Chapter 5

Scientific Exploration of Mars

UNDERSTANDING MARS

The planets have fascinated humankind ever since observers first recognized that they had characteristic motions different from the stars. Astronomers in the ancient Mediterranean called them the wanderers because they appear to wander among the background of the stars. Because of its reddish color as seen by the naked eye, Mars drew attention. It has been the subject of scientific and fictional[3] interest for centuries.[4] In recent years, planetary scientists have developed increased interest in Mars, because Mars is the most Earthlike of the planets. “The study of Mars is [therefore] an essential basis for our understanding of the evolution of the Earth and the inner solar system.”[5]

Planetary exploration has been one of the National Aeronautics and Space Administration’s (NASA) primary goals ever since the U.S. civilian space program was started in 1958.[6] As the next planet from the Sun beyond Earth, and the subject of intense ground-based observations prior to the first satellite launch, Mars has received particular attention. After sending three Mariner spacecraft on Mars “flybys” in the 1960s,[7] NASA successfully inserted Mariner 9 into an orbit about Mars[8] on November 13, 1971. It was the first spacecraft to orbit another planet (box 5-A). For the first 2 months of the spacecraft’s stay in Mars’ orbit, the most severe Martian dust storms ever recorded obscured Mars surface features. After the storms subsided and the atmosphere cleared up, Mariner 9 was able to map the entire Martian surface with a surface resolution of 1 kilometer.[9]

Images from Mariner 9 revealed surface features far beyond what investigators had expected from the earlier flybys. The earlier spacecraft had by chance photographed the heavily cratered southern hemisphere of the planet, which looks more like the Moon than like Earth. These first closeup images of Mars gave scientists the false impression that Mars was a geologically “dead” planet, in which asteroid impacts provided the primary agent for altering its surface geology. Mariner 9 showed instead that Mars also had huge volcanoes, complex fault zones, and an enormous canyon some 2,800 miles long just south of the equator, named Vanes Marineris by the NASA spacecraft team.[10] Detailed examination of numerous channels and valleys suggests that

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[1] The term “planet” derives from the Greek word meaning to wander.

[2] Observations of Mars dominated the scientific interest of Percival Lowell, founder of Lowell Observatory. He popularized the incorrect notion that the surface of Mars was covered with canals, a claim first advanced by Giovanni Virginio Schiaparelli in 1877.

[3] For example, the interplanetary invaders of H.G. Wells’ 1897 novel *War of the Worlds* were supposed to have come from Mars. Early in this century, Edgar Rice Burroughs wrote an entire series of adventure novels set on Mars.

[4] See John Noble Wilford, *Mars Beckons* (New York, NY: Knopf, 1990), for a highly readable historical summary of the interest in Mars by Western civilization.

[5] National Research Council, Space Science Board Committee on Planetary and Lunar Exploration, *Strategy for Exploration of the Inner Planets: 1977-1987* (Washington, DC: National Academy of Sciences, 1978), p.43.

[6] The National Aeronautics and Space Act of 1958 was signed by President Dwight D. Eisenhower on July 29,1958, and became law on Oct. 1, 1958.

[7] Mariners 4, 6, and 7 successfully returned surface images and other data. Manner 3 failed before reaching the planet.

[8] NASA planned to send two identical spacecraft t. Mare) in part to provide redundancy in case one spacecraft failed. Placing the two spacecraft in different orbits would have allowed the two to provide a complete survey of the planet relatively quickly. However, the first spacecraft, Mariner 8, was lost when the Centaur stage on the Atlas-Centaur launch vehicle malfunctioned shortly after liftoff.

[9] This implies that objects equal to or greater than about 1 kilometer diameter could be distinguished on the images. In practice, the ability to resolve surface features also depends on other factors, e.g., the viewing conditions, surface contrast, and processing capabilities.

[10] Edward Clinton Ezell and Linda Neumann Ezell, *On Mare: Exploration of the Red Planet 1958-1978* (Washington, DC: National Aeronautics and Space Administration, 1984), pp. 288-297.

Box 5-A – Findings of Mariner 9

Mariner 9 reached Mars in late 1971 and became the first spacecraft to orbit Mars. During the first several weeks of its orbital stay, Mariner 9 encountered a dust storm that completely obscured the surface. Over time, however, the spacecraft provided a complete record of the surface features on Mars at resolutions of 1 to 3 kilometers, which allowed NASA and the U.S. Geological Survey to compile a topographic map of the planet. About 2 percent of the surface in specific areas was imaged at 100- to 300-meters resolution. Mariner 9 discovered massive volcanic mountains, deep channels that reveal evidence of fluid flow in the distant past, and layered sediments in the polar regions. Mariner 9 revealed a hemispherical global dichotomy (half the planet has craters dating from the early history of the planet, while the other half has few craters).

observations of the cloud systems revealed westerly winds in winter and easterly winds in the summer, weather fronts, lee wave clouds, ice fogs, and other atmospheric meteorological phenomena. Mariner 9 observations led to the realization that Mars has experienced both secular and periodic (cyclic) climate changes.

An infrared interferometer spectrometer evaluated the extremely small amount of atmospheric water vapor, and demonstrated that it exhibits strong seasonal variations. The Mariner 9 ultraviolet spectrometer showed that the amount of ozone in the atmosphere, which is found only in the polar regions, vanes with the seasons. It is greatest during the winter, when it reaches some 2 percent of the ozone in Earth's atmosphere, and falls to zero in the Mars summer. The virtual lack of ozone allows ultraviolet light to reach the Martian surface and destroy any organic compounds present in the soil.

SOURCE: W.K. Hartmann and O. Rasper, *The Discoveries of Mariner 9*, NASA SP337 (Washington, DC: U.S. Government Printing Office, 1974); Michael C. Malin, Arizona State University, 1991.

flowing water was once common on Mars.[11] Some scientists speculate that before this water disappeared from the surface, it may have made life possible.[12]

The scientific arguments for finding evidence of extinct or existing life on Mars had been noted as early as 1959.[13] However, only after the Mariner 9 images were available did scientists have direct evidence of the past existence of water that might have supported life. This finding lent additional support to those scientists interested in searching for evidence of extinct or present life on Mars and spurred development of life-seeking instruments on the Mars Viking spacecraft that were then in the design stages.

The Viking program launched two spacecraft toward Mars in 1975.[14] They were carried into orbit by two Titan III launch vehicles on August 20, 1975 and September 9, 1975, respectively. After searching the surface with high-resolution cameras to select safe landing sites, the Viking craft landed on the surface in 1976, photographed the surroundings, analyzed the soil, and tested for evidence of life (box 5-B). The test for life on Mars was inconclusive, although nearly all scientists agree that it showed that no living organisms existed at the Viking sites.[15] These tests, however, made the unexpected discovery that Martian soil in the vicinity of Viking landers is highly reactive

[11] Michael H. Carr, "Mars: A Water-rich Planet," *Icarus*, vol. 68, 1986, pp. 187-216; "Water on Mars," Nature, vol. 326, 1987, pp. 30-35.

[12] Christopher P. McKay and Carol R. Stoker, "The Early Environment and Its Evolution on Mars: Implications for Life," Reviews *of Geophysics*, vol. 27, No. 2, 1989, pp. 189214.

[13] See the summary history of the early search for life on Mars in Ezell and Ezell, op. cit., footnote 10, ch. 3.

[14] Orginally planned for launch in 1973, the Viking launches were slipped to 1975 as a result of a severe budget squeeze.

[15] This conclusion is based not only on the biology experiments but other experiments that attempted to detect organic material in the soil. The conclusion that life does not exist at the Viking sites cannot be extended to other sites on the planet where conditions more conducive to life, e.g., hydrothermal vents, might exist.

Box 5-B – Findings From the Viking Mars Landers

NASA sent two Viking spacecraft to Mars in 1975, which reached Mars orbit in 1976 after nearly a year in transit. Upon reaching Mars orbit, the orbiters surveyed the surface at high resolution to select the best landing sites for the Viking 1 and 2 landers. Both landers separated from their parent craft and executed soft landings at different sites in July and September, 1976, respectively. Viking 1 landed at a site on Chryse Planitia at 22.3 North latitude, 48.0 degrees longitude. Viking 2 landed at the same longitude on Utopia Planitia 25.4 degrees North of Viking 1. The orbiters then began to relay visual images and other data from the landers back to Earth. Although both orbiters and landers were expected to complete their missions within a few months, they lasted far beyond their design lifetimes and continued to transmit data to Earth for several years.

The Viking landers took the first closeup photographs of the surface and transmitted panoramic views of the rocky Martian landscape. They also documented the weather throughout their lifetime on the surface, finding that atmospheric temperatures ranged from a low of –120 degrees Celsius (about the freezing temperature of carbon dioxide, the major constituent of Mars' atmosphere) to a high of -14 degrees Celsius. The landers experienced dust storms and measured the daily barometric pressure (about 1 percent of the barometric pressure on Earth).

The Viking orbiters determined that the north polar ice cap, which lasts through the northern summer, is water ice. They also mapped about 97 percent of the surface. They further showed that the climate in the northern and southern hemispheres differs greatly, as a result of the summer dust storms that originate in the south.

Although a search for life on Mars was the primary experiment for the landers, neither found evidence of life or of organic compounds in the soil. Mars appears to be self-sterilizing. At present, the combination of ultraviolet light that saturates the surface, and the extreme dryness of the soil prevent the formation of living organisms

Orbiter 2 ended its mission on July 25, 1978; Orbiter 1 reached the end of its useful life on August 7, 1980. NASA received the last data from Lander 2 on April 11, 1980 and from Lander 1 on November 11, 1982.

SOURCE: G.A. Soffen, "The Viking Project," *Journal of Geophysical Reviews, vol. 82,* pp. 3959-3970; NASA/ Jet Propulsion Laboratory Fact Sheet on Viking.

Photo credit: National Aeronautics and Space Administration

First panoramic view by Viking 1 from Mars, showing a rook-strewn surface. The blurred spacecraft component near left center of the left-hand image is the housing for the Viking sample arm, which had not yet been deployed. The spacecraft component in the center of the right-hand image are color charts for lander camera calibration.

chemically, favoring rapid destruction of organic molecules.[16]

Although those who had hoped to find evidence of life on Mars were disappointed in the Viking findings, the evidence of water in an earlier stage of Mars evolution continues to intrigue scientists, both because of what it means for the geological and climatological evolution of Mars, and for evidence concerning the origins of life. In addition, the observations of Mariner 9 and Viking raised a broad variety of questions concerning the formation and evolution of the planet.[17]

Viking I and II were the last U.S. spacecraft to visit Mars. Since the mid-1970s, NASA has pursued investigations of the massive planets beyond Mars[18] and the mapping of Venus by the Magellan spacecraft.[19] These investigations have radically changed our understanding of the surfaces and atmospheres of these planets.

CURRENT SCIENTIFIC OBJECTIVES

Well before the President announced his proposal for human exploration of the Moon and Mars, the scientific community had spent years studying the next steps in the detailed examination of the planets and concluded that because of its proximity and similarity to Earth, Mars should receive special attention. The Committee on Planetary and Lunar Exploration (COMPLEX) of the National Academy of Sciences Space Science Board in 1978 recommended that "the triad of terrestrial planets, Earth, Mars, and Venus, should receive the major focus in exploration of the inner solar system for the next decade. This priority has not changed over time. The ultimate goal in this exploration is to understand the present state and evolution of terrestrial planets with atmospheres. The comparative planetology of these bodies is a key to the understanding of the formation of the Earth, its atmosphere and oceans, and the physical and chemical conditions that lead to the origin and evolution of life."[20] The NASA Advisory Council's Solar System Exploration Committee (SSEC) in 1983 also recommended that a detailed study of Mars should receive priority.[21] These studies led to a proposal for a spacecraft to carry out a detailed study of Mars' atmosphere and surface from a polar orbit.[22] The resulting spacecraft, which is called Mars Observer,[23] is scheduled for launch in September 1992 aboard a Titan III launcher. The SSEC in 1988 reaffirmed the emphasis on Mars by recommending a Mars sample return mission before the end of the century.[24]

The geological, hydrologic, and atmospheric histories of Mars are long, and apparently complicated. Elucidating these scientific stories will require an extended exploration program. Al-

[16]Norman H. Horowitz, "The Biological Question of Mars;" and Gilbert V. Levin and Patricia A. Straat, "A Reappraisal of Life on Mars;" in Duke B. Reiber, *The NASA Mars Conference, vol. 71* in *the American Astronautical Society Science and Technology Series* (San Diego: Univelt, 1988), pp. 177-185; 186-208.

[17]See, for example, the extensive set of issues in Duke B. Reiber, op. cit., footnote 16.

[18]The so-called Grand Tour of the outer planets by the Voyager spacecraft resulted in exciting new findings about the planets Jupiter, Saturn, Uranus, and Neptune, their rings and their moons.

[19]NASA launched Magellan toward Venus on the space shuttle *Atlantis* in May 1989. It arrived at Venus in August 1990. The Magellan spacecraft has returned highly detailed radar images of the cloud-covered Venusian surface using a synthetic aperature radar.

[20]National Research Council, Space Science Board Committee on Planetary and Lunar Exploration, *Strategy for Exploration of the Inner Planets: 1977-1987* (Washington, DC: National Academy of Sciences, 1978), p. 34.

[21]NASA Advisory Council Solar System Exploration Committee, *Planetary Exploration Through Year 2000: Part One: A Core Program* (Washington, DC: National Aeronautics and Space Administration, 1983).

[22]A spacecraft in polar orbit periodically crosses the North and South Poles as the planet rotates beneath. By appropriately matching the spacecraft's optics with its altitude, it is possible to image the entire planet in a specified number of orbits, just as the polar-orbiting meteorological satellites image Earth.

[23]It was Originally termed the Mars Geoscience and Climatology Orbiter.

[24]NASA Advisory Council, *Planetary Exploration Through Year 2000: Scientific Rationale* (Washington, DC: U.S. Government Printing Office, 1988), pp. 83-85.

though our current understanding of Mars suggests a number of intriguing questions, future research on the planet, both from orbit and by in situ studies is likely to provide many surprises and lead to whole new lines of questioning. Current questions of scientific interest concerning Mars can be summarized under four broad categories:[25]

1. ***The formation of Mars*** – Insights into the formation of Mars will be derived from chemical and physical information revealed by analyzing surface materials and by estimating the thickness of the crust, mantle, and core, and determining their densities. Better understanding of the conditions that existed during the formation of Mars would assist scientists in understanding the formation of the entire inner solar system, including the Moon and Earth. Because many of the data required for understanding the formation and the evolution of a planet are the same, and acquired by the same instruments, specific data requirements are discussed in the next paragraphs on the evolution of Mars.

2. The geologic ***evolution of Mars*** – From its formation to the present, Mars has undergone many changes in its surface structure and composition. Like its sister planets, Venus and Earth (and the Moon), Mars has experienced continuous bombardment by meteoroids, asteroids, and comets. Also, like Venus and Earth, it has had a long and complicated history of volcanic activity. In addition, the surface has been extensively modified by wind and water action. Despite these similarities, Earth and Mars are very different. Clues as to why the two planets evolved so differently will be found in the morphology of the surface, in the composition, lithology, and distribution of the surface materials, and in the structure of the planet's interior.

Estimates of composition, physical structure, and distribution of surface materials can be acquired by remote sensing from orbit. The morphology of the Martian surface is now known roughly at a resolution of 200 meters. Mars Observer will photograph small areas at a resolution of 2 meters. However, detailed studies of chemical composition, mineralogy, and ages of surface materials would require relatively sophisticated, mobile[26] analytical stations on Mars[27] and the return of samples to Earth. Samples and surface measurements are required to calibrate the orbital remote sensing data. Samples are also required on Earth because many of the crucial measurements, e.g., determination of ages, isotopic ratios, and percentages of trace elements, can be done only in the most sophisticated laboratories here on Earth. Moreover, scientists cannot predict in advance what measurements would be most important. Having samples available on Earth allows scientists to return repeatedly to the samples with different instruments and make appropriate measurements as their understanding evolves.

Determination of the gravity field and topography, coupled with seismic data, and other types of depth sounding, will allow scientists to determine the internal density of Mars and how it changes with depth and surface position. This is crucial for determining not only the gross structure of the planet, such as the thickness of the crust and how it varies with location, but also local structures such as ice deposits.

[25] This discussion derived primarily from Mars Science Working Group, *A Strategy for the Scientific Exploration of Mars*, Draft, September 1990.

[26] Or a network of stations.

[27] These instruments would be much more sophisticated than the instruments aboard the Viking spacecraft, particularly in sample acquisition and handling.

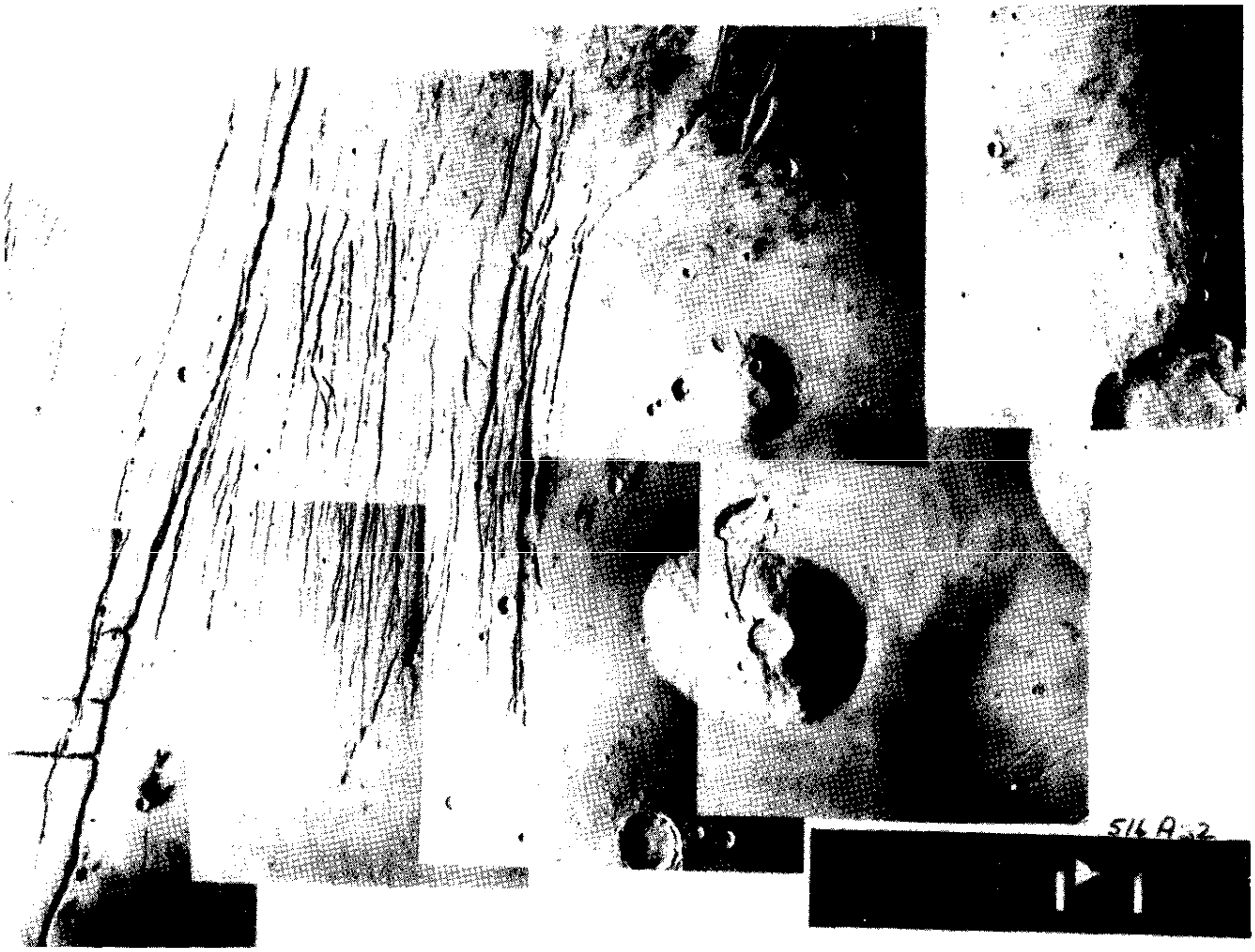


Photo credit: National Aeronautics and Space Administration

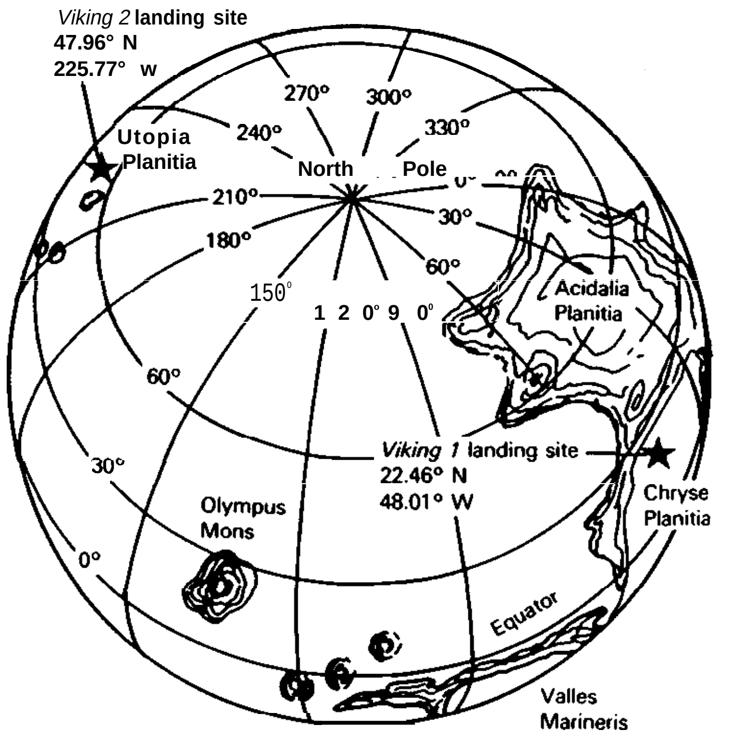
Mosaic of pictures from Viking Orbiter 1 shows the northeast margin of the Tharsis Ridge, the youngest volcanic region of Mars. An area of intense crustal faulting can be seen at left, and a cluster of volcanic mountains with Prominent summit caideras is visible at right. The volcanoes range from 65 kilometers to 400 kilometers across.

3. ***Climate change –*** Observations of the Martian surface by Mariner 9 and by the Viking spacecraft, which show numerous channels and dry river valleys apparently caused by water erosion, suggest strongly that the Martian climate has changed radically over time. Liquid water is unstable everywhere on the Martian surface under present climatic conditions. It will either freeze or sublime. Determination of the amount of volatile compounds in the surface[28] soil and rocks would help determine whether the climate did indeed change, or whether another, unknown mechanism is responsible. Spectrometers aboard Mars Observer will provide a global assessment of the inventory of surface volatiles, but detailed studies from the surface would allow scientists to assess whether water in some form[29] might still exist as ice below the surface.

Previous data on the Martian atmosphere has enabled atmospheric scientists to create atmospheric circulation models in order to understand daily and seasonal variations of the atmosphere. Additional seasonal data

[28] Revealed, e.g., by the amount of ice, hydrated and carbonated minerals, and sulfur, phosphorus, and nitrogen, in the surface soil and rocks.
[29] For example, in the form of ice, or bound in minerals.

Figure 5-1 –A View From the Martian North Pole Shows the Location of the Two Viking Sites



SOURCE: National Aeronautics and Space Administration

acquired both from orbit and on the surface would enable scientists to begin to understand the mechanisms that cause onset of dust storms, and other large-scale atmospheric phenomena.

Scientists have postulated a much thicker atmosphere of carbon dioxide and nitrogen for early Mars. By closely examining sites of early meteoritic bombardment, which may retain important clues about the atmosphere of early Mars, scientists hope to test this hypothesis. High concentrations of carbonates and nitrates in the soil would suggest that the planet held a thicker atmosphere containing carbon dioxide and nitrogen. Carbonates would also confirm evidence of liquid water earlier in Mars' evolution.

4. ***Search for life – The*** question of whether life existed on Mars at some time in the past has drawn the attention of both scientists and laymen for centuries. Liquid water is essential to life as we know it. The apparent presence of lakes and rivers on Mars at one time implies warmer climates and suggests that conditions necessary to the formation of life might have existed at some time in the past. Did life start and then die out as conditions on the planet changed? The Viking results indicate that life is very unlikely today. Not only was no life detected, but also no organic molecules. Apparently the soil oxidizes and destroys complex organic molecules. However, the prospects for life in the distant past, when water was abundant at the surface, are different. Indeed, past condition on Mars may have been similar to those on Earth when life started here. Biologists conclude, therefore, that the most promising place to look for past life is in ancient sediments that formed when clima-

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atic conditions might have been more favorable.[30] Because of the possibility of past life, some scientists hypothesize that life might have survived to the present in specialized niches, e.g., volcanic hydrothermal vents, and that the Viking spacecraft looked in the wrong places.[31] They believe that more definitive life-seeking experiments need to be done before the planet is irretrievably contaminated with terrestrial organisms.

Photo credit: National Aeronautics and Space Administration

This mosaic of the Mangala Vallis region of Mars was taken by Viking Orbiter 1. The central region of the mosaic contains vast channel systems that appear to have been carved by running water in the distant past. Numerous impact craters also appear in the image.

PLANNED AND POTENTIAL ROBOTICS MISSIONS

Scientists have proposed a number of observations of Mars from a distance or missions to the surface in order to collect scientific data on the planet. In addition to identifying new areas of inquiry, data acquired from orbit about Mars would assist in guiding the selection and design of future Mars investigations, including both robotic and human missions. However, only in situ, local measurements can tackle some questions. For example, the investigation of seismic activity, which allows scientists to determine elements of its internal structure and how it changes over time, would require instruments on the planet. Detailed investigations concerning the composition and age of Martian material would require the return of samples for study on Earth. "Thus, the global and in situ studies of the planet and the return of Martian material are complementary components of an overall program of investigation; each of the components is absolutely necessary."[32] A recent examination by the Mars Science Working Group reiterates the importance of this three-pronged approach — global, in situ, and sample return studies.[33] Missions either in preparation or proposed are summarized below:

- ***Observations by Hubble — The*** wide field and planetary camera on the Hubble Space Telescope is now being used to make long-term observations of Mars from Earth orbit, providing low-resolution, but useful, synoptic data of the atmosphere and surface of Mars throughout the Martian year.[34] Although the wide field and planetary cameras are limited in resolution because of the errors in figuring the Hubble's primary mirror, these data will provide an important

[30] Christopher P. McKay and Carol R. Stoker, "The Early Environment and Its Evolution on Mars: Implications for Life," Reviews *of Geophysics, vol.* 27, No. 2, 1989, pp. 189-214.

[31] R.A. Wharton, Jr., C.P. McKay, R.L. Mancinelli, and G.M. Simmons, Jr., "Early Martian Environments: the Antarctic and Other Terrestrial Analogs," *Advances in Space Research,* vol. 9, 1989, No. 6, pp. (6)147-(6)153.

[32] National Research Council, Space Science Board Committee on Planetary and Lunar Exploration, op. cit., footnote 5, p. 49.

[33] Mars Science Working Group, *A Strategy for the Scientific Exploration of Mars,* Draft, September 1990.

[34] NASA press release, Mar. 18, 1991.

baseline for later observations from Mars polar orbit.

- ***Mars Observer —*** Mars Observer can be expected to provide data relating to many scientific questions about Mars (box 5-C). After it arrives in the vicinity of Mars in 1993, it will go into a Mars polar orbit, which will allow the Mars Observer Camera (MOC) to image the entire planet.[35] MOC will be capable of viewing locations anywhere on the planet, at resolutions between 300 meters and several kilometers, within any given 24-hour period. It will be able to acquire an image of the entire planet at any resolution between 2 and 7.5 kilometers per picture element in a single 24-hour period, limited only by the data rate returned from the spacecraft. MOC will be able to image the entire planet at a much higher 300 meters per picture element in 7 to 28 days, depending on the data rate.

  MOC is presently scheduled to cover about 0.5 percent of the planet at resolutions between 1.5 and 12.0 meters per picture element, using its high resolution optics. During an extended mission (should one be authorized), it would be possible for the MOC to map the entire planet at 12 meters per picture element in about 600 days, again depending on the possible data rate and the allocation of other spacecraft resources. The ability of an orbiting spacecraft to make observations of deep scientific importance of a planetary surface are exemplified by the results from the Venus Magellan spacecraft[36] and the Viking orbiters.[37]

- ***Mars*** **'94** – The Soviet Union currently plans to send an orbiter to Mars in 1994. As it approaches Mars, the orbiter will deploy two small meteorology stations and two dartlike penetrators that will drop to the surface. The orbiters will make a variety of remote sensing observations complementary to those on Mars Observer. The penetrators will analyze the soils and make seismic measurements. In 1996 or later, the Soviet Union plans to send another spacecraft, which will deploy a balloon contributed by France, and a small rover, designed and built by Soviet engineers. The balloon is designed to inflate during the day and float above the planet. At night, cooling temperatures will cause it to drop down to the surface where an attached instrument package can gather surface data.

- ***Mars Environmental Survey (MESUR) – The*** proposed MESUR mission[38] arises out of an interest in designing a flexible, relatively inexpensive means of providing in situ data on weather, seismic activity, and chemical and physical properties of the Martian soil at various locations on the planet. It would make use of Delta II launch vehicles to send several Martian probes every 2 years, potentially starting in 1998. The probes would be designed as small, spin stabilized, free-flyer spacecraft, based on technology developed primarily for Pioneer Venus and Mars Viking spacecraft. As conceived, four MESUR probes could be launched on each Delta II launch vehicle, and would separate shortly after release from the launch vehicle for the long journey to Mars. When they arrived at Mars, they would use a parachute and airbag to land on the surface, where each would deploy an antenna to communicate with a communications relay orbiter sent separately. It would also be possible to transmit data di-

[35] The prospect that Mars Observer would still function after a Mars year in orbit is high. Therefore, the spacecraft could be expected to continue to collect data after completing its primary mission. Processing and storing the mass of data from these observations will be a difficult and complex task.

[36] Richard A. Kerr, "Magellan Paints a Portrait of Venus," Science, Vol. 251, 1991, pp. 1026-1027.

[37] G. A. Soffen, "The Viking project," *Journal of Geophysical Reviews,* vol. 82, pp. 3959-3970.

[38] Scott Hubbard and Robert Haberle, *The Mars Environmental Survey (MESUR): Status Report*, NASA Ames Research Center, Feb. 25,1991.

Box 5-C — Mars Observer

The Mars Observer spacecraft will provide detailed information about the surface of Mars and its atmosphere. Originally termed the Mars Geoscience and Climatology Orbiter, the concept for Mars Observer arose from study of the items of greatest scientific interest on Mars. NASA plans to launch Mars Observer toward Mars in September 1992 aboard a Titan III launch vehicle. It should arrive in August 1993, where it will remain in a “parking orbit” until December, when it is lowered into a circular mapping orbit 380 kilometers above the surface. It will then begin systematic observations of Mars at a variety of surface resolutions. A polar orbit will allow a suite of instruments aboard the spacecraft to collect data over the entire surface of the planet during its planned 687-day (one Martian year) mission lifetime.

Scientific objectives:

- determine elemental composition and mineralogical character of the Martian surface;
- measure the global surface topography;
- measure the gravity field;
- measure the magnetic field and establish its nature; and
- develop a synoptic database of climatological conditions (alterations of atmospheric dust, volatile materials) throughout a seasonal cycle.

Planners expect this mission to provide data that would allow planetary scientists to characterize Mars as it currently exists and create the framework for investigating its past. The data will lead to abetter understanding of the geological and climatological history of Mars and the evolution of its interior and surface. It will also give planetary scientists the necessary data for comparing Mars with Venus and Earth.

Mars Observer instrumentation:

Instrument	*Scientific objectives*
Gamma-Ray Spectrometer and Neutron Detector	Determine elemental composition of Mars surface.
Mars Observer Camera (optical wavelengths; 7.5 km, 480 m, and 1.4 m surface resolution)	Obtain daily global synoptic views of Martian clouds and surface; monitor surface and atmospheric features at moderate resolution; examine surface areas of interest at high resolution.
Thermal Emission Spectrometer (Michelson interferometer operating at infrared wavelengths)	Determine and map composition of surface features (minerals, rocks, and ice); study atmospheric dust; measure thermophysical properties of surface; determine atmospheric characteristics.
Pressure Modulator Infrared Radiometer	Map thermal structure of atmosphere in three dimensions over time; map atmospheric dust and condensates; map seasonal variations of atmospheric pressure and vertical distribution of water vapor; monitor polar radiation balance.
Mars Observer Laser Altimeter	Provide a global topographic grid to precision of 30 meters; measure selected areas to precision of 2 meters.

Continued on next page

Box 5-C — Mars Observer- Continued

Instrument	*Scientific objectives*
Spacecraft Radio Subsystem	Use radio system to determine atmospheric properties; characterize small-scale structure of atmosphere and ionosphere; develop a global, high-resolution model of Mars gravitational field; determine both local and broad-scale density-structure and stress state of Martian crust and upper mantle.
Magnetometer and Electron Reflectometer	Establish nature of Mars magnetic field; map Martian crustal remnant field; characterize solar wind/Mars plasma interaction.
Mars Balloon Relay	Use buffer memory of Mars Observer Camera to relay data from Soviet/French balloons expected to be deployed over Mars in late 1995 (Mars '94 spaceprobe).

Operations and Data Analysis

Mars Observer will generate many millions of bytes of data per day. The NASA Deep Space Network will gather the spacecraft data and transmit them to the Jet Propulsion Laboratory (JPL) Space Flight Operations Center in Pasadena, California. However, the various science teams supporting the mission will be located throughout the United States and the world. They will be connected electronically to JPL. Mission data will be stored in a project database.

SOURCE: A.L. Albee and D.F. Palluconi, "Mars Observer's Global Mapping Mission," *Eos*, vol. 71, No. 39, pp. 1099,1107, Sept. 25, 1990.

rect to Earth at a very slow rate, should communications with a relay orbiter fail.

A network of perhaps 20 instrumented landers would enable two scientific approaches not possible by other means: 1) simultaneous measurements at many widely separated sites for global seismic and meteorological measurements; 2) a variety of measurements at diverse and widely separated surface sites, including surface chemistry and highresolution imaging. The network approach would also allow mission managers to keep the funding profile relatively flat over several years, which has programmatic advantages.

Because instruments would be located at a number of sites, the MESUR experiment as a whole would be less prone to failure. Even if several units failed, the remaining units would still provide useful information: Because it could use existing launch vehicles it would require no new launch system. Because the project would extend over several Martian launch windows, information obtained from the preceding mission could be used to enhance selection of the following study sites. In addition, if funding permitted, the various subsystems could be improved, or altered over time to gather additional data.

- ***Rover*** **—** A rover, or collection of small rovers,[39] on the surface of Mars could execute a variety of scientific tasks, from simple observation to sample collection and analysis. Instruments mounted on a rover could, for example, analyze the Martian soil, which

[39] See, e.g., David P. Miller, "Mini-Rovers for Mars Exploration," Proceedings *of the Vision-21 Symposium, Cleveland,* OH, April 1990.

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might be toxic to humans.[40] Rovers could also be used in characterizing and selecting sites for a possible visit by human crews[41] and, as noted earlier, they could provide support to human crews on the surface.

With funding from NASA, the Jet Propulsion Laboratory has studied rover technologies for over two decades and has produced a six-wheeled rover,[42] and the Field Robotics Laboratory of Carnegie Mellon University has demonstrated a six-legged "Ambler,"[43] both of which can navigate across rugged terrain semiautonomously. The Massachusetts Institute of Technology Artificial Intelligence Laboratory has explored the use of minirovers for exploration.[44] The design and cost of an actual rover mission would depend on the ability of robotics engineers to improve the rover's ability to navigate autonomously,[45] and reduce the size and weight of rovers to make them capable of being launched on existing launch vehicles and deployed on the surface with existing technology.

- ***Sample return –*** Scientists who study Mars express a high level of unanimity on the importance of returning samples from the surface of Mars.[46] They note that the samples returned from the Moon have transformed our scientific understanding of the formation of the Moon and its subsequent evolution. Although it is possible to design and develop instruments to carry out limited experiments on the surface of Mars, returning samples to Earth for laboratory analysis is far more productive. First, it is difficult to design robotic in-situ experiments that would be flexible enough to take into account surprises found in Mars surface material.

Returning samples to Earth allows them to be examined by hundreds of investigators using a wide variety of scientific techniques. Samples are a permanent acquisition and can be used over a long period to answer questions that arise as we learn more about the geology of Mars. Radioactive age dating, for example, is of fundamental importance and can only be done in a laboratory with returned samples.

The experience of examining the lunar samples has demonstrated that scientific techniques have improved and evolved over time, allowing investigators to answer questions of the lunar samples that would have been unanswerable 20 years ago. Some powerful techniques, e.g., ion-probe microanalysis, and several mass-spectrometric techniques for determining ages of samples, did not even exist 20 years ago. Mars is much more complicated than the Moon, geologically, and will require more extensive study.

To be most effective in understanding the geology of Mars and the evolution of the planet, a sample return mission would have to gather samples from several locations. It should also gather both surface and subsurface rocks, as the surface soils are suspected to be quite different in composition and chemistry from the rocks.

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40 The high reactivity of Martian soil might endanger human life if breathed, even though human explorers will be encased in spacesuits. The probability is high, for example, that fine Martian dust could find its way into habitation areas. Hence, its properties should be better understood.

41 Donna S. Pivirotto, "Site Characterization Rover Missions," presented at the American Institute of Aeronautics and Astronautics Space Programs and Technologies Conference and Exhibit, Huntsville, AL, Sept. 25-27, 1990.

42 Jet Propulsion Laboratory, *NASA Planetary Rover Program, JPL 1990 Annual Technical Report* (Pasadena, CA: Jet propulsion Laboratory, Jan. 15, 1991), p. 5.

43 Eric Krotkov, John Bares, Martial Hebert, Takeo Kanade, Tom Mitchell, Reid Simmons, and William Whittaker, "Ambler: A Legged planetary Rover," *1990 Annual Research Review,* the Robotics Insitute, Carnegie Mellon University, pp. 11-23, 1991.

44 C.M. Angle and R.A. Brooks, "Small Planetary Rovers," MIT Artificial Intelligence Laboratory, Cambridge, MA, Apr. 27, 1990.

45 Autonomy costs more, but is likely t. make it possible to operate a rover on the surface of Mars despite communications delays Of up to 40 minutes.

46 James L. Gooding, Michael H. Carr, and Christopher P. McKay, "The Case for Planetary Sample Return Missions: 2. History of Mars," *Eos,* vol. 70, No. 31, Aug. 1,1989, pp. 745, 754-5; Mars Science Working Group, *A Strategy for the Scientific Exploration of Mars,* Draft, September 1990.