

Thirty Years After: The Science of the Viking Program and the Discovery of a “New Mars”

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Sub-title: Thirty years ago, in 1976, two Viking Orbiters achieved Mars orbital insertion and then two Viking Landers soft-landed to the surface of Mars. The more than a dozen instruments on each Orbiter and Lander provided a new picture of the Red Planet.

Introduction

On June 19, 1976, the Viking 1 Orbiter achieved orbital insertion around Mars. On July 20, the Viking 1 Lander soft-landed on the surface of Mars in the Chryse Planitia (22 degrees north, 48 degrees west) becoming the first human-made object to land on Mars. The Viking 2 Orbiter achieved Mars orbital insertion on August 7. On September 3, the Viking 2 soft-landed in Utopia Planitia (44 degrees north, 226 degrees west). By September 3, four Viking Mars spacecraft—two in orbit and two on the surface, were simultaneously collecting new and previously unobtainable data and transmitting that data back to Earth.

The first Mars missions, Mariner 4 (passed within 9850 kilometers of Mars on July 14, 1965), Mariner 6 (July 31, 1969) and Mariner 7 (August 5, 1969), all flyby missions, showed Mars to be a desolate, inhospitable, moon-like body. The thinking about Mars changed with Mariner 9, which achieved Mars orbital insertion on November 13, 1971. Mariner 9 showed that Mars was an intriguing object with very diverse and puzzling geological features, including very large impact craters (for example, Argyre, see Figure 1) and the largest canyon (Valles Marineris, see Figures 2 and 3) and the largest volcano (Olympus Mons, see Figure 4) in the Solar System.

The Viking Project was the first truly “one NASA” project with NASA’s Langley Research Center responsible for the development and management of the entire Viking Mission. The Jet Propulsion Laboratory (JPL) was responsible for the orbiters, the tracking and data acquisition and mission control. The Glenn Research Center, formerly called the Lewis Research Center, was responsible for the launch vehicle. The Kennedy Space Center was responsible for the launch. The Martin Marietta Aerospace Corporation, now Lockheed-Martin Corporation, built the landers and also had the responsibility for its integration with the JPL-provided orbiter. Other NASA centers, including the NASA Ames Research Center, the Goddard Space Flight Center and the Johnson Space Flight Center, provided scientific and engineering support to the Viking Project.

Viking Science Instruments

The two Viking Orbiters and Landers carried a very impressive array of scientific instrumentation. The instrumentation on the Orbiters included: (1) two vidicon cameras for imagery from orbit, called the visual imaging subsystem (VIS), (2) an infrared spectrometer for Mars Atmospheric Water Detection (MAWD), and (3) an infrared radiometer for thermal mapping (IRTM). The entry science instrumentation included (1): a retarding potential analyzer to study the ionosphere, (2) a mass spectrometer for atmospheric composition measurements and (3) sensors for measurements of atmospheric pressure, temperature and acceleration to characterize the structure and dynamics of the atmosphere during entry. The Landers had: (1) two facsimile cameras for imaging, (2) three different biology experiments to search for metabolism, growth, or photosynthesis, (4) a gas chromatograph mass spectrometer (GCMS) for molecular and atmospheric analysis, (5) an X-ray fluorescence spectrometer for inorganic analysis, (6) sensors for pressure, temperature, wind velocity for surface meteorological measurements on a deployed boom, (7) a three-axis seismometer (The seismometer on Viking 1 Lander failed to uncage, becoming the only Viking instrument that did not return usable data.), (8) a magnet on the Lander sample arm observed by the cameras and (9) various engineering sensors to measure physical properties of the surface. In addition, the radio and radar systems on the orbiters and landers provided measurements of atmospheric parameters, celestial mechanics and a test of General Relativity.

Orbiter Science

The Viking Orbiter VIS obtained 52,000 images of the Mars surface from orbit, with larger format and a spatial resolution of about 100-150 meters, about a factor of 10 increase compared to the Mariner 9 cameras, which had a spatial resolution of 1 – 1.5 kilometer. The objectives of the VIS included characterization of potential landing sites in sufficient detail to support the landing site choice, to study the topographic, photometric, and colorimetric characteristics of the surface, to investigate in greater detail the various interesting geologic features (volcanoes, impact craters, canyons, channels, faults, polar cap formations, etc.) discovered by Mariner 9. Some examples of Viking Orbiter imagery follow.

Figure 1 is a color picture of Mars was made from three frames shuttered nine seconds apart by the Viking 1 Orbiter on June 18. Each of the three pictures was taken through a different filter - red, green and violet. Just below the center of the picture and near the morning terminator is the large impact basin Argyre. Interior of the basin is bright, suggesting ground frost or a ground haze. Bright area south of Argyre probably is an area of discontinuous frost cover near the south pole. The pole, itself, is in the dark at lower left. North of Argyre, the "Grand Canyon" of Mars, called Valles Marineris, can be seen near the terminator. Markings elsewhere on the planet are mostly due to differences in brightness; however, color differences are present, suggesting compositional differences. Area at the top is the eastern side of the Tharsis volcanic region and is bright because of cloud activity.

Figure 2, a mosaic of Mars is a compilation of images captured by the Viking Orbiter 1.

The center of the scene shows the entire Valles Marineris canyon system, over 3,000 km long and up to 8 km deep.

Figure 3 is a color image of Valles Marineris, the great canyon of Mars; north toward top. The scene shows the entire canyon system, over 3,000 km long and averaging 8 km deep, extending from Noctis Labyrinthus, the arcuate system of graben to the west, to the chaotic terrain to the east. This image is a composite of Viking medium-resolution images in black and white and low-resolution images in color; Mercator projection. The image extends from latitude 0 degrees to 20 degrees S. and from longitude 45 degrees to 102.5 degrees. The connected chasma or valleys of Valles Marineris may have formed from a combination of erosional collapse and structural activity. Layers of material in the eastern canyons might consist of carbonates deposited in ancient lakes. Huge ancient river channels began from Valles Marineris and from adjacent canyons and ran north. Many of the channels flowed north into Chryse Basin, which contains the site of the Viking 1 Lander and the future site of the Mars Pathfinder Lander.

Figure 4 is a color mosaic of Olympus Mons volcano on Mars from the Viking 1 Orbiter. The mosaic was created using images from orbit 735 taken 22 June 1978. Olympus Mons is about 600 km in diameter and the summit caldera is 24 km above the surrounding plains. The complex aureole terrain is visible at the top of the frame. North is up.

The Water Vapor Mapping (MAWD) instrument mapped the distribution of atmospheric water vapor and found that it is highly variable, changing with local time, elevation, latitude and season. Atmospheric water vapor was found to vary from 0 parts per million (ppm) in the winter hemisphere to 85 ppm near the polar region of the summer hemisphere. The atmosphere above the north polar cap in midsummer was found to be saturated, providing strong evidence that the permanent ice cap is composed of water. The water vapor in the atmosphere is concentrated near the surface and moves from one hemisphere to the other during the changing seasons.

The Infrared Thermal Mapping (IRTM) instrument mapped the temperature and thermal inertia of the surface. The question of the composition of the Martian polar caps was partially settled by Mariner 7 measurements. The southern winter pole cap was found to be at a temperature consistent with frozen CO₂. A similar result was found for the northern winter cap from Mariner 9 measurements. The composition of the permanent or residual polar caps was a subject of debate prior to Viking. Viking measured the temperature of the permanent (residual) polar cap at 200-215K, indicating that the permanent cap is composed of water ice, a result consistent with the MAWD measurements. The amount of water deposited at the poles was found to be many orders greater than in the atmosphere.

Entry Science

Figure 5 is an artist's conception of the sequence of events that took place just prior to the Viking landing on the surface of Mars. Above right, the Viking spacecraft, composed of an orbiter and a lander, has been in orbit around Mars since June 19, 1976, taking pictures of the planned landing site to ascertain its safety before releasing the lander (top,

left) for its three- to five-hour descent. Protected by an aeroshell, the heat-sterilized lander hurtles into the thin Martian atmosphere at a speed of about 10,000 mph, to be slowed first by aerodynamic drag until the shell is discarded, then by parachute (center) and finally by retrorockets to assure a gentle landing. Instruments will study the structure and composition of the Martian atmosphere as the lander drifts down.

During entry, the Viking Landers obtained the first in situ measurements of the pressure, temperature and composition of the atmosphere of Mars. The Viking Lander entry mass spectrometer measured the chemical and isotopic composition of atmospheric constituents and discovered the presence of nitrogen (N_2) at 2.7% and argon (^{40}Ar) at 1.6%. The entry mass spectrometer also obtained the first measurements of the ratio of ^{14}N to ^{15}N in the atmosphere.

On the surface, the Viking GCMS measured nitrogen and argon-40 in the atmosphere with results consistent to those obtained with the entry mass spectrometer. The GCMS also measured the isotopes of carbon (^{12}C and ^{13}C) and oxygen (^{16}O and ^{18}O) in carbon dioxide (CO_2), carbon monoxide (CO) and oxygen (O_2), and nitrogen (^{14}N and ^{15}N), other isotopes of argon (^{36}Ar and ^{39}Ar), neon, krypton, and xenon (^{129}Xe and ^{132}Xe).

The isotopic abundance of carbon and oxygen in the atmosphere of Mars was found to be similar to that in the Earth's atmosphere. A surprising result was the discovery that ^{15}N is enriched with respect to ^{14}N by a factor of 1.62 ± 0.16 . The measured enrichment of in ^{15}N may be attributed to the selective escape of ^{14}N from an atmosphere initially rich in N_2 (McElroy et al., 1976a). The measured ratio of ^{15}N to ^{14}N suggests that Mars had a significantly denser atmosphere in its past. The denser atmosphere is also consistent with the Viking Orbiter images suggestive of flowing water on Mars. (The current atmosphere pressure on Mars of about 8 millibars cannot support the presence of liquid water on the surface of Mars. For comparison, the surface atmospheric pressure on Earth is 1013 millibars.)

The GCMS searched for the presence of organics on the surface of Mars, but did not find any organics. This was considered a very surprising null measurement, since organics are regularly and continuously supplied to a planetary surface by meteorite impact.

Lander Science

Lander Imagery

The Landers took 4500 images of the surface from the surface. The surface and sky were found to have an orange to brownish color. The color of the sky was due to large amounts of wind-blown surfaced dust in the atmosphere. The rocks on the surface were found to be basaltic igneous.

Figure 6 is the first photograph ever taken on the surface of the planet Mars. It was obtained by Viking 1 just minutes after the spacecraft landed successfully early today. The center of the image is about 1.4 meters (five feet) from Viking Lander camera #2.

We see both rocks and finely granulated material--sand or dust. Many of the small foreground rocks are flat with angular facets. Several larger rocks exhibit irregular surfaces with pits and the large rock at top left shows intersecting linear cracks. Extending from that rock toward the camera is a vertical linear dark band which may be due to a one-minute partial obscuration of the landscape due to clouds or dust intervening between the sun and the surface. Associated with several of the rocks are apparent signs of wind transport of granular material. The large rock in the center is about 10 centimeters (4 inches) across and shows three rough facets. To its lower right is a rock near a smooth portion of the Martian surface probably composed of very fine-grained material. It is possible that the rock was moved during Viking 1 descent maneuvers, revealing the finer-grained basement substratum; or that the fine-grained material has accumulated adjacent to the rock. There are a number of other furrows and depressions and places with fine-grained material elsewhere in the picture. At right is a portion of footpad #2. Small quantities of fine grained sand and dust are seen at the center of the footpad near the strut and were deposited at landing. The shadow to the left of the footpad clearly exhibits detail, due to scattering of light either from the Martian atmosphere or from the spacecraft, observable because the Martian sky scatters light into shadowed areas.

Figure 7 is the first color picture of Mars was taken July 21--the day following Viking 1's successful landing on the planet. The local time on Mars is approximately noon. The view is southeast from the Viking. Orange-red surface materials cover most of the surface, apparently forming a thin veneer over darker bedrock exposed in patches, as in the lower right. The reddish surface materials may be limonite (hydrated ferric oxide). Such weathering products form on Earth in the presence of water and an oxidizing atmosphere. The sky has a reddish cast, probably due to scattering and reflection from reddish sediment suspended in the lower atmosphere. The scene was scanned three times by the spacecraft's camera number 2, through a different color filter each time. To assist in balancing the colors, a second picture was taken of a test chart mounted on the rear of the spacecraft. Color data for these patches were adjusted until the patches were an appropriate color of gray. The same calibration was then used for the entire scene.

Figure 8 is Viking 2's first picture on the surface of Mars was taken within minutes after the spacecraft touched down on September 3, 1976. The scene reveals a wide variety of rocks littering a surface of fine-grained deposit. Boulders in the 10 to 20-centimeter (4 to 8-inch) size range-- some vesicular (holes) and some apparently fluted by wind--are common. Many of the pebbles have tabular or platy shapes, suggesting that they may be derived from layered strata. The fluted boulder just above the Lander's footpad displays a dust-covered or scraped surface, suggesting it was overturned or altered by the foot at touchdown. Just as occurred with Viking 1's first picture on July 20, 1976, brightness variations at the beginning of the picture scan (left edge) probably are due to dust settling after landing. A substantial amount of fine-grained material kicked up by the descent engines has accumulated in the concave interior of the footpad. Center of the image is about 1.4 meters (5 feet) from the camera. Field of view extends 70 from left to right and 20 from top to bottom. Viking 2 landed at a region called Utopia in the northern latitudes about 7500 kilometers (4600 miles) northeast of Viking 1's landing on the Chryse Plain 45 days earlier.

Meteorology

The Lander meteorology instruments found that the surface atmospheric pressure varies seasonally by about 30% due to the condensation of carbon dioxide at the polar caps. The first weather report from the surface of another planets was given by Seymour Hess, Head of the Viking Meteorology Team:

Light winds from the East in the late afternoon, changing to light winds from the southeast after midnight. Maximum winds were 15 miles per hour. Temperatures ranged from minus 122 degrees Fahrenheit just after dawn to minus 22 degrees Fahrenheit...Pressure steady at 7.70 millibars.

Biology Experiments

The Viking Landers contained three different biology experiments to search for the presence of life on Mars; the Pyrolytic Release Experiment (The Carbon Assimilation Experiment), the Labelled Release Experiment and the Gas Exchange Experiment.

The Carbon Assimilation Experiment or The Pyrolytic Release Experiment

The Carbon Assimilation Experiment was designed to detect the synthesis of organic matter in Martian surface material from atmosphere CO or CO₂ or both. The experiment assumes that Martian life would be based on carbon and that this carbon would necessarily cycle through the atmosphere. In two papers, the Carbon Assimilation Experiment Science Team summarized all of the experimental data, including the results of the two experiments on Mars and concluded “that they are unlikely to have a biological explanation.”

The Labelled Release (LR) Experiment

The Labelled Release Experiment seeks the detection of heterotrophic metabolism by monitoring radioactive gas evolution following the addition of a radioactive nutrient containing seven ¹⁴C-labelled organic substrates to surface material. The LR results were entirely consistent with a possible biological interpretation.

The Gas Exchange Experiment (GEX)

The GEX periodically samples the headspace gases above a Martian surface sample incubating under dry, humid, or wet conditions and analyzed the gases with a gas chromatograph (GC). The GEX was designed to distinguish between gas changes arising from microbial metabolism and those arising from purely chemical reactions or physical phenomena, such as sorption and desorption, by recycling the soil sample. A chemical or aq physical reaction would be reduced or eliminated in subsequent cycles, whereas a biological system would perpetuate itself. The gas changes from the former would be reduced or disappear; from the latter they would continue or increase. The GEX Science Team concluded that the measured response of the Martian surface samples to water

vapor resulting in O₂ output was ascribed to the presence of superoxides in the Martian surface material and that all the gas changes observed in the experiment could most easily be explained or demonstrated by plausible chemical reactions that required no biological processes.

Viking Project Scientist, Gerald A. Soffen, summarized the results of the Viking Biology Experiments in the following statement:

The biological results were by far the most complex of all investigations. There was no unambiguous discovery of life by the Viking landers, and three of the results appear to indicate the absence of biology in the samples tested. Nevertheless, the experiments gave significant results revealing the chemical nature of the Martian surface and at least one result that could still be consistent with a biological interpretation. One experiment indicates that the Martian soil has an agent capable of rapidly decomposing organic chemicals used in the medium or that life is present...In another experiment the addition of water vapor to the Martian sample caused a vigorous release of oxygen for a few hours. This oxygen release is heat stable. Heating the dry sample generates large amounts of CO and CO₂. In one experiment a small amount of carbon dioxide (or carbon monoxide) was incorporated into the organic fraction (or made organic de novo). This process does not appear to be stimulated by light or the addition of water vapor. The surface of Mars is obviously highly reactive and contains at least one and probably several highly oxidizing substances. While inorganic chemical reactions may be sufficient to explain the data seen, biological processes cannot be ruled out at this time.

Conclusions

Viking discovered a Mars that was very different from the Mars found by Mariner 4, 6 and 7. The new, exciting, more Earth-like Mars was hinted at by the Mariner 9 orbiter and confirmed by Viking. Viking discovered some very fundamental things about Mars. Viking discovered the presence of nitrogen in the atmosphere. A key ingredient needed for life. Viking made the first measurements of the isotopic composition of carbon, oxygen, nitrogen and the noble gases in the atmosphere of Mars. The ratio of ¹⁵N to ¹⁴N suggested that Mars may have lost more than 99% of the total mass of its atmosphere. The denser atmosphere in the past may explain the presence of flowing water earlier in the history of Mars first discovered by Mariner 9 with additional and higher spatial resolution examples provided by the Viking Orbiters. Viking did not measure organics or life at the surface of Mars. But, Viking did discover a surface unlike any other on the Solar System—a surface exhibiting very high chemical reactivity, most probably formed by the deposition of chemically active atmospheric gases, like hydrogen peroxide (H₂O₂) and ozone (O₃), onto the surface of Mars.

Viking Project Scientist, Gerald A. Soffen, believed that the Viking exploration of Mars came at an important time in history when humankind was just becoming aware of the Earth as a planet. Soffen added: “Comparative planetology was conceived with Mariner and born with Viking.” After Viking, our picture of Mars would never be the same!

General Bibliography

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