Reports

Scientific Results of the Viking Missions

Abstract. *The two Viking missions to Mars have been extraordinarily successful. Thirteen scientific investigations yielded information about the atmosphere and surface. Two orbiters and landers operating for several months photographed the surface extensively from 1500 kilometers and directly on the surface. Measurements were made of the atmospheric composition, the surface elemental abundance, the atmospheric water vapor, temperature of the surface, and meteorological conditions; direct tests were made for organic material and living organisms. The question of life on Mars remains unanswered. The Viking spacecraft are designed to continue the investigations for at least one Mars year.*

Two unmanned Viking spacecraft have been orbiting Mars for several months, collecting data about the surface and atmosphere (*1*). Each has deployed a lander that has been operating on the surface taking pictures and performing analytical experiments. The Viking 1 orbiter which was placed in an elliptical orbit around Mars on 20 June is in a synchronous orbit with a period of 24.6 hours and is inclined 37.74° to the equator. The Viking 2 orbiter arrived on 7 August with a similar period and its inclination was 55° to the equator. Landing occurred at 2237 G.M.T., 3 September. The periapsis of each orbiter is about 1,500 km and the apapsis is about 33,000 km. On 30 September, the engine was fired on Viking 2 to perform a maneuver that would increase the orbital inclination. This plane change resulted in an inclination of 75°, which permits a considerable improvement for viewing the polar regions. Both orbiters have been precessed around the planet by changing their period: orbiter 1 from 11 to 24 September and orbiter 2 from 30 September to the present. This change of 30° per day allows for extensive mapping of the north polar regions. The summer solstice began in the northern hemisphere in early July, and therefore the Viking 2 orbiter is able to view the changing polar events through the seasons during which the polar hood is formed and the seasonal polar cap is formed. Because of an engineering problem encountered during the release of the lander 2 (one gyro is not functioning properly), the back portion of the bioshield remains attached to orbiter 2. While this causes some problem in restricting the viewing, by maneuvering the spacecraft, it is possible to overcome the difficulty.

After the landing of the second spacecraft, the first lander (VL1) was placed in a reduced mode of operation. Certain monitoring—for example, meteorology—was continued through the direct link with Earth, but the relay to the orbiter was suspended. The second landing site (VL2) is at 47.89°N, 225.86°W. Its operation continued for 2 months. During that period, all instruments performed these investigations successfully. Samples for the analytical experiments were obtained from the surface in a manner similar to those for VL1 as well as from under two different rocks (*2*). This rock pushing, rock rolling, and sample gathering from beneath the rocks were among the most complex operations performed by the flight team. The maneuvers required extensive activity by the engineers to determine the sequences and hazards and by the scientists to determine the specific rocks to be moved and the sampling strategy employed. In one particular way, Mars was not cooperative. Since the elemental analysis of the fine material was similar, it was decided to attempt to gather a sample of small pebbles for the x-ray fluorescence spectrometer. This complicated procedure required numerous operational events to sort out the fine particles and deliver the remaining pebbles into the spectrometer. The procedure was performed on two different occasions, and still netted us no sample.

All four spacecraft were powered down during the period of solar conjunction (11 November to 13 December). At the beginning period, a radio science experiment to test the general relativity theory was performed. This was done by determining the influence of the solar corona on the transmission from the spacecraft. Both pairs of orbiters and landers were used to measure the attenuation of the signals by the sun: the 42-minute round-trip travel time for light is determined to an accuracy of 10^{-7} second.

The investigations performed on Mars from 20 June until 11 November 1976 are summarized below.

Orbiter imaging. The cameras onboard the orbiters provided the primary data source for the final selection of the landing sites. The Chryse area (20°N, 40° to 50°W) has been thoroughly mapped by the mosaics of several thousand photographs (*3*). The Chryse Basin is a low region into which several ancient rivers empty. While there is no evidence of an ancient ocean, the general region is flat. The source and sink of fluid that created this region is still disputed. The Utopia site, primarily selected because of its northern latitude, is a volcanic terrain covered by a mantling that appears to have been deposited from more northerly regions. It was anticipated that large sand dunes would be found in this region, but these were not seen in the lander pictures. Besides being used in the selection of the landing site, the cameras have begun a long-term survey of certain geological regions as well as some general mapping of the planet. Seasonal changes of the surface that take place will be photographed. In general, there is a good deal of heterogeneity observed in the northern hemisphere. Areas that were believed, on the basis of Mariner data or of ground-based observations to be smooth plains have proved to have extensive cratering, fluvial activity, volcanism, erosion, and possibly some glaciation. Large regions exhibit catastrophic flooding but leave no evidence of sedimentary basins. Most of the surface appears old. The crater density ranges from about one-tenth to the same as that of the moon. The younger areas (fewer craters) are on the floor of the great canyon, the Tharsis area, and the polar regions. The morphology of craters on Mars is distinctly different from that on the moon or on Mercury. The presence of numerous small craters suggests that wind erosion plays a minor role. Diffuse morning clouds, wave clouds associated with surface features, and discrete equatorial clouds have been observed. The polar regions reveal vast areas of layered deposits, sand dunes, and areas free of ice which suggest a complex climate history.

Mars atmospheric water detector (MAWD). An infrared spectrometer operating at the 1.38-μm region, mounted on the scan platform, was used to detect water vapor in the Mars atmosphere. This scanning device was used to measure the latitudinal variations and diurnal variations, and, by operating over a complete martian year, it will be able to measure the seasonal changes. The southern hemisphere, which is at the onset of winter, has very little water vapor (0 to 0.3 precipitable micrometer) (*4*). In contrast, the northern (southern) hemisphere shows a significant amount of water (up to 75 μm at 70° to 80°N), ranging over almost three orders of magnitude. The north polar region shows a slight drop in water vapor abundance. There is also a strong diurnal repetitive cycle in certain regions, peaking out in the local midafternoon. Negative correlation exists between the elevation and the water vapor abundance, as might be expected. On the basis of the abundance of water vapor in the polar region, a lower limit can be put on the atmospheric temperature, namely, 205°K; this value indicates that the permanent polar cap consists of water ice, and indeed was confirmed by the IRTM (infrared thermal mapper) investigation (*5*).

Infrared thermal mapper. An infrared radiometer measuring thermal emission of the surface and atmosphere is mounted with the cameras and spectrometer—all three instruments overlapping the same viewing area. The atmospheric temperature above 20 km varies from 165°K near dawn to 185°K at 1415 lander local time (L.L.T.) (*5*). This variation is believed to be initiated at the lower levels and are radiatively propagated by dust in the atmosphere. This is consistent with an optical extinction of 0.25, a value consistent with the lander data (*6*). The temperature of the surface is highly variable, the annual variation becoming modulated closer to the equator. The daily temperature range measured at the landing site is about 183° to 265°K. A calculation was made of the temperatures of the soil samples collected from under the rock, this being about 230°K. Observations of the volcanic regions have indicated that there is a low thermal inertia in the south Tharsis region suggesting a

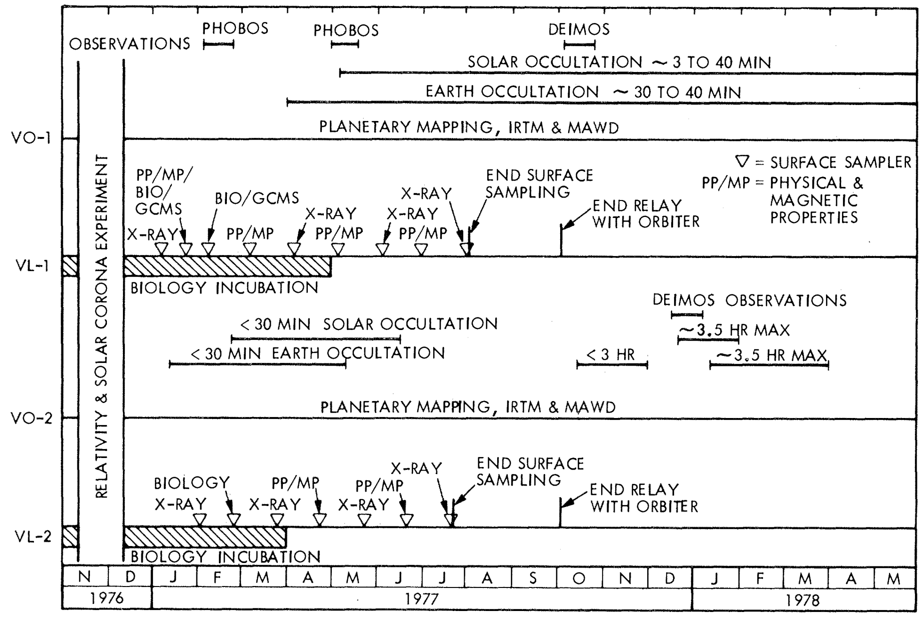

Fig. 1. Viking extended mission profile is a general compilation of the major events that will take place during the next phase of the Viking mission.

fine material—the product of aeolian sorting. The measurement of 125°K at the south pole is lower than the condensation temperature of CO_2 and possibly is due to the pole experiencing a dynamic condensation; this possibility gains support from the observation of a constant daily decrease in the surface pressure measured by the lander meteorology investigation.

Entry science. During the descent through the Mars atmosphere the physical structure and chemical composition were measured (*7*). The atmospheric pressure and temperature were recorded and a density profile has been calculated yielding a mean molecular weight of 43.34. Comparison of the entry of Viking 1 in the afternoon with that of Viking 2 in the morning revealed a diurnal difference in temperature near the surface consistent with the IRTM data. The Mars upper atmosphere consists mainly of CO_2 with small amounts of N_2, Ar, CO, O_2, O, and NO. The isotopic ratio of carbon and oxygen is similar to that on Earth, but the enriched ratio of ^{15}N to ^{14}N suggests that Mars has had a denser atmosphere in its past. This denser atmosphere could account for the appearance of ancient rivers seen in the photos. (The current pressure of 7.6 mbar would not support liquid water.) The atmosphere is well mixed to heights above 120 km. The ionosphere was also measured to determine the nature of the charged particles. These data will be used in developing models to reconstruct the atmosphere and its history.

Lander imaging. Hundreds of photographs have been taken at each of the landing sites. Both sites are dominated by a variety of rocks among fine-grained material (*6, 8, 9*). Chryse and Utopia are similar in some ways and different in others. Both areas reveal the bright red color of the surface and the pink sky. The Chryse site contained drifts of fine-grained sediment that appeared in the lee of large boulders. The shape of the drifts and the layering indicates that there have been extensive periods of erosion and deposition. Chemical weathering of the rocks is also apparent. At each site, both vesicular and fine-grained rocks were observed. The fairly angular appearance of some rocks might be due to aeolian effects. The scattering of light by aerosols has been used to determine that these particles are of the size range of 1μm, and the extinction is about 0.5 at this time. The Utopia site is cut by a trough which is believed to be part of a larger polygonal pattern seen from orbit. Considering the significant difference of the two sites as seen from orbit, it is striking how similar they are at the local level. This may be due to the fact that the large-scale features reflect the ancient processes and the local planetwide weathering is contemporary. No macroscopic biology has been seen nor any changes in the scene.

Physical and magnetic properties. The cameras were used to determine certain physical and magnetic properties of the soil (*2, 9, 10*). Pictures of stroke gauges, sample digging, footpad movement, areas underneath the lander, and rock movement were used to determine the bulk density, particle size, angle of internal friction, cohesion, adhesion, and penetration resistance of the Mars soil. Small permanent magnets on the sampler collected material indicating that the surface contains a few percent of magnetic material, very likely magnetite. This suggests that the rocks are not completely weathered and opens the question of whether the origin of this magnetic fraction is pyrogenic or metamorphose.

Meteorology. A meteorological weather station to measure changes in pressure, temperature, wind speed, and direction has been operating on both landers since touch down (*11–15*). Generally the weather at both sites has been repetitive and mild, as expected for this season. The daily temperature varies from 190° to 240°K, the peak being at about 1450 L.L.T. The pressure at each site is in the range of 7 to 8 mbar. Pressures vary daily by about 0.3 mbar, but there was a steady, falling, average pressure during the first 20 sols after landing on Mars by about 5 percent due to the CO_2 condensation at the winter cap. The wind's direction at each site goes through a complete oscillation each day. Wind speeds average a few meters per second, the peak gust being only 19 m/sec. This speed is still too small to raise dust particles anticipated during the major storm seasons of perihelion.

Seismology. The seismometer on VL1 failed to be uncaged, but the Viking 2 seismometer is functioning normally (*12*). To date no quakes have been detected on Mars.

Inorganic chemistry. An x-ray fluorescence spectrometer was used to determine the elemental composition of samples at each of the sites (*13*). Both sites have yielded analyses of the fine-particle material that are strikingly similar: Si and Fe in large amounts and Mg, Al, Ca, and S in significant amounts. Modeling suggests that the main components are believed to be SiO_3 (45 percent) and Fe_2O_3 (18 percent). Next most abundant are Al_2O_3 (5 percent), MgO (8 percent), CaO (5 percent), and SO_3 (8 percent). The alkaline metals are in very low abundance. This composition represents a mafic igneous parent rock and suggests an iron-rich clay with small amounts of magnesium sulfates, carbonates, and iron oxides. It would appear that the surface of Mars is less differentiated than that of Earth.

Molecular analysis. Two samples from each site have been analyzed for organic material with successive use of volatilization, pyrolysis, and detection by gas chromatography–mass spectrometry (GCMS) (*14*). The sensitivity of the method reaches in the neighborhood of parts per billion, and no organic compounds have been detected at this level. This instrument was not designed as a life detection instrument (neither the quality of information, nor the sensitivity permits detecting the biomass directly). The absence of organics in the sample was somewhat surprising considering the likelihood of carbonaceous chondrites reaching the Mars surface or the possibility of de novo synthesis. Explanations involving dilution in the regolith and destruction by ultraviolet light or oxidation are all plausible. The GCMS was also used to measure the Mars atmosphere; it is ideally suited to measure isotopic ratios. Based on measurement of N, A, Xe, and Kr and their isotopic abundances, it is likely that a history of Mars outgassing will emerge.

Biology. Three experiments were conducted to test directly for life on Mars (*15, 16*). The tests revealed a surprisingly chemically active surface—very likely oxidizing. All experiments yielded results, but these are subject to wide interpretation. No conclusions were reached concerning the existence of life on Mars.

Radio science. Communication and radar systems were used to perform certain experiments (*17*). The locations of the landers were determined by tracking telemetry. The orientation of the spin axis and spin rate was accurately determined. Some dielectric properties of the surface were measured, suggesting a pumicelike texture.

Future activity. Plans for operating the four Viking vehicles for the next 2 years have begun. During this time several experiments will be completed. Several more surface samples will be collected by each lander for further chemical and biological analysis. Pictures will be taken from the surface and from orbit (several tens of thousands will be taken by the orbiters). The seasonal events will be followed by the orbiting vehicles as well as by the meteorology, cameras, and atmospheric analysis instruments. The long-term sensing by the seismometer is considered extremely important. Physical and magnetic properties investigations will expand their use of the sample arm.

Among the first activities will be the lowering of the Viking 2 orbiter periapsis to 800 km to improve the resolution of the cameras. Concomitant with this will be a change in the inclination of orbiter 2 by another 5° (to 80°) to further improve the viewing of the polar events. Viking is destined to significantly advance our knowledge of Mars.

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18. The Viking Mission is a part of NASA's Office of Space Science, Planetary Exploration Program, and is managed by the Langley Research Center. The orbiters were built by the Jet Propulsion Laboratory and its subcontractors. The landers were built by Martin Marietta Corp. and its subcontractors.

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