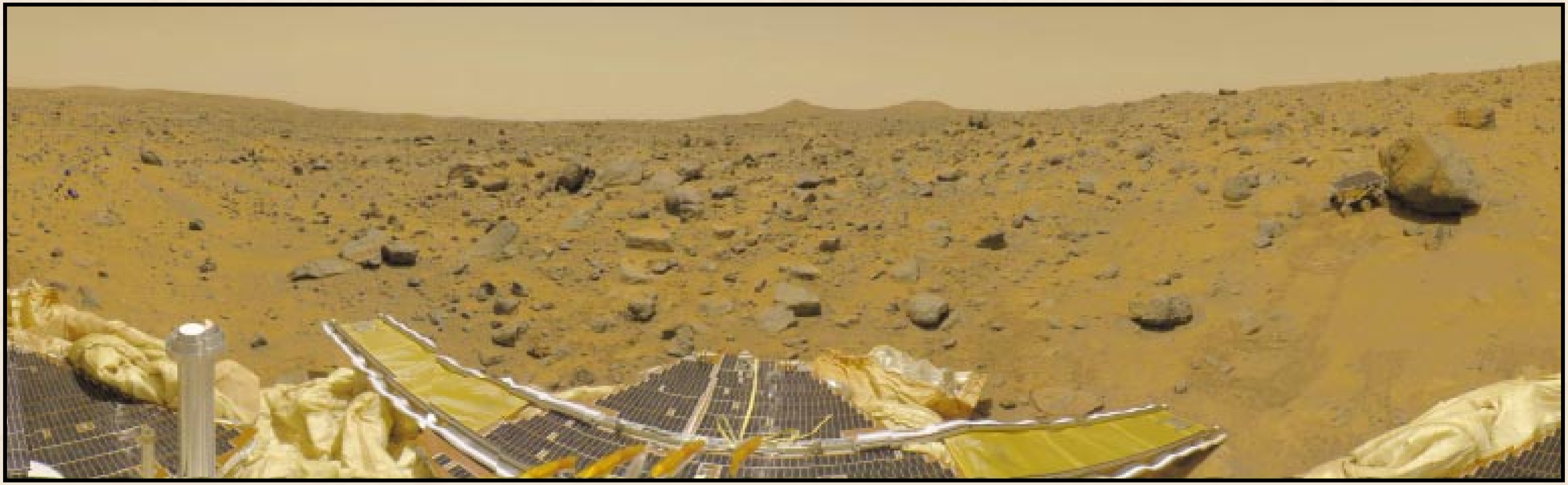
# MARS
## P • A • T • H • F • I • N • D • E • R



ROVING ON THE RED PLANET

National Aeronautics and
Space Administration

## Return to Mars!

*As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.*

NASA Vision Statement
NASA Strategic Plan

From the beginning of time, humans have looked up at the heavens and wondered what lay beyond the world that we know. Over time, we have learned much about the universe and our place within it, but much remains to be explored. The questions are among the most profound that we face: How did the universe form? Are there planets like Earth around other stars? How did life arise on Earth? Has it ever existed elsewhere in our solar system or elsewhere in the universe? What can we learn about other planets that will help us to understand our own? What else can we learn about our own planet? Will humans ever leave Earth for another planet—and why? and when?

These are the questions that occupy the people of NASA and shape our work. Our unique contribution to this undertaking is the perspective that we offer from the air and from space. By sending airplanes, spacecraft, rockets, and people into the heavens, we not only open new frontiers, we tap into fundamental streams of knowledge and discovery. This produces information not only to enrich the soul and the mind, but also to guide our decisions and make us wiser stewards of our home. We explore space because it is exciting, because it challenges us to be our best, and because it makes practical sense. Exploration and discovery are, as they always have been for humanity, the pathways to our future.

Most recently, we have focused attention on one of the most intriguing places we know of: Mars. Of all the planets in the solar system, Mars is the most like Earth. Although Mars has a thinner atmosphere than Earth, it also has weather seasons and an Earth-like day (called a sol) lasting 24 hours, 37 minutes. Mars also has a diverse and complex surface, including ice and winding channels made by flowing water in the distant past. Although the present cold, dry conditions on Mars are considered hostile for life forms, scientists have evidence that Mars was once warmer and wetter and had a much denser atmosphere early in its history. Life may have arisen in ancient Martian lakes or springs. If so, fossil evidence of life might be found.

Mars was not always the dry wasteland that it is now. Billions of years ago, early Mars may have been very similar to early Earth, with flowing water and possibly even seas. Understanding why the two planets evolved from that point to the very different states we see today can tell us much about what makes Earth such a unique and special place. Exploring Mars will provide us with a better understanding of significant events humanity may face in the future as Earth continues to evolve. What are the factors involved in natural changes in a planet's climate and weather, for instance? Such exploration will also tell us if Mars is a place where humans may someday be able—and want—to live and work.

Mars has experienced a complicated geologic history. On its surface are vast expanses of sand dunes, gorges, polar ice caps, huge volcanoes, and gigantic canyons. The giant Olympus Mons volcano is three times as tall as Mt. Everest and larger than Montana; it's the largest volcano in the solar system. Valles Marineris is three times as deep and ten times as long as the Grand Canyon. With a land area equal to Earth's, Mars offers a potential wealth of natural resources. The essentials for life support, including air and water, can be found or manufactured there. These resources will be essential for humans to live and work on Mars as we continue to explore the Red Planet.

There are many questions to be answered and many challenges to be met. Our explorers will first be robotic—unmanned spacecraft, landers, and rovers. These mechanical descendants of Magellan and Lewis and Clark—designed to scout ahead—will probe the soil, measure the atmosphere, map the surface, and gradually understand the lay of the land. Using this information, we will decide together if the next step is to sends humans and how best to do so. Like solving a riddle, exploring another planet is an ongoing series of steps, not a one-shot deal.

This is an exciting time to be alive, and to be explorers. As we send missions to Mars—and elsewhere in the universe—all are welcome and encouraged to go along for the ride.

## Mars Pathfinder

Mars Pathfinder is the first of these trailblazers. The first spacecraft to set down on Mars since the two Viking Landers in 1976, Mars Pathfinder is a mission to test key technologies for future science missions. It is the first ever to send out a robotic rover to independently explore the surface of Mars. Launched on December 4, 1996, Mars Pathfinder took seven months to reach Mars, and then successfully landed in a region known as Ares Vallis (Mars Valley) on July 4, 1997. The lander unfolded and a small rover, named Sojourner (after the American abolitionist, Sojourner Truth), rolled onto the Martian soil.

Mars Pathfinder also delivered science instruments to the surface of Mars to investigate the structure of the Martian atmosphere, weather, surface geology, and elemental composition of Martian rocks and soil. The Mars Pathfinder project is one of the first of the NASA Discovery program, which offers a class of frequent, low-cost space missions and is part of a long-term program of Mars exploration being conducted by NASA's Office of Space Science. The Jet Propulsion Laboratory, an operating division of the California Institute of Technology, manages the Mars Exploration Program for NASA.

### Mars Pathfinder Mission Objectives

- Prove that it is possible to successfully deploy "faster, better, and cheaper" spacecraft (three years for development and cost under $150 million)
- Demonstrate a simple, low-cost system, at fixed price, for placing a science payload on the surface of Mars at one-fifteenth the Viking price tag
- Exhibit NASA's commitment to low-cost planetary exploration by completing the mission for a total of $280 million dollars, including the launch vehicle and mission operations
- Demonstrate the mobility and usefulness of a microrover on the surface of Mars

## Mission Operation and Science

Mars Pathfinder is investigating the surface of Mars with three primary science instruments. On the lander are a stereoscopic imager with spectral filters on an extendable mast known as the Imager for Mars Pathfinder (IMP) and the Atmospheric Structure Instrument/Meteorology package (ASI/MET), which acts as a Martian weather station, gathering pressure, temperature, and wind measurements. On the rover is the Alpha Proton X-ray Spectrometer (APXS), which measures the elements present in rocks and soil. Sojourner also has one color and two black-and-white cameras. These instruments allow investigations of the geology and surface characteristics at scales of a few millimeters up to hundreds of meters, the geochemistry and evolutionary history of soils and rocks, the magnetic and mechanical properties of the soil as well as the magnetic properties of the dust, the atmosphere, and the rotational and orbital dynamics of Mars.

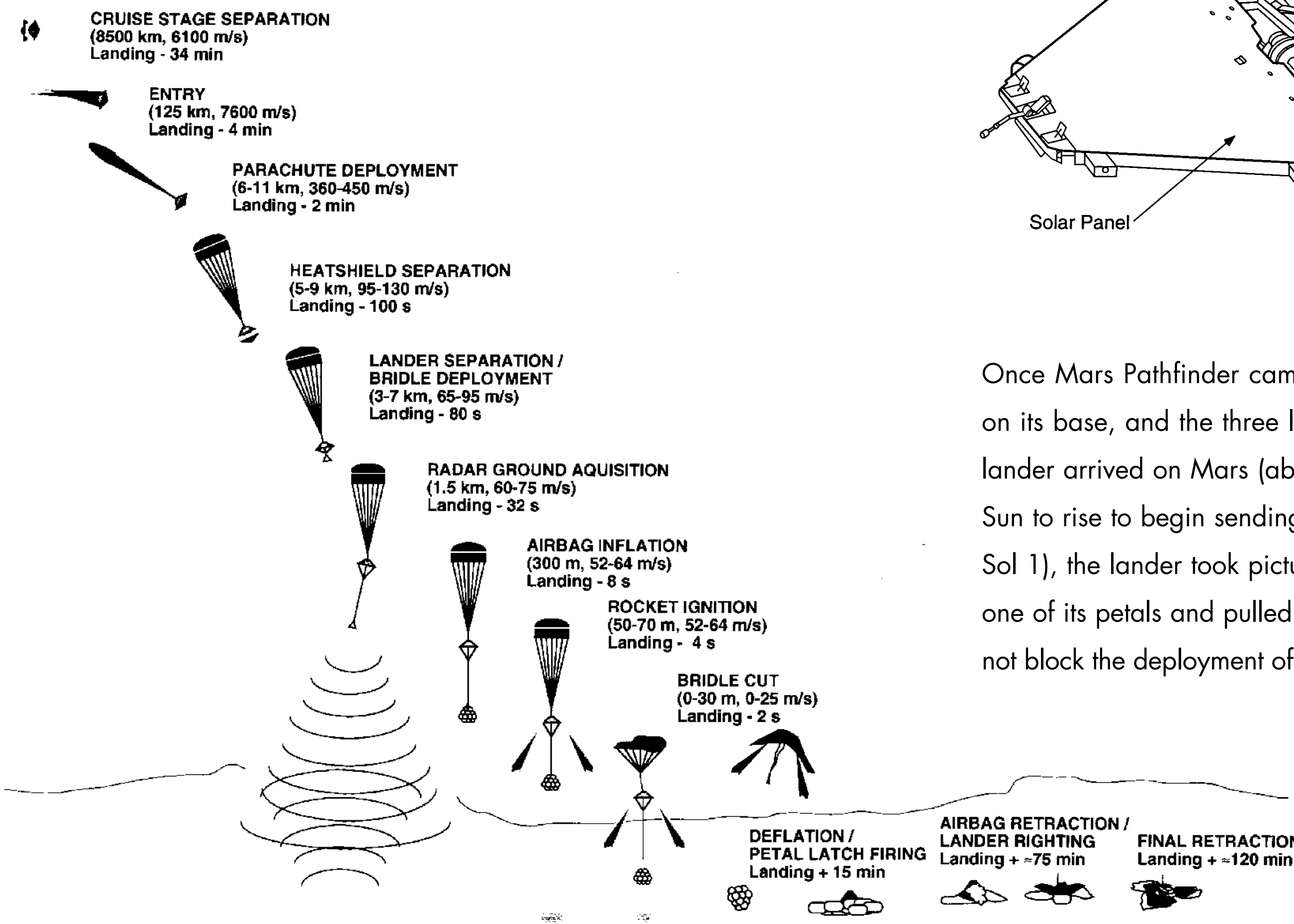
Downstream from the mouth of a giant catastrophic outflow channel, this landing site offers the potential for the identification and analysis of a wide variety of crustal materials, from the ancient, heavily cratered terrains, to intermediate-aged ridged plains, to reworked channel deposits. Sojourner's mobility provides the capability of "ground truthing" a landing area over hundreds of square meters on Mars. Examinations of the different surface materials are allowing first-order scientific investigations of the early differentiation and evolution of the crust, the development of weathering products, and the early environments and conditions that have existed on Mars.

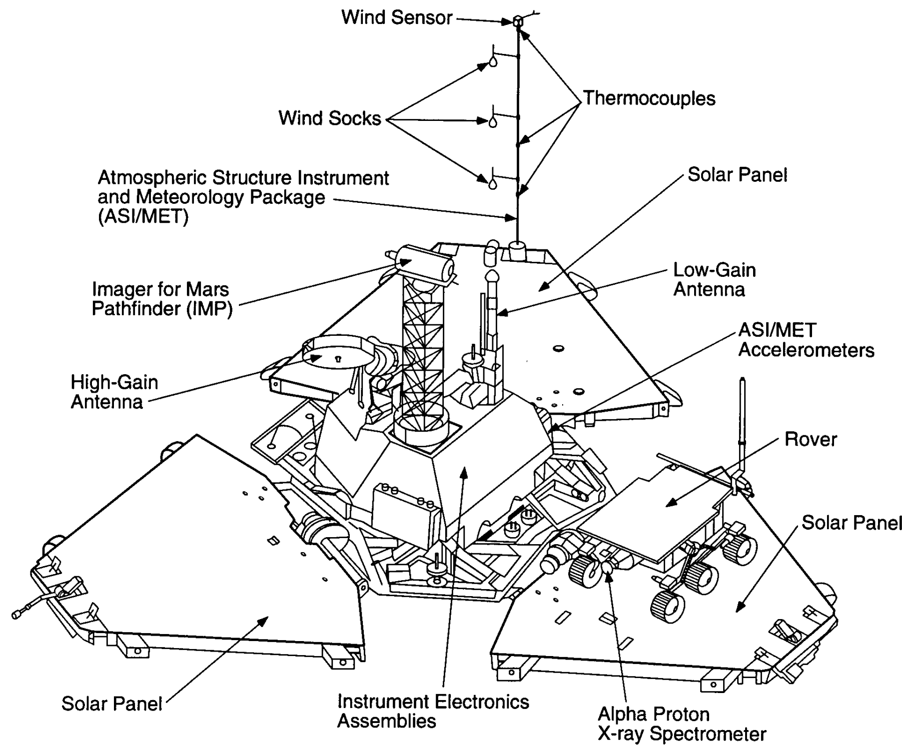
### Mars Pathfinder Science Objectives

- Surface morphology and geology at meter scale
- Petrology and geochemistry of surface materials
- Magnetic properties and soil mechanics of the surface
- Atmospheric structure, as well as diurnal and seasonal meteorological variations
- Rotational and orbital dynamics of Mars

# Entry, Descent, and Landing

Mars Pathfinder's dramatic entry, descent, and landing worked exactly as engineers had designed, placing the lander and rover safely onto the surface. The sequence of events included the use of a heat shield and a large parachute, the lowering of the lander on a bridle, the use of a radar altimeter to tell the lander how far it was from the surface, rockets to stop the lander in mid-air, and giant airbags to cushion its fall after the parachute and backshell detached. Amazingly, this entire process—from entry into the atmosphere to landing—took just a little over four minutes.



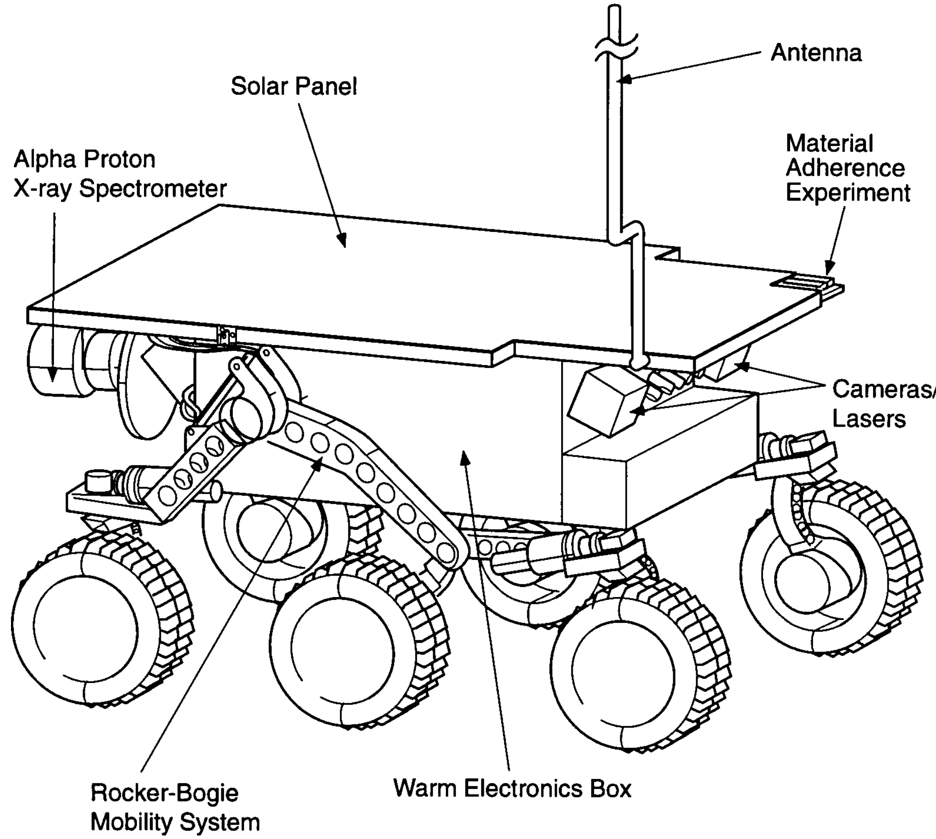

*Mars Pathfinder Lander*

Once Mars Pathfinder came to rest, the airbags deflated with the lander resting on its base, and the three lander petals unfolded. It was early morning when the lander arrived on Mars (about 3:00 a.m. local time), so the lander waited for the Sun to rise to begin sending data to Earth. During its first day on Mars (known as Sol 1), the lander took pictures and made weather measurements. It also lifted up one of its petals and pulled in more of a deflated airbag so that the airbag would not block the deployment of the rover's ramps.

## The Next Day

On Sol 2, Sojourner rolled down its ramp and onto Martian soil. Over the next several sols, Sojourner visited rocks named Barnacle Bill, Yogi, and Scooby Doo by the scientists. The rover also made measurements of the elements found in these rocks and in the Martian soil. The lander photographed Sojourner and the surrounding "marscape" and made weather observations. The Mars Pathfinder mission exceeded all of its mission objectives and has sent back important data and beautiful views of Ares Vallis.

*Mars Pathfinder's Sojourner Rover*




## Sojourner Truth

The name Sojourner was chosen for the Mars Pathfinder rover after a year-long, worldwide competition in which students up to 18 years old were invited to select a heroine and submit an essay about her historical accomplishments. The students were asked to address in their essays how a planetary rover named for their heroine would translate these accomplishments to the Martian environment.

Valerie Ambroise, of Bridgeport, Connecticut, submitted the winning essay about Sojourner Truth, an African-American reformist who lived during the Civil War era. An abolitionist and champion of women's rights, Sojourner Truth, whose legal name was Isabella Van Wagenen, made it her mission to "travel up and down the land," advocating the rights of all people to be free and the rights of women to participate fully in society. The name Sojourner also means "traveler."

## A New Era of Mars Exploration

Mars Pathfinder is the first in a series of spacecraft that will visit the Red Planet over the next decade. This exciting program of exploration is designed to send low-cost spacecraft to Mars every 26 months from 1996 to 2005. Each mission will build on the work done by its predecessors and will use the latest technology to revolutionize our understanding of the planet and its evolution. We are working closely with other nations on joint efforts that will expand the range of science data we can obtain. Ultimately, all this information will help us answer exciting questions about life on Mars and whether to send human explorers to the Red Planet. Upcoming U.S. missions include:

**September 1997: *Mars Global Surveyor*** (launched in November 1996) will orbit Mars and maps the planet's surface and atmosphere. It will look for evidence of surface water, study surface geology and structure, and examine changes in Martian weather for at least one Martian year (a little less than two Earth years).

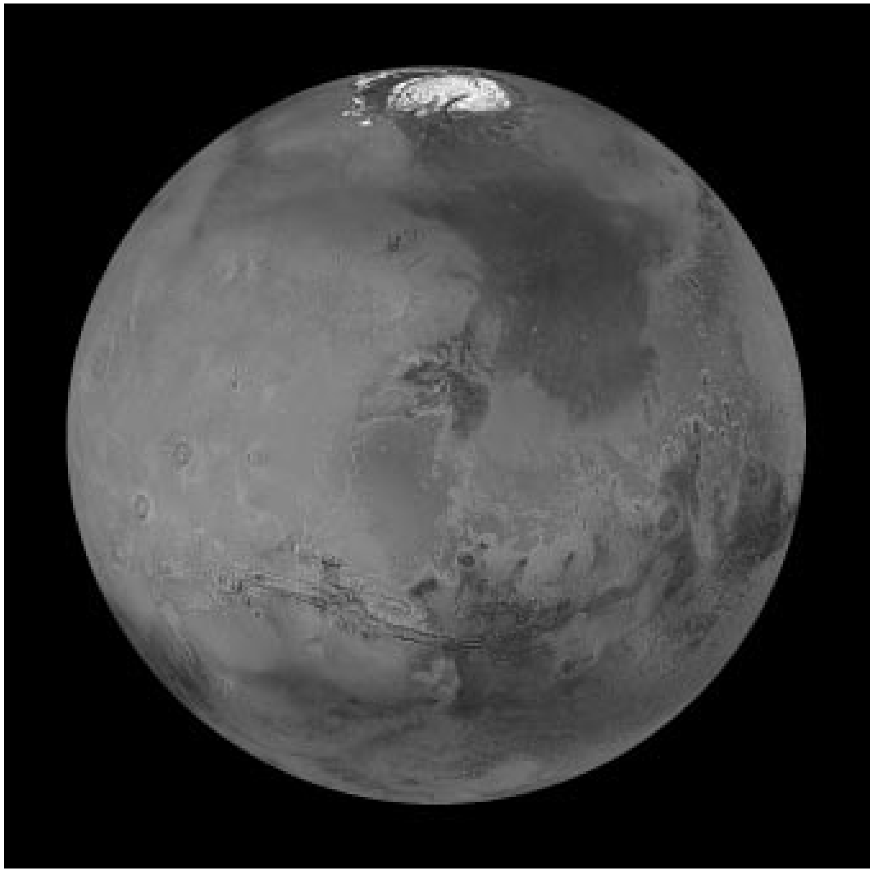
**1998–99: *Mars Surveyor '98 Lander and Orbiter.*** The lander will set down near the edge of Mars' south polar cap and focus on studies of geology, weather, and past and present water resources. Before touchdown, it will release two microprobes that will drop into the soil to search for the presence of subsurface water. The orbiter will examine the atmosphere and changes in water vapor during the Martian seasons.

**2001: *Mars Surveyor '01 Lander and Orbiter.*** The lander will carry a rover capable of traveling dozens of kilometers to gather surface dust and soil samples. There will also be tests 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.

**2003: *Mars Surveyor '03 Lander and Orbiter.*** This lander will also carry a wide-ranging rover to collect samples from a different part of the planet. The orbiter will provide the complex links needed for communications and navigation for this and future surface missions.

**2005: *Mars Sample Return Mission.*** This exciting and ambitious mission will descend to the surface, collect the samples acquired by either the '01 or '03 mission rover, and then blast off and return the sample back to the Earth for study by 2008.

**Beyond 2005:** These missions will be determined by what we learn and what we still need to know. The journey will continue. . . .



## Mars Facts

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### Fourth Planet From the Sun

**Distance From the Sun:**
Minimum: 206,000,000 kilometers
Average: 228,000,000 kilometers (1.52 times as far as Earth)
Maximum: 249,000,000 kilometers

**Eccentricity of Orbit:**
0.093 vs. 0.017 for Earth (0.00 is a perfectly circular orbit)

**Distance From Earth:**
Minimum: 56,000,000 kilometers
Maximum: 399,000,000 kilometers

**Year:**
1.88 Earth years = 669.3 Mars days (sols) = 686.7 Earth days

**Day:**
24.6 Earth hours

**Tilt of Rotation Axis:**
25.2° vs. 23.5° for Earth

**Size:**
Diameter = 6,794 kilometers vs. 12,756 kilometers for Earth
Surface Gravity: 0.38 (or ~1/3) Earth's gravity
Mass: $6.4 \times 10^{26}$ grams vs. $59.8 \times 10^{26}$ grams for Earth
Density: 3.9 grams/cc vs. 5.5 grams/cc for Earth

**Surface Temperature:**
Cold
Global extremes: –125°C (–190°F) to 25°C (75°F)
Average at Viking 1 site: high –10°C (15°F); low –90°C (–135°F)

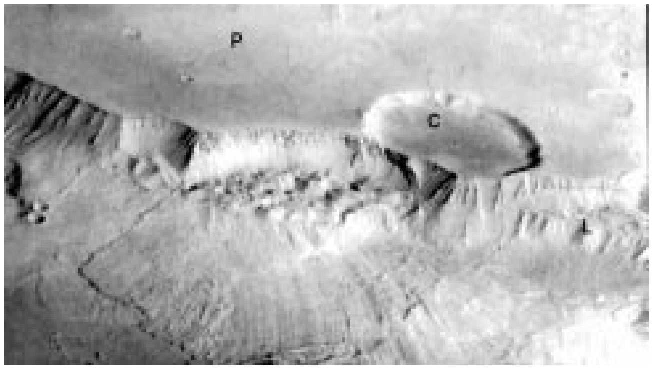
**Atmosphere:**
Thin, unbreathable
Surface pressure: ~6 millibars, or about 1/200th of Earth's
Contains 95% carbon dioxide, 3% nitrogen, 1.5% argon, ~0.03% water (varies with season), no oxygen. (Earth has 78% nitrogen, 21% oxygen, 1% argon, 0.03% carbon dioxide.) Dusty, which makes the sky pinkish. Planet-wide dust storms black out the sky.

**Surface:**
Color: Rust red
Ancient landscapes dominated by impact craters
Largest volcano in the solar system (Olympus Mons)
Largest canyon in the solar system (Valles Marineris)
Ancient river channels
Some rocks are basalt (dark lava rocks); most others unknown
Dust is reddish, rusty, like soil formed from volcanic rock

**Moons:**
Phobos ("Fear"), 21 kilometers diameter
Deimos ("Panic"), 12 kilometers diameter

## Activity 1: "Old, Relatively"

For exploring Mars, it is important to know which events happened in which order and which areas are older than others. A simple way of figuring out the sequence of events is "superposition"—most of the time, younger things are on top of older things, and younger (more recent) events affect older things.




To learn more about this image, visit the World Wide Web site at:
***http://cass.jsc.nasa.gov/education/K12/gangis/mars1.html***

**Superposition in Your Life**
Is there a pile of stuff on your desk? On your teacher's? On a table or floor at home? Where in the pile is the thing you used most recently? The thing next most recently? Where in the pile would you look for something you put down 10 minutes ago? When was the last time you or your teacher or parent used the things at the bottom of the pile?

**Superposition on Mars**
Using superposition, we can sort out many of the complicated events in the history of Mars. For example, you can sort out all the events that affected the area in the image above. It is a small part (60 kilometers across) of the wall of the great canyon system of Valles Marineris. Toward the top is a high plateau (labeled "P"), with a large circular impact crater ("C"). It formed when a huge meteorite hit Mars' surface. Below the plateau is the wall of Valles Marineris. Here, the wall has been cut away by huge landslides ("L"), which leave bumpy rough land at the base of the wall and a thin, broad fan of dirt spreading out onto the canyon floor. In the canyon wall, almost at its top, alternating layers of light and dark rock are exposed.

To discover the history of this region, start by listing all the landscape features you can see, and the events that caused them (do not bother listing every small crater by itself). Now list the events in order from oldest to youngest. [Hints: How many separate landslides are there? Is the large crater ("C") younger than the landslides? Are the landslides younger than the rock layers at the top of the canyon wall? Are the small craters older or younger than the landslides?] Sometimes, you cannot tell which of two events was younger. What additional information would help you tell?

*—(From A.H. Treiman, Lunar and Planetary Institute, 1997)*

## Activity 2: "Geography and Mission Planning"

These locations on Mars were considered by mission planners as possible landing sites for the two Viking landing craft.

| Latitude | Longitude | |
|---|---|---|
| 22°N | 48°W | (Viking Site) |
| 20°N | 108°E | |
| 44°N | 10°W | |
| 7°S | 43°W | |
| 46°N | 150°W | (Viking Site) |
| 44°N | 110°W | |
| 5°S | 5°W | |

If Martians sent spacecraft to these same latitudes and longitudes on Earth, what would they find? Would they find life or evidence of an advanced civilization? Use a globe or world map to identify these spots on Earth. Use geography reference books to describe what the Martians would see at each site.

If you were a Martian, why would you explore Earth? Does Earth have resources you might need? What would you want to know about Earth? Where would you land first and why?

*—(From B.M. French,* The Viking Discoveries, *NASA EP-146, October 1977)*

**For Reference: Mars Map**
U.S. Geological Survey (1991) Topographic Maps of Polar, Western, and Eastern Regions of Mars, U.S. Geological Survey Miscellaneous Investigations Map I-2160. USGS Information Services, 1-800-USA-MAPS

## Image Caption

This image is a portion of a full-color, 360-degree panorama of Ares Vallis (Mars Valley), where Mars Pathfinder landed on July 4, 1997. Visible next to a rock named Yogi is the rover Sojourner. She has backed up to Yogi and has placed the Alpha Proton X-ray Spectrometer instrument against the rock to determine its elemental composition. Yogi is approximately 6.5 meters (20 feet) from the Mars Pathfinder lander and stands about 1 meter (3 feet) high. Sojourner is 30 centimeters (1 foot) tall.

In the lower left corner of the image is the ramp that Sojourner used to roll off the lander petal and onto the Martian soil. To the right is a portion of the deflated airbag from the adjacent petal. Sojourner's tracks across the soil are plainly visible and are darker than the undisturbed soil.

A dusting of very fine-grained material is also seen on a number of the rocks in the view. Dust finer than talcum powder has gathered to the left of Barnacle Bill, the pitted football-shaped and -sized rock just above the end of the ramp. Dust particles suspended in the thin Martian atmosphere give the sky its color.

At one time in Mars' past, a large amount of water rushed across this area. The direction of flow was to the north, which is toward the upper right corner of this picture. The flood waters cut a series of gullies in the plain. A trek across this "marscape" toward the horizon would carry you up and down a series of hills and valleys.

On the horizon can be seen two hills nicknamed the Twin Peaks. They are about 1 kilometer (0.6 mile) away. To their right is the rock known as the Couch, more than 150 meters (500 feet) away.

Images and other data from Mars Pathfinder are relayed via the antennas of NASA's Deep Space Network. With stations in Spain, Australia, and California, contact with the lander is possible whenever it is on the near side of Mars. Each day, controllers send commands and receive scientific and engineering data when Earth is above the Martian horizon at the Ares Vallis landing site.

## Web Sites

### Mars

| | |
|---|---|
| Ames Center for Mars Exploration | **http://cmex-www.arc.nasa.gov/** |
| Lunar and Planetary Institute | **http://cass.jsc.nasa.gov/expmars/expmars.html** |
| Mars Multi-Scale Map | **http://www.c3.lanl.gov/~cjhamil/Browse/mars.html** |
| Mars Landing Sites | **http://www.mars-sites.arc.nasa.gov/** |
| Marls Global Surveyor Project | **http://mgs-www.jpl.nasa.gov/** |
| Mars Pathfinder Project | **http://mpfwww.jpl.nasa.gov/** |
| Mars K–12 Curriculum Guide *(Arizona State University)* | **http://esther.la.asu.edu/asu_tes/TES_Editor/ CURRIC_GUIDES/curric_guideMENU.html** |
| Mars Surveyor Orbiter | **http://nssdc.gsfc.nasa.gov/cgi-bin/databse/ www-nmc?MARS98S** |
| Mars Surveyor Lander | **http://nssdc.gsfc.nasa.gov/cgi-bin/ database/www-nmc?MARS98L** |
| Viking Orbiter Image Archive | **http://barsoom.mss.com/http/vikingdb.html** |
| Viking Lander Image Data | **http://www-pdsimage.jpl.nasa.gov/PDS/ public/viking/vl_images.html** |

### Tours of the Solar System

| | |
|---|---|
| Views of the Solar System *(Calvin Hamilton/Los Alamos)* | **http://bang.lanl.gov/solarsys/** |
| The Nine Planets *(Bill Arnett/SEDS)* | **http://seds.lpl.arizona.edu/nineplanets/ nineplanets.html** |
| Welcome to the Planets (JPL) | **http://pds.jpl.nasa.gov/planets/** |
| NASA Spacelink | **http://spacelink.nasa.gov** |
| Planetary Photo Journal | **http://photojournal.jpl.nasa.gov** |

### Education

| | |
|---|---|
| NASA On-line Resources for Educators | **http://www.hq.nasa.gov/education** |
| Lunar and Planetary Institute | **http://cass.jsc.nasa.gov/lpi.html** |

# More About Mars

## Books

Beatty, J.K., and A. Chaikin, eds. (1990) *The New Solar System,* Third Edition, Sky Publishing Corp., Cambridge.

Carr, M.H. (1981) *The Surface of Mars,* Yale University Press, New Haven. A highly readable account of our knowledge of Mars at the end of the Viking program.

Christiansen, E.H., and W.K. Hamblin (1995) *Exploring the Planets,* Second Edition, Prentice-Hall, Englewood Cliffs, New Jersey.

Cooper, H.S.F. (1980) *The Search for Life On Mars: Evolution of an Idea,* Holt, Rinehart, and Winston, New York.

Lowell, P. (1895) *Mars,* Houghton, Mifflin, Boston, New York. Percival Lowell's fascinating, passionate, and highly erroneous interpretations of his longtime observations of Mars. Especially interesting when read with Sheehan's *Planets & Perception.*

Murray, B. (1989) *Journey Into Space: The First Thirty Years of Space Exploration,* W.W. Norton, New York. Describes humankind's robotic exploration of Mars and the rest of the solar system, as witnessed by this former director of the Jet Propulsion Laboratory.

Sheehan, W. (1988) *Planets & Perception: Telescopic Views and Interpretations, 1609–1909,* University of Arizona Press, Tucson. An introduction to the physical, social, and psychological pitfalls of observing distant worlds, especially Mars. This makes an excellent companion to Lowell's *Mars.*

Sheehan, W. (1996) *The Planet Mars: A History of Observation and Discovery,* University of Arizona Press, Tucson. A popular history of discoveries and ideas about Mars, emphasizing the era of visual and telescopic observations.

Viking Lander Imaging Team (1978) *The Martian Landscape,* NASA SP-425. A compilation of photographs obtained by the Viking Landers.

Viking Orbiter Imaging Team (1980) *Viking Orbiter Views of Mars,* NASA SP-441. A compilation of photographs obtained by the Viking Orbiters.

Wilford, J.N. (1990) *Mars Beckons,* Alfred A. Knopf, New York.

## Science Fiction

Since telescopes first revealed seasonal color changes on Mars, Earthlings have been fascinated with the possibility of life on the Red Planet. These classics (among hundreds of others) trace human notions of Martian "society" through the 20th century and hold up a mirror to the concerns and crises of our own.

Bradbury, Ray (1950) *The Martian Chronicles,* various publishers.

Heinlein, Robert (1986) *Red Planet,* Del Ray Books, Ballantine.

Wells, H.G. (1898) *The War of the Worlds,* various editions, various publishers.

EW-1997-08-128-HQ