Chapter 6: Viking and the Resources of Mars

> Additional automated missions will most certainly occur, but the ultimate scientific study of Mars will be realized only with the coming of man—man who can conduct seismic and electromagnetic sounding surveys; who can launch balloons, drive rovers, establish geologic field relations, select rock samples and dissect them under the microscope; who can track clouds and witness other meteorological transients; who can drill for permafrost, examine core tubes, and insert heat-flow probes; and who, with his inimitable capacity for application of scientific insight and methodology, can pursue the quest for indigenous life forms and perhaps discover the fossilized remains of an earlier biosphere. (Benton Clark, 1978)[1]

The New Mars

In the 1960s, most automated missions beyond low-Earth orbit—the Rangers, Surveyors, and Lunar Orbiters—supported the piloted Apollo program. In the 1970s, as NASA's piloted program contracted to low-Earth orbit, its automated program expanded beyond the Moon. Sophisticated robots flew by Mercury, Jupiter, and Saturn, and orbited and landed on Venus and Mars.

Though they were not tailored to serve as precursors to human expeditions in the manner of the Rangers, Surveyors, and Lunar Orbiters, the automated missions to Mars in the 1970s shaped the second period of piloted Mars mission planning, which began in about 1981. The first of these missions, Mariner 9, took advantage of the favorable Earth-Mars transfer opportunity associated with the August 1971 opposition to carry enough propellant to enter Mars orbit. It was launched from Cape Kennedy on 30 May 1971.

In September, as Mariner 9 made its way toward Mars, Earth-based astronomers observing the planet through telescopes saw a bright cloud denoting the onset of a dust storm. By mid-October it had become the largest on record. Wind-blown dust obscured the entire surface, raising fears that Mariner 9 might not be able to map the planet from orbit as planned.[2]

On 14 November 1971, after a 167-day Earth-Mars transfer, Mariner 9 fired its engine for just over 15 minutes to slow down and become Mars' first artificial satellite. Dust still veiled the planet, so mission controllers pointed the spacecraft's cameras at the small Martian moons Phobos and Deimos. In Earth-based telescopes they were mere dots nearly lost in Mars' red glare. In Mariner 9 images, Phobos was marked by parallel cracks extending from a large crater. Apparently the impact that gouged the crater had nearly smashed the little moon. Deimos, Mars' more distant satellite, had a less dramatic, dustier landscape.

The giant dust storm subsided during December, theatrically unveiling a surprising world. Mars was neither the dying red Earth espoused by Percival Lowell nor the dead red moon glimpsed by the flyby Mariners.[3] From its long-term orbital vantage point, Mariner 9 found Mars to be two-faced, with smooth northern lowlands and cratered southern highlands. The missions to the Moon confirmed that a relationship exists between crater density and age—the more densely cratered a region, the older it is. Hence, Mars has an ancient hemisphere and a relatively young hemisphere.

Mars is a small world—half Earth's diameter—with large features. The Valles Marineris canyons, for example, span more than 4,000 kilometers along Mars' equator. Nix Olympica, imaged by Mariner 6 and Mariner 7 from afar and widely interpreted as a bright crater, turned out to be a shield volcano 25 kilometers tall and 600 kilometers wide at its base. Renamed Olympus Mons ("Mount Olympus"), it stands at one edge of the Tharsis Plateau, a continent-sized tectonic bulge dominating half the planet. Three other shield volcanoes on the scale of Olympus Mons form a line across Tharsis' center.

Most exciting for those interested in Martian life were signs of water. Mariner 9 charted channels tens of kilometers wide. Some contain streamlined "islands" apparently carved by enormous rushing floods. Many of the giant channels originate in the southern highlands and open out onto the smooth northern plains. The northern plains preserve rampart craters—also called "splosh" craters—which scientists believe were formed by asteroid impacts in permafrost. The heat of impact apparently melted subsurface ice, which flowed outward from the impact as a slurry of red mud, then refroze.[4]

Mariner 9 depleted its nitrogen attitude-control propellant on 27 October 1972, after returning more than 7,200 images to Earth. Controllers quickly lost radio contact as it tumbled out of control. A week later, on 6 November 1972, mission planners using Mariner 9 images announced five candidate Viking landing sites.[5]

Viking 1 left Earth on 20 August 1975 and arrived in Mars orbit on 19 June 1976. Its twin, Viking 2, left Earth on 9 September 1975 and arrived at Mars on 7 August 1976. The spacecraft consisted of a nuclear-powered lander and a solar-powered orbiter. The Viking 1 lander separated from its orbiter and touched down successfully in eastern Chryse Planitia on 20 July 1976. Viking 2 alighted near the crater Mie in Utopia Planitia on 3 September 1976.

The first color images from the Viking 1 lander showed cinnamon-red dirt, gray rocks, and a blue sky. The sky color turned out to be a processing error based on preconceived notions of what a sky should look like. When the images were corrected, Mars' sky turned dusky pink with wind-borne dust.[6]

The Vikings confirmed the old notion that Mars is the solar system planet most like Earth, but only because the other planets are even more alien and hostile. A human dropped unprotected on Mars' red sands would gasp painfully in the thin carbon dioxide atmosphere, lose consciousness in seconds, and perish within two minutes. Unattenuated solar ultraviolet radiation would blacken the corpse, for Mars has no ozone layer. The body would freeze rapidly, then mummify as the thin, parched atmosphere leeched away its moisture.

By the time the Vikings landed, almost no one believed any longer that multicellular living things could exist on Mars. They held out hope, however, for hardy single-celled bacteria. On 28 July 1976, the Viking 1 lander scooped dirt from the top few centimeters of Mars' surface and distributed it among three exobiology detectors and two spectrometers. The instruments returned identical equivocal readings—strong positive responses that tailed off, weak positive responses that could not be duplicated in the same sample, and, most puzzling, an absence of any organic compounds the instruments were designed to detect.

Viking 1 and Viking 2 each scooped additional samples—even pushing aside a rock to sample underneath—and repeated the tests several times with similar equivocal results. Most scientists interpreted the Viking results as indicative of reactive soil chemistry produced by ultraviolet radiation interactions with Martian dirt, not of life. The reactive chemistry probably destroys any organic molecules.[7]

Improved cameras on the Viking orbiters, meanwhile, added detail to Mariner 9's Mars map. They imaged polygonal patterns on the smooth northern plains resembling those formed by permafrost in Earth's Arctic regions. Some craters—Gusev, for example—looked to be filled in by sediments and had walls breached by sinuous channels. Perhaps they once held ice-clad lakes.

The Viking images also revealed hundreds of river-size branching channels—called "valley networks"—in addition to the large outflow channels seen in Mariner 9 images. Though some were probably shaped by slowly melting subsurface ice, others appeared too finely branched to be the result of anything other than surface runoff from rain or melting snow. Ironically, most of the finely branched channels occurred in the southern hemisphere, the area that reminded people in the 1960s of Earth's dead Moon. The flyby Mariners might have glimpsed channels among the Moonlike craters had their cameras had better resolution.

Low pressure and temperature make free-standing water impossible on Mars today. The channels in the oldest part of Mars, the cratered southern highlands, seem to point to a time long ago when Mars had a dense, warm atmosphere. Perhaps Mars was clement enough for a sufficiently long period of time for life to form and leave fossils.[8]

The Viking landers and orbiters were gratifyingly long-lived. The Viking 1 orbiter functioned until 7 August 1980. Together with the Viking 2 orbiter, it returned more than 51,500 images, mapping 97 percent of the surface at 300-meter resolution. Though required to operate for only 90 days, the Viking 1 lander, the last survivor of the four vehicles, returned data for more than six years. The durable robot explorer finally broke contact with Earth on 13 November 1982.[9]

Viking was a tremendous success, but it had been widely billed as a mission to seek Martian life. The inconclusive Viking exobiology results and negative interpretation placed on them helped dampen public enthusiasm for Mars exploration for a decade. Yet Viking showed Mars to be eminently worth exploring. Moreover, Viking revealed abundant resources that might be used to explore it.

Living off the Land

During the period that Mariner 9 and the Vikings revealed Mars to be a rich destination for explorers, almost no Mars expedition planning occurred inside or outside NASA. The Agency was preoccupied with developing the Space Shuttle, and Mars planners independent of NASA—who would make many contributions during the 1980s—were not yet active in significant numbers.

Papers on In-Situ Resource Utilization (ISRU) were among the first signs of re-awakening interest in piloted Mars mission planning. ISRU is an old concept, dating on Earth to prehistory. ISRU can be defined as using the resources of a place to assist in its exploration—the phrase "living off the land" is essentially synonymous. In the context of space exploration, ISRU enables spacecraft weight minimization. If a spacecraft can, for example, collect propellants at its destination, those propellants need not be transported at great expense from Earth's surface. In the 1960s, ISRU was studied largely in hopes of providing life-support consumables. By the 1980s, the propellant production potential of ISRU predominated.

NASA first formally considered ISRU in 1962, when it set up the Working Group on Extraterrestrial Resources (WGER). The WGER, which met throughout the 1960s, focused on lunar resources, not Martian. This was because more data were available on lunar resource potential, and because lunar resource use was, in the Apollo era, potentially more relevant to NASA's activities.[10]

The UMPIRE study (1963-1964) recommended applying ISRU to establish and maintain a Mars base during long conjunction-class surface stays. Doing this would, of course, demand more data on what resources were available on Mars. NASA Marshall's UMPIRE summary report stated that "[t]his information, whether it is obtained by unmanned probes or by manned [flyby or orbiter] reconnaissance missions, would make such a base possible," making the " 'cost effectiveness' of Mars exploration . . . much more reasonable than [for] the short excursions."[11]

Fifteen years after UMPIRE, the Vikings at last produced the in-situ data set required for serious consideration of Mars ISRU. The first effort to assess the potential of Martian propellant production based on Viking data spun off a 1977-78 NASA JPL study of an automated Mars sample-return mission proposed as a follow-on to the Viking program. Louis Friedman headed the study, which was initially inspired by President Gerald Ford's apparently casual mention of a possible "Viking 3" mission soon after the successful Viking 1 landing.[12] Robert Ash, an Old Dominion University professor working at JPL, and JPL staffers William Dowler and Giulio Varsi published their results in the July-August 1978 issue of the refereed journal Acta Astronautica.[13]

They examined three propellant combinations. Liquid carbon monoxide and liquid oxygen, they found, were easy to produce from Martian atmospheric carbon dioxide, but they rejected this combination because it produced only 30 percent as much thrust as liquid hydrogen/liquid oxygen. Electrolysis (splitting) of Martian water could produce hydrogen/oxygen, but they rejected this combination because heavy, energy-hungry cooling systems were necessary to keep the hydrogen liquid, thus negating the weight-reduction advantage of in-situ propellant manufacture.

Liquid methane/liquid oxygen constituted a good compromise, they found, because it yields 80 percent of hydrogen/oxygen's thrust, yet methane remains liquid at higher temperatures, and thus is easier to store. The Martian propellant factory would manufacture methane using a chemical reaction discovered in 1897 by French chemist Paul Sabatier. In the Sabatier reaction, carbon dioxide is combined with hydrogen in the presence of a nickel or ruthenium catalyst to produce water and methane. The manufacture of methane and oxygen on Mars would begin with electrolysis of Martian water. The resultant oxygen would be stored and the hydrogen reacted with carbon dioxide from Mars' atmosphere using the Sabatier process. The methane would be stored and the water electrolyzed to continue the propellant production process.

Ash, Dowler, and Varsi estimated that launching a one-kilogram sample of Martian soil direct to Earth would need 3.8 metric tons of methane/oxygen, while launching a piloted ascent vehicle into Mars orbit would need 13.9 metric tons. These are large quantities of propellant, so conjunction-class trajectories with Mars surface stay-times of at least 400 days would be necessary to provide enough time for propellant manufacture.

Benton Clark, with Martin Marietta (Viking's prime contractor) in Denver, published the first papers exploring the life-support implications of the Viking results. His 1978 paper entitled "The Viking Results—The Case for Man on Mars" pointed out that every kilogram of food, water, or oxygen that had to be shipped from Earth meant that a kilogram of science equipment, shelter structure, or ascent rocket propellant could not be sent.[14] Clark estimated that supplies for a 10-person, 1,000-day conjunction-class Mars expedition would weigh 58 metric tons, or about "one hundred times the mass of the crew-members themselves." The expedition could, however, reduce supply weight, thereby either reducing spacecraft weight or increasing weight available for other items, by extracting water from Martian dirt and splitting oxygen from Martian atmospheric carbon dioxide during its 400-day Mars surface stay.

Clark wrote that Mars offered many other ISRU possibilities, but that they probably could not be exploited until a long-term Mars base was established. This was because they required structures, processing equipment, or quantities of power unlikely to be available to early expeditions. Crop growth using the "extremely salty" Martian soil, for example, would probably have to await availability of equipment for "pre-processing . . . to eliminate toxic components."[15]

The Vikings' robotic scoops barely scratched the Martian surface, yet they found useful materials such as silicon, calcium, chlorine, iron, and titanium. Clark pointed out that these could supply a Mars base with cement, glass, metals, halides, and sulfuric acid. Carbon from atmospheric carbon dioxide could serve clever Martians as a foundation for building organic compounds, the basis of plastics, paper, and elastomers. Hydrogen peroxide made from water could serve as powerful fuel for rockets, rovers, and powered equipment such as drills.

During the 1980s, the Mars ISRU concept generated papers by many authors, as well as initial experimentation.[16] Robert Ash, for example, developed experimental Mars ISRU hardware at Old Dominion University with modest funding support from NASA Langley[17] and from a non-government space advocacy group, The Planetary Society.[18] That a private organization would fund such work was significant.

Before ISRU could make a major impact, piloted Mars mission planning had to awaken more fully from its decade-long post-Apollo slumber. Post-Apollo Mars planning occurred initially outside official NASA auspices. This constituted a sea-change in Mars planning—up to the 1970s, virtually all Mars planning was government-originated. In the 1980s, as will be seen in the coming chapters, individuals and organizations outside the government took on a central, shaping role.