NASA Facts

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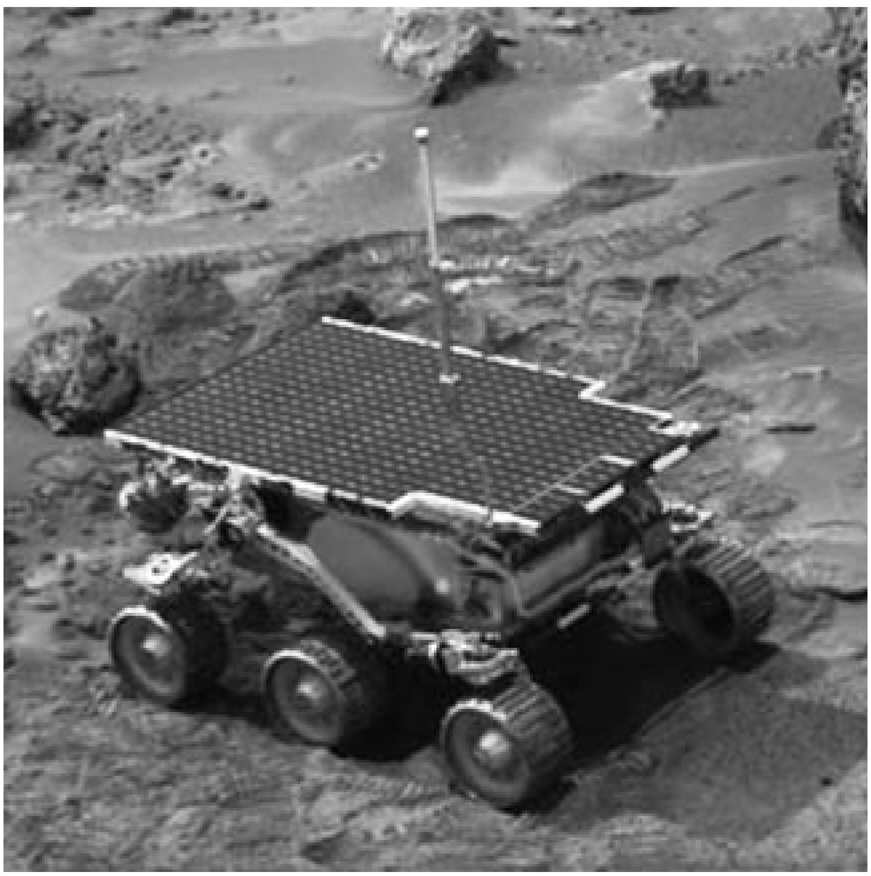
Mars Pathfinder

Mars Pathfinder was the first completed mission in NASA's Discovery Program of low-cost, rapidly developed planetary missions with highly focused science goals. With a development time of only three years and a total cost of $265 million, Pathfinder was originally designed as a technology demonstration of a way to deliver an instrumented lander and a free-ranging robotic rover to the surface of the red planet. Pathfinder not only accomplished this goal but also returned an unprecedented amount of data and outlived its primary design life.

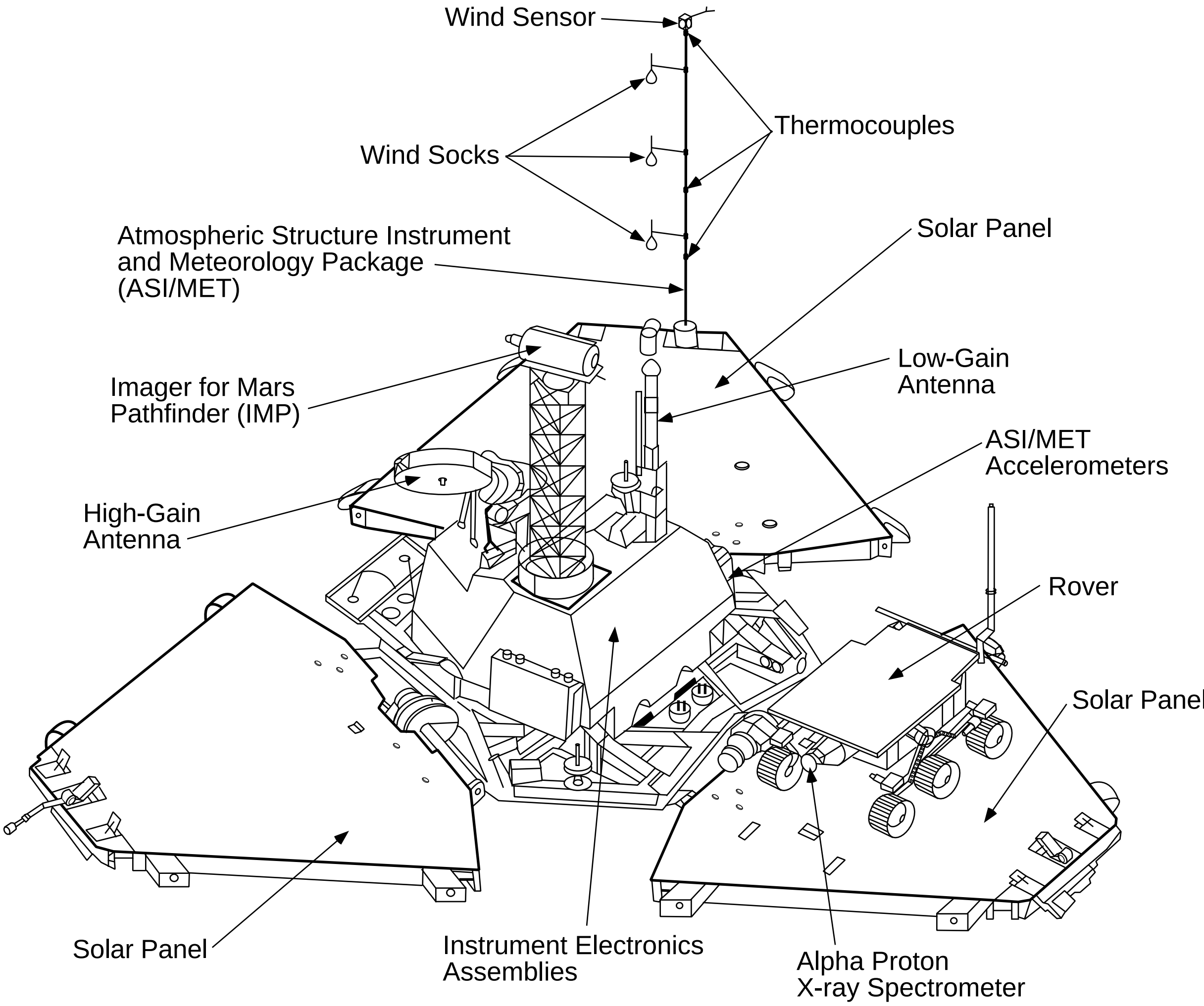


Pathfinder used an innovative method of directly entering the Martian atmosphere, assisted by a parachute to slow its descent through the thin Martian atmosphere and a giant system of airbags to cushion the impact. It was the first time this airbag technique had been used. After the entry vehicle entered Mars' atmosphere from its interplanetary trajectory, it successfully completed a 4-1/2-minute sequence of complex and precisely timed events, ending in a touchdown which left all systems intact.

The landing site, an ancient flood plain in Mars' northern hemisphere known as Ares Vallis, is among the rockiest parts of Mars. It was chosen because scientists believed it to be a relatively safe surface to land on and one which contained a wide variety of rocks deposited during a catastrophic flood. In the event early in Mars' history, scientists believe that the flood plain was cut by a volume of water the size of North America's Great Lakes in about two weeks.

The lander, formally named the Carl Sagan Memorial Station following its successful touchdown, and the rover, named Sojourner after American civil rights crusader Sojourner Truth, both outlived their design lives — the lander by nearly three times, and the rover by 12 times.

From the landing on July 4, 1997, to the final data transmission on September 27, 1997, Mars Pathfinder



returned 2.3 billion bits of information, including more than 16,500 images from the lander and 550 images from the rover, as well as more than 15 chemical analyses of rocks and soil and extensive data on winds and other weather factors. Findings from the investigations carried out by scientific instruments on both the lander and the rover suggest that Mars was at one time in its past warm and wet, with water existing in its liquid state and a thicker atmosphere.

Overall, the Pathfinder mission was a great success, providing scientists with large amounts of data, pioneering many new technologies, and demonstrating the feasibility of developing, designing launching and operating a planetary mission according to NASA's new "faster, better, cheaper" philosophy.

Mission Overview

Mars Pathfinder was launched atop a Delta II-7925 launch vehicle from Cape Canaveral Air Station in Florida on December 4, 1996. The launch vehicle included a Star 48 solid rocket as the third-stage booster.

During the spacecraft's seven-month journey to Mars, four trajectory correction maneuvers fine-tuned its flight path. NASA's Deep Space Network of giant dish antennas provided the two-way communications link for command, tracking and telemetry operations. Except for some difficulty with two of the spacecraft's five Sun sensors early in the flight, all critical spacecraft subsystems performed as expected.

At 1:42 p.m. PDT on June 30, 1997, the flight team commanded the spacecraft to switch into its mode for entry, descent and landing on Mars. On July 3, 1997, at about 4 a.m. PDT, the spacecraft passed into the sphere of Mars' gravitational influence. Early on July 4, 1997, Pathfinder was heading for its approximately 100- by 200-kilometer (60- by 120-mile) landing ellipse.

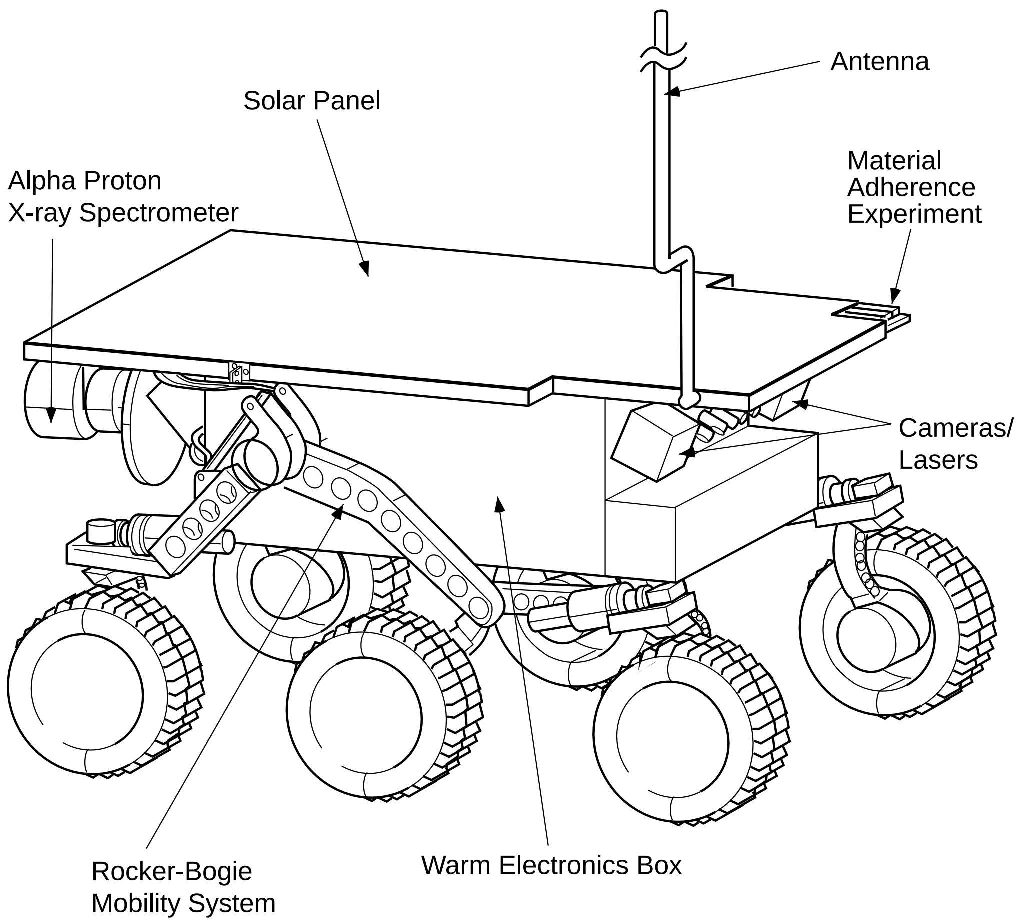
The sequence of entry, descent and landing events was as follows: release of the cruise stage (34 minutes prior to landing), entry into Mars' upper atmosphere (4 minutes to landing), deployment of the 11-meter-diameter (36-foot) parachute (2 minutes to landing), release of the heat shield, release of the lander from the backshell and descent of the lander on a 20-meter (65 foot) tether, acquisition of altitude information by the radar altimeter, inflation of the airbags (8 seconds to landing), firing of the rocket-assisted deceleration engines, cutting of the tether, and free-fall of the lander to the Martian surface.

The airbag-cushioned lander hit Martian soil at 10:07 a.m. PDT on July 4, 1997, at a speed of 14 meters per second (31 miles per hour). Measuring 5.8 meters (19 feet) in diameter, it bounced like a giant beach ball about 15 times, as high as 15 meters (50 feet), before coming to rest 2-1/2 minutes later about 1 kilometer (six-tenths of a mile) from the point of initial impact. The landing coordinates were 19.13 degrees north latitude, 33.22 degrees west longitude, in the boulder-strewn Ares Vallis flood plain. Fortuitously, the lander came to rest right side up on its base petal, thereby eliminating the need for the spacecraft to right itself while deploying its petals.

An antenna mounted on one of the lander's petals sent confirmation back to Earth that Pathfinder had landed. Approximately 90 minutes after landing, engineering data received by the flight team indicated that Pathfinder had fully deployed its petals and was awaiting sunrise on Mars to begin its mission. The lander came to rest about 20 kilometers (12 miles) southwest of its targeted landing spot and was resting on the surface at a very slight tilt of about 2.5 degrees.

Pathfinder's first transmission via the lander's low-gain antenna was received on time at 2:07 p.m. PDT on July 4, 1997, or "sol 1" (a Martian day, or sol, is 24 hours, 37 minutes). The transmission contained preliminary information about the health of the spacecraft and rover; the spacecraft's orientation on the surface; data about its entry, descent and landing; and a first look at the density and temperatures of the Martian atmosphere.

Pathfinder's first transmission via its high-gain antenna, beginning at 4:28 p.m. PDT the same day, returned to Earth the first images taken by the lander's camera, including a color mosaic of the boulder-strewn Ares Vallis flood plain. Some of the images revealed that one of the airbags had not fully retract-



ed, and was obstructing opening of one of the rover ramps.

Also on its first day on Mars, Sojourner, which was programmed to communicate with the lander as frequently as every 10 minutes, was not “completing full sentences” in its transmissions to the lander. This communication problem — which engineers concluded was the result of a problem with the modem on the lander used to communicate with the rover — was solved the next day.

After receiving hundreds of new images of the Ares Vallis outflow channel, the flight team spent the rest of sol 1 retracting the airbag obstructing the rover ramp. On the night of July 5, late in the second Martian day, or sol 2, Sojourner stood up to its full height of 30 centimeters (1 foot) and rolled down the lander’s rear ramp, which was tilted at 20 degrees from the surface, well within the limits of safe deployment. Sojourner then positioned its primary science instrument, an alpha proton X-ray spectrometer (APXS), face-down in the Martian soil to take 10 hours of measurements overnight.

On sol 3, Sojourner performed two science experiments: a soil mechanics experiment designed to demonstrate how the rover’s wheels and mobility system operate on the Martian surface; and a trip of about 36 centimeters (1.2 feet) to a rock nicknamed Barnacle Bill, against which Sojourner placed the APXS overnight to gather data on its composition.

Over the course of the next 2-1/2 months, Sojourner collected data on an additional 14 rocks — including those nicknamed Yogi and Scooby Doo — and on nearby soils. It also performed a number of technology experiments designed to provide information that will improve future planetary rovers. These experiments included terrain geometry reconstruction from lander/rover imaging, basic soil mechanics by studying wheel sinkage, path reconstruction by dead reckoning and track images, and vision sensor performance. Additional Sojourner experiments studied vehicle performance, rover thermal conditions, effectiveness of the radio link, and material abrasion by sensing the wear on different thicknesses of paint on a rover wheel.

The last successful data transmission cycle from Pathfinder was completed at 3:23 a.m. PDT on September 27, 1997, which was sol 83 of the mission. A final signal without any spacecraft data was received on October 7. The Pathfinder team attempted to reestablish contact with the spacecraft for several months until March 1998, but were unable to regain contact. Although the cause of the loss of communication with the lander may never be known, engineers suspected that depletion of the spacecraft’s battery and a drop in the operating temperature of the spacecraft, which was kept warm by the battery, were to blame. (The battery was only designed to operate for one month.) The rover had completed an APXS study of a rock nicknamed Chimp when it was last heard from. Assuming that the lander was not functioning after the loss of signal, it is assumed that the rover would have gone into a contingency mode within a few days -- either circling the lander repeatedly or standing in place, awaiting instructions. The Pathfinder mission was declared officially concluded in March 1998.

The only objective left unfinished at the time communications was lost was completion of a high-resolution 360-degree image of the landing site nicknamed the “Super Pan,” of which 83 percent was received on Earth. Other complete panoramas had already been received.

Mars

One of five planets known to the ancients, Mars is known as the red planet because of its reddish color. At times it is the third brightest planet, after Venus and Jupiter. Mars was named by the Romans for their god of war.

The fourth planet from the Sun, Mars is about 1.5 times farther from the Sun than Earth is. Radio signals take between 2-1/2 and 20 minutes to travel one way between Earth and Mars. Mars revolves around the Sun once every 687 Earth days, and its day, or “sol,” is slightly longer than Earth’s, at 24 hours 37 minutes. Because Mars’ axis tilts at 25.19 degrees (Earth’s polar tilt is 23.43 degrees), it has Earth-like seasonal changes.

Mars’ diameter is 6,780 kilometers (4,217 miles), about half the size of Earth but twice the size of Earth’s Moon. Mars’ mass is 1/10th that of Earth, and its gravity is 38 percent as strong as Earth’s. Mars has an elliptical orbit; its distance from the Sun ranges from 206.7 million kilometers (128.4 million miles) to 249.2 million kilometers (154.8 million miles), with an average distance of 227.7 million kilometers (141.5 million miles). No planet-wide magnetic field has been detected on Mars, although localized ancient remnant fields have been detected in various regions by the orbiting Mars Global Surveyor.

Mars' atmosphere is composed chiefly of carbon dioxide (95.3 percent), nitrogen (2.7 percent) and argon (1.6 percent), with traces of oxygen, carbon monoxide and water vapor. Surface atmospheric pressure on Mars is less than 1/100th that of Earth's average atmospheric pressure; its surface temperature averages -53 C (-64 F), varying from -128 C (-199 F) during polar night to 27 C (80 F) during midday near the equator when Mars is at its closest point in orbit around the Sun.

The highest point on Mars is Olympus Mons, a huge shield volcano more than 27 kilometers (16 miles) high and 600 kilometers (370 miles) across, covering about the same area as Arizona. The Martian canyon system known as Valles Marineris is the largest and deepest known canyon in our solar system. About 5 to 10 kilometers (3 to 6 miles) deep, 100 kilometers (60 miles) wide and extending for more than 4,000 kilometers (2,500 miles), it dwarfs America's Grand Canyon.

Mars' two irregularly shaped moons are the larger Phobos ("fear"), 28 by 20 kilometers (17 by 12 miles); and the smaller Deimos ("terror"), 16 by 10 kilometers (10 by 6 miles). Both are named for the sons of the Greek god of war.

Earlier missions to Mars began with the Mariner flybys of the 1960s. In 1965, the first successful flyby of Mars, Mariner 4, provided the first closeup images of another planet. Along with the 1969 Mariner 6 and 7 flybys, it provided images of a moonlike planet pocked with impact craters. In 1971, Mariner 9 orbiter provided evidence of dry flood channels and volcanism on Mars.

In 1976, the Viking 1 and 2 missions each sent an orbiter and lander to Mars. The Viking landers monitored the weather, detected nitrogen in the atmosphere for the first time and analyzed soil samples near the landing sites, finding no evidence for the presence of life. The Viking missions also established that Mars has channels that were probably cut by ancient rivers. Nearly two decades later, the Mars Observer orbiter was lost while preparing to enter Martian orbit in August 1993.

Spacecraft

At launch, the Mars Pathfinder spacecraft weighed 894 kilograms (1,973 pounds), including its cruise stage platform, heat shield, back shell, solar panels, propulsion system, low- and high-gain antennas, lander, rover, parachute, airbags and 94 kilograms (207 pounds) of fuel. It stood 1.5 meters (5 feet) tall and measured 2.65 meters (8.5 feet) in diameter. During interplanetary cruise, 2.5 square meters (27 square feet) of gallium arsenide solar cells provided the 178 watts of electrical power required by the spacecraft.

Upon entry into the Martian atmosphere, the entry vehicle weighed 584 kilograms (1,288 pounds). Upon landing, and after airbag deflation, the Pathfinder lander weighed 370 kilograms (816 pounds). The pyramid-shaped lander stood about 0.9 meter (3 feet) tall, with three triangular-shaped sides, or petals, hinged to the base platform.

Each petal was covered with solar cells — a total area of 2.8 square meters (30 square feet) — that supplied up to 1,200 watt-hours of power to the lander for daytime operations and to charge the silver zinc batteries for nighttime use.

When unfolded and lying flat, the lander measured 2.75 meters (9 feet) across, with the mast-mounted camera standing about 1.5 meters (5 feet) above the ground.

The lander was controlled by a derivative of the commercially available IBM RAD6000 computer, radiation-hardened to survive the flight. The computer featured a computing speed of 20 million instructions per second and 128 megabytes of dynamic random access memory for storage of flight software and engineering and science data, including images and rover information. Six megabytes of non-volatile memory stored flight software and time-critical data.

Sojourner Rover

The Pathfinder rover was named after Sojourner Truth, an African-American crusader who lived during the U.S. Civil War era and traveled throughout the country advocating the rights of all people to be free. The name Sojourner, which means "traveler," was the winning entry in a year-long competition in which students 18 years and younger submitted essays on the historical accomplishments of a heroine of their choosing.

The microwave-oven-sized rover weighed about 10.6 kilograms (23 pounds), plus about 5 kilograms (11 pounds) of mounting and deployment equipment. Once deployed, the rover measured about 65 centimeters (2 feet) long by 48 centimeters (1.5 feet) wide by 30 centimeters (1 foot) tall. By comparison, during the cruise to Mars, Sojourner was folded in its stowage space and measured only 18 centimeters (7 inches) tall.

The rover's maximum traveling speed on Mars was 1 centimeter per second (2 feet per minute). It was powered by a 0.25-square-meter (1.9-square-foot) solar array on its top surface. Non-rechargeable lithium thionol chloride D-cell-sized batteries provided limited stored power.

The six-wheel, rocker-bogie suspension system provided a great degree of stability and obstacle-crossing capability for crossing the uneven Martian surface. The aluminum wheels, which could move independently of each other, were 13 centimeters (5 inches) in diameter, with stainless steel tread and cleats for traction. Sojourner was able to scale boulders higher than 20 centimeters (about 8 inches).

The rover carried two finger-sized black-and-white cameras in front, a color camera in back, an alpha proton X-ray spectrometer (APXS) for determining the elemental composition of rocks and soil, and a set of experiments for testing material adherence and wheel abrasion. A laser system worked in conjunction with the two forward cameras to detect and avoid obstacles.

The robotic rover — capable of autonomous navigation and performance of tasks —communicated with Earth via the lander. Sojourner's control system was built around an Intel 80C85 computer processor, with a computing speed of 100,000 instructions per second and 500 kilobytes of random access memory mass storage.

Science Instruments

The payload of science instruments carried aboard Pathfinder included the lander's camera, the atmospheric structure instrument/meteorology package and the rover's alpha proton X-ray spectrometer.

❑ The lander's **Imager for Mars Pathfinder** (IMP) camera was a stereo imaging system with color capability provided by a set of selectable filters for each of the two camera channels. It was developed by a team led by the University of Arizona at Tucson, with contributions from Lockheed Martin Corp.; Max Planck Institute for Aeronomy, Katlenberg-Lindau, Germany; Technical University of Braunschweig, Germany; and the Orsted Laboratory, Niels Bohr Institute for Astronomy, University of Copenhagen, Denmark. The principal investigator was Dr. Peter Smith.

In addition to imaging the surface, the camera provided stereo images used to navigate the rover. A number of atmospheric investigations were also carried out using the imager. Aerosol opacity was measured periodically by imaging the Sun through two narrow-band filters. Dust particles in the atmosphere were characterized by observing Phobos, one of Mars' moons, at night, as well as the Sun during the day. Water vapor abundance was measured by imaging the Sun through filters in the water vapor absorption band and in the spectrally adjacent continuum.

A magnetic properties investigation was included as part of the imaging investigation. A set of magnets of different field strengths was mounted in a variety of locations around the lander. Images taken over the duration of the lander mission were used to determine the accumulation of magnetic species in the wind-blown dust. Multispectral images of these accumulations may be used to differentiate among likely magnetic minerals.

The imaging investigation also included the observation of wind direction and speed, using wind socks that were located at various heights on a 1-meter-tall (40-inch) mast. The wind socks were imaged repeatedly by the imager; orientations of the wind socks were measured in the images to determine the wind velocity at three different heights above the surface. This information was then used to estimate the aerodynamic roughness of the surface in the vicinity of the lander and to determine the variation in wind speed with height. Because the Viking landers had wind sensors at only one height, such a vertical wind profile has never been measured on Mars. This new knowledge will help to develop and modify theories for how dust and sand particles are lifted into the Martian atmosphere by winds, for example. Because erosion and deposition of wind-blown materials have constituted such an important geologic process on the surface of Mars, the results of the wind sock experiment will be of interest to geologists as well as atmospheric scientists.

❑ The **Atmospheric Structure Instrument and Meteorology Package** (ASI/MET) was an engineering subsystem that acquired atmospheric information during the descent of the lander through the Martian atmosphere and during the entire landed mission. Dr.

Alvin Seiff of San Jose State University, San Jose, CA, was the instrument definition team leader. Dr. John T. Schofield of JPL was team leader for the science team that used the data acquired by the package.

Data acquired during the entry and descent of the lander permitted reconstruction of profiles of atmospheric density, temperature and pressure from altitudes in excess of 120 kilometers (75 miles) from the surface.

The accelerometer portion of the atmospheric structure instrument was designed to measure accelerations over a wide variety of ranges from the micro-G accelerations experienced upon entering the atmosphere to the peak deceleration and landing events in the range of 30 to 50 G's.

The package also included several sensors on the lander to measure pressure, temperature and wind. They recorded weather at the landing site throughout the mission.

❑ The rover's **Alpha Proton X-ray Spectrometer** (APXS) was designed to determine the elements that make up the rocks and soil on Mars. It was a derivative of instruments flown on the Soviet Vega and Phobos missions and identical to the unit that flew on the Russian Mars '96 landers, which were lost shortly after launch. Thanks to the mobility provided by the Mars Pathfinder rover, the APXS not only took measurements of the Martian dust but, more importantly, permitted analysis of rocks in the landing area. The alpha and proton portions were provided by the Max Planck Institute for Chemistry, Mainz, Germany. The X-ray spectrometer portion was provided by the University of Chicago. Dr. Rudolph Rieder of the Max Planck Institute for Chemistry was principal investigator; co-investigators were Dr. Thanasis Economou of the University of Chicago and Dr. Heinrich Wanke of the Max Planck Institute for Chemistry.

The instrument was able to measure the amounts of all elements present (except hydrogen and helium) which make up more than about 1/10th of 1 percent of the mass of the sample rock or soil. The spectrometer worked by bombarding a rock or soil sample with alpha particles — charged particles equivalent to the nucleus of a helium atom, consisting of two protons and two neutrons. The sources of the particles were small pieces of the radioactive element curium-244 onboard the instrument. In some cases, the alpha particles interacted with the rock or soil sample by bouncing back; in other cases, they caused X rays or protons to be generated.

The "backscattered" alpha particles, X rays, and protons that made it back into the detectors of the instrument were counted, and their energies were measured. The number of particles counted at each energy level is related to the abundance of various elements in the rock or soil sample, and the energies are related to the types of elements present in the sample. A high-quality analysis requires about 10 hours of instrument operation while the rover is stationary and may be done at any time of day or night.

Major Science Results

❑ Chemical analyses returned by Mars Pathfinder indicate that some rocks at the landing site appear to be high in silica, suggesting differentiated parent materials. These rocks are distinct from the meteorites found on Earth that are thought to be of Martian origin.

❑ The identification of rounded pebbles and cobbles on the ground, and sockets and pebbles in some rocks, suggests conglomerates that formed in running water, during a warmer past in which liquid water was stable.

❑ Some rocks at the landing site appear grooved and fluted, suggesting abrasion by sand-sized particles. Dune-shaped deposits were also found in a trough behind the area of the landing site known as the Rock Garden, indicating the presence of sand.

❑ The soil chemistry of the landing site appears to be similar to that of the Viking 1 and 2 landing sites, suggesting that the soil may be a globally deposited unit.

❑ Radio tracking of Mars Pathfinder provided a precise measure of the lander's location and Mars' pole of rotation. This in turn suggested that the radius of the planet's central metallic core is greater than 800 miles (1,300 kilometers) but less than roughly 1,250 miles (2,000 kilometers).

❑ Airborne dust is magnetic with each particle about 3 microns in diameter. Interpretations suggest the magnetic mineral is maghemite, a very magnetic form of iron oxide, which may have been freeze-dried on the particles as a stain or cement. The iron may have been leached out of materials in the planet's crust by an active water cycle.

❑ Whirlwinds called dust devils were imaged and frequently measured by temperature, wind and pressure sensors. Observations suggested that these gusts are a mechanism for mixing dust into the atmosphere.

❑ Imaging revealed early morning water ice clouds in the lower atmosphere, which evaporate as the atmosphere warms.

❑ Abrupt temperature fluctuations were recorded in the morning, suggesting that the atmosphere is warmed by the planet's surface, with heat convected upwards in small eddies.

❑ The weather was similar to weather encountered by Viking 1; there were rapid pressure and temperature variations, downslope winds at night and light winds in general. Temperatures at the surface were about 18 F (10 C) warmer than those measured by Viking 1.

❑ The atmosphere was a light yellowish-brown color due to fine dust mixed in the lower atmosphere, as was seen by Viking. Particle size and shape estimates and the amount of water vapor in the atmosphere are also similar to Viking observations.

❑ Scientists were able to use Viking images at a scale generally greater than 1 kilometer (0.6 mile) per pixel, along with analysis of similar geography on Earth, to correctly predict a rocky plain safe for landing and roving with a variety of rocks deposited by catastrophic floods.

Project/Program Management

Mars Pathfinder was managed for NASA's Office of Space Science, Washington, D.C., by the Jet Propulsion Laboratory, a division of the California Institute of Technology.

At NASA Headquarters, Kenneth W. Ledbetter was program manager and Joseph Boyce was program scientist.

At JPL, the position of project manager was held successively by Anthony J. Spear and Brian K. Muirhead, who also served as flight system manager. Project scientist was Dr. Matthew Golombek. Richard A. Cook was mission operations manager, John B. Wellman was science and instruments manager, Dr. Jacob R. Matijevic was rover manager and Allan Sacks was ground system manager.

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