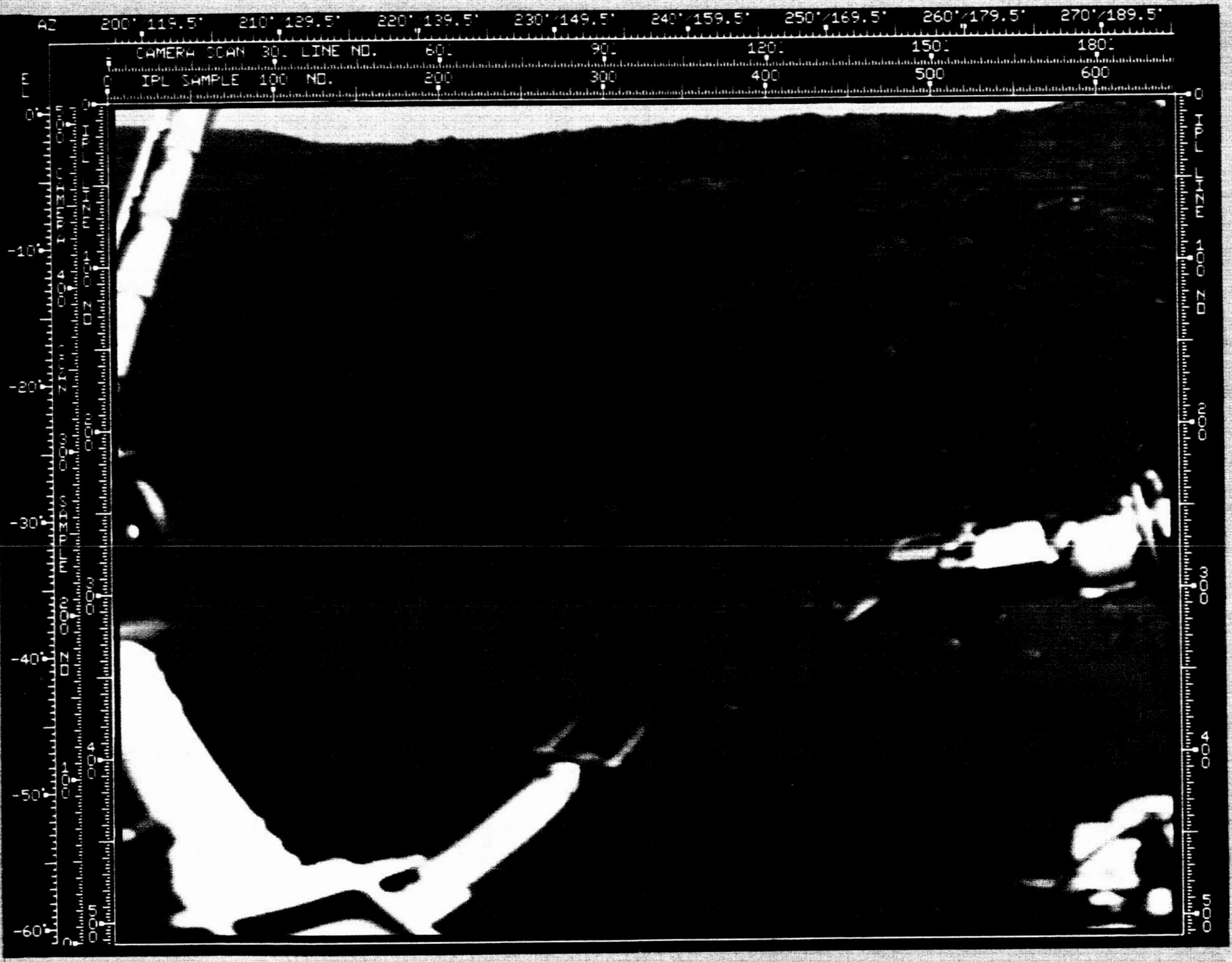
NASA SP-408

VIKING 1
EARLY RESULTS



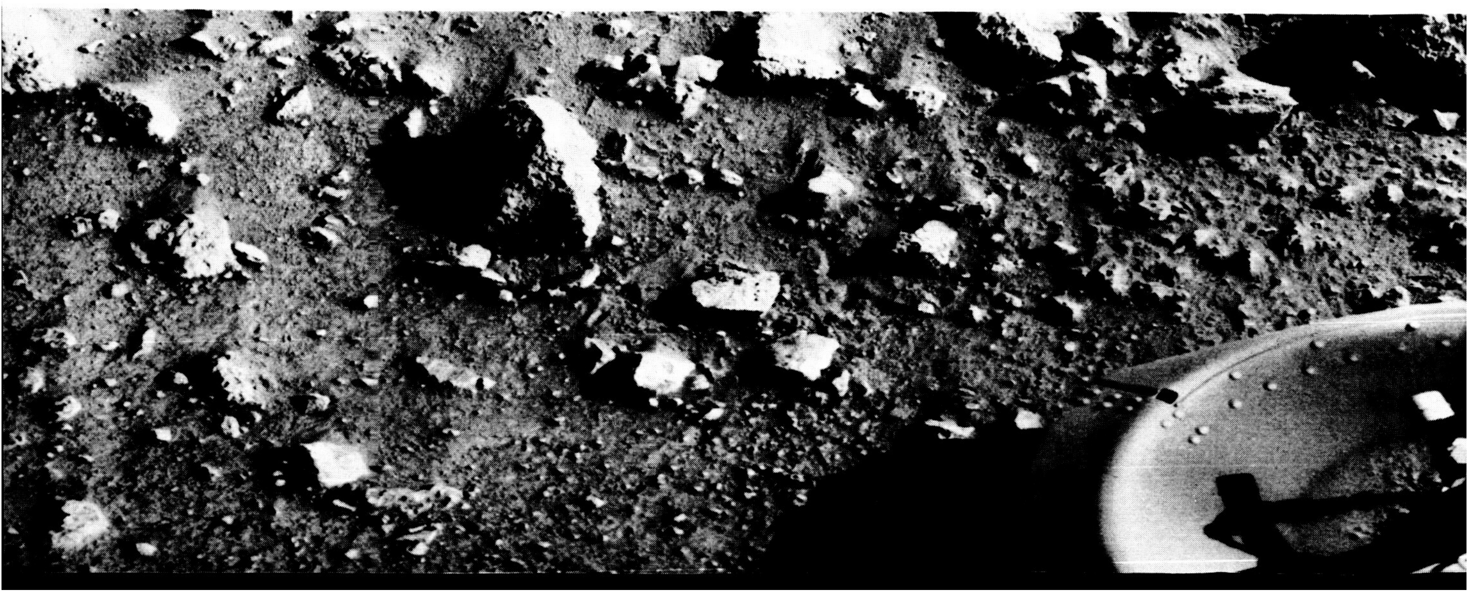
NATIONAL
AERONAUTICS
AND SPACE
ADMINISTRATION

VIKING 1
EARLY RESULTS

Above: *A sweeping 100° panorama of the Viking 1 landing site on the Chryse Planitia basin, taken about 7:30 a.m. local Mars time. Diagonal structure in middle is the meteorology instruments boom.*

Cover photograph: *The surface of Mars just before the initial sample was taken on July 28, 1976. Sample was taken at −31° elevation (left scale) and 215° azimuth (top scale). The trench dug is shown in chapter 5.*

Below: *The historic first photograph sent back from Mars minutes after the successful landing of Viking 1 on July 20, 1976.*



VIKING 1
EARLY RESULTS

NASA SP-408

Scientific and Technical Information Office 1976
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

FOREWORD

EVEN after fourteen years of planetary exploration by unmanned spacecraft, the concept of dispatching automatic machines millions of miles from our home planet to penetrate the boundaries of the unknown still seems extraordinary. Man has never before undertaken anything like this. Where once sturdy seamen and valiant explorers risked years of their lives—and their very lives—in a quest for glory, wealth, and the extension of their politico-religious beliefs, we now rocket off sensitive electromechanical scouts to do our bidding and send back information about the new worlds they have encountered. This is truly a new process, characteristic of our times and skills, ideally adapted to the hostile character and distances of the solar system.

The Viking lander that began the on-site examination of Mars several weeks ago is incomparably the most versatile automated explorer ever built. (Imagine *throwing* a self-powered laboratory 460 million miles through space, soft-landing it delicately at a chosen spot on an alien world, and then commanding it to conduct and report on subtle biological, chemical, and physical measurements!) Seen whole, Viking is by far the most ambitious and venturesome automated exploration that man has ever attempted. It is a descendant of our earlier efforts on Earth to reach the poles or, before that, to cross the unknown oceans.

Why do we do this curious thing? Why is man preeminently an exploring animal? Plainly our motives are many, and intertwined. An unbounded curiosity seems to be part of man's brain, an element in his genetic heritage. We have done this at least since a remote predecessor felt a powerful need to see what was on the far side of a mountain. Early explorations were driven by direct self-interest; their goals were trade, land, power, and gold. Now we are impelled by motives that are almost as coolly rational as those that govern the design of our spacecraft: we explore other worlds that we may better understand our own. It is still self-interest, in a more intellectual form.

Mars is in some ways strangely earthlike. It is of a size with our planet, has days and nights, seasons of its years, and a thin atmosphere characterized by wind and clouds—i.e., weather. By some theories Mars may be a kind of proto-Earth, earlier in the sequence of planetary evolution, a place where the geologic and atmospheric processes are far less complicated than they are on our white-whorled blue planetary home. Thus knowledge of Mars may have the most immediate implications for bettering our knowledge of Earth, and every new insight in comparative planetology may be the greatest of treasures sent home by the Viking explorers.

JAMES C. FLETCHER, *Administrator*
National Aeronautics and Space Administration

August 16, 1976

PREFACE

SOME measure of the rapidity of change in planetary exploration is reflected by the contrast between the 1962 Mariner 2 mission to Venus and the 1976 Viking missions to Mars. In the first case, our first successful planetary flyby, a modestly instrumented probe managed a miss distance of 34 700 km and returned several hours of data. In the present case, highly sophisticated orbiters and landers are each day returning rich harvests of new information about Mars. At this writing, the data stream began weeks ago and will very possibly continue for months. Although the Viking spacecraft were designed for 60-day missions, there is no evident technical reason why the exciting flow of new information will not continue a great deal longer than that.

During a mission such as Viking—an exhausting if exhilarating time of sleep deficits, quick-looking the data, queuing up for future spacecraft commands, interrelating results from many different instruments, and working around the anomalies that beset the best of spacecraft—it is almost impossible for an investigator to concentrate on thorough and thoughtful analysis of the results received. So this little volume, which includes no information later than August 13, 1976, is not put forward as "instant science" but only as a preliminary and tentative account of early conclusions. It should be further noted that the findings reported here are those of the investigators concerned with each experiment. It can be confidently predicted that the views will be refined and perhaps extended in some cases when this historic mission comes to its end.

JOHN E. NAUGLE, *Associate Administrator*
National Aeronautics and Space Administration

August 19, 1976

CONTENTS

Introduction

The Viking Project is a modern scientific adventure at the frontier of space. Like any scientific exploration, it requires the imagination and labor of a multitude. In the few short weeks that the Viking 1 spacecraft have operated on and near Mars, discoveries have been made that have changed some theories, confirmed others, and, in the tradition of science, opened more questions than they have closed.

Mars has revealed much more variety than anticipated. In the search for the first landing site, photographs were obtained showing some of the most remarkable features carved by wind and water ever seen by man. The forces of fluid in motion left an indelible history on the surface of Mars that will be examined for decades. New features of enormous dimension, and always different, were found daily—wide gorges, scarps, faults, flat valleys, mottled erosion, ancient shorelines, deep basins, blocky terrain, knobby terrain, tablelands, sunburst craters, pedestaled craters, secondary craters, ejecta from craters—the descriptive geology goes on and on.

Once cameras were on the surface the pictures revealed a very familiar scene. The Viking 1 Lander came softly to rest in a rocky desert with vast sand dunes reminiscent of the American Southwest desert. Rocks range from pebble size to boulders several meters across. Surprisingly or not, the true color of the landing site was red. Everything within sight including the sky is some shade of pink or red. Many rocks reveal the weathering of wind and time. The chemistry of the loose dirt collected by the soil sampler is an iron-rich basalt, familiar to the geochemist.

But the chemical surprises came first from the atmosphere and then from the biological experiments. Before Viking was launched, there was a flurry of interest in scientific circles about the amount of argon in the Mars atmosphere. Because of its inert nature this element is important in tracing the history of the atmosphere. Guesses and theories as to argon abundance hovered around 20 percent. Another critically important atmosphere constituent, nitrogen, had never been detected. Viking has for the first time made direct measurements of the atmosphere such that now a complete analysis, including many chemical isotopes, is available. Nitrogen was discovered, argon and its isotope measured, oxygen, its charged forms, and upper limits to the other noble gases were measured.

In the biological experiments that are still going on, a remarkable surface chemistry has been discovered. The surface material is highly desiccated but made of minerals that are very hydrated; water is chemically bound but very little absorbed in the surface. The material is highly oxidized, appears to have oxygen adsorbed in its surface, and among its constituents are some very strong oxidizing components. All of this chemical activity is still rather mysterious and poses a difficult milieu in which to study biology.

The weather on Mars during this summer period is benign by Martian standards: winds of only 10 to 15 m/sec and, so far, predictably from the east to southwest. Temperatures have been somewhat surprising; the hottest part of the day occurs in late afternoon. The surface pressures at the landing site were within predicted ranges but have been steadily falling. This is consistent with an earlier discovery that the winter pole of Mars is now condensing out the carbon dioxide. There appears to be considerable cloudiness in the northern hemisphere during this time of the year.

It appears that the explorations of Viking 1 have already made scientific history. The Viking Team is anxious to share our new knowledge with the world at large.

JAMES S. MARTIN, JR. *Viking Project Manager* *Langley Research Center*	GERALD A. SOFFEN *Viking Project Scientist* *Langley Research Center*

1

The Viking Mission

Program Goals

The objective of the Viking mission is to advance significantly "knowledge of the planet Mars by means of observations from Martian orbit and direct measurements in the atmosphere and on the surface. Particular emphasis [is to] be placed on obtaining biological, chemical, and environmental data relevant to the existence of life on the planet at this time or at some time in the past, or the possibility of life existing at a future date."

By observing the physical and chemical composition of the atmosphere, the daily and seasonal changes in wind, temperature, pressure, and water vapor content near the surface, the texture of surface materials, their organic and inorganic composition, and some of their physical properties, the Viking mission is enabling scientists to define the present conditions under which any Martian biological processes would have to take place. In addition, the Viking 1 Lander is attempting to collect direct evidence as to whether biological processes are now occurring.

The Viking mission is providing information that will lead toward an eventual understanding of the history of Mars. Visual imagery and infrared observations of the surface from orbit are revealing the geologic processes that have shaped the planet's surface features. They can also indicate past alterations in the composition of the atmosphere and the surface materials. Such information is, of course, relevant to the questions of Mars' evolution as a planet, as well as to bio-organic evolution, and also to the development of our understanding of Earth's place in the history of the solar system.

Unlike earlier ventures in planetary exploration, Viking offers investigators the rich new dimension of simultaneous observation. The added value is immense. Simultaneity gives a chance to relate observations on a global scale with findings tied to a spot on the surface. The viewpoint and scale are so different as to stretch investigators' imaginations. Patterns of vast aeolian deposits seen from orbit can be compared with the shape of aeolian deposits around a pebble. Infrared temperature measurements from the Orbiter indicate a freezing of part of the atmosphere onto the south polar cap; and at the same time, a sensor at Chryse Planitia feels the reduction of atmospheric mass.

Sometimes the viewpoints are so far apart they are hard to reconcile. The Orbiter sees places where low-lying fogbanks of water ice appear and dissipate daily—while the Lander's biology instrument sees surface particles that react actively to a whiff of water vapor. Plainly Mars is nonuniform; plainly it will take time and thought to understand all that we see.

Detailed accounts of several of the earliest scientific findings of the Viking mission are scheduled to appear in a series of reports in the August 27 issue (Vol. 193, No. 4255) of *Science.*

Mission Plan

Two identical Viking spacecraft, each consisting of an Orbiter and a Lander capsule, were launched on August 20 and September 9, 1975. With arrivals at Mars 7 weeks apart, Viking 1 and Viking 2 will conduct many of their operations concurrently. However, the mission plan allows the Viking 1 Lander to complete its period of high-level activity before having to share the Martian surface with the Viking 2 Lander.

Each spacecraft arrives in the vicinity of Mars on a trajectory that would take it past the planet. During the approach, the cameras and infrared sensors obtain global views of the entire disk of the planet in different spectral bands. Then a prolonged operation of its rocket engine reduces the spacecraft's velocity so that it is captured into orbit. The orbit is highly elliptical (fig. 1–1). At periapsis, which is placed over the landing site, the orbit is 1500 km above the surface. An apoapsis altitude of about 32 600 km produces an orbital period that is synchronous with Mars' sidereal period of 24.6 hours, so that the spacecraft passes over the landing site daily, at the same local time. Raising or lowering the apoapsis altitude produces an asynchronous period that brings a different part of the planet's surface under each revolution's orbital track. The Viking 1 orbit is inclined 33.4° to the equatorial plane.

After the landing site certification process (described in ch. 2) has been completed, preparations are made to separate the Lander from the Orbiter. When it separates, the Lander is still enclosed in its aeroshell and base cover. The whole assembly is called the descent capsule. Four of the aeroshell's small rocket engines fire to slow the capsule into a descent trajectory. After coasting for several hours, the descent capsule enters the atmosphere and begins to decelerate because of aerodynamic drag. The aeroshell's ablative heat shield burns away, carrying with it the intense heat of entry.

At an altitude of about 6 km, a parachute is deployed to slow the Lander further, and the aeroshell separates from the Lander. The parachute and the base cover are discarded at about 1.4 km, and the Lander's own set of three terminal descent engines brings it down to a soft landing.

The deorbit and landing sequence is controlled entirely by the Lander's computer, according to instructions that the ground controllers fed into it before separation. There is no possibility of real-time control when it takes a radio signal 18 min to travel the more than 300 million kilometers that separate the two planets. At landing, the Lander's computer has enough instructions to operate the Lander and its instruments for 60 days on its own. Once communication with Earth is established, these commands are modified and updated, normally every few days.

The Lander receives all its instructions directly from Earth (fig. 1–2). The daily rotation of Mars permits about 9 hours for communications. The Lander sends its data to Earth in two ways. The transmitter that communicates directly with Earth can operate for about 70 minutes per day. At a data rate of 500 bits (computer binary digits) of information per second,

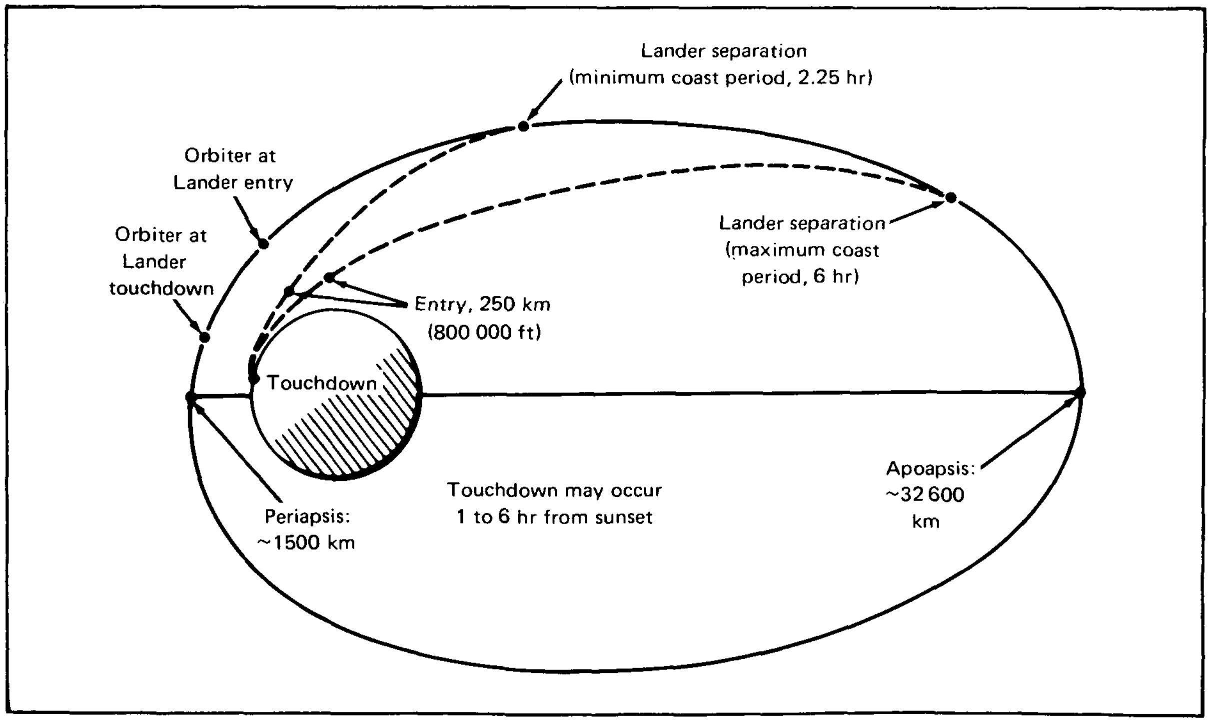


FIGURE 1–1.—Spacecraft relationships during landing.

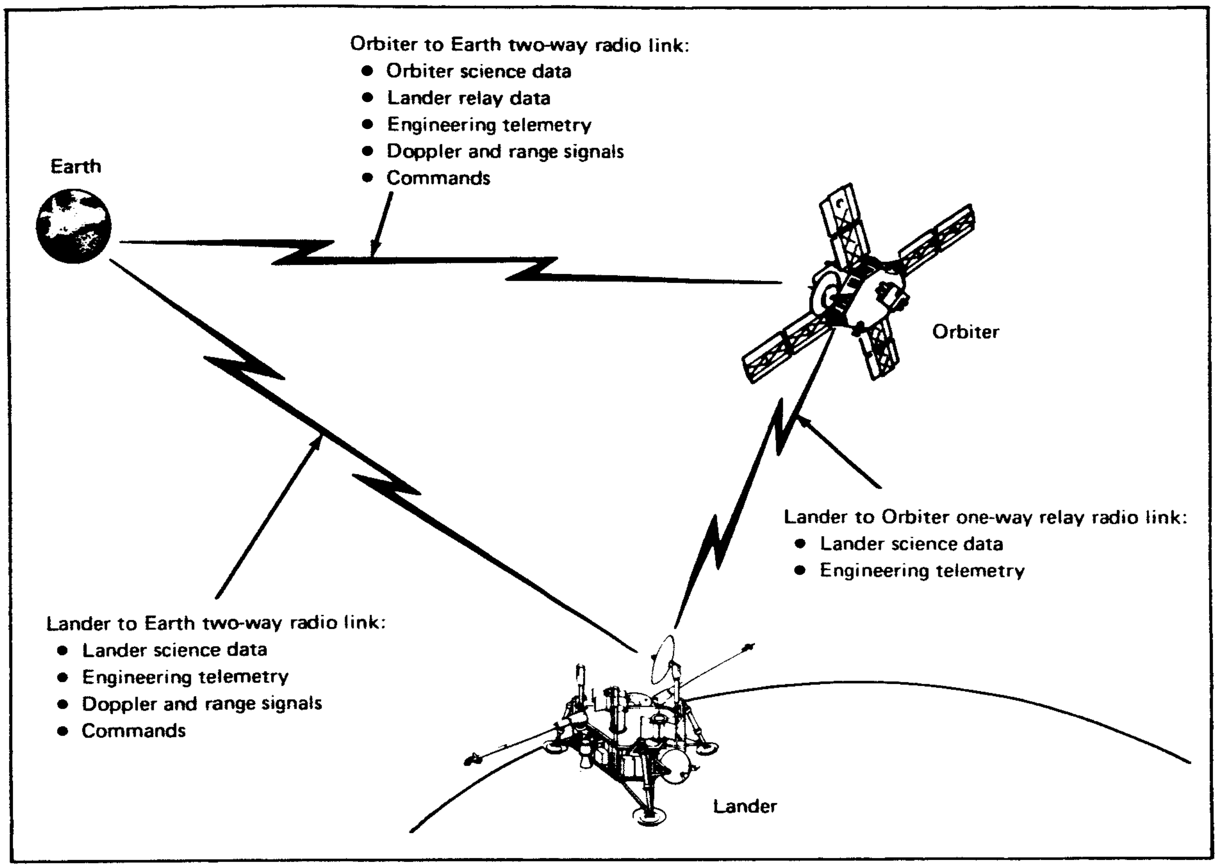


FIGURE 1-2.—The basic radio links used in Viking 1.

about 2 million bits can be delivered each day over this direct link. Later in the mission, increasing distance will cut the data rate in half. A far larger volume of data reaches Earth through the Orbiter relay link. The Lander can transmit data to the Orbiter whenever the latter is more than 25° above the local horizon and within a range of 5000 km. This daily communication window varies from 10 to more than 40 min, and while it is open the Lander sends 16 000 bits of information per second. At the time of this writing, the daily relay communication link has averaged about 42 minutes. This has permitted the entry of about 40 million bits of Lander data daily into the Orbiter's tape recorder for transmission to Earth.

Since the total amount of scientific information acquired from the Lander is largely determined by the availability of the Orbiter relay link, the mission plan requires an Orbiter to be in synchronous orbit over each Lander during the Lander's period of high-level activity. After the Viking 1 Lander has completed the investigations that require a high data rate, it will go into a reduced mission mode. This relieves the Viking 1 Orbiter of its data relay duties and permits it to start its "global walk." With the orbital period reduced to 23.1 hours, the track then walks around the planet, shifting about 22.5° westward on successive revolutions. A large number of orbital science observations will be possible of areas that cannot be adequately observed from the present synchronous orbit.

At present, the Viking 2 spacecraft is in an asynchronous orbit at a higher inclination, so that considerable global exploration is already in progress. On the assumption that the Viking 2 landing is successful, much flexibility exists in providing relay support for either Lander with either Orbiter. At a later stage of the mission, a plane change maneuver is planned for the Viking 2 Orbiter, to increase its orbital inclination to about 75°. This will permit its instruments to observe the north polar region when the polar cap is at its minimum size.

On November 25, 1976, Mars and Earth will be in conjunction, lined up on opposite sides of the Sun. Beginning about the middle of November, as conjunction is approached, communications between Earth and the Vikings will be interrupted by the effect of the solar corona. In anticipation of the blackout, the Landers will be powered down to a safe condition, and the computers aboard the Landers and Orbiters will be loaded with sufficient instructions to carry on by themselves. The primary mission will have been completed, but the spacecraft are expected to survive the blackout period and carry out an extended mission. The ability to continue observations over a full Martian year would provide a very important bonus for several of the scientific investigations.

Mission Operations Strategy

As one can deduce from the mission plan, the Viking mission operations are preeminently characterized by their complexity and their flexibility. There will be as many as four space vehicles operating simultaneously, at a vast distance and with an intricate pattern of communication links. The conventional way to deal with this complexity would be to operate in a preplanned, highly programmed mode. Yet, if the scientific exploration potential of the Viking mission is to be fully exploited, the operations must be capable of adapting to what is being learned. From the beginning, the planning has been for an adaptive mission. The operations organization, procedures, and computer programs have all been designed for the exceedingly difficult task of maintaining flexibility and full control concurrently.

At any stage of the mission, there is a current Mission Profile Strategy in being that describes how the rest of the mission is to be conducted. As both science data and data concerning the health of the spacecraft are acquired, they are used to revise this plan weekly in a long-range planning activity. Long-range planning is primarily concerned with the period 11 to 17 days prior to execution. It concludes with a Science Requirements Strategy that defines the desired mission to an intermediate level of detail.

Medium range planning starts with the Science Requirements Strategy, and concentrates on the period 6 to 10 days prior to execution. A daily meeting results in a Final Mission Profile that lists all mission profile events in time sequence. This is the basis for the sequence and command generation process, which in general takes up to 5 days.

Some activities, particularly aboard the Lander, need a faster response. A Lander Science Experiments Operations Strategy has been designed to have the general capability to respond to data that arrived on the next-to-last communication downlink for many of the Lander experiments. (This is, approximately, a 2-day turnaround time on selected operations.) Making this very demanding capability work smoothly has been a major requirement on the mission operations system, and it has been met so well that the operation almost looks easy.

Mission Events to Date

Viking 1 was inserted into orbit on June 19, 1976. The Lander was scheduled to separate from the Orbiter on July 4, if a landing site could be certified in the intervening time. Because the Orbiter's visual imagery raised doubts about the suitability of the prime site that had been selected before the mission, the separation was postponed to permit the examination of other portions of the Chryse basin. A site about 900 km west of the prime site was finally certified, and the Lander touched down there on July 20. The Lander's location is 22.27° N, 48.00° W.

The orbit of the Viking 1 Orbiter, which was initially synchronous over the prime site, was adjusted on July 8 to let the Orbiter "walk" westward in the search for a more suitable landing site. Another adjustment on July 14 stopped the walk, so that the Orbiter is now in synchronous orbit over the Lander. This track also permitted the Viking 1 Orbiter to examine a broad area of Cydonia as a preliminary phase of the Viking 2 landing site search.

At the present writing (three weeks after the landing), all of the Lander's instruments are working with the exception of the seismometer, whose three sensing masses have failed to uncage from their flight configuration. On July 28, the surface sampler delivered samples of the Martian surface to the biology, the molecular analysis, and the inorganic chemistry instruments. All three instruments have completed the first cycle of experiments with these samples.

On August 7 the Viking 2 spacecraft was put into orbit. Its inclination is 55°, and its present asynchronous period of 27.4 hours permits it to explore new areas on each revolution.

2

The Viking Orbiter: Carrier, Relay, Observatory

The Viking 1 Orbiter is the second American satellite to explore Mars from orbit. Like its predecessor, Mariner 9, it put itself into orbit, is examining the planet's surface with several instruments, and is transmitting the resulting data to Earth. It also has some additional duties to perform. Having carried a dormant Lander into orbit, it turned its instruments to the detailed examination of the prime landing site. When that site revealed itself to be more hazardous than expected, the Orbiter was released from its repetitive track to explore a broad region to the west until a suitable landing site could be found. Its orbit was then resynchronized over the newly certified site, and the Orbiter became the launch base for the landing operation. With the Lander safely on the surface, the Orbiter has become a facility for relaying data. Its instruments monitor the region around the Lander so that any changes they can detect (for example, atmospheric temperature, water vapor content, clouds, and dust storms) can be correlated with the Lander's contemporaneous observations. Meanwhile, since the orbital track covers the Cydonia region, the Viking 1 Orbiter's instruments are examining the area surrounding the Viking 2 prime site. Other areas of the planet under the orbital track are also being examined. Later, when it can once more be released from synchronous orbit, it will carry its three instruments on an excursion of exploration around the planet.

Although the Orbiter (fig. 2–1) bears a family resemblance to Mariner 9, the additional functions have required some important changes in design. The concluding section of this chapter describes the main design features of the Orbiter and its instruments.

The three instruments that constitute the Orbiter's scientific payload are the visual imaging subsystem (VIS), the infrared thermal mapper (IRTM), and the Mars atmospheric water detector (MAWD). All three are mounted on one planetary science scan platform (fig. 2–2), whose orientation with respect to the Orbiter is motor-driven about two axes. The instruments are boresighted to point in a common direction. With this arrangement, the three instruments can be aimed at the surface during much of the desired portion of the orbital period, while the Orbiter maintains its solar orientation to generate electrical power most efficiently. The scan platform can be commanded to look at any target within view on the planet's surface. If stereoscopic observations are desired, the VIS looks ahead just before passing over the site, and then looks back at the same area.

The VIS consists of a pair of identical cameras and telescopes. Its first, and most exacting, requirement is to cover the necessarily large Viking landing sites with contiguous photography in high resolution, so that their suitability for a safe landing can be assessed. Visual images obtained from the periapsis (orbital low point) altitude of 1500 km have a ground resolution of about 100 m. Application of this VIS capability to just a few of the many scientifically interesting areas of the Martian surface has already added greatly to knowledge of the geologic processes that have shaped the planet.

The IRTM consists of a group of infrared radiometers designed to measure and map variations in the

ORBITER IMAGING TEAM

Michael H. Carr
William A. Baum
Karl R. Blasius
Geoffrey Briggs
James A. Cutts
Thomas C. Duxbury
Ronald Greeley
John E. Guest
Harold Masursky
Bradford A. Smith
Lawrence A. Soderblom
Joseph Veverka
John B. Wellman

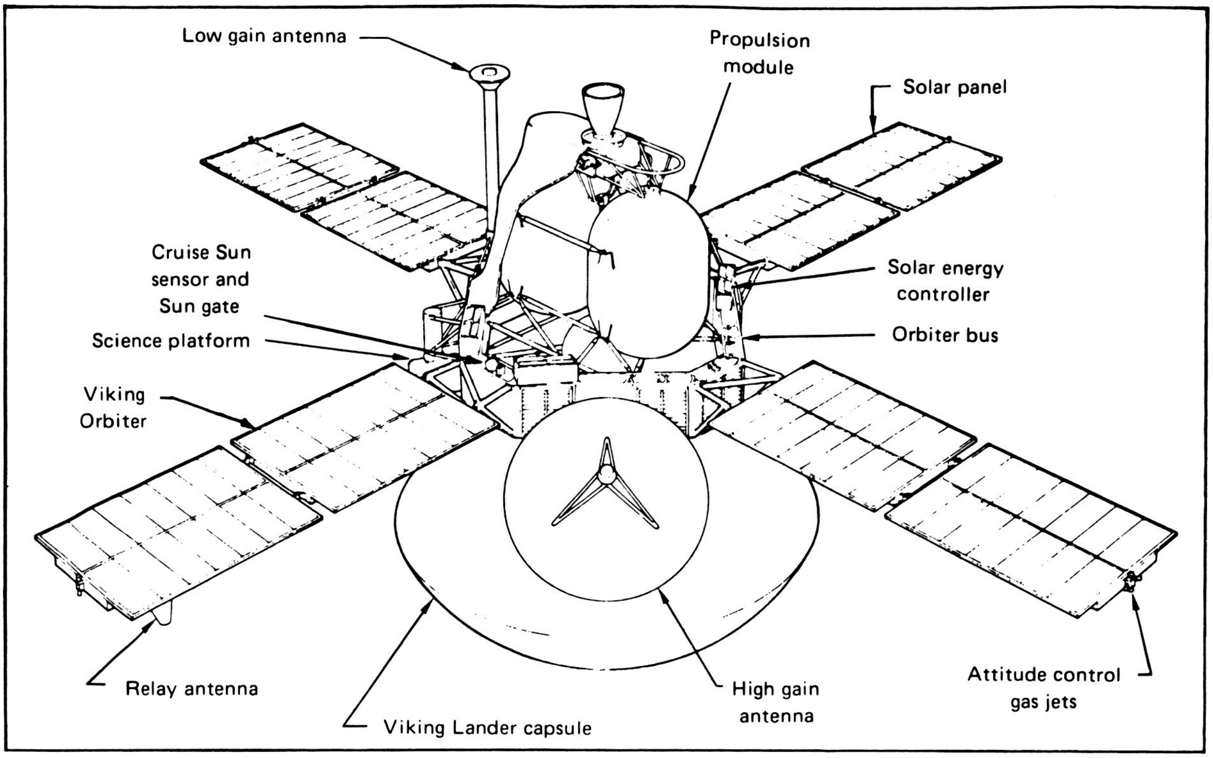


FIGURE 2–1.—The main elements in the Orbiter spacecraft.

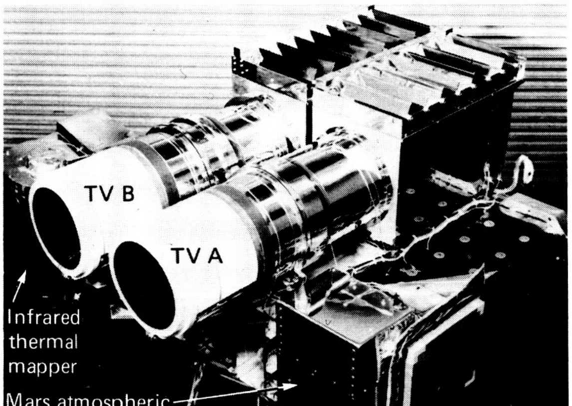


FIGURE 2–2.—The science scan platform aboard the Orbiter.

temperature of the planet's surface. Variations from place to place under similar conditions of solar illumination can indicate differences in the composition and roughness of the surface materials, as well as the existence of areas where internal heat may be flowing out. Variations in the nighttime cooling rate reflect differences in the average size of surface particles. The instrument also measures stratospheric temperatures over broad areas, and their variations with time.

The MAWD is an infrared spectrometer that is designed to map the distribution of water vapor over the planet. Water vapor is a minor constituent of the Martian atmosphere that is of the greatest importance to understanding the meteorology, the geology, and the biology of the planet. Life on Earth is completely dependent on the availability of water, since many biochemical reactions take place in aqueous solutions.

THERMAL MAPPING TEAM

Hugh H. Kieffer	Guido Munch
Stillman C. Chase	Gerry Neugebauer
Ellis D. Miner	Frank Palluconi

WATER VAPOR MAPPING TEAM

C. Barney Farmer	Daniel D. LaPorte
Donald W. Davies	

Measurements by the MAWD constituted one input to landing site consideration. Later in the mission, when the Orbiter is in a nonsynchronous orbit, the MAWD will observe the global distribution of water vapor and its variation diurnally and seasonally to attempt to discover the sources and the movements of the vapor.

How the Viking 1 Landing Site Was Certified

A good landing site is one that affords a high probability of landing safely and obtaining a surface sample and that is likely to provide significant scientific information about Mars and its history. The prime site was in the Chryse plain, near the mouth of the big channel system discovered by Mariner 9. Since the channels appeared to have been formed by running water, it was reasoned that the material at the mouth should represent the material gouged from the highlands south of the basin, as modified by both wind and water transportation.

With regard to landing safety, it was recognized from the beginning that any landing without the benefit of visual guidance entailed some risk. The Viking landing dispersion ellipse (within which it could be expected to land with 99 percent probability) is 100 by 220 km. Clearly, it would be impossible to guarantee the absence of landing hazards within so vast an area. The purpose of site certification, then, is to maximize the probability of landing success.

The site factors that affect landing safety are topographic configuration, surface roughness, bearing capacity, and the prevalence of hard surface protuberances such as boulders. The last factor is of particular concern because the Viking Lander has only 22 cm of ground clearance.

The main tool for assessing the site hazards is the Orbiter's visual imaging subsystem. Features that might be a hazard to the Lander are mapped from the images; then an assessment is made of the probability of the Lander's encountering such hazards, given the aiming errors. Stereoscopic photography by the VIS makes it possible to plot the topographic configuration directly. The stereoplotting instruments and the photogrammetrists trained in their use are available at the U.S. Geological Survey's astrogeology laboratories in Flagstaff, Ariz. The problem is the coarseness of the detail at the VIS monoscopic ground resolution of 100 m, compared to the dimensions of the Lander. It can be assumed that a site that is rough on the 100-m scale will be rough at the scale of the Lander. Unfortunately, the reverse is not necessarily true. Once the areas that are visibly hazardous have been eliminated, the real usefulness of the VIS pictures is in providing scientists with an understanding of the geological processes that have been in operation at the site and in the surrounding regions. A knowledge of the processes permits an estimate of the probability of landing hazards far below the limit of image resolution.

There are two sources of information about a site's fine-scale surface characteristics. These are the Viking Orbiter's infrared thermal mapper and radar observations from Earth. Their information tends to be cryptic without the knowledge of surface processes that comes from the interpretation of the VIS images.

The Viking IRTM is capable of providing information about the thermal inertia of a site's surface materials. A predominantly sandy surface, for example, gets warmer in the daytime and colder at night than a boulder field. In the case of the Viking 1 site, unfortunately, the Orbiter did not pass over the area at a suitable time of day.

Radar observations can tell something about surface roughness at a scale of about 100 to 200 times the wavelength of the radar signal, which is comparable to the Lander's dimensions. Plains that show extreme radar scattering are often rough on a fine scale. Sand dune areas on Earth, for example, exhibit such scattering of airborne radar signals. Since the returned signal power is also affected by the nature of the surface materials, radar data should be interpreted in the light of the available geological information.

Radar observations of Mars can only examine a small region close to the sub-Earth point (the point closest to Earth at the time of observation). The rotation of Mars moves the sub-Earth point rapidly in longitude, while its latitude travels slowly across the Martian tropical and sub-tropical zones with the orbital motions of the two planets. As it happened, various parts of the region surrounding the Chryse prime site at 19.5° N and 34° W began to become accessible to radar observation just a few weeks before Viking 1 went into Mars orbit. Observations made a few degrees south of the prime site indicated that the region was somewhat

LANDING SITE STAFF

H. Masursky	J. F. Newcomb
N. Crabill	E. D. Vogt

rougher than the Martian average, but not decisively so.

Once the spacecraft was in orbit and VIS coverage of the prime site began to come in, it became apparent that the channels, instead of ending just upstream from the site, ran right across it. As a mosaic of VIS photographs shows (fig. 2–3), the channels are incised sharply in the surface of the plain, leaving "islands" to stand between them. The channels provide evidence of a strong northerly flow of fluvial currents that carved grooves and eddy channels in the islands. The upstream ends of many islands, such as the one at the bottom of the figure, are marked by old craters, whose outer ramparts resisted the fluvial erosion. Their downstream ends have the tails that are characteristic of fluvial deposition.

The channels themselves are marked with irregular, blotchy depressions where the surface was stripped away by erosive action. Figure 2–4 shows such a patch of "scabland." Evidently, the prime site was an area of both erosion and deposition by strong currents. While the site was extremely interesting scientifically, its complexity made it very difficult to estimate the proportion of the surface that might be studded with fields of dangerous blocks.

Project officials made the decision to delay the landing in order to allow time to study the region to the northwest where the streams were more likely to have deposited the less blocky material they transported. The area was photographed by pointing the cameras off to the west of the orbital track, rather than by shifting the track. The fluvial channels diminished in that direction, and the terrain appeared smoother.

A new landing zone was tentatively selected, at a place that would be observable by radar over the July 4 weekend. The observations were made from the very large radio observatory at Arecibo, Puerto Rico. They showed an area of markedly weak radar signal returns centered at 44° W, in the zone that was under consideration for landing. Although the exact cause of the radar "anomaly" at that location was not determined, the indication was quite clear that the Lander should avoid it. Accordingly, the project officials decided on July 7 to alter the orbit the next day so that the Orbiter could explore further westward in the Chryse plain.

Photographs taken by the VIS in the next few days showed the smooth-appearing plain extending a few more degrees to the west before the channels that once drained the highlands west of the Chryse plain were encountered. Figure 2–5 is a mosaic of the region, showing the channels in the south and west parts and the ellipse centered on the landing site that was finally selected. (The outer ellipse represents the 99 percent landing dispersion probability zone, and the inner ellipse represents a 50 percent probability.) The low ridges that twist across the smooth plain very closely resemble the ridges in the mare regions of the Moon, which are basaltic lava plains. On the Moon, the mare ridges are not as hazardous to a landing vehicle as they may appear—in fact, Surveyor 5 landed safely on one such ridge in 1967.

FIGURE 2–3.—Meandering channels in the northeast Chryse region.

The Arecibo radar data indicated that the total returned power was up to normal Martian levels in the region to the west of the 44° W anomalous area, and that the apparent fine-scale slopes averaged about 5° at 47.5° W, diminishing perceptibly to the west. The site that was certified, at 22.4° N, 47.5° W, represented a good balance between the visible and radar roughness, in an area where it appeared that the surface processes were well understood.

Some Martian Features Observed by the Visual Imaging Subsystem

In the course of surveying possible landing sites and observing additional areas that are accessible from the orbital track, the VIS has taken many photographs of notable features of the Martian surface that graphically

FIGURE 2–4.—Eroded patches scarred some channels.

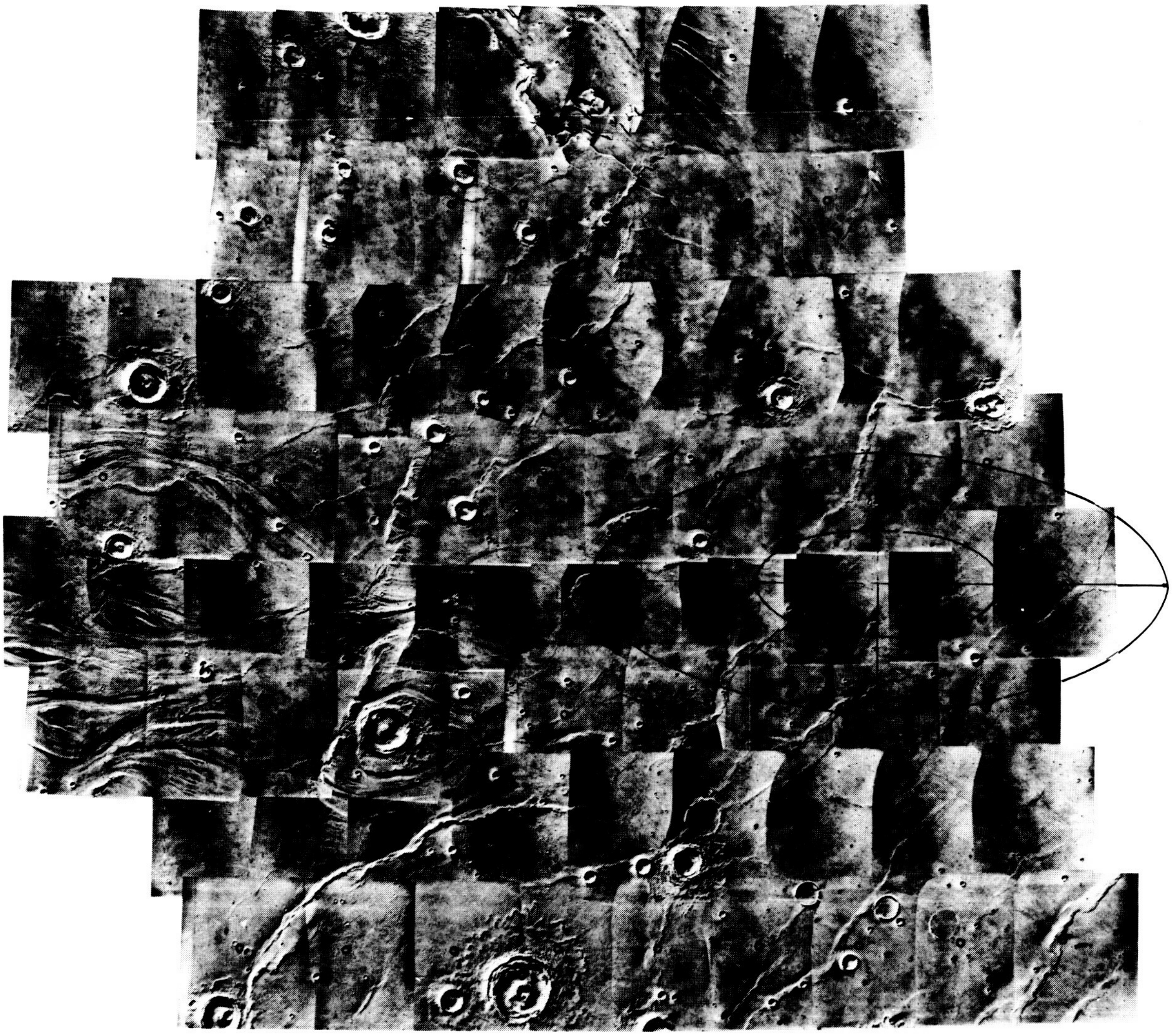


FIGURE 2–5.—Mosaic of landing site in Chryse Planitia.

demonstrate some of the processes that have shaped the surface. It has also photographed some distinctive atmospheric phenomena. A few of the spectacular photographs are included here.

Figure 2–6 is a mosaic looking across a section of Valles Marineris, the huge canyon system discovered by Mariner 9. The far wall, which is about 2 km high, has collapsed repeatedly, in a series of massive landslides. The apron from the slide in the center overcoats previous aprons. The near wall also has a fresh-appearing landslide apron. Evidently, collapse is an important part of the process of widening canyons here. Streaks seen on the canyon floor point to wind erosion as an agent for removing the debris. Stratification is evident in the upper part of the far wall. The layers indicate a succession of deposits that might be lava flows, volcanic ash, or wind-blown material.

Figure 2–7 shows a valley whose head (right) is a jumbled mass of debris from the collapse of the surface. The streamlined forms extending down the valley suggest that here the removal of subsurface material by flowing water may have been the agent of collapse. A possible source of the water is the melting of subsurface ice. Near the top of the picture, a sinuous rille very much like those that are common on the Moon wanders across the plain. Although the Apollo

FIGURE 2–6.—Section of the Valles Marineris canyon system.

FIGURE 2–7.—Jumbled debris at the head of a valley near one Viking 2 site.

15 astronauts landed near a large lunar sinuous rille and briefly explored its bank, the origin of these features is still in dispute.

Relatively fresh impact craters on Mars appear different from those typical of the Moon and Mercury. The material ejected from the craters seems to have flowed as a fluid.

Figure 2–8 shows the crater Arandas, about 25 km in diameter, with its conical peak and distinct rim. The material outside the rim forms an apron that ends in lobate flow scarps. In the lower left corner, the flow has been deflected around a small crater.

The crater Yuty, in figure 2–9, is another impact crater whose ejecta blanket was formed by fluid flow. The leading edges of the flow evidently carried the largest blocks of debris, which left a prominent ridge when the flow ceased. The debris flows shown here and in the preceding photograph may be lubricated by gas or water derived from melting and vaporization of subsurface ice.

Figure 2–10 shows an entirely different kind of crater—the caldera of the giant volcano Arsia Mons. A caldera is formed by the collapse of a volcano's summit. Arsia Mons, in the Tharsis region, is about 17 km

FIGURE 2–8.—Flow patterns around the crater Arandas.

FIGURE 2–9.—Flow patterns around the crater Yuty.

FIGURE 2–10.—The caldera of the volcanic crater Arsia Mons.

high, and its caldera is 100 km across. In this early morning photograph wispy clouds obscure much of the caldera's floor. Many lava flows can be seen on the flanks of the volcano.

The largest volcano on Mars (if not in the solar system) is Olympus Mons, whose summit protrudes through a wreath of clouds in figure 2–11. Olympus Mons is about 600 km across at the base and approximately 25 km high. Its multiringed caldera formed through a series of subsidence episodes. The clouds extend up the flanks of the volcano to an altitude of about 19 km, leaving the summit cloud-free. The cloud cover is densest on the western side of the mountain, and beyond it (upper left) is a well-defined train of wave clouds. In the northern spring and summer seasons this cloud cover builds up during the day, and becomes large enough in the afternoon to be seen from Earth. The clouds are believed to be composed of water ice condensed from the atmosphere as it cools while moving upslope.

Early Results of the Infrared Thermal Mapping Experiment

One of the important objectives of the experiment is to investigate the diurnal temperature variation at many areas of the planet. Since that requires the observation of each area at different times of day, data of that type will be quite limited until the Orbiter can be released from synchronous orbit. In the meantime, the experiment is acquiring other interesting kinds of information.

A global view is obtained when the Orbiter is well away from the periapsis of its orbit. Considerable thermal structure is apparent in such a view. Figure 2–12 illustrates the global surface temperatures obtained 4½ hours before periapsis on one revolution. The planetary disk is half illuminated, and surface temperatures on the daylight side rise to above 240 K at noon on the equator. (The Kelvin temperature scale begins at absolute zero, so that temperatures are always positive numbers. The gradations are the same as those of the Celsius scale, and 0° C is equivalent to 273 K.) The contour (isotherm) interval in the figure is 10 K on the daylight side, and 2 K on the night side. The most conspicuous thermal feature is Arsia Mons, the southernmost of three large volcanoes on the Tharsis ridge. It is near the morning terminator, and the high elevation puts the east-facing slopes in the sunlight while nearby areas are still at their unexpectedly low predawn temperatures. The comparatively straight isotherms just east of the morning terminator indicate that the temperature rises quite uniformly at first. Toward noon the temperature is more affected by the area's surface reflectivity.

About three hours before periapsis, the Viking IRTM can view the southern hemisphere to the south pole. These are the first observations made of the polar regions in midwinter, and the results are interesting. Figure 2–13 illustrates the observed temperatures. The isotherms are drawn at 10° intervals down to 150 K, and 1° intervals below that. The lowest temperature observed is 134 K, just off the south pole. Temperatures below 148 K had not been expected, because

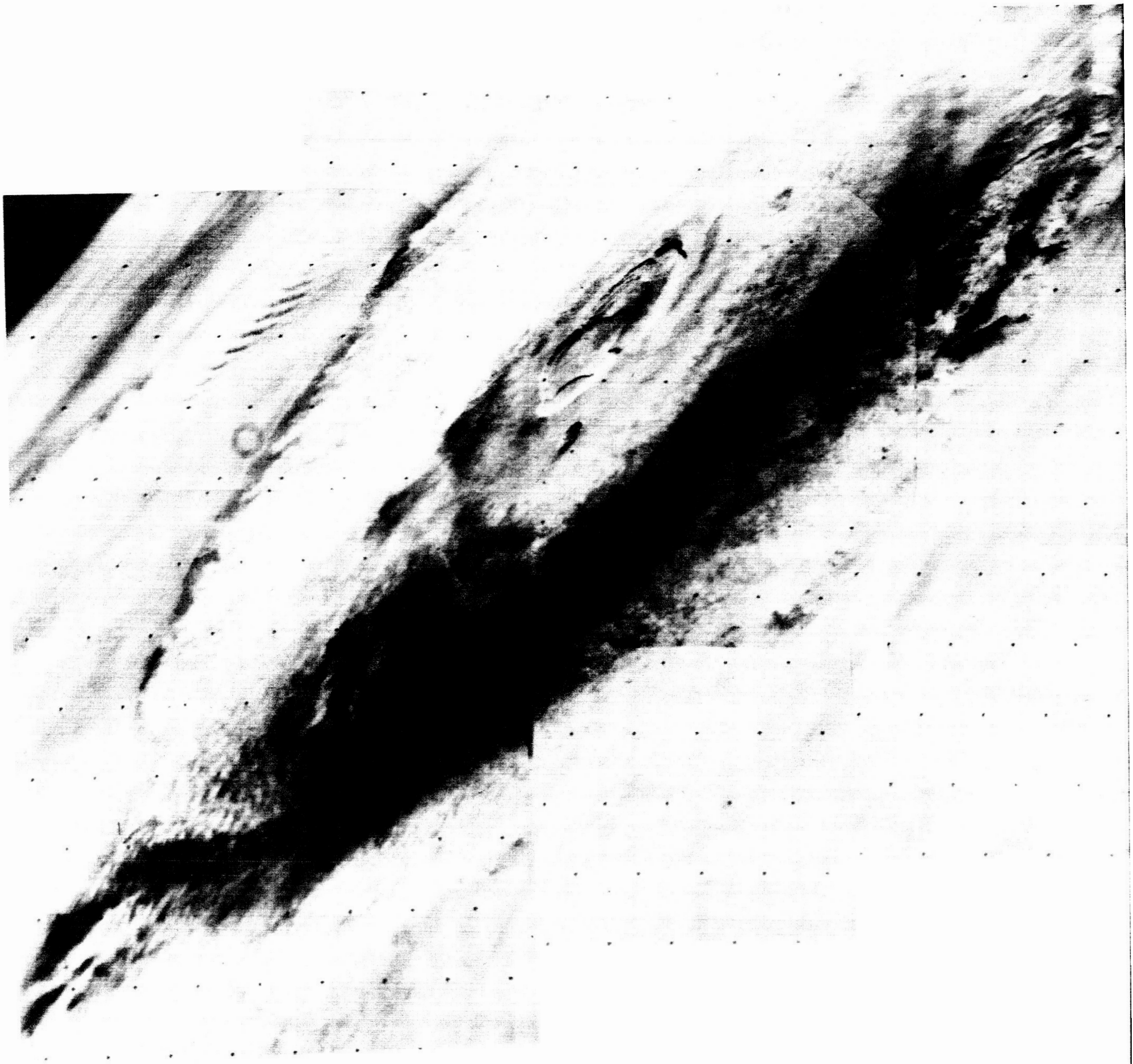


FIGURE 2–11.—Olympus Mons, wreathed in clouds.

that is the equilibrium temperature for the sublimation of frozen carbon dioxide at the mean atmospheric pressure of 6 millibars. At this stage of the winter season, the polar cap of frozen carbon dioxide is actively growing, and as much as a fourth of the entire atmosphere may eventually freeze onto the ground. The loss of atmosphere is even felt in the northern hemisphere, according to indications from the Viking 1 Lander's meteorology experiment (discussed in ch. 6). One hypothesis to explain the low polar temperatures is that the active removal of CO_2 from the atmosphere over the polar cap substantially in-

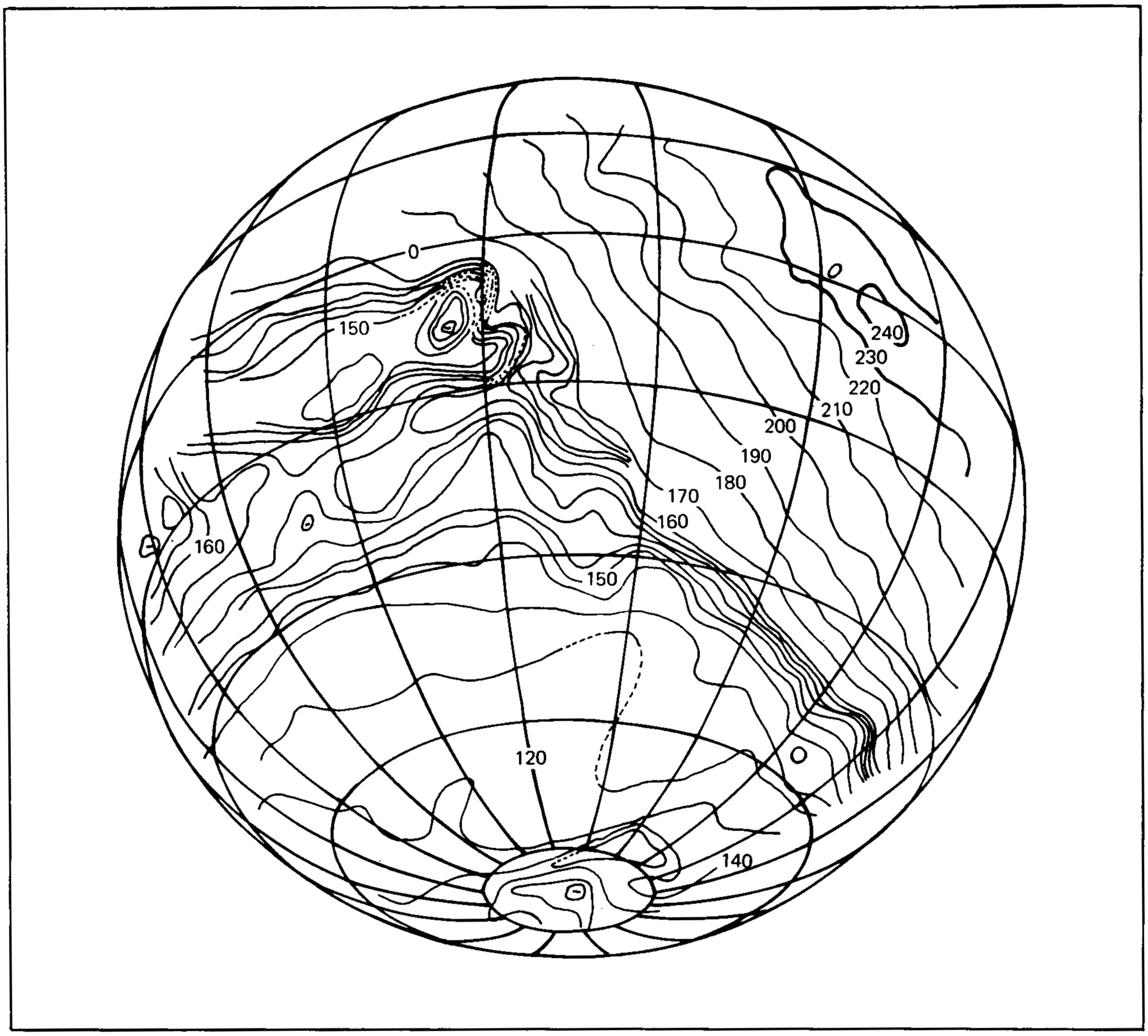


FIGURE 2–12.—Global surface temperatures.

creases the local concentration of noncondensable gases such as argon, nitrogen, and oxygen in the lowest layer of the atmosphere. As the partial pressure of CO_2 is reduced, the equilibrium temperatures are also decreased. Further observations are needed to rule out the possibility of an alternative explanation, involving a high-level cloud of frozen CO_2, thick enough to impede observation of the ground.

Another interesting feature in the figure is the presence of several temperature troughs, with a depth of 2 or 3 kelvins, that appear to emanate from the south pole. The arcuate shape of these troughs is reminiscent of the shape of weather patterns around the Earth's poles. Further observations will establish whether they represent a pattern of the global scale atmospheric circulation.

Early Results of the Atmospheric Water Vapor Mapping Experiment

Like the IRTM experiment, the water vapor mapping experiment is temporarily limited in the accomplishment of its objectives by the synchronous orbit in which it is operating. In order to map the variations in the water vapor content with location and with

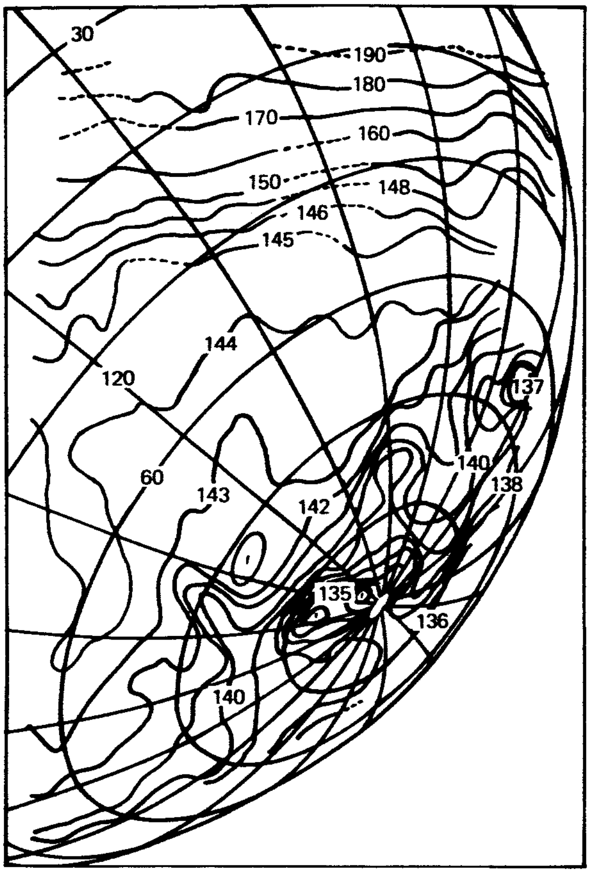


FIGURE 2–13.—Observed temperatures of south polar regions.

time, the experiment needs to observe each area of interest at different times of day. Additionally, since the experiment is much concerned with seasonal variations, an extended period of observations is required.

The measurements that have been made to date are mostly in the southern hemisphere, which is the dry one at this season. They show a strong latitude dependence, increasing gradually northward across the equator.

Figure 2–14 is a map of the low-resolution observations made about 90 min before periapsis on several early revolutions. A water vapor value (in precipitable micrometers, as explained in the instrument description) is printed in the center of each ten-degree square observed. The cross-hatched line shows the position of the terminator. (The finer curves are not related to the water vapor values; they are elevation contours on the base map.) The local time of the observations is indicated across the top. In addition to the latitude dependence, the plot shows another interesting point: the apparent independence of the values in a latitude band from the time of day. This is somewhat surprising, because at one location (10° N, 83° W) that was monitored over a local time interval of about 6 hours, the water vapor content rose steadily from dawn until noon. Perhaps the monitored location has a different mechanism (such as ground fog) for the release of vapor from the solid phase, or perhaps the areas to the west of that location simply have more water. Observations from nonsynchronous orbit should eventually clear up that question.

The Orbiter

The design of the Viking Orbiter (fig. 2–1) differs from that of Mariner 9 in several important respects. To reduce its velocity enough to be captured into orbit while bearing its passenger, the Viking Orbiter carried three times as much propellant as Mariner 9. The structural augmentation required to support the larger tanks resulted in a total Orbiter weight (with propellant and without the Lander capsule) of 2325 kg.

The requirement placed on the Viking Orbiter to provide high-resolution images of the Viking landing sites has not only determined the characteristics of the visual imaging subsystem; it has caused the use of an entirely new type of tape recorder for spacecraft data storage. Whereas the Mariner 9 television cameras operated on a 42-sec cycle, the Viking Orbiter cameras must take a new picture every 4.5 sec to provide contiguous coverage of a landing site. This means that visual information must be recorded at a rate of more than 2 million bits per second, and then played back at the very much lower rates set by the communication link. The five available playback rates are 1, 2, 4, 8, and 16 thousand bits per second. This tremendous disparity between the recording and playback data rates is dealt with by recording the visual information in parallel on seven channels of an eight-channel tape. The eighth channel is used to record data from the Orbiter's other two scientific instruments, other Orbiter telemetry, and all the data transmitted by the Lander in the relay mode of communication. During playback, only one channel is read out at a time. Even with this approach, the recorder's mechanical tape drive must operate through an extraordinarily wide range of tape speeds. The Orbiter has two tape recorders, each capable of storing 640 million bits (55 television frames plus the data stream recorded on the eighth channel).

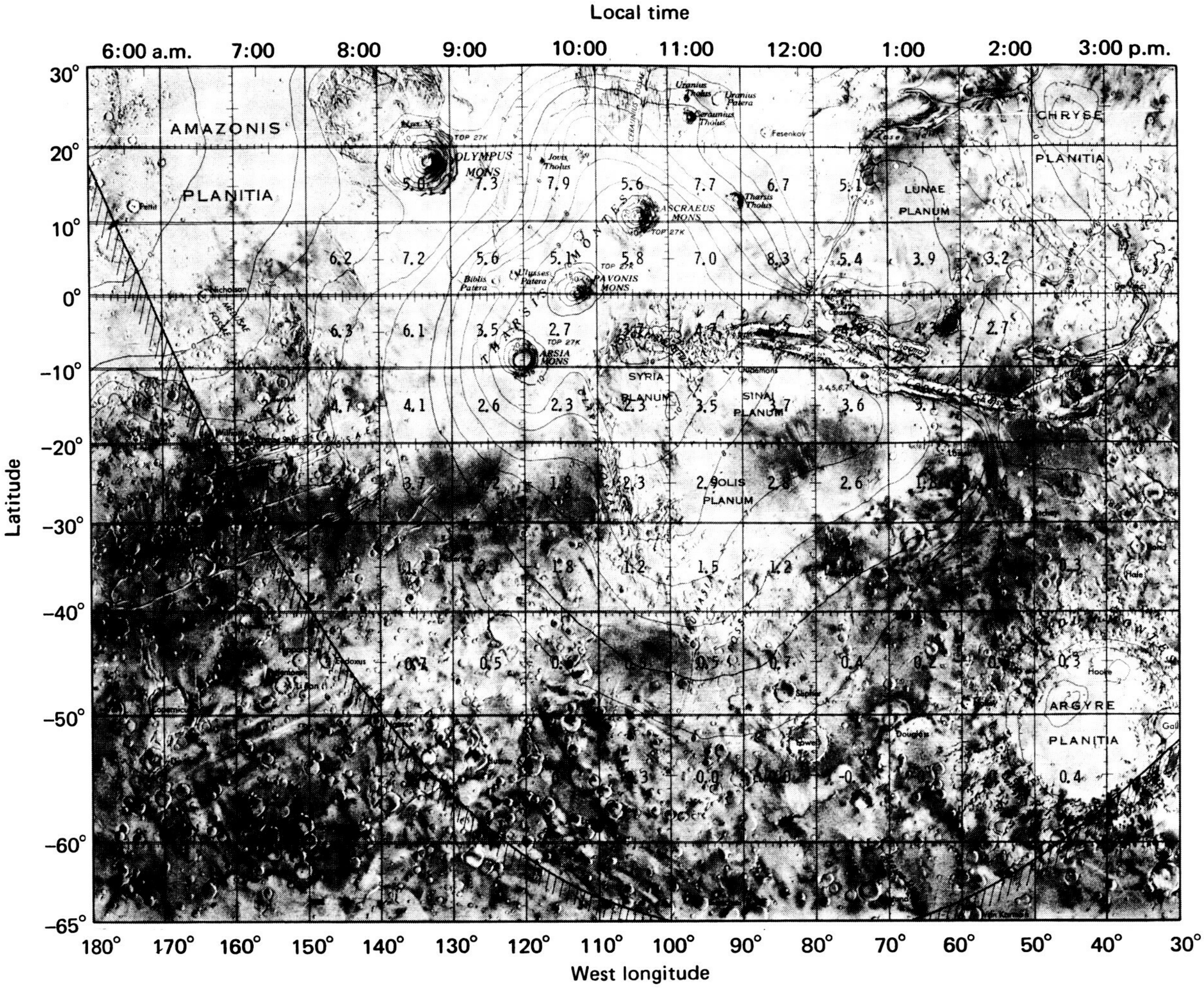


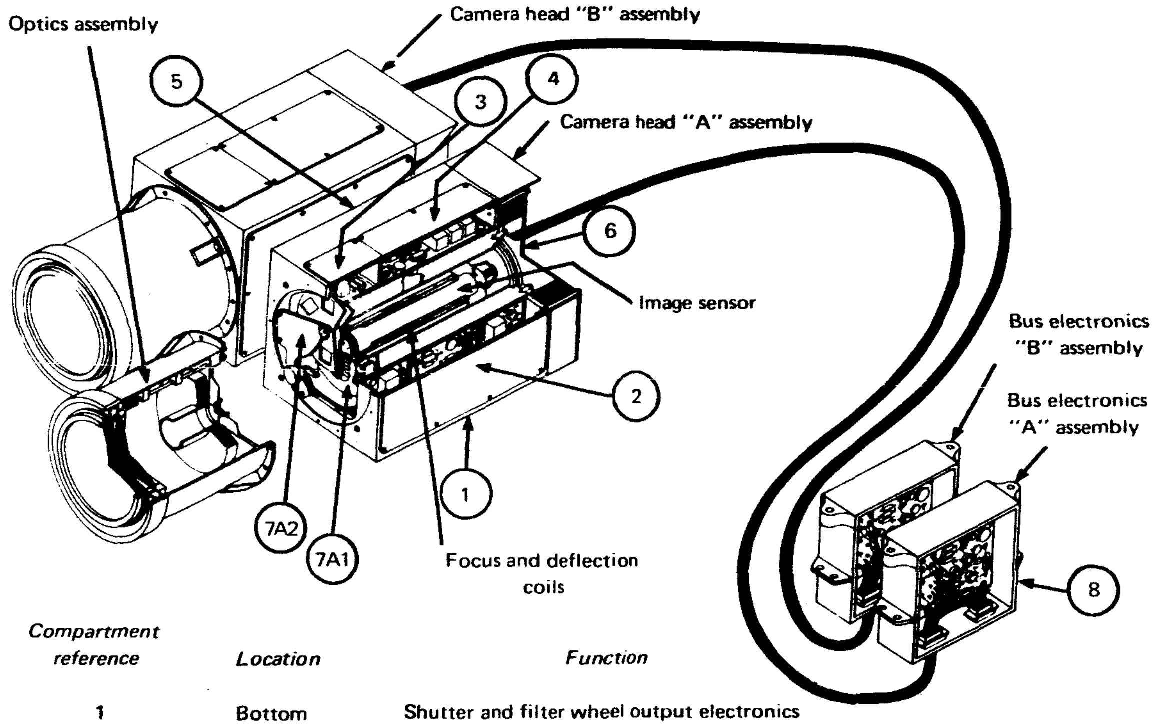
FIGURE 2–14.—Atmospheric water vapor observations.

The Viking Orbiter needs more electrical power than its Mariner predecessor. The four solar panels, with a combined area of 15 m^2, generate 620 W at the distance of Mars from the Sun. They differ in appearance from those of the Mariner series because each is divided into two subpanels. The division made it possible, by double folding, to stow these larger panels within the launch-vehicle fairing. The Orbiter normally flies with the solar panels facing the Sun. When it must be in some other attitude, as well as at peak-load periods, two 30 A-hr storage batteries supplement the solar power.

The Orbiter's communication system has a few duties to perform beyond those of the system used on Mariner 9. It must receive signals from the Lander for relay to Earth. It must also transmit simultaneously in the S-band (at 2295 MHz) and in the X-band (at 8415 MHz). The simultaneous transmission capability is an important part of several radio science investigations. The signals at both frequencies are directed to Earth by the high-gain antenna, a parabolic dish 1.5 m across. The antenna, mounted on the side of the Orbiter, is motor-pointed about two axes. This enables the flight team to keep the antenna's narrow beam directed at the Earth despite the changing angular relationship between the Earth, the Sun, and the Orbiter. The high-gain antenna also receives the S-band signals from the stations of the Deep Space Network. During periods when the Orbiter is not oriented toward the Sun, and the Earth is not in the beam of the high-gain antenna, limited two-way communication in the S-band is maintained through the low-gain antenna. The field of coverage of this antenna, which is mounted atop the Orbiter, exceeds a hemisphere. The Viking Orbiter has a third antenna, mounted on the outer end of a solar panel, that receives the signals from the Lander that are to be relayed to Earth. This communication between the Lander and the Orbiter is one-way, at the UHF frequency of 380 MHz. It was turned on shortly before the separation of the Viking 1 Lander, and operated at a 4000-bit-per-second rate until touchdown, when the Lander immediately switched to the normal 16 000-bit-per-second rate. (In fact, the Orbiter telemetry event noting this change was one of the first definite indications of the landing.)

Visual Imaging Subsystem

The VIS, similar to that of Mariner 9, consists of two television cameras and their associated electronics. A camera comprises a telescope, a shutter, a filter wheel, and a vidicon tube (fig. 2–15). The two VIS cameras are the same in all respects, with Cassegrainian telescopes of 475-mm focal length, and identical six-sector filter wheels. The field of view of each camera is about 1.5° by 1.7°, so that from the periapsis altitude of 1500 km each frame covers an area 41 by 46 km on a side. The axes of the two cameras diverge by about 1.4° in the direction perpendicular to the ground track. The cameras operate alternately, with the shutter of one camera exposing a frame when the other camera is midway through scanning its frame. With each camera repeating its cycle every 4.5 sec, the coverage of successive frames from the same camera is contiguous along the ground track. Thus, the product of a photographic sequence near periapsis is a swath



Compartment reference	*Location*	*Function*
1	Bottom	Shutter and filter wheel output electronics
2	Left side	Digital sequencing logic
3	Top front	Video amplifier chain
4	Top rear	Analog to digital converter
5	Right side	Vidicon analog controls
6	Rear	Vidicon power supply
7A1	Front	Shutter assembly
7A2	Front	Filter wheel assembly
8	Bus electronics	Low voltage power supply

FIGURE 2–15.—Visual imaging subsystem aboard the Orbiter.

of contiguous coverage 80 km wide and about 1000 km long.

The filter wheel in each camera makes it possible to select the wavelength bands in which the image is produced. Imaging of the same areas with different filters permits the differentiation of various surface materials and atmospheric conditions by spectral reflectances. One filter in the wheel is clear, permitting passage of the entire wavelength band, from 350 to 700 nm, to which the vidicon target is sensitive. (Wavelengths between 350 and 400 nm are in the near-ultraviolet, while the remainder of the band is visible.) A red, a green, and a blue filter divide the full band into three bands that overlap slightly. Of the two remaining filters, the violet filter passes only the wavelengths from 350 to 450 nm, and the minus-blue filter blocks those wavelengths while passing the remainder of the visible spectrum.

A shutter allows the image formed by the telescope to reach the faceplate of the vidicon during an interval that can be varied between 0.003 and 2.7 sec. When the vidicon target has been exposed to a light image, it holds the image in the form of a two-dimensional array of static charges. The target is then scanned by an electron beam that neutralizes the image and converts it to a time-varying signal. The beam scans the target in 1056 lines, each composed of 1182 picture elements (pixels).

A pixel, a somewhat theoretical concept when the television signal is in analog form, becomes a real entity if the signal is converted to digital form. In the Viking Orbiter, the flight data subsystem (FDS) digitizes analog information from all instruments. It accepts the signal from the VIS one scan line at a time, dividing the signal waveform into brief sampling intervals that correspond to single pixels. Each pixel is assigned one of 128 discrete intensity levels. Since 128 equals 2^7, it takes seven binary digits (bits) to distinguish that many levels. Each pixel becomes a seven-bit word when it enters the tape recorder. A frame of VIS imagery comprises 1¼ million pixels, or 8 700 000 bits of data. With pictures taken from periapsis, each pixel represents a square on the surface about 40 meters on a side.

The flight data subsystem feeds the digitized visual data into seven data channels of the tape recorder. Successive pixels enter successive channels. Channel 1, for example, will record the first, eighth, fifteenth, etc., pixel of each scan line. This system of parallel recording produces on the tape an intricately scrambled record of the image. The tape is played back one channel at a time for transmission to Earth. It is only after all seven channels have been received that the pixels can be sorted out to reconstruct the image on the vidicon target.

Infrared Thermal Mapper

The IRTM (fig. 2-16) is a 28-channel infrared radiometer. Each of its four telescopes has an interference-type filter that passes radiation in a selected wavelength band. In the focal plane of each telescope are seven antimony-bismuth thermopile detectors that measure the intensity of radiation in the spectral band, or a portion of the spectral band, passed by that telescope's filter. The fields of view of the detectors are splayed out in the cross-track direction. A detector's typical 0.3° field of view covers an 8-km circle on the surface from periapsis altitude. The forward motion of the Orbiter brings a ground point successively into view of a detector in each spectral band.

Thermal emission from the Martian surface is measured in four bands: 6.1 to 8.3 μm, 8.3 to 9.8 μm, 9.8 to 12.5 μm, and 17.7 to 24 μm. Seven detectors respond to reflected sunlight in the band from 0.3 to 3.0 μm. One detector measures radiation between 14.56 and 15.41 μm, in the CO_2 vibration band, to measure the stratospheric temperature.

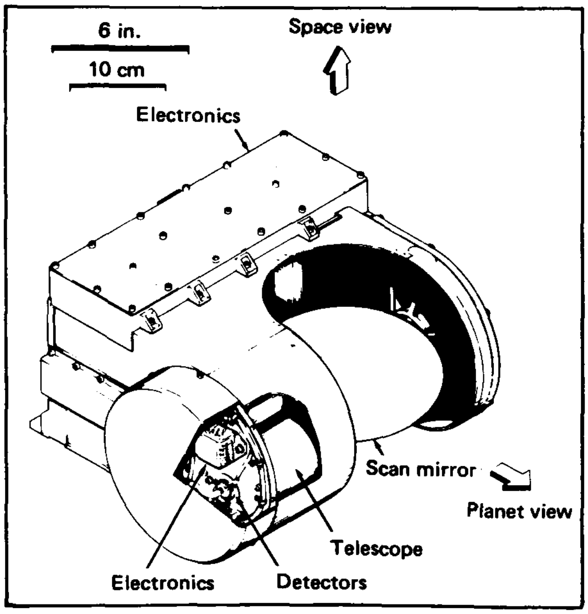


FIGURE 2-16.—Infrared thermal mapper.

Mars Atmospheric Water Detector

This instrument is designed to map the distribution of water vapor over the planet. Water vapor is a minor constituent of the Martian atmosphere that is of the greatest importance in understanding the meteorology, the geology, and, above all, the biology of the planet. Life on Earth is completely dependent on the availability of water, since all biochemical reactions take place in aqueous solutions. The prime landing sites for Viking were mainly places where water vapor was expected to be relatively abundant. Measurements by the MAWD to confirm this expectation constitute one input to the certification of a landing site. Later in the mission, when the Orbiter is in a nonsynchronous orbit, the MAWD will observe the global distribution of water vapor, locate areas where higher concentrations might indicate volcanic activity or subsurface ice conditions, and investigate the daily and seasonal variations in the abundance of water vapor.

The MAWD (fig. 2–17) is an infrared spectrometer operating at five selected wavelengths within the water vapor absorption band at 1.38 μm. By measuring the proportion of the incident solar radiation that is passed by the atmosphere at those wavelengths, it determines the amount of water vapor the radiation has passed through. Comparison of the five channels also derives the atmospheric pressure at the level where the absorption takes place, thus permitting an estimate of the altitude of the water-vapor-bearing layer.

Radiation entering the instrument is focused by a small telescope and reflected by a collimating mirror onto a diffraction grating of 12 000 lines per centimeter. The grating spreads out the spectral band onto an array of five lead sulfide detectors. The field of view at any instant is a 0.12° by 0.92° rectangle, providing a ground footprint from periapsis altitude that is 3 km wide and 24 km long. A scanning mirror in front of the telescope sweeps the Martian surface in a 15-position scan perpendicular to the ground track. The 15 contiguous rectangles covered in one scan have a combined width of 45 km. The scan is repeated every 4.5 sec.

The instrument is sensitive to variations in water vapor abundance of about one precipitable micrometer of water. (The conventional way of expressing abundance is the thickness of the layer of rainwater that would be formed if all the water vapor in the atmospheric column above a given location could be condensed out.) Abundances observed in the Martian atmosphere before the Viking mission have not exceeded 50 μm.

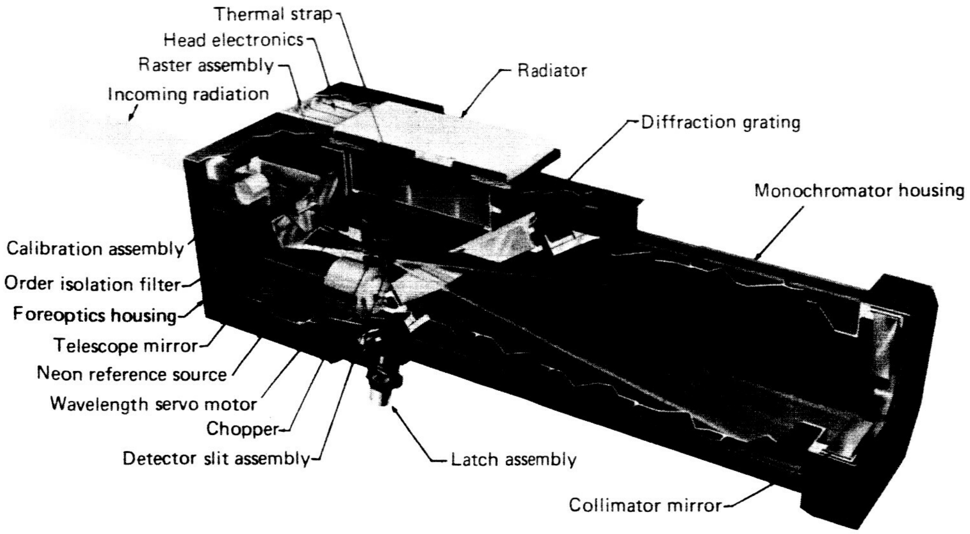


FIGURE 2–17.—Mars atmospheric water detector.

3

Entry and Landing: A Traverse of the Atmosphere

The Viking Lander's passage through the Martian atmosphere during its landing provided an exciting opportunity for direct measurement of some of its constituents and properties. Since the Lander's mode of descent changed several times during the passage, and the various instruments operated through different altitude ranges, an account of the sequence of events (fig. 3–1) is an appropriate introduction to the entry science investigations.

The descent capsule that separated from the Orbiter consisted of the Lander, an aeroshell, and a base cover. The Lander was enclosed, the deorbit engines and the instruments that first sensed the environment were part of the aeroshell, and the parachute was in the cover.

The descent trajectory first took the capsule through the undisturbed interplanetary medium. This is a magnetized gas of ions and electrons streaming away from the Sun at hypersonic velocity, which is called the solar wind. Closer to the planet the Lander passed through a disturbed region where the solar wind is diverted to flow around the planet. Beneath this interaction region lies the Martian ionosphere, a zone of charged particles generated by photo-ionization of the Martian atmosphere. The retarding potential analyzer that analyzed the charged particles (electrons and ions) was turned on shortly after deorbit. At that time the aeroshell was facing away from the Sun so that the instrument, which was sensitive to sunlight, could observe the interaction region without interference.

The descent capsule encountered an appreciable atmosphere at about 250 km. In preparation for this, the upper atmosphere mass spectrometer was turned on early to allow it to warm up, and the capsule was oriented so that the aeroshell and its heat shield faced in the direction of travel. The capsule was traveling at about 16 000 km/hr before atmospheric drag began to slow it. The intense heat generated by the atmospheric drag was carried away from the aeroshell by the ablation of the heat shield's substance. Both instruments ceased operating at about 100 km, where the atmospheric pressure exceeds 0.003 millibar. The aeroshell's other two instruments, a pressure and a temperature sensor, continued to operate until the aeroshell itself was jettisoned.

ENTRY SCIENCE TEAM

Alfred O. C. Nier
William B. Hanson
Michael B. McElroy
Alfred Seiff
Nelson W. Spencer

The capsule experienced its peak deceleration somewhere between 24 and 30 km above the surface. For a while its path leveled off into horizontal flight because of the aerodynamic lift provided by the aeroshell. Continued deceleration caused the capsule to resume its descent. By the time its radar altimeter indicated an altitude of 6.4 km, it was traveling slowly enough (an estimated 1600 km/hr) to deploy a parachute. Seven seconds after parachute deployment, the aeroshell separated from the Lander. The aeroshell's remaining lift caused it to drift well away from the landing site.

Temperature and pressure sensors on the bottom of the Lander were then exposed to the atmosphere and took over the measurement functions. The radar altimeter switched to an antenna on the Lander to continue its measurements. The Lander's three legs were extended to the landing position. About a minute later the parachute slowed the Lander's fall to about 60 m/sec. During this time the effects of winds on the Lander's horizontal travel could be observed. Then a signal from the radar altimeter at 1200 m

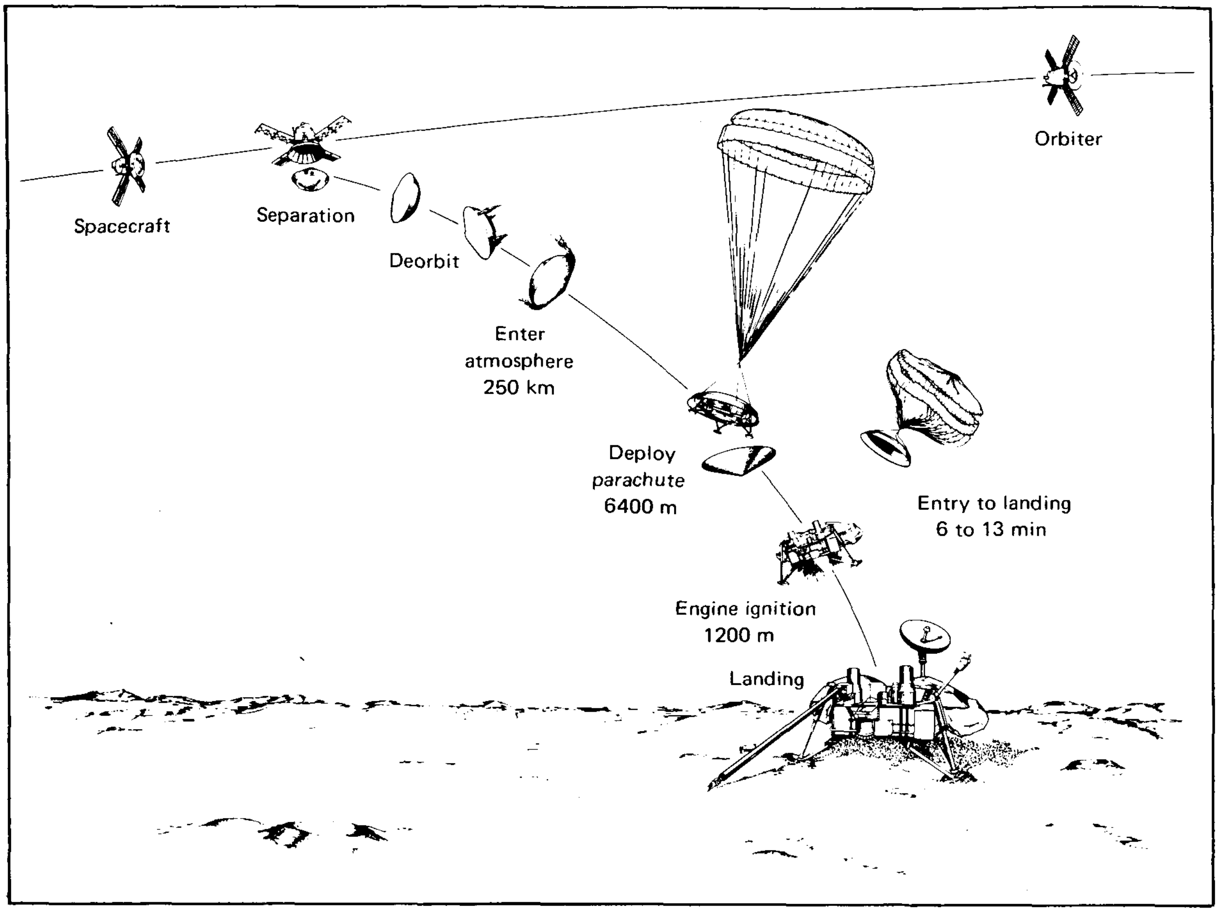


FIGURE 3–1.—Diagram of sequence of landing events (not to scale).

ignited the Lander's three terminal descent engines and caused the jettison of the parachute and the base cover.

Retarding Potential Analyzer

This instrument measured the energy distribution of solar wind electrons and ionospheric photoelectrons, the temperatures of the electrons in the ionosphere, and the composition, concentrations, and temperatures of positive ions. At the highest altitudes, the analyzer examined the interaction of the solar wind with the upper atmosphere. This information is likely to be important to the understanding of the nature of the Martian atmosphere, because the planet's weak (or nonexistent) magnetic field should permit deeper solar wind penetration than occurs on Earth.

Data obtained by the retarding potential analyzer during the descent of the Viking 1 Lander show that the major constituent of the Martian ionosphere is O_2^+ (singly ionized molecular oxygen). It is about nine times as abundant as CO_2^+ (singly ionized carbon dioxide), which is the primary ion produced by the interaction of sunlight with the Martian atmosphere. This important new finding lends support to theoretical analyses by M. B. McElroy and J. C. McConnell that called attention to the reaction of atomic oxygen with CO_2^+ that would produce carbon monoxide and the more stable ion, O_2^+. The temperature of the observed ions at an altitude of 130 km was about 160 K.

The retarding potential analyzer (RPA) consisted of a series of six wire grids located behind an opening at the front of the aeroshell and in front of an electrometer collector (fig. 3–2). The first, second, and

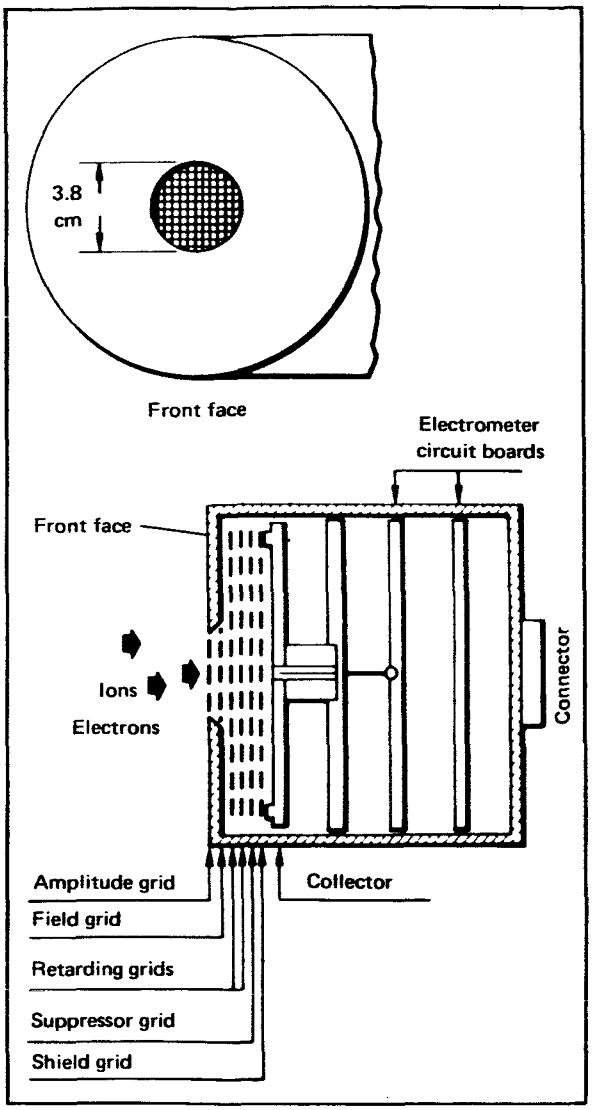


FIGURE 3–2.—Schematic diagram of the retarding potential analyzer.

sixth grids were grounded to the aeroshell. The third and fourth grids were connected electrically and made up the retarding grid. The electric potential on the retarding grid was swept through a series of positive and negative voltages. During the sweeps, a steady voltage of opposite sign was applied to the fifth, or suppressor, grid. As the voltage was varied, different portions of the population of ions and electrons could penetrate the grid structure and produce a current in the electrometer. The cycle of voltage sweeps was repeated every four seconds. By knowing at what point in a retarding voltage sweep a measurement of the electrometer current took place, scientists can determine the temperature and concentration of various ions and electrons.

Upper Atmosphere Mass Spectrometer

This instrument analyzed the molecular composition of the atmosphere during entry. It provided a qualitative and quantitative analysis of all electrically neutral gases whose molecular weight is 50 atomic mass units or less. It also measured their isotopic abundances. A knowledge of the identities and concentrations of the various gases as a function of altitude is basic to understanding the development of the atmosphere and the processes that maintain the present balance.

The upper atmosphere mass spectrometer obtained data from 230 km to 100 km during the descent of the Viking 1 landing capsule. Figure 3–3 is a sample mass spectrum obtained at an altitude of about 135 km. As expected, the main neutral constituent of the upper atmosphere is carbon dioxide, which produces the peak at mass 44. The abundance of nitrogen, which shows up at mass 28 (along with carbon monoxide) and at mass 14, is 6 percent that of CO_2 at that altitude. The peaks at 40 and 20 are due to argon, whose abundance relative to CO_2 is 1.5 percent. Molecular oxygen, at mass 32, constitutes about 0.3 percent. Atomic oxygen is detectable at mass 16. Smaller peaks in the spectrum are produced by gases containing the less common isotopes of these elements. The relative abundances of the carbon and oxygen isotopes are close to their terrestrial values.

Nitrogen was detected in the Martian atmosphere for the first time during the Viking 1 entry. The existence of nitrogen is significant because at least a small quantity of that element has always been regarded as necessary for the existence of life. Mass spectra obtained at higher altitudes show a higher proportion of nitrogen, which is lighter than the other atmospheric gases.

The measured abundance of argon indicates that the much higher values that had been inferred from indirect data obtained by the Soviet Mars 6 probe were incorrect. This finding was of immediate practical importance because it resolved a dilemma as to the conduct of a Lander scientific investigation. The low argon abundance measured during entry permitted the investigators to use the gas chromatograph mass spectrometer (described in ch. 7) to analyze the uncontaminated gases at the bottom of the atmosphere

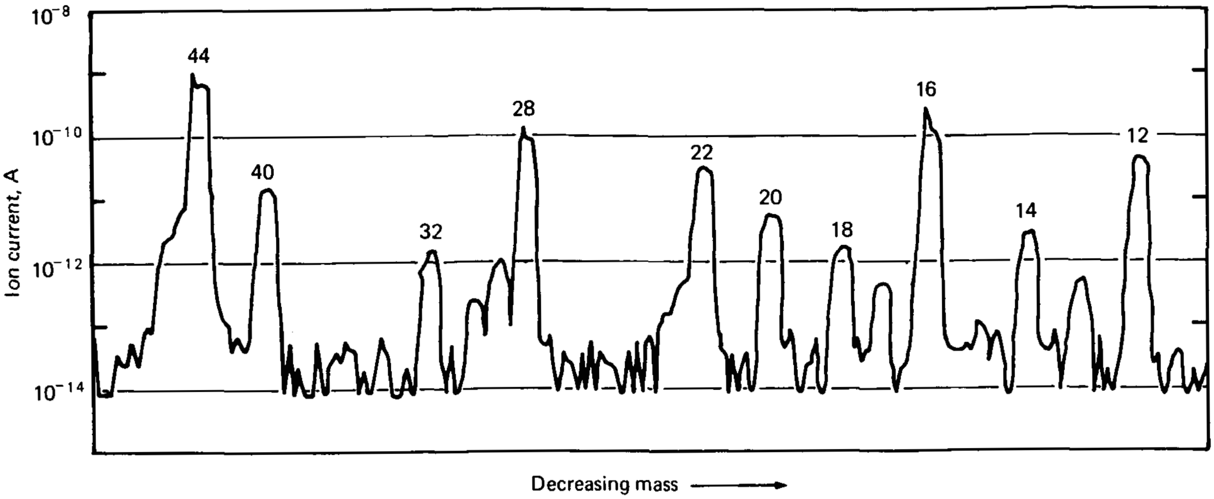


FIGURE 3–3.—Mass spectrum obtained at about 135 km.

before loading it with a sample of surface material for organic analysis. Argon in the concentrations predicted by the earlier data would have endangered the further usefulness of the instrument.

The upper atmosphere mass spectrometer (UAMS) is a double-focusing (electric and magnetic) mass spectrometer in which the gases entering the port (fig. 3–4) are first ionized by bombardment with a beam of electrons. Most of the resulting ions have a single positive charge (due to the loss of one electron by collision), and some are doubly charged. Some of the ions are products of the dissociation of gas molecules by the electron beam. The ions are then accelerated toward the analyzers by a voltage that is varied with time. The voltage between the plates of the electric analyzer is varied concurrently with the accelerator voltage sweep. After leaving the electric analyzer, the ions pass between the poles of a magnet following curved paths. The path through the magnetic analyzer of an ion that was accelerated by some given voltage depends on its mass-to-charge ratio. Mass spectra are obtained at the two fixed ion collector slits by the sweep of the accelerating voltage. A mass spectrum is shown as a plot of the quantity of ions collected at each mass-to-charge ratio.

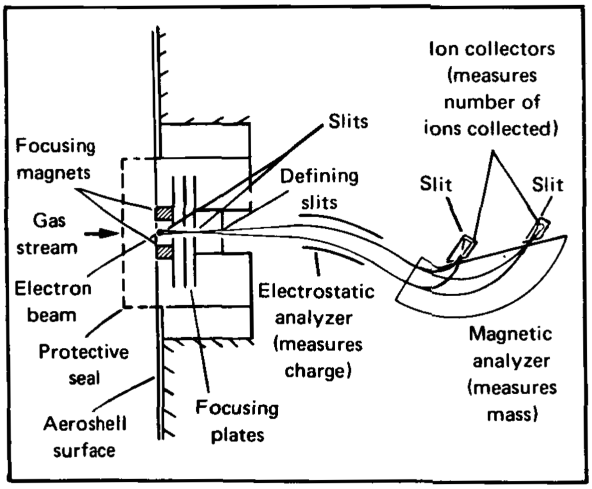


FIGURE 3–4.—Schematic of the upper atmosphere mass spectrometer.

The intake port of the UAMS is at the surface of the aeroshell. It was covered by a protective seal before the Viking launch, and a vacuum was maintained in the instrument until the seal was removed just after the deorbit burn. A mass spectrometer can only operate under near-vacuum conditions; hence the UAMS became inoperable below about 100 km.

Lower Atmosphere Structure Experiment

The primary objective of this experiment was to obtain vertical profiles of the density, pressure, and temperature of the atmosphere from an altitude of 90 km down to the surface. The first measurements from which the density profile could be derived were of the descent capsule's retardation due to atmospheric drag. The sensors were the accelerometers that were

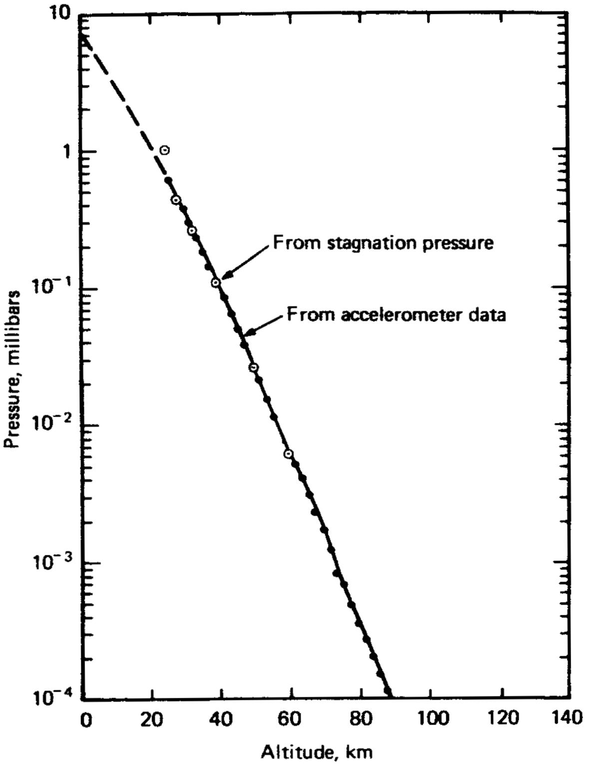


FIGURE 3–5.—Atmospheric pressure profile from 90 km to landing (preliminary).

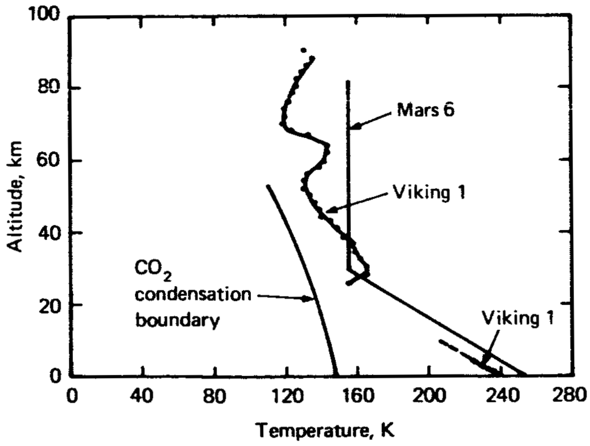


FIGURE 3–6.—Temperature of the atmosphere measured from 90 km to landing (preliminary).

part of the Lander's inertial reference unit, which provided a continuous input for the guidance and control of the descent.

Pressure and temperature measurements came at first from the two instruments in the aeroshell. Because of the very high initial velocities, the pressure sensor actually measured the stagnation pressure (the pressure of the atmospheric molecules against the aeroshell surface), from which the ambient pressure could be derived later. Similarly, the temperature probe, located near the aeroshell's outer rim, measured the recovery temperature of molecules flowing around the aeroshell. During the parachute descent, after the aeroshell had been jettisoned and the Lander's own surface environment pressure and temperature sensors were operating, the velocity was low enough to make the dynamic correction of the readings negligible.

The altitude information needed for the construction of profiles came from the radar altimeter. A by-product of the radar altimeter measurements was information about the terrain elevation profile under the Lander's path. The terminal descent and landing radar, which provided control information for the final phase of the landing, also measured the drift of the Lander with the wind during the parachute descent.

Figure 3–5 shows the atmospheric pressure profile from 90 km to ground level derived from the first analysis of the Viking 1 landing data. The points derived from the deceleration data and the stagnation pressures are indicated. They are consistent with each other and with the directly sensed measurements below 3.5 km. The pressure at the surface was 7.3 millibars.

The temperature of the atmosphere between 200 and 140 km, obtained from the RPA and UAMS data, averages about 180 K. The temperature profile from 90 km to the ground is shown in figure 3–6. The Viking 1 curve is derived from deceleration data between 90 and 30 km, and from direct sensing below 3.5 km. There are local temperature peaks at 64 and 30 km. The entire profile was above the condensation boundary of carbon dioxide (also shown) at the time of entry.

4

On the Surface: A Look Around

The function of the Viking Lander is to enable its set of instruments to carry out experiments and observations on the Martian surface. After it has brought the instruments safely to the selected site, it must maintain a favorable environment for them, it must execute complicated instructions for their operation, and then it must transmit the resulting data in properly arranged form back to the earthbound scientists. There is one important thing it must *not* do: bring life to the planet in the form of terrestrial microorganisms.

The Lander's body is basically a hollow six-sided box, about 0.5 m thick and 1.5 m wide, that provides a controlled environment for four of the instruments and for much of the equipment that supports and controls all of them. The box has three long and three short sides, so that it looks like a triangle with blunted vertices. The landing legs, which are attached outside the short sides, give the Lander a ground clearance of 22 cm.

When the Lander is seen from above, its basic shape is obscured by a cluttered superstructure that includes such components as the terminal descent engines, the tanks that contained their propellant, and the two power generators in their wind covers. The remaining protuberances and appendages, which relate to the science instruments and their data, are labeled in figure 4–1.

The electrical power for operating the Lander comes from a pair of 35-W radioisotope thermoelectric generators (RTG). Each generator contains a bank of thermoelectric elements that convert the temperature difference between their ends into electrical power. The source of heat for an RTG is the radioactive decay of plutonium-238. Unconverted heat is conveyed by a thermal switch to the interior of the Lander body as needed to maintain the internal temperature during the night. The wind covers over the RTG's conserve heat for this purpose during periods of high winds. At times of high activity, the 70 available watts are supplemented by four nickel-cadmium batteries inside the Lander body. The batteries were developed especially for the Viking Lander, as they are the first of this type that can withstand the final sterilization treatment that the entire Lander was subjected to before launch: 40 hours in an oven at a temperature of 113° C.

The operation of all the equipment aboard the Lander is controlled by the guidance, control, and sequencing computer (GCSC). By the time the Lander reaches the ground, the GCSC has accomplished its most time-critical task, but it still must run all the surface activities. The GCSC has two identical general-purpose computer channels, each possessing a plated-wire 18 000-word memory. One channel is operational, and the other is in reserve. The operational channel executes its stored instructions in sequence, and it decodes and stores new commands from Earth. It also checks its own condition periodically. If its status should become unsatisfactory during the mission, the GCSC would automatically switch over to the reserve channel. It would then do just what a human controller should do under those circumstances: shut down all nonessential activities and call for help. Help would come in the form of new commands from Earth. In about a week the operations crew could convey sufficient instructions to the new GCSC channel to enable it to carry on a science mission.

Three units within the Lander's body handle the flow of scientific data from the various instruments. These are the data acquisition and processing unit (DAPU), a data storage memory, and a tape recorder. The DAPU collects the engineering and scientific data, converts any analog information to a digital format, and feeds it as required to the data storage

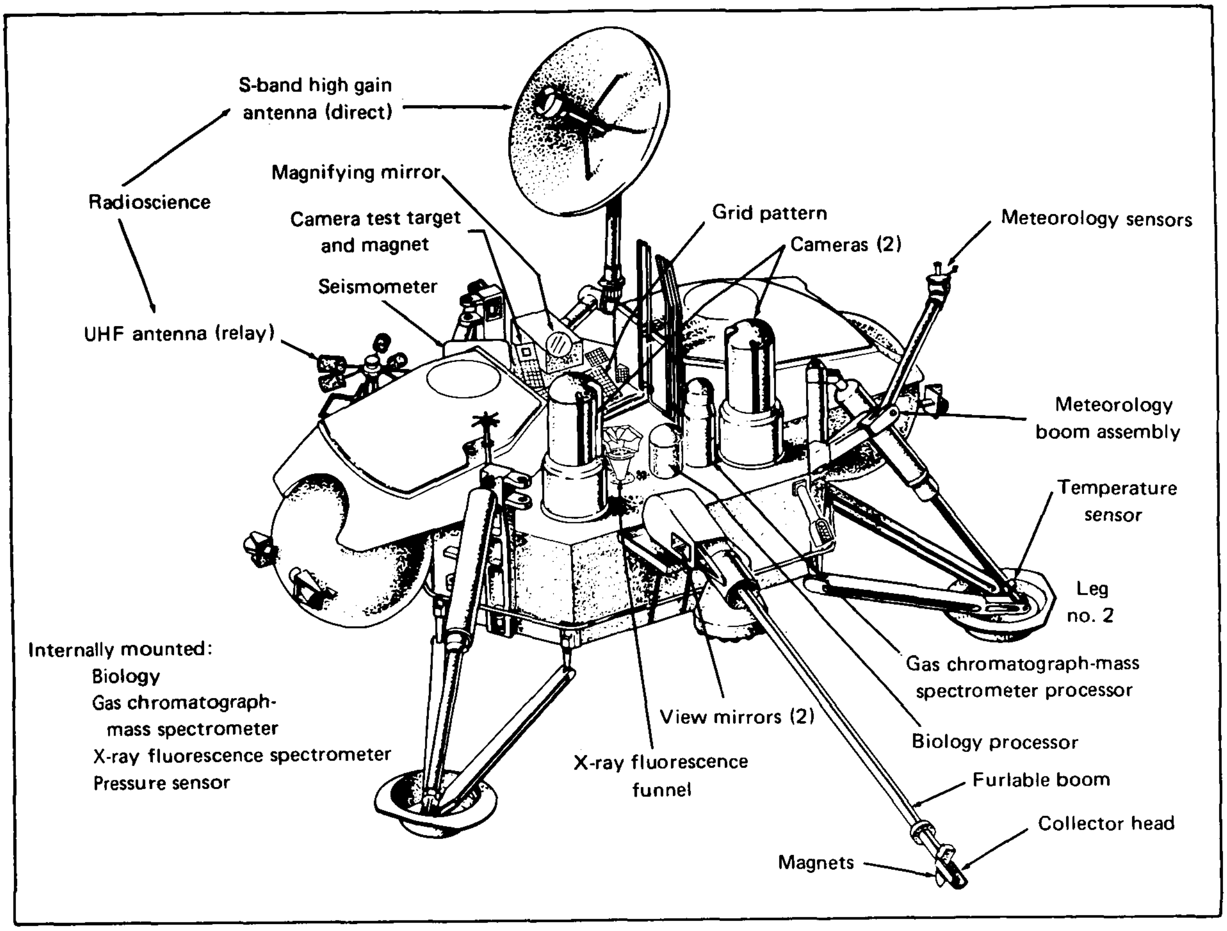


FIGURE 4–1.—External features of the Viking Lander.

memory for short-term storage, to the tape recorder for longer-term storage, or to one of the transmitters for either direct or relayed transmission to Earth. The data storage memory can store 8200 words, of 24 bits each. Its data are normally transferred periodically to the tape recorder for bulk storage. The tape recorder uses a tape made of phosphor bronze coated with nickel cobalt as a recording medium. Its four tracks can store a total of 40 million bits.

Direct transmission to Earth makes use of a high-gain antenna—a parabolic dish 76 cm in diameter that can be pointed to Earth by a computer-controlled motor drive. Transmission to the Orbiter uses a fixed UHF antenna.

Lander Imaging Investigation

The broad objectives of the imaging investigation are to characterize the Martian landscape and its variations, to perform celestial observations from Mars, and to provide support for the other investigations.

Just seconds after the Viking 1 Lander touched down on the Martian surface, camera 2 began to photograph a portion of the surface in the vicinity of Lander footpad 3. It took 5 min of camera scanning to produce that historic high-resolution photograph (fig. 4–2), and the imaging investigation was off to a running start. On that first day, the camera also acquired a low-

LANDER IMAGING TEAM

Thomas A. Mutch	Sidney Liebes, Jr.
Alan B. Binder	Elliott C. Morris
Friedrich O. Huck	James A. Pollack
Elliott C. Levinthal	Carl Sagan

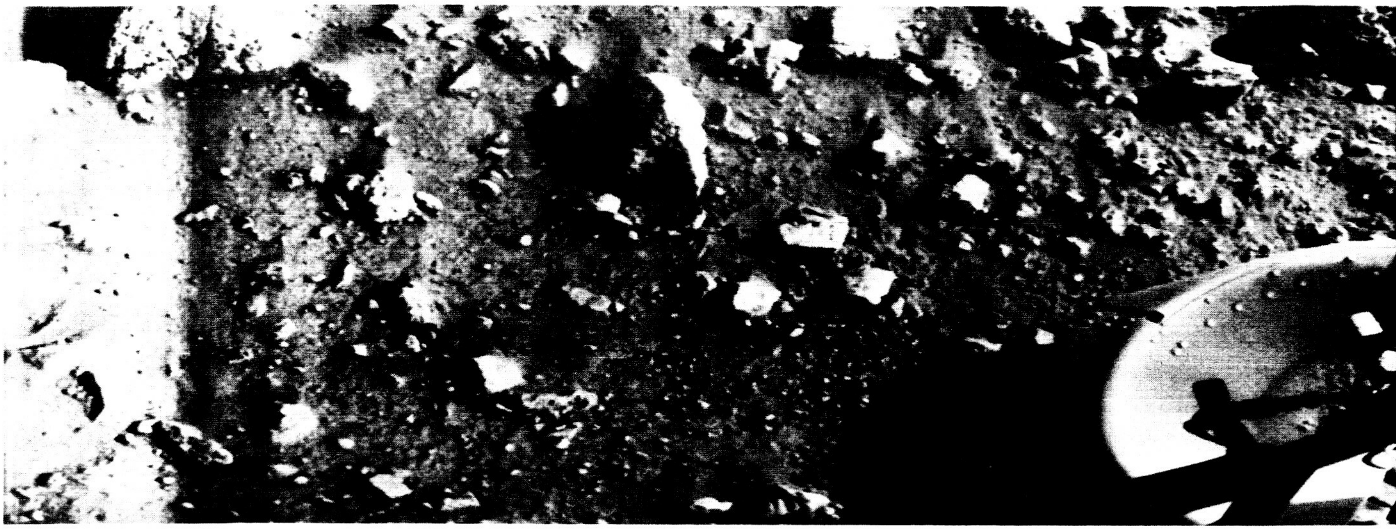


FIGURE 4–2.—The historic first photo from the Viking 1 Lander.

resolution panoramic view covering some 300° of the terrain surrounding the Lander. It was apparent that the Martian surface at the site is strewn with both blocky and angular rocks in a granular matrix of fine material, and that some of the granular material has been transported by winds.

The first photograph shows that footpad 3 barely penetrated the surface, and that some fine particles were deposited inside the footpad's concave upper surface as a result of the landing. It is most likely that the dark band near the left edge of the picture is due to the temporary shadowing of the site (for a few tens of seconds) by a cloud of dust raised by the landing. The camera builds up its picture as a left-to-right sequence of rapid vertical scans (see the camera description in a later section), so the time during which the scene was darkened is readily estimated. The area to the left of the dark band includes rocks with wind-deposited tails of fine granular material. Shadows in the photograph show visible detail, mainly due to the scattering of light in the atmosphere.

A color photograph taken the day after the landing showed that the fine, granular material is colored rust-red, and most of the rocks are coated with a stain of the same color. Some of the rock exposures are darker and appear less red. The Martian sky is bright (particularly in the direction of the Sun), and is colored a creamy pink. Apparently, the atmosphere carries many very fine particles (on the order of 1 μm) in suspension, and this dust is predominantly red: i.e., it absorbs blue light. A later color photograph is on the cover of this book.

Camera 1 went into operation on the third Martian day and produced a new panorama (fig. 4–3) to sup-

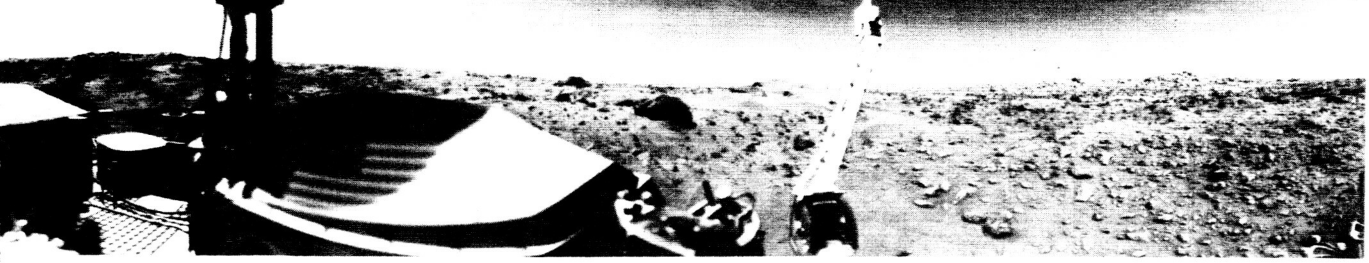


FIGURE 4–3.—Panorama produced by Lander camera 1.

plement the first-day panorama taken by the other camera. The middle third of this panorama covers a portion of the landscape not visible to camera 2, while the left and right thirds provide stereoscopic coverage of the duplicated terrain. Looking from left to right, the Lander parts include the windscreen covering one radioisotope thermoelectric generator, with painted American flag and Bicentennial emblem; the flat-topped housing of the seismometer; a grid painted on the Lander's deck to monitor dust accumulation; the struts that support the high gain antenna; the second RTG windscreen; the stroke gage of a landing leg; and the meteorology boom. The sky brightens in the Sun's direction, at the left and far right. A horizontal cloud layer is visible halfway between the horizon and the top of the picture. The landscape is gently undulating, with several apparently shallow craters in the middle distance and near the horizon, which is about 3 km away. Angular rocks with a variety of textures—some pitted, some striated, some fine-grained and apparently dense—litter the surface. The large boulder to the left of the meteorology boom is about 8 m from the camera, and measures about 1 by 3 m. The surface to the right of it is covered with dunes of wind-blown material. (This dune field is displayed strikingly on the title page.) The rock-free area just to the right of the meteorology boom's deployment hinge was selected as the site for collecting the first surface sample, and it was studied stereoscopically in order to provide detailed instructions for the surface sampler.

Figure 4–4 shows the site as photographed by the two cameras on the first- and third-day panoramas. The white lines are a grid of profiles generated by a computer in response to the control motions of a

FIGURE 4–4.—Landing site as photographed by both cameras. White lines are part of a photogrammetric study.

photogrammetrist who observed the pair stereoscopically. The instructions for the surface sampler operation were based on the fourth profile from the left.

The removal and deposition of the fine material by wind action in the neighborhood of variously shaped rocks is exhibited in figure 4–5. The surface of fine material is hollowed out where the upwind face of a rock presents a sharp obstacle to the wind. Wind stagnation on the leeward side of rocks causes the deposition of taillike ridges. Evidently, the winds that are strong enough to move these particles have a prevailing direction, from northeast to southwest.

The winds that the meteorology experiment has measured since the landing have not moved particles in the size range visible to the cameras. From time to time, the cameras are operated in the single-line-scan mode in order to detect the motion of wind-blown particles, or possibly moving organisms. The right side of figure 4–6 illustrates this mode. The camera maintains a fixed azimuth while one line is repetitively scanned. If anything moved across the line of the camera's scan, the variation from left to right would show up prominently. To date, nothing has been seen to move. If strong winds should occur at the Lander site during the mission, a combination of the single-line-scan camera operation and the meteorology data could determine the wind velocity necessary to transport these particles.

Astronomical observations also employ the single-line-scan mode to determine the elevations and times of transit of the Sun and the two satellites Phobos and Deimos.

The imaging investigation has been providing support for other Lander investigations, both with planned sequences of photography and with photographs made specially to help solve the problems that have arisen. Examples of such support photography are in the chapters covering those investigations.

Lander Camera System

Two identical cameras are positioned on short masts atop the Lander (fig. 4–1), about 80 cm apart. From their viewpoints 1.3 m above the surface, they have a clear view of the area that the surface sampler can reach.

They are facsimile cameras, operating on the principle used for many years to scan news photographs for transmission by radio or telephone lines. The principle is fundamentally different from that of the television cameras in the Viking Orbiter. In a tele-

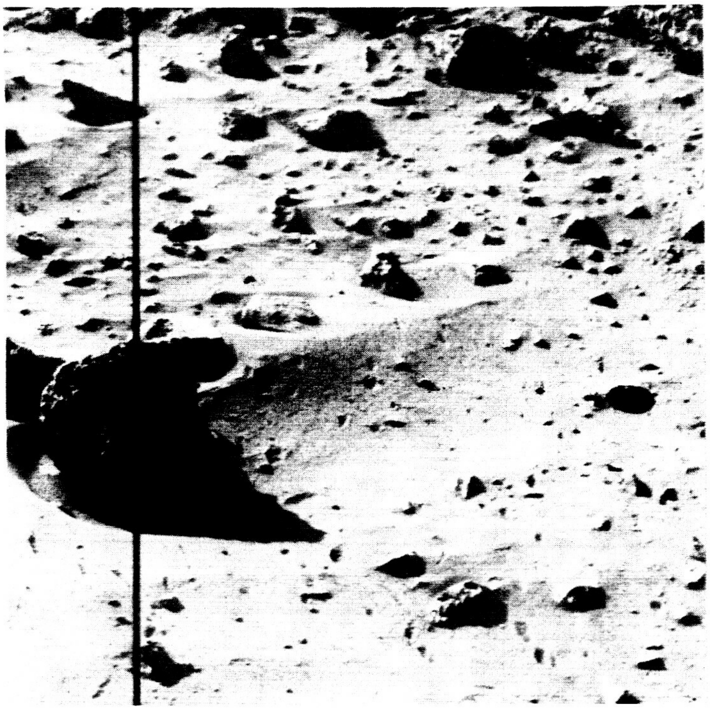


FIGURE 4–5.—Effects of wind on fine surface material.

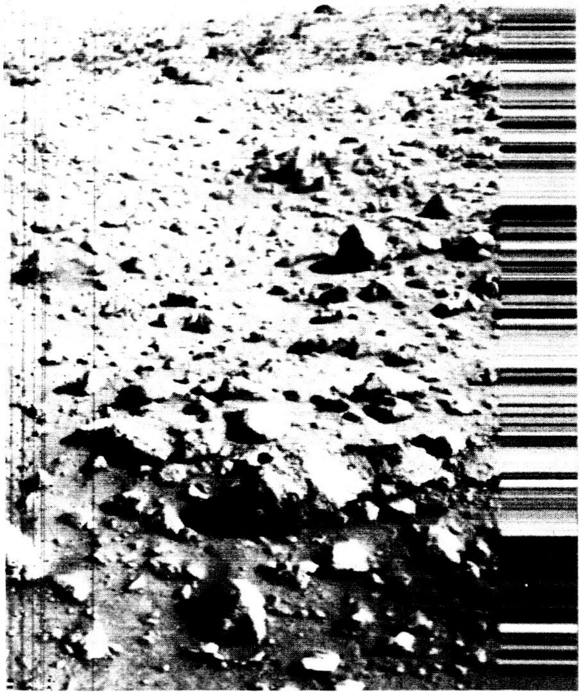


FIGURE 4–6.—Single-line-scan mode is shown at right.

vision camera, a complete two-dimensional image that has been produced on a photosensitive target is read off, one picture element (pixel) at a time, by the scan of an electron beam. In a facsimile camera, the sensor can only see one pixel at a time, and the image is presented to the sensor piecemeal by mechanical or optical-mechanical scanning.

Figure 4–7 illustrates the basic operation. The scene outside the camera is scanned in elevation by the nodding of a mirror. Each time the mirror nods, the pixels along one vertical scan line are presented successively to the sensor. The entire camera then rotates through a very small angle in azimuth, so that the line scanned by the next nod of the mirror adjoins the line previously scanned. Only when the pixels are assembled back on Earth by successive exposure along scan lines on a film is an image formed.

The actual configuration of a Lander camera is indicated in figure 4–8. The design reflects concern with protection from the environment—temperature extremes and wind-blown sand. The camera and the mast on which it is mounted are covered with several layers of thermal insulation. The only gap in the insulation is the slit over the entrance windows that admits light to the scanning mirror. To survive dust storms, the camera can be rotated so that the slit is under a narrow post that serves as a dust cover. Because of the post, the camera's field is reduced to 342.5° in azimuth. Since there may be suspended dust during much of the time the camera is operating, there are two entrance windows. If the outer window is degraded by dust erosion, it can be swung out of the way to expose a second window. Dust that settles on the window can be blown off by brief jets of pressurized carbon dioxide.

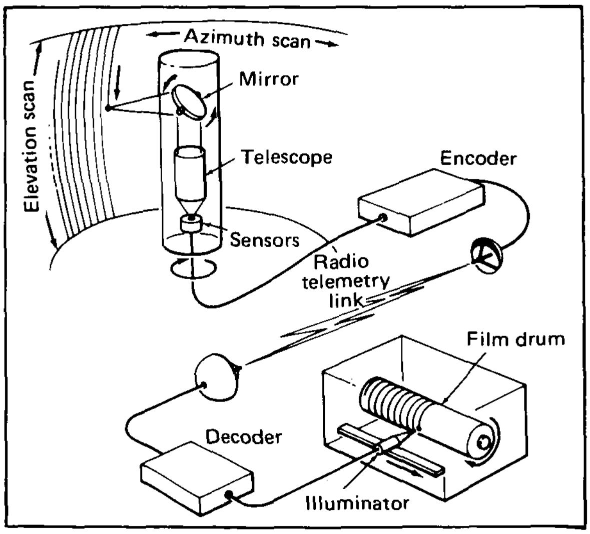


FIGURE 4–7.—Basic principles of the Lander camera.

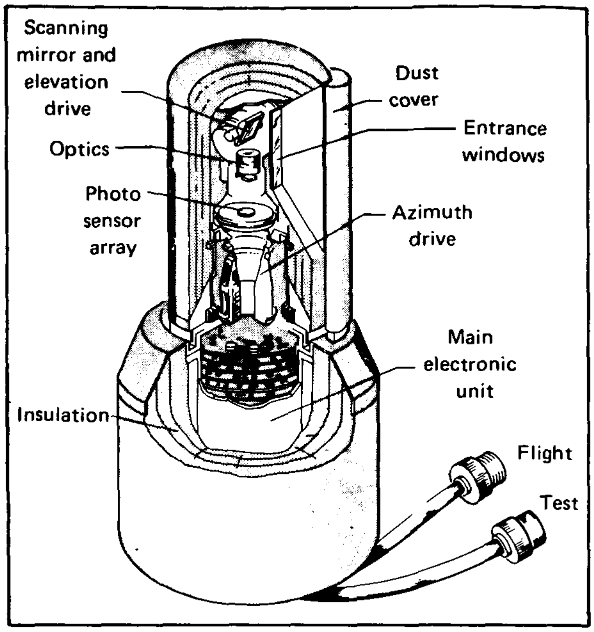


FIGURE 4–8.—Configuration of the Lander camera.

Instead of a single light sensor, the Lander camera has an array of twelve tiny sensors in the focal plane of the optical system. Each sensor is a solid-state photosensitive diode. All the diodes see the same scene, but during a scan the system is processing electrical signals from a single diode. The selection of sensor signals for processing depends on the mode in which the camera is operating.

Four sensors are available for the high-resolution mode. They are located at different distances along the optical axis, so that the entire scene from 1.7 m to infinity is in sharp focus on one or another sensor. These diodes have panchromatic sensitivity, and their fields are limited by pinhole apertures to 0.04°. At that field angle a pixel covers 2 mm at a distance of 3 m. In high-resolution operation, the mirror scans 20° in elevation at a time. The center of the elevation scan can be shifted up or down. Successive scans are 0.04° apart in azimuth.

The color mode uses three sensors fitted with red, green, and blue filters. The size of a picture element is increased to 0.12°. At that resolution, a single focus position is sufficient. The mirror scans 60° in elevation. The signals from the three sensors are processed on successive scans. Since the 0.04° azimuth angle between scans is now only one-third of a pixel, a full-color picture is imaged.

An infrared spectral mode uses three sensors whose peak sensitivities are at wavelengths of 0.85, 0.95, and 0.98 μm. The field angles and scans in this mode are the same as in the color mode. The wavelengths were chosen to permit identification of mineral groups.

The survey operational mode uses the eleventh sensor, which has panchromatic sensitivity and a 0.12° field of view. Since the scans are 0.12° apart in azimuth, this mode provides a panoramic survey with relative rapidity.

The sensitivity of the twelfth diode, which has a red filter, is further reduced electronically so that it can image the Sun. The camera makes astronomical observations in the single-line-scan mode, so that the imagery provides a record of the altitude and time at which the celestial body crossed the projected scan line. The Sun sensor is employed only for solar observations; other bodies are observed by a panchromatic sensor.

The camera electronics digitize each pixel as a six-bit word. The camera has two scanning rates: 250 and 16 000 bits per second. The slow rate is compatible with the direct communication link from the Lander to Earth. This permits real-time imaging during periods when the Lander is transmitting directly. The fast rate is the same as the rate of data transmission to the Orbiter, so that real-time imaging is also possible in the relay mode. Much of the time, though, the cameras operate at the fast rate and feed the imaging data into the Lander's tape recorder.

The cameras can scan at either bit rate in all operational modes. At 250 bits per second, it takes 5½ min to scan one azimuth degree in the high-resolution and color modes, or a third of that time in the survey mode. At 16 000 bps the times are reduced to 5.28 and 1.75 sec, respectively. Thus, a complete panorama can be scanned in the survey mode in just 10 min at the fast rate.

5

Handling and Sampling the Surface

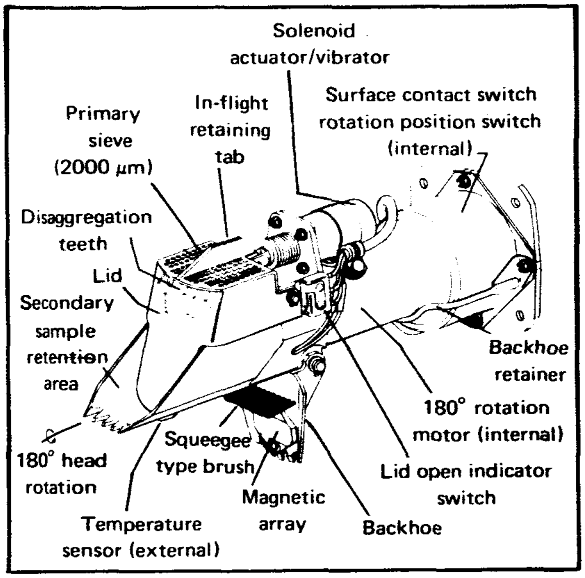


FIGURE 5–1.—The main features of the collector head.

The Lander's chemical and biological investigations all work with samples of the Martian surface material. The primary function of the surface sampler is to dig selected samples out of the surface and deliver them to the instruments that will analyze them. In addition, as experience with the Surveyor landers showed on the Moon a decade ago, much information is gained about the surface materials by *just digging* and analyzing the results. For the Viking mission, these activities are formalized as part of the physical properties and magnetic properties investigations.

The surface sampler consists of a collector head on the end of a retractable boom. The arm that houses the boom is attached to the Lander body (see fig. 4–1) where it can be swung both horizontally and vertically. The boom is ingeniously constructed with two ribbons of stainless steel, welded together along the edges. When it is extended, the two layers separate at the center to form a rigid tubelike structure. The boom is 3 m long when fully extended. When retracted, the boom flattens as the layers are squeezed together. The retracted portion is rolled up inside the arm housing. A flat cable sandwiched between the stainless steel layers brings electrical power to the collector head mechanisms.

The collector head (fig. 5–1) is basically a scoop with a movable lid, and a backhoe hinged to its lower surface. Where the scoop is attached to the end of the boom, a rotation motor functions as a mechanical wrist. To fill the scoop, the lid is first raised and the boom is extended along or into the surface. During the filling the backhoe lies flat, pointing backward. The lid is then closed to cover the sample. The top of the lid forms a sieve with 2 mm holes. When the collector head is positioned over an instrument inlet, it is then inverted and the lid vibrated. Only particles that are smaller than 2 mm are delivered to the instrument inlets. If a coarser sample is desired for the inorganic chemistry investigation, the screening can be performed before delivery. The other two instruments have their own inlet filters.

The surface sampler can also dig trenches. With the backhoe in the position shown in the drawing, the collector head is lowered to the surface, and the trench is dug by retracting the boom. The excavated material can be scooped up for a sample, if desired. If the Lander should happen to land on a hard surface, the brush on the front of the backhoe could be used to sweep the overlying dust into a pile that could be scooped up.

The temperature sensor on the bottom of the collector head is a source of both engineering and physical properties data. The motors that operate the surface sampler are instrumented to provide readings of the motor current required to scoop, excavate, lift, and transport the surface materials. This is another source of data for the physical properties investigation.

Before sterilization the collector head was chemically cleaned (to prevent sample contamination), and then enclosed in a protective shroud and pressurized with sterile inert gas.

Operational difficulties were experienced with the surface sampler on two occasions. Special procedures had already been developed to handle such problems. The intense teamwork that solved these difficulties included the use of images from the Lander cameras on Mars, and a full-scale Lander in the Science Test Laboratory at Mission Control. The first problem was the failure of the boom latch pin to drop because of insufficient extension of the boom during the initial sequence. When the boom was then retracted, the latch pin prevented the completion of the sequence. The solution was to extend the boom beyond the initial position. After it was extended further, a photograph verified that the sampler was at its correct extension and that the pin had been released (fig. 5-2). The pin itself was later seen in another photograph (fig. 5-3) where it had impacted the surface.

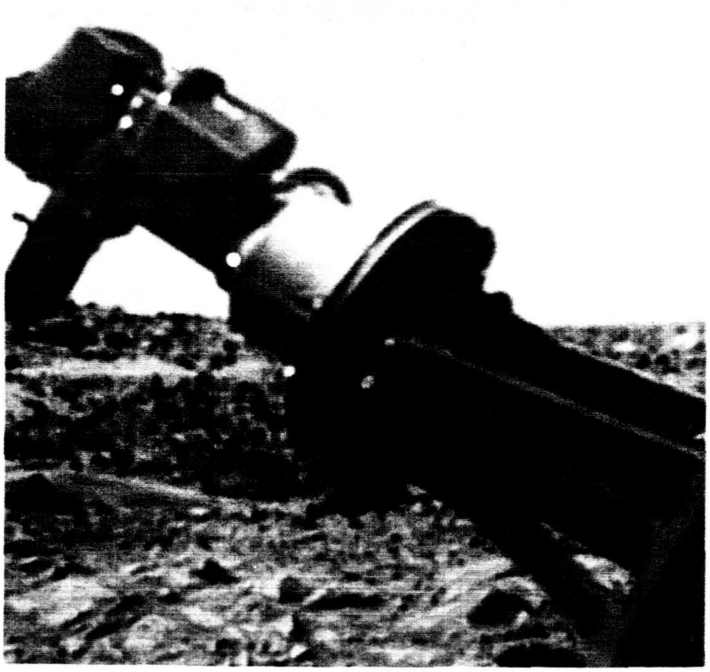


FIGURE 5-2.—The sampler at its correct extension.

FIGURE 5-3.—Lying on the ground (arrow) is the troublesome pin.

On the Lander's eighth Martian day, the surface sampler dug into the surface and delivered samples to the biology, molecular analysis, and inorganic chemistry experiments. Figure 5-4 shows the trench created in the fine, granular surface by the sampling operation.

The second difficulty was experienced when the boom failed to retract after acquiring a second sample, and the cameras were again used to obtain information about the extension of the boom. Knowing the boom position facilitated the design of a sequence of motions that permitted the resumption of sampling operations.

Physical Properties Investigation

The purpose of the physical properties investigation is to determine the characteristics of the Martian soil using the Lander imaging system, the surface sampler, and the engineering sensors data. These data were aug-

FIGURE 5–4.—Trench created by the first sampling. (Cover photo shows this area just before sampling.)

mented by performing some simple experiments using the materials at hand. Some special instruments were used such as strategically placed mirrors, stroke gages, and some markings on top of the Lander deck.

The first picture taken after landing included a footpad and its interaction with the surface. Later, pictures imaged the stroke gages showing the amount each landing leg was compressed during landing.

Before the surface sampler was put into use, the shroud protecting the collector head was ejected downward. The camera then imaged the shroud's impact area and the previously photographed footpad (fig. 5–5). Analysis of these pictures indicates that material was dislodged by the impact. Another impact study was performed when a boom latch pin was dropped onto the surface and imaged.

All the time that the surface sampler was acquiring samples for the analytical instruments, the record of its motor currents and the images of the sample sites were providing data on the physical properties of the material.

The Lander cameras periodically image three grid patterns on the top of the Lander body to record any accumulation of wind-deposited material or material dropped during sample delivery. The cameras likewise image the impressions made by the material that was dumped from the surface sampler after sample delivery. Whenever a camera images one of the camera test charts on top of the Lander, it provides information on the ultraviolet dosage that the surface is subjected to, by recording the darkening of two degradable coating squares on the reference test charts.

Some of the experimental activities planned for the later stages of the surface mission are digging controlled trenches, dumping a scoopful of material on one of the grids, picking up a small rock and dropping it on the surface, and dropping loose material when the meteorology instruments show that a steady wind is blowing. A 4× mirror mounted near the middle reference test chart is used to observe the Martian surface material. The material is transported to the 4× mirror on the front porch (secondary sample retention area). (See fig. 4–1.) In addition, two other mirrors are used, one on either side of the surface sampler boom housing. Surface erosion caused by landing engines is observed with one. A temperature sensor (used by the Entry Team) attached to the inside of a footpad is observed with the other mirror to verify its contact with the surface. Certain locations that cannot be seen directly, in front of the Lander, under the Lander, and on the Lander body, can be imaged by these mirrors, if required.

PHYSICAL PROPERTIES TEAM

Richard W. Shorthill	Henry J. Moore II
Robert E. Hutton	Ronald F. Scott

Some Early Results

The physical properties investigation found the surface material at the landing site to be slightly stiffer than the "lunar nominal" soil model that had been used during the designing and for the testing of the landing gear system. The Viking 1 Lander landed with a vertical velocity of 2.5 m/sec and a lateral component less than 0.5 m/sec. The stroke gages showed that the crushable struts of leg 1 compressed 5.7 cm. The footpad penetration is unknown because the cameras cannot see that location. Leg 3 stroked 8.3 cm, and its footpad penetrated 3.6 cm, as measured from shadows on the first surface photograph (see fig. 4–2). Leg 2 only stroked 3.2 cm, and its footpad is completely buried in the surface material (fig. 5–6). The mate-

FIGURE 5–5.—Surface marking (arrow) caused by ejection of the sampler shroud.

rials around footpad 2 are deformed as far as 60 cm from the footpad center. They are part of a rock-free dune that includes the site of the first surface sample trench.

Before the samples were taken, the physical properties investigation was able to estimate the "sampleability" of the materials around the Lander by studying images of the impact areas of the surface sampler shroud, the troublesome boom latch pin that fell free when the sampler arm was extended for the second

MAGNETIC PROPERTIES INVESTIGATION

Robert B. Hargraves

FIGURE 5–6.—Footpad 2 buried in slumped surface material.

time, and the interaction of footpad 3 with the surface at touchdown.

Magnetic Properties Investigation

The objectives of this investigation are to estimate the abundance of magnetic particles in the surface material and to identify the types that are present.

The degree of differentiation of the original mineral composition is basic to the understanding of a planet's evolutionary history. The mobilization of iron and its concentration in the core is a key episode in the Earth's history. It is important to learn as much as possible about the occurrence of iron on Mars. The extent of oxidation and hydration of the magnetic minerals also gives insight into the past composition of the planet's atmosphere.

The means for detecting magnetic particles in the surface materials are quite simple. There are two pairs of permanent magnets on the surface sampler's backhoe. Each pair consists of a ring magnet, about 25 mm in diameter, with a magnetic disk of opposite polarity in the center. The pairs are mounted at different depths from the surface of the backhoe. There are thus local differences in the strength of the magnetic field.

In collecting samples, the collector head brings the backhoe into intimate contact with the surface material. The particles adhering to the back surface of the backhoe are imaged directly by the cameras, and the front of the backhoe can be brought before a magnifying mirror on top of the Lander. Imaging in high resolution and color is possible in both cases. The magnets can be cleaned between samplings by oscillating the collector head.

There is another magnet pair on one of the

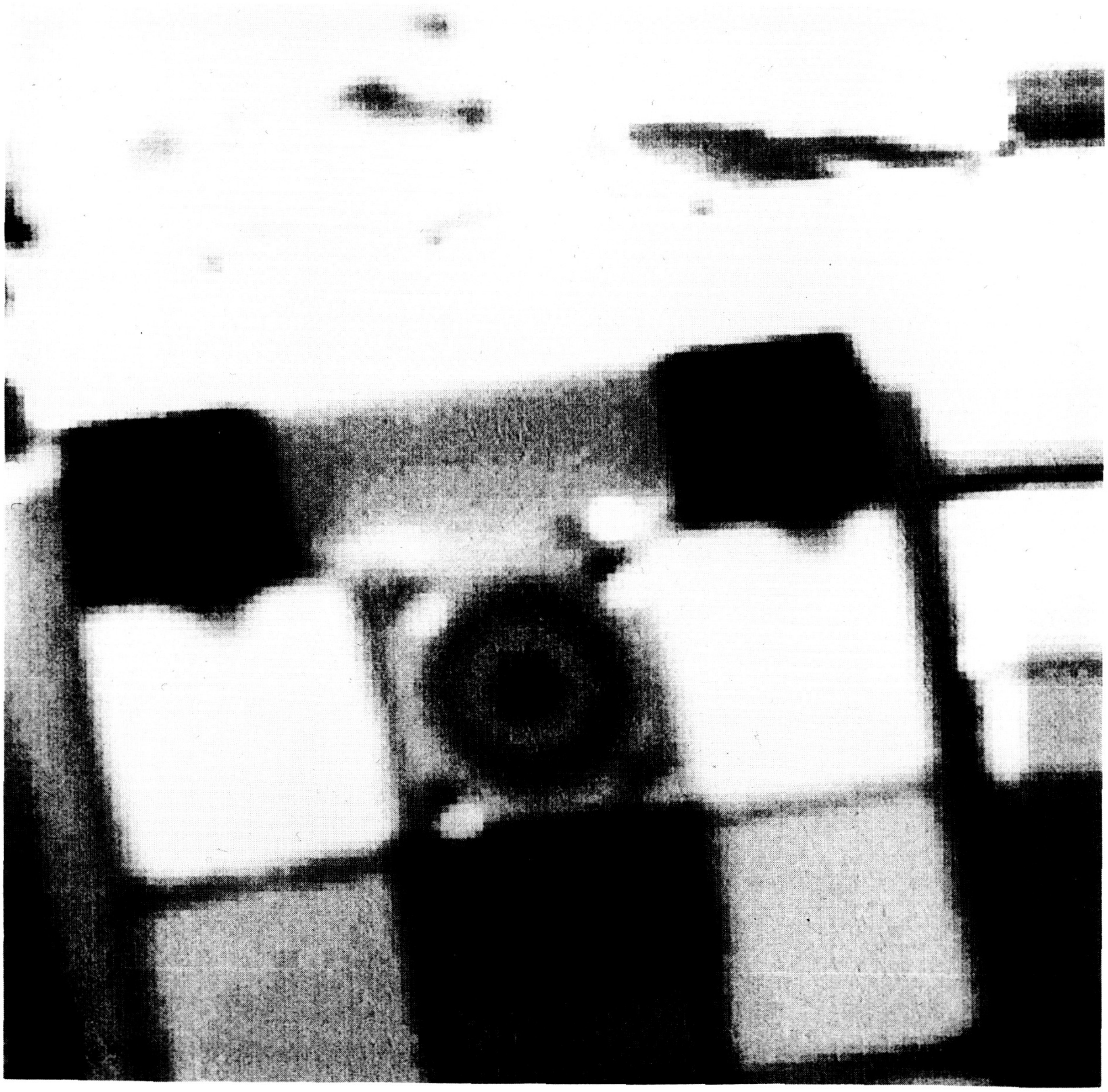


FIGURE 5–7.—Dark bull's-eye pattern atop the camera calibration chart indicates the presence of magnetic particles in wind-blown dust.

camera test charts on top of the Lander. Each time a camera images the chart for the purpose of calibration, it records the presence of any magnetic particles in the wind-blown dust.

An Early Result

The magnet pair at the top of a camera reference chart has captured windborne magnetic particles during its first two weeks on Mars. In figure 5–7, which is enlarged from a Lander image of the chart, the adhering particles render the magnetic field of the tiny magnet pair as a dark bull's-eye pattern. The optical characteristics of the atmosphere at the Lander site indicate that particles about one micrometer in size are held in suspension. Additional particles may have been tossed into the atmosphere by the landing or the sampling operations. Particles in that size range can adhere to the magnet, in the absence of strong winds, even if they are only very weakly magnetic, as for example hematite and goethite. Large particles of those minerals will not adhere, whereas magnetite and iron particles of a much greater size will. Some of the surface material from the first sampling site was held on the backhoe magnets.

6

The Lander Environment

The three investigations considered in this chapter deal with very diverse aspects of the environment into which the Lander has plunged. The meteorology investigation concerns itself with the lowest layer of the atmosphere and with its variations with the time of day and from day to day. The seismology investigation is concerned with the stability of the ground beneath the Lander and with the information that occasional ground vibrations might supply about the structure of the solid planet. (Unfortunately, it has not been possible to operate the Viking 1 seismometer because of failure to release the sensing coils from the caged condition that protected them in flight.)

The radio science investigations use tracking data and variations in received signal properties to determine the coordinates of the Lander's position, local surface electrical parameters, atmospheric and ionospheric profiles, local and global gravitational field properties, and a number of other Mars and solar system environmental phenomena.

Meteorology Investigation

By making direct measurements of the atmosphere's temperature and pressure and the direction and speed of the winds over an extended time period, the Lander provides scientists with their first direct opportunity to learn how another planet's atmosphere works. The atmosphere of Mars is a particularly interesting one for comparison with Earth's because some of the circumstances are so similar (for example, the rotation rate, and the inclination of the planet's axis to the orbital plane that causes seasonal variations), while the differences (such as the absence of oceans and the scarcity of water vapor) should make the Martian case simpler to deal with theoretically.

METEOROLOGY INVESTIGATION TEAM

Seymour L. Hess	Jack A. Ryan
Robert M. Henry	James E. Tillman
Conway B. Leovy	

Knowledge of the weather that prevails at a given time is necessary for some Lander activities, such as imaging and sampling, and important for the analysis of data from other instruments.

Some Early Results of the Meteorology Investigation

The Viking 1 Lander set up its meteorology station (fig. 6–1) at a season in which conditions in its subtropical location are very steady. The data for the third full Martian day that are presented here (fig. 6–2) can be considered typical of the daily weather so far. The upper plot shows the air temperature and pressure. The plot starts at midnight, local Lander time, and goes to the following midnight. The minimum temperature, which comes just after dawn, was −85° C (188 K) on that day. There is a gap in the data at the time of maximum temperature because of the daily relay transmission session, but the shape of the curve indicates a maximum temperature of about −29° C (244 K) around 3:30 in the afternoon. The pressure shows a daily variation of about 0.2 mb between extremes.

The lower plot shows wind direction and velocity. Directions are shown in degrees clockwise from north; thus, a wind from the east is shown at 90°, and a west wind at 270°. No values are shown below 80° or above 280° because so far no northerly winds at all have been observed. Wind velocities are shown in meters per second. The typical pattern has light easterly winds in the late afternoon, shifting to south by midnight with wind velocity diminishing. During the

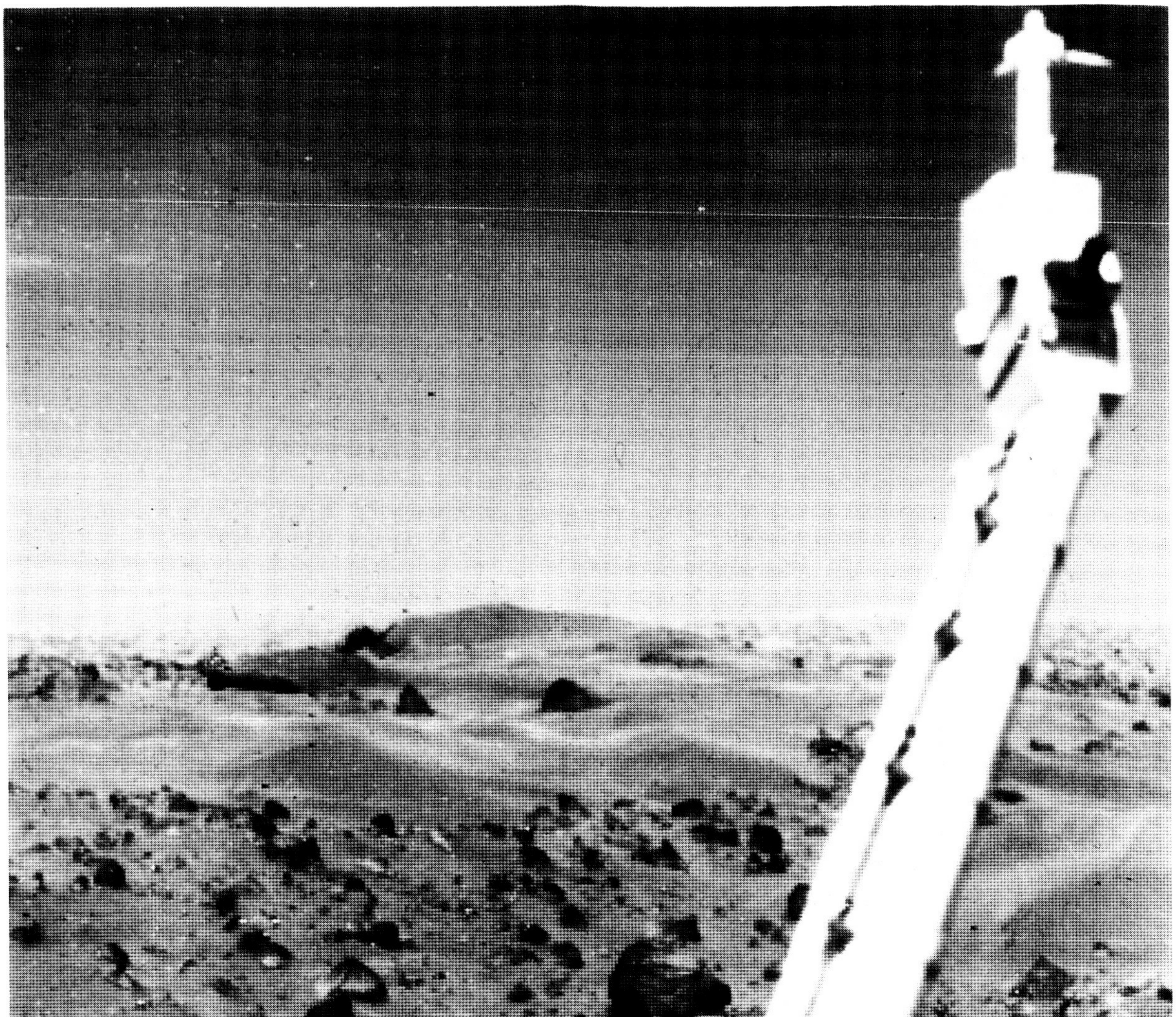


FIGURE 6–1.—The Lander meteorological instruments atop their boom.

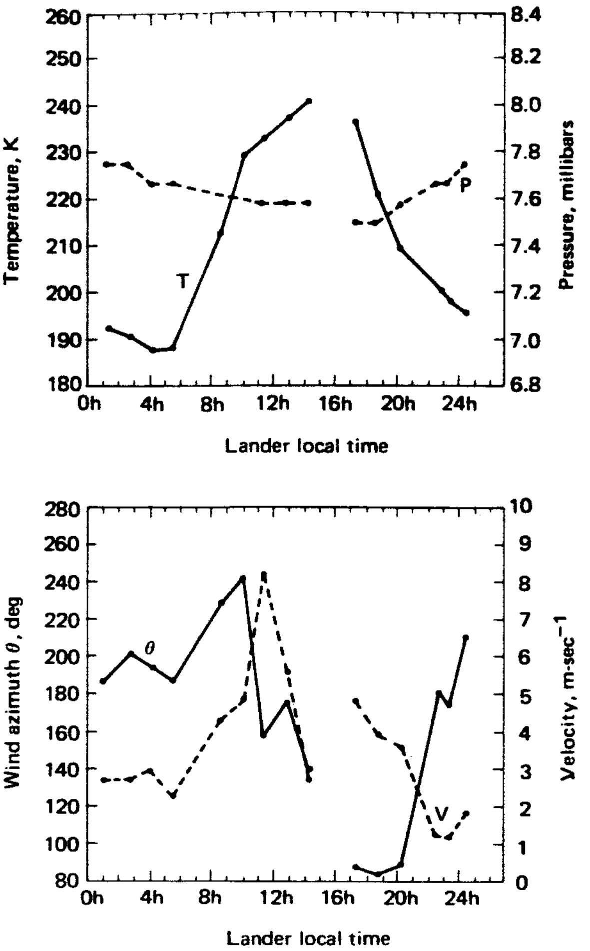


FIGURE 6–2.—Weather data for the third full day on Mars.

night the wind blows from the southwest, often with oscillations in direction and speed. Wind speed increases and becomes gusty during the day, with variable direction. Maximum wind speeds per observation period are below 9 m/sec, with gusts up to about 15 m/sec.

The air temperatures are measured at a height of 1.6 m, which is about face height for the average person. The infrared thermal mapper (IRTM) on the Viking Orbiter measures the temperature of the ground. During the night, the ground and air temperatures should agree. Figure 6–3 shows that the night and early morning ground temperatures measured from orbit (dots) do indeed coincide with the observed air temperatures (pluses). As the Sun gets higher, it should heat the ground as shown by the solid curve, which is theoretical because the IRTM has not observed the landing site between 8 in the morning and about 4 in the afternoon. Assuming that real ground temperatures follow the curve fairly well, there is about a 25° difference at noon between the air and ground temperatures. The effect of this expected temperature difference is to stir up strong convection, just as it does in the Earth's desert regions. As the observations indicate, the convection is characterized by gusts that fluctuate rapidly in direction.

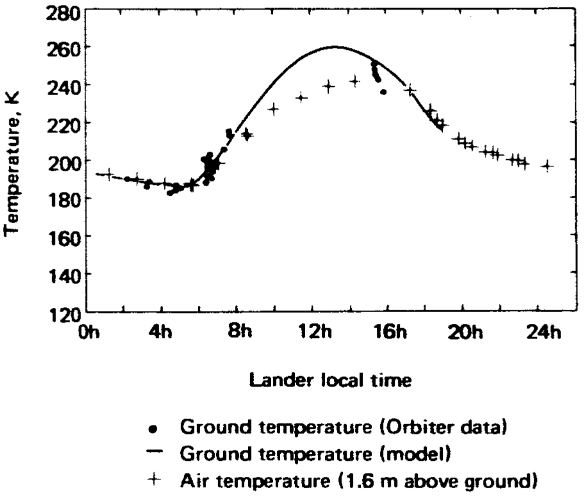


FIGURE 6–3.—Air temperatures on Mars measured by Orbiter and by Lander.

During the first three weeks of weather observation, there has been a day-to-day decline, on the average, in the atmospheric pressure. The average rate of decline has been 0.012 mb per Martian day. Such a decline in readings could conceivably be the result of a slow leak in the pressure sensor, but this is considered unlikely. The more probable explanation is the removal of carbon dioxide from the atmosphere by condensation onto the south polar ice cap. At this season, the north polar cap is at its minimum extent, while the southern cap is actively growing. With CO_2 composing about 95 percent of the atmosphere, the planet evidently undergoes a large seasonal loss of atmospheric mass. Calculations based on the observed rate of pressure loss, the area of the south polar ice cap, and the latent heat of sublimation being dissipated by radiation to space, produce an average temperature over the ice cap that is in general agreement with the unexpectedly low temperatures measured there by the infrared thermal mapper that are discussed in chapter 2.

Meteorology Instruments

Most of the meteorology sensors are located at the end of the meteorology boom (fig. 6–1). The boom, deployed right after the landing, is immovable thereafter. It serves to keep the sensors at a distance from the Lander's heat sources and from protuberances that might distort the wind flow.

The ambient temperature is measured by a set of three fine-wire thermocouples. Because of their thinness, they can respond quickly to temperature fluctuations, but are subject to breakage; hence the use of three thermocouples, operating independently. The remaining sensors on the meteorology boom are exposed to the wind. They measure the wind's speed, direction, and temperature. The basic wind sensor is a hot-film anemometer. This is a thin thermocouple probe, coated with a platinum layer, and overcoated with aluminum oxide for protection against abrasion by wind-borne dust. An electric current in the platinum layer heats the probe, while the wind takes away the heat. The wind speed perpendicular to the probe is measured by the electric power needed to keep the probe at a fixed temperature above the surrounding air.

The Viking Lander anemometer has two heated probes oriented 90 degrees apart, with an unheated probe between them to measure the reference temperature. Automatic circuitry that compares the three temperatures gives the total wind speed. It also provides a sensitive but ambiguous indication of wind direction, because the sensors give the same readings for winds in opposite directions. To resolve the ambiguity, the meteorology boom has the equivalent of a wet finger held up to the wind. It is a quadrant sensor, a heated core surrounded by four thermocouples 90 degrees apart. The relative temperatures of the thermocouples determine the quadrant from which the wind is blowing.

The temperature sensor mounted on the bottom of the surface sampler's collector head (fig. 5–1) is a particularly useful supplement because it can be moved about. An experiment is planned to measure near-surface vertical temperature profiles by collecting temperature measurements at various elevations of the soil sampler boom.

The instrument that measures atmospheric pressure is located on the bottom of the Lander, and was used to measure the vertical pressure profile during the parachute phase of the descent. Its design adapts the principle of the aneroid barometer to the low pressure of the Martian atmosphere. The sensor is shielded from the wind.

Meteorology readings are obtained during about twenty periods per day. Each period includes several instantaneous measurements to provide an indication of rapid fluctuations in the measured values.

SEISMOLOGY INVESTIGATION TEAM

Don L. Anderson	Gary V. Latham
Fred Duennebier	George Sutton
Robert L. Kovach	Nafi M. Toksoz

Seismology Investigation

One of the basic questions to be answered concerning any solid planet is the level of internally generated movement, or tectonic activity. The Earth, which was differentiated early in its history into core, mantle, and crust, is a tectonically active planet. Its crust comprises a number of large plates that are in motion relative to each other, giving rise to most of the earthquakes that we experience. The surface of Mars, as revealed in Mariner 9 photography, provides evidence of considerable tectonic activity in the past. The failure of the Viking 1 seismometer to uncage its three sensing coils makes the seismology investigation dependent on Viking 2 for any data about the present level of seismic activity on Mars.

Each Lander has a set of three miniaturized seismometers arranged in a mutually perpendicular manner. This three-axis seismometer is housed in a cubical package on top of the Lander. Any ground motion is transmitted through the Lander's legs to the body and to the seismometer package. Low-frequency vibrations that originate within the Lander are also sensed. In order to distinguish these, the scientists have a record of the motors that are operating aboard the Lander and the wind conditions.

With a three-axis seismometer, it is possible to locate a seismic event approximately, and thus to identify regions of tectonic activity. Analysis of the seismic data will indicate the wave-transmission characteristics of the material beneath the surface at the Lander site, and should tell something about its physical state and even its composition.

Radio Science Investigations

Radio science investigations deal with tracking data (very precise measurements of distance and line-of-

RADIO SCIENCE INVESTIGATION TEAM

William H. Michael	Mario D. Grossi
Joseph P. Brenkle	Irwin I. Shapiro
Dan L. Cain	Charles T. Steizried
John G. Davies	Robert H. Tolson
Gunnar Fjeldbo	G. Leonard Tyler

sight velocity), and with small variations in frequency, phase, or amplitude of the received signals. Some of the determinations to be derived from the tracking data are the global gravity field of Mars and local gravity anomalies, precise locations of the Landers and the radius of Mars at each landing site, the orientation and possible motion of the spin axis, the dielectric properties of the local surface, and refined locations of Mars and Earth with respect to the fixed, inertial frame defined by the distant quasars. When the Viking Orbiters pass behind the planet later in the mission, signal variations at the beginning and end of occultation will provide information on Martian atmospheric and ionospheric properties, and on the radius of Mars at the various occultation locations.

During the conjunction of Mars and the Sun in November, as the line of sight between Earth and Mars passes through various regions of the solar corona, the variations in the S-band and X-band signals from the Orbiters will yield new information on the properties of the solar corona. The conjunction will provide an opportunity for a test of general relativity theory by measuring the effect of the Sun's intense gravitational field on the signal's travel time.

It is characteristic of radio science investigations that it takes a long time to get the answers. Some observations must be taken over long intervals to yield significant results. From analysis of the first few days of tracking data from the Viking 1 Lander, however, it has been possible to satisfy some of the radio science objectives—determination of the Lander position and the orientation of the spin axis of Mars.

It has been determined that the aerocentric coordinates of the Lander are 22.27° N latitude, 48.00° W longitude, and 3389.5 km from the center of Mars. The spin axis orientation, referred to the Earth's mean equator and equinox of 1950.0, is 317.35° right ascension and 52.71° declination. The location results indicate that Viking 1 landed about 28 km from its targeted landing site, well within the expected landing dispersions. The radius to the center of Mars is within 1 km of some previous, less direct measurements, and provides a reference point for other Viking measurements involving topographic parameters.

The results for the spin axis orientation represent a statistically significant improvement over previous results. Since long arcs of Lander tracking data provide an excellent data source for these determinations, additional data will improve these estimates and could provide information on pole motion.

7

Composition of the Surface

The inorganic chemistry and molecular analysis investigations undertake a rather wide range of chemical analyses with their two miniaturized instruments. The two investigations supplement each other in several important ways. When they analyze samples of the same material, they yield basically different kinds of information.

The inorganic chemistry investigation determines the total abundance of each chemical element in a sample that may be a mixture of compounds, whereas the molecular analysis investigation seeks to identify individual compounds. Gaps in each analysis due to the limitations of the method are filled to a considerable extent by the results of the other analysis.

Taken together, they have provided important data on the degree and nature of differentiation of the planet's original components. They should, in the course of the mission, provide other information that is basic to an understanding of the significance of the results obtained in the biology experiments.

Inorganic Chemistry Investigation

This investigation was added to the Viking Lander after Mariner 9 showed that Mars must have had a complex geological history. Its instrument, an X-ray fluorescence spectrometer (XRFS), is small and light, and uses very little power.

Fluorescence is the process in which substances emit electromagnetic radiation as a consequence of the absorption of radiation that is of higher energy. When placed in a beam of high-energy X-rays, every element emits X-rays of lower energy. For each element there are a few characteristic fluorescent X-ray energies. Measurement of the emitted energies identifies the element. Elements whose atomic number is lower than that of magnesium (the first 11 elements of the periodic table) cannot be individually distinguished in this direct way by the Viking XRFS. Although the important elements carbon, nitrogen, and oxygen are therefore not determined directly by the XRFS, many geochemically diagnostic heavier elements are determined with good accuracy. Determination of the lighter elements depends on combining indirect methods with data from the molecular analysis investigation on molecules that contain them.

INORGANIC CHEMISTRY INVESTIGATION TEAM

Priestley Toulmin III	Klaus Keil
Alex K. Baird	Harry J. Rose
Benton C. Clark	

The first result achieved by the inorganic chemistry investigation was a preliminary measurement of the argon content of the atmosphere at the Viking 1 landing site. Argon was determined to be no more than 2 percent, by volume, of the atmosphere. This result, which confirmed that of the upper atmosphere mass spectrometer, was operationally important in that it helped to clear the way for the use of the gas chromatograph mass spectrometer for atmospheric analysis.

When the XRFS was supplied with a sample of the surface material (fig. 7–1), the first return of data was sufficient to detect the presence of the elements iron, calcium, silicon, titanium, and aluminum as major constituents. The accumulation of additional counting time permitted a more complete determination of the abundances of these elements, resulting in the very preliminary estimates given in table 7–1. Continuing data analysis is refining the accuracy of these determinations, as well as permitting the identification of several additional elements and estimates of their abundance.

The Viking XRFS is illustrated in figure 7–2. Except for the funnel into which the samples are dropped, the instrument is inside the Lander body. In the

FIGURE 7–1.—The sampler above the instrument hopper.

measurement chamber the sample is exposed to two sources of high-energy X-rays coming from perpendicular directions. The sources are the radioactive isotopes cadmium-109 and iron-55. Each source is flanked by two gas-filled proportional counter detectors. The output of the detectors is a series of electrical pulses with voltages proportional to the energy of the fluorescent X-rays. An element is identified by its characteristic energies, and the count rate of the pulses indicates its concentration.

The precision of the quantitative analysis increases with counting time. The unit length for an analysis is about eight hours. A sample can be analyzed several times to provide more counting time. When the in-

MOLECULAR ANALYSIS INVESTIGATION TEAM

Klaus Biemann
Duwayne M. Anderson
Alfred O. C. Nier
Leslie E. Orgel
John Oro
Tobias Owen
Priestley Toulmin III
Harold C. Urey

TABLE 7–1.— *Inorganic Chemistry Investigation Preliminary Estimates (percent by weight)*

Aluminum	2–7 percent
Silicon	15–30 percent
Calcium	3–8 percent
Titanium	0.25–1.5 percent
Iron	12–16 percent

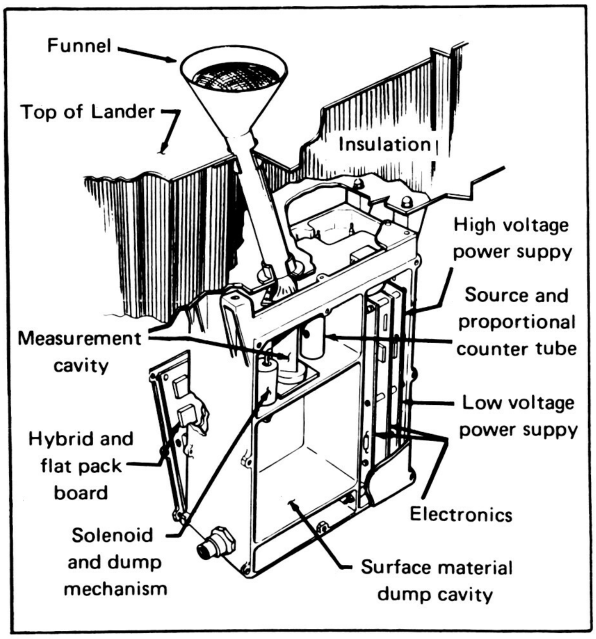


FIGURE 7–2.—The X-ray fluorescence spectrometer.

vestigation is finished with one sample, it is dumped from the measurement cavity into the dump cavity below.

Molecular Analysis Investigation

The primary objective of the molecular analysis investigation is the recognition and identification of organic molecules in the surface samples. (In general, organic molecules are those that include chains of carbon atoms.) Knowledge of organic matter in the surface materials bears on the question of Martian life in several ways. The living matter of all terrestrial organisms is composed of organic molecules. When organisms die, some of the organic molecules are broken down into inorganic gases and salts, and some are converted into other organic molecules. Organic molecules can also be produced by nonbiological processes. Finally, the food of all heterotrophic (nonphotosynthesizing) organisms is composed of organic molecules. Thus, all organic molecules identified on Mars are of great scientific interest.

The instrument designed for this investigation can also determine the concentrations of the various organic and inorganic gases in the atmosphere. In this mode it uses the mass spectrometer in two different ways: it can analyze the atmosphere by bleeding it directly into the instrument through a tiny leak, or it first removes the carbon monoxide and carbon dioxide, which represents the bulk of the atmosphere. In the latter mode, the minor constituents can be detected with higher accuracy and at lower levels.

A series of atmospheric analyses was performed during the fourth and fifth days after the Viking 1 landing. The results are summarized in table 7–2.

Aside from the confirmation of the presence of nitrogen, the most interesting result was the determination of the ratio of argon-36 to argon-40. This is lower than the ratio in the Earth's atmosphere by a factor of ten. The noble gases provide a useful measure of the degree of outgassing a planet has undergone because they cannot be cycled in and out of the atmosphere by chemical combination. The isotope ^{36}Ar is part of a planet's primordial composition, while the abundance of the more common isotope ^{40}Ar increases with time due to the radioactive decay of potassium-40. One possible theoretical consequence of the ratio that was determined for Mars is that Mars has not outgassed to the extent that the Earth has, and that its atmospheric pressure may never have exceeded 100 mb.

TABLE 7–2.—*Sol 4 and 5 Atmospheric Analyses of Composition at Surface (Gas Chromatograph Mass Spectrometer)*

Gas	Composition
Carbon dioxide (CO_2)	Approximately 95 percent
Oxygen (O_2)	0.1–0.4 percent
Nitrogen (N_2)	2–3 percent
Argon (^{40}Ar)	1–2 percent
^{36}Ar/^{40}Ar	1:2750 ± 500
Gas not detected	**Preliminary detection limit**
Neon (Ne)	10 ppm
Krypton (Kr)	20 ppm
Xenon (Xe)	50 ppm

The first sample was acquired for molecular analysis on the same day (Sol 8) as the biology and inorganic analysis samples. The molecular analysis was delayed for some time because of the concern that made it uncertain that the sample had been delivered to the instrument.

The analysis at 200° C indicated that some carbon dioxide and very little water had been evolved. No organic molecules were detected.

When the sample was heated to 500° C, copious amounts of water were driven off, as well as some more carbon dioxide. No complex organic molecules (with three or more carbon atoms) were detected, down to the limit of about one part per million. A more refined analysis of the data by elaborate computer processing is in progress to determine the presence, if any, of other organic molecules below the one part per million level.

The water that appeared at 500° C was driven off from minerals that are rather stable hydrates. The paucity of water evolved at 200° C indicates that very little water is adsorbed on the mineral grains, and that the hydrated minerals do not decompose at that rather low temperature.

The molecular analysis investigation employs a gas chromatograph mass spectrometer (GCMS). Figure 7–3 is a schematic diagram. The heart of the instrument is a mass spectrometer operating on the same principle as the upper atmosphere mass spectrometer described in chapter 3: ionization of the incoming gases, followed by the separation of their ionization products on the basis of mass-to-charge ratios.

A mass spectrometer is particularly useful in dealing with a wide range of organic compounds because it provides specific information on the structure of a

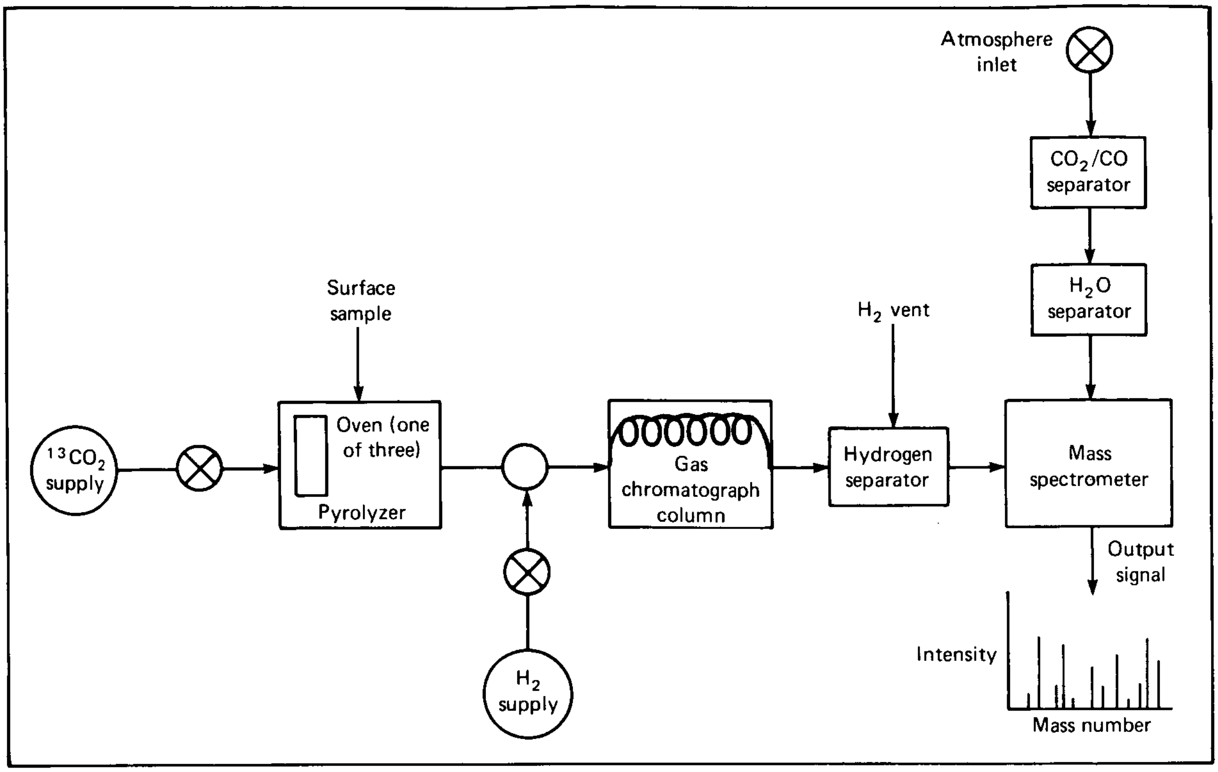


FIGURE 7–3.—Schematic of the gas chromatograph mass spectrometer.

molecule—the arrangement of the carbon atoms and the places of attachment of the functional groups of atoms. Mass spectra can be interpreted even when the molecules were previously unknown, and the molecular structure of an organic compound is often a good indicator of its origin.

This mass spectrometer can only measure ions whose mass-to-charge ratios are between 12 and 200 atomic mass units. At the low end this excludes hydrogen and helium molecules. The instrument's range covers the majority of simple organic molecules, including those formed by the thermal degradation of complex molecules and organic atmospheric gases.

A mass spectrometer can only work with gases or vaporized substances, and mass spectra are easiest to interpret when the different vapors are introduced one at a time. The other components of the GCMS are there to extract any organic material from the sample in vaporized form by the use of heat, and to separate the delivery of the vapors to the mass spectrometer in the time dimension by gas chromatography.

Like the XRFS, the GCMS is located inside the Lander body, with only the intake funnel extending above it. After a surface sample is dropped into the funnel, it is ground up before delivery to an oven. The oven is rapidly heated to a temperature of 200° C (392° F), to release adsorbed atmospheric gases and organic compounds that are volatile at that temperature. The released gases are swept out of the oven and into the gas chromatograph column by a stream of carbon dioxide gas. The sweeping gas is labeled with carbon-13, so that it can be distinguished from Martian CO_2 by the mass spectrometer.

The gas chromatograph column is a coiled thin tube filled with coated beads. The vapors entering the column are separated from each other by their different degrees of retention on the beads. Slow heating of the column progressively releases the various vapors to a stream of hydrogen that sweeps them out. The vapor-laden stream passes through a palladium tube where the hydrogen diffuses away, because palladium is permeable only to hydrogen, the smallest of all molecules. The vapors then enter the mass spectrometer.

The mass spectrometer produces a complete mass spectrum every 10 seconds for the entire 84 minutes of the gas chromatograph cycle. Thus, each mass spectrum represents a very small group of gases.

The sample in the oven is then heated again to 500° C. This very high temperature volatilizes some of the remaining organic molecules, and decomposes others into smaller, more volatile molecules. The thermal decomposition of complex molecules is called pyrolysis. The vapors released by the second heating of the sample are delivered to the mass spectrometer as before. An intermediate temperature of 350° C can also be employed if the results of early analyses indicate the need. The scientists who analyze mass spectra must try to reconstruct the molecular structure of the organic molecules that were pyrolyzed from the mass spectra of their pyrolysis products.

8

The Search for Life

A Paradox

It is a paradox that the Viking biological investigations team had to design their experiments for a mission that would acquire much of the information they needed for their designs. Yet it would have been unthinkable to pass up the opportunity presented by the Viking mission to make an attempt at detecting certain kinds of life processes.

It can be assumed that living organisms are reasonably well adapted to their environments, and that they are composed of chemicals that are available to them. In any case, knowledge of the organic and inorganic chemicals found in the surface materials and the atmosphere, and of the physical state in which they occur, provides boundaries on the kinds of biochemical reactions that might be detected. In the absence of such prior knowledge, the Viking biologists had to make some assumptions about the nature of Martian metabolic activity. It is a virtue of the Viking biology instrument that the three types of experiments it conducts are based on different assumptions about the requirements of hypothetical Martian microorganisms.

It was considered possible that nothing of significance would happen in any of the experiments. The failure to detect a reaction would not necessarily indicate the absence of life on Mars; the assumptions about the nature of the life processes might all be incorrect, or the particular landing site might be barren.

As it turned out, the results have been at once surprising, puzzling, and scientifically stimulating. In each of the experiments, the sample of Martian soil has reacted in some fashion. At the time this is written, the meaning of the results in terms of the overall question is not clear. There have been chemical reactions; it remains to be determined whether any of the reactions is associated with biological or chemical activity. The biology instrument's next cycle of activity is being planned to continue the investigation which has already raised such interesting questions. The results obtained with each experiment are presented following the description of the experiment.

It was understood from the beginning that compelling evidence would be required before positive results from any of the experiments could be regarded as a biological response. The planned procedures for the three experiments are designed to obtain part of this evidence. Information that the molecular analysis investigation may provide about organic chemicals in the surface materials would be extremely important evidence. Other evidence will have to come from new laboratory experiments on Earth.

Biology Instrument

The three biology experiments all involve the incubation of portions of the same sample under controlled conditions. The biology instrument (fig. 8–1) houses all of them, distributing measured amounts of the sample to each, carrying out the complex sequence of operations and supplying the consumable substances that each requires, maintaining the incubation conditions, and finally collecting all the data for transmission to Earth.

The instrument carries out all three experiments simultaneously. The first biology analysis cycle, which started on the eighth day after the Viking 1 landing, has been completed as of this writing. The mission

BIOLOGY TEAM

Harold P. Klein	Gilbert V. Levin
Norman H. Horowitz	Vance I. Oyama
Joshua Lederberg	Alexander Rich

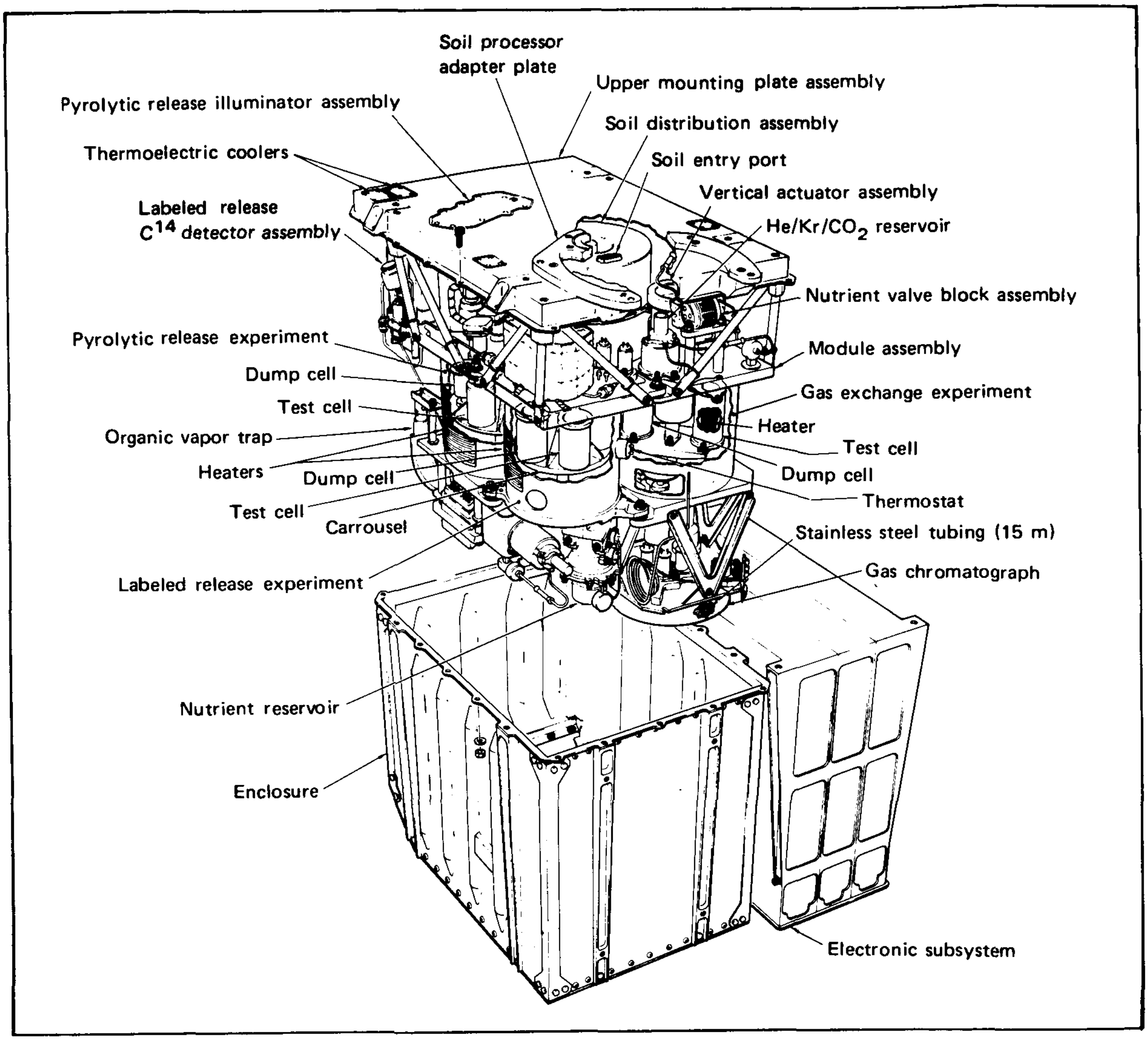


FIGURE 8–1.—The Viking biology instrument contains three separate experiments.

plan originally called for three cycles, separated by seven-day intervals. However, the timing is flexible and, within limits, the incubation periods each experiment requires can be altered as the mission proceeds. After the first cycle, the individual experiments can also be supplied with material from different surface samples.

The three experiments are the pyrolytic release experiment, which looks for the biological synthesis of organic molecules from labeled gases; the labeled release experiment, which looks for the assimilation of labeled nutrients with the release of gases; and the gas exchange experiment, which looks for metabolically caused changes in the composition of the gases in contact with living organisms. A description of each experiment follows.

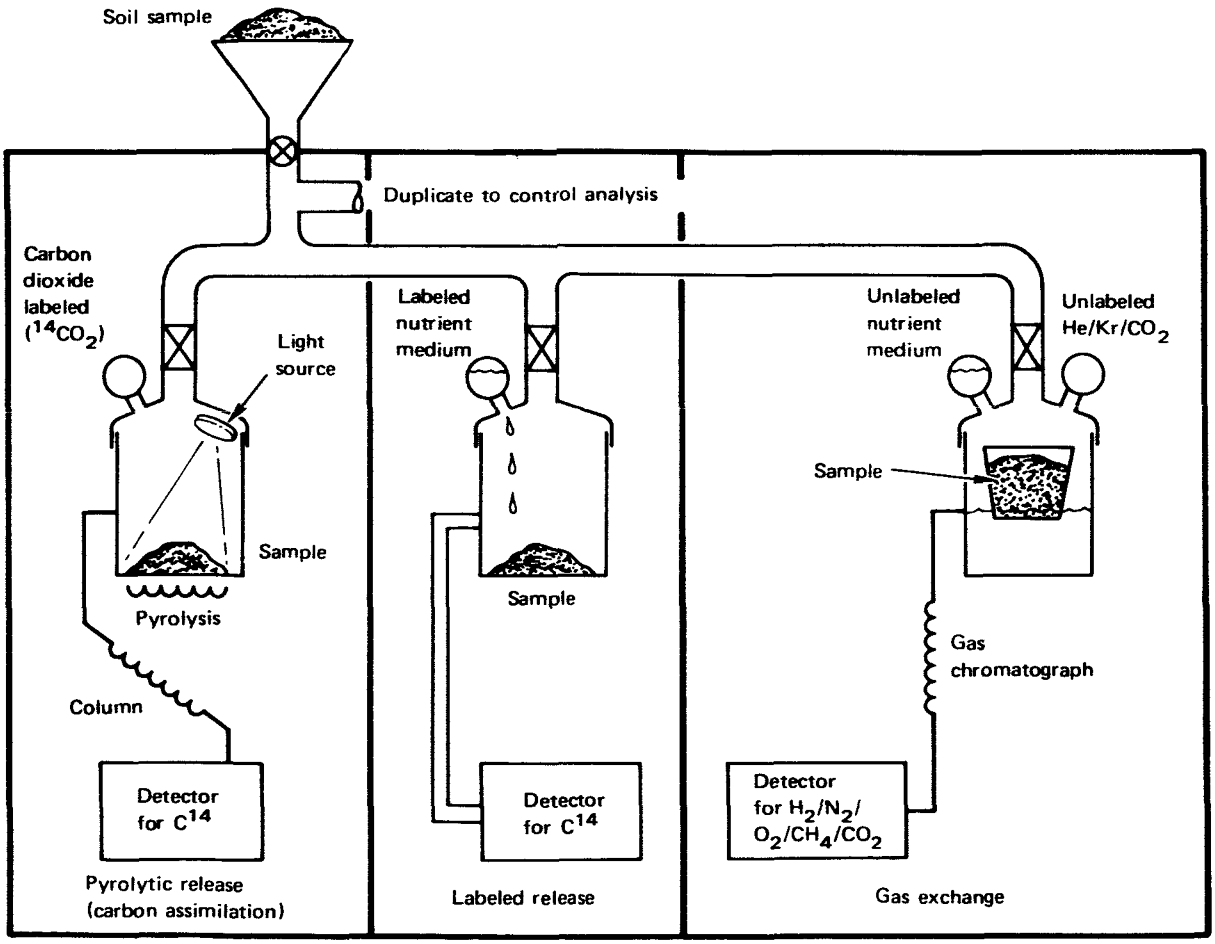
Pyrolytic Release Experiment

This experiment assumes that Martian life is based on molecules containing carbon, and that the carbon is cycled through the atmosphere. On Earth, the photosynthesis of organic compounds from carbon dioxide and water by green plants is the most important process that fixes atmospheric carbon in living matter. Algae and bacteria assimilate atmospheric carbon by a different photosynthetic process. In addition, plant and animal cells alike accomplish some assimilation of carbon dioxide in the absence of light. A number of terrestrial bacteria can also assimilate carbon monoxide. The emphasis in this experiment is on departing as little as possible from Martian conditions.

The experimental procedure is to incubate the soil sample for five days in a chamber (fig. 8–2) under Martian conditions, except that carbon dioxide and carbon monoxide labeled with the radioactive isotope carbon-14 replace a part of the natural atmospheric gases. The chamber is illuminated by artificial sunlight to supply energy for photosynthesis.

The illumination differs from the sunlight that falls on the Martian surface in only one respect: ultraviolet wavelengths shorter than 310 nm were filtered out because they are known to activate nonbiological syntheses that would mimic positive results in the experiment.

After incubation, the test chamber is heated to 625° C, to pyrolyze any organic material. A stream of helium gas sweeps the vaporized pyrolysis products onto a chromatographic column commonly referred to as the organic vapor trap. Unreacted CO_2 and CO pass through the organic vapor trap into a radiation detector downstream. The carbon-14 contained in this "first peak" is counted to aid in interpretation of the test. If the vaporized pyrolysis products contain organic materials, they are trapped on the organic vapor trap and are released during the elution phase. This involves heating the vapor trap to 700° C so as to combust the trapped organic compounds to CO_2. If the detector shows a second radioactivity peak at this



(Test cells contain Martian atmosphere.)

FIGURE 8–2.—Simplified schematic diagram of each biology experiment.

point, it is an indication of possible biological assimilation of CO_2 and CO. Although photosynthesis would produce a high second peak, the method is sensitive enough to detect the kind of nonphotosynthetic assimilation that all terrestrial cells accomplish.

The procedure described above was followed with the surface sample in the Viking 1 biology instrument. The radiation level measured in the first peak was about 7400 counts per minute. The second peak was measured at 573 cpm. After subtracting 477 cpm, which is the background radiation level, the net level of the second peak is 96 cpm. This is a numerically significant peak, since the predicted level in the absence of any carbon assimilation was only 15 cpm.

Before ascribing the net second peak to biological activity, it is necessary to eliminate any other possible causes. The remaining procedures of the pyrolytic release experiment are designed to eliminate as many as possible. The first procedure that will be carried out is a control experiment. A second portion of the original soil sample will be heated in a clean chamber to a temperature of 160° C for 3 hours. This is a regime that effectively sterilizes terrestrial soils. Then the incubation, pyrolysis, and counting procedures will be performed exactly as they were the first time. If the measured second peak is as high as it was on the unsterilized sample, that would eliminate biological activity as the cause of the earlier results. If the sterilized sample produces a significantly lower second peak, the next step is to repeat the first test with another sample of soil freshly acquired from the Martian surface.

Labeled Release Experiment

This experiment assumes that the biochemical reactions of Martian microorganisms require water, that the organisms assimilate some relatively simple organic molecules and ions, and that they release gases containing part of the carbon from the nutrients. The nutrients selected (formate and lactate, the amino acids glycine and alanine, and glycolic acid) are assimilated by many terrestrial microorganisms, and they may be present on other planets as products of nonbiological synthesis. For this experiment they are all labeled with carbon-14.

The soil sample is placed in an incubation cell (fig. 8–2) with enclosed Martian atmosphere, and moistened with a small quantity of water containing the dissolved mixture of labeled nutrients. During the incubation period, the atmosphere above the sample is continuously monitored by a set of radioactivity detectors. If any microorganisms excrete any carbon gas, such as carbon dioxide, carbon monoxide, or methane as a result of assimilating the labeled nutrients, the radioactivity of the enclosed atmosphere will build up. A curve of cumulative radioactivity as a function of time might indicate the metabolic growth rate of the organisms.

At the end of the incubation period, which is carried out in darkness, the test cell and detector chamber are purged of radioactive gases with helium. The experiment can then be repeated with new samples in fresh test cells. There are four test cells available, so that if any sample indicates positive results a fresh portion of that sample can be heat-sterilized and then incubated as a control.

The results of this experiment were startling initially, and continue to present surprises. As soon as the few drops of nutrient solution were injected into the incubation chamber, the radioactivity rose steeply from the previous background level of 750 cpm. Clearly, gases were being released that included the labeled carbon from the nutrients. The rate of increase began to slacken within a day, and the radioactivity became almost level after a week at about 10 000 cpm. Seven days after the first injection, a few more drops of the nutrient solution were injected into the incubation chamber. For a very brief time more labeled gas was released, and then the total radioactive gas rapidly decreased by about 30 percent and subsequently rose very slowly.

A possible nonbiological explanation for the initial burst of labeled gas emerges in the light of the finding by the gas exchange experiment that its sample released oxygen rapidly to the atmosphere in the presence of water vapor. If the soil particles are coated with a strong oxidizing agent (possibly caused by ultraviolet activation) they could not only release oxygen from water vapor (if present) but they could oxidize some of the labeled nutrients to release $^{14}CO_2$. There is much laboratory work to be done on the effect of strong ultraviolet radiation on minerals. In the incubation chamber, the release of CO_2 would level off with the depletion of either the oxidant or the oxidizable component of the nutrient solution. Several possible reasons for the subsequent reduction in radioactivity are being investigated.

This experiment will now perform a control cycle on a portion of the same soil that gave the initial results. The soil will be heated to a temperature sufficient to kill terrestrial microorganisms. The test and control responses will then be compared. In addition, an extended incubation of a new sample will be run through September and October. Meanwhile, the chemical oxidant theories will be tested in the laboratory to help interpret the results from Mars.

Gas Exchange Experiment

This experiment, like the labeled release experiment, assumes that Martian biochemical reactions are aqueous. It also assumes that metabolic activity involves some exchange of chemicals between the organisms and the atmosphere. Beyond that, it tests a pair of contrasting assumptions about the food requirements of the microorganisms in the soil sample. One is that the soil contains sufficient nutrients to sustain some biological activity when a little water vapor is supplied. The other is that there are microorganisms in the soil that require one or more of the common nutrients of terrestrial life for their growth.

The soil sample in this experiment is suspended in a porous cup above the floor of the incubation chamber (fig. 8–2). The atmosphere surrounding it is composed of carbon dioxide, krypton (introduced as a calibration standard), and enough helium to attain the desired atmospheric pressure. A rich mixture of common nutrients in water solution is added to the bottom of the chamber. For the first seven days of incubation the liquid level is below the cup, so that only water vapor is transferred to the soil sample. Then, if there are no indications of metabolic activity, additional solution is introduced to bring the liquid level up to the sample, so that the soil imbibes the nutrients during the remainder of the incubation period. The entire incubation takes place in darkness.

Small samples of the atmosphere in the chamber are drawn off periodically for gas analysis. A stream of helium carries the gas sample through a long, coiled chromatograph column that detains individual gaseous components for different lengths of time. The gases in a simple mixture can be identified by their arrival times at the thermal conductivity detectors. The significant gases are krypton (as a standard), hydrogen, nitrogen, oxygen, methane, and carbon dioxide. Monitoring the concentrations of these gases at different times during the incubation should make it possible to distinguish those changes due to the release of adsorbed gases and nonbiological chemical reactions from those that result from metabolic activity.

This experiment uses a single test cell. After an incubation cycle, a fresh sample can be added on top of the old one, the nutrient-rich medium can be pumped out and replaced by fresh medium, and the atmosphere can be flushed out and replaced to start a new incubation period. If a cycle shows evidence of biological activity, the drained test cell can be heated to sterilize the sample before running a new incubation.

The results to date of this experiment have also been surprising. When the nutrient solution was introduced to the bottom of the chamber (so that the soil was not in contact with it), oxygen was rapidly released to the atmosphere. The amount was about 15 times as much as could be accounted for from known sources. The oxygen content soon leveled off. Carbon dioxide was also rapidly released, and then leveled off concurrent with the O_2. The amount of CO_2 produced was consistent with desorption of CO_2 from soil surfaces. Then the nutrient level was raised sufficiently to wet the soil for the first time. No additional oxygen was released. There has been a decrease in the CO_2 content after the wetting of the soil.

A reasonable explanation of the initial release of oxygen was mentioned in connection with the labeled release experiment. The Lander site is a desert, and the surface may not have encountered high atmospheric humidity in a very long time. The surface particles have an iron oxide coating, and are exposed to solar ultraviolet radiation that the Earth's surface does not receive. The possibility of forming an oxidizing coating by a photocatalytic process has been studied some, but there is much experimental work to do. The decrease in CO_2 after wetting is most readily explained by the presence of an alkaline core under the coating.

Appendix A

VIKING SCIENCE TEAMS

ORBITER IMAGING

Michael H. Carr, U.S. Geological Survey, Menlo Park
William A. Baum, Lowell Observatory
Karl R. Blasius, Science Applications, Inc.
Geoffrey Briggs, Jet Propulsion Laboratory
James A. Cutts, Science Applications, Inc.
Thomas C. Duxbury, Jet Propulsion Laboratory
Ronald Greeley, University of Santa Clara
John E. Guest, University of London
Harold Masursky, U.S. Geological Survey, Flagstaff
Bradford A. Smith, University of Arizona
Lawrence A. Soderblom, U.S. Geological Survey, Flagstaff
Joseph Veverka, Cornell University
John B. Wellman, Jet Propulsion Laboratory

THERMAL MAPPING

Hugh H. Kieffer, University of California—Los Angeles
Stillman C. Chase, Santa Barbara Research Center
Ellis D. Miner, Jet Propulsion Laboratory
Guido Munch, California Institute of Technology
Gerry Neugebauer, California Institute of Technology
Frank Palluconi, Jet Propulsion Laboratory

WATER VAPOR MAPPING

C. Barney Farmer, Jet Propulsion Laboratory
Donald W. Davies, Jet Propulsion Laboratory
Daniel D. LaPorte, Santa Barbara Research Center

ENTRY SCIENCE

Alfred O. C. Nier, University of Minnesota
William B. Hanson, University of Texas
Michael B. McElroy, Harvard University
Alfred Seiff, Ames Research Center
Nelson W. Spencer, Goddard Space Flight Center

LANDER IMAGING

Thomas A. Mutch, Brown University
Alan B. Binder, Science Applications, Inc.
Friedrich O. Huck, Langley Research Center
Elliott C. Levinthal, Stanford University
Sidney Liebes, Jr., Stanford University
Elliott C. Morris, U.S. Geological Survey, Flagstaff
James A. Pollack, Ames Research Center
Carl Sagan, Cornell University

BIOLOGY

Harold P. Klein, Ames Research Center
Norman H. Horowitz, California Institute of Technology
Joshua Lederberg, Stanford University
Gilbert V. Levin, Biospherics, Inc.
Vance I. Oyama, Ames Research Center
Alexander Rich, Massachusetts Institute of Technology

MOLECULAR ANALYSIS

Klaus Biemann, Massachusetts Institute of Technology
Duwayne M. Anderson, National Science Foundation Office of Polar Programs
Alfred O. C. Nier, University of Minnesota
Leslie E. Orgel, The Salk Institute for Biological Studies
John Oro, University of Houston
Tobias Owen, State University of New York
Priestley Toulmin III, U.S. Geological Survey, Reston
Harold C. Urey, University of California—San Diego

INORGANIC CHEMISTRY

Priestley Toulmin III, U.S. Geological Survey, Reston
Alex K. Baird, Pomona College
Benton C. Clark, Martin Marietta Aerospace
Klaus Keil, University of New Mexico
Harry J. Rose, U.S. Geological Survey, Reston

METEOROLOGY

Seymour L. Hess, Florida State University
Robert M. Henry, Langley Research Center
Conway B. Leovy, University of Washington
Jack A. Ryan, McDonnell Douglas Corporation
James E. Tillman, University of Washington

SEISMOLOGY

Don L. Anderson, California Institute of Technology
Fred Duennebier, University of Texas
Robert L. Kovach, Stanford University
Gary V. Latham, University of Texas
George Sutton, University of Hawaii
Nafi M. Toksoz, Massachusetts Institute of Technology

PHYSICAL PROPERTIES

Richard W. Shorthill, University of Utah
Robert E. Hutton, TRW Systems Group
Henry J. Moore II, U.S. Geological Survey, Menlo Park
Ronald F. Scott, California Institute of Technology

MAGNETIC PROPERTIES

Robert B. Hargraves, Princeton University

RADIO SCIENCE

William H. Michael, Langley Research Center
Joseph P. Brenkle, Jet Propulsion Laboratory
Dan L. Cain, Jet Propulsion Laboratory
John G. Davies, University of Manchester
Gunnar Fjeldbo, Jet Propulsion Laboratory
Mario D. Grossi, Raytheon Corporation
Irwin I. Shapiro, Massachusetts Institute of Technology
Charles T. Steizried, Jet Propulsion Laboratory
Robert H. Tolson, Langley Research Center
G. Leonard Tyler, Stanford University

Appendix B

VIKING KEY PERSONNEL

NASA HEADQUARTERS

N. W. Hinners, Associate Administrator for Space Science
R. S. Kraemer, Director, Planetary Programs
W. Jakobowski, Program Manager
R. S. Young, Program Scientist

LANGLEY RESEARCH CENTER

D. P. Hearth, Director

VIKING FLIGHT TEAM

J. S. Martin, Jr., Project Manager
A. T. Young, Mission Director
G. A. Soffen, Project Scientist
J. D. Goodlette, Chief Engineer
B. G. Lee, Science Analysis and Mission Planning Director
P. T. Lyman, Spacecraft Performance and Flight Path Analysis Director
M. J. Alazard, Mission Control Director
G. N. Gianopulos, Mission Control Computing Center Systems Engineer
D. J. Mudgway, Deep Space Network Manager
H. W. Norris, Senior Staff (Orbiter Operations)
W. O. Lowrie, Senior Staff (Lander Operations)
H. E. Van Ness, Senior Staff (External Affairs)
R. L. Crabtree, Deputy Mission Director
L. Kingsland, Deputy Mission Director (Planning)
C. W. Snyder, Orbiter Science Group Chief
G. C. Broome, Lander Science Group Chief
J. D. Porter, Mission Planning Group Chief
R. A. Ploszaj, Orbiter Performance Analysis
R. W. Sjostrom, Lander Performance Analysis
W. J. O'Neil, Flight Path Analysis
M. M. Grogan, Sequence Development
L. S. Canin, Flight Control
D. D. Gordon, Data Support
W. B. Green, Image Processing Staff Leader
H. Masursky, Landing Site Staff Leader
K. S. Watkins, Administrative Support Office
K. W. Graham, Ground Data Systems Support
R. J. Polutchko, Lander Support Office Chief
K. H. Farley, Lander Support Engineering
F. D. Nold, Lander Support Operations
B. A. Claussen, Lander Support Software

The collection of information and photographs for this publication ended on August 13, 1976. The publication was prepared by the NASA Scientific and Technical Information Office and in particular by Leon Kosofsky. A recently retired NASA engineer and scientist, Mr. Kosofsky drew on data and preliminary interpretation courteously made available to him by the Viking Project Office and members of the Viking science teams.

NASA-Langley, 1976