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On Mars

As anticipated, the information relayed to Earth by the Viking spacecraft has greatly affected man's perceptions and understanding of the planet Mars. The increase in basic, directly confirmed knowledge of the Red Planet began even before the landings. Once in orbit, the spacecraft began transmitting the first of tens of thousands of images of the planet and its satellites.

IMAGES FROM ORBIT

Heterogeneity was the most striking aspect of Mars as scientists identified a greater variety of terrains than known to exist on the moon or Mercury. Conway B. Leovy, a member of the meteorology team, noted: "Unlike the moon, whose story appears essentially to have ended one or two billion years ago, Mars is still evolving and changing. On Mars, as on the earth, the most pervasive agent of change is the planet's atmosphere, itself the product of the sorting of the planet's initial constituents that began soon after it condensed from the primordial cloud of dust and gas that gave rise to the solar system 4.6 billion years ago."[1]

Some information about the nature of the Martian atmosphere had been derived from telescopic observations and from earlier Mariner missions, but those sources of data were "unverifiable and subject to misinterpretation." With the exception of its significantly different composition and its being "less than a hundredth as dense as that of the earth," the atmosphere of Mars behaves much like that of our own planet. "It transports water, generates clouds and exhibits daily and seasonal wind patterns." Responding to seasonal changes in the heat generated by solar radiation, localized dust storms occur and sometimes grow in strength until they cover the entire planet, a fact with which Mariner and Viking specialists were familiar. Global dust storms appear to be a phenomenon unique to Mars, which lacks large bodies of water that would prevent their buildup.

Atmospheric weathering of the primitive crystalline rocks on Mars has reduced them to fine particles that have oxidized and combined chemically with water to produce the reddish minerals so apparent in the color images returned from the Viking landers. Whereas on Earth the dominant weathering process has been from the movement of liquid water, on Mars the primary agent of change has been the wind. It erodes the landscape, transports the dust, and deposits it elsewhere on the planet. The Viking landing sites appear to have been "severely scoured by winds." In addition, pictures taken by the orbiter cameras reveal deep layers of wind-borne sediment in the polar regions, while dunefields of Martian dust and sand much larger than those on Earth were observed near the north pole.[2]

The geologic history of Mars, according to orbiter imaging team leader Michael H. Carr, "shows evidence of floods and relatively recent volcanic eruptions, at least in the hundreds of millions of years that geology uses as a measure." There are also features that resemble terrestrial river systems. "Apparently tremendous floods occurred many times over Mars' history, indicating that the planet must have been drastically different in the past."[3]

Earlier Mariner flights indicated the presence of volcanoes on Mars; Viking measured their extent and variety. A large portion of the northern hemisphere is covered by volcanoes, some spreading broad lava fields for hundreds of kilometers. Others, such as Olympus Mons and Arsia Mons, rise some 27 km above the reference surface level of the planet. Distinct lava flow patterns can be seen 300 km from their source in Arsia Mons, with the general pattern of the terrain indicating that the lava may have traveled up to 800 km, the distance from Washington, D.C. to Cincinnati, Ohio.[4] Geologists who have studied the Viking photographs believe that the nature of volcanic activity on Mars is essentially the same as that on Earth—the movement of a basaltic, low-viscosity lava. One kind of volcano appears to be unique to Mars: the patera, or saucer-shaped, volcano with a low profile covering a vast area. Alba Patera, with a maximum diameter of 1600 km, is probably the largest such volcano on the planet. A similar volcano centered on Denver would have spilled its lava across all of Colorado, Wyoming, Utah, large parts of New Mexico, Kansas, Nebraska, South Dakota, and corners of Montana, Idaho, Arizona, Texas, and Oklahoma. Scientists think that the caldera—the crater formed by the collapse of the central part of the volcano—of a patera is the result of simultaneous lifting and collapsing of the sides of the volcano, probably repeated many times over a long period. According to Carr, "the total volumes of lava erupted to produce single flows are orders of magnitudes greater than they are in terrestrial lava flows, and the total volumes of lava erupted from essentially a single-vent volcano are enormous."[5] Production of sufficient magma (molten rock) for such lava flows cannot be explained, but as Carr pointed out, the plains regions appear to have been formed several billion years ago by this movement of lava.[6]

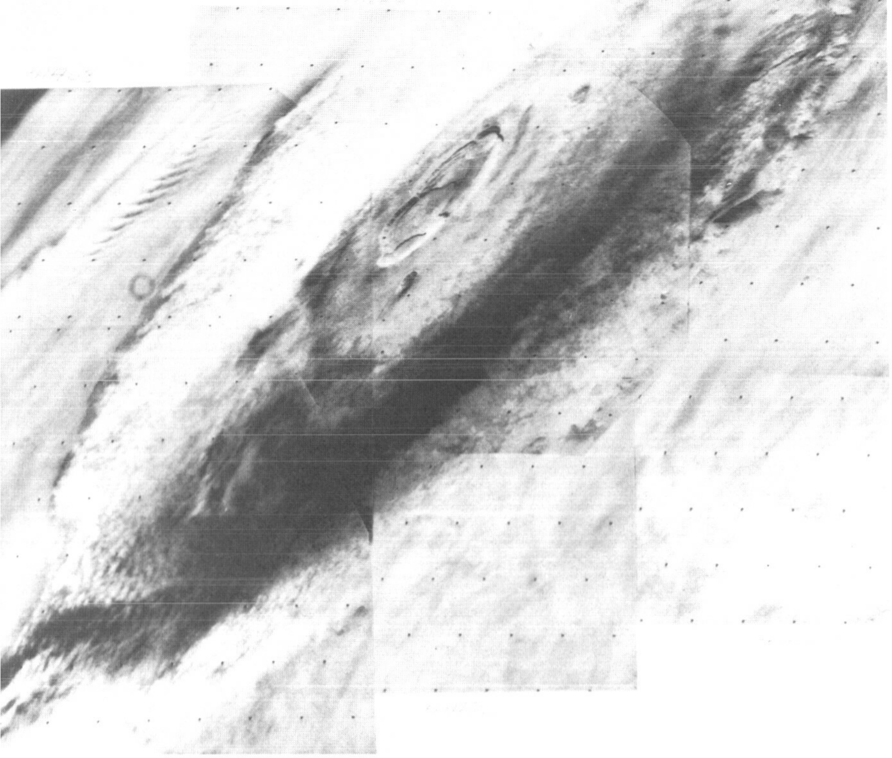
In addition to lava, the movement of water also has affected Martian topography. The large riverlike channels are one of the big Martian puzzles. Carr and his colleagues believe there are two major kinds of water features:

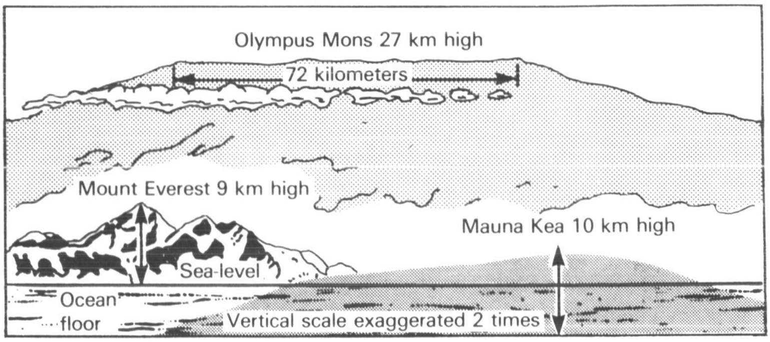
> There are the large flood features and then there are dendritic or branching drainage features that resemble terrestrial river systems. It appears from the crater counts that the fine terrestrial-like river channel systems are older than the flood features. It appears that the large flood features came in middle Mars history. There was a period of vast floods, then the flooding for some reason ceased or became less frequent because we don't have flood features with crater counts comparable to those we find on the Tharsis volcanoes. Very early in Mars' history, dendritic drainage patterns developed; in Mars' middle history it had a period of flooding, and then mostly after that the volcanics of Tharsis accumulated. This general picture has come out of the Viking data.
>
> A lot of skeptics didn't believe there had been any period of surface drainage. Some said all those things could easily have been formed by faulting and so on. The Viking pictures are full of examples of dendritic channels. I can't believe there are many skeptics left. I think we have really established that there was this early period of surface drainage. There can be very little doubt about that.[7]

The scientists are still left with explaining where all the water for the floods and rivers came from. More important, where did it go?

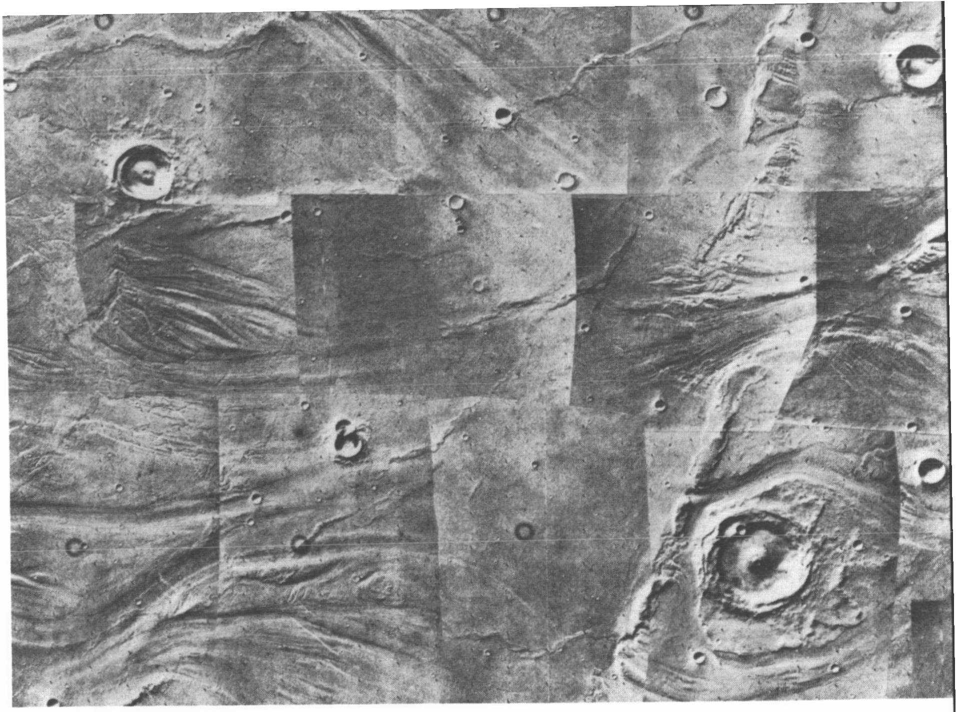
Because of low atmospheric pressure at the surface, there are no contemporary large pools, rivers, or collection basins filled with water, and because of low temperatures the atmosphere cannot contain much water. However, there is probably a great quantity in the permanent polar caps and within the surface. The low pressure permits water to be present only in the solid (ice) or gaseous (water vapor) state. One possible explanation for the apparently contradictory vision of rushing rivers on Mars was presented by Gerald A. Soffen: "Broad channels formed when subsurface water-ice (permafrost) was melted by geothermal activity from deep volcanic centers. When the melting of the permafrost reached a slope the interstitial water suddenly released great flows, sometimes a hundred kilometers wide that modified the channels."[8] Seasonal heating of the permafrost may have occasionally released large flows of water, as well—a possible explanation for the channels that originate in box canyons and spill onto the plains. The easiest method of accounting for the dendritic channels is to conjure up a Martian rainstorm, but that suggestion raises many problems, all of which hinge on the basic question: "How is it possible that these ancient rivers could [have] existed and there be none today?" Obviously, atmospheric pressure would have to have been different during such a period. This hypothesis seems to be supported by studies of the Martian atmosphere encountered by Viking.

If the atmospheric pressure once was sufficient to permit the formation of liquid water, how long ago was that? This is still a subject of some debate. Harold Masursky and his colleagues estimated the relative age of the channels by counting the number and judging the age of the craters in and near the channels. The different kinds of channels appear to have been created in

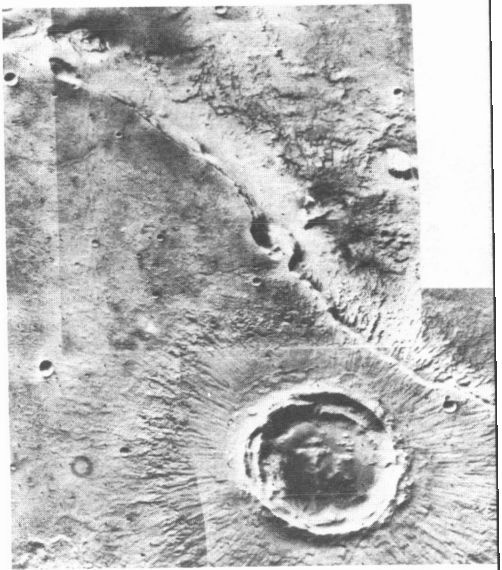


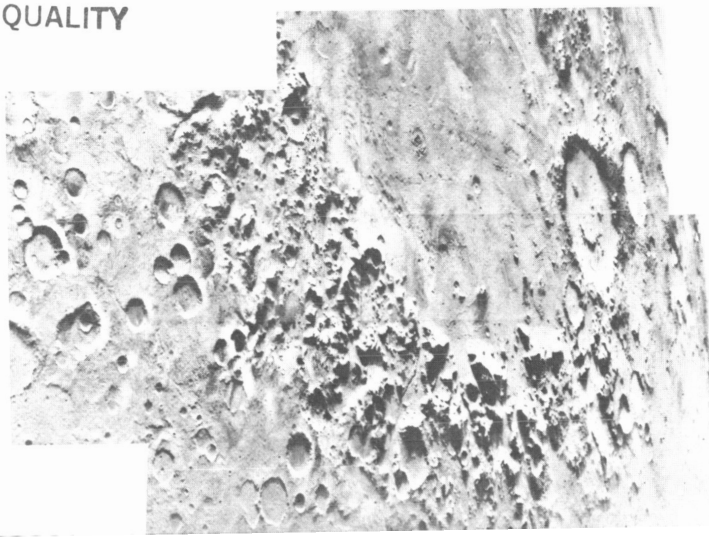


The Martian volcano Olympus Mons, at top, was photographed by the Viking 1 *orbiter 31 July 1976 from a distance of 8000 km. The 27-km-high mountain is wreathed in clouds extending 19 km up its flanks. The clouds are thought to be principally water ice condensed as the atmosphere cools. The crater is some 80 km across. At left, Arsia Mons, called South Spot during the* Mariner 9 *mission, is shown in a mosaic of photos taken 22 August. The crater is 120 km across, and the peak rises 16 km above the Tharsis Ridge, itself 11 km high. Vast amounts of lava have flooded the plains.*



A 9 July mosaic of Viking 1 *orbiter photos above shows lava flows broken by faults forming ridges. Apparently a small stream once flowed northward (toward upper right) from Lunae Planum, crossed the area, and descended toward the east. In places water may have formed ponds behind ridges before cutting through. At right, a fresh young crater about 30 km across, in Lunae Planum, is near a dry river channel running alongside a cliff in possible lava flows (Kasei Valley). Below, an oblique view across Argyre Planitia (the relatively smooth plain at top center of the photo) shows surrounding heavily cratered terrain. Brightness of the horizon to the right (with north toward upper left) is due mainly to a thin haze. Above the horizon are detached layers of haze 25 to 40 km high, thought to be crystals of carbon dioxide (dry ice). Both the lower photo mosaics were taken 11 July.*





different epochs, or episodes, and all of them at least 50 million years ag and perhaps as long ago as several billion years.[9]

In addition to the effects of lava and water, shifting of the permafrost also is believed to have influenced the texture of the planet's surface. Investigators assume the existence of permafrost, sometimes to the depth of several kilometers and generally thought to have been present for billions of years. Carr stated:

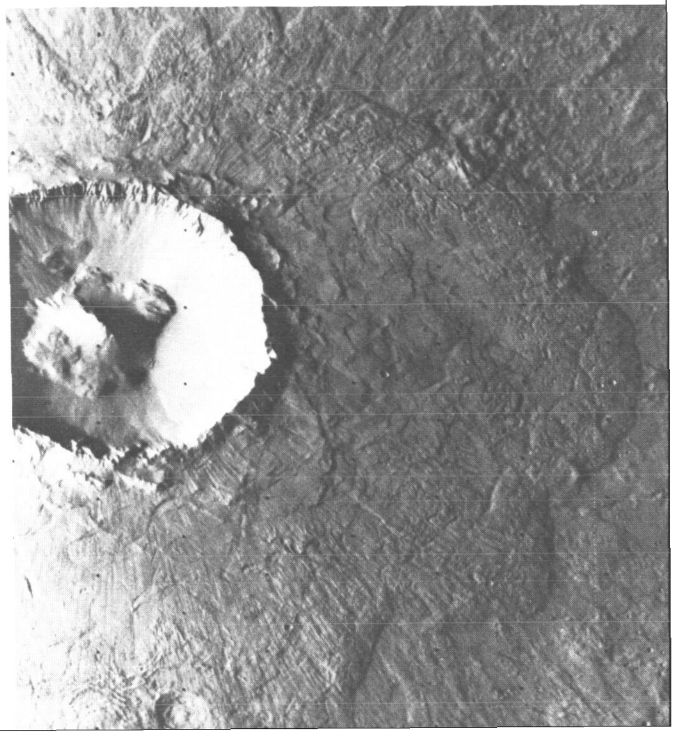
> To me one of the more exciting things we've observed is the abundant evidence of permafrost. The most striking features indicative of permafrost occur along the edge of old crater terrain. They form by mass movement of surface material probably aided by the freezing and thawing of ground ice. Another possible indicator of ground ice is the unique character of material ejected from impact craters that is quite different from the pattern on the Moon and on Mercury. We interpret the difference as due to ground ice on Mars. The impact melts the ground ice and lubricates the [ejecta] that is thrown out of the crater so when it lands on the ground it flows away from the crater in a debris flow and forms the characteristic features we have observed.

Slow movement and a freeze-thaw cycle could account for the chaotic, jumbled terrain seen over vast stretches of the Martian surface. Irregular depressions caused by localized collapsing of the crust when permafrost thawed could have formed the flat-floored valleys in Siberia and the tablelands of Mars. Large polygonal-patterned regions on Mars resemble the ice wedges in terrestrial glacial areas.[10]

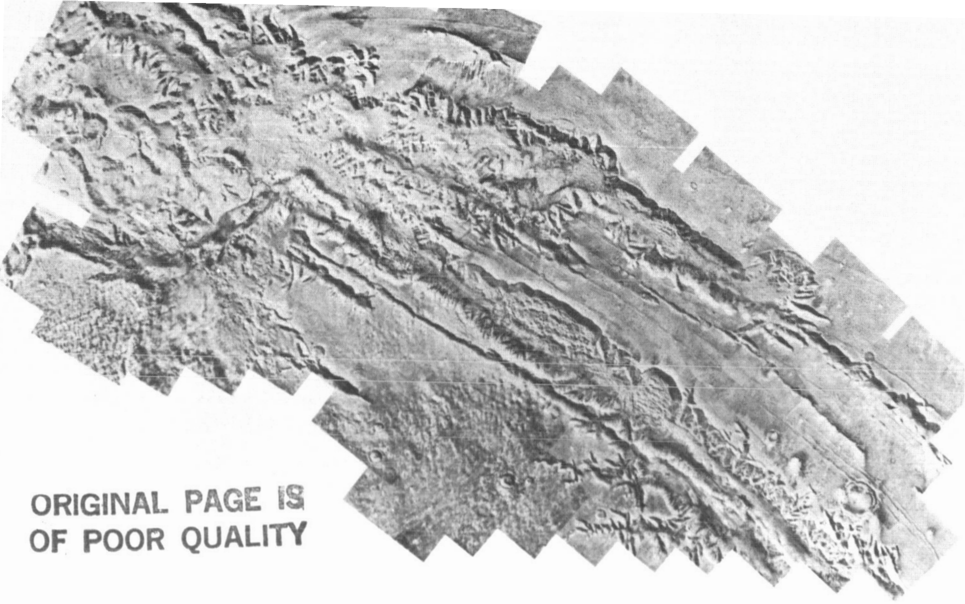
The Martian class of lobate craters is distinct. Unlike lunar craters and those photographed on Mercury, which have radial sunburst patterns caused by ejected debris, on Mars debris apparently flowed smoothly away from the points of impact of many craters. Craters on the moon and Mercury typically had a coarse, disordered texture close to the rim that became finer farther out, grading almost imperceptibly into dense fields of secondary craters. "The most distinctive Martian craters have a quite different pattern. The ejecta commonly appears to consist of several layers, the outer edge of each being marked by a low ridge or escarpment." Recognized in *Mariner 9* photographs, the shape was attributed to erosion caused by the wind. With improved-resolution Viking photographs, the geologists have changed their minds; they theorize that on Mars objects also struck the surface with explosive force, but the difference lay in the heating of the permafrost. Resulting steam and momentarily liquid water transported surface materials away from the point of impact and created the distinct lobate flow patterns around the central point. Where the crater ejecta patterns do resemble those on the moon and Mercury, geologists believe that the permafrost was too far below the surface to have been heated, or else possibly absent.[11]

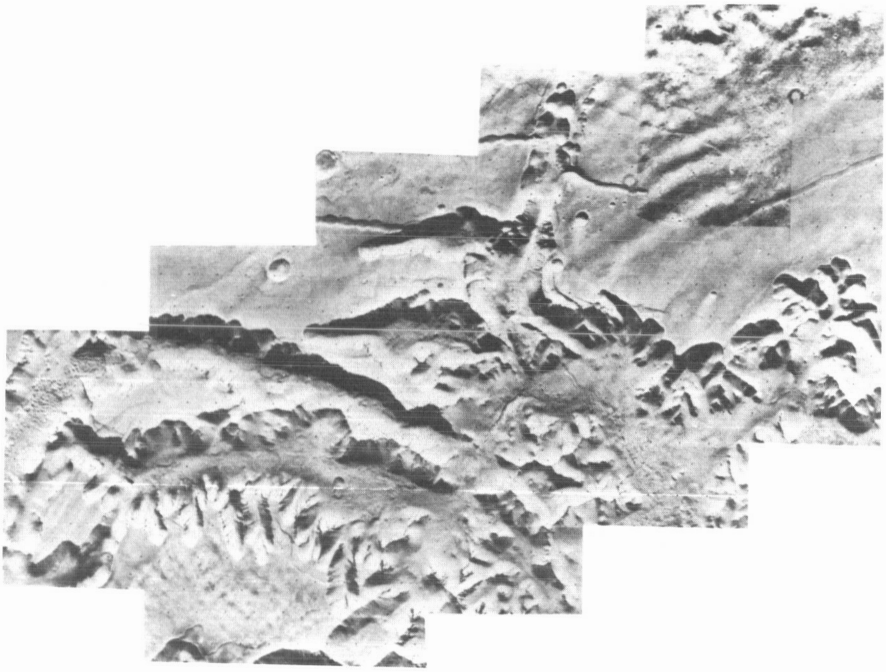
On a planet that has many spectacular features, one of the most interesting is the Valles Marineris, the Grand Canyon of Mars. First observed by *Mariner 9* cameras, only the gross proportions of the canyon system were appreciated at the 1- to 1.5-km resolution. A small sample of higher resolution *Mariner 9* photographs (100–150 meters) hinted at the huge landslides and related features that would be seen on the canyon walls and floors. The images from Viking were much better (resolution of objects as small as 40 meters), and many parts of the 4000-km-long canyon system were photographed in stereo, the combination permitting geologists to understand more precisely the processes that formed it. Significantly, neither volcanic activity nor erosion caused by flowing water seems to account for the changes in the Valles Marineris. After examining the Viking photos, Karl R. Blasius and his colleagues believe that tectonic shifting of the planet's crust may have enlarged the canyons. Volcanism was not seen in the Viking images, they point out, and evidence of fluvial activity was only indirect, from chaotic terrain. But tectonic activity appeared to have been prolonged, deepening canyons and offsetting erosion and deposits that would have broadened and filled them. Vertical adjustment of crustal blocks under north-south and east-west extensional stresses appeared to have been the primary process. Some blocks may also have tilted, forming "peculiar slopes near canyon rims and on the intratrough plateau and possibly causing the formation of strings of collapse pits." The history of canyon erosion and deposits was also more complex than had been realized. "Layered materials, including some very regularly imbedded sediments first recognized in the Viking images," were highly diverse and widespread.[12]

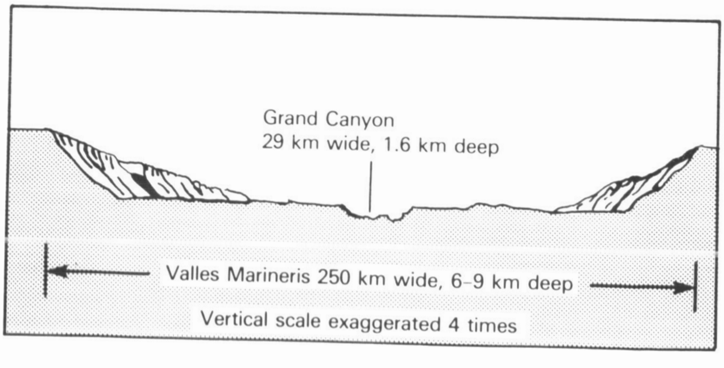
One of the basic reasons for studying the Valles Marineris was an interest in the interrelations through time of the volcanic and tectonic forces that produced the large volcanoes to the west—Olympus Mons and the Tharsis craters, which include Arsia Mons—and the development and



Material appears to have flowed out of the Arandas crater on Mars, rather than being blasted out by the meteorite impact. Radial grooves on the surface of the flow may have been eroded during the last stages of the impact process. Photographed 22 July 1976 by the Viking 1 *orbiter at 43°N latitude, 15° longitude, Arandas is about 25 km in diameter.*







More than 100 photos form the top mosaic mapping Valles Marineris, huge Martian complex of canyons. Taken by the Viking 1 *orbiter 23–26 August 1976, they are centered at 5° south latitude, 85° longitude, with north at the top. Ten photos taken 22 August form the center mosaic of the western end of the canyon. The volcanic plateau is deeply dissected into connected depressions.*

evolution of the canyon lands. Both geological regions are young in terms of the life of the planet, and changes in both areas likely have continued to the present. Mars and Earth may thus be more alike in geological terms than previously expected. The Viking images have contributed to a new field of study called comparative planetology. Undoubtedly, the wealth of new information gathered by the cameras on the orbiter was ample reward to the people who had fought so strongly to send an improved imaging system to Mars to complement the scientific instruments. As Mike Carr and his associates had predicted in October 1970, "The high-resolution imaging system may be considered as the 'meat and potatoes' low-risk but guaranteed-significant-gain experiment in the mission."[13]

Further analysis of the photographs taken over the Chryse and Cydonia regions during and after landing site certification had indicated that many of the assumptions specialists had made on the basis of *Mariner 9* photography had to be changed. Viking science investigators benefited from approaching the planet at a time when it was far from the sun, since lower solar radiation nearly eliminated the worry about dust storms.[14] The clarity of the Viking orbiter images indicated that the Martian atmosphere probably had never cleared during the *Mariner 9* mission. *Viking 1* arrived at Mars just before the beginning of summer in the northern hemisphere and soon after aphelion. Every Viking scientist reaped benefits from the clear orbiter images, and Ronald Greeley and his geologist colleagues had specific comments about the importance of the Viking orbital pictures in the Chryse and Cydonia regions: "High-resolution Viking orbiter images show Chryse Planitia to be much more complex than had been suspected from Mariner 9 images. Ancient heavily cratered terrain appears to form the basement for the basin. Much of its heavily cratered terrain is mantled with deposits that may be of aeolian, fluvial, or volcanic origin."[15] They were certain that the *Mariner 9* view of Mars had been "simplistic." From a close examination of the southern hemisphere, scientists had made some false assumptions about the northern half of the planet. "From Viking photography it is suggested that not only is the northern hemisphere more complicated than was expected, but as . . . predicted, although the present surfaces are young, some of the rocks exposed at the surface may be old."[16]

Orbiter photographs coupled with data from the infrared thermal mapper (IRTM) gave scientists a new understanding of the polar caps, too. The Martian poles change dramatically with the seasons. When the Viking craft arrived at the planet, the northern cap had shrunk to its minimum size, revealing the permanet cap, which—contrary to some expectations—consisted of water ice. The part that had dissipated had been made of solid carbon dioxide, dry ice. Meanwhile, the southern ice cap expanded. The northern polar region displayed terraced deposits, indicating an episodic pattern of rapid erosion and deposition of materials. "An unconformity within the layered deposits suggests a complex history of climate change during their time of deposition."

Table 52
Geological Evolution of Martian North Polar Region

Stage 1	Onset of polar activity. Moderate aeolian modification of ancient volcanic terrains.
Stage 2	First depositional period. Layered deposits of silicate dust and possibly interbedded ice accumulate to thickness of several kilometers.
Stage 3	First erosional period. Erosional attack of layered deposits results in landscape of gently curving scarps and channels with terraced slopes.
Stage 4	Second depositional period. More layered deposits accumulate unconformably on top of units formed in first depositional period.
Stage 5	Second erosional period. Further erosional attack of layered deposits results in exhumation of earlier formed landscapes and reveals unconformable contacts between deposits of first and second depositional period. Some eroded material reaccumulates as girdle of sand dunes between 75°N and 80°N.
Stage 6	Recent period. Ice in permanent polar cap assumes its present form and distribution.

While this scenario might not represent a completely accurate explanation of the manner in which the polar terrain evolved, James A. Cutts, Karl Blasius, and associates argue that "it does offer a credible framework . . . against which further observations and theoretical models may be tested."[17]

Meanwhile at the south pole, the infrared thermal-mapping team had observed some interesting temperatures. In their first report in *Science*, Hugh H. Kieffer and his colleagues noted that "areas in the polar night have temperatures distinctly lower than the CO_2 condensation point at the surface pressure." From the atmospheric pressure of 6 millibars at the south pole, the mapping team had anticipated temperatures of about -125°C, the equilibrium temperature for carbon dioxide at that pressure, but, when initial results came in, temperatures as low as -139°C were recorded. The infrared specialists decided that this extra cooling was attributable to a freezing out of the carbon dioxide, leaving a higher concentration of noncondensable gases (such as nitrogen and argon) than is normal for the atmosphere elsewhere. Since these gases would not condense into solid form at -139°C, that could explain the cooling, but other questions were raised by this theory.[18] How did the noncondensable gases concentrate in the polar region? What did this phenomenon mean for global circulation patterns? What did it tell scientists about the movement of carbon dioxide and other gases from one pole to the other during the change of seasons?

Once again, new knowledge raised as many interesting questions as it answered.

By the end of the primary mission, the infrared thermal-mapping team had begun to devise theories to answer some of the questions. Large-scale patterns in the temperatures of Mars appear to be similar in size to continental weather patterns on Earth. Viking scientists believe that these patterns may be associated with cloud patterns. As team leader Hugh Kieffer put it, "It's possible we're seeing what I call continental scale weather." Temperatures shortly before dawn in some places are much cooler than expected. Over the Valles Marineris, the temperatures were unexpectedly quite warm before dawn. Kieffer noted that "the temperatures just before dawn are more directly related to the physical properties of the surface because there is no solar energy being absorbed during the 12 hours of night. This means the temperatures are a good indication of how well the surface can hold its heat."[19]

Infrared thermal-mapping measurements indicated wide daily temperature variations on Mars. The typical day-night variation on Earth is 5° to 10°C, but on Mars the temperature can go from a low of -133° to a high of 4°C. The reason for this wide range is not yet fully understood, nor is the tendency of the temperatures in the afternoon to drop much more quickly than expected. Keiffer reported that in several regions on Mars temperatures begin toward the middle of the afternoon to drop more rapidly than predicted until just before dusk. They may be 10 to 15 degrees cooler than expected. Then they "cease to drop so rapidly and slowly merge with the predictions for the evening." In the afternoon, "the only atmospheric regions that are cooler than the surface are very high and thus we don't know what process at the moment is causing this rapid surface cooling." The process "may be related to clouds in some way, but most of the atmosphere near the ground, where one expects clouds to form, is, in fact, warmer than the surface just before sunset."[20]

A more important contribution from the infrared thermal-mapping experiment was the discovery of the nature of the polar ice cap. One of the major questions posed by the *Mariner 9* data was the composition of the residual polar cap left when the winter polar cap, made of frozen carbon dioxide, retreated in midsummer. A major controversy existed over whether this summer cap was also frozen carbon dioxide or was frozen water. According to Viking data, the temperatures of the residual cap are near -68° to -63°C, making a case for water frost. Also, the brightness of the frost "indicates it has a lot of dirt mixed in with it. The dirty nature of the ice had also been seen now by the orbital imaging system." Apparently there is no permanent reservoir of carbon dioxide in the polar regions of Mars, a finding that tends to rule out the theory of a rapid climate change induced by the instability of the carbon dioxide on the planet. "This means we still don't have an adequate explanation of how the atmosphere could have been of sufficient density to sustain the liquid water that appears to have flowed at one time in streams and rivers on the surface of Mars," said Kieffer.[21]

MEASURING THE ATMOSPHERE

The water-vapor-mapping investigation was designed to map the distribution of water vapor over the planet and to determine the pressure of the atmosphere at the level where vapor is present. Understanding the distribution of water vapor is crucial to understanding the geological features of Mars and the possibility of the existence of life. Viking's measurements of water vapor varied, depending on the location, season, and time of day.

Specialists discovered a direct correlation between elevation and the amount of water vapor present, with the lowest points on the planet having the greatest concentrations and the highest features the minimum. More water vapor was found during the summer season than during winter, when it was barely perceptible. In regions of rough terrain, there were marked daily variations in water vapor, and C. Barney Farmer and his team believed the variations were attributable to local phenomena—shifting wind patterns, dust, or a thin cloud or haze that is present at dawn but dissipates by noon. For example, early in the first mission one site was monitored over a six-hour period. The water vapor content in the atmosphere rose steadily from dawn until noon. This water could have been brought into the area from another region by the wind, or the haze or dust in the air could have affected the instrument's measurements. Whatever the cause for the change, the increase would be considered minute when compared to Earth's atmosphere with 1000 times as much moisture.[22]

During the Viking primary mission, the Martian water vapor underwent a gradual redistribution, the latitude of the maximum amounts moving from the north polar region toward the equator. Interestingly, while the amounts of vapor at some latitudes changed dramatically, the total global water remained almost constant at the equivalent of about one cubic kilometer of ice. The largest amounts observed were found over the dark polar region, which is inaccessible to Earth-bound observers. Maximum vapor column abundances of about 100 precipitable micrometers were measured adjacent to the residual cap itself—"a very large amount considering the temperature of the surface and atmosphere in this region." The Mars atmospheric water detector also confirmed the conclusion that the residual cap is made of frozen water and that the atmosphere above it is saturated with vapor during the polar summer.[23]

Orbital science investigations had given a better grasp of the global nature of Mars, and the entry science experiments provided the first direct measurements of the physical and chemical composition of the planet's atmosphere. The scientists were for the first time "getting their hands on" some more tangible data. Entry science investigations consisted of measurements by the retarding potential analyzer, the upper-atmosphere mass spectrometer, lander accelerometers, the aeroshell stagnation-pressure instrument, and the recovery temperature instrument. The analyzer had been designed to study the nature of the ionosphere. The mass spectrometer was to provide mass spectra for the constituents of the upper atmosphere.

Three of the instruments—the lander accelerometers, the aeroshell stagnation-pressure instrument, and the recovery temperature instrument—made up the lower-atmosphere structure experiment, which measured the density, temperature, and pressure profile of the atmosphere as the lander approached the surface. As with other experiments and Viking hardware, the entry investigations had been based on the common "Mars engineering model" adopted early in the project. That model described the nature of the planet as it was believed to be, from the best knowledge then available. As Jerry Soffen recounted, the model was developed to set the boundaries for design, prescribing the atmospheric envelope, the variety of possible surfaces, range of textures, radiation environment, etc. This "working manual" was constantly reviewed by scientists both within and outside the project and used by all the engineers. The Mars engineering model "was an excellent crossroads for scientists and engineers." With the mission definition, it "truly spelled out what we were trying to do and the planetary constraints we believed existed."[24]

The lander's mode of descent altered several times before touchdown, and the entry instruments operated during different phases of the entry process. At separation, the lander capsule—consisting of the aeroshell and basecover surrounding the lander—was deorbited by ignition of the deorbit engines. The capsule began the first part of its descent trajectory through the undisturbed interplanetary medium of ions and electrons. The interplanetary medium streams away from the sun at hypersonic velocities in what is called solar wind. Closer to the planet, the lander capsule passed through a disturbed region where the solar wind is diverted to flow around and past Mars. Beneath this zone of interaction lay the Martian ionosphere, a region of charged atomic particles. It was in the ionosphere, 3 minutes after the completion of the deorbit burn, that the retarding potential analyzer began 18 sampling sequences, during which 71 seconds of data were collected.

Entry has been arbitrarily defined as starting at 250 kilometers, although the atmosphere is only readily apparent from about 91 kilometers. From separation to entry required about 3 hours. At entry, the lander capsule was oriented with the aeroshell and its heatshield facing the direction of travel; before the atmosphere exerted an appreciable drag, the capsule would accelerate to about 16 000 km per hour. Almost 1 hour before the lander reached the 250-km mark, the upper-atmosphere mass spectrometer was turned on for a 30-minute warmup period. The spectrometer and the retarding potential analyzer would continue to take measurements until the capsule system sensed 0.05 gravity, at which time they would shut down. The capsule-mounted temperature sensor was then deployed. With pressure sensors (deployed 10 minutes before entry), it would continue to function until the aeroshell was jettisoned (12 seconds after the radar altimeter sensed an altitude of 5.9 km).

At about 27 km above the surface, the capsule reached its peak deceleration and for a time its path leveled off into a long glide, because of the aerodynamic lift provided by the aeroshell. As the effects of atmospher friction and gravity overcame the lift, the capsule resumed descent. By th time its radar altimeter indicated an altitude of 6.4 km, the capsule was traveling slowly enough (an estimated 1600 km per hour) to deploy the parachute. Seven seconds later, the aeroshell separated from the lander, and the remaining lift in the lightened aeroshell permitted it to drift well away from the landing site. Twelve seconds after aeroshell separation, the lander legs were deployed, at which time the footpad temperature sensor began collecting data, doing so until touchdown.[25]

From the retarding potential analyzer, new information about the Martian ionosphere was collected through measurements of the solar wind electrons and ionospheric electrons, the temperatures of the electrons, and the composition, concentrations, and temperatures of positive ions. At the higher altitudes, the analyzer examined the interaction of the solar wind and the upper atmosphere. The planet's weak (or nonexistent) magnetic field permits the solar wind to penetrate closer to the surface of Mars than it does to Earth's surface. Data obtained during descent indicates that singly ionized molecular oxygen (O_2+) is the major element of the upper atmosphere, with peak concentration at an altitude of 130 km. Singly ionized molecular oxygen is about nine times as abundant as singly ionized carbon dioxide (CO_2+), the primary ion produced by the interaction of sunlight with the Martian atmosphere. This new finding lends support to theoretical analyses by M. B. McElroy and J. C. McConnell, which call attention to the reaction of atomic oxygen with CO_2+ that would produce carbon monoxide and the more stable ion O_2+. The temperature of the observed ions at 130 km was about -113°C.[26] Viking measurements of O+ ions moving away from the planet coupled with *Mariner 9* observations of hydrogen escaping from the planet's upper atmosphere suggest that the planet has been losing the basic ingredients for water for billions of years. Perhaps some of the water that once carved the massive channels on the surface of Mars slowly escaped in the form of ionized hydrogen and oxygen.

The upper-atmosphere mass spectrometer obtained data about the identities and concentrations of the various gases from 230 to 100 km. As expected, the main constituent of the upper atmosphere is carbon dioxide, with small amounts of nitrogen, argon, carbon monoxide, oxygen, and nitric oxide. Taken together, what do these upper atmospheric measurements suggest? The discovery of nitrogen was a particularly pleasant surprise. As Tobias Owen of the molecular analysis team commented, the search for nitrogen in the Martian atmosphere goes back several decades, and he was "delighted" that they finally had found it. When he first became interested in Mars during the 1950s, "it was an established doctrine that the pressure on Mars was eighty-five millibars, plus or minus three millibars, and that the atmosphere was well over ninety-five percent nitrogen." As time passed, predictions changed; both the surface pressure and the amount of nitrogen decreased. As the estimated amount of carbon dioxide grew to more than 95 percent of the gas in the atmosphere, detection of any nitrogen eemed unlikely. This outlook was disheartening to the exobiologists who elieved that nitrogen was an essential ingredient in any environment in which life might have evolved. But the upper-atmosphere mass spectrometer did detect nitrogen. Happily, Toby Owen said, "And now we finally got it; it's really there."[27]

Michael McElroy of the entry science team went even further. According to him, Mars was a very "cooperative" planet, and it had given the Viking scientists some bonus information. Beyond defining the chemical composition of the atmosphere, they discovered some "clues as to the evolution of the planet from its isotopic abundance." Mars has more of the heavy form of nitrogen than does Earth, which allows specialists to theorize that Mars is "remarkably Earth-like although it has gone through a different evolutionary history." McElroy explained that there are two abundant isotopes of nitrogen: Mass 14, which is the common form, and Mass 15, which is less common. They are both present in Earth's atmosphere and in the Martian atmosphere, but Mars has rather more of the heavy component than does Earth. The implication is that Mars must have lost the light material over time. The initial amount of nitrogen on Mars was apparently similar to the initial amount on Earth, but slightly lower gravity on Mars allowed the lighter nitrogen to escape. Perhaps Mars has "evolved to a larger extent than the Earth because of this escape process."[28]

While the presence of 2.5 percent nitrogen in the atmosphere opened the door for speculation about possibilities of organic material, the levels of argon led to other theories, some of which were contradictory to the one used to explain the presence of nitrogen. Argon was measured at 1.5 percent, considerably less than indicated by the indirect measurements made by the Soviet Union with its *Mars 6* mission in 1974. The discovery that Soviet scientists were mistaken was welcome to Klaus Biemann and his colleagues on the molecular analysis team, because it relieved their worry that argon might choke the gas chromatograph-mass spectrometer. The low amount of argon in the atmosphere would not prevent that instrument from performing a series of atmospheric analyses on its way to the surface before it could be contaminated by organic compounds from the Martian soil.[29]

A low concentration of argon also had significant implications when it came to reconstructing the early Martian atmosphere. The two common isotopes of argon are argon-36 and argon-40. The former is an inert element produced in the interior of stars such as our sun, and the latter is created during the radioactive decay of potassium-40. Both isotopes have been released over time from the rocks of planets, and it is generally held that the relative amount of the two says something about how the atmosphere evolved. For Mars, this theory poses some interesting problems and questions. Toby Owen proposed the following scenario during a 28 July 1976 Viking science symposium at JPL. Using the Earth's atmospheric history as a guide, Owen argued that one could by analogy plot the evolution of the Martian atmosphere back over time. One way to make this analysis for the two planets was to use argon-36 as the common piece of information. It was assumed that Earth and Mars were formed at the same time and from th same inventory of gases in the solar nebula. If that is true, then Earth an Mars should have about the same ratio of argon-36 and argon-40 in their atmospheres. They do not. Earth is relatively poor in argon-36; it is held that this gas was lost early in the evolution of the terrestrial atmosphere. Scientists thought that they could deduce from the amount of argon-36 in the Martian atmosphere the gases that have been lost. Viking measurements indicate that the planet should have lost 10 times the amount of carbon dioxide and nitrogen now measured in the atmosphere. But the loss was not out into space; it was hidden in some form on the planet itself. Ten times the present amount of carbon dioxide constitutes a considerable amount of material to hide. Owen reported: "I'm suggesting that somewhere between 1 and 10 times the present amount of CO_2 is missing on Mars . . . and some fraction could still be present in the form of CO_2 trapped in the [polar] caps. The other part of this reconstruction, which is interesting, is that it implies a couple of tens of meters of water on the surface which must also be sequestered somewhere."[30] The water could have become permafrost, but this explanation disagrees with the theory that the water left the planet in the form of ionized hydrogen and oxygen.

Although no general agreements have been reached on how the upper atmosphere of Mars was formed, one point seems certain: that atmosphere was significantly different in the past. Just as the evolution of Earth's atmosphere helped determine the nature of its environment, the evolution of Mars is linked with the development of its atmosphere. As Jerry Soffen concluded: "It appears that there was a considerably denser atmosphere in the past, somewhere between 10 and 50 times the present value of 7.5 millibars at the surface. This denser atmosphere would account for the possibility of the ancient river [beds] seen from the orbiter."[31] Whatever explanation the scientific community comes to accept, Viking has made two points very clear—the Red Planet's environment has not been static, and in the past was very dynamic.

The lower atmosphere structure experiment provided vertical profiles of the density, pressure, and temperature of the atmosphere from an altitude of 90 km to the surface. Accelerometers, part of the lander's inertial reference unit, acted as sensors for the initial measurements from which the density profile was derived. The profile was determined by observing the retardation of the capsule's descent by atmospheric drag. Pressure and temperature measurements came at first from the two instruments in the aeroshell. Because of the high initial velocities of the lander capsule, the pressure sensor determined the pressure of the atmospheric molecules against the aeroshell surface; the actual pressures were determined analytically later. In a similar fashion, the temperature probe, near the outer rim of the aeroshell, measured the temperature of molecules flowing around the aeroshell. During the parachute phase of the descent, after the aeroshell had been jettisoned, the lander's pressure and temperature sensors provided this information.

Altitude data for construction of profiles came from the radar altimeter. A by-product of the radar altimeter measurements was information about the terrain beneath the lander. The terminal descent and landing radar system, which controlled the very last stage of the landing, also measured the extent to which the lander drifted because of winds above the point of touchdown. Pressure and temperature variations were measured by the two landers at selected intervals during the descent (table 53). The temperature in the region between 200 and 140 km above the surface averaged about -93°C; for the region between 120 and 28 km it was -130°C. At touchdown, the *Viking 1* atmospheric temperature was about -36°C, and *Viking 2*'s reading was -48°C.[32]

Table 53
Structure of Martian Atmosphere

Altitude (km)	*Viking 1*		*Viking 2*	
	Pressure (mb)	Temperature (°C)	Pressure (mb)	Temperature (°C)
120.0	0.000 004 14	-136.85	0.000 001 99	-157.15
108.0	0.000 018 40	-126.75	0.000 013 00	-152.05
96.0	0.000 080 20	-127.25	0.000 066 00	-122.95
84.0	0.000 387 00	-128.95	0.000 288 00	-131.75
72.0	0.002 050 00	-134.05	0.001 680 00	-142.25
60.0	0.009 110 00	-127.65	0.008 540 00	-135.85
48.0	0.044 500 00	-124.55	0.039 200 00	-102.45
36.0	0.198 000 00	-107.05	0.158 000 00	-108.75
28.0	0.483 000 00	- 89.35	0.404 000 00	- 99.95
4.5	5.160 000 00	- 51.05*	5.222 000 00	- 51.95
4.0	5.390 000 00	- 50.53	5.483 000 00	- 51.55
3.5	5.635 000 00	- 48.45	5.747 000 00	- 51.05
3.0	5.885 000 00	- 46.65	6.015 000 00	- 50.55
2.5	6.150 000 00	- 44.85	6.282 000 00	- 50.05
2.0	6.427 000 00	- 43.05	6.564 000 00	- 49.55
1.5	6.707 000 00	- 41.35	6.853 000 00	- 49.15
1.0	6.994 000 00*	- 39.45*	7.160 000 00*	- 48.55*
0.5	7.301 000 00*	- 37.65*	7.480 000 00*	- 48.05*
0.0	7.620 000 00*	- 35.85*	7.820 000 00*	- 47.55*

*Extrapolated.
SOURCE: Alvin Seiff and Donn B. Kirk, "Structure of the Atmosphere of Mars in Summer at Mid-Latitudes," *Journal of Geophysical Research* 80 (30 Sept. 1977): 4367, 4371.

Compared to the scientific instruments aboard the orbiter or th lander, the entry experiments were very short-lived. They operated onl during the descent to the surface. Still, these instruments provided investigators with several new insights into the Martian environment and clues that, when coupled with orbital and landed data, would help frame new hypotheses about the evolution of the planet.

As interesting as the orbital pictures and measurements were and as informative as the entry data instruments were, the best was to come. Science aside for a moment, the reception of the first pictures from the lander cameras had to be the most exciting event for many project participants, scientists and engineers alike. For the public, the surface pictures were certainly the main event.

ON THE SURFACE

The first lander's first picture, of footpad 3 (a 60° high-resolution image), demonstrated to everyone that the craft was safely down on the surface. Minutes later, camera 2 began taking a real-time picture, a 300° panoramic view of the scene in front of the lander. These shots had been planned to provide the maximum amount of immediate information so that images of value would already have been collected should something unforeseen terminate the operation of the lander. Thomas A. Mutch, lander imaging team leader, recalled, "The planning for these first two frames was exhaustive." Characteristically, everyone had some advice about the best photographs to take. More than a year before the landing, team members had been called to Washington to brief NASA Administrator James Fletcher on camera strategy. "In the event of a botched landing, the first two images might constitute our only pictorial record of Mars." The pictures would be sent to the orbiter in the first 15 minutes after landing and thence to Earth. Not for 19 hours, including the first night on Mars, would it be possible to communicate again with the lander.

Some of Mutch's associates argued with the decision to photograph the footpad and then the view in front of the lander. One challenged, "If you were transported to an unknown terrain, would you first look down at your feet?" Mutch had to agree that the common mental image of the explorer was that of an individual shading his eyes with his hand looking far away to the horizon. He records that his counter argument was rather pedestrian. He thought—in the terms of a photogeologist—that the first picture of the footpad would be technically the better of the two:

> A primary photogeologic goal, perhaps because it is so easily quantifiable, is increase in linear resolution. Looking straight down, the slant range was abut 2 m, yielding a linear resolution of approximately 2 or 3 mm. Looking toward the horizon, nominally 3 km distant, the linear resolution would have been reduced toward two or three orders of magnitude.
>
> Our logic would have been persuasive if the surface of Mars had been generally flat, but covered with small objects of unusual form. As it turned

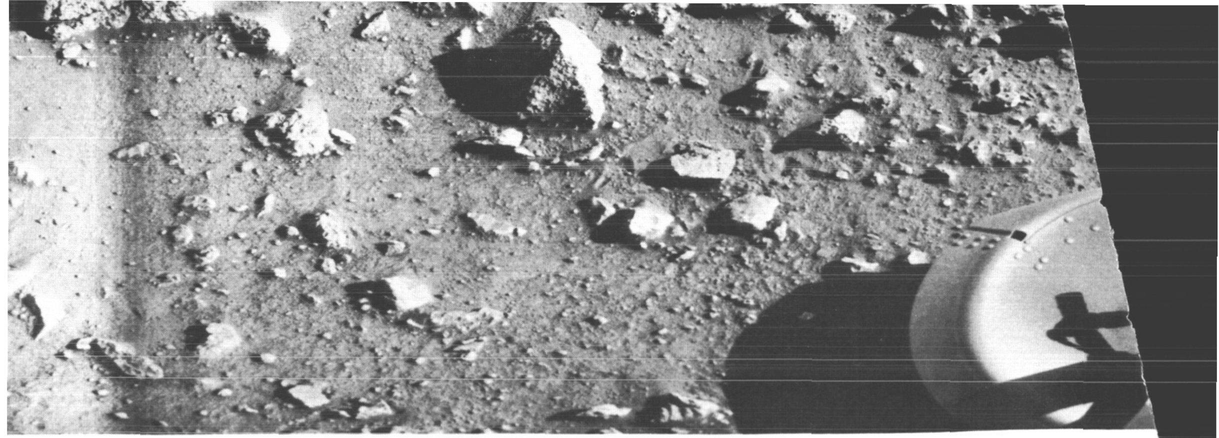
> out, this was not the case. The rock-littered surface in the near field is relatively undistinguished, but the undulating topography and diverse geology of the middle and far field is spectacular. From both an exploratory and scientific perspective, the panorama to the horizon is the more impressive of the first two pictures.[33]

This self-effacing evaluation is characteristic of many of the Viking scientists, but especially of Tim Mutch. Seated in the "Blue Room" as the first electronic picture data began appearing on the television monitors throughout the Jet Propulsion Laboratory facilities, Mutch in almost a boyish manner commented, "The neat thing about pictures is that everyone can do their own analysis. We're really quite superfluous here." The images from the lander were reconstructed, picture element (pixel) by picture element from left to right, just as they had been taken by the camera on Mars. After going through the decoding process in the ground reconstruction laboratory, the image was shown throughout JPL a few lines at a time. From left to right, the first pictures of Mars began to evolve on the monitors. Reactions were varied, but nearly all were happy ones. For Tim Mutch, it was "a geologist's delight." Jim Martin saw the first picture in very practical terms—Viking was so far a success. He expressed his appreciation to the entire Viking team and to the "10 000 people across the country who deserve a part of the credit given to me." Mission Director Tom Young was also pleased with the performance of his spacecraft. As for the pictures, he said, "quality was consistent with what we should get, but they have exceeded my expectations." The quality was very good, and Young added that "Mars has demonstrated that it is photogenic!"[34]

The Colors of Mars

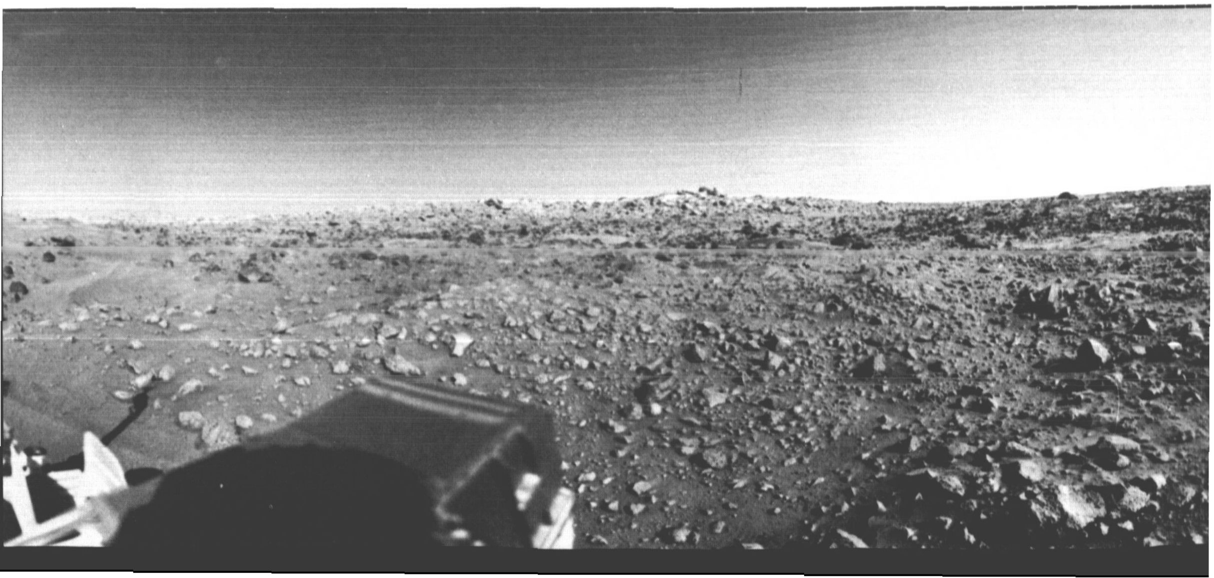
The first two photos of Mars received on 20 July 1976 were followed by a color photograph on the 21st. A lot of people would not forget that first color picture. Mutch tells the tale as well as anyone. During the first day following the early morning landing of *Viking 1*, his team was preoccupied with analysis and release of those first two images, "which, in quality and content, had greatly exceeded our expectations." So much were they concentrating on the black and white pictures, that they were "dismally," to use Mutch's word, "unprepared to reconstruct and analyze the first color picture." Mutch and his colleagues on the imaging team had been working long hours, along with everyone else, during the search for a landing site. Despite enthusiasm, people were tired. Many of the Viking scientists in the upcoming weeks would have to learn to present instant interpretations of their data for the press. For the first color photograph, haste led to processing the Martian sky the wrong color.

In a general fashion, Mutch and his team understood that a thorough preflight calibration of the camera's sensitivity to the colors of the spectrum was necessary. They also knew that they would need computer software programs to transform the raw data efficiently into an accurate color



The first photograph (above) from the surface of Mars, taken minutes after the Viking 1 *lander touched down on 20 July 1976. Center of the image is about 1.4 meters from the lander's camera no. 2. Both rocks and finely granulated material are visible. Many foreground rocks are flat with angular facets. Several larger rocks have irregular surfaces with pits, and the large rock at top left shows intersecting linear cracks. A vertical dark band extending from that rock toward the camera may have been caused by a one-minute partial obscuring of the landscape by clouds or dust. The large rock in the center is about 10 centimeters across. At right is a portion of the spacecraft's footpad, with a little fine-grained sand or dust deposited in its center at landing.*

Below is the first panoramic view by Viking 1 *on the surface. Horizon features are about 3 km away. A collection of fine-grained material at left is reminiscent of sand dunes. Projections on or near the horizon may be rims of distant craters. Some of the rocks appear to be undercut on one side and partially buried by drifting sand on the other. The housing of the sampler arm, not yet deployed, and the low-gain antenna are at left. In the right foreground are the color charts for camera calibration, a mirror for the magnetic properties experiment, and part of a grid on top of the lander body. At upper right is the high-gain antenna for direct communication between the lander and Earth.*



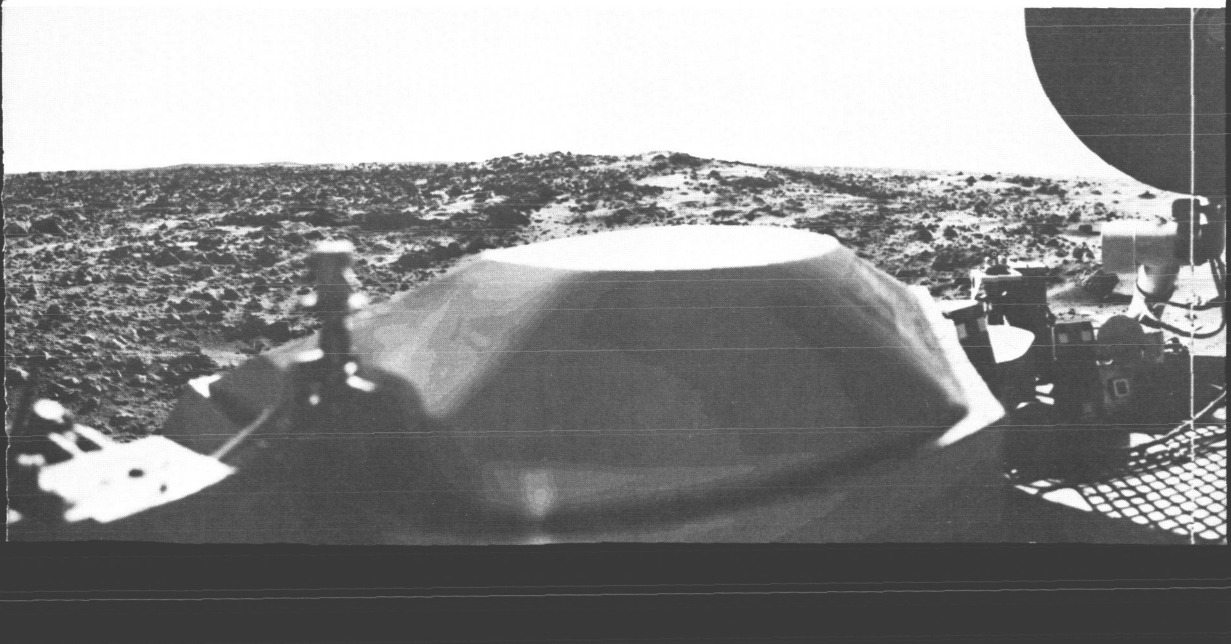
representation. "What we failed to appreciate were the many subtle problems which, uncorrected, could produce major changes in color. Furthermore, we had no intimation of the immediate and widespread public interest in the first color products—for example, intuitively corrected color images were shown on television within 30 minutes following receipt of the data on Earth." Although they resisted at first, the lander imaging team was obliged to release the first color prints within 8 hours of having received the image.[35]

Instinctive reactions and intuition can lead to mistakes when dealing with an alien world. Here is Tim Mutch's first public reaction to the color photograph:

> Look at that sky—light blue sky—reddish hue. It's a very exciting thing to see this distinct reddish coloration to the surface. These are subtle hues. It's a geological scene, a natural scene. Even in the deserts here on Earth the reds are not crayon reds as painted by a child. This is a surprisingly terrestrial-like desert scene.[36]

But to borrow Carl Sagan's phrase, to see this picture in terms of deserts on our own planet was an "Earth chauvinism." The photo was of Mars, not of Earth; the sky should have been red. When James A. Pollack of the imaging team told a press conference on July 21 that the Martian sky was pink, he was greeted with some friendly boos and hisses. Sagan, in a way that only he could, chided the newspeople the following day: "The sort of boos given to Jerry Pollack's pronouncement about a pink sky reflects our wish for Mars to be just like the Earth."[37]

There were three sensors with blue, green, and red filters in the focal plane of the camera to record the radiance of the scene in blue, green, and red light. The multilayer, interference filters used in the lander cameras (filters that could withstand the rigors of sterilization) have an irregular spectral response. The blue channel, for instance, responds slightly but significantly to light in the infrared portion of the spectrum. The unwanted part of the signal must be subtracted, "so that the absolute radiances at three specific wavelengths in the blue, green and red are represented." Subsequently, color prints were produced by exposing conventional color film to



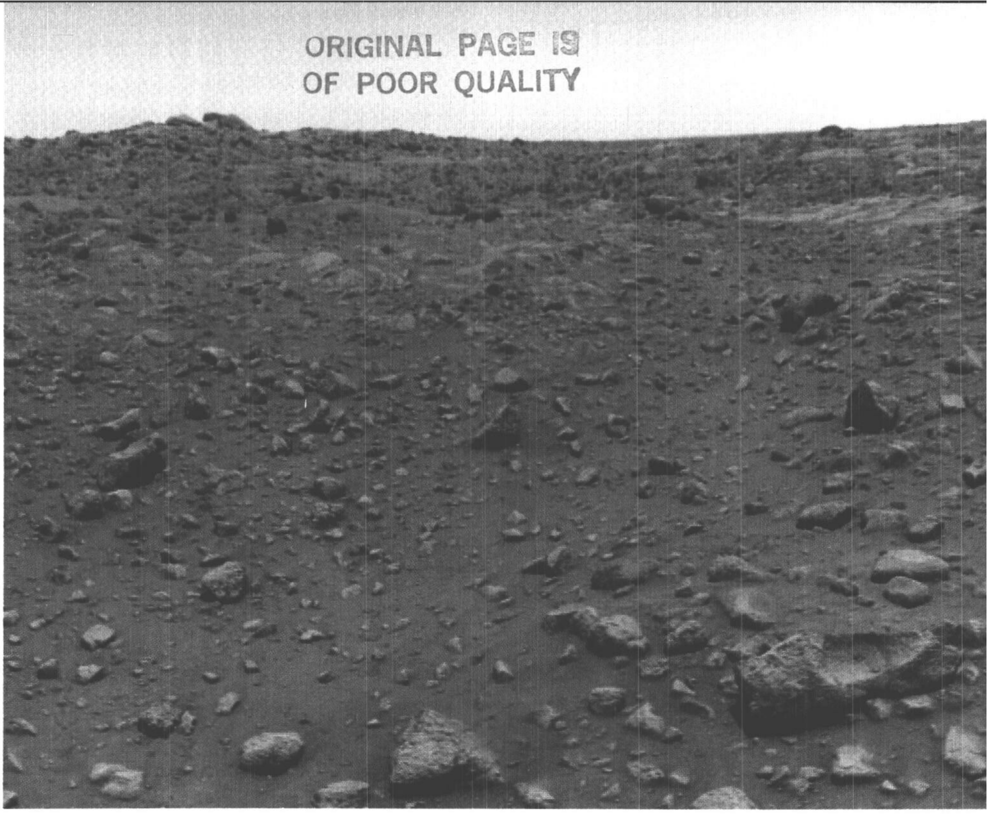
individually modulated beams of blue, green, and red laser light, scanning the film with the same geometry employed in the camera.

Before the flight, the cameras had been calibrated and the sensitivity of each sensor-filter combination determined. "Qualitative tests indicated that simple normalization of the voltages for the three color channels . . . was sufficient to produce reasonable color images. In making that judgment our attention was generally directed to saturated colors in the natural scene and test target." When the first color data were received, Mutch's specialists used the same normalization techniques to calibrate the image. "The result was surprising and disquieting. The entire scene, ground and atmosphere alike, was bathed in a reddish glow. Unwilling to commit ourselves publicly to this provocative display, we adjusted the parameters in the calibration program until the sky came out a neutral gray." The soil and rocks demonstrated good contrast, and the colors "seemed reasonable." This was the picture released eight hours later. "But to our chagrin," Mutch recalled, "the sky took on a bluish hue during reconstruction and photoreproduction. The media representatives were delighted with the Earth-like colors of the scene."

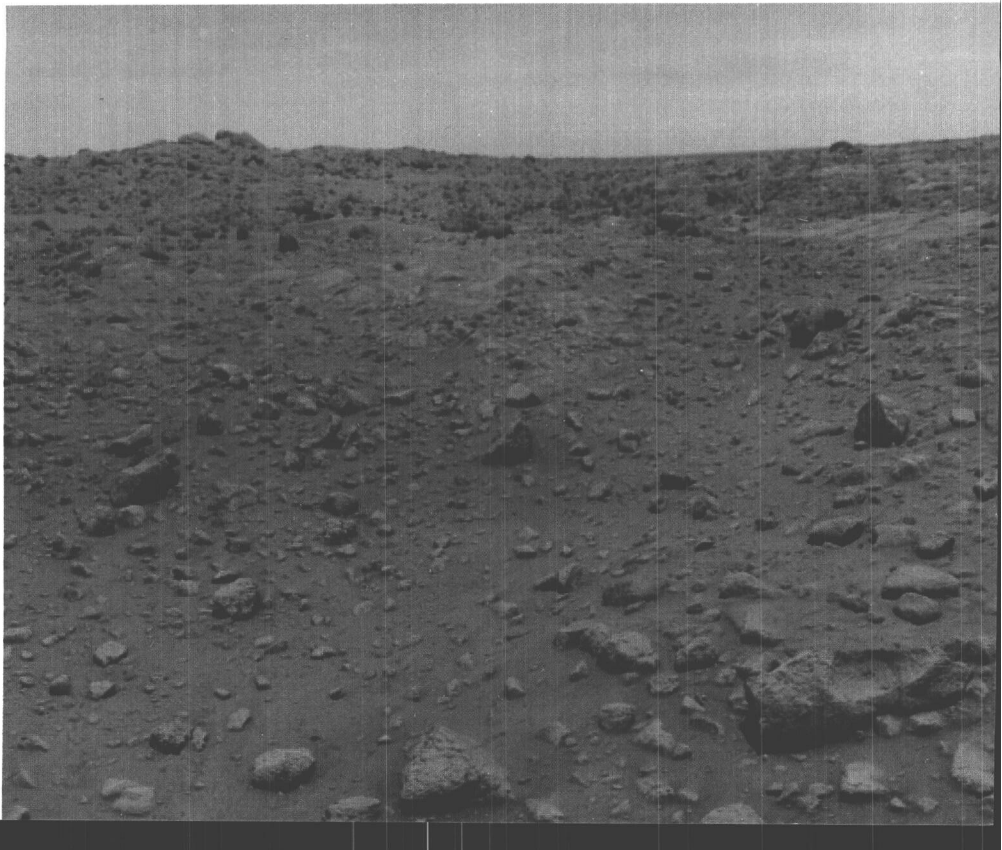
While the television and newspaper reporters hurried to get this color print before their respective audiences, continued analysis supported the reality of an orangish tint throughout the scene. The atmospheric coloration was due to the presence of suspended soil particles in the thin air. Mutch recalled: "Several days after the first release, we distributed a second version, this time with the sky reddish. Predictably, newspaper headlines of 'Martian sky turns from blue to red' were followed by accounts of scientific fallibility. We smiled painfully when reporters asked us if the sky would turn green in a subsequent version." Experience with color imaging over the next year indicated that the colors of Mars might vary, but the sky would retain its reddish hue. "In summary," Mutch said, "the color of the Martian scene, perceived by the necessarily abnormal eyes of Viking, is elusive. In response to the inevitable question: 'Is that exactly how it would look if I were standing on Mars?' a qualified 'yes' is in order."[38]

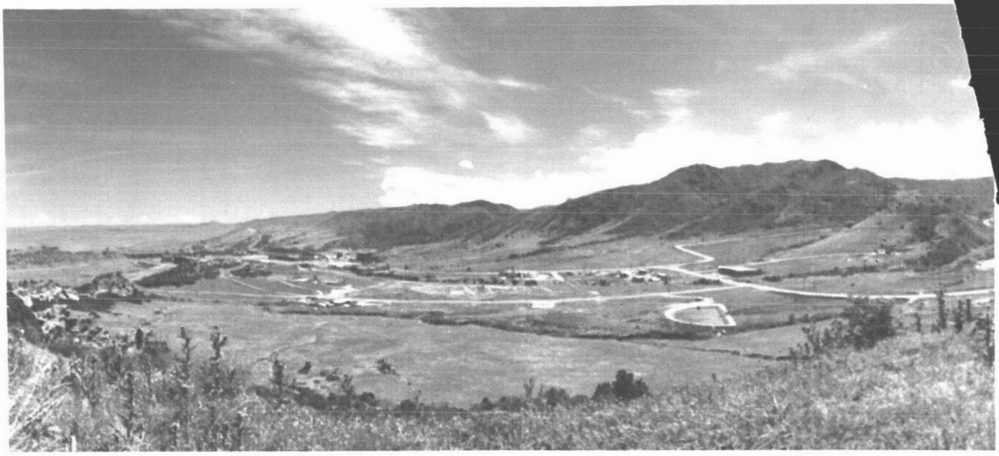
A Real World

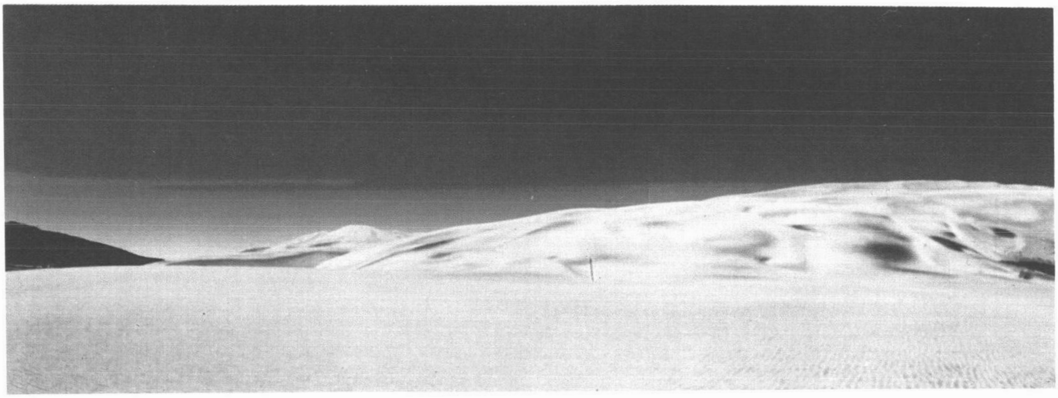
No matter what the color of the sky, the Viking pictures created a new reality for many people. Jerry Soffen said that, if any one thing stood out in his mind, "Mars had become a place. It went from a word, an abstract thought, to a real place." Soffen doubted that he would ever have an adventure like climbing Mount Everest, but he knew that it existed because other people had been there and had taken pictures of it, just as people had been to other extraordinary places on Earth. And now, their "guy" had made it to Mars. "He was not a person, but he was a close friend." For many associated with the Viking project, the lander had become personified. "It is like a person invented by a committee. And we sent him there and he did his thing. . . ." Before the Viking missions Mars was a fictional or fantasy



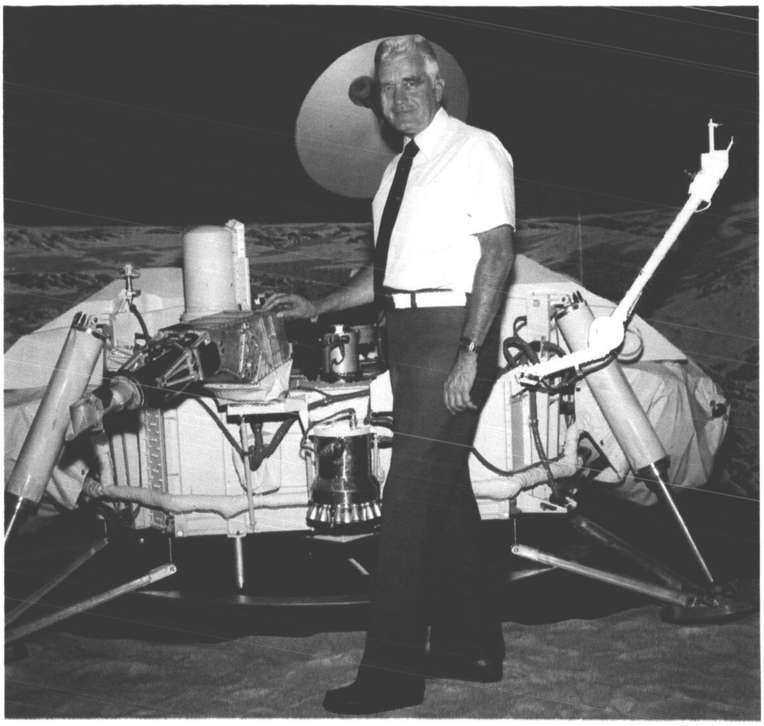
Two variations of the first color photo from the Viking 1 *lander, taken on the Mars surface 21 July 1976. The blue-sky version above was released the same day. Below is the true red-sky version released 26 July. The red cast is probably due to scattering and reflection from sediment suspended in the lower atmosphere. To assist in balancing the colors, a photo was taken of a test chart mounted on the rear of the spacecraft and the calibration then applied to the entire scene.*





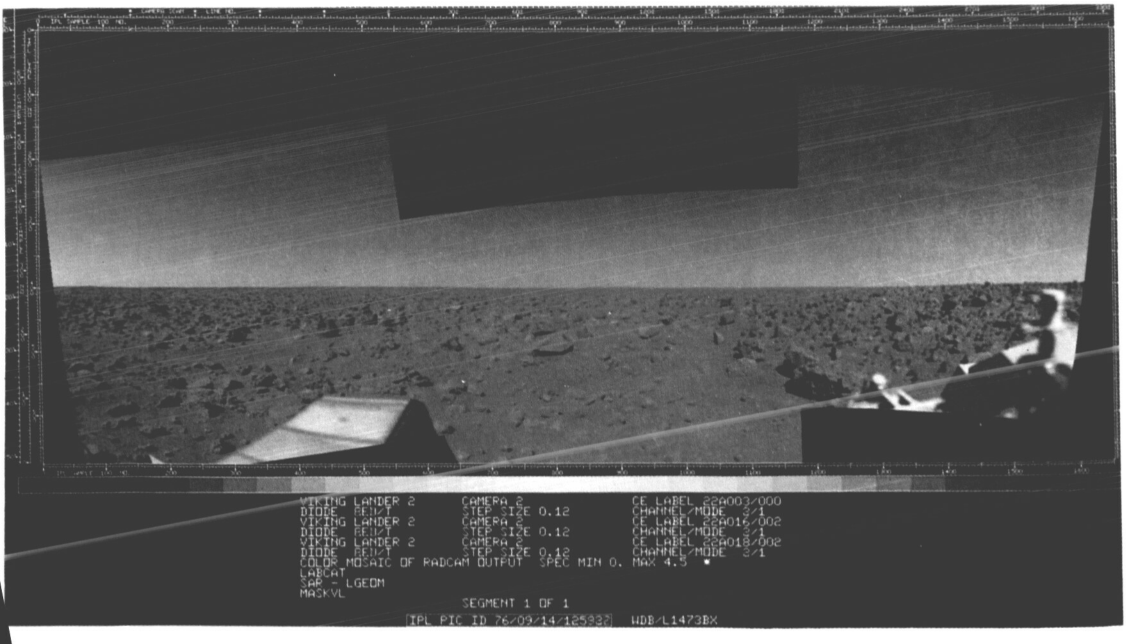


The two photographs above were taken with the Viking lander camera during tests in the summer of 1974. At the top is a panoramic shot from a site overlooking the Martin Marietta Corporation factory in Denver. The lower photo was taken at the Great Sand Dunes National Monument in southwestern Colorado. The lander camera is a facsimile camera, different in design from the television and film cameras which have been used on many space missions. The field of view is not imaged simultaneously. Instead, adjacent vertical lines are successively scanned. Reflected light from each of the "picture elements" in the line is recorded on a very small photodiode in the focal plane of the camera. Twelve diodes are available for use, each optimized for a different distance and a different part of the visible near-infrared spectrum.



Photos permit comparison of the color of the Viking lander on Mars (at left) and Earth (above)—especially the orange cables. Tim Mutch used this guide to show that the red-sky rendition of the Mars landscape was the correct one. In the Earth photo, Jim Martin stands beside the science test lander in the Von Kármán Auditorium at Jet Propulsion Laboratory.

Photos taken by the Viking lander camera provide comparison of an Earth scene (above) and one on Mars (below). In a photo taken near the Martin Marietta Denver facility during tests in 1974, tan and reddish sedimentary rocks have been tilted and eroded to form prominent cliffs. Data from three diodes (blue, green, and red) were combined for the color picture. Colors have not been balanced; the blue contribution is unnaturally large. For mission photos, colors were carefully calibrated. The Martian horizon stretches across nearly 200° in the composite of three color photos taken 4 September 1976 (center), 5 September (right), and 8 September (left). A thin coating of limonite (hydrated iron oxide) colors the surface predominantly rusty red, although some dark volcanic rocks can be seen. The horizon is flat because the photo has been rectified to remove the effects of the 8° tilt of the spacecraft.



place—the planet of Flash Gordon or some world peopled by Edgar Rice Burroughs. School children learn about the orderly progression of planets, and one of them has the same name as the world of many science fiction dramas. One Mars had physical, scientific properties like Earth; the other was a fantasy land. Now they could think of Mars as a genuine world. The shift from an object to be studied to a real place might not have been important scientifically, but it was a big change intellectually.[39]

Soffen pointed out that his personal involvement with the planet was not unlike that of the other Viking scientists. It had been eight years since the beginning of Viking. With the landing, the investigators were hungry for every bit of knowledge, any new speculation that would lead to a better understanding of the nature of Mars. Before the first photographs were received from the lander, Mars was more a scientific problem than an actual planet. When scientists talked about atmospheric conditions, they were describing numerical quantities that had an engineering significance for the designers. But it was difficult to think in terms of real clouds, real winds, real temperatures in the way we discuss our own weather. As the science fiction writers had built imaginary worlds on which their stories could take place, the scientists too had created a Mars that seemed to fit their assumptions. But the planet created from earlier known scientific facts had very little similarity to the Mars that the orbiter and lander cameras portrayed. Mars as a real place was much more complex and interesting than any that had been conjured up in the minds of scientists. The new Mars of Viking has as many complicated processes at work as does Earth.

Geologist Tim Mutch also had some personal reflections on what they had found awaiting them on Mars:

> If you were to tell a geologist that you were going to go out to two places on Earth with your little Brownie to take one or two rolls of film at each locality and then were to come back and from this interpret the history of the planet, he would think you were out of your mind, the most absurd thing he had ever heard of. In a sense it is. So one should not overestimate the exclusive model that you can generate from pictures.

But one thing that could be said definitively was that the terrain of Mars was not bland. A complicated history is exposed particularly in the photographs taken at the *Viking 1* site. "From a geological point of view, there is clearly a sequence of events represented. . . . involving fundamentally different processes—for example, impact, wind, volcanic activity, possibly fluvial activity and possibly ground ice."

The specialists confirmed a diversity of rock types on Mars, indicating several petrographic types; that is, rocks that probably have different mineralogy and at least have different texture. More boulders seem to be on the surface than can be accounted for by impact processes; perhaps the weathering of bedrock or the deposition of rocks by fluvial mechanisms account for them. And the bedrock visible in the Viking images indicates that some process, either fluvial or alluvial, is stripping off the soil to reveal the rock. At the *Viking 2* site, the rocks are more homogeneous. "They are highly pitted, due either to volcanic vesiculation or to some peculiar process we simply do not understand," reported Mutch. Some scientists think *Viking 2* landed on a widespread, fine-grain sediment mantle—the polar mantle. The boulders littering the scene were probably imposed, either as broken lava flows or as ejected boulders from a nearby crater.[40]

Seeing another planet up close opened the way for a comparison of two evolving worlds. With the passing of the romantic Mars and the gradual acceptance of the new Red Planet has come both excitement and disappointment. Looking at a tangible place is far more exciting than ruminations about abstract places, but the absence of life was a blow to many who had hoped to discover life or who had hoped that life might have had a chance to evolve. The biological and organic investigations indicated that the prerequisites for life on Mars were not evident at either landing site.[41]

SCIENCE ON MARS

Weather

When Viking touched down on the surface, weather reports started streaming their way to Earth. Martian weather was clear, cold, uniform, repetitious. Seymour L. Hess, meteorology team leader, reported on conditions at Chryse Planitia on sols 2 and 3:*

> Winds in the late afternoon were again out of a generally easterly direction but southerly components appeared that had not been seen before. Once again the winds went to the southwesterly after midnight and oscillated about that direction through what appears to be two cycles. The data ended at 2:17 PM (local Martian time) with the wind from the ESE, instead of from the W as had been seen before. The maximum mean wind speed was 7.9 meters per second (18 mph) but gusts were detected reaching 14.5 meters per second (32 mph).
>
> The minimum temperature attained just after dawn was almost the same as on the previous Sol, namely -86°C. . . . The maximum measured temperature at 2:16 PM was -33°C. . . . This [was] 2° cooler than measured at the same time on the previous Sol.
>
> The mean pressure was 7.63 mb, which is slightly lower than previously. It appears that pressure varies during a Sol, being about 0.1 mb higher around 2:00 AM and 0.1 mb lower around 4:00 PM.[42]

During the course of the Viking lander experiments, Hess and his fellow meteorologists discovered two interesting facts about Martian weather patterns. One was the extreme uniformity of the weather, presum-

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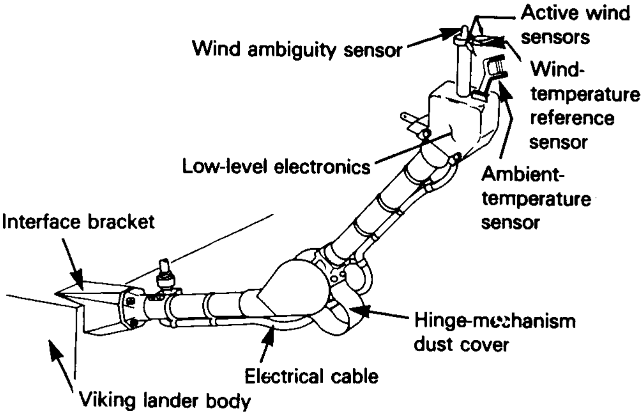
**Sol* is used to designate the Martian day, which is 39.6 minutes longer than an Earth day; 20 July was listed as sol 0 because just a few hours were left in the sol (local lander time) at the time of landing. Sol 1 began late on 20 July, at the first lander 1 midnight.

Table 54
Mars and Earth Temperatures
21 July 1976

	Mars	Earth	United States
Lowest temperature	-85.5°C	-73°C (Soviet Vostok Research Station, Antarctica)	2.7°C (Point Barrow, Alaska)
Highest temperature	-30.0°C	47.2°C (Timimoun, Algeria)	42.7°C (Needles, California)

ably due to the Martian atmosphere, which is much simpler than Earth's. The Red Planet has only very, very small amounts of water vapor and no oceans—makers of extreme weather on Earth. Earth's atmospheric and surface water contribute substantially to the variability of its weather. The second discovery was the seasonal variation of pressure. When Viking first landed, its instruments detected a steady decrease in the mean pressure from day to day. But in the extended mission, the pressure at both landing sites reached its lowest value seasonally and began to rise again. The Viking meteorologists think this variation is due to the condensation of carbon dioxide on the winter cap and its release as spring comes to the northern hemisphere. This process would remove a major constituent from the atmosphere at a certain rate, changing the pressure accordingly.

At the second Viking site, 48° north, the temperatures dropped as expected during the Martian winter. Early in the mission, the minimum temperature was about -87°C, but during winter the minimum temperature at dawn was -118°C. Frost on the surface was first observed in mid-September 1977. At the time, the second lander was recording nighttime temperatures of -113°C, and a photo of the frost was taken at -97°C. With winter, the wind speeds increased slightly, especially at the *Viking 1* site, with several interruptions in what had been a regular pattern of wind



Viking lander's meteorology boom and sensors in deployed configuration.

direction. There were several periods of northerly winds all day for several days in a row, associated with temporary drops in temperature—Martian cold fronts. Hess and his colleagues had thought winter, with the fallout of carbon dioxide, would greatly increase wind speeds and variability. There were some wind directional changes and gusts, but no noticeable changes of patterns in wind direction or speed were recorded.[43]

Hardware Problems

While Hess and his meteorological colleagues began to compile weather data for the *Viking 1* landing site, other experimenters were having their difficulties. First, the seismometer was not functioning. Its seismic sensor coils had been "caged" mechanically to prevent damage to these sensitive components during the shock of landing. Following touchdown, a fusible pin-pulling device was to have detonated, unlocking the seismometer so it could begin full operation. For some reason, perhaps a broken or misconnected wire, the fusible device failed to work, and the instrument remained in the caged position. While the *Viking 2* seismometer performed satisfactorily, the *Viking 1* failure prevented the seismology team from locating the approximate origin points of recorded seismic activity.[44]

Don Anderson and his colleagues on the seismology team was afraid that the sensitive seismometer on Viking would be hampered by the high winds on Mars. But during the night from about 6 p.m. through the next morning, the winds die down to about virtually zero and there are essentially no seismic background noises. During that time, the seismometer can be operated "at a very high sensitivity." Marsquakes as small as a magnitude of 3 at a distance of about 200 kilometers can be recorded. By comparing a Marsquake with a similar Earthquake, the specialists estimated the mean crustal thickness at the *Viking 2* landing site to be about 14 to 18 km, about half the thickness of the crust in the continental parts of Earth and about 50 percent greater than the average thickness of the oceanic crust. Viking scientists think the crust on Mars may be as thick as approximately 80 km, much thicker than the crust under continental regions on Earth.

An unexpected result of the seismic experiment was a great amount of information about the winds on Mars. A very sensitive wind detector, the seismometer picks up the wind pressure on the lander, from which characteristics of the wind can be determined. Like the meteorologists, the seismology team detected the cold fronts. The wind pattern "changed very rapidly on the 131st Martian day. The winds . . . started to blow all night until 2 or 3 a.m. indicating a substantial change in the weather patterns. If very high winter winds had continued at night, they could have generated the massive dust storms we have observed in the winter time." However, orbiter photographs have shown only a few isolated dust storms, with none reaching the magnitude of the planetwide dust storm of 1971.[45]

Another cause for concern for the Viking team appeared on the second day of landed operations. The lander's UHF transmitter had been designed to operate at three different power levels—1 watt, 10 watts, and 30 watts—depending on the rate of data transmission required. During the relay-link portions of the mission, the 30-watt power level was scheduled for use, to permit the transmission of the maximum amount of scientific data. From the observed performance of the initial landed relay link, confidence in the system was high. During the first relay, approximately 30 million bits of data were transmitted to the orbiter, recorded, and subsequently transmitted to Earth, all within a few hours after the information left the surface of Mars.* Success, however, was short-lived.

On 22 and 23 July, the UHF transmitter switched over to the 1-watt power level without instructions to do so. Tom Young told the press, "In the one-watt mode you can get slightly over seventeen minutes' worth of data from the Lander to the Orbiter." The mission had been designed so that slightly more than 18 minutes of data would be transmitted to the orbiter as it passed overhead, so the problem was not a critical one, but it did pose a vexing limitation. At the 30-watt level, the lander could transmit telemetry to the orbiter for 30 to 32 minutes.[46]

On the morning of 24 July, the UHF transmitter switched back to the 30-watt power level. Tom Young reported this second mysterious power change at the news briefing that day: "When we had the relay [of information] today, lo and behold, it came up in the 30-watt mode, operating as we would like for it to. So our statistics, to date, are two relay periods in the 1-watt mode, two periods in the 30-watt mode. We are continuing the analysis of this particular anomaly.[47] The radio specialists suspected that the problem lay in the power-mode control-logic subassembly of the UHF transmitter. To counteract this trouble, commands had been prepared to order the guidance control and sequencing computer to eliminate the electronic "noise" causing the problem. Before this command was sent up, the tansmitter switched back to the 30-watt power level. The change supported the theory that the problem was associated with noise susceptibility. Following the self-correction, the UHF transmitter performed as expected until one week before the end of *Viking 1*'s primary mission. At that time, telemetry indicated that there were potentially new problems with the 30-watt level. To avoid a catastrophic failure and to extend the transmitter's life for use in the "follow-on" mission, the lander performance analysts decided to use the 10-watt power mode for the last sols of the basic mission.[48]

The landed relay communications for *Viking 2* did not demonstrate any anomalies. On sol 21 of the second landed mission, orbiter 1 was moved into position over lander 2 to provide a relay link. This maneuver permitted mission planners to send orbiter 2 on an extended "walk" around the planet, to photograph the poles and other regions of Mars and scan them

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*The relay links for the first 11 sols were pre-programmed for redundant playback and transmission to Earth of the lander-recorded data so as to prevent loss of any important information.

with the infrared thermal mapper and the Martian atmospheric wate detector. Orbiter 1 continued to provide the communications link for the second lander during the remainder of *Viking 2*'s primary mission.[49]

A more serious problem emerged in the first days after *Viking 1*'s touchdown when the surface sampler arm became stuck. On Thursday, 22 July, the surface sampler assembly was rotated so that the protective shroud covering the sample collector head (scoop) could be jettisoned. During this operation, the sampler boom was to be extended a few centimeters and then returned to the stowed position. Extending the boom was no problem, but on retraction it stuck. At first, Jim Martin and crew thought the problem was one of electronics. At 6:30 p.m. on the 22d, Martin told reporters preliminary indications were that perhaps the soil-sampler control assembly—the receiver for computer commands—had "some kind of an electronic problem." He could switch to a redundant soil-sampler control assembly if that was the problem, but, "the concern I have at the moment is that unless we can solve or understand this problem and solve it in fairly short order we are likely to run the risk of impacting the soil acquisition sequence on Sol 8."[50]

By 10 p.m. on the 22d, Martin's team had arrived at a new theory. Prefacing his remarks to the media with, "It has been a very busy day," Martin addressed the problem of the sampler. Everyone knew that loss of the sampler would be a major setback for Viking science activities. Without it, no samples would be delivered to the biology instrument, the gas chromatograph-mass spectrometer, or the x-ray fluorescence spectrometer. Martin believed that his people, who had worked all evening, had "isolated the most probable cause of the problem. It turns out, contrary to my expectation, not to be an electrical problem." Instead, it was apparently a simple—if anything can be simple when working with a piece of equipment millions of kilometers away—mechanical hangup. Martin pointed out "that there is a locking pin that is part of the shroud latching system"; that pin "was supposed to drop to the Martian surface during the boom extension. . . . It now appears that the extension that had been commanded in the sequence was not long enough to allow this pin to drop free."

Martin had observed a duplication of the difficulty on the science test lander, which was housed in a glass-walled room next to the auditorium in which the press briefings were held at JPL. Commenting on the fishbowl atmosphere in which his people had been working, Martin told the reporters, "I went in and looked at it myself when some of you weren't looking." The stuck pin was "certainly a plausible and possible failure mode." To test this theory, "we plan to send up a new command sequence on the Sol 5 command load which will go up at around midnight Saturday night," 24 July. Mission analysts thought that extending the boom to about 35 centimeters would let the pin fall. Martin added, "If by some chance the pin was retained within the mechanism, which I really believe is doubtful, we don't ever intend to retract it as far as we did in the original sequence." That way, they would avoid another difficulty; at a certain point the boom extraction motor would clutch on purpose and then shut itself off to avoid damage to the motor. If the pin did not drop free this time, the boom would be ordered to extend far enough so that the "no-go" signal would not be given.[51]

Two photographs taken by the lander camera on sol 5, 25 July, showed that the retaining pin did fall free, landing on the ground in front of the craft.[52] The apparent ease with which this problem had been diagnosed and corrected hid the months of training and preparation for such mission operations. Subsequently, more serious troubles were to plague the soil-sampler assembly, but each time training and ingenuity permitted the team to work out solutions and keep the mechanism functioning. Adaptability was one of the key elements of Viking's landed operations.

Communicating with the Spacecraft

Before separation from the orbiter, the lander had been given an initial computer load (ICL, or "ickel"), which contained all the computer commands necessary for a basic 60-day mission, even if there were no further communications from Earth. With normal communications between the spacecraft and mission control, the mission programmers could modify the initial computer load as needed to get the most out of the lander. Commands were "uplinked" to the lander from JPL through the stations of the Deep Space Network to the orbiter and then to the guidance, control, and sequencing computer. The command uplinks, made in three-day cycles, were the responsibility of the lander command and sequencing team of the lander performance and analysis group.

Agreeing on the commands to be sent to the lander, programming them, and checking them out through simulations was a complex series of tasks, which required a great deal of work and interaction among many persons. An example is the decision to photograph the sampler boom immediately after acquisition of a sample. The requirement would first be sent to the lander imaging team, which had three three-person squads who handled such requests. These uplink squads, plus a "late-adaptive squad" responsible for last-minute alterations, would investigate the picture called for and determine if it could be combined with others or if it had to be taken by itself. The series of pictures for a given sol was then described and combined into a science requirement strategy that was passed on to the Lander Science Systems Staff, which had the difficult task of matching wants (requirements) with the constraints imposed by the lander systems and the other tasks that had to be accomplished.

The Lander Science Systems Staff received the uplink plans in the form of computer printouts called science instrument parameters—specific commands to the guidance, control, and sequencing computer. Lander imaging had 56 commands available, and each could be adapted to special requirements. Once approved by the Lander Science Systems Staff, the parameters were passed on to the lander computer simulations personnel, who ran through the commands to see if there were any software or hard-

Viking Surface Sampler

The Viking lander's chemical and biological investigations all used samples of surface materials excavated by the surface sampler. In addition, as the experience with lunar Surveyor spacecraft demonstrated, there was much to learn about the surface simply by digging in it. In the Viking mission, digging was part of the physical properties and magnetic properties investigations.

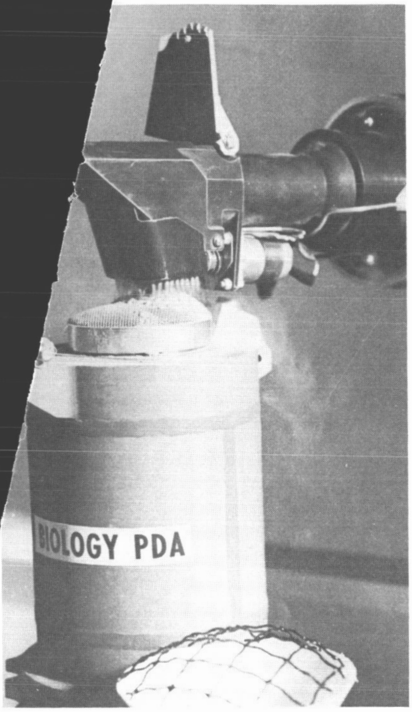
The surface sampler consisted of a collector head attached to the end of a three-meter retractable boom. The arm housing the boom could be moved both horizontally and vertically. The boom itself was constructed from two ribbons of stainless steel welded together along the edges. When extended, the two layers opened to form a rigid tube. When retracted, the boom flattened. A flat cable sandwiched between the boom layers transmitted electrical power to the collector head.

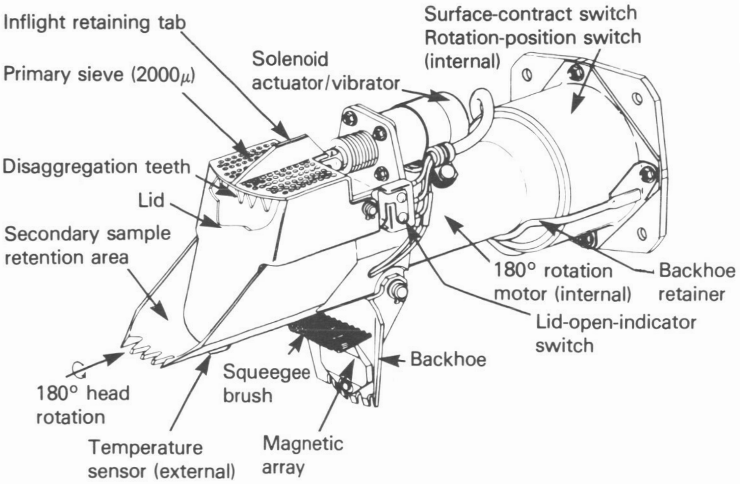
The collector head was basically a scoop with a movable lid and a backhoe hinged to its lower surface. Where the scoop is attached to the end of the boom, a motorized rotator acted as a mechanical wrist to permit manipulation of the collector head. To fill the scoop, the lid was first raised and then the boom was extended along or into the surface. Once full, the lid closed. The top of the lid had holes two millimeters in diameter, which formed a sieve. When the collector head was positioned over one of the inlets for the instruments, it was inverted and vibrated. Only particles smaller than two millimeters were delivered to the instrument inlets. Coarser samples could be delivered to the x-ray fluorescence spectrometer, if desired. The gas chromatograph-mass spectrometer and the biology instruments had their own filters to control the size of material introduced into their sample processing assemblies.

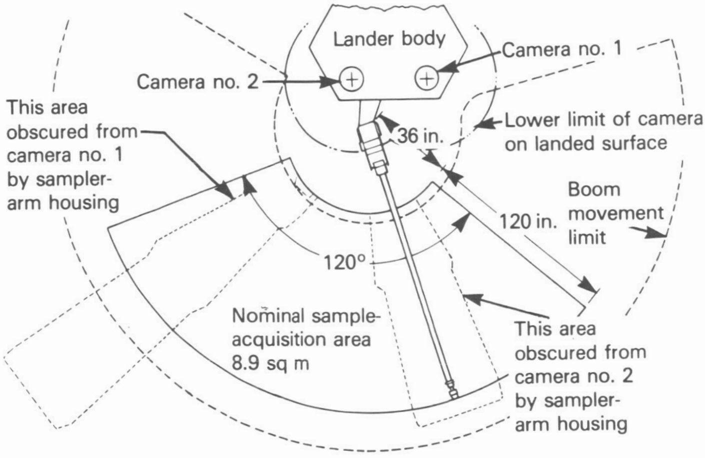
The surface sampler could also dig trenches, by lowering the backhoe to place the sampler head on the surface, and then retracting the boom. Excavated materials could be scooped up for sampling. A brush, magnets, temperature sensor, and other instrumentation also provide data concerning the physical properties of the materials.

ware conflicts. Considerations such as electrical energy required or the thermal impact of a command were also determined. Following simulations, the request was codified into a "lander sequence." After all the necessary changes (massaging) were completed, the command was entered into the ground-based computer and relayed to the Deep Space Network for transmission to Mars.

Uplink teams preparing lander sequences worked about two weeks ahead of the time the command was to be executed. Changes could be made in the planned uplink until about 48 hours before it was loaded into the

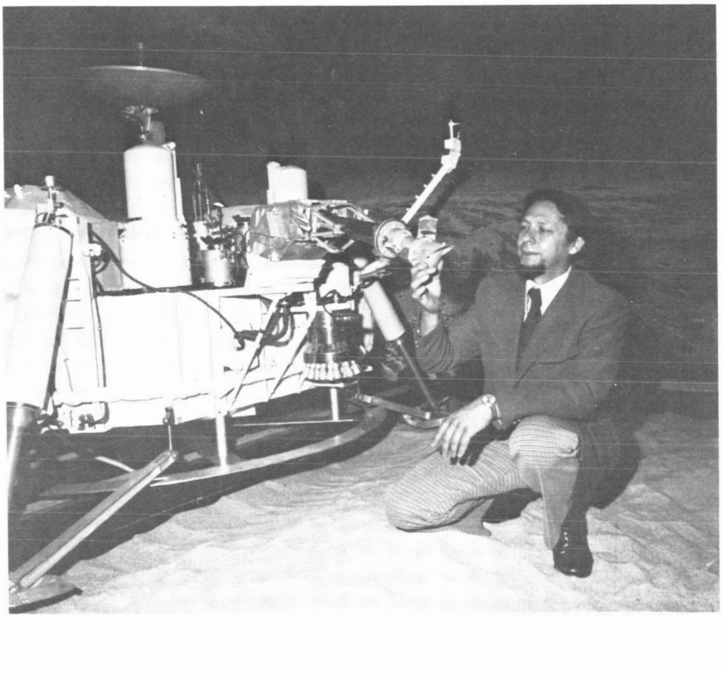






Sampler-Arm Area of Operation

A premission photo, above, shows how the surface-sampler collector head deposits its contents into the biology-instrument processor and distributor assembly. The collector head and the area of the sampler arm's operation are sketched at right. Below, project scientist Gerald Soffen examines the collector head on the science test lander at JPL.



computer. Obviously, uplinking was a precise, demanding business. Mistakes were totally inadmissable. Although out of the limelight, the people responsible for talking with the lander had a difficult task. Occasionally, nerves wore thin when the requirements of different science teams conflicted. The uplinkers were expected to satisfy everyone's needs, and for the most part they did.[53]

Sampling the Martian Surface

Scientifically, the most important experiments aboard the lander were those which sampled the planet's surface. Of these, the chemical analyses were interesting, but the biological experiments were a disappointment. As with other investigations, Mars again turned out to be a more complex riddle than anticipated and, while there is still disagreement over the exact causes of some of the reactions observed, most—but not all—of the Viking scientists have come to the opinion that detection of life on Mars is a very unlikely prospect.

The first soil samples were acquired on sol 8, 28 July. Four samples were dug, with the first being deposited into the biology instrument distributor assembly, the next two into the GCMS processor, and the fourth into the funnel of the x-ray fluorescence spectrometer. All the commands were successfully executed, but there was no positive indication that the gas chromatograph-mass spectrometer processor had been properly filled. A second acquisition attempt still did not provide a "sample level detector 'full' indication." The sampler system, having completed its programmed sequences in a normal manner, parked the boom as planned. On Earth, the lander performance specialists began to analyze the possible causes of the anomaly: (1) insufficient sample acquired in the collector head because the same sample collection site had also been used for the biology sample; (2) insufficient time allowed for the sample to pass from the funnel through the sample grinding section and then through the fine (300-micrometer) sieve into the metering cavity of the instrument; (3) grinder stirring spring not contacting the sieve; or (4) sample-level-detector circuit faulty. Since the "level-full" detector consisted of a very fine wire stretched across the cavity to which the sample material was delivered, it was also possible that it had broken when the soil was dropped into the funnel.[54]

An anomaly team headed by Joseph C. Moorman, who had worked closely with the builders of the GCMS, went to work on this problem. While preparations were made for another sample to be collected on sol 14, 3 August, Martin and Young had to decide whether to proceed on the assumption that the GCMS had actually been filled and chance wasting one of the two remaining ovens on an empty chamber (the specialists had determined that one of the ovens was inoperable during the GCMS in-flight checkout) or pick up another sample on sol 14. Conservatism and caution argued for the latter decision, and the managers chose that option. But the boom did not cooperate. It jammed.

The surface-sampler control-assembly sequences performed normally through the 12th command. During the execution of the 13th (boom retraction to 26.7 centimeters), trouble showed up; when the computer issued the 14th command, the assembly would not respond. Examination of photos taken on sol 14 revealed that the sampling trench had been dug as ordered, but the collector head was not over the GCMS funnel where it was supposed to be. An image received on sol 15 showed the back of the boom. Three possible reasons for this new anomaly were considered: (1) failure of the surface-sampler control-assembly electronics; (2) failure of the boom motor or related equipment; or (3) jamming of the boom, precluding proper retraction. Causes 1 and 2 were rejected after analyzing the proper performance through the first 12 commands. Jamming had most likely caused the difficulty since the failure appeared to be similar to the "no-go" response encountered with the sol 2 shroud-pin jam.

Frozen carbon dioxide or surface material were rejected as possible causes of jamming the boom, because of the absence of a slowly increasing motor load, which the investigators would have detected. Discussion of the anomaly with the boom designers revealed that a similar problem had occurred during early test phases, and they believed it was caused when a series of successive retract (or extend) commands had been issued. In testing, the successive commands tightened the boom element on the storage drum, and the boom element tended to wind around the drum in a 5- or 6-sided configuration rather than in a perfect circle. This arrangement caused intermittent high loading when the "points of the hexagon" passed under the boom restraint brake shoes. The reliability of the system was further weakened when operated at low temperatures; the motor torque limiter finally decoupled, and movement of the boom ceased. Two major operating procedures were proposed to meet the problem: (1) All sequences were to be revised to eliminate successive extend or retract commands, avoiding excessive tightening of the boom element on the drum. The command reversals would cause the extend or retract "flip-flop" gear to disengage the load during each cycle, allowing the motor to attain full speed and operating torque before it reengaged the load in the opposite direction. (2) Future operations were to be performed within one to two hours of the peak temperature during the Martian sol. An uplink diagnostic sequence was designed for sol 18; the boom would be used in each axis of operation—extend, retract, up elevation, down elevation, clockwise, and counterclockwise. The sequence was executed properly and no anomalies were met. Following Martin Marietta's instructions, all activities of the sampler arm were redesigned "to exclude, wherever possible, successive extend or retract commands, and to perform these operations during the warmest part of the sol." The Viking team had no further problems with the sampler boom on either lander, and operating temperature restrictions were eventually waived because of the need to acquire early morning biology samples. Preflight testing and the documentation of those procedures had paid off.[55]

The sol 14 anomaly forced Martin and Young to reconsider their decision not to analyze the "possible" sample acquired on sol 8. Influenced by early results from the biology experiments, the molecular analysis team urged that the contents of the gas chromatograph-mass spectrometer be analyzed. Jim Martin and Tom Young agreed.

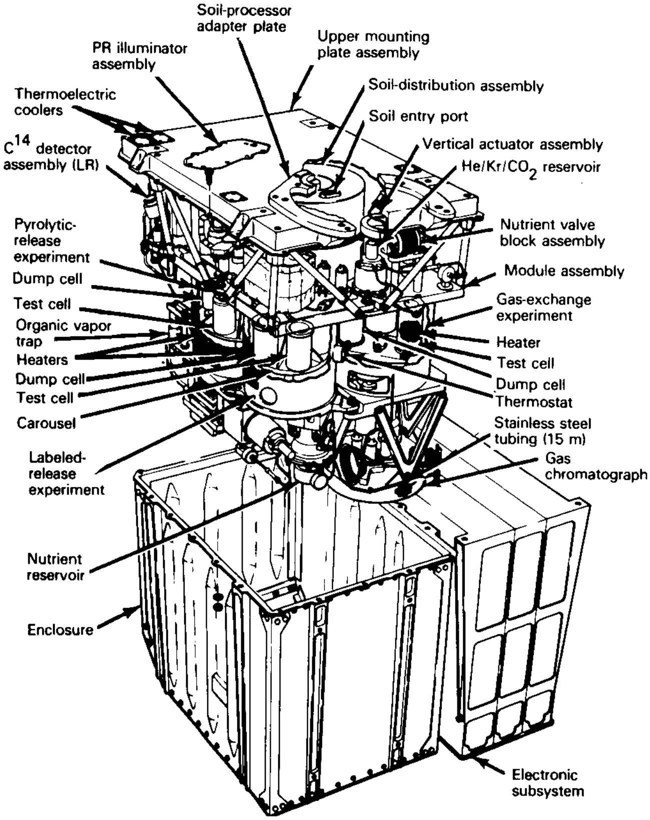
Biology. At the 1:30 p.m. news briefing on 31 July 1976 (sol 11), Jim Martin made an announcement. Prefacing his remarks with, "I wanted to state that it's been project policy for seven years to make data available to the media when we have [them]," Martin noted that this day was "no exception. We have received biology data that we believe to be good data." Engineering telemetry indicated that the biology instrument was performing "extremely well," perhaps too well, since early reactions from the gas-exchange and labeled-release experiments were very positive. That could possibly be the consequence of biological activity, but Martin was cautious: "I think Chuck Klein will continue to caution you that the biology experiment is a complex one. We've seen that Mars is a complex planet. There are many things that we do not understand." The scientists were proceeding systematically and methodically.[56]

Biology Team Leader Harold P. Klein and his colleagues had already conducted a number of tutorials for the news people covering the Viking mission, and at each session where they presented analytical details they took time to explain the experiment in question. The biologists started with the basics. Each Viking lander carried an integrated biology instrument, which contained three experiments designed to detect the metabolic activity of microorganisms should they be present in the soil sampled. First, the gas-exchange experiment would determine if changes caused by microbial metabolism occurred in the composition of the test chamber atmosphere. Second, the labeled-release experiment, also known as Gulliver, would determine if decomposed organic compounds were produced by microbes when a nutrient was added. Third, the pyrolytic-release experiment would detect, from gases in the chamber, any synthesis of organic matter in the Martian soil. A change could be the result of either photosynthetic or nonphotosynthetic processes.

On 31 July, Klein told the press: "What we are proposing to do for you today [is] to give you a status report on the three experiments and we'd like to then focus on one of the experiments, the labeled release experiment, a little more closely since some of that data is exciting and interesting." First, all three instruments were working normally. "We have no anomalies, no problems despite what some of the press or other news media have said." He had heard rumors that the biology instrument was "sick, dead in the water." The truth was that the instrument was in good shape, and he had two important, unique facts.

First, the gas-exchange experiment had given them reason to believe that "we have at least preliminary evidence for a very active surface material. . . . We believe that there's something in the surface, some chemical or physical entity which is affording the surface material a great activity." But, adding a word of caution, he noted that the reaction observed in the gas-exchange experiment might be mimicking some aspects of biological activity. Second, the labeled-release experiment's radioactivity counters were measuring "a fairly high level of radioactivity which to a first approximation would look very much like a biological signal." The highly active nature of the soil, however, caused the biology team members to be cautious. "That second result must be viewed very, very carefully in order to be certain that we are, in fact, dealing with a biological or non-biological" phenomenon.

Klein reported on the sequencing of the three biology experiments. Norman Horowitz's pyrolytic-release experiment had been started first. After the soil had been injected into the test chamber and carbon 14-labeled carbon dioxide added, the xenon lamp had been turned on; incubation would last until at least sol 14, when the first results might be available. Vance Oyama's gas-exchange experiment had also received its soil sample on 28 July, but the incubation process was not begun until the morning of the 29th, when the chamber containing the soil and Martian atmosphere was injected with a mixture of carbon dioxide, krypton, and half a cubic centimeter of nutrient. About two hours later, gas in the chamber was analyzed—a calibrating measurement against which all subsequent analyses would be measured. Calling for the lights in the Von Kármán Auditorium to be turned off, Klein had a chromatogram based on the first gas exchange results projected on the screen behind him:



Biology instrument

> What we saw were five peaks—little tiny peaks: neon, over here on your left and that's explainable by the neon that we used in the nutrient chamber itself and that's our indication that we, in fact, injected nutrient and that's fine—there's nothing unusual about that. Then you see nitrogen and that amount of nitrogen can be accounted for by the nitrogen in the atmosphere and a small amount of nitrogen that we know was contaminating our CO_2 krypton mixture. Then we see this oxygen peak which I will come back to in a moment. And then as a shoulder beside the oxygen, you see a small peak and that's a combination of argon and carbon monoxide and that amount of gas would be consistent with current estimates of argon and carbon monoxide in the atmosphere.

A large krypton peak, Klein explained, was present because they had added krypton in a specifically known amount to provide a standard reference for determining the amount of other gases that might be present. He turned back to the oxygen peak: "You will see at the base of that oxygen peak, a little bar—that's the amount of oxygen down there that we can account for, or could account for from all known sources in the atmosphere or in the contamination of our gas mixture." But the instrument on *Viking 1* was indicating 15 times more oxygen than the scientists could account for from known sources. The results from the second measurement made 24 hours later showed that all the gases had remained the same except oxygen. It had increased by 30 percent. After ruling out all other possible causes, the scientists concluded that the oxygen had to be coming from the soil itself. While one possible explanation for the increase was biological activity, other explanations were possible, too.[57]

A possible alternative answer to why the initial amount of oxygen had been released lay in the desert area of landing site; the Martian samples contained peroxides and superoxides, which when exposed to abnormal (non-Marslike) humidity in the instrument quickly released oxygen. The related release of carbon dioxide suggested that the samples had an alkaline core. Although such reactions had not been witnessed on Earth, the scientists believed that the intense ultraviolet radiation bombarding the surface of the Red Planet could have produced unique photocatalytic effects. Still, there was much to be explained, including the reactions observed from the labeled-release investigation.

Gulliver was sending back some surprises. As with the gas-exchange experiment, the labeled-release experiment added a small amount of nutrient to the soil sample. It also produced a large amount of gas after that injection. Where the gas-exchange produced a spectrum of the gases, the labeled release measured the amount of radioactivity produced by the carbon-14 "labeling" material in the nutrient. Shortly after the addition of the nutrient, the radiation counts rose sharply, leveling off at about 10 000 counts per minute.

Gil Levin gave the audience at JPL a brief resume of the activities since the injection of the nutrients, which had occurred at about 1:45 p.m. PDT on

30 July. That injection had consisted of about 0.1 milliliter, or about 2 drops, of liquid. As Levin noted, "If any organisms are present that can utilize the nutrient and if these organisms behave biochemically—roughly as terrestrial organisms do—they should imbibe the nutrient and exhale a radioactive gas." Resulting radioactivity was measured periodically by a radiation detector. The result on Mars was very interesting. It was similar to ones encountered with living organisms detected in terrestrial soil, but Levin warned, "We are far too early in the game to say that we have a positive response." There were too many factors that had to be weighed and tested. "All we can say at this point is that the response is very interesting, be it biological or non-biological, it is unanticipated."

As in the gas-exchange experiment, there was a possibility that the soil itself contained catalysts, minerals, inorganics that produced some breakdown of the radioactive compounds. "The effect of water introduced into the dry Mars soil may cause violent chemical reactions that would disintegrate a portion of our medium." As a consequence, Levin thought that any speculation about the biological or nonbiological nature of the response would have to await further data.[58]

By 1 August, the production of oxygen in the gas-exchange experiment had decreased considerably, thus supporting the belief that the release was the function of oxides in the soil. In a 2 August update on the labeled-release experiment, Levin noted that they had examined the radioactivity curve very carefully. They had found no evidence of any doubling of cells. No growth appeared to be taking place, but the curve did not seem to behave as scientists would have expected it to for chemical reactions either. "We find that the chemical reaction took place at a very rapid rate initially, and then uncharacteristically slowed down and took a long time to plateau." The curve detected with the labeled-release experiment did not agree with known responses for either chemical or biological reactions.[59]

Data returned by the pyrolytic-release experiment and reported by Norman Horowitz on 7 August were equally confounding. Once again, the specialists had detected a reaction, but they did not know what it meant. "There's a possibility that this is biological," Horowitz said, but "there are many other possibilities that have to be excluded." The results obtained the night before were interesting but he emphasized that they were not ready to say that they had discovered life on Mars. "The data point we have is conceivably of biological origin, but the biological explanation is only one of a number of alternative explanations." He told the press:

> We hope by the end of this mission to have excluded all but one of the explanations, whichever that may be. I want to emphasize that if this were normal science, we wouldn't even be here—we'd be working in our laboratories for three more months—you wouldn't even know what was going on and at the end of that time we would come out and tell you the answer. Having to work in a fishbowl like this is an experience that none of us is used to.

He also cautioned the reporters that they were being included in the analysis phase of the experiments. They were "looking over the shoulder of a group of people who are trying to work in a normal way in an abnormal environment."[60] The scientist's caution was prompted by his knowledge that "we well might be wrong in anything we say. Anyone who has carried out a scientific investigation knows that the pathway of science is paved not only with brilliant insights and great discoveries, but also with false leads and bitter disappointments. And nobody wanted to be wrong in public on a question as important as that of life on Mars."[61]

Later in a November 1977 *Scientific American* article, Horowitz was able to speak more authoritatively about the results that had been observed in all three experiments. In the gas-exchange experiment, "the findings of the first stage of the experiment were both surprising and simple." Immediately following the addition of the moisture to the sample chamber—the soil sample was not directly wetted—carbon dioxide and oxygen were released. The evolution of gases was short-lived, but the pressure in the chamber increased measurably. At the Chryse site, the amount of carbon dioxide increased by about 5 times, and the amount of oxygen increased by about 200 times in little more than one sol. At the landing site in Utopia, the increases were smaller but still "considerable." Upon reflection, Horowitz stated that "the rapidity and brevity of the response recorded by both landers suggested that the process observed was a chemical reaction, not a biological one." Horowitz felt that the appearance of the carbon dioxide was readily explainable: "Carbon dioxide gas would be expected to be adsorbed on the surface of the dry Martian soil; if the soil was exposed to very humid atmosphere, the gas would be displaced by water vapor." The presence of the oxygen was logical but harder to account for, since so much oxygen would seem to require an oxygen-producing substance, not just the physical release of preexisting gas. There was just not that much oxygen available in the atmosphere—past or present—to account for the quantities measured. Horowitz argued that it was "likely that the oxygen was released when the water vapor decomposed an oxygen-rich compound such as a peroxide. Peroxides are known to decompose if they are exposed to water in the presence of iron compounds, and according to the X-ray fluorescence spectrometer . . . the Martian soil is 13 percent iron."

At both sites, the second phase of the gas-exchange experiment was "anticlimactic." When the sample was saturated with the aqueous nutrient, more carbon dioxide and oxygen were produced. The additional evolution of carbon dioxide was probably a continuation of the reaction observed in the humid stage of the experiment. Horowitz believed that the amount of oxygen then diminished because of its combination with the ascorbic acid in the nutrient medium. "And so . . . it became clear that everything of interest happened in the humid stage of the experiment, before the soil came in contact with the nutrient!" Thus, in November 1977, Horowitz confidently stated that the gas-exchange experiment had detected "not metabolism but the chemical interaction of the Martian surface material with water vapor at a pressure that has not been reached on Mars for many millions of years."[62]

In the labeled-release experiment, there was a similar rapid surge of gas into the test chamber when the nutrient solution was added to the soil. This release tapered off shortly after the passage of one sol. Horowitz noted, "The gas, undoubtedly carbon dioxide, was radioactive, showing that it had been formed from the radioactive compounds of the medium and not from compounds in the Martian soil." He also believed that other nonradioactive gases were evolved when the water in the nutrient medium came in contact with the sample, but that these could not be detected by the instrument. "The production of radioactive carbon dioxide in the labeled-release experiment is understandable in light of the evidence from the gas-exchange experiment suggesting that the surface material of Mars contains peroxides." Formic acid, which was one of the compounds in the labeled-release nutrient, is oxidized with relative ease. "If a molecule of formic acid (HCOOH) reacts with one of hydrogen peroxide (H_2O_2), it will form a molecule of carbon dioxide (CO_2) and two molecules of water (H_2O)." The amount of radioactive carbon dioxide produced in the experiment was only slightly less than would have been predicted if all the formic acid in the nutrient had been oxidized in this manner.

Going a step further with his analysis, Horowitz said that if the source of the oxygen in the gas-exchange experiment was peroxides in the soil decomposed by the water vapor, then the labeled-release experiment should have decomposed all of the peroxides with the first injection of nutrient. The second injection should have produced no additional radioactive gas. That was what happened. "When a second volume of medium was injected into the chamber, the amount of gas in the chamber was not increased; indeed, it decreased. The decrease is explained by the fact that carbon dioxide is quite soluble in water; when fresh nutrient medium was added to the chamber, it absorbed some of the carbon dioxide in the head space above the sample."

In the labeled-release experiment, the stability of the reaction to heating at various temperatures was examined. Heating reduced and subsequently stopped the reaction. This result has been interpreted by some to be evidence in favor of biological activity, but Horowitz, although conceding that the effects of heating could be explained by biological activity, said that these results were also consistent with a chemical oxidation in which the oxidizing agent is destroyed or evaporated at relatively low temperatures. "A variety of both inorganic peroxides and organic peroxides could probably have produced the same results."[63]

The third biology experiment, pyrolytic release, differed from the others in two basic respects. First, it attempted to measure the synthesis of organic matter from atmospheric gases rather than the decomposition of that matter. Second, it was designed to operate under pressure, temperature, and atmospheric composition that were nearly the same as those on the planet. During the actual operation of the pyrolytic-release investigation, the temperatures ran higher than those normally encountered on Mars because of heat generated within the lander. A sample of the soil was sealed in the test chamber along with some of the planet's atmosphere. A xenon arc lamp simulated the sun. Into this Martian microcosm, small amounts of radioactive carbon dioxide and carbon monoxide were introduced. After five days, the xenon lamp was turned off, and the atmosphere was removed. The soil was then analyzed for the presence of radioactive organic matter.

Analysis of the soil began with heating it in the pyrolyzing furnace—hence, the name pyrolytic release—to a temperature high enough to reduce any organic compounds to small volatile fragments. Those "fragments were swept out of the chamber by a stream of helium and passed through a column that was designed to trap organic molecules but allow carbon dioxide and carbon monoxide to pass through." In this process, radioactive organic molecules would be transferred from the soil to the column while being separated from the remaining gases of the incubation atmosphere. Any organic molecules would be released from the column by raising the column's temperature. Simultaneously, the radioactive organic molecules would be decomposed into radioactive carbon dioxide by copper oxide in the column and transported to the radiation counter by the helium carrier gas. If, as a result of this process, organic compounds had been formed, there would be detectable radioactivity; if there were no organics, there would be no radioactivity.

Horowitz noted that, surprisingly, "seven of the nine pyrolytic-release tests executed on Mars gave positive results." The negative results occurred with samples obtained at *Viking 2*'s Utopia site. The amount of radioactive carbon dioxide obtained by the experiment was small; still, it was enough to furnish organic matter for between 100 and 1000 bacterial cells. Significantly, "the quantity is so small . . . that it could not have been detected by the organic-analysis experiment," the gas chromatograph-mass spectrometer (see below). Though small, the quantity was important, because as Horowitz expressed it, "it was surprising that in such a strongly oxidizing environment even a small amount of organic material could be fixed in the soil." Even more important to him was the fact that "the pyrolytic-release instrument had been rigorously designed to eliminate non-biological sources of organic compounds." To encounter positive results from the Martian soil in spite of all the precautions was in the biologist's word "startling."

However, on reflection, it appeared that the findings of the pyrolytic-release experiment had to be interpreted nonbiologically. The reaction did not respond to heat in a manner consistent with a biological reaction. Martian microbes, accustomed to the very low temperatures on that planet, would have been killed by the elevated temperatures experienced during the test, the investigators thought. "On the other hand, it is not easy to point to a non-biological explanation for the positive results." Investigations into this curious reaction have continued in terrestrial laboratories, and until "the mystery of the results . . . is solved, a biological explanation will continue to be a remote possibility."[64]

Gas Chromatograph-Mass Spectrometer (GCMS). While the results of the biology experiments did not seem as bleak in the summer of 1976 as they have appeared subsequently, there was considerable concern during the missions about the proper interpretation of the reactions being witnessed. During August 1976, the Viking scientists believed that the GCMS was one possible tool for deciding if the reactions observed in the biology instrument were biological or chemical in origin.

As one observer noted, the gas chromatograph-mass spectrometer was the court of appeals in the event that the biological experiments did not present a clear verdict.[65] With the initial uncertainties from the biology experiments, the molecular analysis team decided to gamble that the GCMS had received its sample on sol 8 (see pages 398-400) and made the first analysis on 6 August (sol 17). Klaus Biemann reported to the press on the molecular analysis—"the first half of the first sample experiment of the organic analysis"—the following day. The soil sample was there! And the oven had worked as planned. There was always speculation among the news representatives about what new hardware problems might appear, but this time the scientists could report, "It did work as predicted, heated to 200° and stayed there for thirty seconds. The entire gas chromatograph mass spectrometer worked well like all gas chromatograph mass spectrometers do." Although the molecular analysis team was obviously pleased that its instrument was working well, the results from the GCMS would be the source of the most frustrating data for those exobiologists who were hoping to find life on the Red Planet.

About 300 mass spectra, electronically provided graphs identifying the molecules detected in the Martian soil sample, were returned by the first run of the GCMS. The molecular analysis specialists were particularly interested in determining if carbon compounds were in the sample, since biochemistry is largely the chemistry of carbon. The basic structure of the carbon atom enables it to form large and complex molecules that are very stable at ordinary temperatures. While no carbon compounds were detected in the first sample analysis, there was no great concern, since it was believed that the sample would have to be heated to 500°C before the organics would be broken down and detected by the instrument. The only surprising aspect of the first data was the very small amount of water released by the sample.[66]

On 12 August, the GCMS experiment was run again with the first sample being heated to a maximum temperature of 500°C. Biemann reported that this analysis "to our surprise, evolved a large amount of water. Indeed so much that it gives us trouble in analyzing the data." Still, the critical point of this analysis was that there were probably no organics. If the reactions observed in the biology instrument were the consequence of life, then it was expected that the GCMS would detect organic compounds in the same soil. Neither this analysis nor the subsequent one at the *Viking 1* site, nor those carried out at the *Viking 2* landing area, produced traces of organic compounds at the detection limits (a few parts per billion) of the GCMS.[67]

Failure of the gas chromatograph-mass spectrometer to detect organic compounds was devastating for those who believed that life on Mars was possible. For Jerry Soffen, the GCMS results were "a real wipe out." Once he assimilated the fact that the GCMS had found no organic materials, he walked away from where the data were being analyzed saying to himself, "That's the ball game. No organics on Mars, no life on Mars." But Soffen confessed that it took him some time to believe the results were conclusive. At first, he argued with Tom Young that there must have been no sample present in the GCMS, because there had to be organics of some sort on the planet. Soffen bet Young a dollar that the second analysis would prove that the instrument had been empty. To his dismay, the data indicated instead that there was a sample in the instrument and that the sample was devoid of organics.

Klaus Biemann, the molecular analysis team leader, had some reflections on the search for organic compounds. Looking in the soil for compounds made of carbon, hydrogen, nitrogen, and oxygen at the level of a few parts per billion, they found none. The gas chromatograph-mass spectrometer could have detected smaller concentrations of organic materials than are present in typical antarctic soil, which is low in organic compounds because there is little vegetation and animal life on that part of Earth. Compared to Antarctica, Mars is devoid of organic material, and a number of conclusions could be drawn from that finding. First, no synthesis of organic compounds is occurring on the surface, at least where the two Vikings landed. Second, if millions of years ago organic compounds did exist, they must have since been destroyed. Third, since organic compounds must be arriving on Mars in the form of meteorites, that material must have been imbedded in the surface very deeply or, more likely, destroyed by the planet's harsh environment. Finally, says Biemann, "if we use terrestrial analogies, we always find that a large amount of organic material accompanies living things—a hundred times, thousand times, 10 thousand times more organic materials than the cells themselves represent." Since the Viking instruments did not detect any large amounts of organic waste material, it is difficult to see how microorganisms could be living at the areas investigated "if they behave as terrestrial organisms do."

Of course, reminded Biemann, "this does not rule out a different kind of living mechanism that would protect its organic constituents very well and, therefore, avoid this waste of a scarce commodity." Martian organisms could have evolved along those lines, and as the environment became harsher and harsher they could have become more and more efficient in using the organic materials they needed. Viking looked at only two samples at each of the two landing sites from depths of 5 to 10 centimeters. If organic materials were produced millions or hundreds of millions of years ago, they could be present at greater depths and protected there from the damaging ultraviolet radiation. The Viking spacecraft could be sitting on an area containing a deposit of organic material a few meters down. There could also be other areas on the planet where the surface material is more protected or where organic material is now being synthesized and not destroyed. To help answer these puzzling questions, Biemann and his colleagues had plans to study in their laboratories the rate of decomposition of certain typical organics under Martianlike conditions, to determine how fast organic materials might be destroyed at the surface.[68]

LIFE OR NO LIFE?

Soffen's disappointment was shared by others on the biology team. For years, they had discussed the scientific possibilities of discovering life or the prerequisites for life on the Red Planet, and Soffen recalled the long debates with his colleagues on the subject. Some, like Wolf Vishniac, had argued that a negative result—that is, no life—was as important scientifically as the discovery of life. But such a discovery had not proved very exciting. Before the Viking landings, Soffen had been very careful in all his public statements to say that they would likely find nothing on the planet, but personally he had wanted to find life.

While Soffen believed that it was possible for life to have developed on Mars, he also thought it likely that the biology instrument, for a host of reasons, had not been designed properly to detect it. However, he was also very confident that if organic compounds had been present, the GCMS would have detected them. For that reason, he had fought for the instrument throughout the evolution of the Viking project. Soffen could have accepted a negative biology result, if there had been a positive measurement of organic compounds. But positive biology results could not be interpreted as indicating the existence of life in the absence of organics. Others have argued that perhaps Viking landed at the wrong places on the planet. Nearer the poles where there was a higher moisture content in the soil and atmosphere, life might exist. Or perhaps, as suggested by Carl Sagan and Joshua Lederberg, there are Martian microenvironments where in small oasislike areas life has evolved and survived. Soffen thought this unlikely since the homogenizing effects of wind and dust storms would have likely distributed any organic material all over the planet. He reluctantly concluded that life on Mars was unlikely.[69]

The apparent absence of life on the Red Planet had a far-reaching philosophical and emotional impact on members of the biology team. The team had never been a cohesive group of investigators, and the results of the biology and GCMS experiments served to accentuate their differences. Norman Horowitz came to the opinion that there is no life elsewhere in the solar system. While he did not rule out the possibility in theoretical terms, he believes, practically speaking, that scientists will never be able to prove the existence of life on another planet. Horowitz noted:

> There are doubtless some who, unwilling to accept the notion of a lifeless Mars, will maintain that the interpretation I have given is unproved. They are right. It is impossible to prove that any of the reactions detected by the Viking instruments were not biological in origin. It is equally impossible to prove from any result of the Viking instruments that the rocks seen at the landing sites are not living organisms that happen to look like rocks. . . . The field is open to every fantasy. Centuries of human experience warn us, however, that such an approach is not the way to discover the truth.[70]

One man who is still not convinced is Gil Levin. He cannot rule out the biological interpretation of the Viking biology experiment results. "The accretion of evidence has been more compatible with biology than with chemistry. Each new test result has made it more difficult to come up with a chemical explanation, but each new result has continued to allow for biology." Furthermore, Levin believed that all of the life-seeking tests showed reactions that "if we had them on earth, we would unhesitatingly have described as biological."[71] But other members of the biology team were not as easily convinced.

Vance Oyama, who fathered the gas-exchange experiment, publicly stated in early 1977 that "there was no need to invoke biological processes" to explain the results obtained from the experiments. While far from being accepted by all his colleagues, Oyama's opinion is one more example of the extent to which differing explanations can be made to account for the puzzling data acquired by the biology experiments. Should Oyama's explanation turn out to be valid, it would affect more than the biology experiments. It would also help explain the nature of the magnetic particles that adhered to the magnets on the sampler head, the interactions between the atmosphere and the surface, and the early evolution of the planet. His theory begins with a simple photochemical effect in the atmosphere: the intense solar ultraviolet radiation breaks down atmospheric carbon dioxide (CO_2) into activated carbon monoxide (CO) and single atoms of oxygen (O). As the ultraviolet radiation continues to bombard the atmosphere, some of the carbon monoxide is further reduced to its constituents, carbon and oxygen. Some of this single-atom carbon combines with carbon monoxide to produce carbene (C_2O). The carbene in turn combines with carbon monoxide to form the first key element in Oyama's theory, carbon suboxide (C_3O_2). Oyama postulated that the carbon suboxide molecules were united to form a carbon suboxide polymer. Intriguingly, the resulting polymer has a reddish cast.

Oyama's theory is consistent with data from the three biology experiments. Looking first at the pyrolytic-release experiment, Oyama noted that the carbon-14 isotope was an important factor in explaining the results observed from this instrument. The decay of the carbon-14 isotope into nitrogen-14 released a beta particle. The resulting energy was more than sufficient to fracture carbon-carbon, carbon-hydrogen, and carbon-oxygen bonds. The breakdown would activate the red carbon suboxide polymer, allowing it to incorporate the available carbon monoxide. Heating that same polymer to about 625°C during pyrolysis would produce about four percent of the original carbon suboxide, with a carbon-14 label. This single carbon suboxide molecule (monomer) would tend to stick to the pyrolytic release experiment's organic vapor trap and with subsequent heating would be released as the critical "second peak" the specialists observed in the experiment's data. Taking this another step, Oyama reported that the presence of water vapor when the sample was exposed to the labeled atmosphere would lower the second peak.[72]

In Oyama's laboratory gas-exchange tests, the prominent release of oxygen was also less the second time. But as Oyama said, the reason was very different. In the Martian atmosphere, the same photochemical breakdown (photodissociation) that led to the formation of carbon suboxide also led to the creation of activated oxygen atoms, albeit by a different route. When these oxygen atoms struck alkaline earths (for example, oxides of magnesium or calcium), they united to form superoxides that would release oxygen upon exposure to water vapor. Oyama argued that less oxygen was released at the Utopia site than at the Chryse site because the greater amount of water vapor in the more northerly landing site had previously freed some of the oxygen in the superoxides near the surface.

In describing the reasons for the results observed in the labeled-release experiment, Oyama presented the following scenario. Hydrogen peroxide formed photochemically in the atmosphere reacted with a catalyst on the soil-grain surfaces to release oxygen, which diffused into the grains, reacting with the alkaline earths and metals to form other superoxides. Atmospheric water vapor could readily convert the superoxides to peroxides, which in turn could combine with water in the nutrient to form hydrogen peroxide, H_2O_2, which would oxidize the labeled components of the nutrients to release the labeled CO_2. John Oro of the molecular analysis team also suggested very early that the results from the gas-exchange tests and labeled release were due to the presence of peroxidelike materials in the surface of the planet. To explain the process, Oyama used the example of chemical reactions in human beings. When hydrogen peroxide (H_2O_2), a commonly used disinfectant, is applied to a wound, it bubbles. This, Oyama said, is caused by the presence of iron in the enzyme catalyst. When the iron combines catalytically with the hydrogen peroxide, it releases bubbles of oxygen. Oyama believed that a similar process is at work on the surface of Mars.

Having searched for possible Martian catalysts, Oyama concluded that there is one likely candidate—a form of iron oxide known as gamma Fe_2O_3, or maghemite. On Earth, this is usually found only around the edges of hydrothermal or magnetic activity, where the temperatures range between 300° to 400°C. The abundance of water on Earth has converted much of the maghemite into a noncatalytic form, but on Mars this material has survived virtually unaltered. Oyama thinks that it probably was produced either b an episode of volcanic heating or by heating that accompanied a period o meteoritic impacts. While this probably occurred early in the planet's history, he believes that it took place after the large quantities of water others suspect once existed had disappeared. Otherwise, the maghemite would have been rendered noncatalytic, just as it has been here on Earth. This explanation is a complex one, but as Jonathan Eberhart, writing for *Science News*, has reported: "Oyama's theory will have to stand the test of time, additional data and competing theories. But it does show that looking for life on other worlds has the potential for making valuable contributions in other fields as well."[73]

That there is still disagreement over the Viking biology results has caused some hard feelings among members of the biology team. Summarizing the situation after the results were in, Jerry Soffen said that he would expect the following responses if Horowitz, Oyama, Levin, and he were asked to participate in another Mars-bound biology investigation: Horowitz would not want to participate; Viking had satisfied his curiosity on the subject. Oyama would probably take part, but he would not expect to discover life. Gil Levin still believed that life may be discovered on the Red Planet. He had started with the goal of proving that there was life on Mars, and for him it was an engineering problem: How do you prove that there is life on Mars? To some of his colleagues, this was the attitude of an engineer, not the professional skepticism of the scientist. Examining his own position, Soffen said that he had never been certain about the possible existence of life on Mars, but he had hoped that it might be found. At no time, however, had he committed himself to proving that it actually existed. Horowitz, on the other hand, had always had such strong doubts about finding life that on several occasions members of the team wondered aloud why he had remained with the group. For Soffen, disappointments aside, he would like to return to Mars and look beyond the horizon shown in the lander photos—looking not for life but for whatever was there.[74]

Biology team leader Chuck Klein also had some thoughts on the search for life. "Before we landed on Mars we had a variety of opinions, ranging from those who expected to see no life on Mars to those who expected to see a rather flourishing—maybe not terribly advanced, but at least a flourishing life on Mars." Judging from all the Viking mission's findings, there is no visible flourishing life. But Klein suggested that the scientists must look more carefully at Mars "and ask whether the sophisticated biology and the chemistry instruments have given us clues as to whether there might be some less obvious kind of life on Mars." Klein believed that they could reject their pre-Viking model of Martian microbial life, "namely the Oyama model, which says that Mars should have micro-organisms similar to large numbers of soil bacteria on this planet." At neither site was there any indication to support that kind of concept of Martian biology. That means that either there are no organisms or any existing organisms do not fit that model.

ORIGINAL PAGE IS
OF POOR QUALITY

Even though two of the biology experiments gave indications that could be interpreted on first inspection as being the result of some simple organisms being present, the molecular analysis team found no detectable organic compounds in the soil samples. The absence of organics made the biology team very suspicious; the weak-to-moderate signals in the two experiments might not be due to biological processes at all. "However, the lack of organics, in and of itself, does not rule out the possibility of organisms but makes that whole idea much less attractive," said Klein. As was noted by other Viking scientists, there is evidence that the surface material of Mars contains chemicals that are highly oxidizing and could interfere with the biological tests and mimic them. "Just as a living organism can, let us say, decompose a steak by eating it and digesting it, the steak can also be decomposed by being thrown into sulfuric acid, with roughly the same end products." The equivalent to the sulfuric acid in the case of the Viking biology experiments could be an inorganic nonbiological oxidizing material. Since this kind of nonorganic material seems to be present on Mars, it could be the cause of the confusing experiment results. "We tried a few tricks on Mars to see if we could devise some experiments that might definitely rule out the possibility that the decomposition seen is due to biology. We have not been able to do that so far." Although the two landing sites were more hostile than the biologists had anticipated, Klein points out that the Viking data do not really say there is no life on Mars.

> We can certainly say that it is not rampant, but we can't be sure there isn't some scraggly form of life for which we just haven't found the right nutrients or the right location or the right incubation temperature or the right environment within which to show its presence. That's why it's going to be very difficult for me, at least, to come out and say that there is no life on Mars. I think that would not be a scientific conclusion.

Klein, for one, wanted to go back to Mars.[75]

The planetary scientists agree that Mars is a fascinating place, and Soffen believes it is significant that no one has criticized Viking or the men who brought it about because life was not found there. Philip Abelson, editor of *Science*, stated categorically in February 1965 that "we could establish for ourselves the reputation of being the greatest Simple Simons of all time" if NASA pursued the goal of looking for extraterrestrial life on Mars.[76] His editorial in *Science* in August 1976 that reported on the initial results of *Viking 1* did not repeat this complaint, however, nor did he make it in either of the two subsequent issues that dealt with the Mars findings.[77] Some writers complained that the Martian microbes had not been given a decent chance—after all, the same ultraviolet radiation that caused the various photochemical reactions postulated by Oyama could also have destroyed the organic remains of many if not all of the Martian microbes—but none faulted the space agency for having made the search.[78]

A November 1976 editorial in the *New York Times* was typical of the press reaction. Noting that Mars had gone behind the sun earlier in

November, interrupting for a time communications between Earth and th Viking spacecraft, the editorial suggested that the "temporary halt in th receipt of new data permits a preliminary evaluation of what has been accomplished since last summer's historic landing." It appeared that "the whole field of Martian studies has been revolutionized and provided with an abundance of new data that will take years to assimilate fully." Findings on Mars would, in turn, force a reconsideration of the hypotheses concerning the origins of life on Earth. Referring to the postulated superoxides in the Martian soil, the *Times* noted, "Now the possibility is being discussed that such a superoxide existed here on Earth in the primeval years and that it is this wierd substance that provided the oxygen that now makes Earth such a hospitable planet for human and other familiar life forms. The classic explanation that the plant life produced most of earth's free oxygen is now being re-examined." Even the experiments of Miller and Urey in the early 1950s regarding the synthesis of prebiotic molecules could be questioned in light of the Viking investigations: ". . . the data from Mars have reminded scientists that electric discharges and accompanying ultra-violet radiation can also break down and destroy complex organic molecules as well as form them. All of a sudden the conventional wisdom about the development of life on Earth seems neither so certain nor so inevitable as it did before the Viking landings last summer." Although most scientists would not agree that the results of Viking were sweeping away the foundations for the studies of the origins of life, they would agree that "the Viking experiments have already been even more fruitful than their backers expected."[79] Perhaps the basic reason that there were no serious complaints about the Viking missions was that Mars had turned out to be a far more interesting place than anyone had predicted and more exciting than generations of scientists had expected.

OTHER RESULTS

Viking's explorations and discoveries did not stop with the search for life. The great disappointment felt by the biologists was tempered to a degree by the wealth of other findings.

Radio Science

One group of Viking investigators who did not have any scientific instruments of their own* on the four spacecraft but whose work assisted many scientists was the radio science team led by William H. Michael of the Langley Research Center. By analyzing the radio beams sent from Viking to Earth, specialists could determine precisely where the landers touched down and certain atmospheric and ionospheric properties of Mars, as well as gather data about the surface and internal properties of the planet and

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*An X-band downlink on the orbiters was added specifically to enhance radio science capabilities and to conduct communications experiments.

about the solar system. The team's work can be divided into three general areas, as shown in table 55.

Table 55
Viking Radio Science Investigations

1. Dynamical, surface, and internal properties of Mars
    - Spin-axis orientation and motion
    - Spin rate
    - Gravity field
    - Figure
    - Surface dielectric constant
2. Atmospheric and ionospheric properties of Mars
    - Pressure, temperature, and density-altitude profiles
    - Electron-number density-altitude profiles
3. Solar system properties
    - Ephemerides[a] of Mars and Earth
    - Masses of Martian satellites
    - Interplanetary medium
    - Solar corona
    - Tests of general relativity

[a] *Ephemerides* are tabular statements of the predicted positions of celestial bodies at regular intervals.

Investigations of the locations of the Viking landers and the dynamical properties of Mars use primarily radio tracking of the landers, with some reliance on radio tracking of the orbiters for calibration. Determination of the gravity field and atmospheric and ionospheric properties use radio tracking of the orbiters, while the solar system and surface properties investigations rely on combinations of orbiter and lander radio tracking data. On Earth, the scientists use the transmitting, receiving, and data collection facilities of NASA's Deep Space Network at the 64- and 26-meter stations in California, Australia, and Spain.[80]

Although radio science operations began during Viking's cruise to Mars when the orbiter high-gain antenna was activated and tracking data were received, this activity was mostly related to checkout procedures, with some effort devoted to data and systems calibration. More immediately useful work began after the first landing, as doppler and range data became available for the first time between Earth and a spacecraft on another planet. From the first few days of tracking, the radio science specialists were able to ascertain "the location of the lander, the radius of Mars at the landing site, and the orientation of the spin axis of Mars." Additional data from both landers led to an initial determination from Viking findings of the spin rate of the Red Planet. After analyzing signal amplitude data from the lander-orbiter relay link, Michael and his colleagues were even able to suggest that the surface material around the first lander had electrical properties similar to that for pumice or tuff, a volcanic rock.

The precision of future Mars maps will be improved considerably, especially in the 30° south to 60° north latitudes, as a result of the radio science team's work during the extended mission's low-altitude gravity survey. As the second orbiter assumed a lower orbit (about 300 kilometers), the scientists measured the effect Martian gravity had on orbiter accelerations. They noted that Olympus Mons produced a very large gravitational acceleration, while prominent, though smaller, perturbations were observed over Tharsis Montes and Elysium Planitia. Results from a bistatic radar experiment will also help specialists identify Martian features, more accurately by shedding light on surface reflectivity, surface roughness, slopes at various scales, and electrical properties of the surface in regions not accessible to Earth-based radar. These surface parameters are derived "from spectral analyses of signals transmitted toward specific locations on Mars from the orbiter antennas, reflected from the surface of Mars, and received at the Earth tracking stations." Besides being useful for mapping and geological interpretations, these findings will simplify the identification of future landing sites on Mars.[81]

Other questions include confirming the Einstein theory of relativity by a time-delay test—measuring how much the spacecraft signals are slowed as they pass near the sun and how the precession rate of Mar's orbital perihelion varies. During conjunction, data were gathered for studies of the solar corona. The team was also interested in more accurately measuring the distance between Earth and Mars and in determining the masses of Martian moons Phobos and Deimos. Viking's extended mission promised to be a busy time for the radio science experimenters, as did the period immediately following actual data acquisition. It would take many years to analyze all the results.

Physical Properties

The physical properties team was to draw conclusions from a composite of data from other experiments, to define the physical properties of the Martian soil. Richard W. Shorthill, team leader, stated that the team had been successful in describing the characteristics of the soil. But what it encountered was unlike any soils on Earth.

At the *Viking 1* site were two kinds of surfaces to investigate, the so-called rocky flats and the sandy flats. The bulk density (the number of grams per cubic centimeter) in the rocky flats area was slightly higher than in the sandy flats. At the second landing site, the bulk density was higher than the sandy area. The team determined the properties of the Martian soil by examining photographs of the trenches dug by the surface sampler. Cohesion (how the particles stick to each other) was ascertained by taking the dimensions of the trenches and the heights of the side walls and noting the collapsed state of the walls. The cohesion exhibited in the Martian trenches was similar to that found on Earth in a trench dug in wet sand. However, since the Martian soil is so very dry, the cohesion must have been caused by the electrical properties of the soil. Adhesion (tendency of the particles to stick to other objects) was determined by observing the soil that stuck to the sides of the surface sampler head before and after it vibrated. "We actually did some laboratory accelerometer tests on the vibrator at Martin Marietta while we were still on the surface of Mars to get a calibration of the adhesive forces," remarked Shorthill. By pushing the surface sampler into the surface until the force of the action turned on a microswitch, the soil's penetration resistance could also be measured.[82]

Magnetic Properties

The magnetic properties experiment produced some interesting data, too. This investigation revealed an abundance of magnetic particles on the Martian surface, in both the soil and the very fine dust. On Earth, the most common magnetic particles are either iron metal or iron oxides, indicating that the red coloration of Martian soil may be caused by a highly oxidized iron, which is normally nonmagnetic on Earth. Robert B. Hargraves, leader of this experiment team, noted that two kinds of iron oxide exist on Earth—magnetite and hematite. Since hematite is nonmagnetic, perhaps the red mineral on Mars is magnetite with a coating of red hematite. But Mars is not Earth. "From what we've seen from the Martian imagery, these magnetic particles themselves appear red and they appear virtually indistinguishable from the average surface material on Mars." Hargraves admits that they have no direct information with which to resolve the mystery of the magnetic red soil, but the specialists planned to continue studying supporting data from other experiments in the hope of determining its properties more accurately.[83]

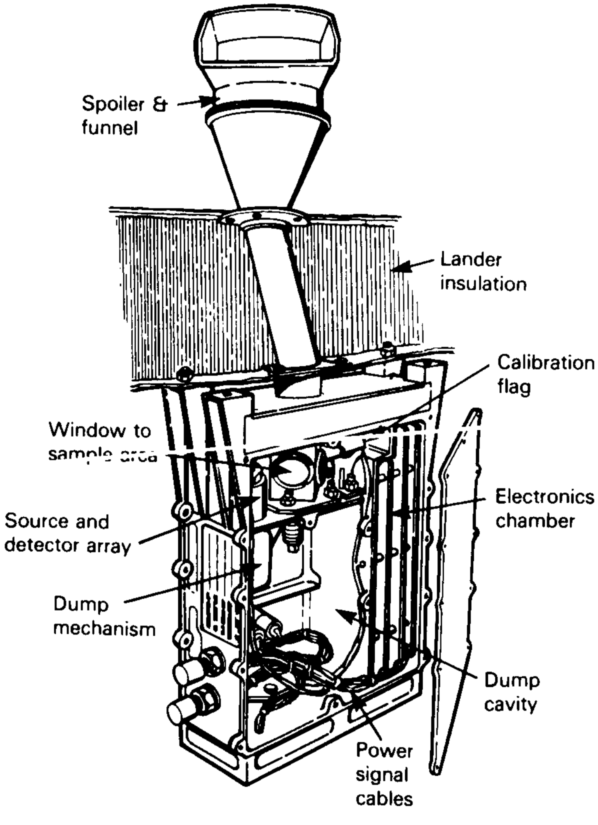
Inorganic Chemistry

In the inorganic chemistry investigation, scientists analyzed the chemical elements in the Martian soil with an x-ray fluorescence spectrometer. Lander 1 acquired five soil samples successfully, three collected during the primary mission and two during the extended mission; the second lander acquired four samples for a combined total of 620 cubic centimeters of Martian soil. Each sample was sifted through a funnel to measure the precise size of the sample and then charged with high-velocity particles from an x-ray source.

When the spectrometer was supplied with a sample, the data were sufficient to detect the presence of iron (12–16%, maximum limits), calcium (2–6%), silicon (15–30%), titanium (0.1–1%), aluminum (1.5–7%), magnesium (0–8%), sulfur (2–7%), cesium (0–2%), and potassium (0–2.5%). Lander 2 attempted to retrieve rock samples three times and failed, because what appeared to be rocks in lander images were actually small crustal particles that crumbled when disturbed. The scientists believe there are pebbles but were unable to analyze one.[84]

Benton C. Clark, deputy team leader of the inorganic analysis team commented that the "most striking factor between the two Viking landing sites is that the soil composition [chemical] is extremely similar in both cases. This is true for all elements we can detect in the soil including the very high" sulfur content, almost 100 times greater than the amount of sulfur found in Earth or lunar soil. One specialist remarked that they would be hard pressed to find such a closely matched pair of samples at such widely divergent sites on Earth, or even on the moon. The chemists think the giant dust storms that occur approximately every two years probably have mixed up the soil very efficiently and distributed it all over the planet as a fairly uniform mixture.

Despite the similarity of the soil from the two sites, different samples from the same location did indicate some differences in soil chemistry. "In one case, we get a higher sulphur content when we pick up a little dirt clod. In other cases, when we push a rock aside and sample the surface directly beneath it, we in general get a lower iron content and a somewhat higher sulphur content." Perhaps the soil under the rock was an older soil, whereas material out in a free area may have been the result of more recent dust storms—"recent in this case meaning the last thousands to millions of years." The chemists' findings have led them to believe that the Martian soil may have been derived from rocks with a very high magnesium and iron content.[85]



X-ray fluorescence spectrometer

The Media

Public interest may have been diminished by the failure to detect life, but many science writers continued to pursue the Viking science results. Almost weekly until the end of the prime mission in November when Mars disappeared behind the sun during conjunction, the press carried reports of scientific news from Mars. As Jerry Soffen told reporters at the second Viking science forum in August 1976, he and his colleagues were gratified by "the splendid coverage" they were getting, and he did not mean just the volume, which was considerable. The scientists had been impressed by the quality, as well:

> All of us really want to thank you and tell you how grateful we are for the remarkable clarity that has emerged as a result of this very open style that we are developing right now. . . . We have tried to each time answer your questions as clearly as we could and I know how difficult it is, as a reporter, to try to cover and clarify issues that seem to emerge one day and sometimes . . . appear to be contradictory on the next day.[86]

One example of the coverage given Viking is a series of articles in *Science News* by Jonathan Eberhart, the journal's correspondent in residence at the Jet Propulsion Laboratory during the primary mission. Respected by all his colleagues, Eberhart had a way of making understandable the complexities of science on Mars. Eberhart reported, among other accounts, efforts to move one of the rocks with the second lander's sampler arm, to find soil that had not been exposed in recent time to harsh ultraviolet radiation. As with all other maneuvers of the arm, the preparations took more than three weeks of consultations with more than a dozen specialists. The first attempt was a failure. The rock, blocking the first sample-acquisition site, refused to budge. Some persons thought that the rock might be frozen in place, but Priestley Toulmin of the inorganic analysis team argued that it was probably just the "tip-of-the-iceberg"; more of the rock was likely hidden below the surface. "Mr. Badger,"* the second candidate for displacement, was successfully moved. As the Viking lander team continued its investigations of the immediate region around the landers—pushing rocks, digging trenches, taking pictures, and measuring their findings—the science writers continued to report on the events.[87]

All the Viking mission activities prompted Gerald Soffen to comment in his Dryden lecture at the American Institute of Aeronautics and Astronautics' 16th Aerospace Science Meeting in Huntsville, Alabama, in January 1978, "How remarkable! We are performing chemical and biological experiments as though in our own laboratories. Taking pictures at will, listening for seismic shocks and making measurements of the atmosphere

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*Henry J. Moore II named four large Martian rocks after characters—Mr. Badger, Mr. Mole, Mr. Rat, and Mr. Toad—from *Wind in the Willows* by Kenneth Grahame.

and surface. All of this from the first spacecraft ever to be landed successfull on Mars."[88]

Management

At the end of the primary mission in November 1976, some major changes took place within the management structure of the Viking Project Office. Several persons who had led Viking since its inception moved on to new positions. Jim Martin left NASA to become vice president of advanced programs and planning at Martin Marietta Aerospace in Bethesda, Maryland.[89] Tom Young, who had been serving both as Viking mission director and as Martin's deputy for JPL operations, took the post of director of lunar and planetary programs at NASA Headquarters.[90] For a time, Soffen maintained his position as Viking project scientist, but he was often called on to be a roving ambassador for the Mars project, traveling around the world telling scientific and lay audiences about the "real Mars" they had discovered. When Viking entered the extended mission phase in mid-December 1976, following the end of solar conjunction, however, many familiar faces still remained to complete the project. G. Calvin Broome had become project manager and mission director, and Conway Snyder, formerly orbiter scientist, first acted and then assumed full authority as project scientist.[91]

With the start of the extended mission, one phase of Mars exploration had come to an end. The goal of landing and successfully operating an unmanned scientific laboratory on the surface had been achieved, and vast archives of new and exciting information about the Red Planet had been amassed. The extended mission properly belongs to the post-Viking era, a period of evaluation and appraisal. With this initial scientific reconnaissance over, the issue facing the National Aeronautics and Space Administration was, What next? Viking, scientists hoped, was only a first step. The debate over subsequent steps would require decisions about not just exploring Mars but also how exploring Mars fitted into the overall scheme of NASA's planetary programs. One chapter closed, it was time to begin a new one.