



Epilogue

Virtually all we do in space is but a prelude to manned exploration and habitation of Mars (Photo 63). Nearly every study of our future space activities agrees that Mars is the ultimate goal. The reasons for this are simple—of all the planets and moons that orbit our sun, Mars is the most like Earth. It has the volatiles that are lacking in the Moon. Its position in the solar system results in surface temperatures not much colder than those on some portions of the Earth. The thin atmosphere diffuses light, helps even out thermal anomalies, and provides a source of water. The polar caps hold great reserves of water, and similar resources may be present in the shallow subsurface of lower latitudes. Like the Earth, Mars has had a long and active geologic history, providing a variety of processes that might concentrate elements and minerals in usable resource deposits.

Unmanned exploration of Mars already has resulted in a large body of data about the planet.⁴⁴ The United States has explored Mars with eight spacecraft, including three fly-bys, two orbiters, and two landers. The Russians have sent a number of probes to Mars in the past and have announced an aggressive program for

⁴⁴For details on Mars' environment, see "Scientific Results of Viking Project," *Journal of Geophysical Research*, vol. 82 (1977), 3959-4681; *Journal of Geophysical Research*, vol. 84 (1979), 7909-8544; and *Journal of Geophysical Research*, vol. 87 (1982), 9715-10,306.

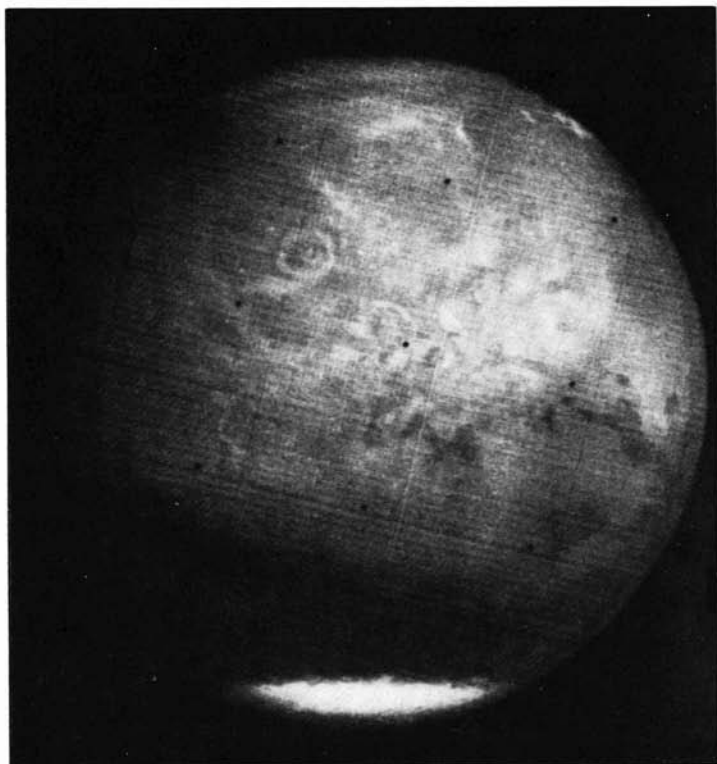


Photo 63. Image of Mars taken by the Mariner 7 spacecraft at far encounter, approximately 471,750 kilometers. North is at the top. The southern polar cap is distinct, as are many light clouds in the central latitudes. The ring-shaped structure at the upper left is the giant volcano Olympus Mons (see Photo 66). (Courtesy of NASA Jet Propulsion Laboratory)

future Mars exploration. We already know more about Mars than we did about the Moon when the United States committed to the lunar program. Let us consider the attractive features of Mars.

Atmosphere: Mars has a dynamic, thin atmosphere composed chiefly of carbon dioxide (about 95 percent), nitrogen (about 3 percent), argon (about 1.5 percent), with minor amounts of oxygen, carbon monoxide, and water vapor and trace amounts of neon, krypton, xenon, and ozone.⁴⁵ The average total atmospheric pressure over the planet is approximately six millibars. Of particular interest is the water vapor, which comprises about 0.03 percent of the atmosphere but is seasonally variable, meaning that modest amounts of water can be extracted from the atmosphere everywhere on the surface of the planet. Also, the density of the atmosphere is adequate for aerobraking of spacecraft arriving at Mars, such that missions from Earth can conserve fuel and total launch weight. The density of the atmosphere is sufficient to protect surface explorers and equipment from micrometeorites and larger incoming meteoroids of as much as several hundred grams. The easy availability of carbon dioxide and water makes agricultural activities relatively simple. Mars' atmosphere is dynamic and generates clouds, including convective clouds, wave clouds, orographic clouds, and fogs. Frosts commonly form on its surface at night. Martian clouds mostly are composed of water ice, but at high altitudes and in the polar regions, temperatures can be cold enough to produce frozen carbon dioxide.

Winds are a common occurrence in the Martian atmosphere. The maximum wind velocity measured by the Viking landers was only 16 meters per second, although winds as much as 100 meters per second have been inferred from measurements of cloud movements. Dunes and other wind erosion and deposition features are present on the surface.

Surface Temperatures: Our best measurements of surface tem-

⁴⁵T. K. Owen, D. R. Rushneck, J. E. Biller, D. W. Howarth, and A. L. Lafleur, "The Composition of the Atmosphere at the Surface of Mars," *Journal of Geophysical Research*, vol. 82 (1977), 4635-4639.

peratures come from the Viking landers, which found a mean summer temperature of about -60 degrees Centigrade at both landing sites, with a diurnal range of about 50 degrees. During winter at the Viking 2 landing site, however, the temperature reached -120 degrees Centigrade, cold enough to condense carbon dioxide. Compare these temperatures with the Earth's South Pole, which has a mean annual temperature of about -50 degrees Centigrade, and in August 1960 recorded a low temperature of -88.3 degrees Centigrade. However, it has been calculated that on the Martian equator on a midsummer day, temperatures may reach 20 degrees Centigrade.

Polar Caps and Permafrost: Due to the eccentricity of Mars' orbit, the southern polar cap is, at maximum extent, much larger than the northern polar cap. The caps are composed mostly of water ice with a minor amount of carbon dioxide that vaporizes quickly during the spring. Thus, the summer caps are composed almost entirely of water ice, which is stable at much higher temperatures than the carbon dioxide (Photo 64). It has been estimated that an amount of water equivalent to a layer of ice 80 to 160 meters thick

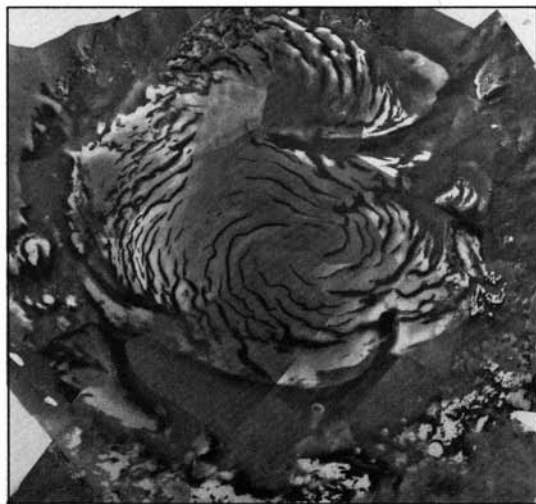


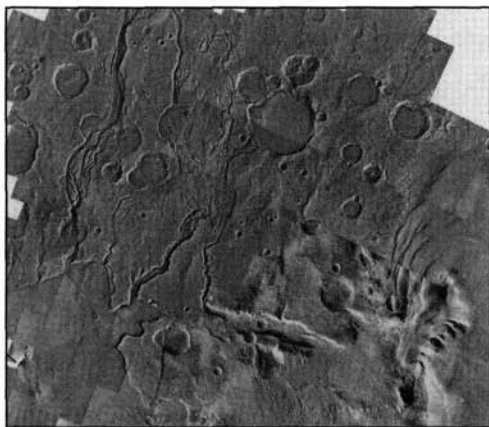
Photo 64. Viking Orbiter image mosaic of Mars' northern polar cap. (Courtesy of U.S. Geological Survey, Branch of Astrogeology)

covering the whole planet has been outgassed by Mars.⁴⁶ Many researchers believe the Martian regolith, the near-surface fragmental layer of the planet, may contain very large quantities of permafrost, based on similarities in patterned ground and other features common to cold areas on Earth, although this remains to be demonstrated by direct measurement. Many erosional features on the surface of Mars appear to be the products of running water (Photo 65); hence, there may also be much water bound in hydrous minerals in the Martian regolith. With the data already in hand, a shortage of water ice and water vapor on Mars does not exist as it does on the Moon.

Size and Rotation: Mars' greater size, about twice the diameter of the Moon, has resulted in a more geologically active planet. The great volcanic constructs (Photo 66) are similar to smaller volcanoes seen in the ocean basins of Earth, but are not recognized landforms on the Moon. The fact that Mars has been more active means that it has had additional opportunities to produce a variety of materials—i.e., certain types of ore deposits. The rapid rotation rate of Mars, about the same as Earth, helps produce some weather and

⁴⁶J. B. Pollack and D. C. Black, "Implications of the Gas Compositional Measurements of Pioneer Venus for the Origin of Planetary Atmospheres," *Science*, vol. 205 (1979), 56-59.

Photo 65. Image mosaic of a portion of Mars' surface showing numerous small channels probably produced by the surface and shallow subsurface movement of water. Field of view diameter is approximately 300 kilometers. (Courtesy of U.S. Geological Survey, Branch of Astrogeology)



provides a familiar day/night cycle, which would require minimum adaptation for humans. The mass of Mars produces a gravitational field on the planet's surface that is about 0.4 that of the Earth, a comfortable working environment.

Surface Materials Diversity: Images of the surface indicate that both volcanic and impact processes have been prominent in shaping the martian surface. In addition, water- and wind-sculpted features are common. Surface sediments of eolian origin, such as dunes and drifts, are abundant in some areas. It is possible that water-layed sediments are common, and even evaporites and carbonates have been suggested as possibilities. A diverse suite of surface materials is available for use as local resources.

Phobos and Deimos: Mars' two small moons offer sites as way-stations that may figure prominently in exploration strategies. Present data, such as density and albedo, strongly suggest these bodies are composed of carbonaceous chondrite, a meteorite type rich in water and other volatiles, including organic compounds. These moons also may be sources of valuable expendables for missions to Mars.

Scientific Interest: Paramount among scientific questions still to

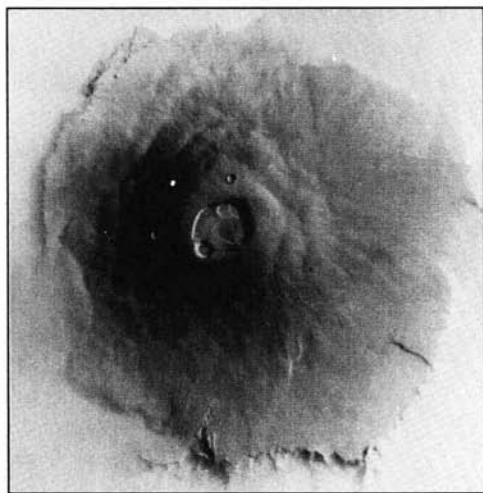


Photo 66. Composite Viking Orbiter image of the giant martian volcano Olympus Mons. The summit of the volcano rises about 26 kilometers above the surrounding plains, and the base of the mountain is approximately 500 kilometers in diameter. (Courtesy of NASA Jet Propulsion Laboratory)

be answered about Mars is whether there is or has been life on the planet. The answer to this question was not provided by the Viking landers, nor could it have been unless the evidence had been unequivocally positive. Absence of proof is not proof of absence! Planetary scientists are eager to establish Mars' geological and climatological history and to compare it with those of the Earth and Moon. The geoscientists, of course, want to examine the widest possible variety of martian rocks to determine what internal and external processes have shaped Mars and to what extent. The interactions of the atmosphere with the regolith and the polar caps offer many interesting questions. Exploration of Phobos and Deimos will be scientifically exciting as well. There is no more interesting object in the solar system than Mars and its moons.

Accessibility: Launch and return opportunities for Mars occur far less frequently than for the Moon. Furthermore, one-way transit time to Mars from the Earth takes about 170 days on minimum energy trajectories. Total mission times of two to three years are presently envisioned using conventional chemical rocket propulsion. Missions to Mars are thus long and difficult journeys. Furthermore, visitors would experience a bleak, cold, and probably barren sphere. Nonetheless, resources such as water and other volatiles are easily available and can be utilized to replenish mission supplies. In terms of total propulsion energy, a properly designed visit to a moon of Mars and a return can require less energy than a mission to the surface of the Moon and back.⁴⁷ A series of unmanned missions must necessarily precede human trips to the red planet, but these missions are within the abilities of present technology. Human trips to the moons of Mars or to the surface of Mars itself need not be delayed for three or more decades, as advocated by some studies.

If we are to participate in the early phases of manned exploration of Mars, we must collaborate with the Soviets. The new space race

⁴⁷For example, see E. A. King, "Mars: The Next Major Goal?" *Lunar Bases and Space Activities of the 21st Century*, W. W. Mendel, ed., Lunar and Planetary Institute (Houston), 795-799.

is already under way, and we are far behind. Such a collaborative program is not unrealistic. An increasing tendency to collaborate on unmanned Mars' missions can be seen, and the Soviets have, in fact, invited us to participate with them in an international effort to send human explorers to Mars.⁴⁸ Not only would such a large joint effort result in a historic and important technical and scientific achievement, but the project could be instrumental in beginning a period of much improved Soviet-American relations. If both countries reduced their military spending appropriately, funds might be profitably spent on a joint program of unmanned and manned Mars' exploration that would stimulate high technology industry in both countries. Similar ideas expressed by Carl Sagan, Jack Schmitt, and Brian O'Leary have met with considerable public support.

Alternatively, we might choose to proceed more slowly by ourselves, planning to arrive at Mars around 2010 with an expedition that is prepared to be the nucleus of a permanent colony. Thus, we are simply redefining what it takes to win the race to Mars. However, if we choose this option, a visionary political decision must be made very soon.

A statement commonly made is that a "return to the Moon" will somehow aid in eventually sending humans to Mars. I very much doubt the logic of this suggestion. The proponents of the Moon-focused space initiative cite the possible production of liquid oxygen from the Moon, but this would require surface mining and a complicated and potentially dangerous chemical reaction, such as the reduction of ilmenite with hydrogen to produce water and oxygen, with the hydrogen being recovered and reused. All of this would have to be accomplished in a hostile, volatile-poor environment. I believe this choice would result in an exceedingly expensive lunar program that might succeed only in using more than enough time and money required for the execution of the early stages of a manned Mars program. While there are good scientific reasons to visit the Moon again, and even if it were possible to harvest re-

⁴⁸L. Jaroff, "Onward to Mars," *Time* (July 18, 1988), 46-53.

sources from the lunar surface, we must not be distracted from the choice exploration target of our solar system—Mars!

The excitement of the Apollo program was that it accomplished a bold leap from the surface of the Earth to the Moon. The deed challenged our technology and engineering skill. Deliberate preparations are being made now for another and even more daring leap. When it comes, I dearly hope the United States will lead in the endeavor. We must!

About the Author

Dr. Elbert A. (Bert) King is professor and former chairman of the Department of Geosciences at the University of Houston, where he has been a full-time faculty member since 1969. He joined the NASA Johnson Space Center in 1963, where his duties for the next six years included monitoring hardware developments, astronaut training, research with meteorites and tektites, mission planning, preparation for the receipt and scientific investigation of lunar samples and numerous other tasks. He was the first Curator of Lunar Samples and was a member of the Lunar Sample Preliminary Examination Team for Apollo 11. Dr. King performed scientific investigations on samples from all the Apollo missions. He is the author of more than 100 technical papers and articles, as well as the textbook *Space Geology*. He has served on numerous NASA scientific committees and advisory groups. He is the recipient of a special commendation from the Geological Society of America and is a Fellow of the Meteoritical Society. Dr. King earned his Ph.D. degree in geology from Harvard University and holds undergraduate and master's degrees in geology from the University of Texas at Austin.

