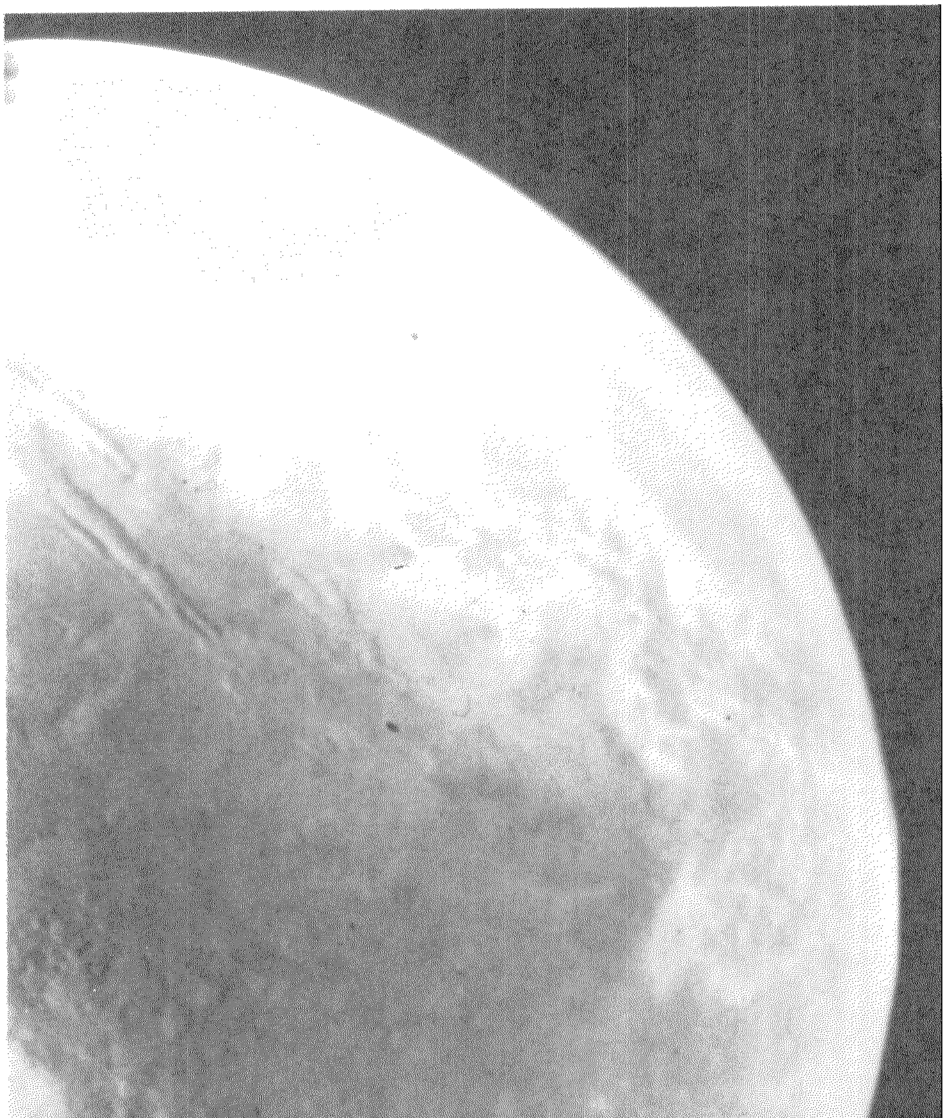
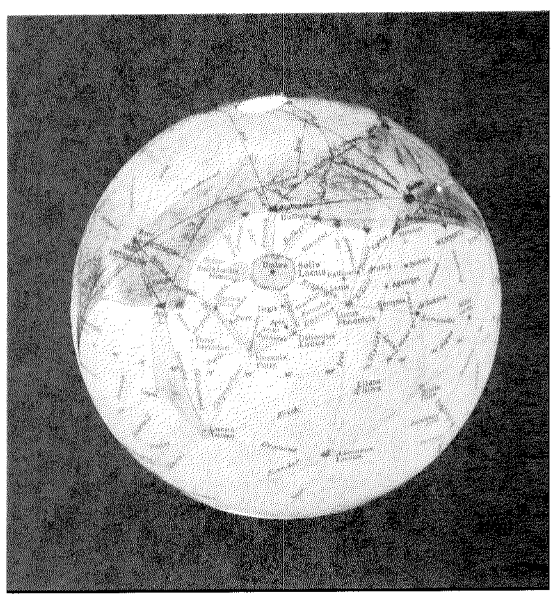


Mars: Myth and Reality

by Norman H. Horowitz



Above: Percival Lowell's 1907 globe of Mars with canals. The place names were given by Schiaparelli. (Lowell Observatory Photograph)
Left: Mars as seen by Viking 1.

Our knowledge of Mars steadily progresses. Each opposition adds something to what we knew before. Since the theory of life on the planet was first enunciated some fifty years ago, every new fact discovered has been found to be accordant with it. Not a single thing has been detected which it does not explain. Every year adds to the number of those who have seen the evidence for themselves. Thus theory and observations coincide.

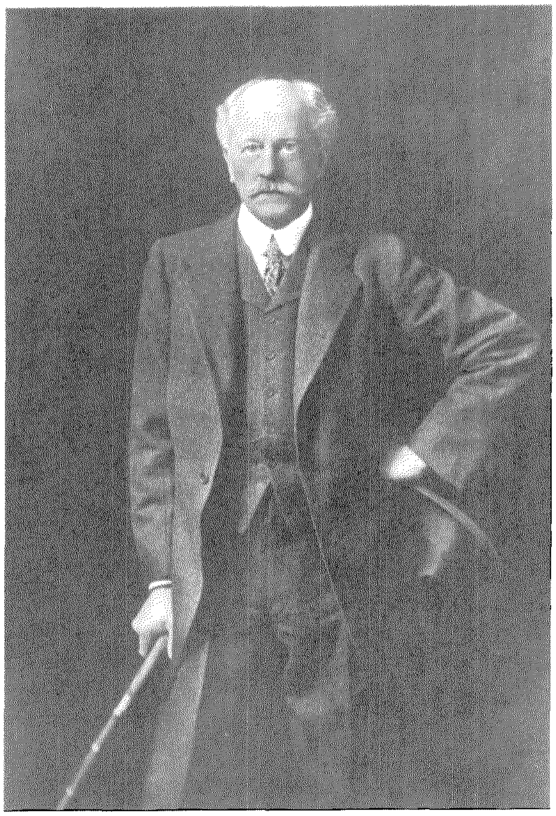
— E.C. Slipher, *The Photographic Story of Mars* (1962)

In *The Golden Bough*, anthropologist Sir James Frazer told us that Mars was originally a god of vegetation, not war. Roman farmers prayed to him for the success of their crops, and the vernal month of March was consecrated to him. In view of this ancient association of the god Mars with the awakening of plant life in the spring, it seems fitting that the planet Mars should be the least hostile of all the extraterrestrial bodies in the solar system, the planet other than the earth that comes closest to providing a suitable habitat for life.

Although only about half the diameter of the earth, Mars looks remarkably earthlike from a distance, and it does share certain similarities. In one of the earliest telescopic studies of the planet in 1659, Christian Huygens discovered a permanent marking on the Martian surface that enabled him to measure the planet's rotational period. He found that Mars, like the earth, rotates on its axis once in 24 hours. Later, more accurate measurements showed that the length of the Martian solar day is exactly 24 hours, 37 minutes, and 22 seconds — a period that became known as a "sol" during the Viking mission in order to avoid confusing it with the terrestrial day. Furthermore, in the present era the spin axis of Mars tilts at an angle of 25 degrees from the plane of its orbit, compared to the 23.5 degree tilt of the earth. This means that Mars has seasons like the earth's, as first one hemisphere and then the other leans toward the sun. The Martian year is 687 earth days in length (669 sols), or about six weeks short of two earth years, so that the Martian seasons last roughly twice as long as those on the earth. Because of the eccentricity of Mars's orbit, however, Martian seasons are not of nearly equal durations as our planet's are. On Mars, for example, northern summer (and southern winter) lasts 178 sols, while northern winter (and southern summer) lasts 154 sols. On the earth, these seasons last 94 and 89 days respectively.

The impression of an earthlike planet is reinforced by seasonal changes on the Martian surface that can be seen through the telescope. The most striking of these changes is the annual advance and retreat of the polar ice caps. Other, more subtle alterations occur at lower latitudes, where the Martian surface is broken up into bright and dark areas. The bright areas, formerly called deserts, are reddish orange in color. The dark areas, in the past called maria (seas) because they were thought to be bodies of water, have been variously described as gray, brown, blue and green. Seasonal changes in color and contrast — the maria appeared a dark bluish green in the late spring and summer, but faded to a brownish tone in fall and winter, then darkened again in the spring — were reported by astronomers in the 19th century. Such changes made it appear more likely that vegetation rather than water covered these areas, an idea that was first advanced in 1860. Some observers also described a network of pencil-thin, straight lines extending for hundreds of miles over the Martian surface. These lines, called "canali" (channels) by Giovanni Schiaparelli (1835-1910), the foremost Mars-mapper of the 19th century, changed seasonally like the maria — they were dark in the local spring and summertime, but faded in fall and winter. Schiaparelli noted that the canali looked like the work of intelligent beings, but he did not commit himself to this interpretation.

These intriguing observations, which were made possible by improvements in telescopes in the 19th century, convinced some people that direct evidence for life on another planet had at last been achieved. One of those



Percival Lowell. (Lowell Observatory Photograph)

stirred by the new findings was Percival Lowell (1855-1916), an American who would found the Lowell Observatory in Flagstaff, Arizona, for the express purpose of studying Mars. Lowell's place in the extraordinary history of Martian biological investigations is special enough to require a more detailed examination.

THE LEGACY OF PERCIVAL LOWELL

Percival Lowell belonged to an eminent New England family: Abbott Lawrence, his brother, became president of Harvard University, and his sister Amy was the Imagist poet. Lowell was not trained as an astronomer — he devoted himself to studies of Japanese and Korean culture, subjects on which he wrote a number of books — and his fascination with Mars developed relatively late in life. According to William Graves Hoyt, author of a recent biography of Lowell, astronomy had long been among Lowell's many enthusiasms, and he was inspired by Schiaparelli's discovery of canali on Mars. Schiaparelli's description, it appears, all but convinced Lowell that Mars was inhabited by intelligent beings. This belief, or near-belief, led him to commit his considerable wealth and talent to the founding of the Flagstaff observatory. Dedicated to the study of Mars, the observatory opened in May, 1894. By July of the same year, barely two months after operations began, Lowell was ready to formulate his very definite views about life on Mars — views from which, Hoyt notes, he did not deviate for the rest of his life.

Although Lowell came to Martian studies late in his career, his authority and influence in matters relating to Mars soon became quite important. His observatory was well equipped and staffed, and it occupied a superior observing site, a fact that Lowell did not neglect to mention when others failed to confirm his observations. Furthermore, the observatory spent almost its entire effort on Mars and missed no opportunity to study it. Lowell therefore accumulated a vast amount of systematic information on the planet, and these intensive studies made him probably the best-informed Mars-watcher of his day. (Criticisms directed at Lowell during his lifetime and later aimed less at his data than at his interpretations of them.) Finally, Lowell tirelessly communicated his great enthusiasm for his subject and his unwavering confidence in the correctness of his conclusions to the general public in books, articles, and public lectures. Through these and other efforts, he succeeded in making Mars a topic of general interest, not one reserved for specialists alone.

Lowell's theory was simple enough. It began with the premise that the polar caps of Mars are composed of water ice. To support this belief, he pointed to a dark blue band, or collar, that appeared around the caps as they began to shrink in the spring and that dwindled with them. Only liquid water, produced by melting of the caps, could explain the collar, he argued, and he often referred to these bands as "polar seas." Lowell knew that, aside from the polar regions, Mars is very dry. Its dark areas could not be bodies of water because, although they changed color seasonally as if drying up, the water apparently lost from them did not turn up anywhere else on the planet. And as others had pointed out, if the maria contained water, they would reflect sunlight, yet such reflections were never seen. Given the dryness of the planet, Lowell deduced that the seasonal disappearance of one polar cap, coupled with growth of the other, meant that water was transferred from one pole to the other: "Meteorological conditions carry (water) to deposit at one pole, then liberate it and convey it to imprisonment at the other, and this pendulumlike swing of water is all in the way of moisture that the planet knows." This semiannual transfer of water was accompanied by a darkening of the dark areas that spread wavelike "across the face of the planet from one pole to the other in the course of a Martian six months." Such regular darkening, he was convinced, demonstrated that plant life exists on Mars. The observations proved, he wrote, that the condition of the planet "is not only compatible with life, but that vegetal life shows itself there as patently as could possibly be expected, and that nothing but vegetation could produce the observed phenomena."

In Volume 1 of the *Annals of the Lowell Observatory*, Lowell continues:

> Now if there were any life of an order higher than the vegetal upon the planet — an order capable of something more advanced than simply vegetating, an order able to turn natural conditions to its own ends — its first and final endeavors would be to contrive means to use every particle of that necessary and yet scanty sustainer of life, water. For there is no organism which can exist without water. In short, irrigation for agricultural purposes would be the fundamental Martian concern. . . .

Lowell then summarizes his observations on the canali and concludes:

> These are just the features a gigantic system of irrigation would present. Upon the above results of the observation is based the deduction I have here put forward, — (1) of the general habitability of the planet; (2) of its actual habitation at the present moment by some form of local intelligence.

And so Lowell arrived at the belief in a civilization on Mars. Abetted by his French contemporary, the astronomer Camille Flammarion (1842-1925), he popularized the familiar drama of a courageous race of Martians, superior to ourselves, struggling for survival on a desiccated and dying planet. Lowell saw nothing speculative in these ideas. In a typical passage from his book, *Mars as the Abode of Life*, he writes:

> In our exposition of what we have gleaned about Mars, we have been careful to indulge in no speculation. The laws of physics and the present knowledge of geology and biology, affected by what astronomy has to say of the former subject, have conducted us, starting from the observations, to the recognition of other intelligent life.

The idea of a Martian civilization, although embraced enthusiastically by the public, was viewed with scepticism by scientists even in Lowell's day, and it did not survive his death. The "canals" — always controversial and now known not to exist — were probably an illusion caused by viewing difficulties. The rest of Lowell's theory, however — the polar ice, the movement of water, the vegetation — not only survived him, but took on new life. It was as if, relieved of its burden of heroic Martians, the Lowellian thesis of an earthlike Mars had acquired scientific respectability and could be accepted as a reasonable approximation to the truth. Lowell's views would eventually be disproved in every significant detail. Yet — and this is the strange part of the story — as observations of Mars continued, they seemed increasingly to show that Lowell was right. As a result, the Lowellian view was widely accepted for most of the 20th century.

The epigraph at the beginning of this chapter, quoted from a book by a longtime associate of Lowell's, summarizes the state of

This 1911 photograph of Mars (the small dot at right) emerging from occultation by the moon (the large hemisphere at left) illustrates why it was difficult to study Mars from the earth in the early part of the century. (Lowell Observatory Photograph) affairs as they appeared to one observer in 1962. The optimism that shines through Slipher's statement could, in fact, be defended in 1962. Unfortunately for this view, new results soon to be obtained would show that this optimism was unfounded and that the Lowellian picture of Mars, with or without canal-building Martians, was pure fantasy. Within a few years, scientific ideas about the planet would take an entirely different turn. The rise and fall of Lowellian Mars in our time is our subject in the rest of this chapter.

PRE-1963, OR LOWELLIAN, MARS

Ice Caps

The waxing and waning of the Martian ice caps proved to early observers that Mars has an atmosphere of some kind, but its composition and its quantity remained a mystery for a long time. Carbon dioxide, now known to be the major component of the Martian atmosphere, was first identified on Mars by the well-known Dutch-American astronomer, Gerard P. Kuiper (1905-1973) in 1947. To make this finding, Kuiper used infrared spectroscopy. In planetary spectroscopy generally, sunlight reflected from a planet is collected by a telescope and broken up by a prism or grating into its spectrum — in this case, its infrared spectrum. This spectrum is then compared to a similarly prepared spectrum from the moon, for example, or, depending on the question being investigated, from a different area of the same planet. Different substances absorb light of different wavelengths, a fact that makes chemical identifications possible. By comparing the spectrum from a planet that has an atmosphere with one obtained from the moon, which has no atmosphere, once the absorption by the earth's atmosphere is subtracted out, what remains is the spectrum of the planet's atmosphere. Because the amount of energy absorbed depends on the amount of absorbing material, such spectra contain quantitative as well as qualitative information. Thus, the observer can say not only what the absorbing gas in the light path is but how much of it there is.

The wavelength region that lies beyond the red end of the visible spectrum, called the infrared, is very rich in specific chemical absorptions. When Kuiper compared the infrared reflections from Mars with those from the moon, he found a diminution in the energy at several wavelengths in the neighborhood of 1.6 micrometers in the Martian spectrum; these wavelengths corresponded to known carbon dioxide absorptions. Kuiper estimated that the amount of carbon dioxide over a given area of Martian surface is twice that over the same area on the earth. From this, he calculated the pressure of carbon dioxide on Mars, taking into account the lower force of gravity on Mars compared with that on the earth. He arrived at a pressure equal to that of 0.26 millimeter of mercury, or 0.35 millibar. Here Kuiper erred. His estimate was too low by a factor of about 16, an error that had important consequences because it allowed Kuiper to argue that the Martian polar caps could not be composed of frozen carbon dioxide (dry ice). If the carbon dioxide pressure were as low as his calculations indicated, an unrealistically low temperature would be required to freeze the gas out of the atmosphere. It was discovered some years later that Kuiper had incorrectly calculated the carbon dioxide pressure, but this finding had no effect on the course of events.

The only other substance that was reasonable for the caps was frozen water — ice, snow, or frost — but other astronomers had already searched without success for water vapor in the Martian atmosphere. Kuiper therefore proceeded to examine the north polar cap of Mars directly by infrared spectroscopy. The analysis was difficult, owing to the small size of the ice cap, but by modifying his spectrometer to improve its sensitivity and by repeating the observations many times, Kuiper finally convinced himself that "the Mars polar caps are not composed of CO_2 and are almost certainly composed of H_2O frost at low temperature." The note of caution discernible in the second part of this statement reflects the fact that the spectrum of the polar cap did not quite match the spectrum Kuiper had obtained for terrestrial snow.

Here Kuiper erred again — the seasonally variable portions of the caps are actually frozen carbon dioxide, not water — but his error would not be discovered for nearly 20 years. Instead, the incorrect result was seemingly confirmed by another investigator, Audouin Dollfus of the Paris Observatory, using a different method, one based on the polarization of reflected light. Ordinary, unpolarized sunlight consists of electromagnetic waves that vibrate in all directions in the plane perpendicular to the direction of propagation of the light ray. In light that has been reflected or scattered, however, or that has passed through certain kinds of materials (such as polaroid), the waves vibrate in only one direction. Such light is said to be polarized. The degree of polarization of reflected light depends on the angle of vision, as well as on the structure, transparency, and other physical properties of the reflecting surface. Dollfus, who had much experience with planetary polarization measurements, decided to apply the method to the ice-cap problem.

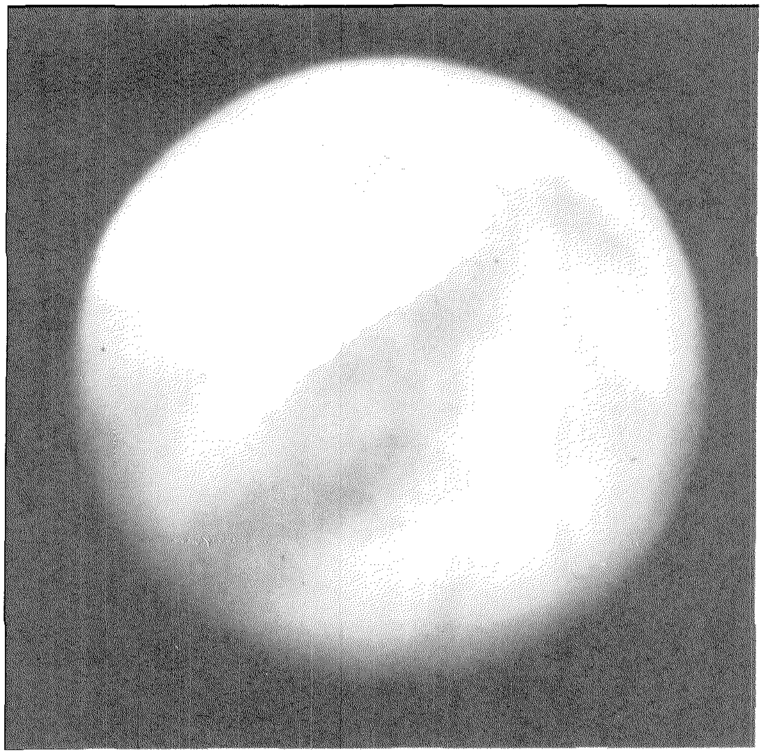
As had Kuiper before him, Dollfus noted that the caps were small and difficult to study. He succeeded in making some measurements, however, and found that the polarization of the caps was much less than that of ice, frost, and snow on terrestrial mountains observed at the same angle. He then performed laboratory experiments showing that the polarization of frost deposits could be made to resemble that of the Martian ice caps if, first, the frost were deposited on a cold surface with a low atmospheric pressure (as would be the case on Mars) and, second, if the deposits were partly sublimed — that is, evaporated without melting — by exposing them to an arc lamp, as might happen to Martian ice caps exposed to the sun. He concluded that the ice caps were probably deposits of hoarfrost.

Dollfus did not perform comparable experiments with solid carbon dioxide, but his apparent confirmation of Kuiper's result convinced many students of Mars that the ice-cap question was solved. The following quotation, for example, reflects the views of a panel of informed scientists, many of whom later made important contributions to our knowledge of Mars, that was appointed by the Space Science Board to advise NASA in the early stages of its planetary program:

> Infrared reflection spectra of the polar caps show conclusively that they are not composed of frozen carbon dioxide, the only condensible substance which might be expected besides water; the reflection spectra are also consistent with the assumption that the polar caps are made of ice. . . . The polarization data indicate that the polar caps are composed of hoarfrost. . . .

Later in its report, this same panel drew an inference identical to the one reached by Lowell in 1898, 63 years before. In their view:

> Since the polar caps are composed of frozen water, their seasonal retreat directly suggests that there is some water vapor in the Martian atmosphere. Because of the alternating formation of polar caps in opposite hemispheres, the circulation in the lower atmosphere must be such that water vapor is transferred from one hemisphere to the other.



Robert Leighton captured the best earth-based photograph of Mars from Mt. Wilson in the early 1950s. Leighton and Bruce Murray, both of Caltech, predicted in 1966 that the polar ice caps were made of solid carbon dioxide, a fact confirmed by Mariner 7 three years later.

Atmospheric Pressure

Mutually supporting errors also produced a spurious conclusion about the atmospheric pressure, another crucial biological parameter. And once again, the effect was to make Mars appear more earthlike than it actually is. In the Lowellian period, the two principal methods used to estimate the Martian atmospheric pressure were photometry and polarimetry. Light is scattered by gas molecules. It is this scattering that accounts, for example, for the blue sky: the atmosphere scatters incoming sunlight in all directions, but because light of short wavelengths (blue and violet) is scattered very much more than long-wavelength (red) light, we see a blue sky when we look away from the sun. Since scattering by its atmosphere affects the surface brightness of a planet, measurement of that brightness at different wavelengths and under different thicknesses of atmosphere (obtained

continued on page 35

Mars: Myth and Reality

continued from page 9

by viewing the planet at different angles) should provide a way to estimate atmospheric pressure. Furthermore, since scattered light is polarized, polarization measurements should provide a check on the result.

But scattering depends not only on the wavelength of the light and the mass of the atmosphere but also on the atmospheric composition and the presence or absence in it of dust and other suspended particles, and therein lies the snag. In order to allow for these and other complications, such as polarization by the planetary surface, investigators before 1963 had to make some unverifiable assumptions before they could derive the atmospheric pressure from their data. The result, in the words of Claude Michaux and Ray Newburn of the Jet Propulsion Laboratory (JPL), was that "Each successive worker pointed out the 'unwarrantable assumptions' of his predecessors and proceeded to make a new set of his own."

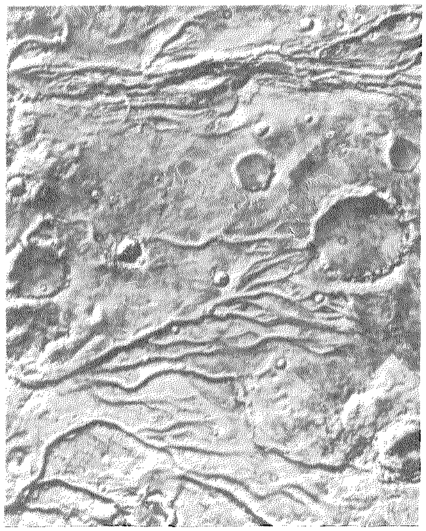
Despite the difficulties, a dozen or so attempts were made after Lowell's time to apply photometric and polarimetric methods to the surface-pressure problem. Their generally concordant results were reviewed by the French astronomer Gerard De Vaucouleurs in an influential book on Mars, the English edition of which appeared in 1954. De Vaucouleurs concluded that the most probable value for the Martian surface pressure was 85 ± 4 millibars. (This was the perfect Lowellian result. In *Mars as the Abode of Life*, published in 1908, Lowell had applied photometric arguments to the problem and arrived at a pressure of 64 millimeters of mercury, or 85 millibars!) After reexamining the evidence, the panel of experts quoted above gave its judgment: "It is unlikely that the true surface pressure differs by as much as a factor of 2 from 85 millibars." Actually, the true surface pressure differs from 85 millibars by a factor of more than 10.

Vegetation

Lowell based his belief that the dark areas of Mars were covered with vegetation on their blue-green color and on their observed seasonal color changes. In the springtime, what he called a "vernal progression" or "verdure wave" moved through these areas and along the canals, starting near the edge of the dark collar surrounding the shrinking ice cap and proceeding toward and beyond the equator. He estimated the speed of the wave at 51 miles per day. In Lowell's scheme, the wave of deepening color proved the sprouting of vegetation as water became available at lower latitudes in its regular swing through the atmosphere from one pole to the other. Lowell recognized that the direction of this wave of darkening, as it came to be called, was opposite to that seen on the earth, where the springtime growth of plants starts in temperate latitudes and moves poleward. But, he argued, this was just what one would expect on a planet where life is limited by the availability of water.

Telescopic observations made after Lowell's time confirmed the existence of the dark polar collar and of seasonal changes in the maria. These phenomena are now thought to result from redistribution of dust by seasonal winds. Or perhaps the polar collar is simply an optical effect produced by a glazed layer of frozen carbon dioxide exposed by sublimation of the overlying carbon dioxide frost. For decades following Lowell's death, however, the vegetation scenario reigned, and, by 1960, it seemed close to being proven.

The story began modestly in 1947-48 when, following the conclusion that the Martian polar cap was composed of water ice, G. P. Kuiper turned his attention to what he called the "green areas" of Mars. His plan was to compare the light reflected from these areas with the spectra obtained from higher plants, lichens, and mosses. Lichens are symbiotic associa-



Dendritic flow channels on Mars are shown west of the Viking 1 landing site in this Viking Orbiter shot. Old impact craters, formed before the flooding and eroded by it, and younger craters are visible. (National Space Science Data Center)

tions between a fungus and an alga. They are green or greenish in color and, like higher plants, they carry out photosynthesis by means of chlorophyll. Extremely hardy, these organisms inhabit cold, dry, forbidding places where few other living things survive.

Kuiper found no resemblance between the higher plant and lichen spectra. Whereas the plant spectrum showed a dozen or so peaks and valleys in its visible and infrared regions, the lichen spectrum appeared featureless and nearly flat over the same spectral range. Dry mosses produced a spectrum like that of lichens. Kuiper did not, for technical reasons, obtain a complete spectrum of the green regions of Mars. Instead, he measured their reflections at four different wavelengths. These observations convinced him that the Martian spectrum was unlike that of green plants and similar to that of lichens and mosses. A featureless spectrum hardly constituted strong evidence for the existence of either of these life forms on Mars, and a nonbiological explanation for the wave of darkening had been proposed. According to this hypothesis, the seasonal changes occurred when inorganic materials on the Martian surface absorbed water vapor from the atmosphere as it moved across the planet in the spring, then lost it in the dry fall atmosphere. Many such absorptive substances are known, and some of them do change color with the uptake and loss of moisture. Ernst Öpik, a noted Estonian-British astronomer, disposed of this hypothesis in 1950 with the argument that dust storms, recognized telescopically as yellow clouds that sometimes obscure the entire planet, would have covered the dark areas long ago if they had been simply inorganic deposits. The fact that the same areas always reappear after such storms, Öpik said, shows that they have regenerative powers.

Considering all the evidence and giving due weight to Öpik's argument, Kuiper concluded that the case for living things in the dark areas "appears very good." He thought it improbable, however, that Martian lichens were identical to those on the earth, because this would imply a highly unlikely parallel evolution — and besides, our lichens do not change color in the fall.

Kuiper's case was, at best, only suggestive, but it was soon strengthened by a spectacular result obtained by W. M. Sinton, a young American astronomer. As Kuiper had done, Sinton investigated the light reflected from Mars, but instead of scanning the whole spectrum, he concentrated on a narrow region in the infrared — in the neighborhood of 3.5 micrometers — where carbon-hydrogen bonds absorb strongly. Since all organic matter contains such bonds, Sinton argued that if plant life were responsible for the wave of darkening, that fact should be revealed by absorption in this region. Tests performed on lichens, mosses, and dried leaves confirmed that the light they reflect does show this absorption feature. Sinton then examined Mars over a period of four nights and found an absorption band centered at 3.46 micrometers, exactly where the tested plant material had absorbed. Two years later, in 1958, he repeated the observations, but with better equipment and with the 200-inch telescope of the Palomar Observatory. This time, he was able to analyze the light from the dark and bright regions separately. He found three bands near 3.5 micrometers — all attributed to organic compounds — in the light that came from the dark regions. The absorptions were weak or absent in light from the bright regions. On the face of it, a stronger confirmation of Lowell and Kuiper could hardly have been imagined.

The Space Science Board panel was not convinced by the Sinton absorption bands, stating that "the possibility that they arise from a combination of inorganic substances does not seem to have been explored sufficiently." On the question of Martian life, however, it concluded:

> The evidence taken as a whole is suggestive of life on Mars. In particular, the response to the availability of water vapor is just what is to be expected on a planet which is now relatively arid, but which once probably had much more surface water. The limited evidence we have is directly relevant only to the presence of microorganisms; there are no valid data for or against the existence of larger organisms and motile animals.

. . .

(A chapter section on the initial "delowellization" of Mars — the work between 1963 and 1969 — is omitted here)

. . .

MARINER 9 AND PRE-VIKING MARS

Once begun, the unraveling of Lowellian Mars proceeded swiftly, and by 1969 the delowellization of Mars was complete. In place of a harsh but recognizably earthlike planet, a Mars came into view that was almost moonlike in its hostility. This new Mars had a thin atmosphere, composed predominantly of carbon dioxide, that provided little protection against solar ultraviolet radiation which penetrated to the surface of the planet almost unfiltered. Furthermore, all attempts to detect the life-essential element nitrogen, the most abundant gas of the earth's atmosphere and the one that was supposed to compose the bulk of Mars's atmosphere in the Lowellian era, had so far failed. It now appeared that nitrogen made up less than 5 percent of the Martian atmosphere, and the possibility that the planet had no nitrogen at all had to be considered. Most ominous of all from a biological viewpoint was the dryness: the low surface pressure meant that water could not exist on the surface of Mars in liquid form, but only as ice or vapor.

The television pictures returned by *Mariners 4, 6,* and *7* were just as discouraging as the atmospheric results. Mars looked more like the moon than an earthlike planet. With a few exceptions, even the familiar surface markings disappeared on close approach, and none could be identified with particular surface features. Even the boundaries between classical bright and dark regions — so clear when viewed from afar — were invisible in pictures that otherwise showed Mars in greater detail than had ever been seen before. It now appears that the bright areas consist of relatively smooth and level ground that has accumulated a more or less continuous cover of light-colored dust. The dark areas, on the other hand, correspond to steeply sloping or heavily cratered regions where the dust layer is not continuous and where the darker bedrock shows through. Of Schiaparelli's and Lowell's canals, the only traces are possible chance alignments of craters and other natural surface features that the eye connects up to form lines.

The prospects for life on Mars seemed so dim by 1970 that there seemed little good reason to emphasize biological questions in planning the spacecraft that would land there in 1976. A radical reversal took place in 1971, however, when another Mariner mission was sent to Mars. Of the two spacecraft launched in 1971, one — *Mariner 9* — achieved orbit around Mars, the goal of the mission, and it operated there for 11 months. Its most important accomplishment was to photograph the entire planet, and as large regions not previously seen by spacecraft came into view, it soon became obvious that Mars was not just another version of the moon, as earlier Mariner pictures had led one to expect, but was a planet with its own complex history.

Several spectacular discoveries led to this conclusion, among them four gigantic, inactive volcanoes, one of which is the largest in the solar system. But the aspect of Mars that has attracted the most attention is undoubtedly its multitude of channels, some of them hundreds of kilometers in length and apparently cut in the past by running water. (These channels, which are invisible from the earth, have no relation to Lowell's canals.) A number of morphologically distinct channel types are seen, but not all of them require running water to explain their origin. Some may have been eroded by glacial movement, for example, and some by flowing lava, to mention two possibilities. Many, however, and perhaps most, were very probably formed by water. Among these are sinuous, meandering streambeds that, with their tributaries, form typical drainage patterns. The source of water for these systems could have been subsurface ice (permafrost) that was melted by geothermal activity and seeped through the surface, but other sources — even rain — have not been excluded. Other Martian channels start abruptly as very large features, as if caused by sudden, catastrophic flooding. Unlike typical drainage systems, however, they frequently diminish in size downstream. It is less certain that these channels were eroded by flowing water, although it is not impossible.

None of this streambed cutting happened in recent times. The evidence indicates that the channels are ancient — billions of years old in most cases, judging from the number of meteoritic impact craters that overlie them. Nor is there any clear evidence that lakes or oceans ever existed on Mars. The rivers did not flow into seas, but — from the evidence that remains — simply petered out, either disappearing into the ground or evaporating.

The possibility that liquid water once flowed on the surface of Mars improved the biological outlook considerably. If conditions during the early history of the planet were so temperate that water could exist on its surface, then life may have originated. If so, it was conceivable that, by adapting to gradually deteriorating conditions, Martian life had managed to survive and was still surviving on the planet. The probability that this was so did not seem very high, but in such matters, *a priori* judgments do not carry much weight when an empirical test can be made. Such a test became the major objective of the Viking mission, the next and climactic chapter in our story of the search for life on Mars. □