class discussion and come to a common understanding of each image. The students also make scale calculations to develop a sense of the sizes of the features in the images.

Key Concepts

- Mars has a complex surface with features such as volcanoes, canyons, dust storms, channels, and impact craters. Many of these features are the largest yet discovered in the solar system. Some, such as mud-flow-ejecta blankets and chaotic terrain, have only been found on Mars.
- Mars has a thin atmosphere.
- Mars has no surface water.
- Mars has many features found on Earth.
- Images provide clues about a planet's geologic processes and history.

Skills

- *Interpreting* images of the surface of Mars.
- *Hypothesizing* about what might have caused the features in the images.
- *Determining* scale

Materials

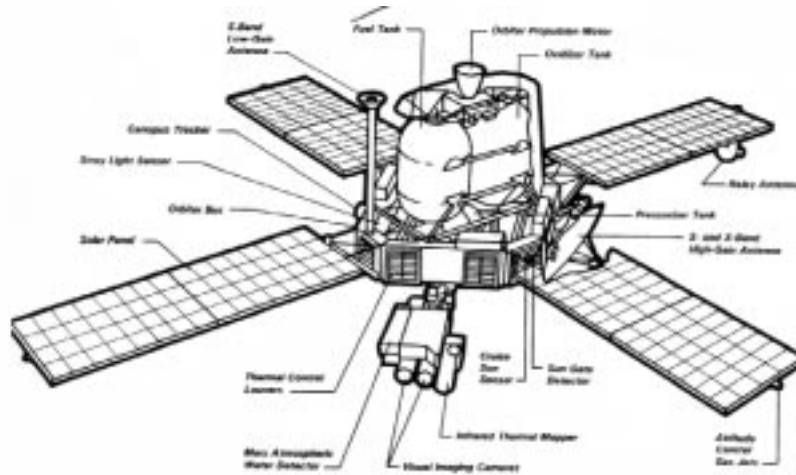
- Image Set
- Large sheets of paper to record ideas from the class discussions.
- Clear transparencies and water-soluble markers (optional)
- Atlas of Earth (several copies for use in the class)

Time

Two to three class periods

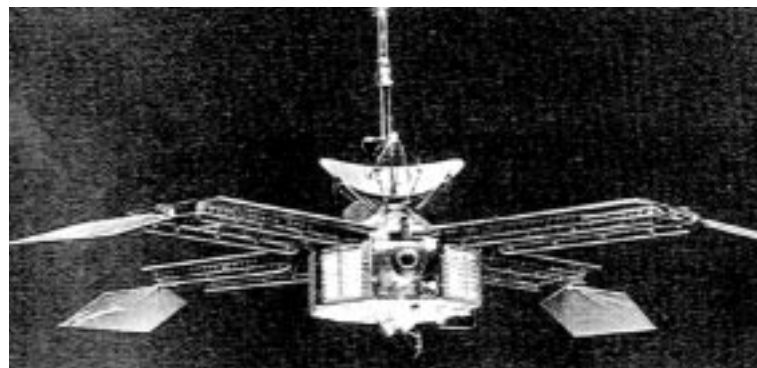


The Mariner and Viking missions to Mars have taken thousands of pictures of Mars from orbit and from the surface, and new missions will provide many more images. These images are essential for scientists wanting to learn more about Mars. It is important for students to have the opportunity to work with images because of their central role in planetary research and because of their power to help students understand key concepts.



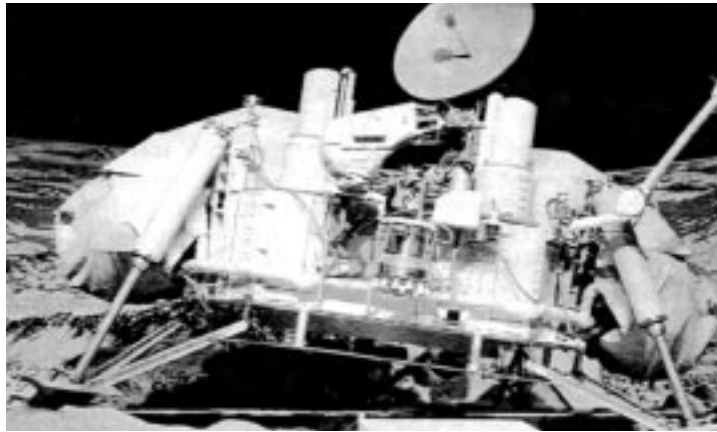
Starting in 1976 the Viking Orbiter returned thousands of images of Mars.

Students should consider the images as “mystery stories.” When you distribute the images, do not explain what they show. Instead, ask your students what they see in the images. Each image has some sample questions to help launch discussions. This early in the module, students may not know enough to give strong answers. Nonetheless, the thinking, problem-solving, and speculating engages students and inspires them to generate questions - the building blocks of meaningful engagement with a topic.



Mariner 4 was the first spacecraft to return images of Mars in 1965.

PROCEDURE



The Viking I Lander

1. Set the tone for students by telling them that this activity recreates the experience many scientists had of seeing unfamiliar images for the first time.
After Viking I and II reached Mars, scientists were inundated with many new views of the planet, and they often felt overwhelmed because most of the views raised more questions than they answered.
2. Have students work in small groups and look through the image set with the goal of understanding what each image shows. They should examine them at two levels. The first level is to generally identify what is pictured in the image. The second level is to examine some of the details and speculate about what might have caused them. Also, how do the different features in the image relate to one another? In each group, one person should record the comments, speculations, and questions raised by the image.
Active involvement is a far more powerful learning experience than listening passively to someone else's discovery. Consequently, each group should examine each image. However, if time is a concern, you could assign a different image to each group and have them report on those images. If any groups get stuck, refer to the "Notes on the Images" below for questions and ideas to help prompt their thinking. To facilitate making comparisons and sketching features, students can mark on clear transparencies.
3. Ask a group to select one of the images and describe what they think it shows. Write their idea on a large sheet of paper that everyone can see. Ask another group for another detail they noticed and what they think it is. Continue until each group has contributed something or no one has more observations to share. Ask students about their answers to the sample questions.
Each image can be the beginning of an involved discussion. Many images are inter-related (see "Notes on the Images" below), and it can be more interesting and valuable to jump around and follow an idea rather than to fully document each image in order. The leaps of intuition, rather than completion, are what characterize success.
4. Proceed until all the images have been described.
5. Have your students pick a feature in one of the images and use the scale to calculate how big it is. Have them record this size. Then have them refer to an Earth atlas to find a region or feature about the same size. Relating a feature to something in a student's own experience and creating a "personal yardstick" helps a student to internalize and to better understand what a feature's size and scale really mean. For example, each crater in Image #2 is about 15 km in diameter, about the size of Manhattan Island.
You may need to teach a lesson to help students understand scale.

NOTES ON THE IMAGES IN THE IMAGE SET

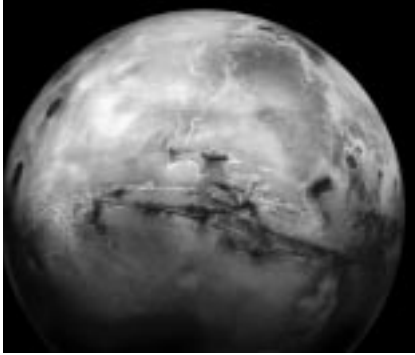


Image 1: Mars hemisphere

This photograph shows Mars as if you were viewing it from 2,500 km above the surface. It is a mosaic of 102 images taken by the Viking I spacecraft in 1976. This view shows some large impact craters, volcanoes (the three round spots on the left. Each volcano is 25 km tall and about 350 km in diameter.), and Valles Marineris, a huge 4,800 km canyon (across the middle of the photograph). In this view, the two Martian polar caps are not apparent.

Sample Questions:

- What is the feature across the middle?
- What do you think the circles on the left side are?



Image 2: Martian surface craters

Craters, formed when meteors strike a surface, cover much of Mars. These craters are located in the heavily cratered uplands about 5,500 km east of *Ares Vallis* (e.g., the Ares Valley). When one impact happens near another, the resulting craters overlap. Note that all crater walls and one crater in particular are severely degraded. Since the squiggles in the bottom of the two upper craters are dune fields, wind is a significant factor in this area and may have helped degrade the craters. The craters have two ejecta patterns – lobed (to the left) and striated (below). Lobed patterns suggest that water-rich material such as mud flowed upon impact. Striated patterns are caused when an impact propels material across the surface at high speeds. (34.79N, 309.14W, Viking Orbiter frame 641A09)

Sample Questions:

- On Earth, what are some things about the size of these craters?
- Why do some of the craters overlap?
- In what order were the craters formed?
- What do the patterns around the craters reveal about the nature of the surface?
- Have you ever seen an impact crater? (*The “Man in the Moon” is a collection of impact craters.*)



Image 3: Crater with a lobed ejecta pattern

In this image there is an “oozy” blanket around the crater. Scientists speculate that when the meteor causing these craters hit, the impact melted ice in the surface layers. The resulting water turned the surface to mud that flowed away from the impact. In Activity 3, your students will do their own crater experiments. (23S, 79W, Viking Orbiter frame 608A45)

Sample Questions

- What do you think caused the shape around the craters?
- Were these craters formed at the same or at different times?

This image shows craters and a 270 km-wide dust storm just at the edge of the South Pole. The winds, induced by great temperature contrasts between the ice cap and the land surface, can create such storms. Dust storms can obscure large areas of Mars, and Earth-based telescopes can even see some of these storms! (70S, 60W, Viking Orbiter frame 248B57)

Sample Questions:

- What could this feature be?
- How big is the feature in this image?
- In what direction is the storm moving?
- Why might there be strong winds over the land next to an ice cap?

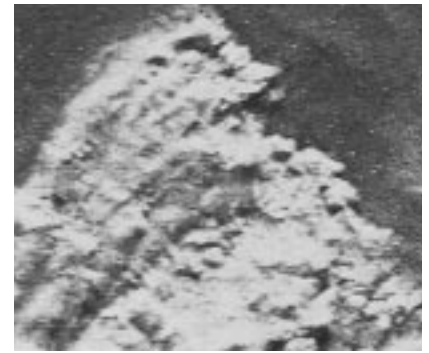


Image 4 : Dust storm on the Martian surface

From 18,000 km away and at an orbital height of about 1,500 km, the Viking I Orbiter took this image of the sky above the *Argyre Planitia* (i.e., the Argyre Plain). Of special interest are the light-colored bands above the horizon. Dust from a dust storm creates a haze in the atmosphere 25-30 km above the planet's surface. This view emphasizes the shallowness of the Martian atmosphere. (47S, 22W, Viking Orbiter Image 34A13)

Sample Questions:

- What is the line on the horizon above the Martian surface?
- How high above the surface is it?
- What causes it to be visible?



Image 5: View of the thin Martian atmosphere

The surface of Mars has volcanoes, none of which are active. These two shield volcanoes formed as low-viscosity basaltic lava flowed from a central vent. The larger one is 6 km tall, 90 x 130-km in diameter, and has a slope of 7 degrees. The smaller one is 3.5 km tall, 60-km in diameter, and has a slope of 5 degrees. They are among the steepest volcanoes on Mars. On both volcanoes, note the lava channels and the impact craters. The long, straight fractures on the left formed when the Martian surface in this region bulged upward. (25N, 95W, Viking Orbiter photomosaic 211-5593)

Sample Questions:

- Which came first, the volcano or the impact craters? How can you tell?
- What might have caused the channels on the sides of the volcanoes?
- What are the lines in this image? What might have caused them?

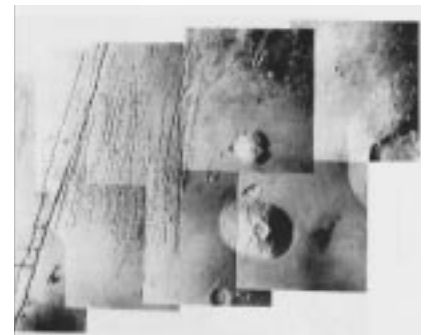


Image 6: Martian volcanoes and fault lines

NOTES ON THE IMAGES IN THE IMAGE SET



Image 7: A section of the Candor Chasm in Valles Marineris

Mars has many canyons, and your students can learn more about them in other modules in the series. This image shows a 100 km-wide by 8 km-deep section of the Candor Chasm of Valles Marineris. Valles Marineris is a huge rift valley roughly as long as the US. Numerous landslides have eroded its edges and widened it. (25N, 95W, Viking Orbiter frame P40381)

Sample Questions:

- What do you think caused the valley?
- What do you think shaped the cliffs on the edges of the canyon?
- How did this canyon get so wide?

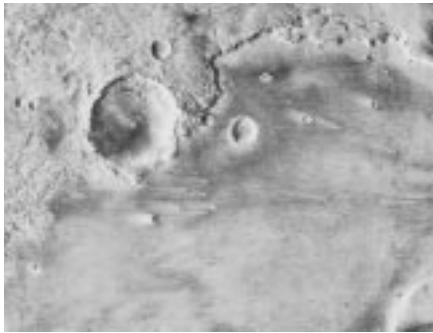


Image 8: Landforms at the mouth of Kasei Vallis

This image shows a rich diversity of geological processes. There are fractured, ridged plains (top center), craters as big as 100 km (several have been severely degraded), lobed ejecta blankets, an enormous channel, and wind streaks (going in the opposite direction of the former water flow). (27N, 58W, courtesy of Arizona State University's Planetary Geology Group)

Sample Questions:

- Explain which came first, the fractures or the large crater in the center-left?
- Which came first, the crater in the bottom-center or the channel?
- Which direction did the fluid flow? Is any fluid apparent now?
- What caused the “tails” behind the small craters in the channel?
- What sequence of events and processes makes most sense in explaining all these features?

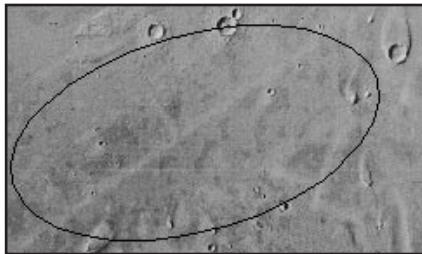


Image 9: Close-up view of the landing site

The 100 x 200 km ellipse, roughly the size of Massachusetts, delineates the expected landing area for Pathfinder at the mouth of Ares Vallis. It is an ellipse rather than a circle because Pathfinder sped in obliquely from the northeast and bounced to a stop rather than using rockets for a controlled, vertical landing. Pathfinder landed just northwest of center (19.35 N, 33.55 W). Note the landforms sculpted by flowing water (suggesting that large-scale floods swept this region), a smooth outwash plain (good for a safe landing and full of sediments from upstream), and impact craters with lobed ejecta blankets (suggesting water or ice-rich surface layers, an idea consistent with flooding). (Detail of USGS photomosaic I-2311)

Sample Questions:

- What is this ellipse?
- How would you describe this region?
- How might the teardrop-shaped landforms have formed?
- What might make this a desirable landing site?

Barringer Crater in Winslow, Arizona is about 50,000 years ago, 1.2 km in diameter, and 180 meters deep. While it takes billions of years to achieve this level of degradation on Mars, Earth's wind and water have severely eroded the crater walls and ejecta blanket in just thousands. The ejecta pattern suggests that Barringer Crater had a striated, not lobed, ejecta pattern. Thus, the surface layers were probably fairly dry at the time of the impact.

Sample Questions

- What planet is this crater on? How can you tell?
- Is this crater more like the one in Image 2 or the one in Image 3? Why?
- Is this a fresh or an aged crater?
- How does this crater compare in size to those in Images 2 and 3?



Image 10: The Barringer Crater in Winslow, Arizona

On July 20, 1976, Viking I landed in the Chryse Planitia and was the first spacecraft to land successfully on Mars. Scientists think the Chryse Planitia is an outwash plain, and one reason Viking I landed here is that it is relatively flat, increasing the chances of a safe landing. Viking's robotic arm dug the trenches in the foreground to reveal the upper surface and to collect sediments for several experiments. Note the wind-deposited dust behind some of the rocks. As measured by Viking, temperatures typically ranged from -85°C to -30°C and wind speeds were around five meters per second, gusting to 25 meters per second. Pathfinder also landed in the Chryse Planitia, roughly 850 km east of this site. (22.4N, 48W)



Image 11: Viking I's view of the Martian surface

Sample Questions

- How big are the largest rocks?
- Does this look like any place on Earth? If so, where?
- Can you tell if it is hot or cold?
- What might scientists learn from sampling in a place like this?
- How does this scene compare to the one around Pathfinder's landing site?

Image 12 shows an expanded view of Pathfinder's landing site. Although there is currently no liquid water on Mars, the landforms strongly suggest that water flowed during an earlier time. There are more streamlined shapes evident in this image than in Image 9, as well as several apparent channels that may have carried water to the landing area. (33N, 20W, Detail from USGS photomosaic I-1345)



Image 12: Wide-area view of the landing site

Sample Questions

- What information does this wide-area view add to your understanding of Image 9?
- Do you see anything that might make this an interesting area to explore?



Image 13: Sojourner, Barnacle Bill and Yogi

On its third day, Pathfinder made this image showing part of a deflated airbag and the area at the end of the lander's ramp. Note that some rocks are rounded and others are angular. Scientists think that the rounded rocks had their edges knocked off by the tumbling action of flood waters, and that the sharp-edged rocks were ejected from nearby impact craters and/or volcanoes. Sojourner used its Alpha Proton X-ray Spectrometer (APXS) and cameras to examine the mineral composition of rocks and soil around the landing site. "Barnacle Bill" is the small rock on the left, and "Yogi" is the large rock at the upper right. See Activity 5 for a discussion of some of the findings and visit Pathfinder's Web site for additional images and science results.

Sample Questions

- How many different general rock shapes can you see?
- What causes rocks to be different shapes? (*Hardness and their weathering history*)
- Is the surface of Mars dusty? How can you tell?



Image 14: Twin Peaks

Pathfinder made this image on the fourth day. "Twin Peaks," the two hills about one kilometer away from the landing site, are of great interest to scientists. Sections of the hills look stratified, and white areas on the left hill, (nicknamed the "Ski Run") may represent a high-water mark from one of the floods that swept this area. The jumbled boulders in the foreground probably were carried from upper portions of Ares Vallis by ice or water.

Sample Questions

- Does this look like any place on Earth?
- Why did the landing site look so smooth when it is really full of boulders?
- What are some ways a plain like this can become littered with rocks?



Image 15: Regional view of the landing site

Image 15 shows the channel of Ares Vallis extending 1,800 km southeast of Pathfinder's landing site. By tracing the channel upstream, you see depressions in the landscape – possible sources of water for Ares Vallis. These are *chaotic terrain*, a unique Martian feature that formed when large areas of permafrost melted (see Activity 4's Background section for a further discussion). The mouth of Ares Vallis is 2-3 km below the head of the channel. As the water flowed downhill, it crossed many different types of terrain and carried sediments from roughly a million-km² area of the surface. This is why Pathfinder found sediments from many rock types at the mouth of this channel. The "one-stop-shopping" possibilities made Pathfinder's landing site exceptionally valuable to scientists wanting to learn more about the geology and hydrology of Mars. Activity 4 asks students to figure out why scientists chose Ares Vallis as Pathfinder's landing site. (Detail from USGS Map I-1551)

Sample Questions

- What information does this wide-area view add to your understanding of Image 12?
- How much water flowed in this region, a little or a lot?
- Do you see any sources for water?
- Why is the area at the end of the channel so smooth? (*It is a floodplain covered with sediment.*)

Image 16 highlights many of the region's interesting features. Channels descend 2-3 km from a plateau that surrounds most of the low-lying Chryse Planitia. The numerous areas of chaotic terrain and the many channels suggest that flowing water was a regional phenomenon. While there are many lobed ejecta blankets in the Chryse Planitia, there are none in the highlands. Since lobed ejecta blankets occur only in water or ice-rich areas, the highlands must have been drier than the plain at the times of impact. Also, the highlands are heavily cratered while the Chryse Planitia is relatively free of craters. Our solar system experienced a period of heavy bombardment by asteroids three-billion years ago. This bombardment created most of the craters on Mars, so the floods that obliterated the Chryse Planitia's craters must have occurred after that time. (Detail from USGS map I-1448)



Image 16: Regional map of Ares Vallis

Sample Questions

- How big is this area?
- Is Ares Vallis the only place where water flowed?
- What is the general topography of this region? Which direction is uphill?
- Where might the water that flowed in these channels have come from?
- Describe the distribution of craters in this region.
- What might explain this pattern of distribution?
- What are some differences between the craters on the plain and in the highlands?
- What might explain the differences between the craters in these two areas?
- What do you think the Chryse Planitia looked like when water flowed in the channels?

Every two years, Mars and Earth align so that a spacecraft can travel efficiently between the two planets. Over the next decade, NASA plans to launch new missions each time Earth and Mars are positioned for efficient travel. Mars Global Surveyor (an orbiter) will map the entire surface of Mars at high resolution. Mars Surveyor '98 (an orbiter, a lander, and two penetrators) will study the Martian atmosphere and climate history. Mars '01 (an orbiter, a lander, and a rover) will study the poles. Even though NASA has planned missions for 2003 (an orbiter, a lander, and a rover), 2005 (rock samples brought back to Earth by a returning spacecraft), and 2007, scientists want to see what the current missions reveal about Mars before deciding where to send these three missions and what kinds of data they should collect. You will use this timeline in Activity 5.



Image 17: -- The Mars Exploration timeline

MARS IMAGE ASSESSMENT WORKSHEET

Use the Image Set to answer the following questions. There are several images that relate to each question, so build the strongest case possible for your answers by finding several examples of supporting evidence.

Question	Y/N	Evidence That Makes You Think So	Image #
Does Mars have an atmosphere?			
Is there evidence for water on Mars?			
Does Mars have volcanoes?			
Does Mars have strong winds?			
Is the surface of Mars dry?			
Does Mars have many craters?			
Is the surface hot by Earth standards?			
Does Mars have landslides?			
Did the surface of Mars ever crack?			
Does Mars have dust on the surface?			
Is Mars an easy planet on which to land a spacecraft?			

MARS IMAGE ASSESSMENT

The following questions have no direct tie in to any particular image in the Image Set. They are more appropriate for short answers, homework, or research projects.

- What kinds of places on Earth most look like Mars?
- Name three ways Mars and Earth are alike and three ways they are different.
- Where might one look to find life on Mars?
- Which features are found on both Earth and Mars? On only one of the planets?



Activity 3: What Can Craters Tell Us About a Planet?

Purpose

To learn some basic concepts about craters on Mars using three investigative techniques: image interpretation, modeling, and Mars-Earth comparisons.

Overview

Students examine images of Martian craters and speculate about what caused them. Next, they model the formation of an impact crater by dropping objects into a tray of powder. They examine the effects of each impact and the features each impact creates. Students re-examine the images of the Martian craters to see if their modeling experience gives them additional insights. They create hypotheses to try to explain a feature not seen in their models, a mud-flow-like ejecta blanket. Students write a plan to test one of the hypotheses and carry out their investigation. Finally, students apply their modeling experiences by making several inferences.

Key Concepts

- Impact craters are caused when a bolide collides with a planet.
- A crater's size and features depend on the mass and velocity of the bolide.
- Impact craters provide insights into the age and geology of a planet's surface.
- The Martian surface contains thousands of impact craters because, unlike Earth, Mars has a stable crust, low erosion rate, and no active sources of lava. So, impact craters on Mars are not obliterated as they are on Earth.

Skills

- *Interpreting* images of craters
- *Comparing* craters on Mars and Earth
- *Modeling* geologic processes
- *Designing and conducting* a Mars-related investigation
- *Collecting and interpreting* data from a classroom experiment
- *Drawing conclusions and Making inferences*

Materials

- Image set
- One tray per group such as a dish pan, pizza box or lid from copy paper box
- Very fine, light and dark colored powders such as silica sand, flour, plaster, mortar powder or grout (comes in different colors), chocolate pudding, powdered cocoa, powdered charcoal or corn meal
- Bolides of various sizes such as golf balls and small rocks (1-4 cm)
- Sieve, large spoon or cheese cloth to sprinkle the dark powder
- Meter stick or string to measure the two-meter dropping height
- Balance
- Card or ruler to smooth the surface of the powder
- Newspaper or drop cloths
- Large sheets of paper to record ideas from the class discussions

Time

Day 1:	Steps 1-7
Homework	Step 8
Day 2:	Steps 9-11
Day 3:	Step 12
Homework	Steps 13 and 14

Preparation

Copy necessary worksheets for Step 2 and, if appropriate, the Extension.



In Activity 2, students had a preliminary experience with image interpretation. In this activity, students use another method of inquiry central to both the scientific process and to the Mars module series – modeling. In this activity, physical models are used to answer two questions: What formed the circular shapes on the surface of Mars? and, What can they tell us about the nature of the surface?

This mini-investigation exemplifies the design of many activities in the Mars Exploration module series. The National Science Education Standards advocate a central role for investigations in science education. By having students ask questions, conduct experiments, collect data, and draw conclusions, this activity helps students learn how to design and conduct their own Mars-related investigations.

Craters on Mars



Bolides are any falling body such as a meteorite and are commonly made of rock, ice, or a combination of rock and ice. When a bolide collides with a planet, it produces an *impact crater* (Figure 3.1). A crater's circular shape is due to material flying out evenly in all directions as a result of the explosion upon impact rather than as a result of the bolide having a circular shape. In fact, almost no bolides are spherical.

Figure 3.1: A bolide smashes into Earth and creates an impact crater.

Materials flung out at high speeds produce *rays*, straight lines radiating away from the impact crater. Materials flung out at slower speeds produce an *ejecta blanket*, a layer of material, sometimes quite thick, immediately surrounding the crater (Figure 3.2).



Figure 3.2: Notice the rays below the craters and the ejecta blanket, primarily to the left. Image Set image 2.



Figure 3.3: The view across the Argyre basin, itself a 1200-km diameter impact basin, shows numerous craters of various sizes. The largest crater is 210-km in diameter. Image Set image 5.

- **Craters come in different sizes**

The largest crater on Mars (and, arguably the largest so far discovered in the solar system) is the Hellas basin measuring 1600 x 2000 km, roughly twice the size of Alaska. However, most Martian impact craters are smaller than 100 km (Figure 3.3). A crater's size depends on the mass and velocity of the bolide. The bigger, faster, or more massive the bolide, the bigger the crater.

- **Craters hint at the age of the surface**

Scientists studying craters on Mars noticed that some areas of Mars have many craters while other areas have just a few (Figures 3.4 and 3.5). The generally accepted theory is that all areas on Mars used to be heavily cratered, and then surface changes such as lava flows, flowing water, or intense dust storms obliterated some of the craters, leaving a younger, smoother surface. Therefore, scientists interpret Figure 3.4 as an older surface (i.e., many craters) and Figure 3.5 as a younger surface (i.e., fewer craters).



Figure 3.4: Dense crater patterns are typical of ancient Martian terrain. Image is 250 km across.

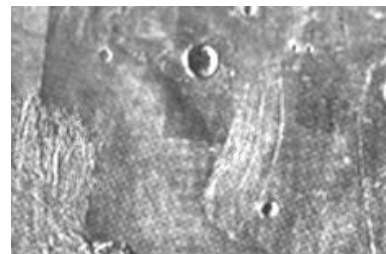


Figure 3.5: Relatively recent lava flows have created a sparsely cratered plain. Crater in upper center is 18 km across.

- **Craters hint at what's under the surface**

The shape of an ejecta blanket depends on the characteristics of the surface hit by a bolide. Some craters on Mars have ejecta blankets like the ones seen in Figure 3.6. The mud-flow-like shape that surrounds the crater gives a clue about the nature of the surface. Scientists believe that the heat and pressure of an impact melted ice under the surface, forming mud. This mud flowed away from the crater, forming a lobed shape. Interestingly, only craters with diameters larger than five kilometers exhibit mud-flow ejecta blankets. Scientists think that meteorites below a certain size do not penetrate deeply enough to melt the permafrost.



Figure 3.6: Image Set image #3.

- **On Earth, ancient craters have eroded away**

Since their formation, tens of thousands of bolides have hit both Mars and Earth. However, very few impact craters on Earth can be seen because Earth's ancient surface has been worn by erosion, covered by lava, and recycled by plate tectonics. On the other hand, Mars has a stable crust and small scale, localized resurfacing, so most of the Martian impact craters still exist.

PROCEDURE



1. Have your students examine Image Set images 2 and 3 and ask them what they think caused the circular shapes. Discuss their ideas and ask them how they might investigate them.

To investigate their questions, students might suggest: looking at additional images, making models to recreate a crater's features, finding similar crater features on another planet or moon, and, of course, going to Mars.

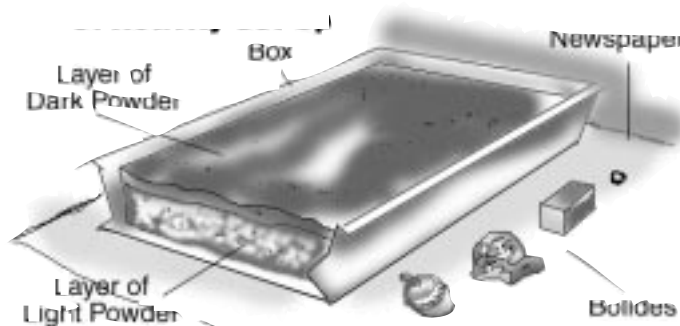


Figure 3.7: Cut-Away view of Activity 3 Set Up.

2. Have some members of the group prepare the test area by spreading newspaper or drop cloths over a cleared part of the floor and setting a box or tray in the center (Figure 3.7). Have the remaining members select the bolides and fill out Worksheet 1.

To understand crater formation and to identify the distinctive features of impact sites, it is best to begin by examining the simplest case – the effect of a bolide on a dry surface.

3. Have students fill the container with about 5-10 cm of the light colored powder (larger bolides require a thicker layer of powder). Have them pack it lightly and smooth it with a card or ruler.

If cost or availability are factors, use fine sand for the first 5-10 centimeters and then sift a 1-2 cm layer of fine, light-colored powder such as grout over it.

4. Have students sprinkle a 1-2 cm layer of dark powder over the light-colored powder, using enough to hide the light-colored powder. Have them gently smooth the dark layer with a card or ruler, being careful not to mix the two layers.

5. Have students drop the largest bolide onto a section of the surface from a height of two meters. Remove the bolide. In their Mars Journals, have students enter the bolide information from Worksheet 1, and sketch and describe the crater, the ejecta blanket and any changes to the surface.

- Did the layers mix? If so, how?
- Which layers are visible in the crater? At the rim? Beyond the rim?
- Is the ejecta thrown out evenly in all directions?
- How large is the crater compared with the bolide?
- Are the bolides generally bigger, smaller or the same size as the craters they form?

To calculate the velocity at impact, use $d = \frac{1}{2} at^2$. Acceleration of free fall is 9.8 meters per second per second. Solving for t gives 0.64 seconds as the time to fall 2 meters. Therefore, the velocity ($V=at$) is 6.3 meters per second, or 22.6 kilometers per hour. To calculate the kinetic energy (K), use $K = \frac{1}{2} MV^2$.

6. Have students repeat Step 5 with another bolide. Make sure the observations include comparisons between the craters. Continue until all bolides have been dropped.

Students should not smooth the surface between bolides because it is important for them to see the pattern of a heavily cratered surface with overlapping ejecta blankets.

7. Have students enter their final observations in their Mars Journals. Then, set the trays aside for later use with student investigations and clean up the test area.

8. Have students open to Image Set images 2 and 3. How are these craters and the model alike and different?

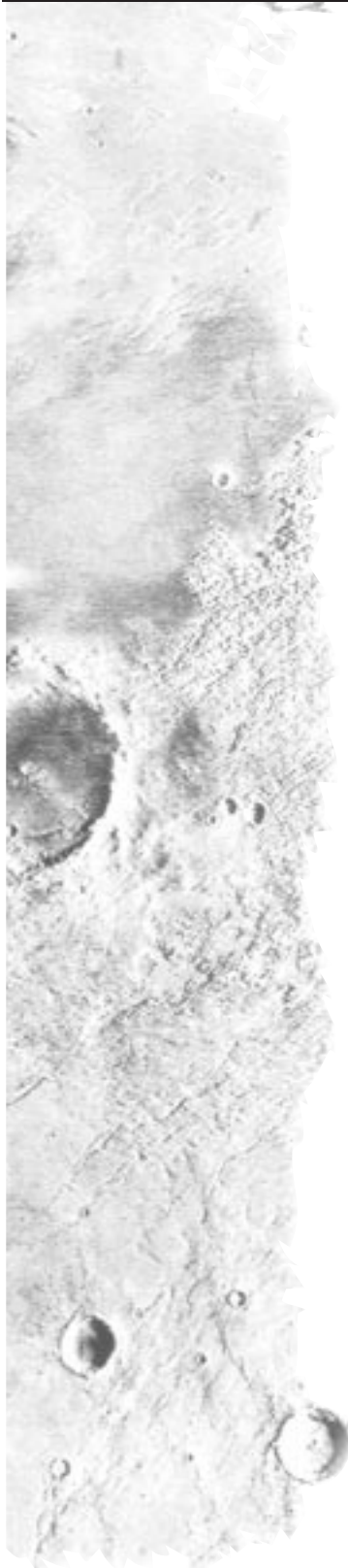
The craters in the model are similar to the actual craters in that they have rims, ejecta, and a circular shape. The ejecta is deposited in all directions and may be striated in the same way as the ejecta below the craters in Image 2. The model is different because meteorites are usually completely destroyed upon impact. Also, the model lacks the features on the crater floors such as rings and dune fields, and the ejecta blanket in the model does not have the mud-flow pattern seen in Image 3.

9. Have the class consider a question that confronted scientists: How did the mud-flow-like ejecta blankets form? Create a list of hypotheses that might include ideas such as:

- the ground contained water or ice that melted after impact, and the muddy ejecta flowed instead of being thrown away from the crater;
- the bolide was made of ice which melted upon impact turning the ground to mud which subsequently flowed;
- the impact might have melted the ground and turned it into lava which flowed away from the crater.

The pattern of ejected material is actually used as a way to identify areas with possible water or ice in the surface layers. By investigating this question, students will mirror the way scientists created models to obtain insights about the Martian surface. Today, the first hypothesis above is the most widely accepted.



- 
10. Have the class decide which of their hypotheses are testable using their setup. Have each group write a plan to investigate one of the testable hypotheses.
 11. Have each group describe their plan. Have the class comment on the strengths and weaknesses of each plan.
 12. If you have time, let each group carry out their critiqued plan. Otherwise, have the class agree on one plan for you to do as a demonstration.
Consider creating a pool of mud outdoors where splattering is less of a concern. Another way to simulate the instant melting and flow of the surface is to heat jellybeans, grapes or potato chunks (a microwave works well) and drop them into pans filled with applesauce or a slurpee-like, ice-water mixture.



*Figure 3.8: The Barringer Crater in Winslow, Arizona.
Image Set image 10.*

13. To demonstrate how models help people understand an unfamiliar situation, have students examine Image Set image 10 (Figure 3.8) and see what they can infer about the soil moisture content at the time of impact.

Though erosion has obliterated most of the ejecta blanket, the traces of material indicate that Barringer Crater's ejecta blanket had a striated, not flowing, pattern. Consequently, one may conclude that the soil was dry at the time of the impact.

14. Another inference students can make is about certain geologic processes on Mars. Since Earth and Mars are neighboring planets, one can assume they had similar cratering histories. Why then does Mars have so many more craters than Earth? What can students infer about the Martian atmosphere? The number of lava flows? The Martian crust?

- a) *Water is the main agent of erosion on Earth. With so many well-preserved craters on its surface, Mars must not have water erosion. Students can reasonably infer that Mars has either a thin atmosphere or one without much water. This could lead to hypotheses about the climate.*
- b) *Lava has covered large areas of the Earth. Students can reasonably infer that Mars had few active volcanoes in the past or that they are widely spaced. This could lead to hypotheses about the type of magma in the Martian core and about what conditions cause Martian volcanoes to emerge where they do.*
- c) *On Earth, plate tectonics creates mountain ranges, recycles crust, causes continents to shift position and spawns volcanoes. Consequently, plate tectonics has altered almost all of Earth's crust and virtually no crust from Earth's early history exists today. Students can reasonably infer that Mars has a stable crust and lacks plate tectonics. This could lead to hypotheses about the Martian core and about the thickness of the Martian crust.*



EXTENSIONS

Generating questions, developing hypotheses, and determining ways to investigate those hypotheses are core elements of the scientific process and are an important focus of this extension.

- Have students examine Images Set images 2 and 3 and fill out Worksheet 2.
- On the board or on a large sheet of paper, record how groups completed each column. Have them determine which questions are testable with their setup.
To keep every group engaged, let each group make only one contribution at a time. Figure 3.9 shows examples of how students might complete the last two columns of Worksheet 2.
- Have groups design and conduct investigations examining one of their questions.
- Have each group prepare a poster report about their investigation and conclusions.

Possible Question	How the Question Might Be Investigated
Why didn't the upper-most crater in Image 2 obliterate the ones below it?	Model: Create craters on top of one another.
Does the bolide speed, size or shape make a difference in the pattern of ejected material?	Model: Drop different sized /shaped objects onto a surface and from different heights.
What caused the pattern of ejected material to be different in the two images?	Model: Drop the same bolide onto different surfaces or different bolides onto one surface.
Of the 2 patterns of ejected material in these images, which is more common on Mars?	Image Interpretation: Examine additional images.
Does the wetness of a surface make a difference in the pattern of ejected material?	Model: Drop an object onto dry, moist, and wet surfaces.
Does Earth have craters like those on Mars?	Image interpretation and Mars-Earth comparisons: Research the topic in a library or on the Web.
What would happen if our bolide disintegrated upon impact?	Model: Use mudballs instead of hard balls.
Can there be so many craters that new craters obliterate old craters, keeping the total number constant?	Model: Drop large numbers of bolides.

Figure 3.9: Examples of how students might complete the last two columns of Worksheet 2.

- e) Figure 3.10 shows how students can also launch their investigations by focusing on the variables that underlie each of their questions.

Variable	How To Investigate	Implementation Recommendations
Nature of the Substrate	Drop the same bolide onto several surfaces, each made from different-sized particles. Students could also vary the moisture level.	Test only one variable at a time.
Bolide Speed	Drop the same bolide onto the same surface from different heights.	Throwing things in a classroom is dangerous. Therefore, drop the bolide from a number of heights. See Step 5 for how to calculate the velocity and kinetic energy.
Bolide Shape	Drop different shaped bolides onto the same surface from the same height.	To keep mass constant, reshape the same ball of clay each time.
Bolide Mass	Drop bolides of different masses onto the same surface from the same height.	To avoid changing two variables, use marbles and ball bearings of similar size or inject a pingpong ball with different amounts of water.
Bolide Size	Drop bolides of different sizes onto the same surface from the same height.	To avoid changing two variables, use different-sized spheres of similar mass such as ball bearings and rubber balls.

Figure 3.10: Students can launch investigations by focusing on the variables that underlie each of their questions.

Assessments

- Analyze students' entries in their Mars Journals.
- The most meaningful assessment is having students conduct their own investigation. Ask students to plan an investigation based on one of their own questions about craters or one you supply. If possible, have them carry out their plan.
- Ask how the craters modeled in this activity are similar to and different from craters on Mars.
- Ask what determines the size of an impact crater.
- Ask what kinds of inferences can be made and insights gained about a planet based on impact craters.
- Have students discuss the role of image interpretation, model making and comparisons with Earth when trying to understand a distant planet for which there is limited information.

WORKSHEET 1

BOLIDE #	BOLIDE DIAMETER (mm)	BOLIDE MASS (g)	CRATER DIAMETER (mm)
1			
2			
3			
4			

WORKSHEET 2 FOR THE EXTENSION

What Can We Say About the Craters in Image Set images 2 and 3?

Interpretations We're Reasonably Sure Of	Questions We Have	How We Might Answer Those Questions



Activity 4: What Is So Special About The Pathfinder Landing Site?

Purpose

To show how much students can learn about Mars and the Pathfinder mission by understanding some of the criteria used to select the Pathfinder landing site.

Overview

Students examine images showing the Pathfinder landing site at three different scales. When examining each image, they discuss what each view adds to their understanding of the landing site. The activity demonstrates how images become clues in a mystery story that stimulates students to wonder, question, and speculate. In addition, it shows how students can use the clues images offer to unlock the mysteries of distant planets.

Key Concepts

- Images are a rich source of information and a stimulus for investigation.
- Scientists are conducting robotic missions to explore Mars.
- Chaotic terrain is thought to have formed when the removal of subsurface magma, water, or ice caused a loss of support, and the ground collapsed under its own weight.
- Chaotic terrain is considered a source for the fluid(s) that created the channels.

- The large channels, chaotic terrain, eroded land forms, and smooth plain at the mouth of Ares Vallis suggest that Mars experienced tremendous floods.
- The floods deposited sediment from nearly one-quarter of the planet's surface at the mouth of Ares Vallis.
- By sampling the rocks at the mouth of Ares Vallis, scientists can see if their hypothesis about Martian floods is correct as well as learn a great deal about Martian geology.

Skill Goals

- *Analyzing* images of Mars for evidence of flowing water
- *Speculating* about processes affecting the surface of Mars
- *Identifying* some of the key Martian landforms
- *Constructing* coherent explanations that are supported by evidence
- *Writing* to synthesize and communicate understanding

Materials

Student Image Sets

Time

One to two classes

BACKGROUND



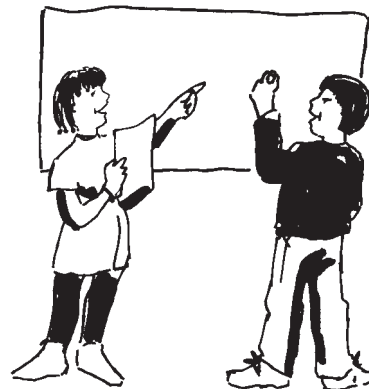
Planetary scientists rely heavily on images to investigate distant places in our solar system. These scientists study images and use the clues they offer to unlock the mysteries of our solar system. In the classroom, too, images serve as important resources for student investigations rather than simply as textbook illustrations.

Can students really use images to understand a distant planet, which geologic processes are at work, or how planetary science is done? Like scientists, students combine image analysis with other research techniques. For example, in the Mars Exploration Program students conduct experiments, make Mars-Earth comparisons, and construct models to understand individual concepts. Images are vehicles for synthesizing these concepts into coherent understandings. Once students can visualize a concept and put it in a context, they are better able to weave together seemingly separate ideas into clear, intelligible explanations. Thus, image interpretation helps students to speculate meaningfully about Mars and Martian geologic processes.



In this activity, students will try to understand scientists' rationale for selecting Ares Vallis as the landing site for Mars Pathfinder. As they review the evidence, students will see that their deductions and inferences connect with actual situations. This success will draw them deeper into the adventure of the mission as well as deeper into the adventure of planetary exploration.

You will see that images are a rich source of information and that they serve as a focal point for inquiry and investigation. Images become clues in a mystery story that stimulates students to wonder, question, and speculate. Students study the images, raise questions, draw on their experiences, and try to figure out possible interpretations. As students experience success in interpreting images, they gain confidence in their own ability to figure things out. Science becomes a set of questions to explore rather than a set of facts to be memorized.



What Is Ares Vallis?

Ares Vallis (i.e., the Ares Valley) is one of a series of channels that descend from a highland plateau to the low-lying Chryse Planitia (Chryse Plain). Ares Vallis originates in three large areas of chaotic terrain, follows a 1,800 km course and terminates in the Chryse Planitia, approximately 2.5 km below its starting elevation. The channel is 25 km wide and about 1 km deep, and many of its features lend strong support to the idea that Ares Vallis is an immense flood channel. For example, the scour marks and longitudinal grooves seen in Martian outflow channels were most likely produced by deep, high-volume, high-velocity flows.

What is so Special About the Landing Site?



Figure 4.1: The Mars Pathfinder Landing Site.
Image Set image #12.

The plain at the mouth of Ares Vallis was the landing site for Mars Pathfinder (Figure 4.1). Mission planners selected it for a number of engineering reasons such as having a relatively smooth surface to minimize landing problems, being at a low elevation to give the parachutes more time to slow the spacecraft, and being at an equatorial latitude where there was ample sunlight for the solar panels to produce electricity for the spacecraft.

Another selection criterion was that Ares Vallis was likely to give scientists an unparalleled opportunity to learn about Mars' geological history. Scientists

believe that the floods which created Ares Vallis eroded rocks and sediments from along its course.

Ares Vallis traverses a range of rock types dating from different periods in the planet's history. The

estimated scale of the floods – the largest known in the solar system - would easily carry an enormous variety of rocks and sediments down to the mouth of Ares Vallis. Scientists hope that, using just one lander, they can sample an immense area of Mars which contains rock types that formed at different stages in the planet's development. Pathfinder is currently providing data that scientists hope will shed light on a number of unanswered questions such as: Was there flowing water on Mars? Did Mars ever have an atmosphere or climate that could maintain liquid water? Did lava, mud or ice form the channels instead of water? What is the composition of the rocks in the highlands?

Chaotic Terrain

A common feature found within Ares Vallis' channels, along its banks, and at its head is *chaotic terrain*, a unique Martian landscape. Scientists think that the removal of ice, magma, or water from below the surface caused a loss of support, and the ground collapsed under its own weight leaving a haphazard jumble of large, irregularly shaped blocks of crust on the depression floor (Figure 4.2). Channels extend downslope from the chaotic terrain, indicating that the fluid that excavated the channels flowed from the chaos.



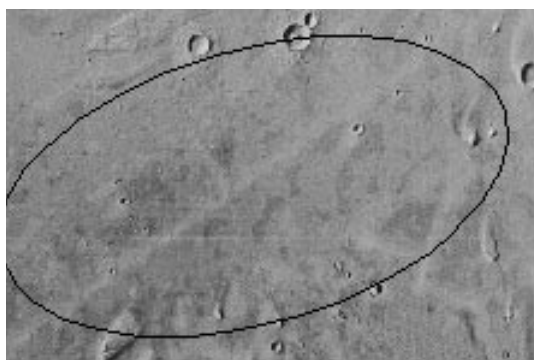
Figure 4.2 The Hydraspis Chaos at the head of the Tiu Vallis.
Image is 300 km across.
NASA I-1343

PROCEDURE



1. Have students examine Image Set image 9. Ask students what they notice about this region that might make it desirable as a landing site.

Students might notice that the area appears relatively smooth, especially in contrast to the deep valleys and dense craters that predominate in other regions of Mars. This observation is important since Pathfinder needs a smooth surface on which to land because of its airbag landing technique and in order for its rover, Sojourner, to explore without confronting insurmountable obstacles.



*A close-up view of the Pathfinder landing site.
Image Set image 9. Scene is 240 x 275 km*

2. Have students examine Image Set image 12, a wider view of the area around the landing site. What information does this broader view add to students' understanding of image 9?

Notice the area around the ellipse. Although there is currently no liquid water on the surface of Mars, the landforms in these images suggest that water flowed on its surface during an earlier stage of its history. The teardrop shapes around some of the craters look as if they might have formed as water flowed around them. Students might also notice a wide channel in the lower right that looks as if it might have carried water to the area of the landing site. Students might speculate that Pathfinder's landing site was once under water. See pages 61 and 62 to find out how the Pathfinder mission has yielded important information about the role of water in Mars' early history.



*The area immediately surrounding the Pathfinder landing site.
Image Set image 12. Scene is 530 x 600 km.*



3. To explore the question of where all the water might have come from, have students examine Image Set image 15 and trace the valley of Ares Vallis as far as they can. Have them speculate about what might have been the source(s) of water.

As students trace the Ares Vallis valley, they may notice that its branches lead to areas of “chaotic terrain” (see the Background section for an explanation). Enormous channels lead away from these areas, suggesting that tremendous amounts of water were released when the permafrost melted.



*The region south of the Pathfinder landing site.
Image Set image 15. Scene is 725 x 1950 km.*

4. Based on their image analysis experiences, have students piece together the story of Ares Vallis and why Pathfinder landed here.

In this step, students mirror the work of planetary scientists by using images from robotic space probes to stimulate speculation and weave various ideas into their own hypotheses. Today, scientists believe that tremendous volumes of water erupted from chaotic terrain, cut massive channels, and spilled out onto low-lying plains. The water flowed over many different types of terrain before it reached the areas selected as the landing site. This water carried sediments from a million-square-kilometer area of the Martian surface. Consequently, the mouth of Ares Vallis is likely to contain sediments from a wide variety of rock types upstream. By sending Pathfinder to this one place, scientists could test the rocks to see if their hypothesis about the floods was correct as well as learn a great deal about Martian geology. See pages 61 and 62 to find out how the Pathfinder mission has yielded important information about the geology and hydrology of Mars.



A panoramic view of the Pathfinder landing site.

PROCEDURE cont.

- 
5. Have students write about why Ares Vallis is a good landing site and what evidence there is to support the idea that this site may provide scientists considerable information about Mars. Students could also comment on other key elements of the mission. For example:

- it is a real mission that is part of an on-going Mars exploration program.
- each mission has its own specific science and engineering goals.
- students can get information about their interests and answer their questions using the data that is easily available on the Web.
- it is people who conceive of, design, build, launch, and run a mission.

Consider having students write an advertising brochure proclaiming the advantages of landing at the mouth of Ares Vallis.

EXTENSION



To explore the science behind the Pathfinder mission in greater depth, use the Mars Exploration Program's module entitled, "The Great Martian Floods and the Pathfinder Landing Site." In this four-week module, students use evidence from their experiments, models, Mars-Earth comparisons, and image analysis to make a case for there once having been water on Mars. They learn how sediment, landforms, and drainage patterns provide clues about a planet's geologic history and about how Mars Pathfinder will use the sediments at the landing site to obtain information about the last four-billion years on Mars.



Activity 5: What Questions Has This Module Raised?

Purpose

To help students develop an on-going connection to the Mars missions.

Overview

Students reflect on their experiences, generate questions based on their module experiences, and pinpoint specific information they would like to obtain. They then read about the instruments on Mars Global Surveyor and relate the information these instruments will provide to their questions. Finally, students create a calendar for the missions and consider how they will access the information returned by the probes.

Content Goals

- Each Mars mission has specific objectives and the instruments it needs to achieve them.
- Space missions arise out of questions people ask about Mars, and students can generate questions worthy of future study.
- Every mission has a specific timetable, and students can follow the progress of each mission in a number of ways.

Skill Goals

- *Identifying* questions that really interest students.
- *Devising* a plan for answering those questions.

Possible Misconceptions

- Three-meter resolution is not very good.
Ask: How far away can you discern a three-meter object? How does this compare to the MGS orbit 400 km (250 mi) above the surface of Mars?
- Robotic space exploration is inferior to manned space travel.
Ask: What would have to change to have people collect this information?
- Space missions are sent up all the time.
Ask: How often are space missions launched? What prevents NASA from launching as many missions as it wants? How long can scientists find interesting information in a set of images? Do you think that people assume that there are frequent space missions because we see so many pictures from space these days?

Materials

Calendar of the missions, length of paper to make a timeline.

Preparation

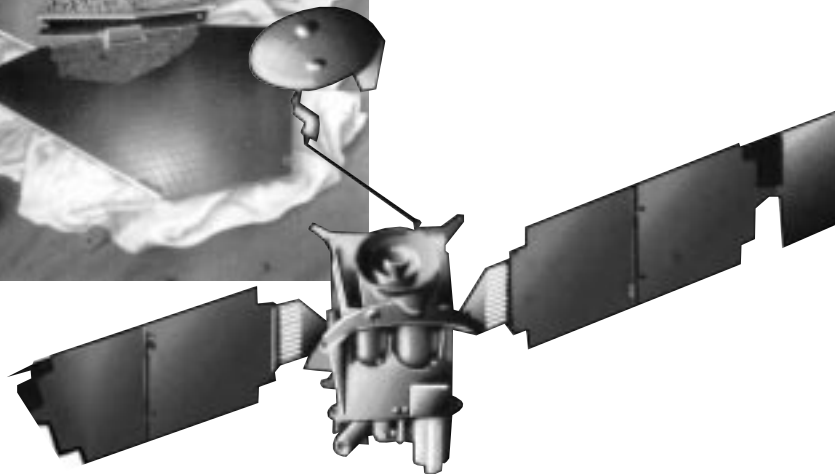
Obtain a computer with Web access to visit some of the mission-related sites.

Time

1 class period



Figure 5.1 Mars Pathfinder (above) and Mars Global Surveyor (right)



At the end of 1996, NASA launched two missions to Mars, the *Pathfinder* and the *Mars Global Surveyor (MGS)* (Figure 5.1). *MGS* will study Mars from orbit 400 km (250 mi) above the surface. *MGS* has three cameras with resolutions as high as 3 m (10 ft). This compares to the highest resolution images from *Viking* of 20 m (65 ft). Other *MGS* instruments include:

- a magnetometer / electron reflectometer to study the planet's magnetic field;
- a radio system to study Mars' gravity field and subsurface mass distribution;
- a laser altimeter to study the planet's surface topography and its overall shape
- a thermal emission spectrometer to study the heat coming from the surface and atmosphere. With this information, scientists can create weather maps and identify the size and composition of surface materials.

After a seven-month, 300 million km (190 million mi) journey, *Mars Pathfinder* landed on Mars July 4, 1997. The mission was primarily an engineering experiment to test key technologies and concepts for possible use in future missions employing landers. The lander contained the radio to communicate with Earth, most of the science instruments, and a rover named *Sojourner* (Figure 5.2). *Sojourner* was used to deploy two imagers and an instrument that determined the composition of rocks and minerals. With its instruments, the *Pathfinder* mission was able to investigate:

- the structure of the Martian atmosphere;
- the weather and meteorology on the surface (wind velocity, pressure, and temperature);
- the surface geology;
- the form, structure, and composition of Martian rocks and soil.

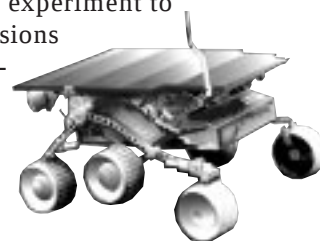


Figure 5.2 The Mars Pathfinder rover, *Sojourner*.

Pathfinder Makes Tracks on Mars

Below are examples of the images and information available at the *Pathfinder* Web site. The site is a fascinating window into the mission. It also can link you to other sites that show how questions and hypotheses unfold from data. In fact, students can investigate their own hypotheses, using the images and data to make a case for their ideas.

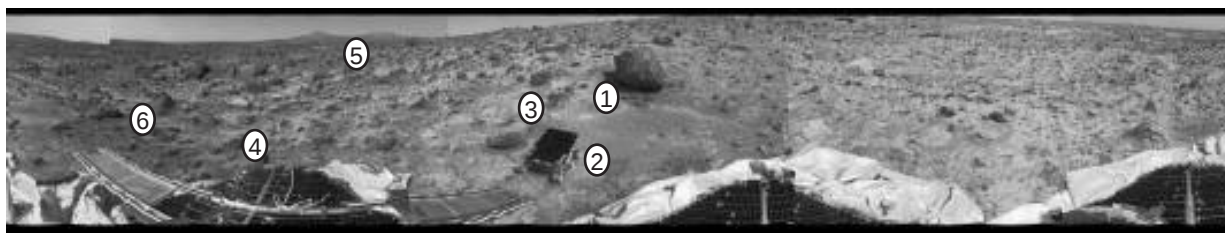


Figure A: A panoramic view of the Martian surface around the *Pathfinder* landing site. 1) Yogi 2) Sojourner 3) Barnacle Bill 4) *Pathfinder*'s solar panels 5) Twin Peaks 6) Rocks tilted by floods



Figure B: NASA determined the location of the landing site by triangulating to known surface features.



Figure C: Twin Peaks (1 km away) seen over Sojourner, still mounted on *Pathfinder*'s solar panel.

After traveling more than 300 million kilometers (190 million miles), *Pathfinder* landed July 4, 1997, 21 years after *Viking I* first touched down on Mars. Cushioned by its 24 airbags, *Pathfinder* bounced 16 times to a near-perfect landing (Figure B).

After opening the solar panels, the cameras took their first look around (Figure C) and several instruments sampled the weather. The sky was clear, the breeze slight, and the temperature -53°C (-64°F), slightly warmer than temperatures measured during the two *Viking* missions. By having students monitor atmospheric conditions such as wind speed, temperature, and dust levels, they can gain insights into the Martian atmosphere and circulation patterns.



Figure D: *Sojourner approaches Barnacle Bill. Yogi is the large rock in the upper right.*

Next, *Sojourner* analyzed “Yogi”(Figure E), a rock five meters (15 feet) from *Pathfinder*. Scientists found that Yogi was a completely different kind of rock than Barnacle Bill. Such a diversity of rock types in a small area suggests that floods swept rocks from areas upstream and deposited them in a jumble on the Chryse Planitia flood plain. The smooth, tilted stack of rocks (#6 in Figure A) lends additional support to the idea of floods. Students can gain insights into the formation of the Martian Surface and into processes that might have altered it by keeping track of the rock types, learning the conditions under which each rock type forms, and examining maps to see where on Mars such rocks might have originated.

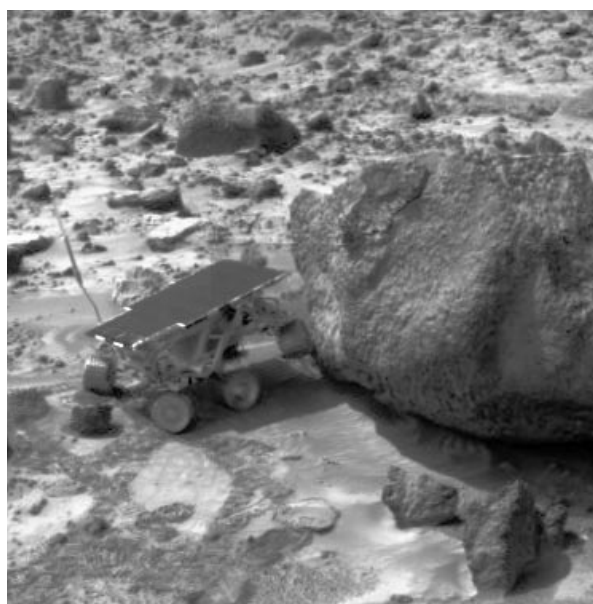


Figure E: *Pathfinder approaches Yogi.*

The images returned by *Pathfinder* are higher resolution than those returned by the *Viking* missions. In addition, the cameras are in stereo and have 24 filters, giving *Pathfinder* an unprecedented multispectral capability. There are 12 distinct filters for geology, 8 for atmospheric studies, and 2 close-up lenses. To access the images and data collected by *Pathfinder* and *Sojourner* and to learn about the science resulting from the mission, visit the *Pathfinder* Web site: [http:// mpfwww.arc.nasa.gov / default.html](http://mpfwww.arc.nasa.gov/default.html)

PROCEDURE



1. Have students reflect on their modeling, image analysis, and experimental work and generate a list of questions. What have they wondered about during the module? What struck them as particularly interesting? What additional information do they wish they had? Which features they would like to see in more detail? Why?

2. Have students read about the instruments on the MGS .

3. Review the missions and the instruments. Which instrument(s) can help answer questions about the Martian floods or craters? Which instruments might help answer some of their questions? What instruments would they like to see on a future mission? Could they imagine themselves designing or operating such an instrument?

Planetary missions take years of preparation. Some of the scientists and engineers have been preparing for the Mars Global Surveyor for over ten years.



KEY

Development

Cruise

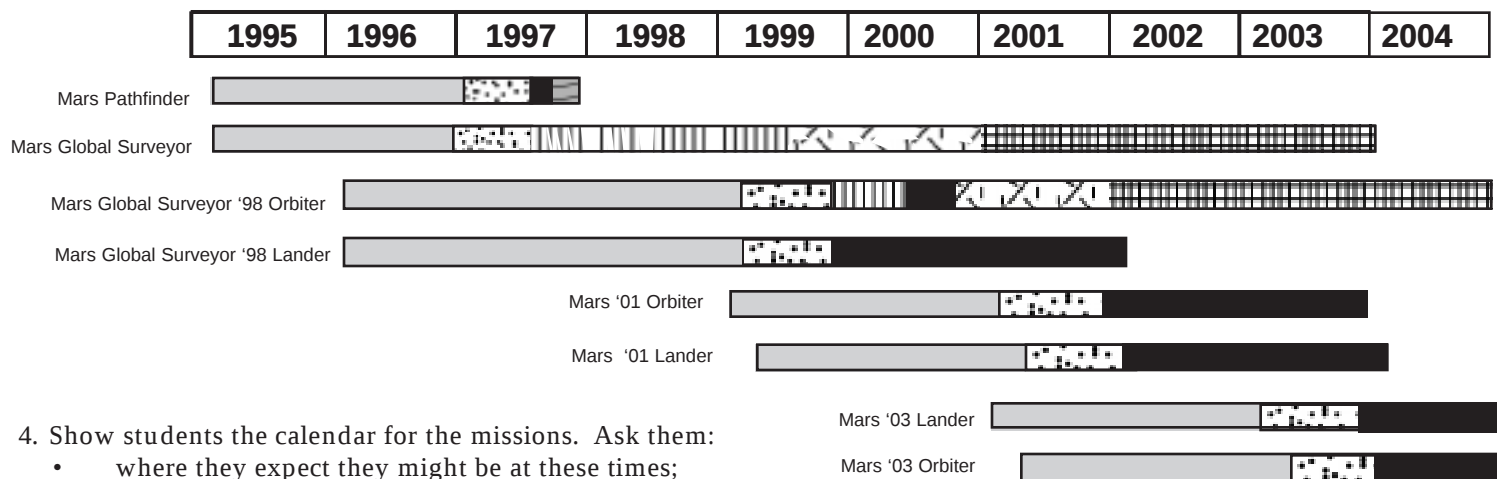
Aero Braking

Prime Mission

Mapping Phase

Relay Phase

Extended Mission



4. Show students the calendar for the missions. Ask them:

- where they expect they might be at these times;
- how might they access information from the instruments or about the mission.

Newspapers, magazines, the Web, television, radio, friends.

5. Have each student devise a plan that outlines how he or she might obtain answers to his or her questions.

6. Put a timeline on the wall. Mark the events listed on the calendar to follow the progress of the missions.

7. Explain that NASA will regularly post new sets of images from its current missions on the World Wide Web. Your students will be able to use computers at school or at home to access these images. With these images, your students can build on the questions and excitement these images raise and extend their studies of Mars.

To learn more about the Mars Exploration Program, explore the following Web pages:

Mars Global Surveyor: <http://mgs-www.jpl.nasa.gov/>

Mars Pathfinder: <http://mpfwww.jpl.nasa.gov>

Jet Propulsion Laboratory <http://www.jpl.nasa.gov/>



Activity 5: What Questions Has the Module Raised?

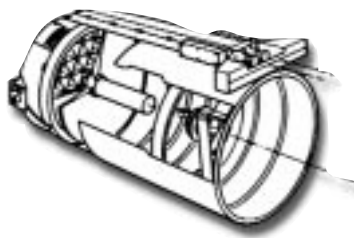
Instruments On Mars Global Surveyor and the Information They Will Provide

(Based on an article by Mike Malin, Principal Investigator on the MGS camera)

In November 1996, NASA launched the *Mars Global Surveyor* (MGS). After a ten-month cruise, the spacecraft began its orbit around Mars. For the first year, MGS gently dipped into the upper portions of the Martian atmosphere, using atmospheric-drag to slow itself down and shrink its orbit. In mid-March of 1999, it began its two-year mapping mission 400 km (250 miles) above the Martian surface. One of the reasons that the MGS mission excites scientists is that it will return a tremendous number of high resolution images as well as the elevation and surface composition data that will help them better understand what those images show. Also, if MGS functions as expected over its planned life, it will return over 700 gigabits of information, more than from ALL previous missions to Mars. It would take over 1,200 CD-ROMs to hold that much data!

“There’s going to be more data from MGS than anyone can imagine.”

Wayne Lee, MGS Mission Planner



Mars Orbital Camera
to take wide angle and
close-up pictures

MGS has two low-resolution cameras capable of recognizing features as small as 500 meters (about 1,600 ft) across and one narrow-angle camera able to see things as small as three meters (10 ft) across. The low resolution cameras will make daily maps of the entire planet enabling scientists to see surface features and dust and ice clouds. The narrow-angle camera, which can see boulders the size of cars, will also image the entire planet and be used to search for traces of beaches and glaciers, the effects of water seeping from canyon walls, and layers in polar deposits that reflect climate changes. It will also take pictures of the two *Viking* landers and the *Pathfinder* lander. These images will finally tie together the ground views these landers have sent us with MGS’s views from orbit. Compared to MGS, the *Viking* orbiters photographed only about 15% of Mars with a resolution of 100 meters (305 ft), and mapped only two tenths of one percent of the Martian surface in sufficient detail to show objects measuring 20 meters (65 ft) in diameter.



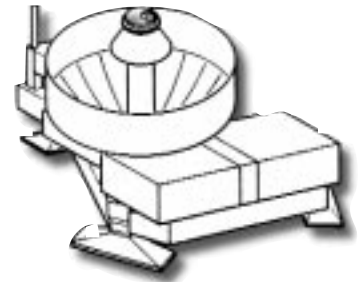
MGS's laser altimeter will tell scientists a great deal about the topography of Mars. Among other things, the altimeter will measure the:

- depths of craters
- heights of volcanoes
- steepness of the cliffs
- slopes of water-carved canyons

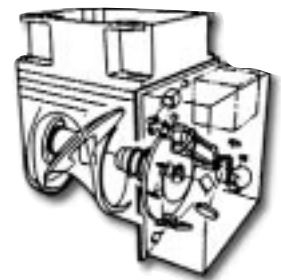
Scientists will also use *MGS's* laser altimeter in conjunction with other instruments to help determine the size and shape of landforms, the global shape of Mars, and the thickness and strength of the crust.

MGS's Thermal Emission Spectrometer (TES) measures the amount of heat coming from the surface and atmosphere at many different wavelengths. TES will determine:

- the atmospheric temperature and pressure at several different altitudes;
- the concentration of dust both on the surface and throughout the atmosphere;
- the size of particles on the surface, from dust grains to bedrock, by comparing the temperature during the day with that observed at night (the same effect that causes beach sand to be very hot during the day and to be cool at night). The sizes of particles on the surface tell scientists how the particles were moved (e.g., by wind, water, or other processes);
- what the Martian rocks, sand, and dust are made of. TES will be able to discriminate volcanic rocks similar to those found in Hawaii (basaltic) from rocks and ash similar to those erupted by Mount Saint Helens (rhyolitic). TES may tell us if Mars has one or both. It will search for minerals left behind when lakes or other bodies of water dried up, and for minerals that formed when the atmosphere was potentially thicker and wetter than it is today.



Laser Altimeter
to measure the heights of
Mars' physical features



Thermal Emission Spectrometer
to measure & map heat
emitted by Mars



Activity 6: What Next?

Purpose

To recommend ways to incorporate the topic of Mars into a classroom and curriculum.

Overview

Space exploration provides many important connections to the classroom, yet how does one tap into what a mission has to offer? This activity presents a variety of approaches for bringing the topic of Mars into the classroom. These range from a modest level of commitment such as maintaining a Mars bulletin board to a high level of commitment such as having students conduct research using recent images and data from Mars.

Different Ways of Integrating a Space Mission into Your Curriculum

Science results based on past missions to Mars are constantly emerging, and plans for new missions are underway. How can a teacher keep the curriculum-connection current? How does a busy teacher navigate all the available resources to find the ones most suited to his or her lessons? What kinds of activities are effective in helping students understand the many aspects of a mission? How does one bring a mission to life in the classroom?

Getting Started has introduced you and your students to Mars, the solar system, and space exploration. It has also provided an opportunity for your students to generate questions, experience inquiry-based learning, refine their analysis skills, conduct experiments, and make Mars/Earth comparisons. Also, they have seen that the very latest data and images from Mars – the same information that scientists are using in their research – are available on the Web. You could stop here, having provided an excellent introduction to Mars and space exploration. However, how can you build on this base and keep the Mars connection to your curriculum open? You might:

1. use one of the other education modules in JPL's Mars Exploration Program.
2. conduct investigations based on questions students have generated, using the modeling, experimentation and analysis skills developed in this module.
3. find a Mars connection to other topics in your curriculum.

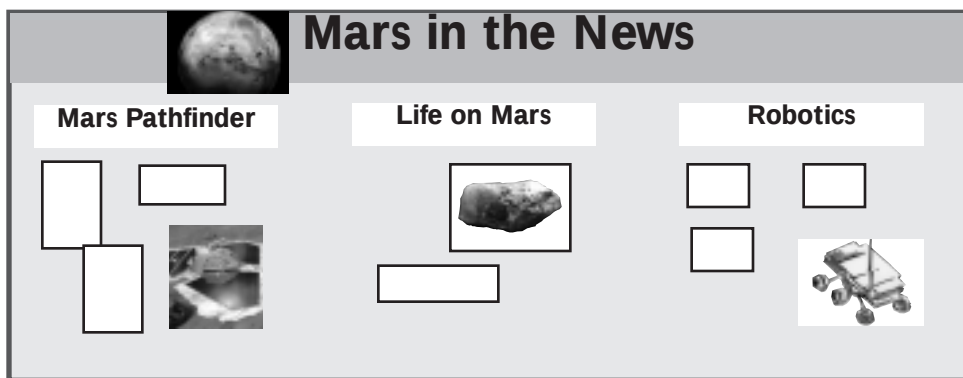


There are many ways to tap into what a mission has to offer. This activity uses the Mars Pathfinder mission to show how you can find out information about a mission and find connections to what you teach. The techniques described here can be used with any mission. Let's look at these approaches to see how one might link the Mars Pathfinder mission to the classroom.

Use a Mars Mission as a Current Event

Typically, the information sources for current events are printed materials, television, radio, and the Web. Occasionally, teachers are able to schedule presentations by people familiar with or involved in an event, and sometimes students can conduct interviews with such people. Formats to share information include bulletin boards, oral reports, student reports, and current event notebooks. Each of these methods involves students in different ways and at different levels of intensity. Below are several ways the Pathfinder mission could be used in a current events context:

- The mission's data and images will be used for decades by scientists researching Mars. Check newspapers and magazines for articles on the science resulting from their work.
- There is an enormous amount of information about the mission the *Pathfinder* Web site, everything from the people involved to the current weather conditions on Mars to the latest results based on Pathfinder data and images to the latest images themselves. The Web site will also link you to other sites related to the mission.
- Shows about Mars air on television or radio, and NASA's cable and satellite channel, NASA Select, has frequent updates about its various missions. Students can take notes on a show and prepare a report based on the information presented.
- A bulletin board is a convenient way to organize and prominently display information. You might organize a bulletin board by topics such as:
 - Mars Pathfinder • Life on Mars • Robotics
 - Mars Global Surveyor • Water on Mars • Questions About Mars
 - Other Space Missions • Human missions to Mars • Future missions to Mars



Sample Bulletin Board Layout

Obtain Images and Data Sets To Analyze and Interpret.

One way to develop students' analytical skills is by having them interpret images or data sets, preferably ones relating to something students are studying or in which they have an interest. For example, students studying weather or geology can make interesting Mars-Earth comparisons by looking at Pathfinder's Martian weather reports and geology data. Having students examine and contemplate images from another planet can lead to exciting questions that can serve as the basis for student-based investigations. Each module in the Mars Exploration Program guides teachers in how to use data and images effectively to develop students' analysis and interpretation skills. In addition, the module activities encourage students to generate questions.



Pathfinder's data and images are available at its Web site. The best way to determine the kinds of data and images available from a mission is to visit its homepage and find out what instruments are on the spacecraft. Each instrument has a specialized purpose. Match topics in your curriculum to the images or data returned by one or more of the instruments. Be creative. For example:

- compare the dust on Earth and Mars. *Pathfinder* has magnets attached at different heights. Images of these magnets will be used to determine the amounts of magnetic minerals in the Martian dust.
- compare seasonal variation on Earth and Mars. *Pathfinder* has instruments to measure the temperature, pressure, and wind speed at various heights above the surface. How do Martian conditions compare to those on Earth? Do temperatures at various heights vary in the same way on both planets?
- use the images of the landing site to create a model of the landing site or have students construct a birds-eye view based on the views from the lander cameras.

Use Student Questions as the Basis for Experiments and Models

As students analyze images or data sets, questions will emerge. Questions such as: What would cause that feature? How might this form? or Why do I usually see these two features together? are springboards for inquiry. Students need to devise a hypothesis, design a model or experiment, collect and analyze data or images, and draw a conclusion. Often, one question leads to another. You can have students take a question they have recorded in their Mars Journals and detail how they would investigate it. Such a plan could be the basis for an investigation or project.



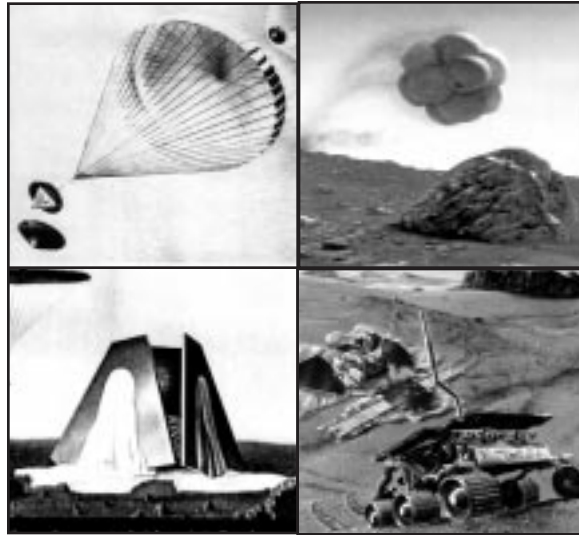
Learn About the Scientists and Engineers Involved in a Mission

For many students, knowing about the people involved in a mission brings it to life. Most mission-related Web pages have pictures and short descriptions of the key people working on a mission. Teachers can profile various individuals as role models or develop career awareness. Occasionally, scientists and engineers host a chat or enable students to send them e-mail messages. For example, the *Pathfinder* team hosted a chat every night for the first few months of the mission. Students can do reports, collages, or posters to bring out the human dimension of a mission.



Donna Shirley, Manager of NASA's Mars Exploration Program

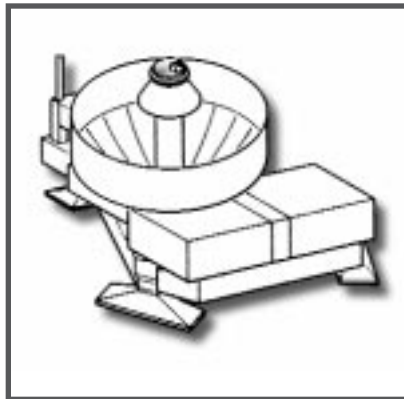
Explore Engineering/Design Issues With Mechanisms, Simulations, and Models



The *Pathfinder* mission offers many examples of how engineers met a variety of challenges:

- landing the spacecraft safely by encasing it in 24 balloons
- constructing a controllable rover
- designing a reliable ramp system so *Sojourner* could drive off the solar panel onto the Martian surface
- building a suspension system that lets *Sojourner* navigate rocky terrain safely
- making instruments to carry out specific tasks
- designing reliable communication systems

Students can make scale models such as NASA's spacecraft paper model kits or



MGS's Laser Altimeter

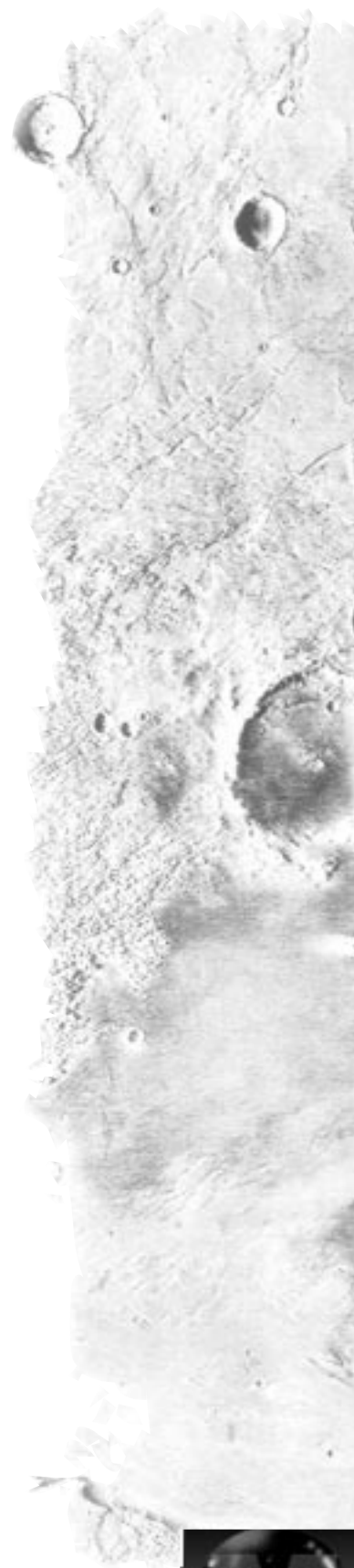
invent mechanisms that carry out specific tasks. For example, students can model how an altimeter works by arranging objects in the bottom of a deli container, covering the opening with paper, and pushing pencils through the paper. By measuring how far down the pencil goes at each position sampled, students can map the arrangement of the objects. An altimeter works on the same principle using a laser beam. The *Pathfinder* Web page has information on each instrument and on how the design team dealt with the various challenges.

Students can become immersed in a topic through simulations such as the Planetary Society's "Red Rover, Red Rover – Rover Simulations" and the Challenger Center's "Marsville" and "Mars City Alpha Kits" which present many engineering challenges. Teachers like simulations because they ask students to integrate many disciplines.

Consider How Conditions on Mars Could Affect Processes that Students Have Studied

Earth is twice the size of Mars, has two and a half times the force gravity, has an atmosphere 100 times denser, and has 150 times the atmospheric pressure at the surface. In addition, Mars has no surface water and the temperature averages around -80°C (-62°F). Earth, life and physical science students can have many fruitful discussions about how the processes they have studied would change under these conditions. As students learn about various topics, they can extend their understanding to Mars. By understanding how a process might function in the Martian environment, students can gain additional insight into the topic they have studied. What consequences do the different conditions found on Mars impose on processes such as the water cycle, weather, or life? These realizations lead to a deeper understanding of the planet.

- What kinds of adaptations might be required to live under such conditions? Students might look at the kinds of adaptations organisms on Earth have made to different environments and speculate about what adaptation would make life on Mars possible.
- Can liquid water exist on Mars? Is there a water cycle? Students could look at how Earth's temperatures and pressures enable water to exist in all three states. By graphing the temperature as water goes from ice to steam, students learn about heat energy, phase change, and atmospheric pressure. After putting these concepts in the context of Earth's water cycle, they are able to discuss the water cycle on Mars, as well as Martian storm patterns, and seasonal cycles.
- Why is our blood based on table salt? Would another substance work as well? Biology or chemistry students could create saturated solutions of different chemicals at a variety of temperatures. By plotting their data, students understand that when the temperature of a saturated solution falls to a certain point, some solute will precipitate. They try the same experiment with table salt. Students are astonished that water holds the same amount of table salt over a tremendous range of temperatures. With this information, students can understand the benefit our blood derives from being based on table salt and can speculate on whether life as we know it could exist on Mars.



APPENDICIES

Appendix Activity #1

Make Scale Models of the Planets

By making models of each planet at the same scale, students see how the planets compare in size.

Appendix Activity #2

Make a Model Solar System

In this activity, students learn about the organization and scale of the solar system. Students make a model of the solar system using the same scale they used for the planet models in Appendix Activity 1. When people see a solar system model in which both the sizes and distances of the planets from the Sun are at the same scale, they are usually surprised by how small and far apart the planets are!

Appendix Activity #3

Find Mars in the Night-time Sky

When ancient astronomers noticed that Mars moved slightly from one night to the next, they considered it a special “star.” If the timing is right, your students will be able to see Mars in the night-time sky. If they observe it over a few weeks, they too will notice that it moves. This activity enables your students to know where and when to look for Mars.

APPENDIX ACTIVITY 1: MAKE SCALE MODELS OF THE PLANETS

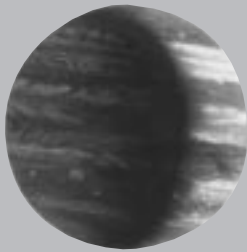
THE PLANETS & THEIR REALITIVE SIZES

Mercury

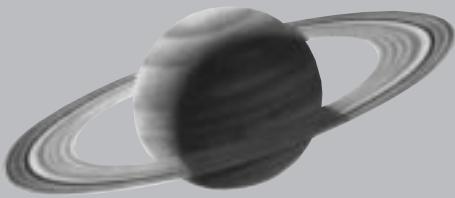
Venus

Earth

Mars



Jupiter



Saturn



Uranus



Neptune

Pluto

For a long time, people thought that the Earth was the center of the Universe, with the Sun, Moon, stars and planets circling around the Earth. This idea made complete sense based on what people saw when they looked up at the sky.

Today we know that the Earth is not the center of everything. The Universe is incredibly huge, with many more stars than we can see at night. Our Sun is just one of those stars, although it certainly is the most important one for us.

Earth and Mars are both planets which go around the Sun. There are a total of nine planets in our Solar System.

Though all nine planets are the same shape — roughly spherical — they vary considerably in their sizes. Looking at them in the sky is no real help in comprehending their sizes because, at great distances, even the giant planets appear as dots. In this activity, you will make models of the planets, in order to compare their sizes.



How Do the Planets Compare in Size?

Materials: paper, scissors, pen or pencil, drawing compass, ruler

At the right is a table called “Sizes of the Planets.” For each planet, it shows the actual diameter in kilometers. It also shows how to create scale models that are one billion times smaller than the real planets.

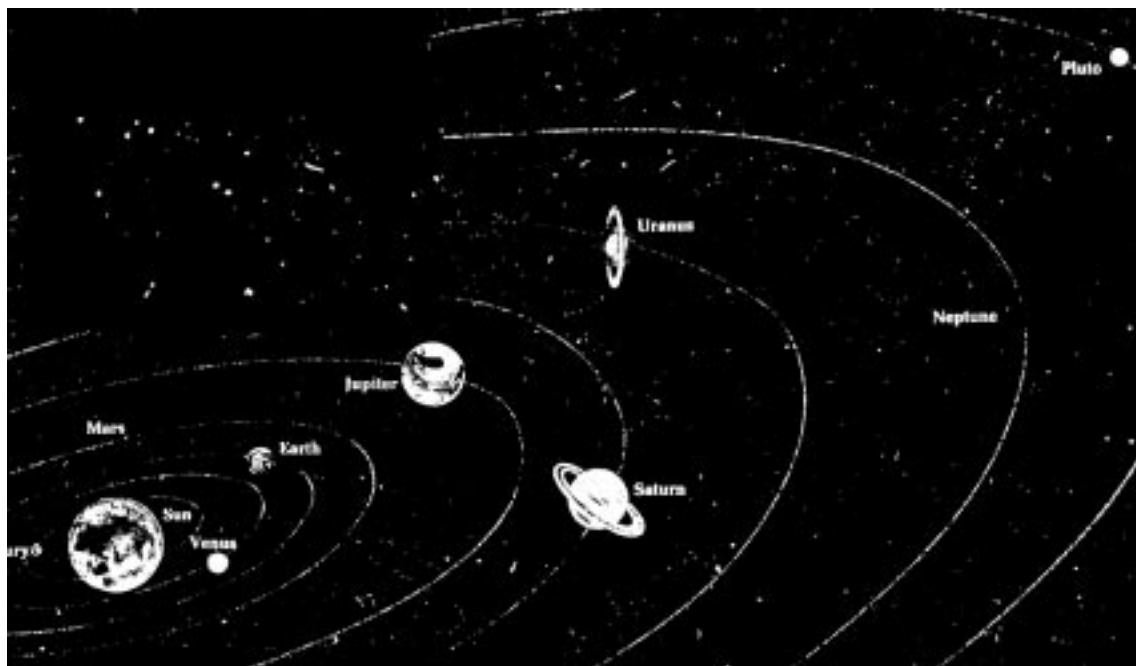
- 1 To make two-dimensional paper models of each planet, find the “scaled diameter” column. Start with the Earth. Earth’s real diameter is 12,800 km. The “scaled diameter,” at one billionth reduction, is 1.3 cm (actually it is 1.28 cm, but it is rounded off to the nearest tenth of a centimeter). Use a compass to draw a circle that is 1.3 cm in diameter and cut it out with scissors. This circle represents Earth.
- 2 Repeat Step 1 with the other planets. For each planet, cut out a circle that is the “scaled diameter.” Label each planet with its name and diameter. (*Mercury and Pluto will be too small to label*).
- 3 After you cut out all the planets, glue or tape them into your journal. One student in the class should set aside the paper planets and not glue them to his or her journal. You will need them for the next activity.
- 4 Finally, make a scale model of the Sun. Tape several pages of newspaper together and cut out a circle that is 139 centimeters in diameter. Label it “Sun.”
- 5 Discuss in class or write in your journal:
 - How do the planets compare in size?
 - Which planet is the largest? Smallest?
 - Which is most nearly the size of Earth?
 - Is Mars larger or smaller than Earth?
 - What surprised you most about this activity?

Sizes of the Planets

Planet	Actual Diameter	Scaled Diameter
Mercury	4,880 km	0.5 cm
Venus	12,100 km	1.2 cm
Earth	12,800 km	1.3 cm
Mars	6,800 km	0.7 cm
Jupiter	142,000 km	14.2 cm
Saturn	120,000 km	12.0 cm
Uranus	51,200 km	5.1 cm
Neptune	48,600 km	4.9 cm
Pluto	2,200 km	0.2 cm
Sun	1,392,000 km	139.2 cm

Scaled diameter is 1 billionth of actual size

APPENDIX ACTIVITY 2: Make a Scale Model of the Solar System



You have made a scale model showing the size of the planets. The next step is to make a model showing how far they are from the Sun.

Make a Scale Model of the Planets in Orbit

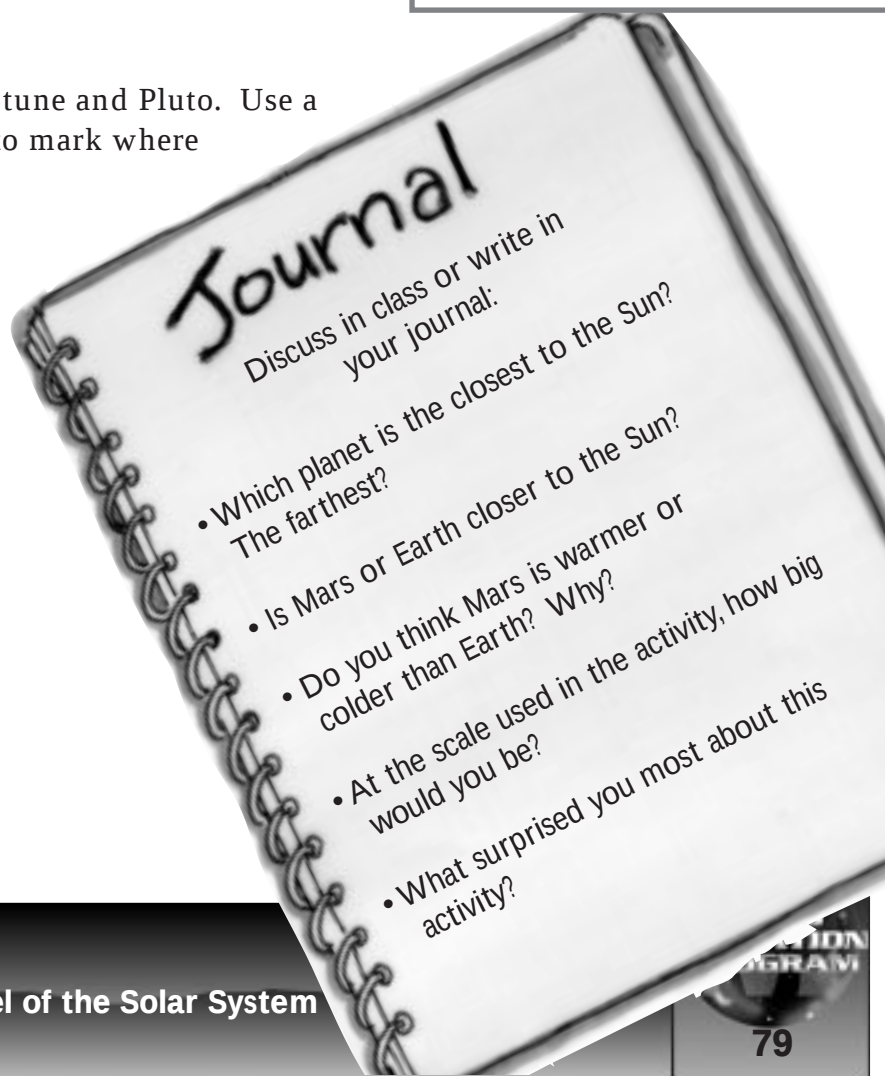
Materials: meter stick or metric tape measure

- 1 At this one-billionth scale, how far is the Earth from the Sun? Go outside with the scale models of the Sun and the planets. Find a large space such as a playing field. Put the Sun on the ground at one end of the field. Walk away from the Sun and stop where you think the Earth belongs at this scale.

- 2 Referring to the data table on the left of this page, look at the actual distance from the Sun to the Earth and the scaled distance. You will see that the Earth is 150 meters away from the Sun at this scale. Put the scaled Earth on the ground at this distance.
- 3 Where would Mars be at this scale? Closer to the Sun? Farther away? Walk to the place where you think Mars belongs.
- 4 Look again at the data table. Find the scaled distance from the Sun to Mars and measure off this distance. Put the paper cut-out of Mars there.
- 5 Now use the data table to correctly position Mercury and Venus. Again put the paper cut-outs there. You have now completed what are called the inner planets.
- 6 The outer planets are even farther away. In fact, they are so far away in this scale model that they will probably not fit on your school property. Try Jupiter.
- 7 Do the same for Saturn, Uranus, Neptune and Pluto. Use a map of the area around your school to mark where these planets would be.

<i>Distances from the Sun</i>		
<i>Planet</i>	<i>Actual Distance</i>	<i>Scaled Distance</i>
<i>Mercury</i>	58,000,000 km	58 m
<i>Venus</i>	108,000,000 km	108 m
<i>Earth</i>	150,000,000 km	150 m
<i>Mars</i>	228,000,000 km	228 m
<i>Jupiter</i>	778,000,000 km	778 m
<i>Saturn</i>	1,424,000,000 km	1,424 m
<i>Uranus</i>	2,867,000,000 km	2,867 m
<i>Neptune</i>	4,488,000,000 km	4,488 m
<i>Pluto</i>	5,910,000,000 km	5,910 m

Scaled distance is 1 billionth of actual distance



APPENDIX ACTIVITY 3:

Find Mars in the Night-Time Sky



Ancient astronomers all over the world were fascinated by “stars” that changed their positions in the sky. The Greeks called them planets, which means “wanderer.” Mars is one of nine “wanderers.”

PART A

Mars is a Wanderer in the Night-Time Sky

Look at the two pictures on below. They are almost exactly alike. They show the position of several stars (and one planet) in the night time sky. The picture on the left is May 1, 1996; the one on the right is May 8, 1996, one week later.

- 1 Find a difference between the two pictures.
- 2 How might you explain this difference?



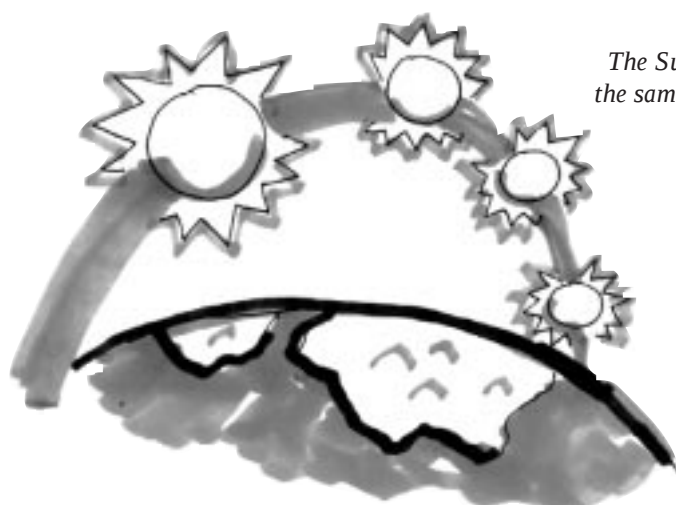
May 1, 1996

May 8, 1996

Go outside at night and look at the stars. Of all those dots of light, which one is Mars? Or, can you even see Mars at all? Here is how to know where to look.

PART B

Where Is Mars?



The Sun and Mars follow the same path across the sky

1 Find the path of the Sun — Mars follows the same path in the sky as the Sun. Notice where the Sun rises, where it is every couple of hours, and where it sets. Practicing tracing this band from sunrise to sunset. You will need to be able to trace the band even when the sun isn't there. This band is called the ecliptic.

2 Find out what time Mars rises — Since the rise time changes constantly, you need to find an up-to-date information source such as an astronomy periodical. Current information can also be found at Web sites such as *Planet Finder*: http://www.cal-web.com/~mcharvey/planet_all.html

Where Do I Look?

To find out exactly where in the sky to look to see a planet, visit Solar System Live, a Web site that provides a planet's coordinates for any time or day.

<http://www.fourmilab.ch/solar/solar.html>

Enter your "Time" and "Observing Site" information. Then, hit "Update." The two numbers you need are:

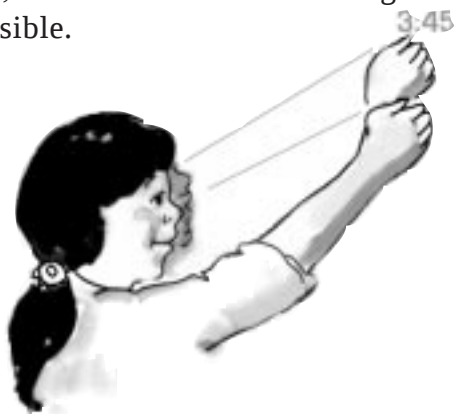
Altitude, the number of degrees above or below the horizon.

Azimuth, the local compass bearing to the planet at your site.

Hit "Ephemeris" for a glossary of terms

3 Decide what time you will look for Mars — The only time that you can look for Mars is after “Mars rise time” (so that it will be in the sky) and at night (so it is dark enough to see Mars). Decide what time you will go outside to look for Mars. You may have to stay up late or get up early.

4 If you look at “Mars rise time” — If you go outside at the “Mars rise time” listed for today, and have a clear view of the eastern horizon, you will see Mars slowly rise at the same place that the Sun normally rises. In fact, it’s probably better to wait an hour or so, in order for Mars to be high enough above the horizon to be visible.



Mars moves about the width of a fist every 45 minutes

5 If you look after “Mars rise time” — Mars will move across the sky following the same band as the sun (the ecliptic). It will take about six hours from the rise time until Mars reaches the highest point in the sky. So, you have to figure out how far along the ecliptic to look. Here’s an easy way to do this.

6 If you hold your fist out at arm’s length, your fist shows how far Mars (or any other planet or star) will move in about 45 minutes. So, if you look 45 minutes after Mars rise, Mars will be about one fist-width above the horizon. If you look 90 minutes after Mars rise, it will be two fist-widths above the horizon.

7 Calculate how many minutes after Mars rise you are looking for Mars, divide by 45 minutes, and you will know how many “fist-widths” above the horizon you should look. Remember, Mars will be moving along the same path that the Sun moves.

8 How will you know if you have found Mars?

- It will be brighter than most stars (but about the same size).
- It might appear reddish.
- After several days, it will be in a different position in relation to the stars around it.



Tycho Brahe was a Danish astronomer who made very careful measurements of the motion of the planets and their rise and set times over many years. His observations helped astronomers understand more about the planets and their orbits around the Sun.

Timeline: 1590

Web Tip

To find sources for planetary facts, rise times, and general information, type “planet finder” (including quotes) into the query box of a Web search engine.

RESOURCES

Posters

Mars Pathfinder and *Mars Global Surveyor*,
(while supplies last)

Mars Exploration Education and
Public Outreach Program
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-6111

Video

Mars Pathfinder, (while supplies last)
Mars Exploration Education and
Public Outreach Program, see above address.

CD-ROMs

Mars Navigator Interactive Multimedia CD-ROM,
describes JPL's *Mars Global Surveyor* and
Mars Pathfinder missions (while supplies last)

Mars Exploration Education and Public Outreach
Program, see above address.

The Mars Educational Multimedia CD-ROM,
provides a Mars atlas, Mars-based lesson plans,
descriptive information about Mars, image pro-
cessing software to extract information from the
images in the Mars atlas and from new images
acquired by future orbiter and lander missions.

The Center for Mars Exploration,
Mail Stop 245-1
NASA Ames Space Science Division
Moffett Field, CA 94035-1000
(415) 604-4217
Recommended ordering procedure:
<http://cmex-www.arc.nasa.gov>

Web Sites

Mars Global Surveyor: <http://mgs-www.jpl.nasa.gov/>

Mars Pathfinder: <http://mpfwww.jpl.nasa.gov>

Jet Propulsion Laboratory: <http://www.jpl.nasa.gov/>

Center for Mars Exploration:
<http://cmex-www.arc.nasa.gov/>

The Planetary Society: <http://planetary.org/tps/>

Arizona Mars K-12 Education Program
http://esther.la.asu.edu/asu_tes/

Periodicals

The Planetary Report

The Planetary Society
65 North Catalina Avenue
Pasadena, CA 91106-2301
(818) 793-5100 (phone)
(818) 793-5528 (fax)

Mars Underground News

The Planetary Society, see above address

Recommended Maps and Photomosaics of Selected Martian Features,

General:

Map of Olympus Mons to Ares Valles	I-1618
Map of Eastern Valles Marineris to Ares Valles	I-1448
Topographic Map of Mars (1:25,000,000) (1 map)	I-961
Topographic Map of Mars (1:15,000,000) (3 maps)	I-2160

Volcanoes:

Photomosaic of Olympus Mons	I-1379
Map and photomosaic of Tharsis volcanoes	I-1922

Canyons:

Map of Central Valles Marineris	I-1253
Photomosaic of entire Valles Marineris	I-1206, I-1207, I-1208, I-1184, I-1381

Floods

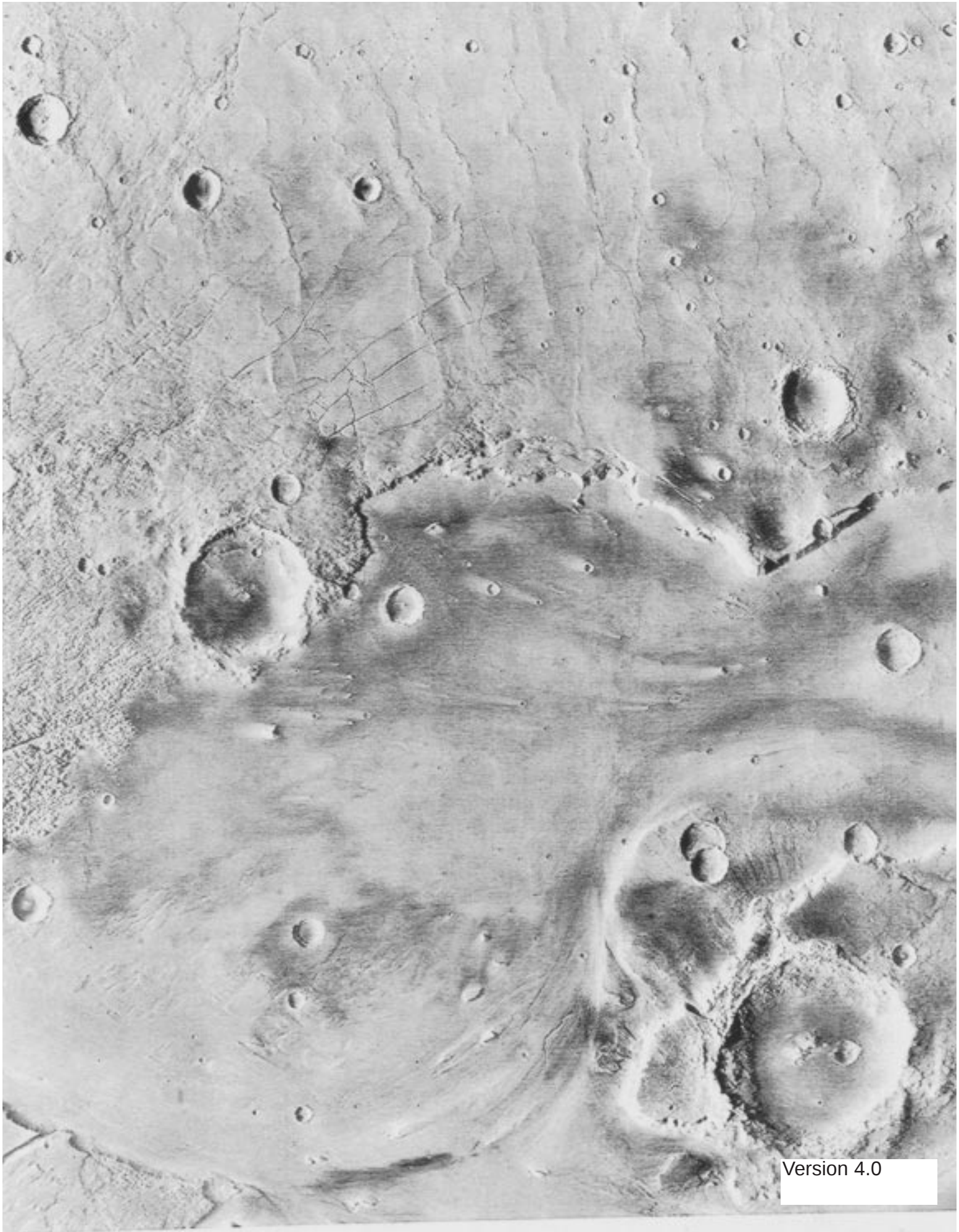
Photomosaic of channels and eroded landforms	I-1652
Photomosaic of Dromore crater with breached ridge	I-1068

Pathfinder

Map of Ares Valles	I-1551
Photomosaic of the flood channels near landing site	I-1343
Close-up photomosaic of landing site	I-1345 & I-2311

(\$4.00, 3-4-week turn around)
United States Geologic Survey
Box 25286
Federal Center, Building 810
Denver, CO 80225
(800) 435-7627





Version 4.0

**MARS
EDUCATION
PROGRAM**

Mars Exploration



**Getting Started
in Mars Exploration
Image Set**



Scale: Mars is 6,787 km in diameter.

Image 1

- What is the feature across the middle?
- What do you think the circles on the left side are?



— 15 km — Scale: Top crater is 15 km across.

Image 2

- On Earth, what are some things about the size of these craters?
- Why do some of the craters overlap?
- In what order were the craters formed?
- What do the patterns around the craters reveal about the nature of the surface?
- Have you ever seen an impact crater?



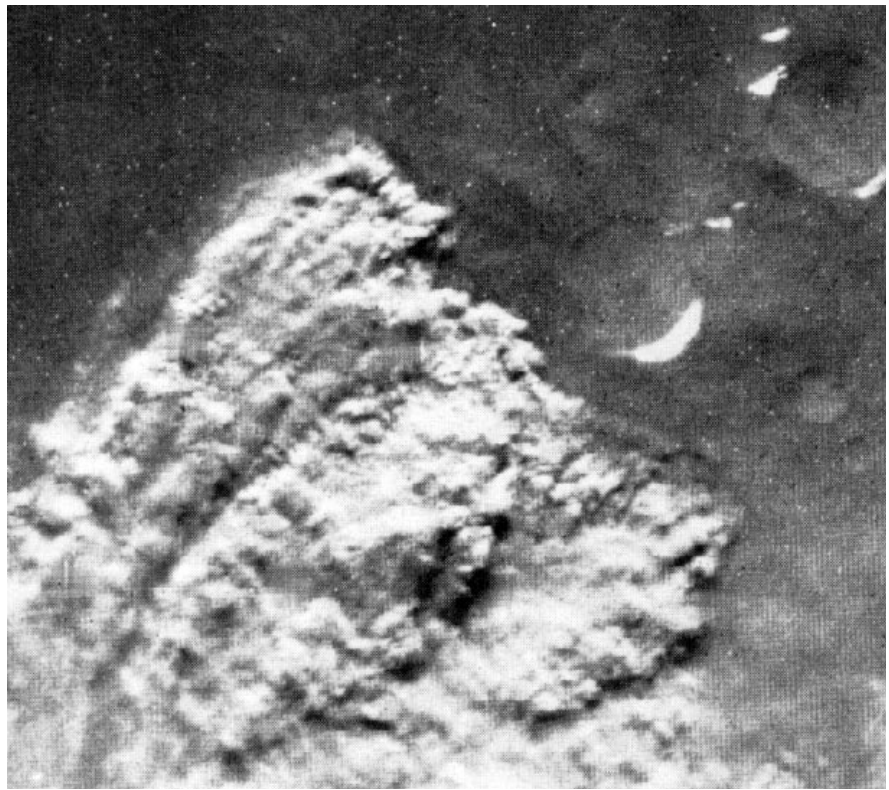
— 30 km — Scale: Large crater is 30 km across.

Image 3

- What do you think caused the shape around these craters?
- Were these craters formed at the same or at different times?

Image 4

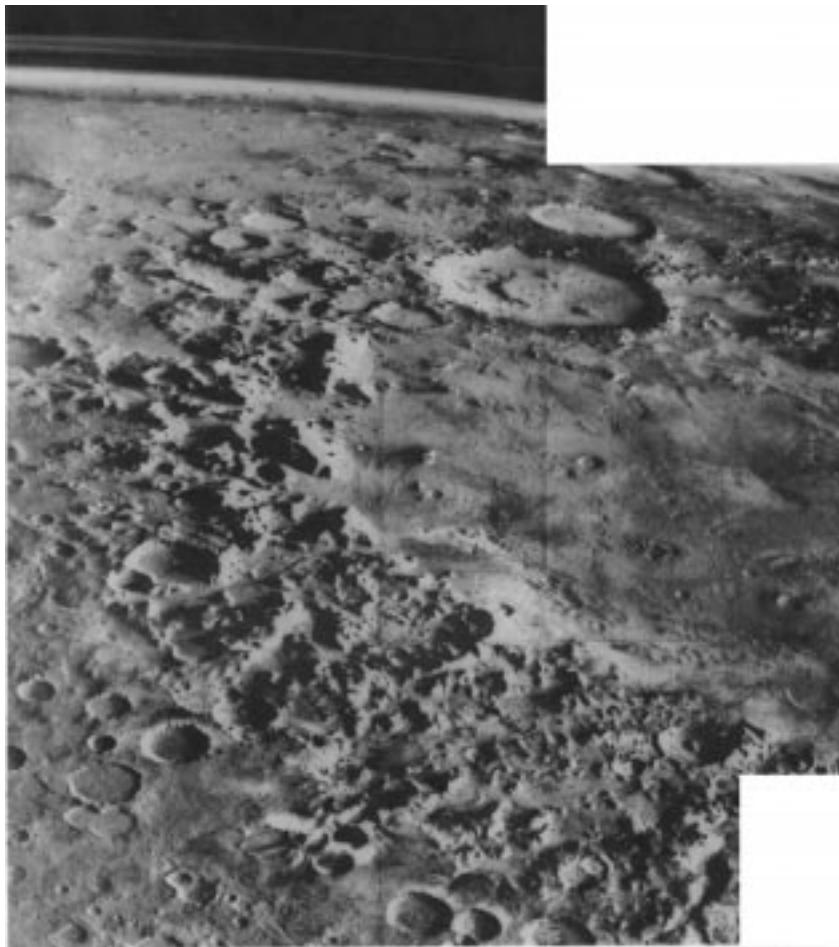
- What might this feature be?
- How big is the feature in this image?



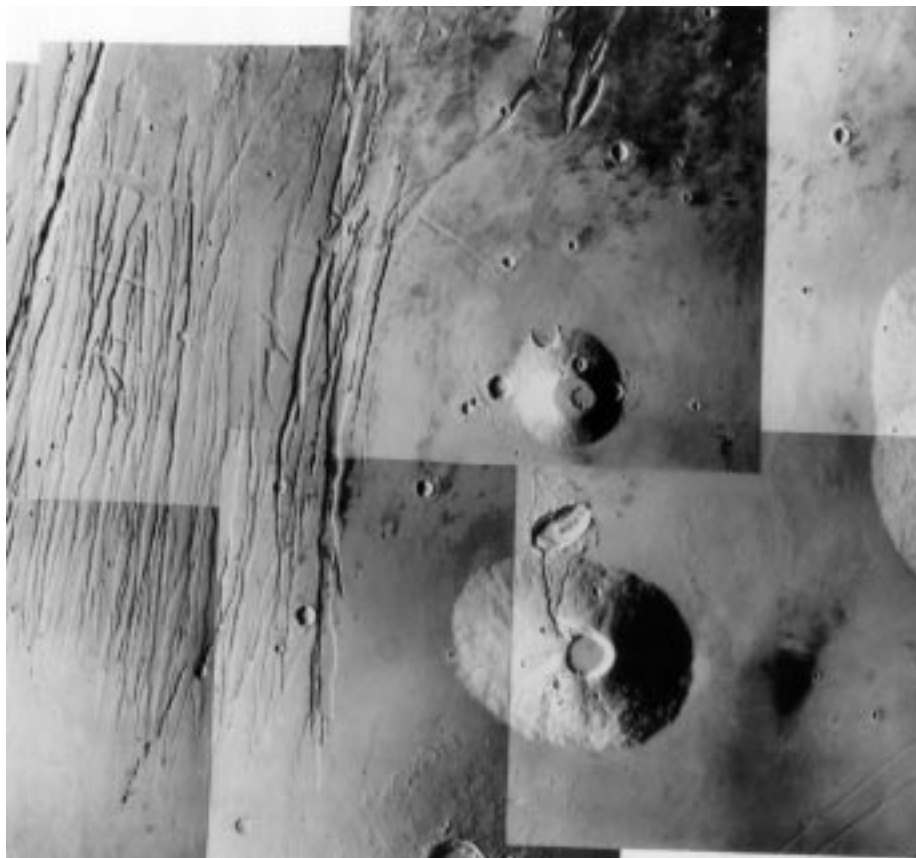
250 km

Image 5

- What is the line on the horizon above the Martian surface?
- How high above the surface is it?
- What causes it to be visible?



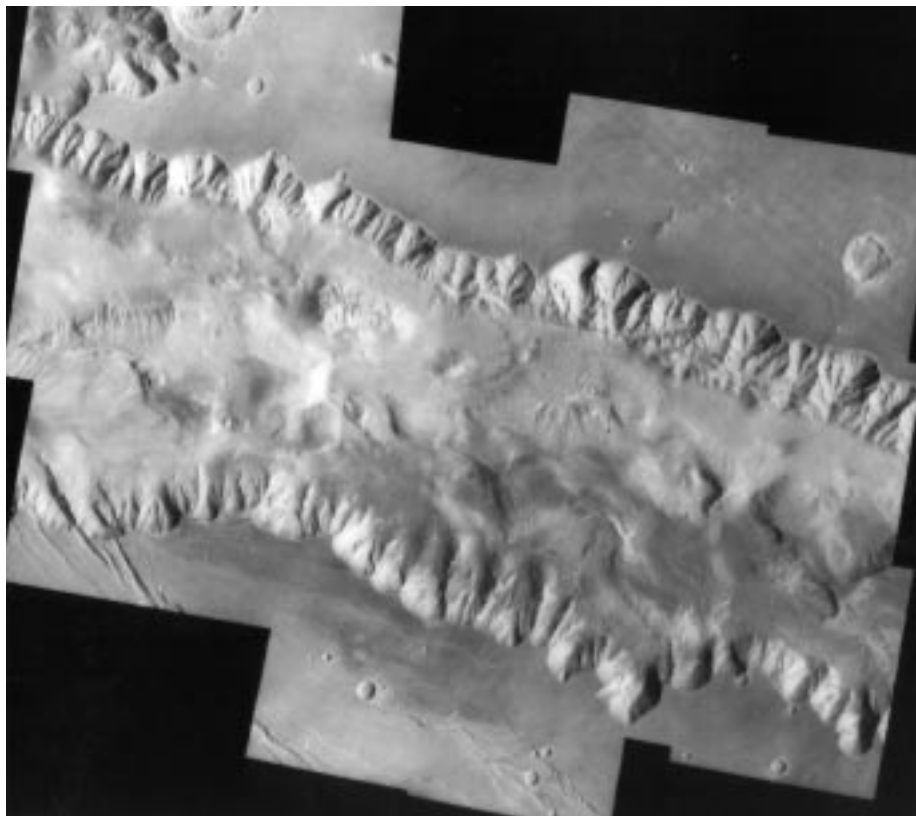
Scale: The large crater in the upper right is 200 km in diameter.



— 100 km — Scale: Lower volcano is 90 x 130 km.

Image 6

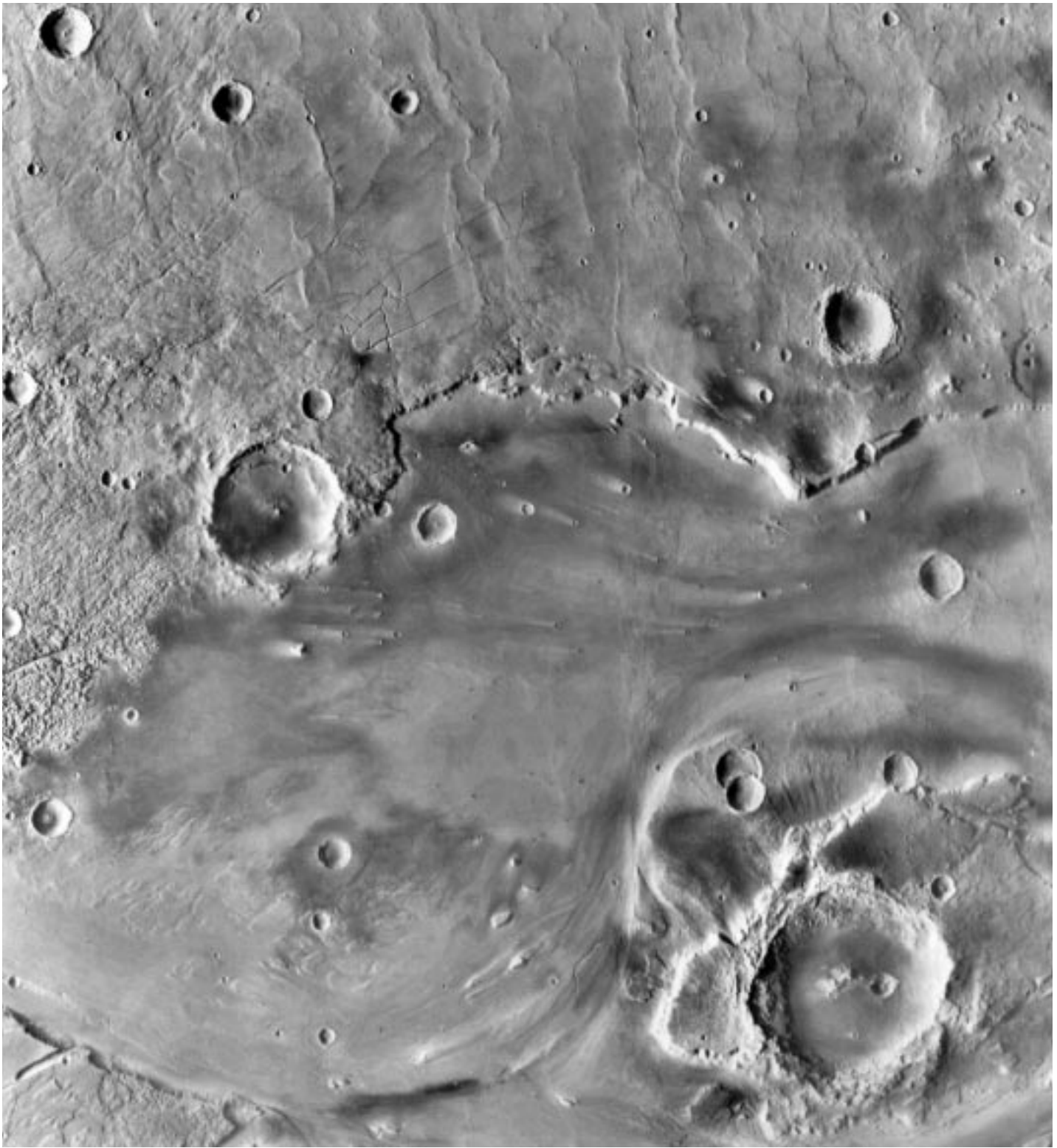
- Which came first, the volcano or the impact craters? How can you tell?
- What might have caused the channels on the side of the volcano?
- What do you think the lines are? What might have caused them?



— 100 km —

Image 7

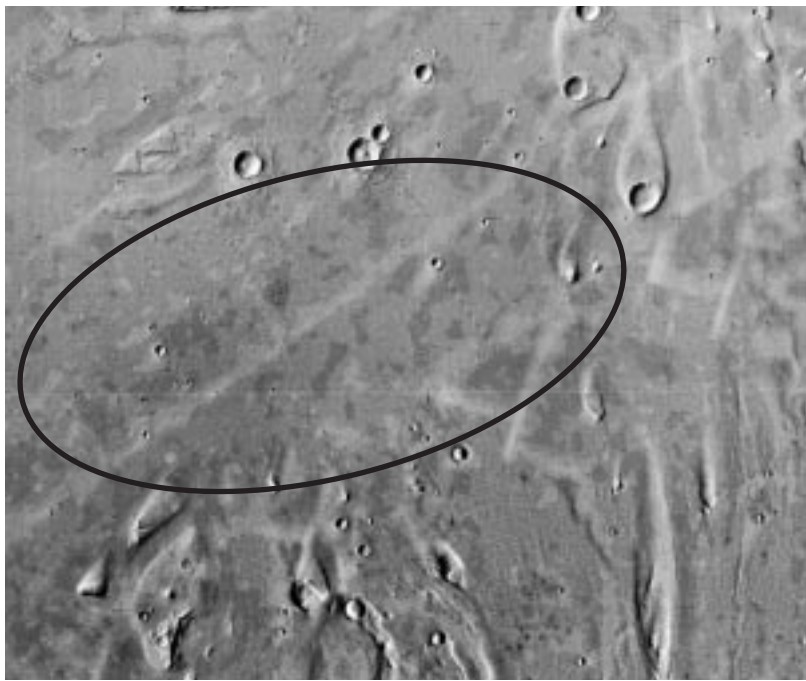
- What do you think caused the canyon?
- What do you think shaped the cliffs on the edges of the canyon?
- How did this canyon get so wide?



100 km Scale: The crater in the lower right is about 100 km across.

Image 8

- Which came first, the fractures or the large crater left of center?
- Which came first, the crater in the lower right or the channel?
- Which direction did the fluid flow? Is any fluid apparent now?
- What caused the “tails” behind the small craters in the channel?
- What sequence of events and processes makes most sense in explaining all these features?



100 km Scale: Ellipse is 100 x 200 km.

Image 9

- What is this ellipse?
- How would you describe this region?
- How might the teardrop-shaped landforms have formed?
- What might make this a desirable landing site?



Scale: Crater is 1.2 km in diameter.

Image 10

- What planet is this crater on? How can you tell?
- Is this crater more like the one in Image 2 or the one in Image 3? Why?
- Is this a fresh or an aged crater?
- How does this crater compare in size to those in Images 2 and 3?



Scale: The view east of Viking 1's landing site. The furthest point of the right-hand most trench is 3 m away from the lander. The smaller trenches are about 10 cm wide.

Image 11

On July 20, 1976, Viking I landed in the *Chryse Planitia* (i.e., the Chryse Plain) and was the first spacecraft to land successfully on Mars. Scientists think the Chryse Planitia is an out-wash plain, and one reason they chose to land there is that it is relatively flat, increasing the chances of a safe landing. Viking I's robotic arm dug the trenches in the foreground to reveal the soil just below the surface and to collect soil for several experiments. Note the wind-deposited dust behind some of the rocks. As measured by Viking, temperatures on a typical day ranged from -85°C to -30°C and wind speeds were around five meters per second with gusts up to 25 meters per second. Pathfinder also landed in the Chryse Planitia, roughly 850 km east of this site.

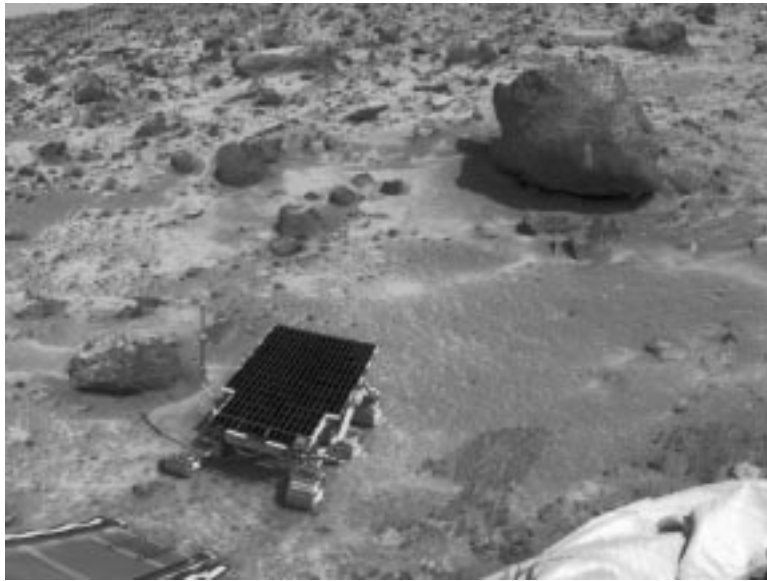
- How big are the largest rocks?
- Does this look like any place on Earth? If so, where?
- Can you tell if it is hot or cold?
- What might scientists learn from sampling in a place like this?
- How does this scene compare to the one around Pathfinder's landing site?



 200 km | Scale: Ellipse is 100 x 200 km.

Image 12

- What information does this wide-area view add to your understanding of Image 9?
- Do you see anything that might make this an interesting area to explore?



Scale: Rover is 65 cm long, 48 cm wide, and 30 cm tall.

Image 13

This image was taken on Pathfinder's third day. Here, Sojourner approaches "Barnacle Bill," the small rock on the left, and "Yogi," the large rock in the upper right-hand corner. Sojourner used its Alpha Proton X-ray Spectrometer (APXS) and cameras to determine the mineral composition of rocks and soil around the landing site. The lander's ramp and part of a deflated airbag are visible.

- How many different general rock shapes can you see?
- What causes rocks to be different shapes?
- Is the surface of Mars dusty? How can you tell?

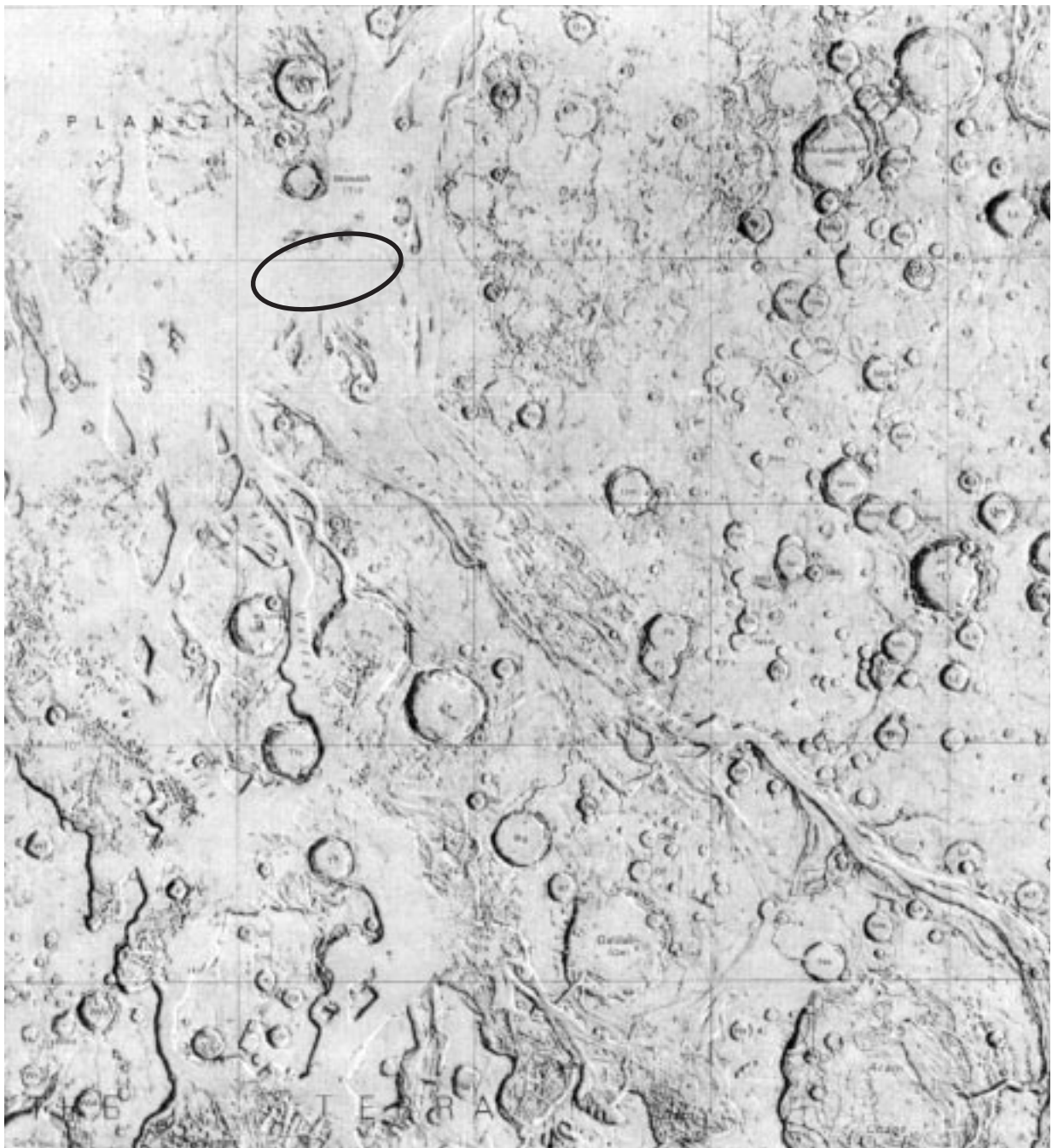


Scale: The Twin Peaks are approximately 1 km away and 50 m tall.

Image 14

This image was taken on Pathfinder's fourth day and shows "Twin Peaks," the two hills about one kilometer away from the landing site.

- Does this look like any place on Earth?
- Why did the landing site look so smooth when it is really full of boulders?
- What are some ways a plain like this can become littered with rocks?




500 km

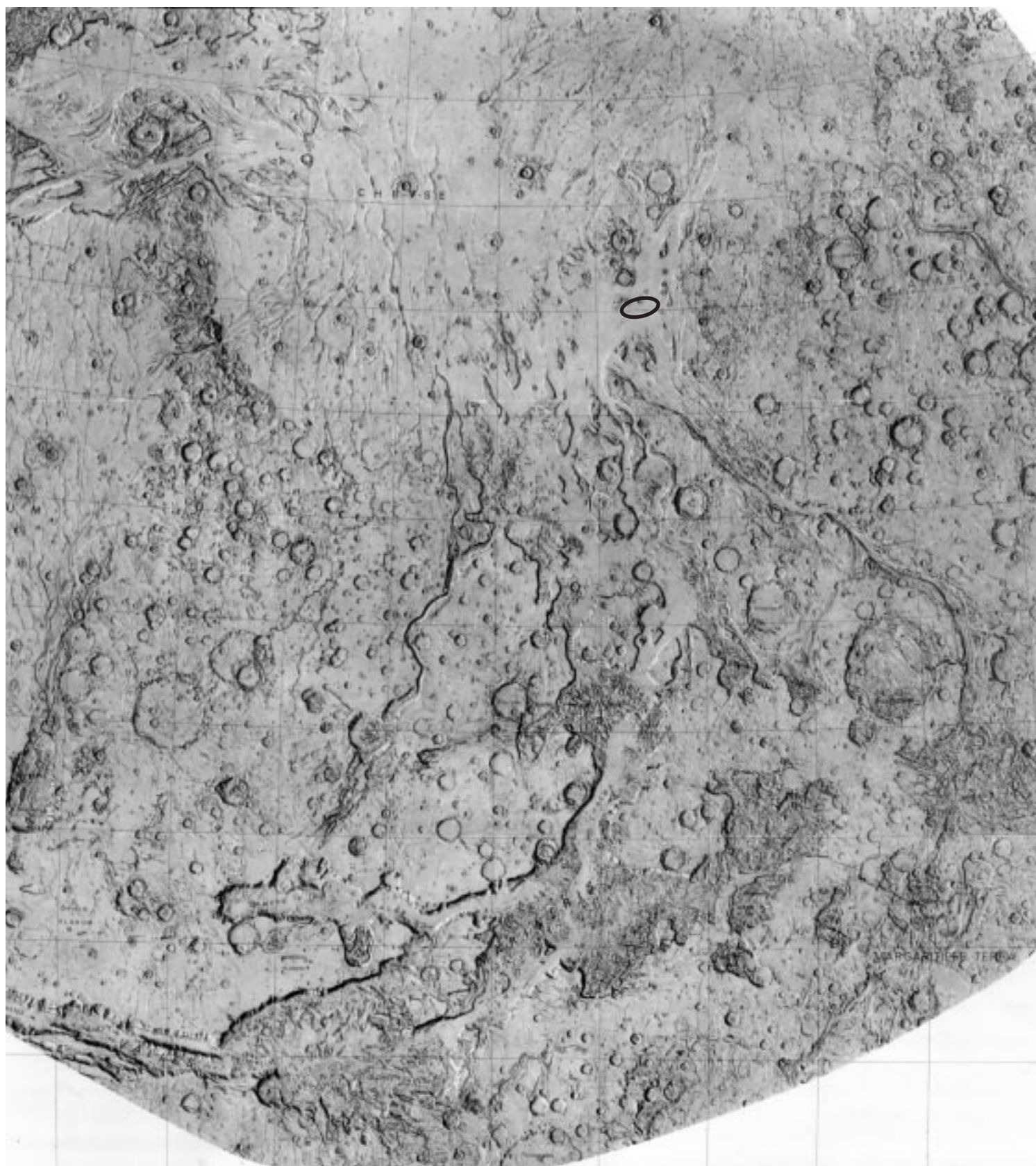
 Scale: Ares Vallis is about 1,500 km long.

Image 15

- What information does this wide-area view add to your understanding of Image 12?
- How much water flowed in this region, a little or a lot?
- Do you see any sources for water?
- Why is the area at the end of the channel so smooth?

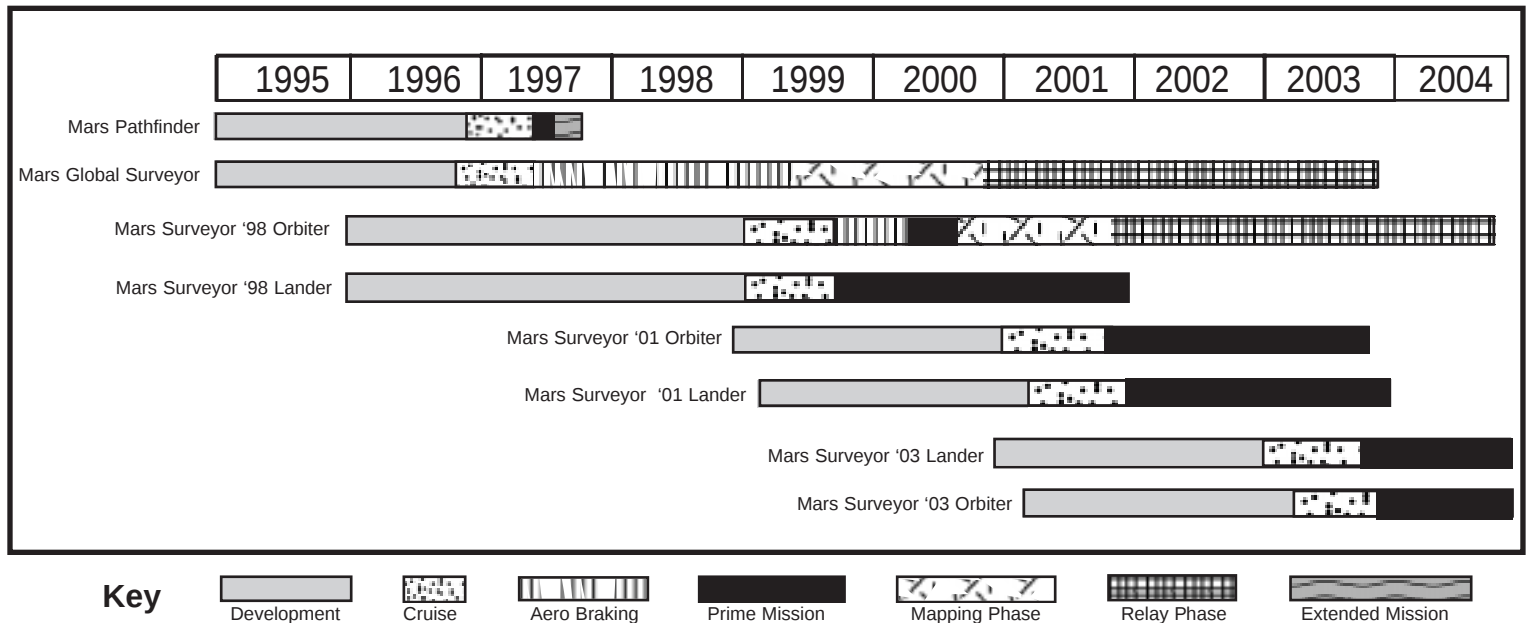
Image 16

- How big is this area?
- Is Ares Vallis the only place water flowed?
- Which direction is uphill?
- What is the general topography of this region?
- Where might the water that flowed in these channels have come from?
- Describe the distribution of craters in this region.
- What might explain this pattern of distribution?
- What are some differences between the craters on the plain and in the highlands?
- What might explain the differences between the craters in these two areas?
- What do you think the Chryse Planitia looked like when water flowed in the channels?



1000 km

Mars Exploration Timeline



Every two years, Mars and Earth align so that a spacecraft can travel efficiently between the two planets. Over the next decade, NASA plans to launch new missions each time Earth and Mars are in a position for efficient travel.

- **Mars Global Surveyor (1997)** The orbiter will map the planet's atmosphere and surface. It will look for evidence of surface water, study the surface geology and structure, and examine changes in Martian weather for at least one Martian year (about two Earth years).
- **Mars Surveyor '98 (1998-99)** The lander will land near the edge of Mars' south polar cap and focus on studies of geology, weather, and past and present water resources. Before touchdown, it will release two microprobes that will drop into the soil to search for the presence of subsurface water. The orbiter will examine the atmosphere and changes in water vapor during the Martian seasons.
- **Mars Surveyor '01 (2001)** The lander will carry a rover capable of traveling dozens of kilometers to gather surface dust and soil samples. There will also be a test of our ability to produce rocket propellant using Martian rocks and soil as raw materials. The orbiter will study the mineralogy and chemistry of the surface, including the identification of water resources just below the Martian surface.
- **Mars Surveyor '03 (2003)** This lander will carry a wide-ranging rover to collect samples from a different part of the planet. The orbiter will provide the complex links needed for communication and navigation for this and future surface missions.

NASA scientists are waiting to see what this current set of missions will reveal about Mars before deciding where to send the 2005 and 2007 missions and what data they should collect.