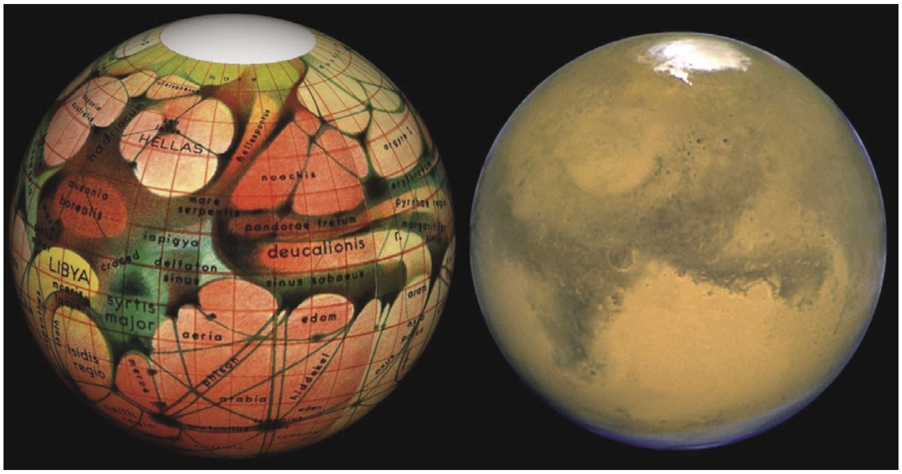
The Fall and Rise (and Fall?) of Life on Mars

by Douglas L. Smith

Top: A color composite of Valles Marineris, the "Grand Canyon of Mars," as seen by the Viking Orbiters. Above: On May 19, 2005, one of JPL's current Mars explorers, the Spirit rover, captured this stunning view as the sun sank below the rim of Gusev crater.

Is there life on Mars? If there is, it has so far eluded our best efforts to find it, but the quest for it has informed our missions to Mars since the early days of spaceflight. Meanwhile, our conception of that life has changed as our understanding of the planet has evolved—from little green men, to little green cells, to perhaps something unlike anything on Earth. The late professor of biology Norman Horowitz (PhD '39), who had been a consultant to NASA since 1960, recalled in his oral history, "Everything that was known about Mars at the time later turned out to be wrong, but everything suggested that there was a good possibility of life on Mars. At least it was plausible."

What was known before the space age had been deduced by squinting at Mars through telescopes. The Martian day is 37 minutes longer than ours, and the planet has a season-inducing tilt of 24 degrees, almost identical to Earth's. Mars has white polar caps, presumably made of water ice, that wax and wane with those seasons. Mars has weather, in the form of globe-girdling dust storms. Astronomers began mapping the planet in detail in the mid-1800s. Giovanni Schiaparelli, in particular, recorded arrow-straight, whisker-thin linear features that ran for hundreds of miles. He called them "channels" (*canali* in Italian) and there was much speculation that they might be artifacts of intelligent life. The notion of a planet-wide network of canals—the last gasp, or perhaps gulp, of an advanced civilization slowly dying of thirst—had met considerable scientific skepticism as early as the 1910s, but Martians remained alive and well, as the widespread panic sparked by Orson



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The map on the left was originally prepared by Eugene Antoniadi (1870–1944), and was redrawn by Lowell Hess for the 1956 book *Exploring Mars*, by Roy A. Gallant. (Image courtesy of Lowell Hess.) The Hubble Space Telescope image at right gives the same view. South is at the top in these images, which are shown inverted, the way they would appear through a terrestrial telescope.

Welles's Halloween 1938 broadcast of *The War of the Worlds*, where Earth was conquered live on the radio, would attest.

Mars's temperature had been taken spectroscopically, giving an equatorial summer high of a balmy 25 °C, although this would plummet by 100 degrees or more overnight. Very little was known about the atmosphere, but Gerard Kuiper had detected carbon dioxide, also spectroscopically, in 1947. How thick that air was was harder to determine. The planet's apparent brightness partially depends on the amount of light scattered our way by gas molecules and airborne dust particles, so by measuring brightness variations over many years and working backward through an elaborate chain of assumptions, the average pressure could be calculated. The accepted figure was 85 millibars, equivalent to about 16 kilometers above sea level on Earth. At this pressure droplets of water, the solvent of life, could exist . . . at least on Martian summer afternoons. Mars also has a seasonal wave of darkening (some observers went so far as to call it "greening") that begins near each pole in the spring and works its way toward the equator as the weather warms. Just what you would expect, in other words, on a living world whose water supply is locked up in an ice cap each winter.

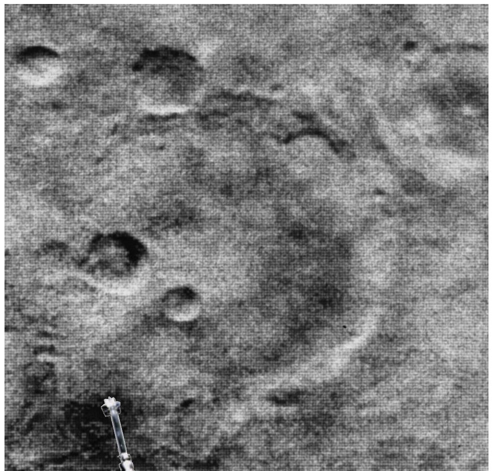
Absent any evidence to the contrary, Mars's atmosphere was assumed to be Earth-like, that is, mostly nitrogen. This was a key assumption, as Earthly life is built up of nitrogen-containing amino acids strung together to make protein molecules. So although no reputable scientists believed in death-ray wielding Martians, smaller, hardier creatures were perfectly plausible. In fact, Caltech professor of embryology Albert Tyler once suggested that the only life-detecting equipment a Mars lander really needed was a mousetrap and a camera.

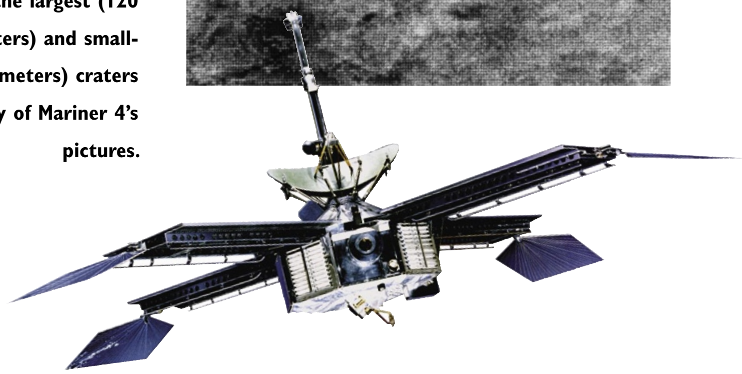
The Death of the Little Green Men

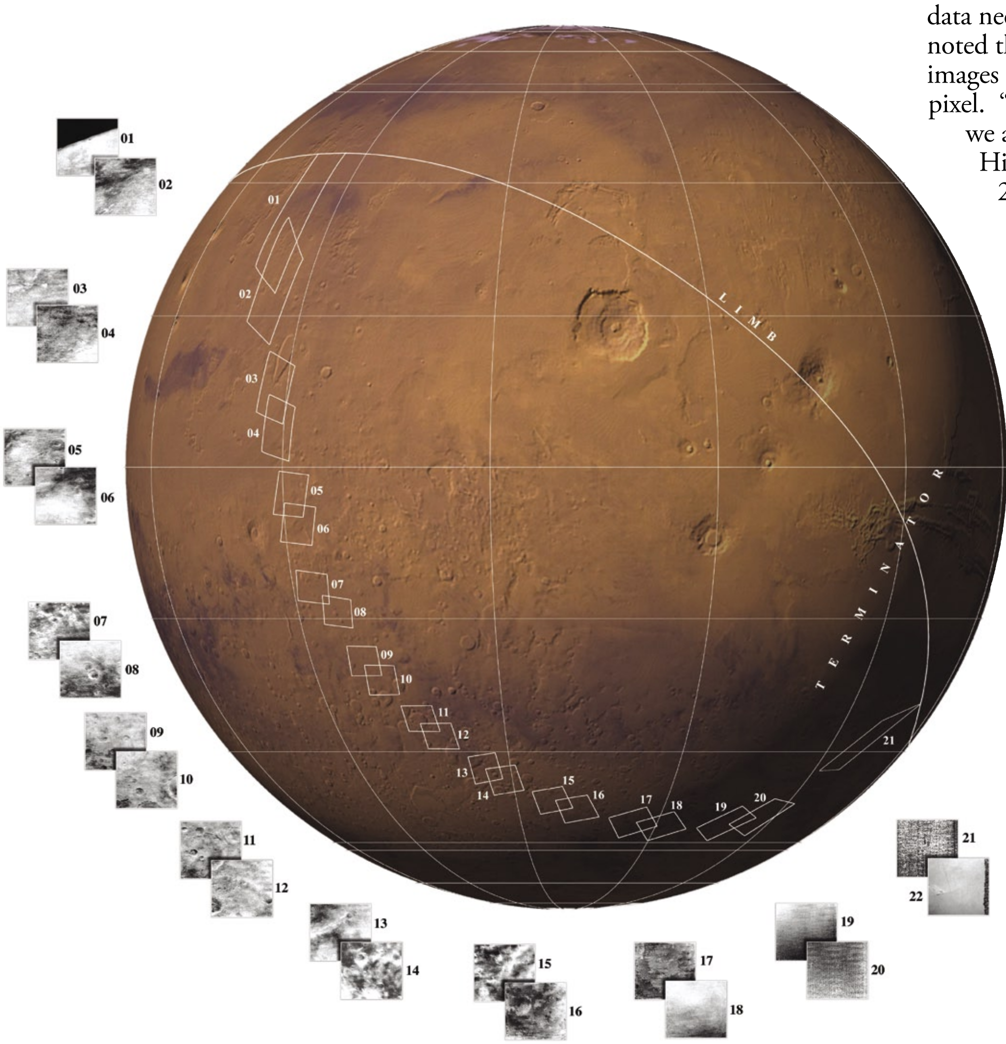
This view began to change in April 1963 because of an infrared spectrum taken at the Mount Wilson Observatory, just north of Pasadena. The water vapor in our atmosphere absorbs strongly in the infrared, so "it must have been a very dry night above Mount Wilson, a very calm night," said Horowitz. "They got this marvelous single plate, and it was interpreted by Lew Kaplan, who was at JPL, and Guido Münch, who was professor of astronomy here—he's now gone to Germany—and Hyron Spinrad." The spectrum's detailed absorption lines allowed Mars's atmospheric pressure to be calculated from first principles. The result was more like 25 millibars than 85, making the presence of liquid water an iffy proposition. "They also identified water vapor in the spectrum; that had never been seen before. They found very little water. And it was obvious that carbon dioxide was a big portion of the atmosphere and not a minor portion."

By this time a flight to Mars was already in the works. The Army still had ties to JPL, and a young first lieutenant named Gerry Neugebauer (PhD '60), doing his ROTC service after graduation, had been put in charge of evaluating science payloads for planetary missions. (Neugebauer, an infrared astronomer with an interest in instrumentation, joined the Caltech faculty as an assistant professor of physics in 1962.) Thus he became the project scientist for Mariner 2, the first spacecraft to fly by another planet—Venus—whose cloud-shrouded surface it found to be hot enough to melt lead. At the same time, Neugebauer was looking to Mars. He had worked with physics professor Robert Leighton (BS '41, MS '44, PhD '47), who would die in 1997. Leighton had been photographing Mars through Mount Wilson's 60-inch telescope, and, with an ingenious image-stabilization system, had created the first time-lapse "movie" of Mars rotating. Neugebauer encouraged Leighton to

Mariner 4 (below) revealed Mars's cratered, moonlike surface. The diagram shows where the pictures were taken. (Number 22 was a partial image.) Image 11 (right), called "one of the truly great scientific photographs of all time" by geologist Sharp, shows the largest (120 kilometers) and smallest (6 kilometers) craters seen in any of Mariner 4's pictures.







propose a photographic experiment—a miniature black-and-white TV camera (there were no color ones back then that were small enough for interplanetary flight)—for Mariners 3 and 4, a pair of spacecraft that weighed a mere 261 kilograms each. Leighton in turn recruited Robert Sharp (BS '34, MS '35) to interpret the images. Sharp, who died in 2004, was chair of the Division of Geological Sciences and an expert on landforms; he brought in postdoc Bruce Murray. (Murray would be on the Caltech faculty for his entire career, and served as director of JPL from 1976 to 1982.)

Recalled Leighton in his oral history, "That really was a landmark experiment. And by today's standards, the equipment we used was so rudimentary . . . to get any pictorial data at all was very difficult." In fact, a camera was not widely welcomed as a good idea. Some scientists (including a few at Caltech) didn't consider pictures to be "real data" as no actual measurements were returned. Furthermore, a camera would soak up a disproportionate amount of telemetry time. The bit rate from the spacecraft was low to begin with, because it would be sending data back over unprecedented distances. The pictures also had to share bandwidth with six other instruments, plus the engineering data needed to run the spacecraft itself. Leighton noted that he and Murray had to fight to get the images encoded at more than a couple of bits per pixel. "JPL was going to use about three bits. But we absolutely insisted upon there being eight." High-def digital this wasn't, but it did give 256 shades of gray—enough so that the team still had a fighting chance of making out some features if they had the bad luck to arrive during a dust storm. "The TV part of the mission would have been a real failure if they'd only used the eight shades of gray that are possible with three bits."

Mariner 3's protective shield failed to jettison once clear of Earth's atmosphere, and the added weight sent the spacecraft into a useless orbit around the sun. Five Soviet Mars missions also failed, but Mariner 4 whizzed by the red planet on July 14–15, 1965, at a respectful 9,846 kilometers. The TV pictures were stored on a tape recorder, to be played back later at a blistering eight bits per second. But first the spacecraft would fly behind Mars while broadcasting a radio signal, whose alteration on passage through Mars's rarefied air would allow its pressure to be measured, directly, from the fringes of space all the way down to the planet's surface. This was truly a do-or-die experiment. For a nail-biting hour and more, Mariner 4 was not only incommunicado behind the planet, but the sun sensor that kept the

Part of Mariner 4's TV team sweats out the arrival of their first pictures. From left: JPL's Robert Nathan (PhD '56), Murray, Sharp, and Leighton. They'd sweat plenty more before it was over—each frame took eight hours to downlink, and the team had to invent the first digital image-processing software in order to bring out any detail at all. The press camped outside JPL's gates during the days of round-the-clock work that ensued. Some reporters threatened to get Lyndon Johnson to intervene to force the images' release, Murray recalled in his book, *Journey into Space*. Presidential ire wasn't the only risk: "In those days, JPL had no food available at night. Our only source of nourishment was an ice cream machine, which led to a weight gain of about 10 pounds per Mars encounter."

solar panels properly oriented was in shadow—if the batteries or the gyroscopes failed, those stored pictures would never be seen.

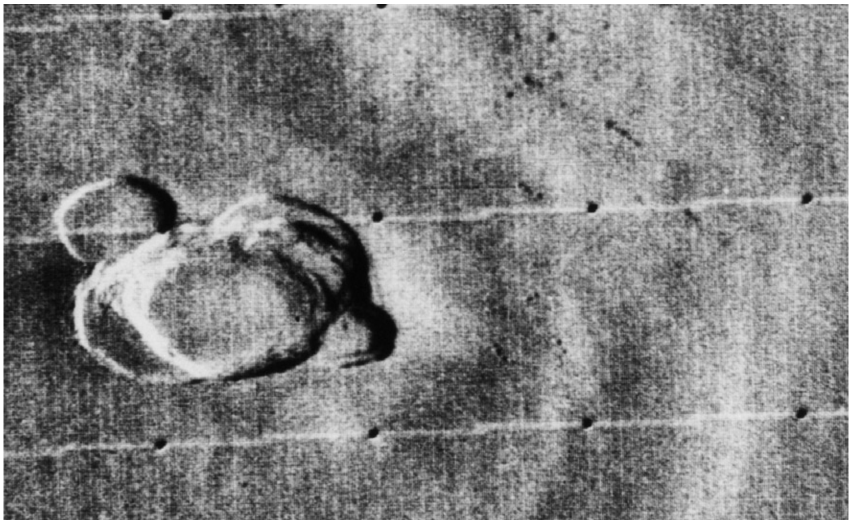
Mariner 4's 21 pictures covered about 1 percent of the planet in a swath along the flight path. They revealed a moonscape untouched by erosion for billions of years, as measured by the crater counts; worse, the radio-occultation experiment showed a surface atmospheric pressure of about five millibars, equivalent to an altitude of some 30 kilometers on Earth. That did it for water droplets. And the magnetic-field experiment, whose team included the late professor of theoretical physics Leverett Davis (MS '38, PhD '41), found no global field. This meant that charged particles from the solar wind, which a magnetic field would have trapped a safe distance away, would blast right through what passed for the Martian atmosphere and kill any creature foolish enough to wander around unprotected. Suddenly Mars had become a very hostile place indeed.

The Blind Men and the Elephant

Things didn't look any better after Mariners 6 and 7, which flew over the Martian equatorial zone and south polar region, respectively, in the summer of 1969. (Mariner 5 went to Venus.) Buzzing the planet at about one-third the distance of their predecessor and returning 200 TV pictures at 16,000 bits per second, the twin spacecraft confirmed the view of the planet as a cold, dry desert. Leighton and his co-authors described the Mariners' flight paths thus in *Science*: "The Mariner 6 picture track was chosen to cover a broad longitudinal range at low latitudes in order to bring into view a number of well-studied transitional zones between light and dark areas, two 'oases' (Juventae Fons and Oxia Palus), and a variable light region (Deucalionis Regio). The picture track of Mariner 7 was selected to . . . include the south polar cap and cap edge, to intersect the 'wave-of-darkening' feature Hellespontus, and to cross the classical bright circular desert Hellas." Mariner 6 discovered the so-called "chaotic terrain"—areas where the permafrost vanishing from a mix of permafrost, dust, and sand grains had caused the surface to slump in peculiar patterns. And Mariner 7 found that Hellas, an impact crater some 2,300 kilometers in diameter, had vast expanses so flat that Sharp coined the term "featureless terrain" to describe them. "There is nothing in the new data that encourages us in the hope that Mars is the abode of life," Horowitz, now a member of the expanded television team, said in the October 1969 issue of *E&S*. "However, there is nothing that excludes that possibility, either." The cameras also failed to see any seasonal surface darkening, which is now thought to be caused by winds blowing light-colored dust off of darker rocks.

These Mariners found traces of oxygen and carbon monoxide—both formed by the breakup of carbon dioxide molecules by ultraviolet light—but still no nitrogen. High doses of that UV light, the kind used to sterilize medical labs, reached the surface, unfiltered by the nonexistent ozone layer. The infrared radiometer experiment, directed by Neugebauer and Münch, showed that the south polar temperature was as low as –125 °C. This is cold enough to freeze carbon dioxide at Martian pressures, implying that the polar ice caps were actually dry ice, not water ice. Readings higher than –112 °C would have been needed for the caps to have been unambiguously water.

Each flyby had a close-up field of view limited to the ground directly beneath it. Recalled Leighton, "There's an area called Hellas that shows up very light-colored, whitish, on various occasions. Being a manifestation of something that seems to change on Mars, it was a good idea to take a look at that. And then there were the polar caps. . . . But the interesting thing is that each of these three spacecraft—going over terrain which all was selected ahead of time and was not selected on the basis of



Olympus Mons, the biggest volcano in the solar system, towers above a dissipating global dust storm in this Mariner 9 picture. Standing three times taller than Mount Everest, Olympus occupies an area nearly as big as the states of Washington and Oregon combined. The crater complex at the summit is almost 64 kilometers in diameter.

really very deep knowledge of anything—managed to uncover a particular type of terrain that had not been seen by any of the previous spacecraft. . . . If you could send three spacecraft past Mars in an essentially random manner, being certain only not to look at the same main area twice, and come back with something new each time, that must mean that the chance of seeing something new again was very great." And so it was.

The rocket carrying Mariner 8 lost pitch control and plunged into the Atlantic within minutes of liftoff on May 8, 1971. But an identical probe, Mariner 9, became the first spacecraft to orbit another planet. Much more sophisticated than, and four times the weight of, Mariner 4, Mariner 9 photographed Mars's entire orb in detail—in some areas, at 100-meter resolution—from its arrival on November 13, 1971, until October 27, 1972. Bruce Murray picked up the tale in *his* oral history:

Might there not, even now, be microbes lurking in the soil or under rocks, shielded from cosmic rays and the ultraviolet sun, waiting in suspended animation for the life-giving kiss of liquid water?

"We got there and there was a dust storm—very dramatic, if you want to think of it in retrospect. It didn't seem very dramatic at that time; it seemed like a very serious problem. All we could see was the outline of the south polar cap . . . and then there was a gradual clearing, like a stage scene, and three dark spots showed up. Couldn't imagine what those were. We finally photographed them, and there were these huge craters. . . . They were the tops of these huge peaks; they were standing high enough [that] the dust was not that thick over them. Then, of course, the dust storm cleared and there they were. The size of these volcanoes is just incredible."

Mariner 9 also revealed a rift system, called the Valles Marineris in the spacecraft's honor, 10 times the length of Earth's Grand Canyon—long enough, if it were laid across the United States, to stretch from San Francisco to Washington, D.C., with a branch reaching up to Canada. Mars thus had a lurid geologic past that might have resembled Earth's. Volcanism and crustal fractures implied a hot, churning interior, and a warmer surface to go with it. And if Mars had an iron core, as Earth does, the moving mass of metal would have generated a magnetic field to keep the solar wind at bay. But what really breathed new life into the question of life on Mars was unmistakable evidence of ancient water. There were features, said Murray, "formed, at least in part, by flooding at times. They are huge. There's nothing on Earth that parallels it. The closest thing . . . on Earth is what's called the Columbia River scablands, which is the area in Idaho and eastern Washington [where the glacial dam that formed] ancient Lake Bonneville broke at the end of the Pleistocene and flooded in one gigantic flood." There were also runoff channels, and things that looked like ancient river beds. Assuming that life had gotten a toehold on a more Earth-like Mars, could it have adapted as the planet slowly assumed its current barren state? Might there not, even now, be microbes lurking in the soil or under rocks, shielded from cosmic rays and the ultraviolet sun, waiting in suspended animation for the life-giving kiss of liquid water?

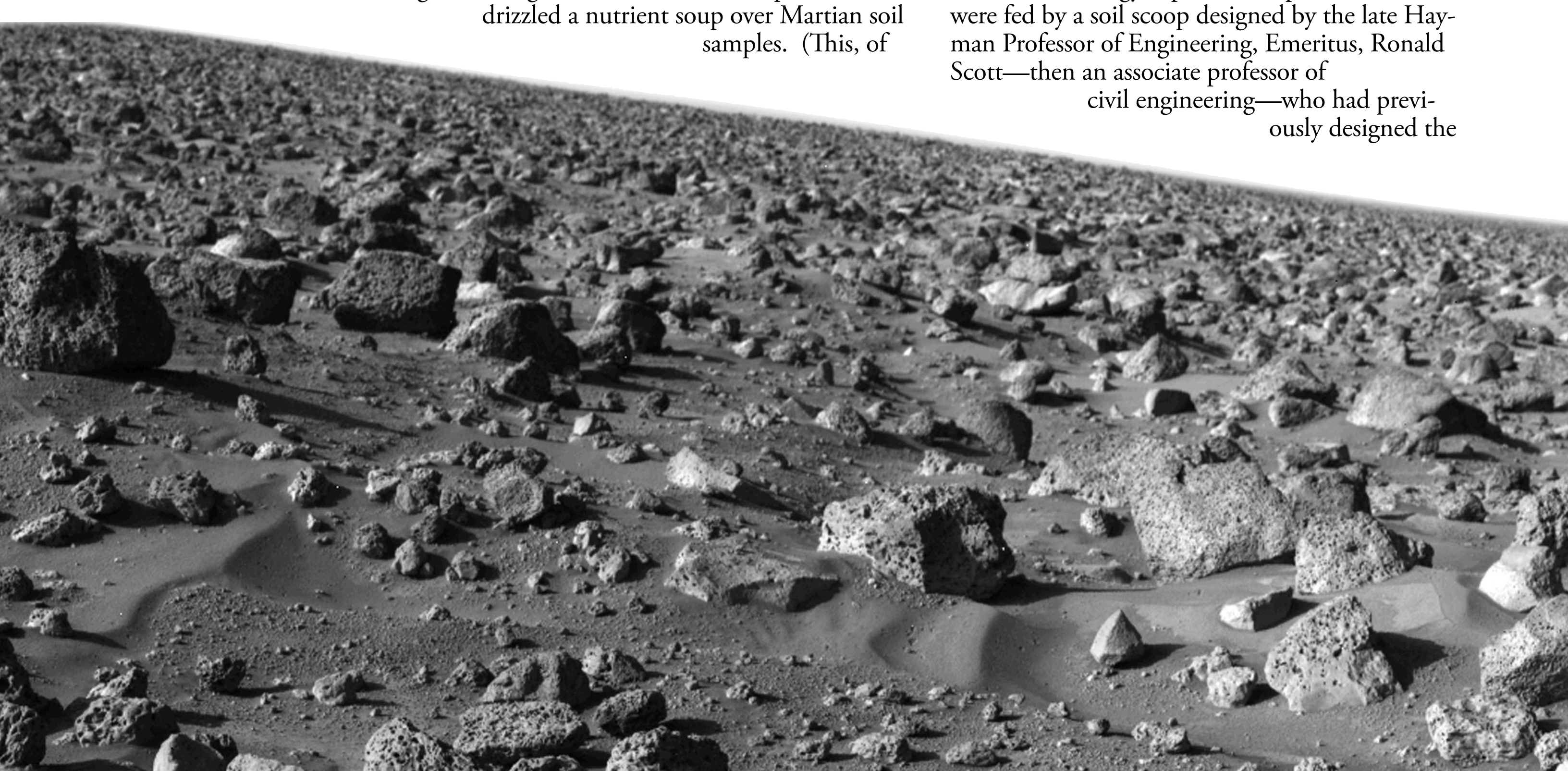
There was only one way to find out, and that was to actually land on Mars—the mission that became Viking. Looking for single-celled life meant turning to biologist Horowitz, an expert on a type of bread mold called *Neurospora*. He was tapped to head JPL's bioscience section, under an unusual arrangement where half his salary was paid by JPL and half by Caltech. He continued teaching one class and maintained his campus laboratory, but the half-time arrangement quickly got skewed, he remarked in his oral history. "I spent most of my time up there."

So how *do* you look for microbial life on an alien world? You cast as broad a net as possible, and Viking carried an extremely versatile instrument that could identify essentially any organic, which is to say carbon-based, compound. Horowitz called it "probably the most important single instrument on the lander." The gas chromatograph–mass spectrometer—or GCMS, as it's known in the trade—works by slowly heating the sample. As the component molecules evaporate or break down, they or their fragments are whisked by an inert carrier gas through a column—the gas chromatograph—packed with absorbent material. The small stuff wafts right through, while larger molecules (or pieces) get held up. The sample thus emerges sorted by particle size. These particles enter the mass spectrometer, where they pass through an electron beam that further breaks them down and gives the fragments a positive charge, and then sorts them by their charge-to-mass ratio. The GCMS was being built by Klaus Biemann at MIT and was already well along, so Horowitz's role was limited to "making sure that there was a lot of ground-based experience with it." The output is a sequence of mass numbers, and the amounts of the sample that have those masses, but the higher each number is, the more combinations of atoms can add up to it. So the operator has to tease out combinations that add up to a plausible breakdown sequence and try to work backward to the original compound. "There's not much general principle or general theory you can go on; you just have to have a library of results you can compare your actual results with."

The GCMS was not explicitly a biology instrument—the gas chromatograph also analyzed the atmosphere during the lander's descent—but there were three other experiments whose sole mission was to find life. All three of them occupied a mere cubic foot of space within the lander—a bacteriological laboratory in a shoebox. Two of them, the gas-exchange and labeled-release experiments, drizzled a nutrient soup over Martian soil samples. (This, of course, meant that the samples had to be kept at a temperaure and pressure where the broth wouldn't flash-freeze or sublime.) The idea was that if any Earth-like bugs were lying dormant, they'd wake up, slurp the soup, and betray their presence in one of two ways. The gas-exchange experiment, designed by Vance Oyama of NASA's Ames Research Center, looked for various metabolic gases with its own gas chromatograph. The labeled-release experiment, invented by a public-health engineer in Washington, D.C., named Gilbert Levin, spiced its consommé with radioactive carbon atoms. If any microorganisms were supping, some of this carbon would eventually show up on their breath, and a Geiger counter would register the emission of "hot" CO_2.

Horowitz thought this was a bad approach. "After the Mariner 4 flyby, it was obvious that the chance of liquid water on Mars was so remote that one had to plan for the contingency that there was no water—that if there was any life on Mars, it was living under conditions that were in no way terrestrial. So we designed an experiment that would work under Martian conditions and that involved no liquid water." In collaboration with University of Texas microbiologist George Hobby, whom Horowitz lured to JPL, and JPL's Jerry Hubbard (who left for Georgia Tech before Viking landed), Horowitz developed a pyrolytic release experiment, which exposed the soil to a sample of Mars's own air that had been spiked with a soupçon of radioactive carbon monoxide and carbon dioxide. The soil was then left to sit in simulated Martian sunlight at midsummer Martian pressures and temperatures. After 120 hours, the soil was heated under a stream of helium to 625 °C—hot enough to break down any organic material and turn it into carbon dioxide. The helium was checked for radioactivity. If any showed up, it must have been cooked out of some Martian microorganism.

All three biology experiments, plus the GCMS, were fed by a soil scoop designed by the late Hayman Professor of Engineering, Emeritus, Ronald Scott—then an associate professor of civil engineering—who had previously designed the



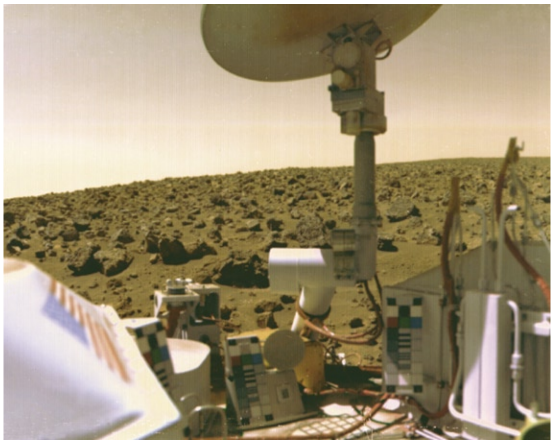
scoop for the lunar soil-mechanics experiment on JPL's Surveyors 3 through 7. The scoop's remote-controlled arm dropped the Martian dirt into a chamber from which it was dispensed, in half-cubic-centimeter lots, into experiment chambers on a rotating carousel as needed.

As part of the instruments' testing and checkout process, Horowitz dispatched JPL microbiologist Roy Cameron to the Antarctic where, just inland of McMurdo Sound, the soil is exposed year-round in ice-free "dry valleys." Their summer temperature tops out near 0 °C, and the year-round average is about 20 below. Any dustings of snow evaporate almost upon landing, due to the strong, dry winds sweeping down from the central Antarctic plateau. "These dry areas are as Mars-like as you can find on the earth," Horowitz explained. "I thought that Roy ought to be spending his time down there instead of in the Sahara and the Mojave and Atacama and so on." During the International Geophysical Year of July 1957–December 1958, a team of microbiologists had taken soil samples in the valleys that were absolutely sterile—unheard-of, since microbes eke out existences in the harshest of climates, which led some people to doubt the quality of the work. Cameron, his colleagues, and a bunch of Caltech grad students spent eight seasons down there, finding that "some 10 to 15 percent of the soil samples contained no bacteria, and the rest had very low bacterial counts." The valleys held saline lakes and ponds whose shores teemed with bacteria, yeasts, and molds, and the farther away the samples were taken from a water source, the fewer bacteria they contained. If there was life, even minimally, in this Mars on Earth, life on the real deal was certainly possible—it all depended on the water.

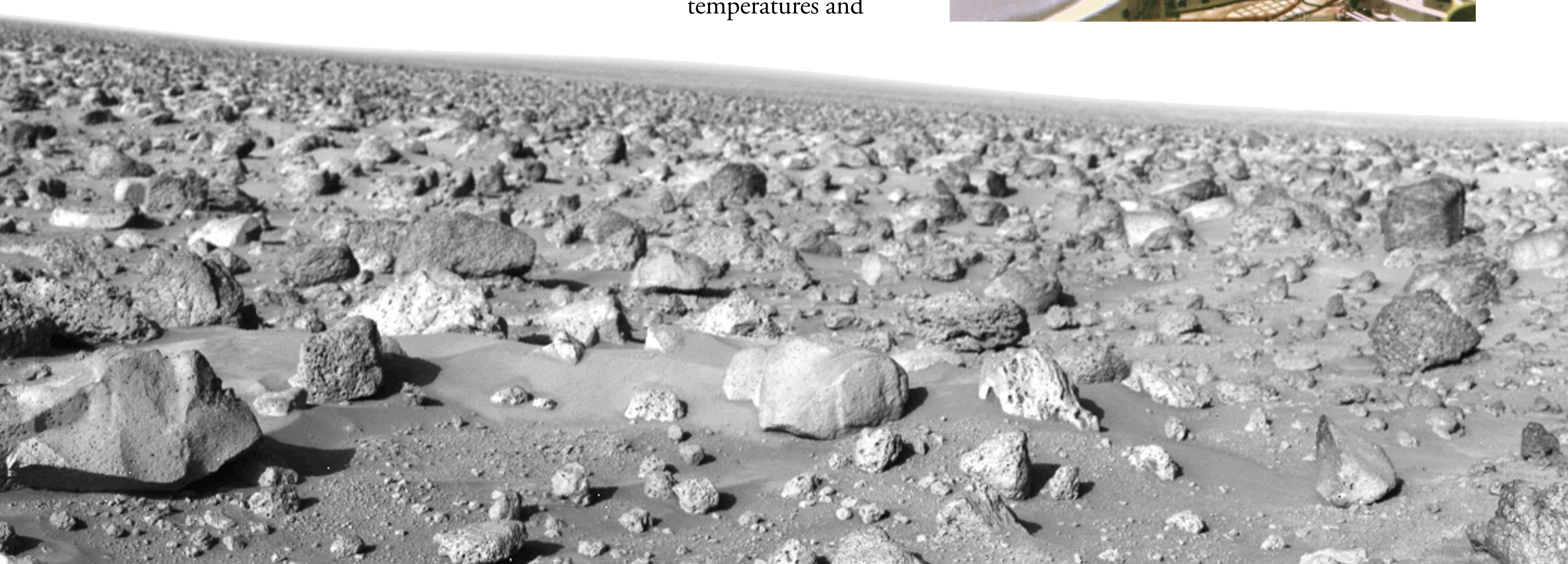
Viking Strikes Out

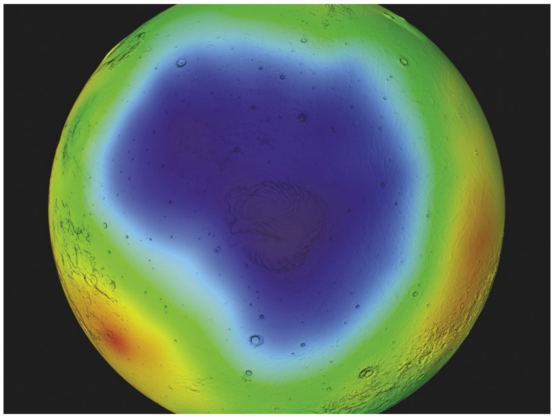
The most ambitious space mission the world had seen, the two Vikings each consisted of an orbiter, designed and built by JPL, and a Volkswagen-sized lander designed and built by Martin Marietta. Upon their arrival at Mars, the orbiters would scout the terrain with cameras and infrared sensors—the latter to look for higher-than-average temperatures and moisture levels. This close inspection proved prudent, as both the primary landing sites, which had been chosen in advance from Earth, turned out to be unsuitable. Safer sites were soon found, but no warm, moist oases, and on July 20, 1976, Viking 1 touched down. The landing had originally been slated for the Fourth of July as part of America's bicentennial celebration, but the delay caused Viking to mark a more apropos anniversary instead—Neil Armstrong's and Buzz Aldrin's first steps on the moon in 1969. Viking 2 followed on September 3. The two landers were placed on opposite sides of the planet, on the Chryse Planitia downstream of some ancient drainage channels (22° N, 48° W) and on Utopia Planitia (48° N, 226° W), respectively. It was summer in the northern hemisphere, the time when life—if any existed—should be flourishing. The nominal missions were 90 days, but all four spacecraft operated for two years, with Lander 1 surviving for more than six and Orbiter 2 for four.

Besides the GCMS and the shoebox lab, each lander carried a complete weather station, two cameras, and a seismometer. Designed and prototyped by Don Anderson (MS '58, PhD '62), then professor of geophysics and director of Caltech's seismo lab, the instruments were built with a latch the manufacturer added to protect the motion sensor in flight. Viking 1's seismometer failed to unlatch, but Viking 2's picked up wind-induced vibrations—terrestrial seismometers routinely record the rustle of the grass as the wind goes by. It



Below and right: This boulder-strewn field reaches to the horizon, which is nearly three kilometers from Viking 2's landing site on Utopia Planitia.





This summertime view of Mars's north polar region shows data from the Mars Odyssey's high-energy neutron detector. The purple and deep blues represent soil enriched by hydrogen, which is a proxy for water, presumably as ice—in some areas up to 90 percent by volume. In the winter, much of this region is covered by frozen carbon dioxide.

also recorded only one event that might have been a Marsquake, showing that the planet is now tectonically dead.

There was a very real concern that the lander itself could ruin the biology experiments. Mock news footage on a *Saturday Night Live* "Weekend Update" segment showed a lander squashing a crowd of Martians waving a banner of welcome. While JPL didn't expect a disaster on quite that scale, the landers' descent rockets were designed to minimize scouring and heating the Martian surface, and specially purified hydrazine (N_2H_4) fuel was used to avoid contaminating the landing site with organic chemicals. (Hydrazine combustion produces only nitrogen, hydrogen, and ammonia gases, plus a trace of water vapor.) And all four spacecraft were rigorously sterilized before launch to prevent any terrestrial microbes from colonizing a new world.

The landers' cameras revealed a sandy, wind-blown, rock-strewn, ocher landscape. No lichens or mosses were seen. (The camera had a close-up resolution of a few millimeters per pixel.) There were no signs of movement among the rocks from frame to frame, and no footprints or animal tracks. And certainly no Martian ever came up and tapped inquiringly on the lens.

Some meteorites contain organic material, so it was anticipated that carbon-based compounds would be found on Mars whether life existed or not. Each lander took two soil samples for GCMS analysis, including one from under a rock at Utopia Planitia. The instrument was sensitive to organic molecules at the parts per billion level, Horowitz wrote in his 1986 book, *To Utopia and Back*, but "the only organic materials found were traces of cleaning solvents left over from the manufacture of the instrument." Case closed. No carbon-based compounds, no life—at least not as we know it, Jim.

But first, the gas-exchange experiment got everybody's hopes up. When Martian soil was exposed to water vapor for a few days before being sprinkled with the nutrient rain, the parched ground released a flood of oxygen. This was unanticipated—methane was the gas people expected to see, based on the metabolism of anaerobic bacteria on Earth. The outgassing lasted for nearly a week, a phenomenon later attributed to highly oxidizing minerals in the soil reacting with the water molecules. Such compounds had been predicted, albeit not in such quantities, as a result of Mars's UV bath. These oxidants also explained the surprising lack of background organics—any prebiotic chemicals had been fried in short order like so many microscopic sliders on the grill. After the outgassing had ceased, the experiment proper began. The dirt was incubated for nearly seven months with no further result.

The labeled-release soil liberated a similar surge of gas upon initial moistening. The sample was then heated for several hours to sterilize it, and spritzed again. No further radioactive gas wafted out. Levin, the instrument's inventor, argued that this proved the initial release had been biological, and the heat had killed the bugs—as intended. Horowitz, citing the negative GCMS results, held that it was simply because all the oxidants in the soil had been used up. "The most likely source of this gas was formic acid [one of the nutrients], a one-carbon compound that is easily oxidized to CO_2 by peroxides," he wrote in *Utopia*.

Horowitz's own experiment gave "weakly positive" results. The very first one, by Viking 1 on Chryse Planitia, released an amount of carbon "small in comparison to that found when using terrestrial soil samples, but . . . far above the background level." However, this effect was not repeated in two later tests on fresh soil, which showed much weaker emissions. The Viking 2 tests at Utopia were even less encouraging. One gave low levels comparable to the latter two Chryse ones, but two more showed nothing above the preflight baseline. "Although the positive signals . . . are still not completely understood, the chance that their source was biological seems negligible," Horowitz concluded. He attributed them to a reaction between an iron-rich mineral, such as maghemite, and carbon monoxide.

Oyama, previously one of the strongest proponents of life on Mars, was convinced by the GCMS results that the planet was sterile, as was Horowitz and most of the scientific community. Levin, however, didn't buy the peroxide explanation, saying that his instrument had detected life in exactly the way it was designed to do—a view he maintains to this day. He is no longer alone. The discovery of possible bacterial fossils in a rock ejected from Mars that landed in Antarctica; photographs by JPL's Mars Global Surveyor of what appear to be fresh, water-carved gullies in the walls of craters; and indications from JPL's Mars Odyssey that permafrost lies within one meter of large parts of the planet's surface have again reopened the question. And Arthur Lafleur, a member of the original GCMS team, now says that millions of microorganisms would be needed for their aggregate organic material to register on the Viking instrument, whereas the labeled-release experiment was capable of detecting far fewer cells—as few as 10, he claims. So if the ultraviolet-induced self-sterilizing soil zone doesn't extend too deeply, Mars may once again turn everything we think we know about it on its head. Only a future lander will find out. □

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