Reports

Status of the Viking Missions

The Viking missions are continuing to perform the planned Mars experiments. In a previous report we established the mission chronology until just after the landing (*1*). Since that time, three major activities have taken place: the sampling of the Mars surface and analysis on board the lander, the orbit insertion of the second Viking spacecraft, and the search for the second landing site at 40° to 50°N latitude.

Activity on the lander. For the first few sols (a coined term for the martian day), the cameras were used to examine the landscape and to determine the hazards of using the sampling arm and its scoop for retrieving the samples (Fig. 1). Prior to landing there was a programmed sequence in the lander computer for automatically deploying the arm to a given azimuth, elevation, and extension. When the pictures of the site were examined, the programmed site was judged hazardous because of the numerous large rocks in the field. The sample site was moved. This meant sending a command to reprogram the computer for the position of the new site.

On sol 2, the shroud covering the sampling scoop was ejected. After some minor problem with a retaining latch pin, the sampling arm was deployed to gather samples for the three analytical experiments, namely, biology, organic analysis, and x-ray fluorescence, in that order (*2–4*). This took place on sol 8. The trench that was dug revealed that the sampler had left its mark in the surface. The engineering data indicated that biology and x-ray fluorescence instruments had each received an adequate sample, but that the gas chromatograph–mass spectrometer (GCMS) used for the organic analyses was interrupted in its sequence because there was either no sample or a sample smaller than necessary to give a full indication. Commands were sent to repeat the dig, at a slightly different location, extending the arm further. This time the arm halted midway through the complex mechanical sequences; the precious sample for the GCMS had been successfully collected but was held aloft 2 m from the intended receiver! On the basis of the conclusion that the sampler problem was due to mechanical restraint, commands were sent to operate the arm during the warmer hours of the sol with a different sequence. The sampler worked flawlessly and has continued to do so.

A decision was made to proceed with the first organic analysis on the assumption that an adequate sample had been acquired on sol 8. This turned out to be correct (*5*).

On sol 17 and sol 27 organic analyses were performed on the first sample which had been collected on sol 8; on sol 32, sol 37, and sol 43 organic analyses were performed on the second sample, which was collected on sol 32. The results are reported (*3*).

The biology instrument having received a sample on sol 8, was initiated and continued to incubate its sample (in the three experiments) for the next 15 sols. The results of the biology investigations indicated that the first sample had been successfully delivered and that the instrument had performed perfectly; the responses indicated that the second cycle would serve as a control for two of the three experiments (*2*). In the biology experiment the control consisted of using a second portion of the same sample. This portion was heated to destroy any biological organisms, and the experiment was repeated for comparison with the first results. Since the instrument has the capability of storing enough sample for both cycles, there was no need for obtaining a new sample for the second cycle. The control cycle was initiated and performed from sol 24 to 38. On sol 36, a second sample for biology was taken from the same general area (to repeat the result) and this was initiated on sol 38.

The x-ray fluorescence instrument received its first sample on sol 8 along with the other two instruments. Owing to the advantage of statistics, the sample was analyzed for a long period of time (*4*). The sample was discarded on sol 26. The data indicated that the sample cell was not completely empty, and that either some fine-grained material was adhering to the window of the detector or that material was bridging across the opening. On six successive days the sequence for

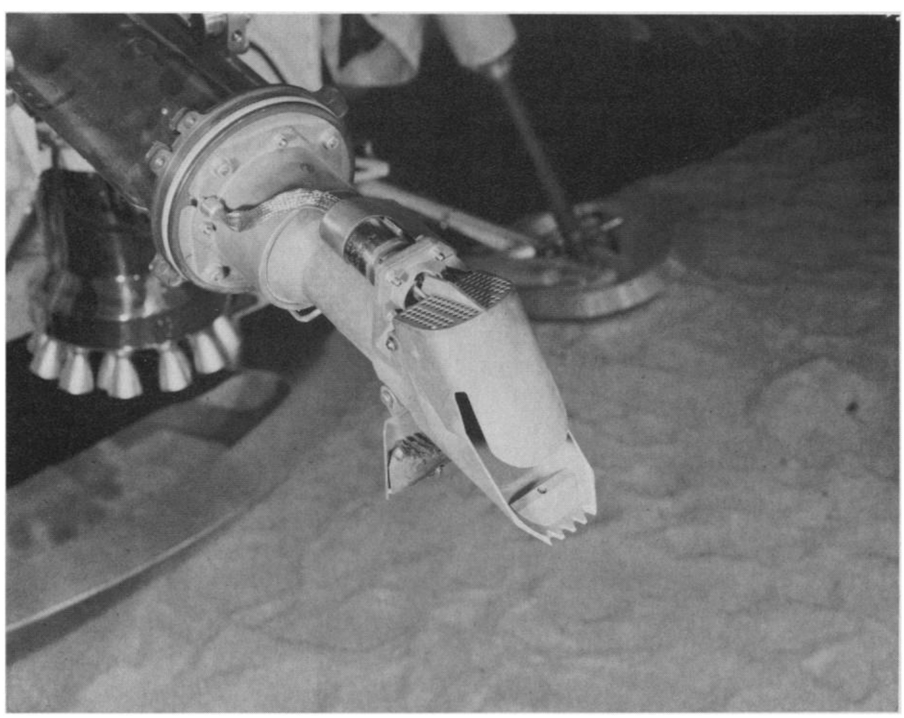

Fig. 1. This photograph, taken at the Science Test Lander Laboratory at the Jet Propulsion Laboratory, is of the collector head unit in the normal acquisition position, with the jaw open. The 2000-μm screen shown at the top is used to deliver sieved samples when the head is inverted. The backhoe is shown in the deployed position [courtesy of L. V. Clark, Viking Project Office, NASA Langley Research Center.

emptying the cell was performed by command. Eventually the background returned to 80 percent of that of an empty cell. The x-ray fluorescence instrument received a second sample for analysis on sol 34 from an area called "rocky flats," one of the few areas among the rocks from which a sample could be safely taken (*6*). After that analysis the x-ray fluorescence received a third sample from another area beside rocky flats. For the analysis of these last two samples, a clever use of the scoop was instituted. By inverting the scoop and vibrating, the sampler sieves out the fine particles less than 2 mm. The sample retained is then more representative of the rocky material than of the fine material that may be secondary aeolian deposition.

During this period the meteorology experiment has continued to collect diurnal data of the pressure, temperature, wind speed, and wind direction. No problems were encountered (*7*).

The cameras were used to obtain data of the surface of Mars in black and white and in color (*8*). Apart from being engineering aids for determining the position of the sampling arm, the cameras were used extensively for examining the footpads, the test charts, the stroke gages on the landing legs, the covers on the biology and GCMS instruments, and the area beneath the retro rockets (*6*). The panorama horizon was studied, and stereoscopic color pictures were taken of the near field. Pictures were taken of Phobos. Studies of the optical thickness were made by taking pictures of the sky and the sunset and sunrise, pictures of the surface were taken in the infrared; pictures were taken of grids, magnets, antennas, instrument covers, and the meteorology sensors. Thus far, more than 300 individual pictures have been obtained from the Viking 1 cameras. The instruments have performed beyond our expectations.

The three-axis seismometer remained caged. Several unsuccessful attempts were made to fire the mechanism that restrains the motion.

Viking 2 Mars orbit insertion (MOI) and search for the landing site. Viking 2 was placed in an orbit around Mars on 7 August 1976 at 11:29 G.M.T. The period of the orbit was 27.42 hours with a periapsis of 1501 km, and an apoapsis of about 33,000 km. The inclination was 55° to the equator and the sun elevation angle was at 119.6°. Initially there was a capability for changing the velocity (ΔV) by 1153 m/sec. The MOI maneuver expended 1101 m/sec, leaving 352 m/sec for subsequent maneuvers. The periapsis was placed at 46°N and 320°W (the area of the original preselected site). The amount of energy required for the change of the plane of inclination needed for observing the polar regions is 162 m/sec (changing from an inclination of 55° to 75°). The rest of the ΔV is allocated for removing maneuver errors and synchronizing the spacecraft over the landing site.

On rev 2 a trim was made to remove execution errors. On rev 6, a trim was made to establish the phasing for viewing the landing sites being considered. From revs 6 to 16 a complete rotation was made around the planet for observation of three areas that represent one-third of all territory at latitudes 40° to 50°N. On rev 16, the decision was made to do a phasing maneuver to stop, and reverse the rotation halting at 226°W, the selected landing site. In the course of the trim, the latitude of the periapsis point changed from 46° to 48°N. The spacecraft was synchronized on rev 18 at 226°W and 48°N.

The search for the second landing site was different from that for Viking 1. Before the arrival of the Viking 1 orbiter, there had been two latitude bands under consideration: one at 6°S and the other at 44°N. the available areas at 6°S were near the canyon lands and were considered among the most geologically interesting sites on the planet in which to land a spacecraft. The latitude at 44°N was selected chiefly because of the interest in landing the spacecraft in a region that is different from the Viking 1 site and still biologically interesting (*9*). The coordinates selected before the arrival of the Viking 2 were 44°N and 10°W. The Viking 1 spacecraft was used to photograph this region. When the photographs were returned, they showed an extremely severe terrain (*10*). Large polygonal blocks reminiscent of the earth's arctic frozen ground were seen. The area was covered by numerous craters. More than 500 pictures were taken. When the second spacecraft was put into orbit around Mars, the orbit was selected to permit viewing of one of the candidate regions to the west of the first candidate. This area (Alba Patera, about 110°W) revealed a fascinating but considerably more hazardous region crossed by many young fracture features. The spacecraft was put into the asynchronous orbit moving 40° per day to view the region to the west, and continued to move about the planet in search of a safe site. The lander is in the Utopia region at 226°W, 48°N, about 200 km from the Crater Mie.

Science summary. On the basis of the Viking reports the following is a reasonable assessment of the planet.

▶ There is extensive evidence of volcanism, fluvial and aeolian erosion, and deposition over the entire surface. The number of craters on the various plains is about a tenth as frequent as on the moon.

▶ Despite the antiquity of the surface, the preservation of the small craters suggests that wind erosion has been very slow.

▶ The floor of the canyon Vallis Marinaris is significantly younger, suggesting contemporary processes.

▶ The morphology of martian crater ejecta is indicative of surface flow rather than ballistic deposition as on the moon and Mercury.

▶ The northern plains is a vast area of polygonal patterns resembling the "patterned ground" of the arctic regions. At higher latitudes, this is muted by a soft mantling.

▶ The rocks in the immediate vicinity of Viking 1 lander are numerous and exhibit a great variety of form, color, texture, and size, all covered by a layer of fine red dust.

▶ The atmosphere is optically thick, with suspended particles giving the sky a pink color.

▶ The atmosphere is well mixed.

▶ Nitrogen and argon and their isotopes have been measured in the atmosphere. The isotopic ratios are different from those on Earth, implying a different atmospheric history and also a significantly denser initial Mars atmosphere.

▶ Atmospheric water vapor varies both with time of day and location. The summer northern polar regions have high water concentration in the atmosphere.

▶ Low thermal measurements of the south polar regions suggest a dynamic condensation of volatiles.

▶ The climate at the landing site is benign and repetitive during the early summer.

▶ Elemental analysis of the sample at the landing site suggests a mixed sample of hydrated minerals, high in iron, and basaltic in nature.

▶ A large (5 to 10 percent) fraction of magnetic material resides in the surface.

▶ No complex organic compounds have been detected on Mars in the two samples analyzed. The detection limits are in the region of 10 to 100 parts per billion.

▶ The biology experiment is indeterminate but has yielded some clues to the chemistry of the surface.

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References and Notes

1. G. A. Soffen and C. W. Snyder, *Science* **193**, 759 (1976).
2. H. P. Klein *et al.*, *ibid.* **194**, 99 (1976).
3. K. Biemann *et al.*, *ibid.*, p. 72.
4. P. Toulmin *et al.*, *ibid.*, p. 81.
5. The commanded locations of the GCMS sample and the biology sample were at the exact same position. It was believed that, after the first material was acquired, the trench would collapse enough for the small sample (100 mg) needed for the GCMS. In the photographs, the walls of the trench were seen to be very vertical. Very probably the sample collected was greater than 100 mg but not enough for the internal sensing system to determine a full condition.
6. R. W. Shorthill *et al.*, *Science* **194**, 91 (1976).
7. S. L. Hess *et al.*, *ibid.*, p. 78.
8. T. A. Mutch *et al.*, *ibid.*, p. 87.
9. Since most biologists have considered that the limiting substance for life on the planet is water, a great effort was made to determine the location of the most likely place for the existence of small amounts of anomalous liquid water. Because of the atmospheric pressure, there are no large bodies of water on Mars. It is now thought that water may possibly exist in the liquid form for brief periods when the pressure and temperature are just right. An alternative to this idea is that if the frozen water gets warm enough, it may become biologically available. Water exists in the polar regions as ice.
10. H. Masursky *et al.*, *Science* **194**, 62 (1976).
11. The Viking Mission is part of NASA's office of Space Science Planetary Exploration Program and is managed by the Langley Research Center. The orbiter was built by the Jet Propulsion Laboratory and its subcontractors; the lander by Martin Marietta Corporation and its subcontractors. I thank A. T. Young, J. Asnis, and P. Sakimoto for technical assistance.

2 September 1976

Mission Operations Strategy for Viking

From the beginning, the Viking mission operations were designed to provide for a certain measure of adaptability. During the early design and then during the personnel testing periods (which involved virtually all of the science team leaders in an operational, rather than scientific, role), there was one recurring question that was applied to the emerging strategy for conducting the Viking mission: How can the science adaptability be maximized while maintaining prudent engineering integrity in the uplink design and commanding process? A tested plan evolved that provided for what might be called "planned adaptability." The top-level blueprint describing the way the operations have been conducted on Viking is called the mission operations strategy (MOS). It is important to understand the architecture of this strategy to appreciate the way in which all the Viking scientific data have been gathered.

On Viking the operational strategy, including sizing the flight operations staffing and the computers, specifying the work shifts, and even defining the organizational structure, was based on a need for scientific adaptability. Simply defined, scientific adaptability, within the Viking context, means the ability to redesign later portions of the mission on the basis of the scientific data accumulated earlier in the mission. Obviously it was the determination of the detailed, quantitative answer to the question of how much could be changed how fast that led to the design of the mission operations strategy.

In a scientifically adaptive mission like Viking, it is clear that the science team leaders themselves become part of the operational activity. Unlike many earlier space missions, Viking requires the processing and analyzing of scientific data as an operational component. For the experimenter to decide how to conduct the second cycle of his investigations in an adaptive manner, for example, it is necessary for him to understand the implications of data from the first cycle. By adding the key elements of scheduling and time lining to this scientific activity, major scientific decision points were defined. Thus, each of the scientific personnel working on the Viking flight team (VFT) became part of the overall effort of scheduling the complex Viking operational activity.

Figure 1 represents an abstract portrayal of the way that the MOS on Viking might appear to the scientist. The two major parameters of the diagram are freedom to change and time before commanding. The overall operational system has been so designed that virtually any single change in the mission can be accommodated if it is defined at least 16 days before desired implementation. This 16-day period is the normal time required for the operational elements to change a sequence completely and verify the accuracy of the new sequence. From that point forward, with major focus points at the management meetings also indicated on the graph (these meetings will be explained in more detail in the next section), the mission design proceeds to evolve in ever more detail, scientific concepts giving way to time lines and sequences, and these in turn being replaced by commands in the binary language of the onboard computer. It is these commands that represent the penultimate translation of the desired scientific sequence. The process next moves inexorably through its last step, where the spacecraft translates the coded message and performs the commanded sequence.

Throughout this report focus has been centered on the Viking lander elements of the MOS. The orbiter has an analogous operational strategy, but since constant communications are maintained with the orbiter, as contrasted with the couple of hours daily available for commanding the lander, the temporal exigencies of the orbiter strategy are not nearly as severe.

One last point should be mentioned before beginning a detailed explanation of the structure of the MOS. The strategy that has evolved may appear to be cumbersome, routine, and even bureaucratically rigid. However, from the beginning it was a design goal to develop a strategy whose rules and procedures would be clear enough that little effort would have to be expended in making the process run regularly. Once the strategy was thoroughly defined, it was reasoned, it would become second nature to all the participants and would allow these critical people to expend their efforts on the less routine, more creative

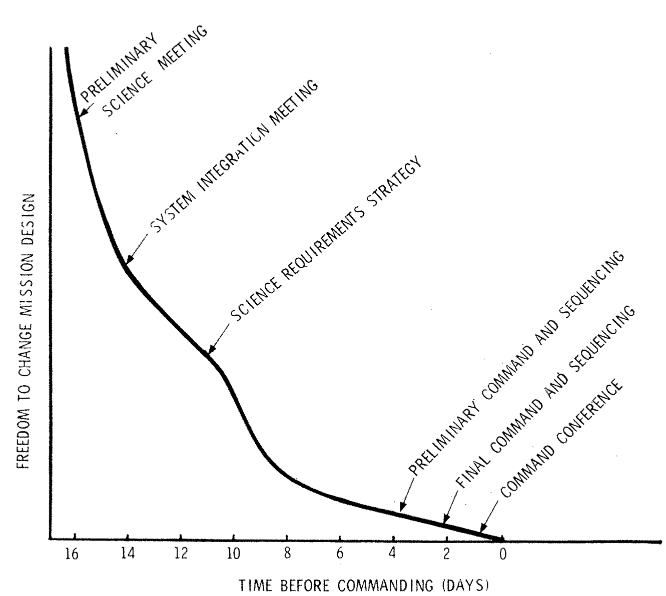

Fig. 1. Time ordinarily required (in days) to effect changes in sequence.