10

Site Certification—and Landing

With site selection behind them, the landing site working group members faced two more tasks—completing their individual commitments to science teams and certifying the Martian landing areas they had chosen. They were reasonably hopeful that the targets were safe ones, but they could be certain only after they had examined additional Earth-based radar studies and the orbital pictures *Viking 1* would send back from Mars. Careful certification of each Viking site would have to be carried out before the landers descended to the Martian surface, but no one expected certification to pose real difficulties now that they were over the hurdle of finding suitable targets. These expectations would be dashed in June 1975.

PLANNING SITE CERTIFICATION

Certification Team

In August 1973, Jim Martin selected Hal Masursky to lead the landing site certification team, with Norman L. Crabill from Langley as his deputy. This group, which functioned as an operational organization rather than a planning body, included members from orbiter imaging, infrared thermal mapping, Mars atmospheric-water detection, and mission planning and analysis teams, as well as radio astronomers.[1] Together they designed a strategy for landing site certification, which R. C. Blanchard of the Viking Project Office presented at the February 1974 meeting of the Science Steering Group. Blanchard broke the certification process down into four periods: 1. Pre-Mars orbit insertion (MOI) for *Viking 1*. 2. Post-MOI and prelanding for *Viking 1*. 3. Postlanding for *Viking 1*; pre-MOI for *Viking 2*. 4. Post-MOI and prelanding for *Viking 2*. Blanchard noted that before the first Viking spacecraft orbited Mars, new sources of data that might possibly affect the landing sites could include Earth-based radar studies of the planet, Soviet missions flown before June 1976, and scientific observations made by Viking as it approached Mars. Analyzing all new information would help them make a "go/no-go" decision concerning the desirability of landing at the prime site latitude and, they hoped, would contribute to "A-1" site (first choice for first lander) certification.

Viking 1 would make extensive observations of the prime site, with special emphasis on the low-altitude photographs obtained during the close approach (periapsis). In addition, two or three picture pentads (groups of five photos) would be taken on each revolution to permit comparison of images taken at different exposures (due to the elevation angle of the sun). The A-1 site would also be studied by the orbiter water-vapor detector and infrared thermal-mapping instrument to determine if the scientists' preconceived notions about the target were valid. *Viking 1* would also observe the second lander's primary target (B-1) from low altitude with two picture swaths and one high-altitude pentad. Should the A-1 site be found acceptable (certified), then the lander would be targeted for that site. If it was not acceptable, then the backup site (A-2) would be examined. Once a landing area was chosen, orbiter trim maneuvers would fix the spacecraft's periapsis near that site.

During the third period, postlanding for *Viking 1* and preorbit insertion for *Viking 2*, information sources available to Earth control would include B-1 site data from the first orbiter, entry and landed science data from the first lander, evaluation of the first site certification procedure, and approach observations made by *Viking 2*. The team would then make its commitment to the B mission target. Once the second craft was in orbit, the men would confirm a B-1 site using additional data from the second orbiter and the further assessment of *Viking 1* science results. Blanchard assured the Science Steering Group that the A-1 and B-1 targets chosen by the landing site working group definitely would be used, unless compelling arguments materialized to require a change. Further, the scientists were reminded that the certification team would continue to be influenced strongly by considerations of safety during the first landing, but hoped that during the second landing it could look for a more scientifically interesting site even if less safe than the first.[2]

The first new data the Viking team received came from the Soviet missions.

Soviet Attempts to Investigate Mars

Much to the dismay of everyone working on Viking, the four flights the Soviets sent to Mars in 1973 raised as many issues as they settled. *Mars 4* and 5 were launched on 22 and 25 July, followed by *Mars 6* and 7 on 5 and 9 August. *Mars 4* came within 2100 kilometers of the Red Planet on 10 February 1974 but failed to go into orbit when the braking engine did not fire. On 12 February, *Mars 5* went into orbit. As no effort was made to detach landers, Western observers assumed that these two Soviet craft were designed to operate as orbiting radio links between landers aboard *Mars 6* and 7 and tracking stations on Earth. *Mars 7* approached its target on 9 March, but the descent module missed the planet by 1300 kilometers when some onboard system malfunctioned. On 12 March, the remaining vehicle separated from its carrier ship, which then went into orbit around the sun.

Mars 6 descended directly to the surface and provided telemetry for 120 seconds before it crashed.[3]

Soviet scientists reporting on the descent and crash-landing of *Mars 6* calculated that it landed at 23°54′ south latitude and 19°25′ longitude in the region called Mare Erythraeum. The landing site was "situated in the central part of an extensive lowland region," part of the global zone of depression extending for several thousand kilometers north and south of the Martian equator. Most of the landing zone (about 75 percent) was heavily cratered. Part of this terrain analysis was based on *Mariner 9* data, but the characteristics of the actual landing zone were determined by the radar-altimeter readings obtained during the parachute descent of the Soviet craft. Additionally, *Mars 6* instruments indicated "several times" more water vapor in the atmosphere than previously estimated, news over which Viking scientists were cautiously optimistic, since it enhanced the possibility of discovering some kind of life forms. *Mars 5* photographs provided additional data on the planet's surface features, and while most of the Soviet findings correlated with previous knowledge and predictions there was one major anomaly.[4]

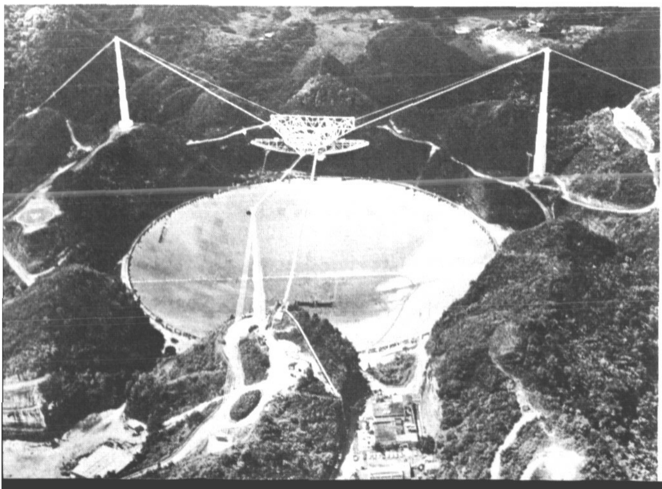
One of the experiments carried on the *Mars 6* lander was a mass spectrometer designed to determine the gaseous composition of the Red Planet's atmosphere. Although the recorded mass spectrum data were not recovered, engineering data on the operation of the vacuum pump appeared to indicate unexpected quantities of noncondensable gases. Soviet scientists interpreted the data as an indication that the atmosphere might contain as much as 15 to 30 percent argon (contrasting with 1 percent in Earth's atmosphere). The Americans had been operating on the assumption that the thin Martian atmosphere contained less than 3 percent argon. A concentration approaching 15 to 30 percent would force some rethinking about Mars and about Klaus Biemann's mass spectrometer experiment. It would mean that the Martian atmosphere had been much denser in the past than the specialists had believed. That would have made the existence of liquid water possible, but it posed a question—what had happened to those atmospheric gases? That was the puzzler. A great concentration of argon would also require some changes in the use of the gas chromatograph-mass spectrometer, since inert gases like argon tended to impede its operation. Obviously, the Soviet Mars missions had not answered many of the U.S. questions, but they had added another element of excitement to the first Viking landing. Everyone would watch closely the results of the entry science team's experiment to see just how much argon it detected as the lander made its way to the surface.[5]

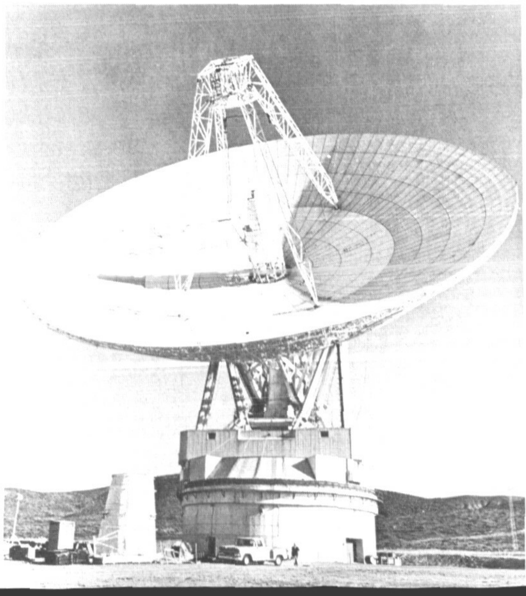
THE SIGNIFICANCE OF RADAR

As Klaus Biemann puzzled over argon in the Martian environment, others on the Viking team were tussling with an equally troublesome issue, radar. As a tool to study planetary surfaces at great distances, radar seemed to have immense potential. A signal of a known strength could be transmitted from one of the large radio astronomy antennas on Earth—Arecibo in Puerto Rico, Goldstone in California, or Haystack in Massachusetts—to the moon or Mars. The returned signal could then be compared with known signal characteristics and a judgment made about soil composition, the dimensions of slopes and rocks, and other characteristics of a specific area. Radar promised to give information on a scale of a few centimeters, where orbital imaging would tell the site certification team only about features that were larger than a football field. Radar thus promised to be a powerful tool for certifying landing sites, except that not everyone believed in its promise, making it a controversial issue. Furthermore, this technique could examine only a restricted range of latitudes on Mars.

While the Viking Project Office had been planning all along to use radar as an aid to landing site certification, Carl Sagan, once again acting as a catalyst, forced the issue early in 1973.[6] On 3 February, Sagan wrote to Jim Martin, and beneath the hyperbole of his prose Martin found some specific steps that could be taken to rectify what Sagan saw "as serious shortcomings in the landing site selection procedures." What worried him most was the interpretation being placed on some of the radar signals received from Mars. Some of Sagan's colleagues saw visually smooth areas as sand or dune fields, but he hypothesized that the low reflectivity of the radar was not due to the scattering effect of sand grains and surface ripples but to the absorption of the signal by a deep layer of dust. "At a recent landing site working group meeting we were all entertained to see a Viking lander sinking up to its eyebrows. . . . While a similar suggestion that lunar landing spacecraft would sink into surface dust has proved erroneous, it by

The 305-meter-diameter radar dish antenna at the Arecibo Observatory of the National Astronomy and Ionosphere Center nestles in the Puerto Rico hills at left below. At right below, the 64-meter dish antenna of the Deep Space Network's Goldstone, California, tracking station faces toward space. Arecibo's reflector surface consists of 38 778 aluminum panels, each about 1 by 2 meters, attached to a network of steel cables. The radar feed mechanism, mounted on a 600-ton triangular platform, is suspended by cables above the dish.





no means follows that quicksand is not a hazard for Mars." He reminded the project manager that the Soviets had suggested that quicksand might have been the cause for *Mars 3*'s failure.

As a consequence, Sagan made some "explicit recommendations." First, he believed more serious theoretical work was needed to understand better the meaning of returned radar data. Second, Earth-looking radar on satellites and aircraft could bounce signals off terrain thought to be analogous to that on Mars, and as a data base was established scientists could compare radar returns from unknown Martian surface areas with known Earth terrains. Third, Sagan thought that major support should be given to Arecibo, Haystack, and Goldstone Observatories so they could examine Mars in detail during the 1973 and 1975-1976 oppositions. He noted that the Arecibo staff was resurfacing its 300-meter radar dish and would be installing a new transmitter. Once these renovations were completed, the observatory would "have a very impressive Mars mapping capability, which should be exploited to the fullest."

Turning to visual imaging, Sagan repeated his concern that smooth surfaces at the 100-meter scale might be rough at 10 centimeters. Had lunar surface data been analyzed to determine if there was any relationship between roughness at the two scales? Hal Masursky's people might look into this matter. And similar correlation of Earth photos should also be studied. He seriously doubted that one could make judgments about the nature of the surface or the scale of the lander from any photographs the orbiter was likely to produce. Sagan believed that radar, properly understood and interpreted, was likely to be more useful in site certification than all the photographs that would be taken.[7]

Sagan's concerns were important ones. Jim Martin and Tom Young considered his recommendations, and on 23 March 1973 Martin wrote to Edgar M. Cortright, director of the Langley Research Center. Martin planned to take three actions as a consequence of Sagan's letter. Arecibo, Goldstone, and Haystack radar facilities would make nearly simultaneous observations of the same areas on Mars during 1973. Since the latitude base that could be studied was limited to 10° to 20° south, none of the candidate sites could be examined, but the information would be valuable because it would contribute to the specialists' understanding of radar's potential in such investigations. The Arecibo team also agreed to make studies in the 1975-1976 period and prepare a quick analysis of its data in the weeks before the scheduled landings.

The second action taken by the Viking Project Office was to set up a radar study team, which would undertake to eliminate some of the ambiguity in interpreting radar data. On 1 March, Tom Young and Jerry Soffen met with Von R. Eshleman and G. Leonard Tyler of Stanford University's Center for Radar Astronomy, where they had been engaged in an active program of analyzing and interpreting lunar radar studies. Tyler agreed to lead the team that would work toward improving interpretation of Mars radar information. Martin told Cortright, "As you are aware, some of the areas with low radar reflectivity are candidate landing sites. We must better understand the meaning of the low radar reflectivity to assure that the current sites are acceptable or guide the selection of proper alternatives." Tyler had his work cut out for him, and Martin arranged for a retreat at which a small group could consider thoroughly the implications of radar studies for Viking.[8]

Tyler presented the results of his study to the landing site working group meeting at Langley on 4 November 1974. Basing his conclusions on data obtained from all three radar facilities, Tyler noted that correlation between radar features and Project Mariner imagery was poor. His study group had learned a great deal: the Martian surface was very heterogeneous on the large scale; Mars tended to have greater variation in surface reflectivity than Earth or the moon; Mars appeared smoother than the moon to the radar; the 100-meter resolution of the orbiter camera system seemed likely to give appropriate information for extrapolating down to the scale of the lander; and data for the 15° to 20° south band of the planet could not be applied to latitudes in the north without variation. Jim Porter, keeping minutes for this meeting, reported that both Tyler and his colleague Gordon Pettengill "laced their presentations strongly with tutorial material which greatly enhanced the ability of the group to understand and correctly interpret their findings."

After listening to Tyler, the landing site working group was unanimous in the opinion that the A and B sites were still the best targets. Although the four targets A-1, A-2, B-1, and B-2 were still believed to be in the correct order of precedence (the Chryse site, A-1, receiving a strong vote of confidence), the team became less enthusiastic in its endorsement of the B sites. They also raised some questions about the C sites that had been located recently at 9° south. The need for new sites had been raised in early 1974 when some of the working group members began to get nervous about what the orbiter's cameras might find. Should the prime and backup sites prove unsatisfactory or if operational difficulties should develop with the spacecraft that would require the selection of some other safe landing spot, they wanted a pair of "super safe" sites where radar, photographic, and topographic information indicated that the spacecraft would have the best chance of landing undamaged. A special subcommittee* had been established to look into possible C sites and make recommendations as early as possible.[9]

The work of the C site subcommittee took longer than the working group anticipated. After meeting in December 1974, the group met again on 6 February 1975 at the Jet Propulsion Laboratory to recommend the study of three latitude bands (8.5°S, 4°S, and 4°-6°N) that would be visible to either the Goldstone or Arecibo radars during August to November 1975. The radar specialists would observe each of these regions as it became

*Subcommittee members included Chairman H. Masursky, N. L. Crabill, J. D. Porter, L. Kingsland, G. L. Tyler, T. Owen, H. Moore, G. A. Soffen, and G. A. Briggs.

accessible and recommend sites based on combined radar and visual criteria to the Landing Site Staff, the new name of the certification team, in September 1975. They would repeat the process in November after the 4° north coverage. From these observations, the Landing Site Staff would develop a final recommendation in April for Tom Young, who had become mission director. A detailed alternate mission design (for the C sites) would be developed between December 1975 and May 1976 by Viking flight team members at JPL.

A general feeling among the subcommittee members was that the second mission should be targeted for one of the C sites, since the available radar data indicated that some regions on Mars were very unsafe for landers. The B sites were so far north that radar coverage would never be possible. Norm Crabill wrote in the minutes of the 6 February 1975 meeting that apparently radar data could be used to reject sites, but it was doubtful that it was sufficient to confirm a site. On the other hand, Sagan and some of his colleagues did not want to rely on photos alone. Despite all their earlier work, the landing site specialists were still nervous about their efforts to find suitable landing points for Viking.[10] Putting aside nagging uneasiness, the Science Steering Group and the Landing Site Staff met in a joint session at Langley to consider the recommended process for selecting the C sites. After more discussion of radar as a tool, further explanations of this complex business by Len Tyler, and additional considerations of the argon problem, the joint group approved the proposed plan for C site selection.[11]

Evolving a Certification Process

Along with radar and C site problems, site certification remained an open issue. In late May 1975, the Viking Project Office released one of the major products of the Landing Site Staff, a draft of the "Site A-1 Certification Procedure." This document described how the landing specialists would establish the acceptability of A-1 for landing and how they would

During the 24 February 1975 landing site working group meeting, Len Tyler explains his complex radar studies of the Martian surface to (left to right) B. G. Lee, William Michael, Thomas Mutch, Don Anderson, Richard Shorthill, Gary Price, and Robert Hargraves.

recommend a target point that maximized the probability of a safe touchdown. Their recommendations would be based primarily on their analyses of low-altitude photographs taken during the first 10 orbiter revolutions. Key to the certification process would be the stereophotographic swaths of the A-1 site taken during the fourth and sixth revolutions—called P4 and P6 photos, as the revolutions were numbered from Viking's periapsides. After playback on video recorders, reconstruction, image processing, and enhancement, these photo frames, in the form of stereo pairs, would be analyzed at the U.S. Geological Survey's Flagstaff facility, where ground elevation, slope angles, and surface roughness would be estimated. This information would be used with photo mosaics made from the orbiter frames to produce geologic maps of the proposed landing site region. Earth-based radar and telescopic observations, oblique and high-altitude photos, as well as Mars atmospheric-water detector and infrared thermal-mapping coverage of the landing site region, would provide supportive information about the nature of the surface. From this data base, landing site specialists would prepare a safety assessment report of the target zone.

During the site certification process, the Landing Site Staff would provide a series of recommendations. Just before the craft was inserted into orbit of Mars, the team would decide either to execute the normal insertion maneuver and proceed with data acquisition or to modify the maneuver if a dust storm or some other anomaly were detected during approach. After playback, processing, and inspection of the imaging system frames from a pass over the A-1 site, it might be necessary to adjust the timing of the orbit or the pointing of the camera platform to obtain optimum coverage of the site on subsequent passes. Four such data-acquisition-adjustment opportunities were planned that would affect the camera sequences at or near P3, P4, P6, and P10. The Viking team would then have to answer the crucial question: would it land the craft or reject the site the team had selected? Recommendations would be made at three points before lander separation from the orbiter. A preliminary commitment to A-1 would be made seven days before separation (at about P9), based on a preliminary assessment of available data. A firm commitment to land would be made three days later, and a precise target point would be established. A final commitment to land, made just before separation, would be determined after examining photos taken during the previous five days to confirm the absence of dust storms and high winds.[12]

In the time that remained before the spacecraft reached Mars, the Landing Site Staff continued extensive preparations for completing site certification as scheduled during the critical period between orbital insertion and lander release. In June and July, a functional test checked the ground-based hardware that would process photos from the orbiter and make the photomosaics and maps. The weakest link in the several-hundred-million-kilometer chain from Mars to the photo analysis labs in northern Arizona seemed to be the 850 kilometers the photographs traveled across the western U.S. Continental Trailways bus express, a leased army aircraft, and datafax were used to strengthen the connection between Los Angeles and Flagstaff. The team did parts of the test a second time, verifying the readiness of the processing equipment and the personnel.[13]

During the last months of 1975 and early 1976, the staff gave considerable attention to timing. Since so much depended on timely certification, scheduling became a paramount concern. The landing site specialists, working closely with the mission design team and the orbiter performance and analysis group, were ready by early February 1976 to test the timeline in what they called the "SAMPD-1" test, an exercise developed by B. Gentry Lee's Science Analysis and Mission Planning Directorate.[14]

Flight to Mars

While the Viking team calculated, planned, and debated where to land, the two spacecraft and their launch vehicles were delivered to the Kennedy Space Center. After completion of the prelaunch checkout, the countdown for *Viking 1* began on 11 August 1975. At 115 minutes before the planned launch command, a thrust-vector-control valve—essential to launch-vehicle directional control—failed to respond properly when tested, and the countdown was halted while the valve was examined. Technicians found that a slight leak of propellant had caused corrosion. The valve probably would have worked, but the project management was not willing to take chances with a $500-million payload. The launch was rescheduled for 14 August.

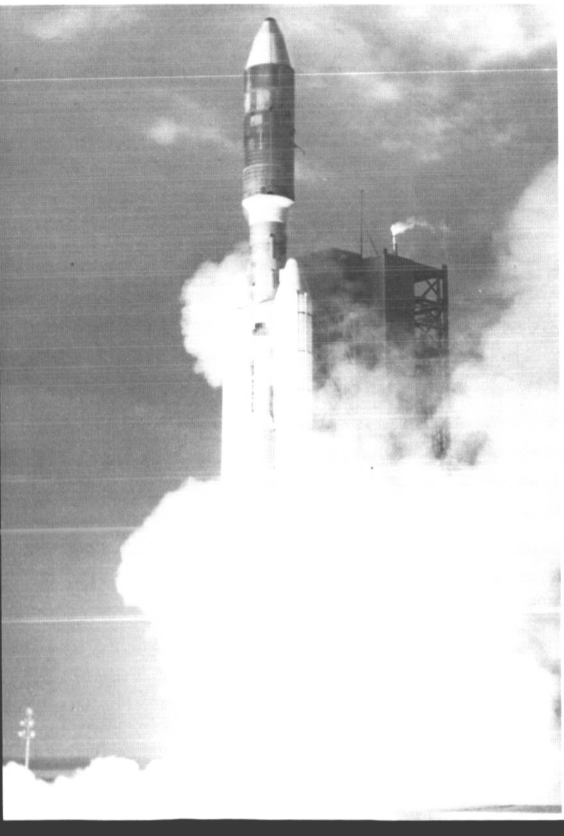
Before the faulty valve could be replaced, another problem was discovered on the 13th. A check of the orbiter's batteries showed they were producing only 9 volts instead of the required 37, having been discharged by a rotary switch that had been turned on inadvertently after the first postponement. Even though the problem was quickly traced and the managers were convinced that it was the result of a failure outside the spacecraft, the batteries still required replacement, a process that would require much time. The entire spacecraft had to be removed from the Titan-Centaur launch vehicle and replaced by the second Viking. Jim Martin and Tom Young had been prepared for such a contingency—the second spacecraft had been tested and was also prepared for launch. This dual readiness for liftoff prevented a costly delay.

Countdown was resumed, and the launch was completed without further incident. *Viking 1* was on its way at 5:22 p.m. EDT, 20 August 1975.[15] The shroud was jettisoned, the spacecraft separated from the launch vehicle, and the solar panels deployed. The star Canopus was acquired by the star tracker on the first try. *Viking 1* was off to a good start.

Repairs were quickly made to pad 41, and the second launch vehicle was readied. Batteries replaced and tested, the first spacecraft was mated to the Titan-Centaur. But new troubles were discovered in the orbiter's S-band radio system during precountdown checkout. When the difficulty could not be solved on the pad, the spacecraft was removed from the launch vehicle for a second time. After replacing part of the S-band hardware, the Viking flight team was ready to try again.

The second launch was a cliff-hanger. The countdown was going smoothly as storm clouds began to gather near the Cape. Seven minutes before the scheduled liftoff, meteorologists at the launch site said that if Viking were not launched within ten minutes the flight would have to be scrubbed because of cloud cover, high winds, and possible lightning. *Viking 2* left its pad at 2:39 p.m. EDT 9 September, just three minutes before the order would have been given to cancel. About five minutes after the Titan and its cargo disappeared into the clouds, an intense rainstorm began and lasted for more than an hour. Eight minutes into the flight, all telemetry from *Viking 2* was lost. Six minutes later, the stream of electronic data returned, and the craft went flawlessly on its way to Mars. Jim Martin may generally have discounted luck in the course of Project Viking, but on 9 September 1975 *Viking 2* was a lucky spacecraft.[16]

The Vikings had begun a journey half way around the sun. For the next 10 months, the landers would be kept in hibernation, with just enough activity to allow the flight team to monitor key systems. When the flight contollers tried to charge the second lander's batteries en route to Mars, the battery charger did not respond to the command. After several days of detailed analyses and tests on the "test lander" at Martin Marietta's Denver factory, the specialists concluded that something inside the battery charger had failed, and they used the backup charger to bring all batteries up to full charge. During November, a complete system checkout indicated that both landers were in excellent condition. Throughout the remainder of the



The Titan III–Centaur launch vehicle thrusts Viking I *upward on 20 August 1975 on its 800-million-kilometer journey from Cape Canaveral, Florida, to a 1976 landing on Mars. The spacecraft was to go into orbit of the planet in mid-1976 and, after verification of the landing site, the lander would separate from the orbiter and descend through thin atmosphere to land gently with its scientific instruments and cameras.*

cruise, lander and orbiter science instruments were prepared and calibrated for Mars operations.[17]

Jim Martin and Tom Young noted in a postmission journal article that on paper the mission operations strategy appeared sound, but the "complexity of the mission made us duly cautious." NASA had never had to operate four spacecraft (two orbiters and two landers) at one time, and the Viking managers had sought to guarantee success by extensively testing the hardware and exhaustively training the flight team. Ground system tests verified the readiness of computer programs and all the interrelated equipment scattered across the United States. Compatibility tests between the ground system and the spacecraft led to many software modifications to facilitate command signals. A comprehensive simulation system trained the flight team and checked out the readiness of the entire system, while intentionally introduced emergencies tested the ability of men and hardware to adapt to unforeseen circumstances. Martin said time and time again that he did not believe in luck. In this highly complex business, one should rely only on hard work and brains. The Viking teams tested and retested their systems, and the results often meant personnel reassignment, schedule changes, and the modification of operational concepts.[18]

Of all the tests conducted during the first half of 1976, the most important was the "A-1 Site Certification Timeline Validation." SAMPD-1, Science Analysis and Mission Planning Directorate test 1, was designed to evaluate the *Viking 1* site certification decision process. Participants had agreed beforehand that this would not be a true simulation, since the data from the test would not be run through the computers. Some of the processing equipment was still not ready and, without better information about the landing sites, to simulate photos of those areas would have been difficult. SAMPD-1 would be an intensive review of exactly what data would be available at each step and how that information would be produced and distributed. From this drill, the Landing Site Staff hoped to identify any necessary procedural changes.

Conducted in early February, SAMPD-1 was judged by different parties a success—or a failure. As mission director, Tom Young was satisfied because the exercise had allowed the flight team to evaluate the certification process and discover its weaknesses. But Gentry Lee, science analysis and mission planning director, looked back on the SAMPD-1 operation as a disaster. Flight team members had repeatedly arrived at certification meetings without knowing why they were there or else had attended them because they had had nothing else to do. After the test, Lee took steps to alleviate the confusion. He asked Norm Crabill, deputy chairman of the Landing Site Staff, to prepare a schedule for all regular meetings of the staff to be held during the actual certification process. Crabill was also called on to devise a procedure that would let all the participants know when Landing Site Staff decisions would cause changes in the flight team's plans. Updating documents, plans, and schedules was a major enterprise, matched only by the need to keep everyone working from the same revised materials.

Table 51
Major Training Tests for Planetary Operations

Test	Date	Purpose
Uplink development exercise (demonstration test 4)	2–15 Dec. 1975	To design primary mission for *Viking 1* for 12 days following touchdown. Also to train for SAMPD and prepare for demonstration tests.
Science Analysis and Mission Planning Directorate (SAMPD) test 1	8–12 Feb. 1976	To evaluate site certification process.
Continuation of demonstration test 4	22 Feb.-2 Mar. 1976	Simulated events of *Viking 1* mission from 52 hrs before separation to 8 days after touchdown, to demonstrate capability to perform all necessary sequences and respond to data gathered.
Demonstration test 5	canceled	Demonstration test 4 success obviated test 5.
Demonstration test 6	31 Mar.-4 Apr. 1976	Simulated events on orbiter 1 from 24 hrs before Mars orbit insertion to 4 days after insertion, to test downlink and uplink processes.
Demonstration test 7	7–10 Apr. 1976	Simulated lander and orbiter operations from day 11, to test activities of active science mission following first sampling of Mars's soil.
Demonstration test 4R	18–22 Apr. 1976	Detailed simulation of mission from 30 hrs before separation to shortly after touchdown, to retest sequences for separation, entry, and landing.
Training test 5	26–29 Apr. 1976	To test landed sequence for 8th Mars day and separation activities, with introduced anomalies.
Training test 3	2–4 May 1976	Simulation to test preseparation and separation activities, with introduced anomalies.
Training test 4	10–11 May 1976	To train for Mars orbit insertion, with introduced anomalies.
Operational readiness test	2–3 June 1976	Final dress rehearsal for MOI of *Viking 1*.

In all, 40 "action items" resulted from SAMPD-1, all requiring resolution before *Viking 1* reached Mars, but once those actions were taken the actual certification process would proceed more smoothly.[19] Subsequent demonstration and training tests were more successful, with each exercise pointing the way toward readiness for the active science part of the mission. On 2 and 3 June, about two weeks before *Viking 1* was to enter orbit of Mars, the last full-dress rehearsal was held without a hitch. The Viking flight team was finished with simulations. It was time for the real thing.

VIKING 1 AT MARS

"Planetary operations" began 40 days before orbital insertion, a date chosen arbitrarily. As the first spacecraft approached Mars, the pace quickened on Earth. Much lay directly ahead—final instrument calibrations, optical navigation, course corrections, approach science observations, Mars orbit insertion, spacecraft navigation, landing site certification, entry, landing, and finally initiation of the landed science experiments.

During preparation for a planned final *Viking 1* course correction maneuver 9 June 1976, 10 days before orbital insertion, the orbiter's telemetry revealed a problem. Helium gas was slowly leaking through the gas regulator that pressurized the orbiter's propulsion system. As Tom Young later described it, a ladder series of pyrotechnically operated valves opened and closed the line from a large helium bottle to the gas regulator, and that regulator was in turn connected to the fuel and oxidizer tanks. The regulator was leaking at a rate that would pose a serious problem. The gas did not leak overboard; it leaked into the fuel and oxidizer tanks, and the pressure could rise so high that not only would the engine stop functioning it would explode.[20]

Should the Viking controllers run the engines in an extra course correction maneuver, or should they fire the last remaining pyrotechnic shutoff valve in the line between the helium tank and the regulator? Another midcourse correction would use up the extra pressure without closing off the gas line, and if the pressure continued to rise after the maneuver it would not be excessive at the time of the final orbital insertion maneuver. But, alternatively, the flight team could close down the pressure line and open it again just before insertion. Jim Martin did not favor the second option because a valve failure would abort the mission. That was a risk he would not take. Martin held "a fairly hairy meeting" at JPL that day, at which he and Young favored another midcourse correction, while nearly all the other members of the team wanted to close the valve. Even John Goodlette, the project's chief engineer, preferred closing the valve. But when Martin telephoned Administrator Fletcher and John Naugle at NASA Headquarters, it was with the news that he was overriding his advisers' suggestion. He was going to make another course correction maneuver on 10 June.[21]

After that burn was executed, the leak continued, but a second engine burn on 15 June reduced the pressure in the tanks to an acceptable level. After orbital insertion, the line between the helium tank and the faulty regulator was closed and the remaining helium posed no further threat. These two maneuvers slowed the spacecraft down, delaying insertion by 6.2 hours. Additional maneuvers could have held the arrival time constant, but the men in Pasadena preferred not to waste the spacecraft's propellant.

Orbital insertion of *Viking 1* required a long engine burn—38 minutes of thrust, which consumed 1063 kilograms of propellant and was more than twice the time of the engine burn required by *Mariner 9* to enter Mars orbit. Viking had to be slowed from its approach speed of 14 400 kilometers per hour to 10 400 kilometers per hour for insertion into orbit. To bring the spacecraft to the proper point at its first periapsis, the mission flight path analysts placed it in a long, looping 42.6-hour revolution of the planet, reaching first periapsis at the time originally scheduled for the second. Previously computed timelines could be maintained with only a minimum of modification.

Great precision characterized Viking's navigation throughout the mission. After orbit insertion, the orbital period was only 12 minutes shorter than planned, even though the mission could have accepted a much larger error at that stage. And periapsis was only 3 kilometers above the predicted 1511. Other parameters were equally precise. A 21 June trim of the initial orbit adjusted the period to 24 hours 39 minutes 36 seconds, by lowering the apoapsis of the orbit from 50 300 to 32 800 kilometers without changing the periapsis. This placed *Viking 1* in the desired orbit, bringing it over the landing site in Chryse once each Martian day. Because of the 42.6-hour first revolution, for scheduling purposes there never was a "first orbit." The P1 calibration photos were lost, and the first photographs of the Chryse region were not received until the third revolution.[22]

Crisis over Chryse

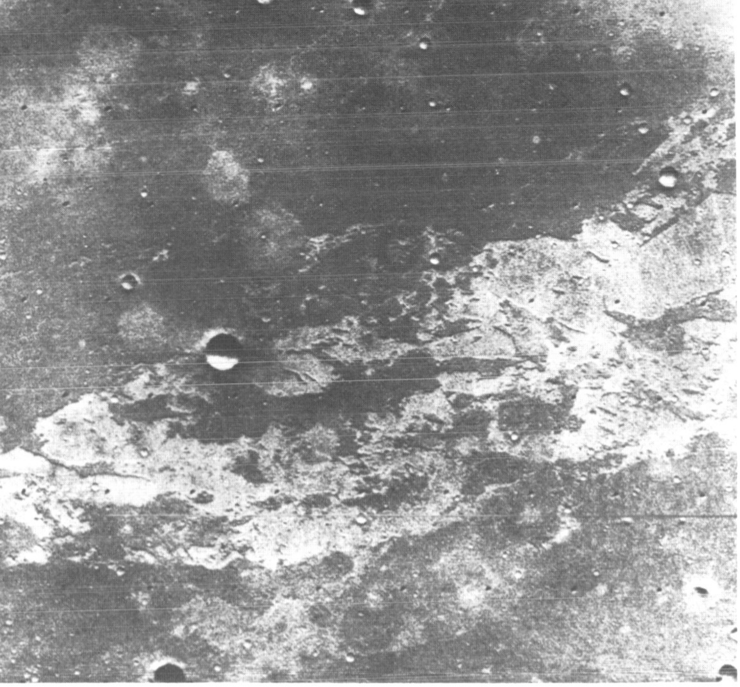
On the evening of 22 June 1976, the Landing Site Staff was holding its fifth meeting in what was to stretch into a series of 48 sessions before both Viking spacecraft were on the surface. During their early discussions, the scientists had concentrated on the readiness of men and machines to certify the landing regions.[23] In the midst of another theoretical session on the problem of extrapolating downward from the scale of the images produced by the orbital camera system to the size of the lander, reality intruded. At 6:09 p.m. PDT, the first picture of the landing site appeared on the overhead television monitor in the meeting room. Gentry Lee later told the press, "You would have believed that all the people in that room were ten years old because we all got up and forty of us ran over to the scope and watched it come in line by line." Mars as viewed by *Viking 1* did not look like the planet photographed by *Mariner 9*. Their landing site, chosen after years of debate, lay on the floor of what looked like a deeply incised river bed.

Surprise, shock, and amazement only began to describe the specialists' reactions to this first picture.[24]

Mike Carr recalled his feelings when the orbiter imaging team members began to look at the P3 data in detail. "We were just astounded—both a mixture of elation and shock. . . ." They were elated at the quality and detail of the pictures but shocked at what they saw. All their data-processing schedules had been based on a preconceived notion of what Mars should look like, and this was not it. The night of 23 June stretched into morning as building 264, which housed the Viking scientists working at JPL, became a beehive of activity. The orbiter imaging team was busy arranging photographs into mosaics, counting craters, and evaluating the geological nature of the region. All that they saw—the etched surfaces, the multitude of craters and islands in the channels (all at the 100-meter scale)—told them that the A-1 site was not a suitable place to land.[25]

The Mars of Viking was strikingly different from the Mars of Mariner for two reasons. First, the Viking cameras permitted the imaging team to see far more detail. And second, they could discriminate ground features more readily because the Martian atmosphere was much clearer. Hal Masursky remarked that large lava flows in the Viking photographs were totally invisible on Mariner images. "There was enough fuzzy in the air so all that stuff just vanished into gently rolling topography. We can see the sharp edges of little tiny lobate lava flows standing on one another." From studying the Mariner findings, the photogeologists had come to believe there were very few small craters on Mars; now they found fields of them. Masursky recalled, "Jim Cutts wanted us to . . . count all these thousands of craters. . . . That's interesting, but it wasn't necessary for site certification. You can take off your socks and count all the craters you need" to know that it was a dangerous place to land.[26] Masursky and his colleagues now understood that the dust had never really settled during the *Mariner 9* mission. Instead of a blurred surface, they now saw a fantastic array of geological detail. Mars was at once an intriguing and forbidding planet.

There were other problems, too. At the Landing Site Staff meeting on the 23d, Gentry Lee said that he was nervous about the analysis effort. Great attention had been given to planning the gathering of data, but the analysis was diffuse. Carr and Masursky shared his concern. As the data continued to pour in, it was obvious that more discipline was needed in evaluating the hazards (craters, depressions, knobs, and islands) and mapping the geological structure of the landing area. Meanwhile, new computer programs had to be written and additional consoles rounded up and plugged into the computer at the California Institute of Technology. A series of task groups was established to take on the work, and a group of JPL summer interns (engineering undergraduates) was put to work counting craters and other hazards. Carr reported that there was a period of floundering, but the landing site team soon got reorganized and back on the track. From that point, despite the long hours, the team worked more efficiently.[27]

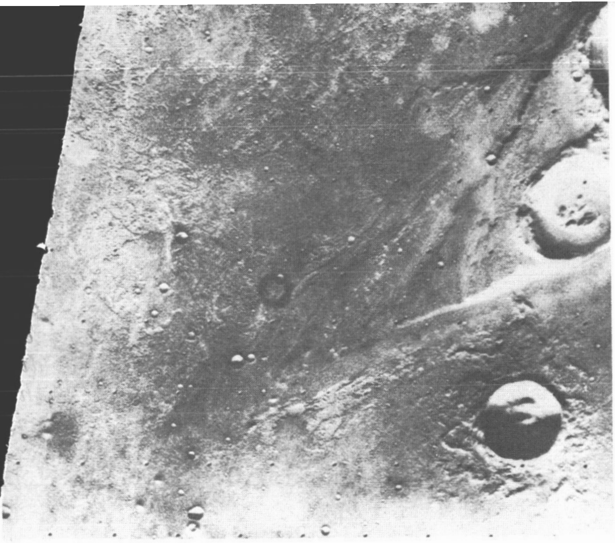


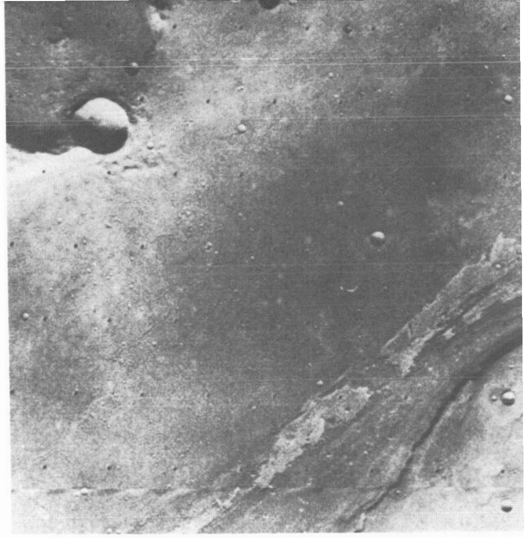
The first closeup of the C region on Mars—the A-1 ca date landing site photograp 22 June 1975 from Viking 1 *bit—changed the Viking sch ule. A channel floor with pressed areas and irregular edg as well as the many craters, d not make an inviting area for th lander. The center of the photo i at about 18°N latitude, 34° longitude. Other photos (opposite) followed.*

At a 24 June Viking press briefing, Lee explained what was going on behind the scenes. Between 300 and 400 persons participated in the site certification process. When the pictures came down from Mars, JPL, the Astrogeology Center at Flagstaff, and several other organizations went to work. Every night, a Landing Site Staff meeting was held, divided into two portions—operational and analytical. Were the photos, mosaics, maps, and the like acceptable and on time? What did it all mean? To find a safe place large enough for a landing ellipse, the team would need more photo coverage, possibly to the northeast or northwest of the prime A-1 site.[28] Apparently the spacecraft could go either direction without upsetting the timetable for a Fourth of July landing.[29] The next 28 hours were just the beginning of a very busy, tension-filled period.

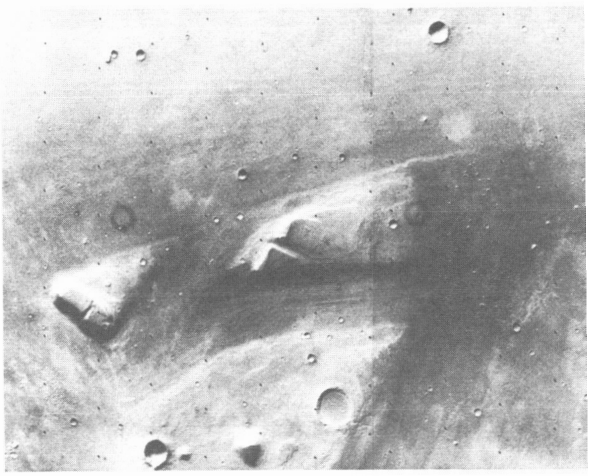
At noon on 25 June, the press heard from Lee and Carr. The Viking Project Office had decided to move the P6 photo coverage 60 kilometers farther to the northeast than previously planned, to avoid the southwestern part of the original landing ellipse where the so-called etched terrain, or scablands, were. Just before midnight on the 24th, the latest P4 photos had come in to fill the gaps in their mosaic. Lee, Carr, Masursky, and nine other members of the imaging team had sat there for more than 30 minutes sliding ellipses around on the mosaic in an effort to find an area where it might be safe to land. So far, there was no safe haven.[30] To study these images, Mike Carr had three groups working for him. Bill Baum led the analysis of atmospheric phenomena. Ronald Greeley was in charge of geological mapping. Jim Cutts and Win Farrell were making quantitative analyses of landing site hazards, and Henry Moore oversaw the mapping of these craters, knobs, and hummocks.

Two landing site meetings were held on the 25th. The discussions centered on one key question, "Do we continue at A-1, or do we prepare to go to A-2?" Masursky summed up the situation:





More photos of the Chryse region on 22–23 June 1976 told the unhappy story. The A-1 landing site was not safe. Above left, a camera on orbiting Viking 1 *photographed an "island" in a rough channel complex with eroded rims. A closer view above right shows a channel and craters. At right, "islands" with etched layers of rock are in the channel of Ares, largest channel in Chryse, in a pair of high-resolution photos. Meteorite-impact craters pepper the surface. Below, a mosaic of 12 photos is the center third of a strip taken by* Viking 1 *on its second low pass over Mars on 23 June. A-1 lies toward its center.*



The P3 reconnaissance coverage was successful in that it provided some room to maneuver the ellipse when the original location turned out to be unacceptable, and we have some overlap on the last Arecibo radar coverage at 17-18°N.

The resolution of the Viking 1 pictures is several orders of magnitude better than Marine 71 at Chryse. We can now see and identify objects as small as 130 meters, so we have a powerful tool for looking at surface texture. . . . Mariner 71 had 2 passes over Chryse—one at very high sun angle, the second at a low sun angle. . . . During the second pass, the planet was much closer and more surface textural details could be seen. The planet appears much more clearly *now* than even during the last of the Mariner 71 mission. The channels (scablands or etched terrain) we are now seeing were the vaguest kind of markings in the '71 pictures; on Viking 1 pictures we can also see layering and ejecta blankets, so we are in a much better position to evaluate site hazards and adjust the ellipse location. We are moving the ellipse around to avoid islands, craters, ejecta blankets and etched terrain. The current location is about 19.35°N and 32.5°W [the so-called A-1 South site] centered in cratered lunar mare type terrain unit. Many successful landings have been made on the moon in that kind of unit.[31]

At the end of the staff meeting, a straw vote indicated that 20 members of the group favored staying with A-1, while 24 wanted to move on to A-2. Jim Martin did not vote, but he indicated that he would take all the views into account before the decided which course to follow.

Martin was not long in making his decision known. A landing site meeting that lasted most of the day on 26 June suspended the regular order of business to let the group concentrate on two options outlined by Gentry Lee. The spacecraft could be moved immediately to the northwest for a possible landing in the region called Chryse Planitia. Photographs of that area would be compared later with Arecibo radar coverage scheduled for 4 and 5 July. Or they could reject Chryse altogether and go directly to A-2. Martin explained that he had decided not to land at A-1 (19.5°N, 34°) or the alternate A-1 (19.35°N, 32.5°) on 4 July because project specialists did not understand the processes that had formed some of the visible topographical features. Without a clear understanding of the geology at the 100-meter scale, predicting what the surface would be like at the scale of the lander would have been nearly impossible. Now that the decision had been made to give up the attempt to land on the Fourth of July, a new strategy could be established.

The team's major concern was that so little time was left for determining a course of action for *Viking 1* because of communications complications that would be posed by the arrival of *Viking 2*. Once the second craft came close to the planet, Earth-based controllers would have to ignore *Viking 1* temporarily. According to Martin, the first new milestone would come on 29 June. By that time, they would have the P8 and P10 photos from the northwestern portion of Chryse. If those images indicated an impossible terrain, the orbiting *Viking 1* would be commanded to move over the A-2 region for landing release on 20 or 22 July. Martin pointed out that it was now essential to get more coverage at the B-1 and C-1 sites. The delay in landing meant they would know less about the surface than they had planned when it came time to find a landing site for *Viking 2*. The Landing Site Staff had hoped to have orbital and surface photography that would establish "ground truth" for the orbital images. According to Masursky, "ground truth" simply meant that you could trust the 100-meter photographs to tell you there was nothing at a smaller scale that would hurt the lander. There was no time for determining such truth now.

Jim Martin especially wanted a couple of passes over the C-1 region so the photographs could be compared with the radar observations made earlier. He believed there would be suitable landing areas northwest of the A-1 site. If better targets did not materialize, they would move *Viking 1* over A-2 after photographing the C-1 area. Martin tersely explained:

> The risk we are running in this change in plans is that we may have 2 landers in orbit at the same time. The last date in July we can land VL-1 is 24 or 25 July. From July 26 through August 8, we can't land VL-1 due to Mission 2 work. If we have any problems in any of this new plan, we will have 2 landers in orbit and we may have to land one after conjunction.

Furthermore, after the November-December conjunction, Viking could not land at the C site because the region would have begun to warm up and the biologically important water would have dissipated. However, they could land the second craft at C-1 before conjunction, leaving the first orbiter and lander circling the planet, temporarily inactive. At the 26 June meeting, Martin asked the group to vote on three options:

a. Do you want to land at A-1S (19.35°N and 32.5°W) on July 4, 1976?
b. Do you want to observe NW of Chryse and plan to land there July 21 with the contingency to go to A-2 and land after August 8 if anything goes wrong?
c. Do you want to go to A-2 as soon as possible, keeping B1 and C1 observations and landing about July 22?

The votes were 24 for option a, 17 for b, 2 for c.

Len Tyler reminded the group, however, that the facilities at Goldstone, Haystack, and Arecibo had already made radar observations in the 22.5° north, 36.1° region that indicated the terrain became rougher to the northwest. He expected the upcoming Arecibo observations to confirm this evaluation, and he predicted slopes of up to 8 degrees. Mike Carr argued that the Viking lander was extremely tolerant of slopes up to 25 degrees and less significance should be given the radar results. The differences in outlook between the radar specialists and the photogeologists were becoming more apparent.[32]

Closing the meeting with, "Safety is the only consideration," Martin went to telephone Washington: there definitely would be no Fourth of July landing. It was after midnight on the East Coast when Nick Panagakos, the NASA Headquarters public affairs officer at JPL, began trying to find Administrator Fletcher. After several hours, Fletcher was reached in San Diego, where he was addressing the American Academy of Achievement. Although disappointed to hear that Viking would not land on the Fourth as planned, he immediately agreed that a safe landing was the paramount concern. He authorized a news release that could be delivered to the eastern newspapers and television networks on Sunday before the media representatives left for California to cover the landing.[33]

> VIKING MISSION STATUS REPORT
> 12:01 a.m., PDT, Sunday, June 27, 1976
>
> NASA has decided to delay the Mars landing date beyond July 4, pending a further investigation of likely sites on the Red Planet.
>
> Project officials feel that the terrain in the pre-selected landing area, called Chryse, may be too hazardous. Orbiter photographs taken during the past few days reveal a much more cratered and rougher area than previously shown.
>
> Officials want to study an area to the northwest of the primary landing site, called Chryse Phoenicia, which may be more suitable than the previously selected site.
>
> A new landing date will be selected in the next several days, depending on what new information is revealed by further site investigation, officials said.
>
> Additional details concerning the rescheduled landing of Viking-I will be discussed at a news briefing at the Viking News Center at 9:00 a.m., PDT, Sunday.
>
> Viking-I has been orbiting the planet since June 19, taking photographs of potential landing sites.

Jim Martin met with the press Sunday morning, 27 June. "After careful examination of the landing site pictures that we have been taking for the last several days, we have decided that the A-1 area . . . appears to have too many unknowns and could appear hazardous." He had decided, and the NASA leadership had agreed, to postpone the touchdown while other areas were examined. He explained the A-1 northwest strategy, which if unsuccessful would be followed by a look at A-2. By going northwest, they hoped to get out of the channel, or "river bed," and into a basin, or "river delta," region. "It has been suggested that the fine material that has been washed out of the river bed . . . has been swept downstream and maybe has collected in this basin. If so we might expect to see sand dune fields, we might expect to see craters filled with sand or dirt." He hoped this could be a better landing site. Noting they had always planned for such a contingency, he outlined the steps they would take during the next week.

After the C-1 photos became available, Martin thought the project team could draw some more decisive conclusions, but he warned the Viking specialists that even after their examinations they still might not come to understand Mars. "Things completely unknown to us" might be going on there, Martin said at the press conference. Available *Mariner 9* photography indicated that A-2 was likely to be rougher than the parts of Chryse seen thus far. Unhappy as they might be, they might have to land at a point in A-1 that they did not like. "If that were to happen, we would land some time between the 8th and 12th of July." A landing at A-2 would take place on the 22d or 23d. At this time, Martin could not be more specific; he and his advisers needed more data.

During the question and answer session that followed the press briefing on the 27th, Martin was asked if any single factor had caused him to decide against A-1. He replied that he had been concerned since he saw the first pictures and a great deal of analysis had been done since then. Hal Masursky had been working 20 hours a day; others on the team had been putting in 16 to 18 hours daily. The telling points came at the meeting on Friday evening and the long session held that day. "I came to the conclusion last night that I had enough concerns about the safety of the landing site that I thought we must go examine additional sites."

No one understood how the Martian "river bed" had been formed. Masursky added to Martin's remarks that the geologists just did not have enough data to make judgments. With just one site, it was hard to say what the surface was like; they needed comparative data. The P9 photos of B-1 and the P12 coverage of C-1 might help. Meanwhile, detailed analysis of existing data, including the reprocessing of photos using the computers, would give them a better idea of the terrain they were up against.[34]

Men and Machines

Behind the scenes, much hard work and intense activity was under way. Viking's cameras had taken some 200 photographs by 27 June 1976, and an additional 40 covering the B-1 site were taken on the 28th. Getting these images was no simple job. Masursky commented that many of the young people he had talked with had thought NASA's unmanned space projects were controlled by one great computer with no human beings involved. For Viking, the computers were essential, but they were only a tool to aid the scientists and engineers. As Masursky put it, "Computers are just like wearing shoes. You need them when you are walking on gravel, but they don't get you across the gravel." Viking was people interacting with the computers and with one another, and according to Masursky it was "an intensely human experience. It was young college undergraduates counting craters. Grunt work is what the photogeologists called it, but it was essential." Hour after hour, they peered through magnifying glasses, counting large craters and those no bigger than a pin prick. It may have been grunt work, but to someone 17 or 18 years old it was exciting to be at the center of a major space project and know your work really counted.[35]

Gentry Lee also talked of the persons who worked outside the limelight. Many Viking team members thought of themselves as Earth-bound sailors guiding their ships across the vastness of space. Jim Martin and Tom Young stood in the command center, surrounded by their technical and scientific advisers. Many of these men became known to the press as they went before the microphones and cameras to explain the problems and progress of the day. Lee, Masursky, Carr, and other members of the science team became familiar faces on the evening news. Even Pete Lyman, head of the Spacecraft Performance and Flight Path Analysis Directorate, took time out from his busy schedule to brief the media on Viking's status. But many others working "in the bowels of the organization" the reporters did not see. Akin to the boiler room crew on a ship, they did all the work necessary to enable the men at the top to pick from several options; they did all the paperwork, computer programming, and system checkouts. Lee noted that he and others toward the top of the project hierarchy got positive reinforcement for their efforts; they got their names in the paper, they got their faces on television. But the stokers in the boiler room just got groused at and told to work faster and harder. At least 60 persons reworked mission blueprints every time a change was made in the proposed landing zone or in the date of the landing. But the esprit de corps was excellent because each person was doing the job for which he had trained. They were doing more than they had expected, but pride being part of the Viking team made the extra effort a matter of honor.[36]

As things worked out, the hard work had just begun. Landing Site Staff members had to schedule their duties around noon status briefings for the press and their evening staff meetings. Sometimes working copies of mosaics were spirited off to the photo lab so that composite pictures could be released to the media. Given the strong interest and positive attitude of the news people, the photogeologists could not really complain, but such incidents were trying. It was not uncommon for new data to be delivered during staff meetings, and Masursky and his colleagues would be called on to make instant analyses before a group of several dozen specialists. Instant science became a way of life during the last days of June and early July. There was no time for idle speculation, no respite for reflection. Decisions had to be made against the clock and the mission schedules. And only human beings could make these decisions.

Which Option?

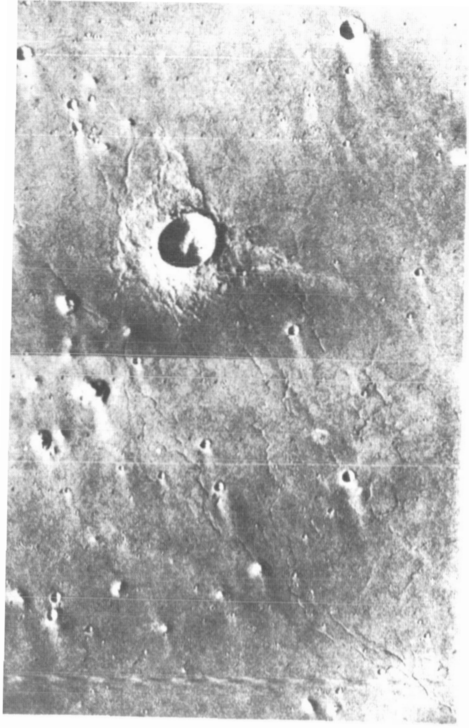
"If one sets off as Columbus did to find a new world, he would not apologize for looking for a safe harbor," Jim Martin commented to the press on 28 June. To give them some idea of the complexity of the decision-making process, the next day Martin distributed to the press a "logic flow diagram so each of you can be your own judge of where we should go based upon the evidence." After some laughter, he added, "I kid you not. You see almost as much evidence as I do. So at each milestone, you can decide which way you would go." At the two-hour Landing Site Staff meeting that evening, the attendees considered that same logic flow chart as they prepared for their big session on the 30th.[37]

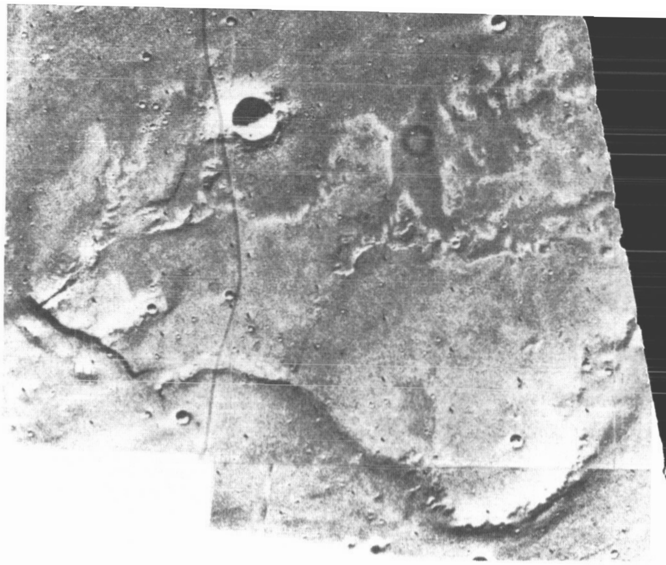
Meeting for the 13th time, for four and a half hours on 30 June, the Landing Site Staff wrestled with the three potential landing targets. During the facilities report, the men in charge noted that fatigue was beginning to catch up with some of their people. In turn, 10 specialists reported their latest information and opinions.

Masursky synthesized the A-1 site selection and certification process: Two and a half years earlier they had put the ellipse at the channel fronts "in the hope of getting wet sediments." This spring they had added one further northwest site, to avoid channel-borne boulders, and one northeast site, to include the best radar location. "In all of this, we did not anticipate that the channels would be incised deeply in the A-1 site region." *Mariner 9* had shown gentle workings in the areas where they could now see stream cratering. Comparative crater counts showed that if they had gone to "A-1 biased" (A-1 revised, formerly called A-1S, 19.35°N, 32.5°), "we would have been in reasonable shape. There is not a significant difference between A-1 and A-1NW. We did have to go further NW to avoid incised channels, but this is not a marked change. Our course is not dramatically different from what we set out on" two and a half years earlier. A-2 seemed less safe at the moment; knobs and craters were more predominant, according to *Mariner 9* findings. In the A-1 region, Masursky said, "the ranking is straightforward. Jim Cutts' crater counts clearly show that we are moving in the right direction. The choice is heavily weighted to the NW." The sun elevation, however, was somewhat higher in the P8 and P10 pictures than in P4 and P6, and lunar experience indicated that as the sun went up craters disappeared from photos.

Overall, Masursky rated the sites: A-2, worst. A-1 revised, next. A-1 NW, best from available data, the most favorable site at the moment.

When Masursky finished his summary, Tom Young asked for a vote by those who had experience or a feel for the factors. No one present was ready to land at A-1 revised. Thirty specialists favored A-1 northwest, while two wanted to go to A-2. Three abstained—Carl Sagan, Len Tyler, and Henry Moore—because there were not enough data to make a decision. Under questioning, Sagan said if he had to he would vote for science and choose A-1 revised. Tyler was strongly negative to A-1 revised and said that A-1 northwest and A-2 looked equally good. Moore favored A-1 northwest and A-2. If Arecibo radar confirmed the site, he would vote for A-1 northwest, but he just did not feel comfortable about trying to land without radar. Jim Martin closed the meeting by reminding the group that he had not made his decision, because not all the P10 photos were available yet.[38]





Views on 27 June 1976 of the A-1 NW Chryse Planitia site, an alternative to the A-1 landing site on Mars, did little to relieve Viking team worries. Viking 1*'s close look, in the two orbiter frames at left, reveals an impact crater, ejecta blanket, many small craters with wind tails (probably dunes), fractures, and knobs of rock. Above, the irregular south edge of a plateau appears to have been shaped by the flow of water.*

Fifty-three persons attended the project manager's 8 a.m. landing site meeting on 1 July. Without "rehashing" the previous night's meeting, Martin wanted to hear any new information from those who had been working all night, and then he wanted another vote. In the course of the discussion, it became apparent that the worrisome factor was the Arecibo radar observations scheduled for 4 and 5 July. John Naugle from headquarters asked the assembled specialists how bad the radar at A-1 northwest had to be "to make us go to A-2." Len Tyler said it was difficult to anticipate the results. If the data were similar to the Goldstone results for A-1, he thought they should go to A-2. Carl Sagan thought that two different situations were possible at A-1 northwest—good quality pictures with mediocre quality radar, or good quality radar with mediocre pictures. For safety, he wanted to see both good-quality radar and good-quality photographs. After some additional discussion of radar by Von Eshleman, Martin called for a show of hands. All present were asked to vote, and to discourage fence-sitting he told them that anyone who abstained would have to explain his position. Should they try to land at A-1 revised? No hands were raised. Should they try for A-1 northwest? All but one voted for this option; he favored the third possibility, A-22.[39]

At the noon briefing, Administrator Fletcher and Jim Martin talked with the press. Fletcher congratulated Martin and his people for their hard work and their apparent success in finding a safe landing site in what the

Administrator called the "Northwest Territory" (A-1NW). Martin reported that the flight team was working toward a landing on 17 July at 3 a.m. PDT. Looking back later, Martin said it had been very troubling to find geological features that the specialists neither expected nor understood. On Friday, 25 June, when the landing team was still struggling with the question of what was going on in that area, Dr. Bob Hargraves from Princeton had made a suggestion that caught Martin's attention. If you do not like this river bed area from which material has been excavated, look for the area where that debris has been deposited. "We started thinking about where that river went." Since the river bed seemed to be going off to the northwest, "that prompted our decision against landing at A-1.[40]

Gentry Lee and Hal Masursky had vivid recollections of that event. Lee commented on the decision to go northwest: "I distinctly remember the point where I believe Jim Martin changed his mind because I may have been an hour or two ahead of him. . . . It wasn't exactly as if light bulbs went off, but Bob Hargraves has a way at times of explaining things in such a—especially big geologic things—in such a way that it becomes very clear." Masursky thought it ironic that the leader of the magnetic properties team could make so easily a point that he, the leader of the landing site certification team, had been trying to get across for 18 months. But when Hargraves had said, "Let's go downstream," it had come at precisely the proper moment for Martin to react. Since Bill O'Neil and his navigators had already worked out the procedures beforehand at Masursky's suggestion, the Landing Site Staff had been able to move quickly once it had decided in which direction to move.[41]

Between 1 and 6 July, as the project team waited for the Arecibo results, the Landing Site Staff continued to evaluate existing information. During an afternoon meeting on the 6th, Tyler telephoned from Stanford, where the Arecibo data were still being analyzed. Generally, the results seemed to corroborate earlier observations that the topography between 30° and 50° longitude was rough—A-1 northwest was at 43°. Farther to the west, it seemed to get smoother. The news was not reassuring.[42]

Renewed Crisis

Two crucial meetings were held 7 July. At 8 a.m. PDT, Len Tyler presented the results of the Arecibo radar observations of early July. His remarks were essentially the same as those given over the telephone the previous afternoon:

> Observations—
>
> 1) Good data obtained from Chryse Planitia July 3, 4. Data to West and to the East obtained July 2 and 5 respectively.
>
> 2) July 3 and 4 provide detailed repeatable results from 41° to 46°W with integrations as short at 0.7° in longitude.

Results—

3) One-half power widths generally corroborate Carpenter['s 1967 observations]. Generally rough between 35° and 50°W, smoother to the East and to the West; with general quantitative agreement.

4) Chryse Planitia is a complex radar area, generally of roughness comparable to area observed by Arecibo SW of A-1 (33°-37°W, 17.5°N). On the average, Chryse Planitia and SW A-1 are not distinguishable by the current observations.

5) Spectra from Chryse Planitia on both July 3 and 4 show a sharp drop (2:1) in total reflectivity at about 44°W (23.2°N). This is interpreted as a marked increase in roughness and/or decrease in reflectivity at that location. However, the apparent abruptness of the change cannot be understood in terms of a simple two-unit model for the scattering, indicating the complexity of the area. (One needs to build specialized models to explain such abrupt behavior on spectra averaging over wide areas.)

6) Spectra from Chryse Planitia on both July 3 and 4 show a "spike" corresponding to *approximately* 42°W, suggestive of a smoother area near that longitude.

7) There is no area within the regions probed in Chryse Planitia, of size greater than about 3° in diameter, as smooth as the Martian average (assuming that the reflectivity is not also anomalously low).

Radar was saying that the surface was rough where the photographs had indicated it was smooth. The question was which to believe—whether photos you can see, but at a scale larger than the lander, or radar, which produces only spectral lines on graph paper but which supposedly has "felt" the surface. Tyler's conclusions were that the southwestern and northwestern regions of A-1 were twice as rough as the Martian average and that west of 50° the surface was back to average. Tom Young closed the morning session by summarizing their choices: (a) Go to A-1NW. (b) Go to A-1WNW—because of new radar results, no Viking visual imaging. (c) Go to A-2—because of old radar, no Viking visual imaging. "We may be surprised at A-2 and there is a timeline problem." Young sent the Landing Site Staff off to study these options before they reconvened at 4 p.m.[43]

Jim Martin summed up the new situation for the press at noon: "The visual images are only really telling us what is observable at . . . 100 meters and up, . . . Rose Bowl size hazards." Tyler and his colleagues believed that radar "feels slopes, boulders, in the order of a meter or a few meters in size." Martin and his men had a decision to make that night—go ahead with the plans for a 17 July landing or use the next day's maneuver to look for a new site in the 50° longitude area. The map looked good, but no detailed photographs had been taken in that region. Should a decision be made to look farther west, any landing would be delayed another three to five days He believed that the radar data looked good; the problem was one of interpretation, and he had to admit that there were differences of opinion as to what the radar was telling them.[44]

Martin, presiding at the 18th Landing Site Staff meeting the night of 7 July, opened by saying: "We must move forward, if not to land, to do other things. We must today tell" the Spacecraft Performance and Flight Path Analysis Directorate what direction (east or west) to go tomorrow. "The outcome of these discussions will be to continue to 23½°N and 43½°W (the A-1NW site), or go over and observe farther west. . . . We must be prepared to continue beyond 6 p.m. tonight to air all viewpoints."

Tom Young took the floor. The fifth Mars orbit trim maneuver had to be executed at 5 the next evening. "We will correct latitude and walk [move the spacecraft] westward. If we decide tonight for A-1NW, we can land on July 17. If we decide to go to WA-1NW [west A-1 northwest], we keep on walking, and land at WA-1NW about July 20 plus one or two days." The calendar of events was a full one:

Thursday, 8 July	P-19, Mars orbit trim 5.
Friday, 9 July	P-20, take 80 frames of monoscopic reconnaissance coverage of WA-1NW to 55°, contiguous to the P-10 coverage.
Saturday, 10 July	P-21, photo coverage.
Sunday, 11 July	P-22, 80 frames contiguous to P-20 coverage.
Wednesday, 14 July	P-24, accept or reject area covered in P-20 and P-22.
Thursday, 15 July	P-25, Mars orbit trim 6.
or	
Friday, 23 July	P-33, Return to A-1NW and land there.

And photography versus radar continued to be a dilemma. Site A-1NW assessment by radar was that it was "bad"; by photos, "good." Site WA-1NW radar assessment was "good," but no photos would be available until P-20 and P-22. Good photos to accompany the good radar of the "far west" would mean a landing there. Bad photos and good radar would mean going back to A-1 northwest. It was obvious that it was difficult to say exactly what the various radar signal returns meant. Sometimes the Landing Site Staff could say with assurance that a particular signal reduced to spectral lines on a graph equaled a specific terrain. Other spectra were just not fully understood. Tyler was the first to say that he did not "want to land without images" of the landing site. Young gave the group two choices—A-1 northwest on 17 July, or go west to west A-1 northwest and try for a landing on the 20th. If the pictures there were bad, return to A-1 northwest and land on the 23d.

The vote, when it came, totaled 23 for site A-1NW and 12 for going west. Essentially, the voting indicated that the scientists were ready to land anywhere and get on with the mission. Landing site and project staff members, surprised by this vote, were still playing it cautious and wanted to look at another location before chancing a landing. Martin told the group he would make public his decision that night.[45] That evening the Viking news center at JPL released a mission status report:

> NASA officials have decided to study a possible new landing area on Mars, some 575 kilometers (365 miles) further west than the previously planned site. This will delay the landing of Viking 1 at least until July 20.
>
> New radar results obtained July 3 and 4 at Arecibo Observatory indicate that a more westerly area of Chryse Planitia may be smoother than the previously selected northwest site. This area . . . has not yet been photographed by Viking.
>
> Viking 1 will perform an orbital trim maneuver at approximately 5 p.m. PDT, Thursday, July 8, to begin moving the spacecraft over to the western region, where high resolution photographs will be taken Friday, July 9, and Sunday, July 11.
>
> If these photographs indicate agreement with the recent radar data, the landing can occur as early as July 20. . . .[46]

Martin gave further details the next day at noon, and Len Tyler briefed the press on the complex business of radar observation and the interpretation of data. He tried to explain such terms as *rms slope,* "root mean square" being a specific kind of mathematical average. He talked about sending a radar beam out to Mars and then 36 minutes later measuring the nature of the reflected signal. Using the analogy of a spotlight he said:

> If Mars were perfectly smooth, one would see a single spot . . . that's about one kilometer in size. That spot would be bright; otherwise Mars would be dark. As you roughen the surface of the planet this single spot breaks up into a multitude of smaller spots so that one sees a speckle pattern around the . . . radar point. . . . This pattern would be bright and otherwise the planet would be quite dim. . . . As you increase the roughness . . . the size of the speckle pattern increases. So a very smooth location on Mars will produce a very tight pattern, and a very rough location produces a broader pattern.

While roughness affected the pattern of the reflected signal, it did not affect its strength. On the other hand, the nature of the surface—hard to soft—influenced the returned signal's power. The Arecibo data indicated a rougher-than-average surface beneath the radar spot when it was aimed at A-1 northwest. With these results the same as Haystack's radar findings of nine years earlier, Tyler had voted to go farther west.[47]

When it was his turn to speak, Hal Masursky frankly indicated that he was puzzled at the discrepancy between the photographs and radar observations. He noted that "if our backs were to the wall we would have . . . [taken] the increased risk of attempting to land in this small area embedded between the radar rough areas" at A-1 northwest. "But since we have the chance of looking just to the west . . . where the radar spectra show a much sharper, cleaner echo, then it seemed prudent to take the additional series of pictures." To put a landing ellipse in a safe part of the A-1 northwest region, "we'd have to put at least half of it outside the photographic coverage and again that didn't seem like a good idea." So Masursky also wanted to look further before committing *Viking 1* to a final landing place.[48]

Viking 1 *Landing Site Decision*

The fifth-orbit trim maneuver was executed just before 6 p.m. PDT on 8 July. After loading the spacecraft's computer memory with the maneuver command, ground controllers had temporarily lost contact with Viking for an expected blackout period, from 4:40 to 6:13 p.m. *Viking 1* performed the 40.77-second engine burn flawlessly and was on its way to look at the "far west." The next day for important decisions would be 14 July, by which time the P20 and P22 photos would be fully evaluated. Then the project team could choose between west A-1 northwest and A-1 northwest.

Meanwhile, the Landing Site Staff was trying to draw conclusions about the B and C sites for *Viking 2*. On 8 July, Barney Farmer reported on his atmospheric water studies over the Capri region (C-1 at 5°S); at this season of the year it appeared warm and dry, not biologically promising. Farmer remarked that if he had his choice free from all other constraints he would land at Hellas Planitia, which because of its low elevation (high pressure) offered the probability of more water and higher temperatures than other sites. His description of Capri led to a phrase popular with the specialists—it was "hotter than Hellas."[49]

On the 12th, the site staff met to consider the insights for the *Viking 1* site gained up to that point from the P10, P20, and P22 photographs. John Guest of the University of London had reviewed the revised and updated geology hazard map and found that neither textured surface nor grooved plains existed in the landing ellipse, except possibly some fine grooving below the resolution limit of the cameras. Additionally, channels disappeared or stopped rather suddenly, and Guest thought this indicative of their being covered over by wind- or water-borne dust or larger particles (a process called mantling) rather than their being below the resolution limit. Hal Masursky believed that existence of this younger, thicker mantling was consistent with the drop in radar reflectivity in that direction. Norm Crabill noted in the meeting minutes, "As we go west, we get into older geologic units and sharper reflectivity, with sharper features appearing further west." Masursky believed that they had reached the best location for a landing. He reported that although the slopes in the new ellipse (47.5° longitude) were as bad as those in A-1 the radar reflectivity was better. Significantly, this region seemed to have relatively few young impact craters, which meant that the area was probably covered with weathered materials that would pose less of a hazard to the lander.

Len Tyler presented findings from the continued radar analysis. Tongue in cheek, he suggested that the reflected signals dropped off significantly either because of scattering caused by the surface or because of a hole through the planet. But, despite the "Chryse Anomaly," he noted that the surface looked better at 47° to 48°. Radar data were once again the subject of considerable discussion among the specialists, but after a couple of hours Martin closed the session. They would reconvene that night to consider the additional P22 pictures processed by then and reach a decision. If they could not do so quickly, they would meet at 3:00 the next morning and continue to meet until they selected a landing site. Some tempers and senses of humor were wearing thin, but Martin continued to display his steady, firm, authoritative manner. A decision needed to made, and he intended to see it through.

Hal Masursky opened that night's session. He saw three possible landing areas: alpha, at 22.4°N, 47.5°; beta, at 22.5°N, 49.0°; or gamma, at 22.0°N, 51.0°. After the staff had moved ellipses around the photomosaics (playing what Masursky called "cosmic ice hockey"), counted hazards, and evaluated radar, alpha looked best. Mike Carr expressed an opinion held by several attendees at that late meeting on 12 July, "Don't prolong the debate, the choice is clear." Too often, he thought, meetings had lasted a specific number of hours simply because it was traditional for them to last that long. He was ready to force the vote.

The alpha site would be a compromise between the hazards visible in the photographs, primarily impact craters and the blocks ejected from them, and the small-scale surface properties "felt" by the radar. A vote was called for, and alpha, at 22.5° north latitude, 47.5° longitude, was the unanimous choice for the spot to land *Viking 1*. The 22d meeting of the Landing Site Staff adjourned at midnight.[50] Mike Carr reflected that he never had any second thoughts once the decision had been made. "I didn't realize how great a strain it had been on me. . . . When the decision was finally made it was as though a tremendous load went off."[51]

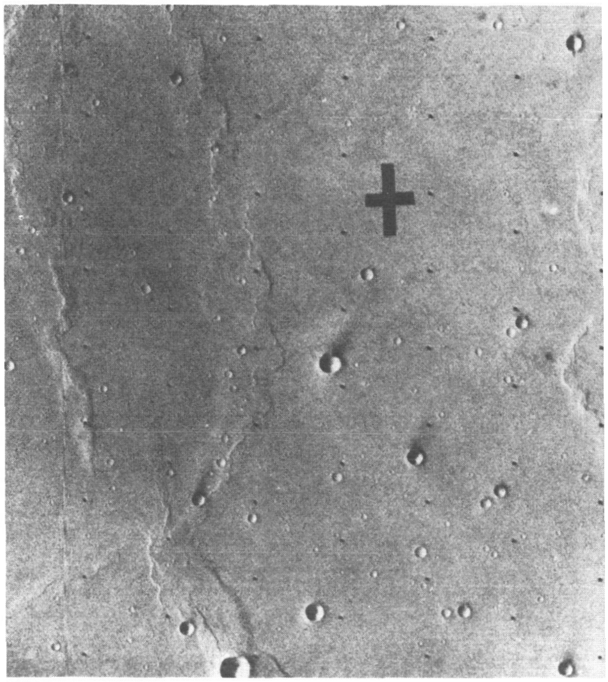
With site certification completed on the 12th and the spacecraft's orbit adjusted on the 16th, the project focused its attention on preparing for a 20 July landing. Final descent trajectory information and minor sequence changes were sent to the orbiter, and a set of commands for entry, landing, and the preprogrammed mission was transmitted to the lander. The same set of commands was transmitted to the Lander Support Office at Martin Marietta, where a computer-simulated mission was being flown.

At 5:12 a.m. PDT on 20 July 1976, the seventh anniversary of man's first steps on the moon, the Landing Site Staff learned that the *Viking 1* lander had touched down safely on Mars 19 minutes earlier. The job half done, the staff continued to evaluate sites for the second spacecraft.

SECOND SITE NO EASIER

On 14 July, after one day off, the Landing Site Staff renewed its work. As part of the project's open policy, several reporters and photographers were permitted to watch the group in action. This meeting concentrated on

Hal Masursky (above) on 12 July 1976 explains the geology apparent in the P22 photos. Jerry Soffen stands on his right. Across the mosaics, standing from right, are Tom Young, Jim Martin, Carl Sagan, Mike Carr, and an unidentified participant. Photo taken by Hans-Peter Bieman. Target for Viking 1 *in Chryse Planitia at 22.4°N latitude, 47.5° longitude is shown in a photo taken 17 July. The area, photographed from 1551 kilometers away, is a smooth plain with many impact craters.*



engineering considerations affecting latitude selection for *Viking 2*. The tenor of the discussions indicated that the C site latitudes were less favored than the B site region to the north, because the former were too high, too hot, and too dry. Debate continued as the Landing Site Staff once again tried to evaluate a landing zone without having seen the surface.[52]

On the 16th, Hal Masursky led off the day's session by asking what they would learn if they could put a spacecraft down in each of the sites they had considered. A-1 was where the largest Martian channel complex opened onto Chryse Planitia. According to Masursky and Crabill, it was "the best area to observe where water and possibly near-surface ice had occurred in large quantities in the past—the optimum place to look for complex organic molecules." B-1 had been selected because it was in a region where high water vapor concentration might be expected; also, at this longitude the two orbiters could provide relay support for either lander. C-1 and C-2 had been chosen because they had appeared safe to the radar team. The landing site team had to choose between B and C for *Viking 2*.[53]

Among others, John Guest, Mike Carr, and Ron Greeley presented their thoughts on the nature of Martian geology in these regions. Harold Klein gave his reasons for preferring B; central to his argument was water. And Josh Lederberg, also believed that there was a better chance for water at the northern latitudes. Vance Oyama dissented, saying that the B region was too cold; the temperature was always below freezing. The next day, only 4 members of the group were in favor of the C sites (5°S), while 30 wanted to go to the B region (44°N). Jim Martin reminded them he would have to make the final choice for the second mission by 3 p.m. 24 July.[54] A poll was taken again on the 21st after the first *Viking 1* pictures of the surface had been studied—3 favored the C latitudes, while about 40 voted for B.[55]

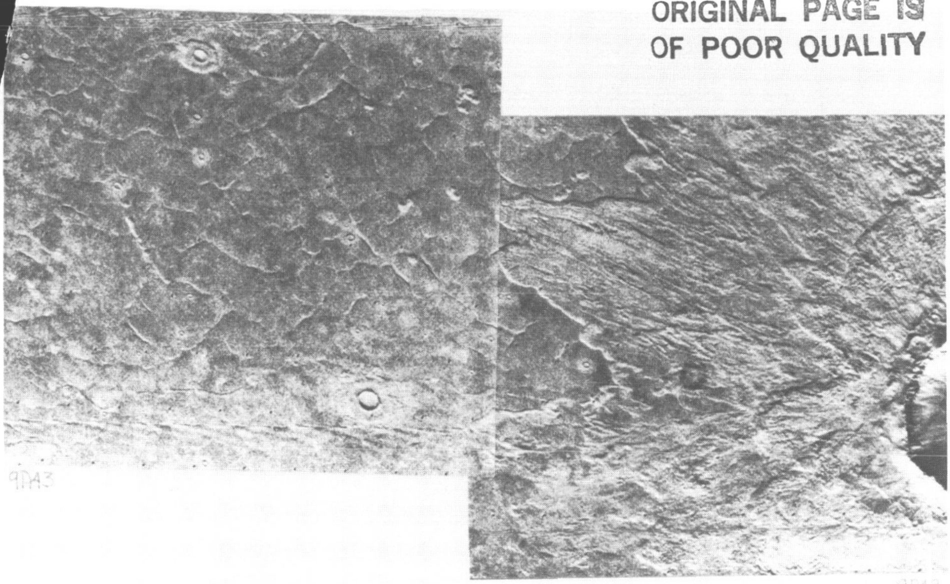
Worries about the B Sites

Cydonia (B-1, 44.3°N, 10°) had been chosen as the *Viking 2* prime site because it was low, about five to six kilometers below the mean Martian surface, and because it was near the southernmost extremity of the wintertime north polar hood. B-1 also had the advantage of being in line with the first landing site, so the *Viking 1* orbiter could relay data from the second lander while the second orbiter mapped the poles and other parts of Mars during the proposed extended mission. While this was a good spot to find water,* Masursky was worried about the geology of the region. He asked David Scott, who had prepared the geology maps, to work up a special hazard map for B-1. After studying the map, Masursky came to the conclusion that the area was not "landable." This analysis, of course, was made with maps based on *Mariner 9* photographs. He told Tom Young and Jim Martin, however, that there was one hope; wind-borne material may have mantled the rough terrain and covered "up all those nasties we see."

The first pictures of B-1 were taken on periapsis 9, and it was worse than Masursky had imagined. "But it was not particularly a shock because I was scared to death of that site before it happened." Masursky proposed a big swath of pictures heading off to the northeast to about 57° north. Somewhere in the "Northeast noodle," he hoped that they would see the mantling develop and cover the rough terrain. Because of engineering constraints, however, *Viking 2* could not land above 50° north. "So," according to Masursky, "we cut off the noodle and . . . called it the 'Northeast rigatoni'—that's a short noodle."[56]

Meanwhile, the lander science team was having some worries of its own with the lander on the surface. The seismometer had failed to respond

*If the pressure was as high as 7.8 millibars and the temperature rose above freezing, liquid water was possible at Cydonia.



The first pictures of the Viking 2 *site were not very promising. Photos of the preselected primary landing site, Cydonia, were obtained 28 June by* Viking 1 *orbiter cameras from a range of 2050 kilometers. The rim of the crater Arandas is on the right edge. Rocks outcrop in the inner well, and ejecta form a lobate pattern with surface ridges and grooves. Small pedestal craters may have been caused by impact and etched out by wind. The center of the left photo is at 43°N latitude and 7.6° longitude; the right, 42.4°N latitude, 7.3° longitude.*

to actuation commands from Earth, and some transient communications difficulties had to be corrected. But most significant for the Landing Site Staff, the sampler arm on the lander had stuck on the third day of the landed mission (sol 3). Although the Viking team was able to diagnose the difficulty, devise and test a solution, and free the sampler boom assembly in time to collect soil samples on schedule (sol 8), the problem emphasized the importance of safely landing *Viking 2*. Simply put, if *Viking 1* failed, then no chances could be taken in choosing a landing site for the second mission. All the tension and pressure experienced during the past month reappeared.[57]

With the second spacecraft about 2.7 million kilometers from Mars, Martin told the press on Sunday, 25 July, that the navigators were going to make an approach midcourse maneuver at 6 p.m. PDT on the 27th to position the craft for orbit insertion on 7 August. Targeting the spacecraft for about 46° north, "we're going into an orbit which will allow us to spend some time observing three possible north latitudes. Two of them are known as B-1 and B-2. . . . We've spent a fair amount of energy looking for landing sites in B-1; so far we haven't seen anything I would like to put an ellipse in." Continued observation of the B-1 "rigatoni" identified a complex history of "aeolian deposition interleaved with erosion stripping." As Masursky and Crabill reported in *Science*, in some places secondary crater clusters peppered the small plains. In other areas, stripping of the uppermost aeolian mantle had left secondary craters protruding as hummocks where crater ejecta had inhibited stripping. "In any case, the small areas of aeolian mantle were not large enough to locate an ellipse in, and the entire B-1 region was rejected."[58] During the 27 July Landing Site Staff meeting, held just before the successful execution of the midcourse correction maneuver, Masursky indicated that there were several nice little spots in B-1 but they were only one-tenth the size of the necessary landing ellipse.[59]

A suitable landing site had still not been found in B-1 when *Viking 2* went into orbit on 7 August at 5:29 a.m. PDT. Project strategy now called for using the second orbiter in the search for a site at Alba Patera (B-2) or Utopia Planitia. Masursky and Crabill noted that coverage of Alba Patera during P4 and P7* "raised and then dashed hopes that it would prove to be a suitable landing site." On revolution four, the photo calibration sequence indicated a possible site in the northern region of Alba where Masursky had located his first ellipse using *Mariner 9* images. As Young and Masursky watched the P7 pictures come in on the digifax machine, the region still looked smooth. Thinking they had found a likely prospect for a landing zone, they decided to get more pictures during the 15th orbit.[60] During the night, the mosaic team pasted up all the P7 photos, and Masursky was shocked by what he saw. Where the individual photos had shown a smooth terrain, the mosaic revealed a territory that was "rougher than hell." The difference was in the computer processing; under the proper processing, the region appeared very rough, covered by textured lava flows. Masursky thought to himself, "I think we've got a problem." He called for a special meeting of the landing team on 17 August.

Gentry Lee opened the 42d meeting with a review of the "fast breaking events" since the previous day. After closer examination of Alba Patera's "smooth" spots, Masursky had concluded that it was not smooth enough. "Nothing in B-2 looks comfortable." Lee also noted that "we have an exhausted crew, as evidenced by the high frequency of errors in the products, from trying to maintain all four options." Those choices had been labeled B-2 early, the earliest site at which they could land; B-2 late, the latest site at which they could land; B-1; and B-3. Earlier that day, the Landing Site Steering Committee, an independent group of scientists advising Martin, had met and decided to drop the first three options and shoot for B-3. This decision was the most controversial action taken during the entire site selection-certification process.[61]

Masursky recalled the events that led to that decision. At the 17 August steering committee meeting, he told Young and the others that B-2 was just no good; they did not need to break their backs getting the P15 photographs. Since B-2 was out, everyone also agreed to drop B-2 early, and Masursky concurred. But then someone suggested getting rid of B-2 late, as well. Masursky protested; they had not "even looked at the rest of the pictures in the B-2 area." However, they dropped the B-2 late option since it

*These orbit numbers (periapsides figures) are for the second mission.

would save work and time. The next recommendation was that a candidate they had been calling "B-1 awful" be scrapped, too. "We were taking six more sets of pictures there . . . to see if we could find a site," Masursky remembered. Dropping "B-1 awful" cut out another option. The meeting had lasted only 15 minutes, when others had lasted hours. Masursky left the session stunned: "We had committed the project to landing at B-3 where we had zero data."[62]

What happened at that meeting? Gentry Lee reflected that each man in the Viking management had a different perspective and a different worry, even though they were all directed toward the same goal. From his perspective as manager of the Science Analysis and Mission Planning Directorate, he worried about his team; by mid-August he had a near mutiny on his hands. His people had to preserve four mission alternatives. To do that, "They had to do every day four times as much work as normal. They had to have a plan for what was going to happen eight days in the future on each of those options and so those poor people were just about to bite the dust." Norm Crabill also noted that the flight team was too tired to jump through any more hoops. Young and Martin saw the signs as well. Masursky was not happy with the decision, but being a team member and a team player he agreed to try for B-3.[63]

B-3 called for a landing late on the afternoon of 3 September. From that location, called Utopia Planitia (47.9° north, 225.9°), 186 photos would begin coming in the night of the 17th and continue being played back until 2 a.m. PDT on the 21st. All observations previously planned through P15 would still be made and processed, but no operational planning would be done for any of the B-1 or B-2 areas.[64] According to Masursky, the B-3 pictures looked terrible. While he was pondering the situation in the photomosaic room at JPL, he was visited by Henry Moore, who picked up a recently completed mosaic of B-2. Moore found what looked like "sand dunes all over that area" and called over his colleague. "Hank, I think you're smoking pot!" was Masursky's first reply, but when he looked at the mosaic he had to concede that there might be dunes. Because of poor exposure, it was difficult to tell, so they worked up special enhancements. "My God, that really looked good. That looks like that area is really covered by dunes." B-2 west was a promising area. Next they spotted smaller dunes in the B-3 region (48–49°N, 220°) that covered the ejecta blanket outside the large crater Mie (100 kilometers in diameter) and actually went into the crater. Farther to the west, some faint marks could be interpreted as the beginning of aeolian-deposited mantling material. This discovery led to a whole new debate: " Do dunes cover rocks, blocks and other hazards created by the erosional and cratering processes that might otherwise menace a lander?"[65]

The dune controversy began on the afternoon of 18 August and continued through the final site review on the 21st. Openly admitting his preference for the B-2 area where they had spotted the dunes, Masursky developed a new argument for landing there. In the absence of lunarlike mantles, dunes offered reasonable protection from rocks and blocks. Big dunes, as seen at B-2, offered better protection than the small dunes seen near the crater Mie. Before the meeting on the 21st, one of the landing site team members told Masursky that they would have to land at B-3. They could not "announce on Tuesday that all options are closed off except B-3, and then on Saturday decide to go back to B-2." Masursky believed they would "do the right thing."[66]

On Saturday afternoon, 21 August, a formal review of two candidate sites—B-2 west and B-3 east—was held. During the first mission search, individual rock units had been mapped but, during the *Viking 2* analyses, hazards had been defined in terms of debris ejected from craters, steep slopes, or areas subjected to different processes (stripping, mantling, and texturing). All these features had been mapped to determine favorable areas, and those mapped features were the center of discussion. Tom Young reminded them that safety was the fundamental issue but that they must try to keep "the science factors visible." And Hugh Kieffer reported on his infrared thermal-mapping instrument (IRTM), which was being used as a substitute for radar since there was no radar information for the northern sites. Masursky identified the five candidate ellipses:

B-3 East	alpha	47.2°N lat.	224.9° long.
B-3 East	beta	48.0°N	228.0°
B-2 West	I	44.1°N	154.9°
B-2 West	II	47.3°N	156.6°
B-2 West	III	43.5°N	153.0°[67]

In their report in *Science*, Masursky and Crabill evaluated these areas. The dunes in the B-2 region appeared to be bigger and apparently thicker than those in B-3. In B-3 there seemed to be some favorable aeolian mantle, even if it showed signs of being pitted. The northern part of B-3 looked better; cracks became shallower and craters were less abundant. Because of defects in some of the B-2 photos and an atmospheric haze that had obscured the surface, the interpreters were cautious in their estimates of the dunes in that zone. Some of the photogeologists believed that the decreasing number of small craters in B-3 would continue down to the scale of the lander. Some felt that the B-2 craters and ejecta blocks, being smaller than those in B-3, were better covered by B-2's bigger dunes and that B-3's smaller dunes might not cover the ejecta from the larger craters there as well. Still others favored site B-3 because they thought it appeared smoothed by uniform mantling. It was Tom Young's opinion that, although the geological conditions at B-2 east and B-3 west were different, the hazards gave them about the same safety ranking.

Continued discussion at the meeting on 21 August centered on the size of the block hazards that they might encounter. Their best analyses predicted that the wind-borne mantling material was sufficient to cover the small blocks thrown out of the craters by meteoritic impact. In the region of the crater Mie, it was hard to project what size blocks could be anticipated. Rocks up to 10 meters in diameter were not ruled out, because of the ejecta measured in the *Surveyor 7* lunar landing site and *Apollo 15, 16,* and *17* high-resolution photographs of the moon. According to Masursky and Crabill, "The block populations depend on the number of small craters below the resolution limit that may excavate blocks from below the wind-laid mantle and the number exposed by deflation. Slopes were deemed acceptable based on Earth analogs, except on the inner margins of craters."[68] Hugh Kieffer's infrared thermal-mapping device did not provide conclusive assistance in selecting a site. When the pictures looked good, there were no IRTM data. Where the IRTM gave good results, there were no photographs. For no site were there both photos and IRTM information. From the IRTM, B-2 looked less blocky than B-3, but with the IRTM the latter looked a good deal like *Viking 1*'s landing point. After nearly two hours of discussion, a dinner break was called.

The meeting reconvened at 6:35 p.m. "Is there demonstrated evidence that a significant increment in safety exists in going to B-2 that warrants changing the current plan to go to B-3?" asked Tom Young. Mike Carr thought the larger dunes in B-2 argued for safety, but then so did the effects of wind in B-3. Klein and Biemann favored B-2 because more water might be present for the biology experiment. After a number of other opinions had been expressed, Young called for a show of hands on two questions: "Should we select B-3E/B-2W or continue to search? If we decide on a specific site tonight, should it be B-3E or B-2W?" Of those voting, 28 wanted a site; 9 wished to continue searching. The B-2 site would be chosen by 20, B-3 by 10.

Jim Martin concluded the open part of the meeting by requesting Tom Young, Gentry Lee, Jerry Soffen, Carl Sagan, Hal Masursky, Norm Crabill, Mike Carr, Hugh Kieffer, Conway Snyder, Brad Smith, Tim Mutch, and Bob Hargraves to attend an executive session of the Landing Site Staff. Young favored B-3 and enumerated his reasons: (1) Safety—B-3 appeared to be mantled, muted, and filled. With all that cover, it was hard to believe that there could be serious hazards to the lander. Since Carr and others were not particularly confident about B-2 because of the visibility problems, Young liked B-3 better. (2) Science—Young saw limited distinction between the two. B-2 might have a slight edge because of more water and higher temperatures, but those elements did not outweigh the safety differential between the two sites. As Masursky and Crabill pointed out, "The most significant scientific distinction had already been realized when the northern latitude band was selected." (3) Operations—The landing would be more straightforward at B-3. To land at B-2 would require additional data analysis, and that would delay the landing significantly (according to Martin, the delay could be as long as two or three weeks). Such a delay, attended by greater operational complexity, did not seem to be justified by his readings of the two sites.

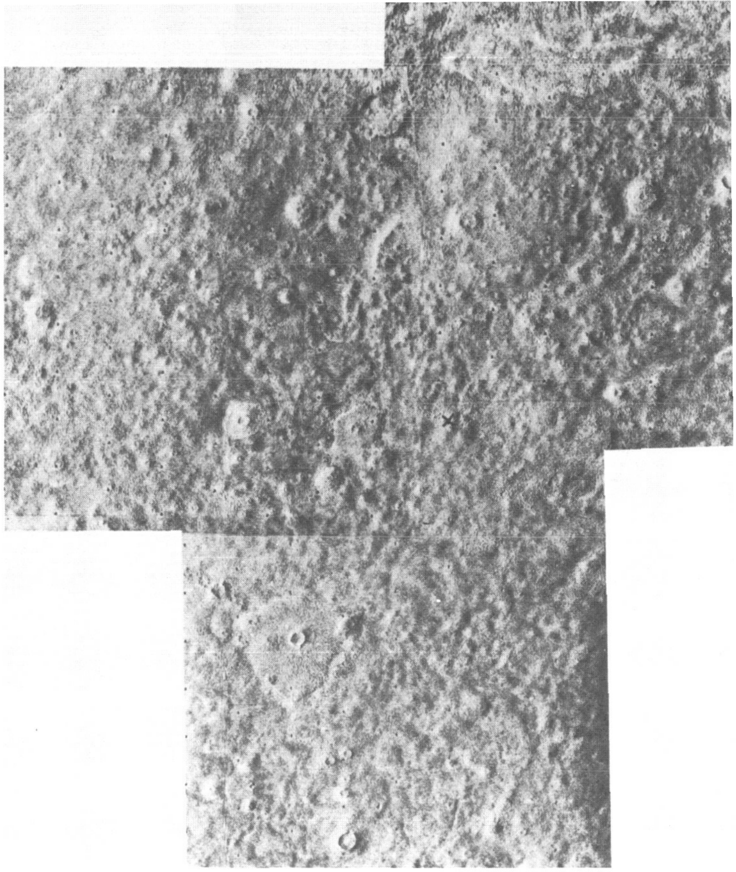
Project Manager Martin agreed with his mission director. He noted that several of the scientists wanted to do more ambitious exercises with the second lander, but he believed that additional observations of B-2 would work an already tired team into the ground. He could not see imposing such a killing load on the flight team. After some brief comments from others, Martin said they would go with B-3. It was safe enough; it had good enough science. There was no radar, but he was willing to take that risk. Gathering around the B-3 east stereo mosaic, the group determined the preliminary coordinates—48.0° north, 226.0°.[69] Final coordinates were chosen on 30 August after reviewing the P20 photographs: 47.89°N, 225.86°.

Renewed Drama

An orbital trim maneuver on 25 August 1976 ended *Viking 2*'s walk around the planet. Two days later a final trim synchronized the periapsis point relative to the landing site, which was centered 200 kilometers from the crater Mie. Before preseparation checkout of the second spacecraft, mission control put the first lander into the "reduced mission mode," permitting the flight team to concentrate on the second craft. At 9 a.m. PDT on 3 September, the Viking Flight Team met for the "go/no-go" separation meeting. With the exception of one of the terminal descent radar beams and a gyroscopic stabilizer that had given them some trouble, there were no problems with the spacecraft; all systems were "go" for separation. The radar problem was solved by locking out the troublesome unit, since the lander could touch down with only three of the landing radar beams functioning. And further analysis of the Y-axis gyro led the specialists to believe that it would not give them any trouble. *Viking 2* was ready for the big moment—separation and descent to the surface.

When asked how he assessed the risks and dangers of the Utopia site as compared to the Chryse site, Martin replied that he believed Utopia was safe. Even without ground-based radar information, he believed the processing of the planet had laid a thick mantle of sand or soillike material over any rocks and obstacles such as seen around lander 1. The Utopia area appeared to have perhaps more undulations, hills, and valleys, but he thought the slopes were gentle, and only 10 percent as many craters were visible. To the query, "Do you call 155 foot [47-meter] high sand dunes a better landing area?" Martin replied:

> Well let me say that there was not unanimity in the selection of this landing site. My job is much easier when everybody gets up and says let's go this direction. Well, here we had a case where people were wanting to go in a couple of different directions. I still believe that from my own



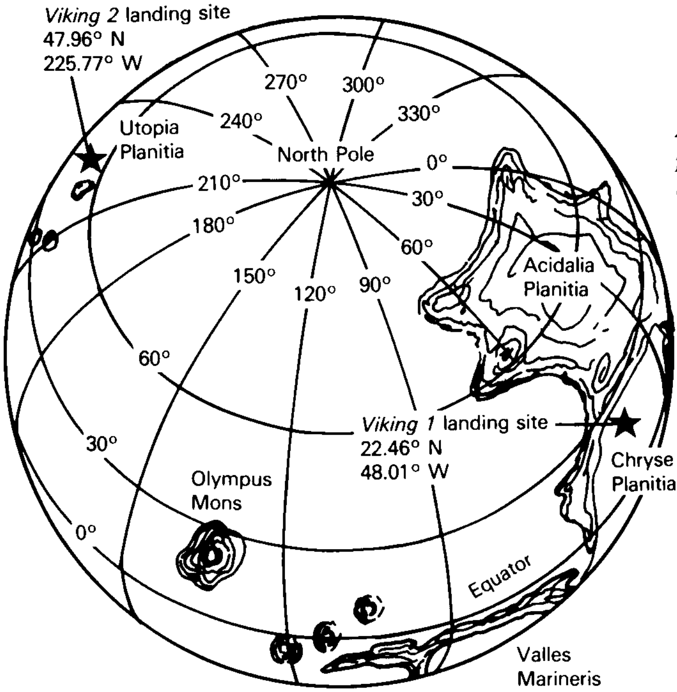
anding site for the second Vik-
g lander is chosen in the east-
n end of Utopia Planitia, 48°N
titude, 226° longitude. These
hree photos were taken by the
Viking 2 orbiter 16 August 1976
from 3360 kilometers away.
Rough ground and craters ap-
pear blanketed by dunes.

> knowledge of big sand dunes, that we can land on essentially any sand dune in the United States. I think the Lander is very tolerant to this kind of hazard. I think it is very intolerant to big rocks. So I would trade sand dunes for big rocks any day.[70]

On 3 September, the world would be able to judge the wisdom of the landing site team's decision.

But there were some heart-stopping moments before Viking mission control knew that the lander was on the surface. Confirmation of separation came as scheduled at 12:39:59 p.m. Three seconds later came an indication that the orbiter had been upset. Twenty-six seconds later the power supply to the gyros on the orbiter cut out; the second power unit went out at 12:41:19. Without power, the inertial reference unit, which kept the orbiter aligned properly in space, could no longer control *Viking 2*. As the spacecraft began to drift off course, its high-gain antenna lost contact with Earth. Within minutes of the failure, the orbiter's computer sensed the problem and commanded the backup inertial reference unit to take over and stabilize the attitude of the spacecraft.

While the men in the Deep Space Network worked to regain contact with *Viking 2*, the lander was on its way to the surface. To monitor the progress of the descending craft, the flight team tensely watched a small stream of engineering data coming down through the low-gain antenna. Throughout the Jet Propulsion Laboratory, project personnel, news peo-



A view from the Martian north pole shows the location of the two Viking sites.

ple, and guests waited, subdued, for each little clue that would tell them all was going well.

At 3:58:20 p.m. PDT (9:49:05 a.m. local Mars time) on 3 September 1976, the second lander touched down safely. Cheers mixed with sighs of relief, though the crisis was not over yet. The Deep Space Network worked with the flight team to get the proper commands to the orbiter. Once the spacecraft locked back onto its celestial reference point—the star Vega—Earth control again began to recover mission data, including the first two photographs taken by the lander's cameras immediately after the craft had reached the Martian surface.[71]

Viking 2's landed photos illustrated a much rockier terrain than even the first site. One rock near the lander's footpad in the first picture looked as if it had been moved during landing. Martin and Young reported that the panoramic second picture revealed "a flat horizon and a landscape strewn with many rocks of various types. The tilt of the horizon indicates that the spacecraft may have landed on a rock." They also noted, "As a surprise, the panorama shows none of the sand dunes expected from the observations from orbit. A generally featureless terrain spreads flatly toward the horizon, more so than at the site of *Viking 1*."[72]

Lessons Learned

After the second landing, seven key Viking team members talked about the landing site selection process. Of the lessons they had learned, had they labeled any as especially significant? If later there were a third mission, what would they do differently? All these men had worked toward the same end—safely landing two spacecraft on the Martian surface—but they had viewed the experience from seven different perspectives.

James S. Martin. Support for his decisions from the space agency's top management in Washington figured highly in Martin's recollections. Postponing the Fourth of July landing had probably been one of his most difficult moves. Martin had been "quite horrified" by the first photographs of Chryse, remembering the rough dry river beds and uneven washes he had walked over in Death Valley. And the river bed they had seen on Mars was many times larger, with cliffs hundreds of meters high. It has been his choice to make, and he had wanted a safer site. Martin remarked that even if Viking had safely touched down on the Fourth of July, the landing "would have been lost among the Tall Ships," a reference to the publicity given the bicentennial parade of ships in New York harbor. That historic date had been chosen in 1970 after a preliminary trajectory analysis singled out the first week in July 1976 for a landing, but the Red Planet had not cooperated. The bicentennial was celebrated without a Viking on Mars.

If Martin were going to land a third Viking, he would make some changes. He was unhappy with the data with which they had had to work. If there were to be a next time, he wanted to equip the lander with a terminal-hazard-avoidance device or a computer-controlled laser guidance system that could evaluate the surface and pick the safest part of a general area in which to land. Both kinds of hardware were available; the latter concept had been used in "smart bombs" in Vietnam. Martin and all his colleagues wanted more information guiding the next Viking on its final approach. A terminal guidance system would eliminate any radar versus photography controversy, Martin suggested, still skeptical about the use of radar.

> I'm not convinced that the radar told us anything useful at all. But on the other hand, I believe that it provided an input and a source of information that [we] could not ignore. . . .
>
> I looked at the radar as a source of data. I frankly never did . . . accept it as an absolute. . . . But I've got to believe that when they get a pass, like at that Northwest Site, and there's something screwy right in the middle of a place that looks just like everything else [in the photographs], the radar is seeing something. For all I know, it was seeing sand dunes . . . it could have been seeing something perfectly safe, but the fact that it was so different scared me off.[73]

A. Thomas Young. Radar played a useful role, Young believed, as he reviewed the background of using radar as an aid in landing site certification. "When we went through the initial selection [process], radar played no role, because we weren't smart enough to know how to use it." But Young and Gerald Soffen had gone to Stanford University to confer with Von Eshleman and Len Tyler.

NASA provided the funds for Tyler and his colleagues to develop the means of interpreting radar data so this tool could be used to evaluate the nature of proposed landing sites on Mars. Young's basic philosophy had been: "Use whatever tools we had available to the maximum extent we could, recognizing that none of them was good enough for absolute site certification." He thought they had probably used this tool before they fully understood what the signals meant. While the technique for interpreting radar data had not matured to the extent that they had absolute confidence in the results, he believed that the radar signals received from the A-1 northwest site did indicate that it was unsafe. Above all, Young commented, they had to be responsible in how they used the data provided them.[74]

Gerald A. Soffen. As project scientist, Soffen was interested in the process of scientists at work and concerned that that work be consistently credible. Caught in a philosophical frame of mind after a few days' rest, Soffen said he believed that the crisis over the landing sites had forced them to study the planet with an intensity that would not have existed if Mars had been as bland as *Mariner 9* had led them to believe. Talking about the days between 23 June and 21 August, Soffen said:

> We learned about Mars in that period. And it is sad to say we will probably never learn as much from the Orbiter pictures . . . as we did during that intensive period—because we had to. Because people were forced around the clock to do work and integrate their efforts in a way that unfortunately they don't do simply because they are inspired. Inspiration works to a very small extent on any person. What drives us is necessity. . . .

Soffen's observation was that, since only so much data could be collected and since they were working against the clock, the scientists could not retreat into the familiar excuse "I need more data."

> Because time was an element that we could not sacrifice, the energies of the people and the brilliance, deduction, the thought, the concerted effort, was as intensive as anything I have ever seen. . . . It was most remarkable. Remarkable because I saw people who otherwise have to take days off, have to take time off, have to relax. Their adrenalin kept them going in a way that I have never seen. . . . That was the moment in which the true concept of a team met its test. It was like an army that was desperately fighting for its life. It was either going to win or it was going to lose. It is not a question of "Maybe I'll survive and they won't." We're all in the same space program.

Soffen believed some important lessons were learned during the search for sites. First of all, they had erred in trusting the Mars maps based on *Mariner 9* findings. He suspected that if someone had shown the Landing Site Staff the actual photographs or had verbally described the surface of the planet to them using the raw data, they would not have had such confidence. "But seeing the U.S. Geological Survey maps, the straight lines and real numbers and real elevations, gave it an air of credence. . . ." A second lesson was that real-time decision-making had to be a combination of effort between mission specialists and managers. Before Viking arrived at Mars, Soffen had formed a four-man landing site advisory group—Josh Lederberg, Brad Smith, Toby Owen, and Carl Sagan—to listen to the site certification deliberations and advise Soffen, Young, and Martin. But events moved too fast. There was no time to reflect and cogitate; decisions had to be made; Landing Site Staff meetings never followed a neat pattern.[75]

Hal Masursky pointed to the same problem. Mosaics, just recently pasted together, were often brought into meetings in progress. There he was, faced with interpreting completely new information on the spot, with everyone waiting for his words of wisdom so a decision could be made. "That's hard to do," he noted. "Emotionally and managerially it's not the right way to do it. You need to work, digest, come to conclusions by arguing and then pass on a recommendation." But there was never time. For example, the team would schedule 8 days for the analysis of a particular issue, but the specialists might be able to devote only 10 seconds of wits-gathering to the problem. Pressure from the mission schedule made the scene tense, and too often general scientists, members of the landing site advisory group, for example, had to defer to specialists. Masursky, among others, was not as concerned about the pace as he was with the precipitous nature of their decision-making. But they had committed themselves to the real-time game, and decisions had to be made on schedule.[76]

One other observation Soffen made dealt with spheres of influence. Position in the project heirarchy had little to do with power of influence over Jim Martin, "an absolute dictator," in Soffen's words. If any one person—regardless of rank—had an idea that made good sense to Martin, he listened and acted accordingly. During early July, it had been Tyler who had held center stage with his radar data. "A week earlier we dismissed what Len Tyler had to say, as though we weren't interested," Soffen recalled. The activity of so many intense individuals working closely together gave the site selection-site certification process a dynamism typical of the entire Viking effort.[77] Such a human endeavor needed discipline.

B. Gentry Lee. If Jim Martin were the dictator, as many had suggested, Gentry Lee was the intellectual disciplinarian. From his vantage point as science analysis and mission planning director, Lee noted that "we went into the site certification process with two distinctly different views of how it was going to operate." Many project personnel members—Lee, Martin, and Young among them—did not want to deviate from the previously selected sites unless it were absolutely necessary, since they were relatively certain they had found the best sites available. All the mission operating plans were designed for those targets, with time and money arguing against changes. But a second group, primarily scientists, wanted to search for even better sites during the certification process. Caught between the two were men like Mike Carr and Hal Masursky, who simply wanted to see that the spacecraft landed safely in a scientifically valid location. Probably the only thing that averted open controversy was the terrible nature of the prime Chryse region.

Lee found himself in the role of interlocutor. Even more important, it was his task to ensure that the operational people and the scientists understood each other's needs and limitations. Lee participated in the Landing Site Staff meetings not only to translate for each group the other's goals and problems, but also to make certain that the discussions remained germane to the issues at hand. When they did not, he turned disciplinarian, "trying to get people back where they belonged."

After Lee looked over the photographs of the Martian surface sent back from the two landers, he concluded that if the flight team had seen the sites that clearly before the landings, it would not have certified them as safe. The team had sought zones that were 99 percent "landable," and to Lee the sites they had chosen now appeared to be hazardous at best. "But the thing that we don't know is how much worse the areas may have been that we rejected." Without the rigorous search-certification operation, they would have had no hope of a successful landing. Lee and Martin agreed that a third Viking landing using the same certification tools would have no guarantee of touching down safely. Before another craft was sent to Mars, Lee hoped they would have a better understanding of radar and infrared thermal mapping. He also had hopes that the low-altitude photography planned for the extended Viking mission, with periapsides as low as 300 kilometers, would give them a totally new look at the surface, including hazards of the 15- to 20-meter scale.[78]

Michael H. Carr. Mike Carr also had something to say about low-level photography. Commenting on the gap between the 100-meter-resolution orbiter imaging photographs and the lander photographs, the leader of the orbiter imaging team said:

> We've got to bring the orbiter down in the extended mission to 200, 300, 400 kilometers and use the scan platform for image [motion] compensation. [We must] squeeze the maximum resolution we can out of the orbiter cameras over significant areas, so that we're getting data at a much finer scale in anticipation of the next [mission]. . . . There will only be one next one—a rover. We just can't afford to have it crash.

Even though cameras would be on board any future spacecraft, Carr believed that the site selection team ought to be armed with data at a scale relevant to the lander. Better photography and a clearer understanding of radar and the infrared system would make the job easier.[79] Both Carr and Masursky thought that image-motion compensation was necessary for any future low-altitude orbital photography of Mars, to prevent the images from smearing.

Harold Masursky. The leader of the landing site certification team said he would like to attach a mechanical image-motion compensator to the Viking cameras. With this device, he knew how he would fly a third mission. The spacecraft would be inserted into low Mars orbit, to take higher resolution site certification pictures. From these low-altitude images, the flight team would be able to avoid hazards of a smaller scale and select key topographical features to which the lander could guide itself, using either laser or television. After a site was approved, the orbiter would obtain a higher altitude and release the lander. All the technology Masursky wanted to use was available. What they did not have was NASA's approval for a third flight—and the funds.[80]

Coming down to Earth, Masursky commented on the effort made by Martin and Young to maintain the scientific integrity of the Viking missions. No matter what problems came up, the management kept reminding everyone that the primary objective was scientific investigation after a safe landing. With many critical issues facing them daily, Martin and Young never forgot the main goal.[81]

Carl Sagan. As a scientist, Sagan was impressed by how "remarkably willing to listen the project manager was." If anything, Sagan had been prepared for resistance to such items as postponing the 4 July landing and taking a closer look at radar data. But Martin had kept an open mind. "It sounds like a reasonable thing for a project manager to do, but that's not always been the case in past missions."[82]

Martin and Young had listened. They had not always accepted the advice given them, but considering the immense task they had faced and their success they must have made the right decisions. They had safely landed two out of two spacecraft, and luck had had very little to do with it. Martin would continue to believe that hard work and discipline were better bets than luck. The site selection-site certification process had been time-consuming, tension-filled, and seldom an "exact" science, but it had worked—and worked on a planet 348 million kilometers from Earth. With two successful landings behind them, the Viking team could turn to the real reasons for its labors—the scientific examination of the Martian surface and the search for possible life forms on the Red Planet.