9

Safe Havens: Selecting Landing Sites for Viking

Since the basic goal of Viking was to conduct scientific experiments on the surface of Mars, the selection of landing sites was recognized early as a topic of major importance. Once the decision was made in November-December 1968 to make a soft landing from Mars orbit, the project engineers and scientists began a long colloquy in which they weighed the demands for lander safety (a crashed lander equaled no science) against the desire to land at locations most attractive scientifically. At first, the discussions were necessarily general in tone; the scientific knowledge (in terms of both physical data and visual images) was still very limited. *Mariner 4*, flying by the planet in July 1965, had yielded new information and the first extraterrestrial images, revealing a heavily cratered, moonlike surface. From *Mariner 4*'s perspective, the planet appeared to have eroded very little. Some scientists concluded that this meant there had not been much wind or water activity on the surface. Other scientists pointed out that *Mariner 4* had sampled only 1 percent of the Martian surface; they wanted to see the other 99 percent, and they wanted to see it more closely.

The Viking Project Science Steering Group began to consider the interplay between landing sites and Viking lander science during its first meeting in February 1969. *Mariner 4* had raised as many questions as it had answered, and data from Mariner 69 (*Mariner 6* and 7), soon to be launched, would not be available until next year. Donald G. Rea, deputy director of planetary programs in the Office of Space Science at NASA Headquarters, during this first Science Steering Group meeting raised the landing site question when he asked for thoughts on how best to use the orbiter in support of the landed science program. Thomas Mutch, a geologist, began the discussion. The lander imaging team he headed had not considered landing site selection, since members thought orbital images were of little value in the site selection process. They assumed that orbital photographs would not be able to pick up geological features smaller than a football stadium (i.e., resolutions in the 100- to 1000-meter range). Ground-based scientists could not possibly see the lander or smaller scale hazards that could affect its safety, and Mutch's team did not believe that orbital pictures would help them pick either a good science site or a good landing spot.[1]

Wolf Vishniac of the biology team disagreed. Orbiter imaging could provide a valuable means for differentiating between places of low and high biological potential. He also believed that a possible strategy for selecting a landing site might be to set one craft down in a dark area and the other in a light area. The difference between Mutch's evaluation and that expressed by Vishniac was in itself illuminating. Mutch was thinking in terms of the small-scale features (measured in centimeters) that the lander would be able to see. Vishniac was basing his comments on the large-scale light and dark features observed through Earth-based telescopes. Between these two scales lay an unknown range of Martian topographical features that would mean the difference betweeen a safe landing and a crash.

The second steering group meeting, at Stanford University a month later, heard additional possibilities for using orbiter imaging in selecting a landing zone. On the large scale, Seymour Hess, the Viking meteorologist, expressed the hope that the orbiter could find a large, flat area on which the lander could be placed, so his weather station would function more effectively. He preferred a place with no surface "relief for 10's to 100's of kilometers." Surely the orbiter images could spot such a tableland. But Klaus Biemann, a chemist from MIT, noted that in the search for life forms, as well as in the molecular analysis his team would make, it was preferable that the first lander sit down in a warm, wet, low site. His ideal site demanded the fewest degrees below freezing, the highest traces of water in whatever form it might be found, and the highest atmospheric pressure (i.e., the lowest elevation) possible; life would most likely survive under those conditions.

In addition to the imaging system, the water-vapor mapping and thermal mapping experiments being planned would give the Viking team clues to the best sites while the lander was still attached to the orbiter, but the exact role of the orbiter would become clear only with time. Defining the mission occupied the Science Steering Group for the remainder of 1969 and most of 1970.[2] By August 1970, Jim Martin believed "that the definition of Viking landing site characteristics, the definition of data and data analysis needed to support the selection of sites, and the integration of engineering . . . capabilities and constraints" should be more coordinated.[3] A. Thomas Young, Viking Program Office science integration manager, led a landing site working group,* which met for the first time as a body at MIT on 2 September 1970. Martin opened the proceedings, indicating that "the actual Viking landing sites would be selected through this group."

C. Howard Robins, Jr., deputy mission analysis and design manager, reminded the group that the Viking system requirements were not being developed for a single ideal mission. Instead, his teams were planning for a

*Other members of the working group were C. H. Robins and G. A. Soffen, Langley Research Center; W. A. Baum, Lowell Observatory; A. Binder, Science Applications Institute; G. A. Briggs and C. B. Farmer, JPL; H. Kieffer, University of California at Los Angeles; J. Lederberg, Stanford University; H. Masursky and H. J. Moore, U.S. Geological Survey; and C. Sagan, Cornell University.

broad spectrum of missions based on the desire to set the lander down anywhere in the latitude band 30° north to 30° south. The hypothetical landing sites being used to develop the "preliminary reference mission" had not been selected for their scientific merit. They had been chosen simply to give the analysis and design specialists something to work with in creating spacecraft design requirements. Finally, he reported that his office would develop the "operational mission design," which would guide the conduct of the real missions, by working hand in hand with the landing site working group.

The working group members began to discuss the desirable features and characteristics of Viking landing sites, with Tom Young suggesting that initially they ignore any potential system or mission constraints. Carl Sagan led off the brainstorming session by considering the problem in terms of three primary areas of investigation—biology, geology, and meteorology. Comments on biology centered on the availability of water, atmospheric and surface temperatures, and ultraviolet radiation. Each of these three variables could affect the possibility of finding life forms.

The meteorologists wished to observe four related phenomena over a period of time—seasonal darkening, the daily night-day cycle, long-term meteorological variations, and the annual polar-cap regression process. They also hoped the lander could be in a position to observe dust devils, ground fog, and ice clouds. William Baum of the Lowell Observatory's Planetary Research Center presented a status report on Earth-based motion studies of clouds on Mars. Cloud patterns were being mapped under the International Planetary Patrol Programs hourly each day, and recent daily photographs had shown significant changes, but he could not say how these alterations might be correlated with seasonal or other patterns.

The first working group meeting closed with a discussion of the relationship between the Mariner 71 mission (*Mariner 9*, launched 8 May 1971) and Viking. Dan Schneiderman, Mariner 71 project manager, hoped Viking personnel members would participate in that mission as observers during the first 100 days and thereafter as users of the orbital cameras to look for potential Viking landing sites. Martin assured the working group members that they would have an opportunity in October to discuss topics of common interest between Mariner 71 and Viking.[4]

FINANCIAL PROBLEMS THREATEN ORBITAL IMAGING SYSTEM

August to October 1970 was a busy time for the Viking project managers and the landing site working group. General discussions quickly gave way to deliberations over specific problems. One of those specifics was the orbiter visual-imaging subsystem, which had been identified as a candidate for elimination or modification to reduce costs substantially. The project stretch-out required paring costs, and Jim Martin and his colleagues sought ways to do so while still saving the orbiter and other key elements of the proposed mission.[5]

The Science Steering Group had identified three alternative approaches to orbital imaging that would save dollars—the Viking camera system already proposed; a slight variation of that system in which the image motion-compensation device was eliminated at an estimated $1-million saving; or a modified Mariner 71 imaging system (using improved optics), at a possible saving of $8 million.[6] At the July 1970 Science Steering Group meeting, Viking project scientist Jerry Soffen had told his colleagues that the cost reduction exercise in progress made it necessary for them to decide which investigations or parts of investigations were the most important scientifically. Each science leader had to defend the costs and merits of his team's experiment and recommend ways to conserve money. When Mike Carr—orbiter imaging team leader and an astrogeologist from the U.S. Geological Survey, Menlo Park, California—had defended the orbiter television camera system, he had argued that the costs were as low as they could be. When asked if the Mariner 71 camera system could be used on Viking as well, he had said emphatically, no.

Carr's orbiter imaging team reported in October that the orbital imaging from Viking would substantially enhance the scientific value of all the other experiments.[7] The imaging system would improve the probability of a safe landing, help define the environment in which the lander experiments would be performed, and permit comparisons of the landing site with other regions on Mars. The team was convinced that the proposed Viking camera system would yield superior pictures. "A modified 1971 camera would provide only minimal support for the Viking mission and would add only little to our knowledge of the planet. The Viking camera system outperforms the [Mariner] 71 camera in . . . very fundamental ways." Mariner 71's camera was a slow-rate vidicon unit, requiring a cycle time of 42 seconds to capture a single image. Viking's fast vidicon worked in a tenth of that time. To get overlapping coverage with the Mariner 71 A-camera, it would have to look at a larger area, losing detail in its resolving power. Mariner 71's B-cameras had a resolution comparable to the Viking system, but with a slow vidicon system it could not produce contiguous frames of coverage and would leave gaps between pictures. Viking's cameras would yield high-resolution and overlapping images, so the Viking team could get the photographic images they needed of the entire landing area in a single pass.

The fast vidicon camera system put other demands on the team, however. On the orbiter, the camera would require a fast, reliable tape recorder to store all the electronic bits into which the images had been coded. The telemetry system and ground-based recorders must be capable of handling the data flow, and the image-reconstruction and processing computers and related equipment would have to process that data as quickly as it was received. But Carr believed that this elaborate complex of machines and men was essential to Viking's success. "The Viking camera will always outperform the [Mariner] system by delivering more resolution per area covered, by allowing greater flexibility in choice of filters and lighting conditions and making more effective use of a lower periapsis."*

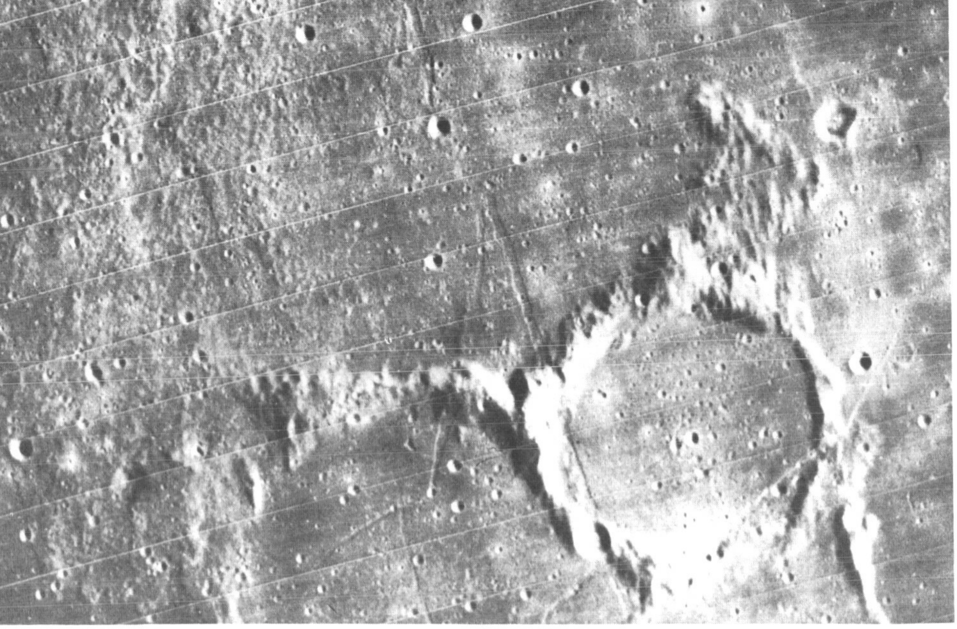
These performance differences were important to site certification. "With only two landers judicious choice of landing sites is essential to ensure that they will result in maximum scientific return." According to Carr and his colleagues, orbital imaging would be the key to site selection by providing:

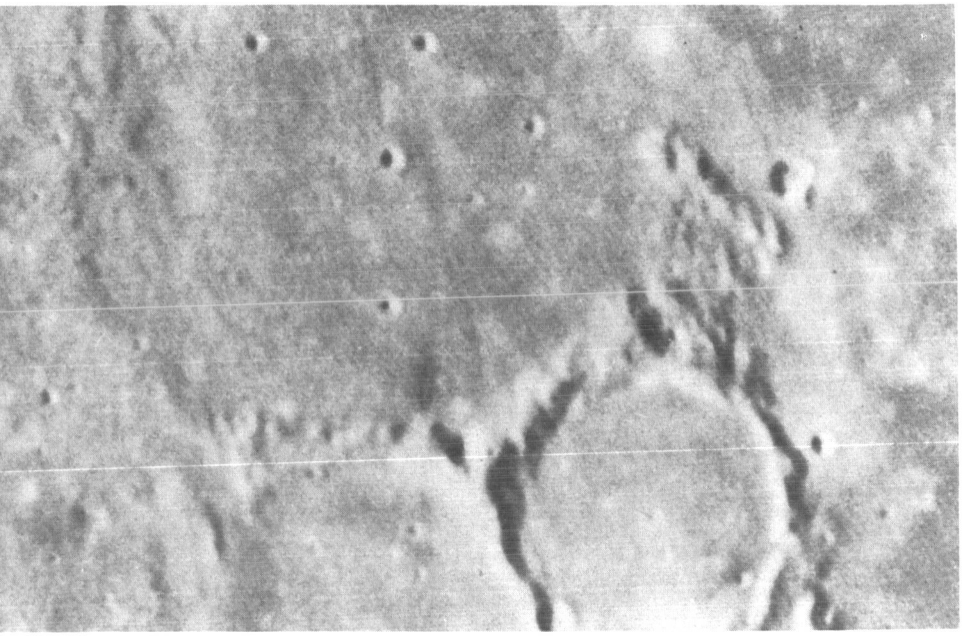
(1) Numerical terrain data (crater statistics, slope frequency distributions, etc.) such that the landability of different sites can be compared and assessed.
(2) Distribution frequencies of features such as craters, ridges, block fields, that are potentially detrimental (or advantageous) to lander experiments.
(3) Absolute and relative elevation measurements as a supplement and check to radar and [infrared] data.
(4) Information on the geologic nature of the potential landing sites.
(5) Information on seasonally variable clouds, condensations, and surface albedo differences both locally and regionally around potential sites.[8]

The orbital imaging team was sure that the difference in results from the Mariner 71 and the Viking systems would be striking. Mariner 71 would be unable to portray objects smaller than 1 kilometer in diameter, while resolution with the Viking system, judged to be about 45 meters, was "close to the limit from which data can be extrapolated to the scale of the lander [2-3 meters]." The orbiter imaging specialists contended that using a modified Mariner 71 system would render the imaging "virtually worthless for obtaining terrain statistics and the distribution of specific features at the scale of the lander or making useful elevation measurements." To make their point, they used 80-meter- and 1-kilometer-resolution photographs of the *Apollo 14* landing site on the moon to illustrate how sensitive geological and topographical analyses were to this change. Most telling was the team's comment that the state of Martian imagery after Mariner 71 would be "roughly comparable to that of the Moon before any spaceflight program."

Besides searching for landing sites, the experts hoped the orbiter imaging system would return data on the activity of the Martian atmosphere, provide a much better understanding of the geological processes, and perhaps even yield clues to the existence or nonexistence of life. And there was the future to look to, they suggested. "The Viking landers will not be the last spacecraft to land on Mars. Others will surely follow and sites will have to be selected. Our whole lunar experience has been that the prime

*Periapsis is the point in an elliptical orbit at which a spacecraft or satellite is closest to any body it is orbiting. Its opposite, or highest point, is the apoapsis. Specifically for Earth orbits, the terms are perigee and apogee; for the moon, perilune and apolune; and for the sun, perihelion and aphelion.





Orbiter imaging team leader Michael Carr used Apollo 14 *photos to explain the difference in image resolution between the cameras of Mariner Mars 71 and Viking orbiters. Resolution of about 80 meters for the top photo of the* Apollo 14 *landing site is slightly worse than the effective ground resolution of the Viking baseline camera. Chief justification for choosing the site was the presence of the Imbrium Basin ejecta, indicated by rough terrain in the west part of the photo. In the bottom photo, at a resolution of about 1 kilometer (comparable to that of the Mariner Mars 71 camera), the area looks bland and uninteresting and the ejecta is not detectable. Details of the terrain are inadequate for assessing landing conditions and topographic and geologic content of the area.*

consideration in selecting any landing site is the availability of imagery." No judgment could be made about the relative merits of different sites for engineering or scientific purposes without adequate images. "In the past, a [lunar] site without imagery has been rejected immediately. There is little reason to believe that for Mars the decision making process is going to be significantly different." It was "imperative to collect as much imagery as possible to provide a decision making base for future missions."

Finally, the imaging team turned to political considerations.

> One of Viking's characteristics is its high-risk, high-gain mode of focusing on a search for life. Negative results on all the biologic experiments is not unlikely; the seismometer may never see a quake. To run a billion dollar mission and obtain largely negative results would be embarrassing politically for the project as well as for NASA as an agency. Whether negative results reflect the lack of life, or the wrong kinds of experiments or the wrong landing locations might be difficult to see. . . .
>
> Thus, the high-resolution imaging system may be considered as the "meat and potatoes" low-risk but guaranteed-significant-gain experiment in the mission.

It was excellent insurance against critics who might say that Viking had been too narrowly focused. The orbiter imaging team urged that the Mariner 71 camera system be dropped from further consideration.[9] The landing site working group recommended to the Science Steering Group that the Viking system be retained, and the steering group and NASA Headquarters concurred.[10]

A year later, money problems recurred. On 19 September 1971, the Science Steering Group met in a special session where the science team leaders got the bad news. Despite all efforts to reduce costs in management and engineering phases, Jerry Soffen had to tell his colleagues they must reduce the overall science costs by $17 million to $22 million. Several methods were mentioned, but each team quickly put in writing reasons why its own experiment should be exempted from the reductions.

The 6-7 October meeting of the steering group at the California Institute of Technology concentrated solely on money matters. Three options for reducing costs were discussed at length. The first called for deleting some routine activities—holding fewer meetings, and the like; perhaps as much as $3 million could be saved here. By simplifying the gas chromatograph-mass spectrometer and the biology instrument, another $5 million or so might be cut. Reducing science activities on board the orbiter could save another million. Other parings and deletions brought the total potential savings to just over $22 million. The second option called for eliminating the gas chromatograph-mass spectrometer, which had a predicted $35-million price tag, but the Science Steering Group preferred not to act on this item until it had a better feel for the technical feasibility of building the instrument.

Option 3 was the removal of the imaging system from the orbiter. As Hal Masursky recalled the scene, Soffen said, "We have a 17-22-million-dollar problem and the Orbiter Imaging System costs 25 million. Any suggestions?" Most of the steering group members were reluctant to recommend removing those cameras until they saw the Mariner 71 photographs. They would make that recommendation only if the Mariner images showed a bland, uninteresting surface. Mike Carr and Hal Masursky believed the imaging system was necessary for site certification regardless of what data Mariner 71 produced. C. Barney Farmer, team leader for the Mars atmospheric water-vapor detection experiment, expressed his concern about the whole idea of using these meetings to effect cost reductions. He went on record indicating his reluctance to recommend the removal of any full investigation. The group postponed a decision on the third option until January-February 1972. Money had been, was, and would continue to be a problem. Still, it was only one part of the problem of searching for a landing site.[11]

PREPARING FOR SITE SELECTION

Besides considering the imaging system and discussing desired landing site characteristics at its October 1970 meeting, the landing site working group also considered what it could gain from Mariner 71. Dan Schneiderman introduced the group to the Mariner project, and Edwin Pounder reviewed mission operations plans for both the prime 90-day mission and the extended mission (for the remainder of the first year in Mars orbit). Pounder went on to outline problems and promises of the project, one of the promises being data that would assist the Viking team in landing site selection. Patrick J. Rygh and Robert H. Steinbacher briefed the working group on mission operations and participation by scientists.

In turn, Hal Masursky and Carl Sagan told the Mariner specialists what the Viking team hoped to learn from Mariner 71. What they wanted was not in the written mission plans but was rather, How do we learn as we go along and then modify our plans accordingly? In NASA shorthand, this tactic was called the adaptive mode—acquiring data from a spacecraft and quickly using it to modify the mission. The Viking team was certain it would need this skill, and it would require discipline, planning, and timely responsiveness to succeed. In the plans for Mariner 71, data processing was not scheduled to catch up with acquisition for a year, and Masursky feared that unless adequately supported, the complete process could take 5 to 10 years, which was obviously too slow to be of value to Viking. Years of work had to be compressed into weeks. On occasion, time for data processing would have to be whittled down to days and even hours.[12]

At its next meeting, 2-3 December 1970, the landing site working group made its initial recommendation for landing sites, so that Howard Robins' mission planning staff could proceed with its work. These proposed sites had been chosen after only four months. Carl Sagan, who had been urging that the site selection process be completely documented, prepared a convenient summary of the thinking—as he saw it—that went into the choices. "The following is a preliminary attempt to integrate coherently a range of ideas which have been suggested on the Viking landing site question, to point out inadequacies in the existing data, and to serve as guide for future discussion." He noted that the "present cycle of discussion on landing site selection is to aid development of the Viking Project Reference Mission #1," a theoretical model that would be used in planning mission operations and designing the spacecraft. Since in some respects this was a training exercise, there was no commitment to the specific landing sites they had selected.

In considering landing sites for the two Vikings, some factors would be certain to change. But those that would likely remain unaltered fell into two categories, engineering and scientific. Under the engineering heading, the 30° south to 30° north latitude range for landing sites was dictated by the angle at which the spacecraft would have to enter the Martian atmosphere to obtain optimum aerodynamic deceleration and proper thermal conditions. Second, nearly all of the working group members agreed that the lander should sit down where atmospheric pressures were the highest. As on Earth, high pressure corresponds with lower elevation, but whereas sea level pressure on Earth averages about 1013 millibars, surface pressures on Mars are 100 times lower. Pressure at the lowest elevation was believed to be close to 10 millibars and at the top of mountains less than 1 millibar, but the uncertainty in these values was 20 or 30 percent at the time. The Viking scientists hoped that Mariner photographs and ground-based radar studies would give them more exact information on atmospheric pressure relative to topographical features. A third engineering concern was the effect that Martian surface winds would have on the spacecraft. The Mars engineering model with which the team was working predicted winds of less than 90 meters per second, but Sagan noted that newer calculations indicated the possibility of winds up to 140 to 200 meters per second.

> If such winds are encountered during landing maneuvers, the survivability of the spacecraft is very much in question; and such winds, even after a safe landing, might provide various engineering embarrassments. It will shortly be possible to predict which times and places are to be avoided. . . . Such considerations obviously require further theoretical study and (with Mariner Mars '71) observational study. But they do indicate how new parameters, not previously considered, can severely impact landing site choices. Such considerations imply that any landing site selected at the present time should not be too firmly imbedded in the Project's thinking.[13]

Other technical factors affecting the choice of a landing spot included the time of day on Mars at touchdown, the size of the landing target, and a pair strategy calling for one very safe (but perhaps less interesting) site and one of greater scientific potential. Depending in part on progress made in developing the lander tape recorder, Sagan thought that it might be desirable to land in the late afternoon to ensure that some lander images of the planet would be transmitted to the orbiter before it passed out of view of the lander, giving the team at the Jet Propulsion Lab maximum assurance of obtaining at least some initial pictures of the surface. They had to face the possibility that the lander could die while the orbiter continued on its way around Mars; it would be 24.6 hours before the orbiter passed over the lander a second time. Should a late afternoon touchdown be called for, those areas with dense cloud development at that time of day would have to be excluded. Turning to the target, or landing ellipse, Sagan indicated that it was currently 400 by 840 kilometers, which would eliminate areas appreciably smaller than this zone. The pair strategy had been devised for reasons of "survivability." One landing site would be selected with "safety considerations weighed very highly"; if the first mission failed on entry, the team would want to have a preselected, extremely safe site for the second lander. "It is therefore necessary to consider some sites almost exclusively on engineering grounds." Sagan hoped planners could "back off from this requirement a little bit and seek out safe contingency sites with at least acceptable science." Alan Binder had made this same point earlier but somewhat more bluntly: "The engineering criteria must reign since it hardly need be mentioned that a crashed lander is not very useful even if it did crash in the most interesting part of the planet."[14] Sagan wrote, "Before any Viking lander is committed to a given site, there must be reasonably extensive Mariner Mars '71 type data, including but not restricted to imagery." He thought that selection of alternative candidate sites should be based on Mariner 71 data, and certification of the various candidates should be based on Viking data, which would be of higher resolution.

Sagan's report then turned to the working group consensus on science criteria for the landing sites. Many members believed it would be useful to pair the first two landing sites in such a manner that each one would be a control for the measurements made at its companion location. A reason for varying from this plan would be positive results from the biology experiments on the first lander; then the Viking team might wish to land the second craft as near the first one as possible to determine if the results could be duplicated. The best guess at the time was that Martian life, "or at least that subset of Martian life which the Viking biology package is likely to detect," would be found where there was water near the surface. But there was still considerable debate about the nature and amount of water that might be found. Low atmospheric pressures and temperatures always below 0°C did not augur well for the presence of liquid water. Still, Sagan and others believed that it was possible to have life-sustaining water present in other forms.

The uncratered terrain observed in the *Mariner 4* photographs was of possible interest. Sagan hypothesized that such terrain must have been recently (in geological terms) reworked. "Whatever the cause of the reworking, but particularly if it is due to tectonic activity, such locales are much more likely *a priori* to have had recent outgassing events and therefore to be of both geological and biological interest." Taking into consideration all these factors, Sagan listed his six favorite landing spots, but several of his colleagues came up with other suggestions of their own.[15]

After considerable freewheeling debate of the kind that characterized many of the working group's meetings, the group recommended three sites for each lander. It wanted to find water, and it wanted to land one craft in the north and one in the south. The mission planners indicated that it would be best to land the first Viking in the northern latitudes, or during the Martian summer. Immediately following the working group sessions, the mission analysis and design team subjected the six candidate sites to a preliminary examination, and its first quick look revealed no apparent difficulties. On 7 December, Jim Martin directed Martin Marietta to proceed with the design of the two Viking missions using Toth-Nepenthes (15°N, 275°)* for the touchdown area of the first lander and Hellas (30°S, 300°) for the second craft.[16]

Early in February, Dan Schneiderman and Jim Martin signed a "Memorandum of Agreement for Viking Participation in Mariner '71 Operations." Two areas were identified for direct Viking participation—mission operations and scientific data analysis. Viking personnel would work as part of the Mariner team. The Viking data analysis group would be housed in the Science Team Analysis Facility at JPL, and a Viking representative would act as an observer at the Mariner science recommendation team meetings, watching the interplay between the science advisers and the mission operations personnel.[17]

The Viking landing site working group did not meet again until April 1971. Meanwhile, the mission planners and the Martin Marietta Corporation evolved the "Mission Design Requirements Objectives and Constraints Document," which outlined for the first time in detail how the two missions would be conducted from launch through operation of the science experiments on Mars. Members of the landing site team and the Science Steering Group met in joint session on the afternoon of 21 April to discuss that document and mission planning in general, but earlier that day the landing site team had considered at length its participation in the Mariner 71 operations.

Tom Young opened the morning session, noting that Robert A. Schmitz would serve as manager of the Viking-Mariner Mars 1971 participation group. His duties included overseeing the Viking data analysis team, which would examine areas related to proposed Viking landing areas. This team would be drawn from two groups of scientists, those who would be working as part of the Mariner 71 operations team—Geoffrey

*Longitude on Mars is always determined in a westerly direction, 0-360°. For more on Martian place names, see T. L. Macdonald, "The Origins of Martian Nomenclature," *Icarus* 15 (1971): 233-40.

Briggs, Michael Carr, Hugh Kieffer, Conway Leovy, Hal Masursky, and Carl Sagan—and part-time participants from the Viking team.* Schmitz also was to act as the Viking observer on the Mariner 71 science recommendation team, which would give him a much broader understanding of the entire Mariner project.

Hal Masursky raised two problem issues in data management for Mariner 71, computer data processing and preparing Mars maps. The flow of data from the Mariner spacecraft would be so rapid that only one-fourth to one-third of the information could be processed in real time or near real time by the Mariner 71 system. At that rate, Masursky predicted it would take 18 months to get a complete set of reduced data records, a serious lag for Viking planners who wanted to use this information to land their spacecraft. And to prepare maps from Mariner 71 photography, stereo plotters and computers for analytical cartography, as well as more experienced cartographers, must be brought in. The photogeologist noted that these problems would be discussed with the JPL Mariner people later in the month. But at Carl Sagan's request, these issues were raised that afternon at a joint session with the Science Steering Group. The advisory body agreed that modest expenditures of Viking funds would be justified if supporting Mariner 71 data processing would contribute to the success of Viking. Masursky would prepare a letter to Jim Martin that clearly defined items that needed support and justifications for using Viking funds.[18]

MARINER 9'S MISSION

Mariner 71 did not get off to an auspicious start, as *Mariner 8*'s launch from Kennedy Space Center on 8 May 1971 ended in failure. Anomalies began to appear in the Centaur stage main engine after ignition. It shut down early, and the Centaur stage and spacecraft fell into the ocean. An investigation team determined the cause of the failure and worked out corrective actions before the 30 May launch of the second Mariner 71 craft.

At 6:35 p.m. EDT, *Mariner 9* began its 398-million-kilometer direct-ascent trajectory toward Mars. Weighing 1000 kilograms at liftoff, the spacecraft carried six scientific experiments: infrared radiometer, to measure surface temperatures; ultraviolet spectrometer, to investigate the composition and structure of the atmosphere; infrared interferometer spectrometer, to measure surface and atmospheric radiation; S-band radio occultation experiment, to study the pressure and structure of the atmosphere; gravity field investigations; and the high- and low-resolution television imaging system, to map the surface of the planet. After a journey of 167 days, *Mariner 9* went into Mars orbit on 13 November 1971, becoming the first spacecraft to orbit another planet. Orbital parameters were close to those planned, and the spacecraft circled Mars twice a day (11.98 hours per

*C. Snyder, T. Mutch, D. Anderson, W. Baum, A. Binder, B. Farmer, R. Hutton, J. Lederberg, H. Moore, T. Owen, R. Scott, J. Shaw, and R. Shorthill.

revolution) at an inclination of 65°. Technicians referred to *Mariner 9*'s path as 17/35—after 17 Martian days and 35 revolutions of the spacecraft the ground track would begin to repeat itself, giving the specialists the same images under essentially the same solar illumination. The Mariner planners had chosen a periapsis altitude of about 1250 kilometers to ensure some overlap when two consecutive, wide-angle A-frame images were recorded looking directly downward at the surface. Gaps between images acquired before or after periapsis could be filled in on a subsequent cycle 17 days later.[19]

The NASA team sent *Mariner 9* to the Red Planet at a time when the southern polar cap was shrinking and the southern hemisphere was undergoing its seasonal darkening, and the spacecraft instruments were designed to observe these phenomena. But Mars gave the Mariner scientists more than they had bargained for. On 22 September 1971, as the spacecraft made its way to its destination, ground-based astronomers noticed a brilliant, whitish cloud, which in a few hours covered the whole Noachis region of Mars. What they saw was the beginning of the greatest, most widespread Martian dust storm ever recorded.*[20]

The progress of the storm was amazing. It spread from an initial streaklike core, some 2400 kilometers in length. On 24 September, the dust cloud began to expand more rapidly to the west, blanketing a large area from the east edge of Hellas (a proposed Viking landing site), west across Noachis in three days, a distance two-thirds of the way around the planet. To the north, Syrtis Major was beginning to disappear beneath the haze. On 28 September, a new cloud developed in Eos, a region later found to be part of the canyon lands of Mars. Peter Boyce, of the Lowell Observatory in Flagstaff, Arizona, reported that his observations taken in the blue-light spectrum had shown a reduction in contrast for several prominent features days before the dust cloud was visible to astronomers. This indicated that Martian dust had been drawn up into the atmosphere some time before the actual cloud could be seen. By the end of the first week in October, clouds or storms had engulfed nearly the entire planet. A zone about 12 000 kilometers long had been obscured in only 16 days. Prospects were dim for a successful mapping of the planet when *Mariner 9* reached Mars on 13 November. At Mariner mission control, there were some worried people, and the Viking team worried along with them.

On 8 November, the first pictures of Mars came back from the spacecraft. While these were essentially calibration shots designed to check out the television system, they were large enough to give a reasonably good view

*C. Capen of the Lowell Observatory theorized in February 1971 that such a storm was possible. Since 1892, astronomers have observed substantial dust storms each time an Earth-Mars opposition coincided with Mars' closest approach to the sun—1892, 1909, 1924-25, 1939, 1956. Because of the eccentricity of its orbit, the radiation received by Mars at perihelion is more than 20 percent stronger than usual. This increase substantially raises atmospheric and surface temperatures, and the resultant instabilities give rise to swirling columns of air that lift dust and debris into the Martian sky.

of the planet. But the dust was all-pervasive; no detail could be discerned. One scientist, in a bit of gallows humor, suggested that they must have visited Venus by mistake, since that planet is perennially blanketed by clouds. His remark was not well received. With the loss of *Mariner 8*, the Mariner 71 project planners had completely reworked the missions they had scheduled for the two spacecraft. *Mariner 8* was to have mapped the planet while *Mariner 9* looked at the variable features of Mars, and both of these tasks were of great interest to Viking planners. The redesign of two missions into one had been accomplished while *Mariner 9* traveled toward the Red Planet.

Mariner personnel members began a series of preorbital sequences to gather science data on 10 November. Originally they had hoped that these long-distance photographs of the whole planetary disk would provide them a global view of the surface. These images would have helped fill the gap between the low-resolution views obtained by *Mariner 4*, *6*, and *7* and the higher resolution closeups they were hoping to take with *Mariner 9*. The first preorbital science picture revealed a nearly blank disk with a faintly bright southern polar area and several small dark spots. The intensity of the storm "shook everybody up," according to Hal Masursky, "because we could in effect see nothing." The key to their elaborate mission plan was a series of photographs that would be used in developing a control net for photomapping. That work was supposed to be done during the first 20 days after the spacecraft went into orbit, but they couldn't see a thing! The revised plan was dumped, and the Mariner operations team searched for items to photograph while waiting for the storm to subside.

Working with classical maps of Mars and more recently acquired radar data, the *Mariner 9* television crew was able to demonstrate that one of the dark spots they could see in the science picture coincided with Nix Olympica (Snows of Olympus). That mysterious feature, often seen topped with bright clouds or frost deposits, was known from radar measurements to be one of the highest areas of the planet. Nix Olympica, towering through the dust clouds, was revealed as a very high mountain, the first Martian surface feature other than the polar cap to be identified by *Mariner 9*. Computer enhancement of the 14 November images revealed volcanic craters in the summits of four mountains protruding through the pall of dust. This unexpected information led to the discovery that Nix Olympica and the three nearby dark mountains were actually enormous volcanoes, which would dwarf any found on Earth. But only these large features were visible. Other mapping sequences of orbital images produced a series of nearly featureless frames. Unhappily for the Viking team, adaptive photography brought pictures of things that did not aid its search for a landing site, like images of the Martian moons, Phobos and Deimos.

By 17 November, craters in certain regions began to appear in the television images as light-colored, circular patches. In similar fashion, an irregular, bright streak appeared running along the "canal" Coprates, through Aurorae Sinus into Eos, the region of chaotic terrain identified by *Mariner 6* and *7*. Radar measurements had shown a depression several kilometers deep in this region. Indeed, the evidence, as incredible as it sounded, had indicated the presence of a huge canyon some 3000 kilometers long and varying in width from 100 to 200 kilometers. Beneath all that dust was a world of amazing topography. The Mariner and Viking science teams anxiously awaited their first clear view of that scene. In late November and early December, the dust storm seemed to be subsiding, but a couple of weeks later that trend slowed to a standstill. Worried scientists were relieved when the clearing process began again during the last days of the year.[21]

While the dust storm had a significant impact on the *Mariner 9* mission, its persistence through the month of November had a devastating effect on two Soviet probes launched on 19 and 29 May. Each of these craft weighed 4650 kilograms (nearly eight times the weight of *Mariner 9*) and consisted of an orbiter and a lander. The lander, containing a sterilized scientific package, was designed to enter the Martian atmosphere protected by a conical heatshield. Once the shield was discarded, the scientific instrument unit would descend on a parachute, and at about 20 to 30 meters above the surface the lander would be slowed further by a braking rocket. Those were the Soviet plans. On 27 November, just before *Mars 2* entered orbit, the lander was ejected from the spacecraft to begin a 4½-hour journey to the surface. But something went wrong, and the lander crashed into the Martian surface at 44.2°S, 313.2°. Five days later, *Mars 3* approached the planet and released its scientific cargo. After the descent, the craft landed safely at 45°S, 168°, and relayed a television signal to its parent craft in orbit. Success was short-lived, as the signal stopped after only 20 seconds. Soviet space scientists concluded that both failures were due to the storm raging on the surface. Unable to decipher the electronically coded television data, the Soviets could not determine what the surface looked like. Not only did the Soviet landers fail, but the dust storm outlasted the lifetimes of the imaging systems on both orbiters. Complementary data would have been useful for both the *Mariner 9* and Viking teams, but the planet would not cooperate. Viking was likely to be the first craft to take pictures on the Martian surface, but only if it landed safely. And for many NASA planners, that was still an open question.[22]

When the Viking Science Steering Group met at JPL in December 1971, one of its primary concerns was to learn what *Mariner 9* could tell it that would affect Viking. Although the men participated in a weekly Mariner science evaluation team meeting designed to summarize the most recent scientific findings, they did not learn anything positive. The severe dust storm had foiled their efforts. Hal Masursky and his colleagues concluded that the Martian atmosphere might never completely clear, especially in the low areas, during the Mariner mission. If *Mariner 9* did not acquire the reconnaissance data they required, Viking would have to perform the task, which made the instruments on the Viking orbiter even more important. The Viking Project Office would have to keep "its options open" and give thought to several different models of the Martian surface, to be prepared for whatever Viking might encounter.[23]

Clouds were clearing over Mars the third week of February 1972, however. During orbits 139 to 178, one mapping cycle of interest to Viking had been completed, covering the region from 25° south to 20° north. A second mapping cycle was in progress, and a third later that month would cover a Viking area yet to be determined. The coverage was reported to be very good.[24]

Mariner scientists devoted the February session of the Science Steering Group to reports summarizing their recent data and comments on the implications for Viking. Most of what they had to say had already been made public during an early February press briefing held at NASA Headquarters. Bradford Smith, deputy team leader for the television experiment, had told reporters that the Martian atmosphere had begun to clear slowly in December, with more rapid progress during the first week of January. Pictures now available of the Martian surface led the science team to conclude that the planet was a far more dusty place than they previously had thought. But at that same press conference, Hal Masursky had some positive words about the dust storm. The first 30 to 40 days of the mission had given the scientists an opportunity to study the dynamics of the Martian atmosphere. "It will be 15 years . . . before such a large dust storm can be seen" again. The storm, however, forced the mission planners to devise a reconnaissance scheme for looking at the planet from a higher altitude and photographing any clear areas with the high-resolution camera. Once the clearing trend started, the Mariner team began a new series of mapping sequences that were at least as complex as the original mission plan.

The mapping process revealed a fantastic planet, strewn with features that caught scientists' immediate attention. Huge volcanoes with attendant lava flows were found in the Tharsis region. And features that had been observed previously—such as three dark areas called North Spot, Middle Spot, and South Spot—were now clearly volcanoes. The caldera, formed by the collapse of the cone, of North Spot was 32 kilometers across, while the width of South Spot's crater was 120 kilometers. But these volcanoes were all dwarfed by Nix Olympica, which was renamed Olympus Mons. To the east of Tharsis, the Mariner team found a high plateau, much of which was 8 kilometers above the surface, that evidenced complex fault zones. Some areas had been uplifted; others had been depressed; in places large blocks had been tilted. "We think this indicates a very dynamic substratum under the Mars crust," Masursky noted. He showed the press some slides of the great chasm, which was some 4000 kilometers long and hundreds of kilometers wide at points. Looking at this complex of valleys and tributaries so recently obscured by dust, Masursky commented, "We are hard put to find a mechanism other than water to form this kind of complex, erosional channel. If it were not Mars, and if water weren't so hard to come by there, we would think that these were water channels." This thought, pregnant with many possibilities, would require considerable analysis.

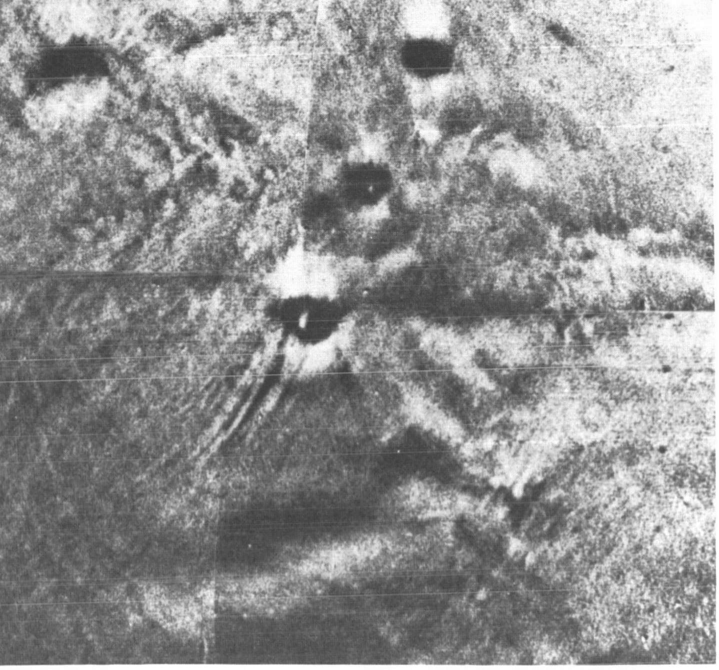
Masursky told the Science Steering Group that the scientific community was changing its thinking about Mars. After the 1969 flyby missions (*Mariner 6* and *7*), scientists still tended to believe, from the 165 low-resolution photographs taken from a distance of 3400 kilometers, that Mars was a dead primordial planet. But the *Mariner 9* photographs illustrated a very different kind of place. The crispness of the edges on the volcanic piles and the absence of cratering seemed to indicate that these volcanoes were, geologically speaking, young. Just how young was uncertain. The fault zones showed that the crust had been broken many, many times. Mars evidently was a dynamic, geochemically evolved planet and not just a static accumulation of cosmic debris as some experts had theorized after the Mariner 1969 flights. With the realization that Mars was an active planet in geological terms, the search for possible life forms became more exciting.[25]

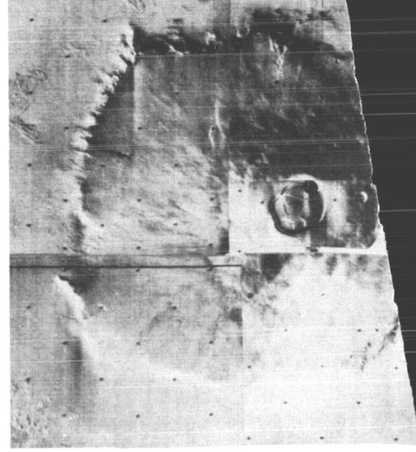
Next at the February meeting, Al Binder described some of the work the Viking data analysis team was doing. A preliminary contour elevation map of the zone of interest to Viking had been compiled from 1967, 1969, and 1971 Earth-based radar observational data, which had been combined with *Mariner 9* S-band occultation findings. To help determine the topography of Mars, the S-band experiment correlated the effects of temperature and pressure differences on radio signals through the thin atmosphere. Such maps would give clues as to which regions deserved a closer look and more detailed mapping later in the summer of 1972.[26]

Jim Martin opened the second day of the Science Steering Group meetings on 17 February with a summary of the cost status of the project, particularly of the experiments. What followed could only be called a tough session. Each team leader explained what was being done in his project area to cut costs and under close cross examination defended his budget against future cuts. Everyone felt the pressure, so Mike Carr was not shy about arguing strongly for his orbital cameras.[27] Prefacing Carr's presentation, Conway W. Snyder, Viking orbiter scientist, described eight possible camera choices for Viking:

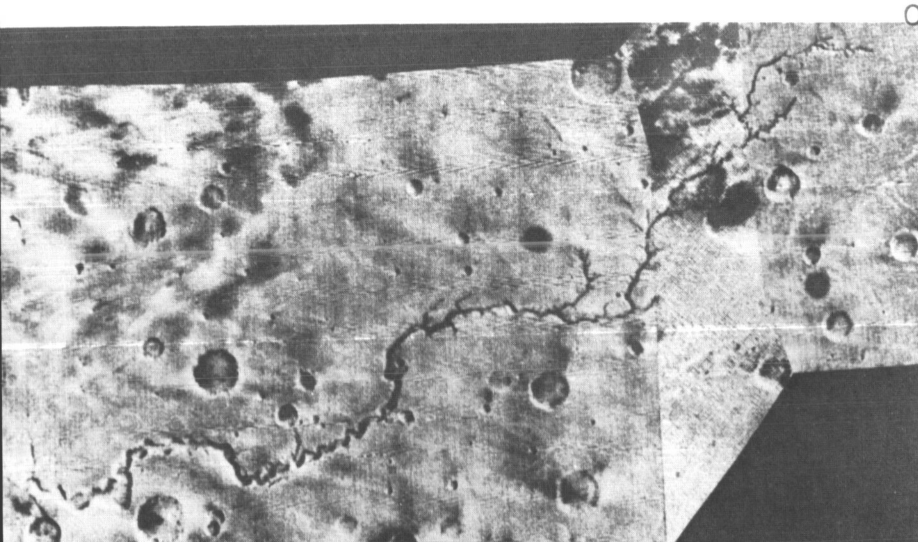
Alternative Choices	*Savings (in millions)*
Delete cameras altogether	$17.80
Use Mariner TV cameras	3.30
Use augmented Mariner TV cameras	3.15
Mariner engineering	5.30
Viking imaging system without image motion compensation	0.40
Viking imaging system without photometric calibration	1.30
Viking imaging system without image intensifier	0.70
Delete above 2 items	2.00

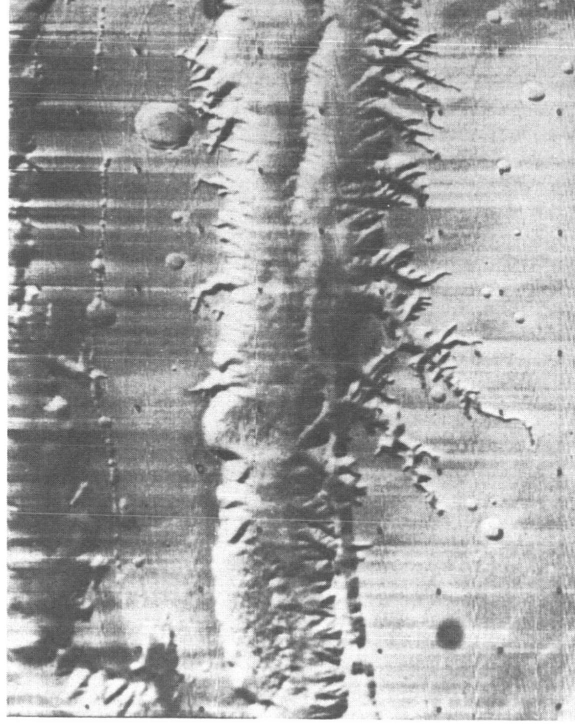
Carr proposed that the photometric calibration and the image intensifier be dropped. This modified imaging system would permit double coverage but at one-half the resolution of the originally proposed system. The



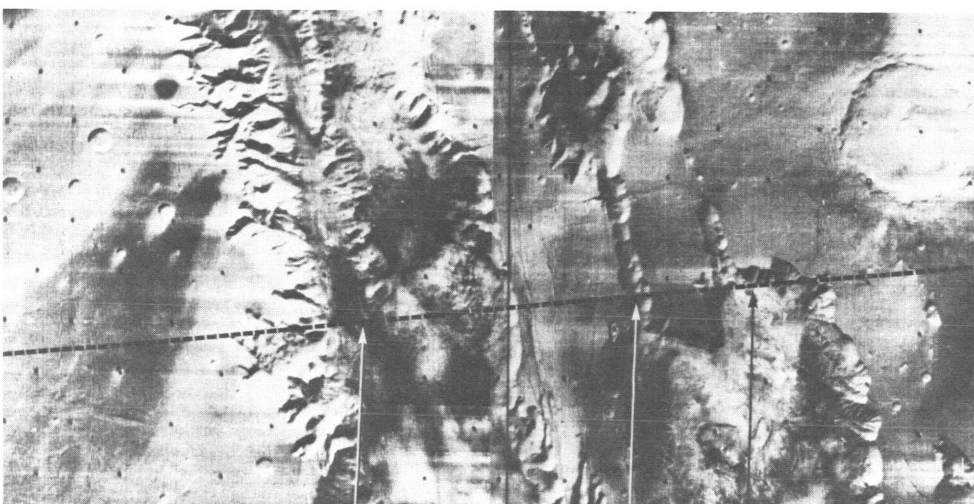


In a mosaic (above left) of photos taken by Mariner 9 *just before going into orbit of Mars in November 1971, computer processing reveals subtle details and swirls of dust. There is no suggestion that the dust storm is dispersing. Arsia Silva, most southerly of the three dark volcanic peaks, is slightly below the equator and 200 km in diameter. Streaks are probably wind-driven clouds. Bright patches near the dark spots are artifacts of processing. Olympus Mons (above right), gigantic volcanic mountain photographed by* Mariner 9 *in January 1972 as the dust storm subsided, is 500 km across at the base, with cliffs dropping off from the mountain flanks to a surrounding great plain. The main crater at the summit—a complex, multiple volcano vent—is 65 km across. Mons Olympia is more than twice as broad as the most massive volcanic pile on Earth. The meandering "river" in the photo below is the most convincing evidence found that a fluid once flowed on the surface of Mars. The channel, Vallis Nirgal, some 575 km long and 5 to 6 km wide, resembles a giant version of a water-cut arroyo, or gulley, on Earth. Mariner infrared spectral data, as well as Earth-based instruments, showed very little water on Mars, however. The Martian valleys also resemble sinuous rilles on Earth's moon believed to be associated with lava flows, but no lunar rilles display the branching tributaries seen here. The channel was first seen on 19 January 1972.*





Mariner 9's *wide-angle TV camera on 12 January 1972 photographed the vast chasm at right, with branching canyons eroding the plateau. These features in Tithonius Lacus, 480 km south of the equator, represent a landform evolution apparently unique to Mars. The resemblance to treelike tributaries of a stream is probably superficial, for many of the "tributary" canyons are closed depressions. Subsidence along lines of weakness in the crust and possibly deflation by winds have sculptured the pattern. The photo, taken from 1977 km away, covers 376 by 480 km. The mosaic of two photos below, taken of Tithonius Lacus region from 1722 km, covers an area 644 km across and shows a section of Valles Marineris. Pressure measurements by Mariner's ultraviolet spectrometer registered a canyon depth of 6 km (the Grand Canyon in Arizona is 1.6 km deep). The dotted line is the UVS instrument's scan path. The profile line below shows measurements converted to relative surface elevations. The photo on the following page shows the full length of the canyon system.*



Panoramic view of the equatorial region on Mars was made from pictures taken by Mariner 9 *from late January to mid-March 1972. Several hundred frames were scaled to size for the composite, which extends from 10° longitude at the right edge to about 140° at left. The photo map stretches more than one-third the way around Mars and covers about 28 million sq km, about one-fifth the planet's surface. The equator bisects the mosaic horizontally. At left, the complex of newly discovered giant volcanic mountains includes Olympus Mons, the largest. At least nine huge volcanoes have been pinpointed in* Mariner 9 *photos. Through the center runs the enormous canyon system Valles Marineris, 4000 km long, some 200 km wide at points, and nearly 6 km deep. (Portions are shown in the previous photos.) On Earth, the canyon system would extend from Los Angeles to New York.*

modified Viking imaging system would also permit all data to be put onto one tape recorder. The reduced resolution (about the same as the Mariner B-frame high-resolution images) was acceptable to the orbiter imaging team since the more important requirement for contiguous images could still be met. Snyder had pointed out that contiguous or overlapping photos could be obtained with the modified *Mariner 9* cameras, but that the process of acquiring such photos on multiple passes would be long and inefficient. The orbiter imaging people took the position that the Mariner systems were not very suitable for Viking site certification; they wanted the modified Viking imaging system. They would, of course, have preferred the original system but were willing to give up parts of the initial concept to help pare the budget.

An executive session of the science group was held the next day. Once again, each team leader explained how he might save money, and NASA Associate Administrator for Space Science Naugle presented his perspective on the budget problem. After a few brief words of praise and the good news that Viking had passed a major hurdle—its fiscal 1973 budget had been established—Naugle stated that the best program operating policy always called for setting a cost ceiling and adhering to it. He did not intend to give Viking financial relief because such a deviation from policy could have long-term disruptive effects on other aspects of the agency's program. True, there were funds being held in reserve, but Naugle stressed that they were a hedge against possible problems during the hardware development phase. Noting that the cost of the science payload had risen from $110 million to $160 million, the associate administrator made it clear that it was now necessary to make hard decisions to avoid more forced cost reductions in the future. While final decisions were not due until 1 March, Naugle gave his preliminary thoughts about cuts: he favored the proposed $2-million modification of the imaging system (Snyder's last alternative).[28]

CANDIDATE SITES

With money problems temporarily set aside, the landing site working group turned once again to site selection. The "Viking '75 Project Landing Site Selection Plan," distributed the second week of February 1972, spelled out the entire process the Viking teams would follow in finding sites. The plan carefully delineated responsibility distributed among the groups within the Viking organization.[29]

At the top of the pyramid, John Naugle's Office of Space Science at NASA Headquarters would have overall responsibility for reviewing the project's proposed landing areas and approving final selections. Jim Martin's Viking Project Office at Langley would oversee the six groups whose activities influenced the selection process. Martin Marietta Corporation's Denver Division, in its role as mission planning coordinator, would have to keep track of all flight and engineering considerations that might influence or be influenced by the landing spots ultimately chosen. Jet Propulsion Laboratory, supervising the design of the orbiter, would ensure that the craft could actually perform the tasks required of it. The United States Geological Survey was charged with making a series of Mars maps (regional, area, topographic, and geologic) to support the site selection process and with analyzing the terrain in the territory mapped.[30] The landing site working group, which established science criteria for landing areas, applied those criteria to candidate spots and recommended the best sites to the Science Steering Group. And the Science Steering Group, after reviewing recommendations, formulated its own site selections for Martin's project office—a simple format for a complex task.

Twenty-five members of the landing site working group met for their fifth meeting, at JPL on 25 April 1972, to discuss a wide variety of topics. James D. Porter of Martin Marietta, Viking mission analysis and design program engineer, brought the working group up to date on the engineering constraints that impinged on the site selection process. One was obvious: north or south of 25° latitude, the spacecraft in orbit would not receive adequate solar radiation on its solar panels to keep its batteries charged. Without that power, the orbiter could not relay messages to Earth. Other problems concerned the surface the lander encountered: slopes it touched down on had to be less than 19°, free of rocks and other hazards greater than 22 centimeters in height. Porter was also worried about winds during descent. A landing area that had winds greater than 70 meters per second was automatically eliminated. Porter's presentation was a status report, and he would be keeping the landing site working group informed as new restrictions were discovered.

As the day's discussions progressed, a lively debate developed over the nature of the processes that had shaped the Martian terrain. Areology, the scientific study of the planet Mars, was still less than a precise enterprise. Tim Mutch, in considering the terrain map (1:25 000 000 scale) that the Viking data analysis team had developed, questioned how the working group could extrapolate terrain information from such a map to determine topographical features as small as 22 centimeters. Several men present believed that rock sizes in the centimeter range could be determined from ground-based radar, since it would supposedly provide information on Martian features that small. Combining radar data with high-resolution images similar to the Mariner B-frame pictures had worked well in selecting landing sites on the moon. Others suggested that the radar-photo analysis approach would not be as simple on Mars; the varying kinds of terrain created by different processes would make interpretation of radar data more difficult. At this meeting, the rift between believers in radar and believers in photography first appeared. That division would widen and characterize many of the discussions held, right up to the time of the Viking landings.[31]

After additional consideration of physical characteristics for landing sites, Howard Robins turned the meeting's attention toward the 35 sites that had been proposed for *Mariner 9* photographic coverage. *Mariner 9* had taken 6876 photos covering 85 percent of the planet. At the time of the meeting, the spacecraft was powered down and would remain so until June, because its position relative to Mars and the sun no longer gave its solar cells adequate exposure. *Apollo 16* was a second factor leading to the suspension of the Mariner mission; during mid-April the Goldstone, California, 64-meter deep space antenna was being used to return Apollo's color television pictures. On 4 June 1972, *Mariner 9* would begin its "extended mission"—to complete the mapping of the planet and take landing site photographs for Viking.

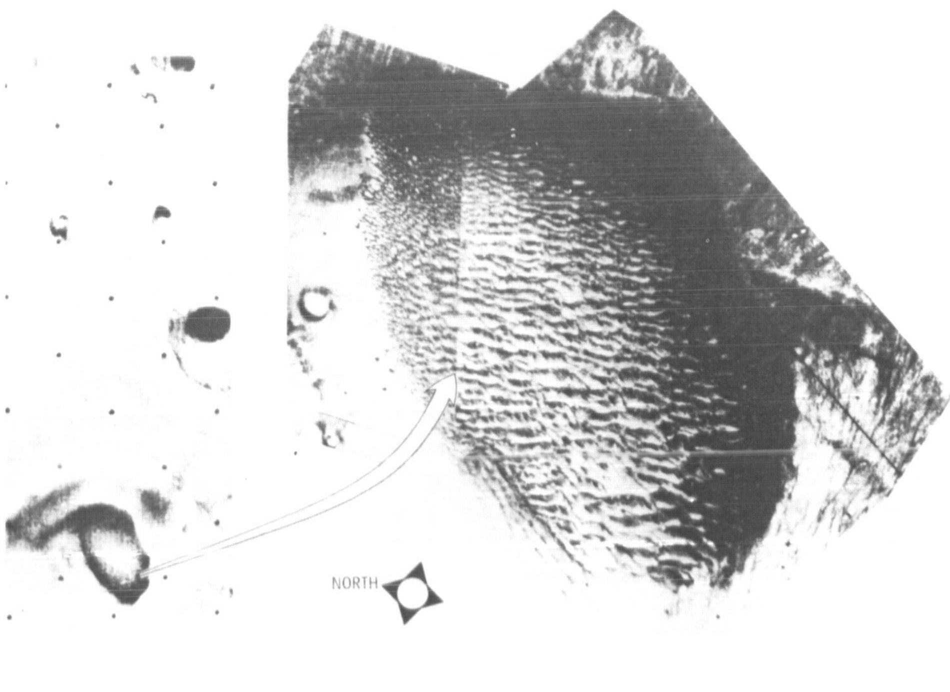
After a rather lengthy discussion, the landing site working group recommended that all 35 sites be photographed.[32] With a dual purpose in mind, I. George Recant, Viking science data manager, decided it would be useful to rank the 35 sites. The information would be valuable "in the inevitable trade-offs which have to be made in the negotiations with the Mariner Project in targeting areas for photography." And he thought that the evaluation exercise would identify "many of the considerations which may be required by the [working group] in the landing site selection process."[33] The next two working group meetings, previously scheduled for June and July, were slipped to August and September, at which time the group would have to determine six 30° by 45° regions that would be topographically mapped by Hal Masursky's Branch of Astrogeological Studies of the U.S. Geological Survey at Flagstaff, Arizona.[34]

During May, George Recant, Tim Mutch, Bob Schmitz, and Travis Slocumb evaluated the 35 areas according to engineering safety and scientific interest, with safety considerations outweighing science by more than five times. After much juggling, which Recant noted was subjective in many ways because "no quantitative methods were used in evaluating most of the criteria," they came up with a "relative rating" of the candidates.[35] Schmitz took the target preferences and worked out a photography schedule with the Mariner team, and on 6 June he advised Martin that three narrow-angle, closeup B-frames and one wide-angle A-frame coverage would be attempted for each target. The B-frames would be large enough to cover an entire landing ellipse. He noted further that sites with a relative score between 90 and 75 would be covered first, 74 to 60 second, and below 60 last. Finally, 24 of the 32 sites—3 sites were dropped from consideration—would be photographed during the first nine weeks of work that summer.[36]

Typical of the complexities brought on by continuous evaluation of data was the proposal to add 4 more targets to the list of 32. On 9 June, Hal Masursky, Al Binder, and James Gliozzi, representing the Viking data analysis team, wrote a memo to Bob Schmitz. The 4 additional sites "are in areas which have become accessible on the basis of Binder's recent revision of the Mars Topography map and updated Viking Lander capability." Masursky and his colleagues pointed out that "these sites are typical of some of the most striking geomorphologic features of the Martian surface which have not been considered in previous targeting exercises." They also presented alternate choices for landing sites should engineering constraints continue to change. If these areas were not established as candidates soon, they feared that these particular kinds of terrain would never be considered if no B-frame pictures were taken, even though upgraded lander capability might warrant selection of such spots. Looking back at their experience with Project Apollo, the data analysis experts realized that no pictures of a location meant its immediate rejection from consideration as a landing site. They hoped to forestall that kind of decision.[37]

It quickly became clear that the Viking planners might be asking for too many photographs. The Mariner team had to divide the attitude control gases aboard the spacecraft between Viking's requests and Mariner's experiments. One investigation in particular, the relativity experiment scheduled for September during solar conjunction, would require a major expenditure of control gases. Since early spacecraft maneuvers had consumed more propellant than anticipated, the total number of Viking target sites to be photographed had been reduced to 24. As of early July, 15 areas had been photographed—once with the wide-angle A-frame camera and three times with the high-resolution B-frame camera. Tim Mutch complained about this cut to Naugle, who while sympathetic could only note that although the Mariner pictures would be an important factor in the Viking landing site selection "Viking Orbiter capability for reconnaissance and site certification can also be used as needed."[38]

A mosaic (at right) of photos taken by Mariner 9's *high-resolution camera B of a Mars feature about 130 km long by 64 reveals dunelike ridges in what shows as a dark patch in a large crater in the photo (at left) taken by wide-angle camera A. Highest resolution of camera B at lowest planned point in orbit could reveal features as small as 60 m and cover an area 16.4 by 20.8 km, while a camera A frame covered 164 by 108 km with a resolution of 800 m.*



On 19 July, Tom Young distributed copies of the 19 Viking target photographs taken by *Mariner 9* to date, in an attempt to accelerate the site selection process so that operational mission design could begin as early as possible. On 13 July, he told the landing site working group that he hoped it would choose regions of primary interest during its 4-5 August session. At a meeting to be held late in September or early in October, Young expected the working group to identify and debate candidate landing sites. Everyone would have his say, but in two months the group would pick primary and backup sites for each lander. A review by the Science Steering Group and the Office of Space Science would follow immediately. It was a tight, busy schedule, but Young believed it was necessary to make the best use of the project's resources and give the scientists time to participate in the mission design process.[39]

When Young met with the landing site working group at Langley Research Center in August 1972, he summarized the many preliminary steps already taken to finding landing areas for *Viking 1* and *2* on Mars. All this had been necessary and useful training for the actual selection process. "I want to be sure we understand the seriousness of the actions we'll be taking. Consider[able] design effort will be expended on designing the mission starting in December and changes will be costly and have schedule impacts," Young emphasized. Therefore, "the sites we are selecting will be *the* landing sites unless we learn something significant from future analysis of our data or [from] a Soviet landing in 1973." He meant that no site changes would be made for minor reasons; they could react only to important findings or new safety considerations. "I want us to select the best sites in December that our collective wisdom will permit."[40]

The debate that followed Young's statements demonstrated just how divergent opinions were among the 33 specialists present. Jim Porter, who kept the minutes of the meeting, noted that during a discussion of the Mars atmosphere each investigator appeared "to have his own technique for determining atmospheres" and total correlation was not achieved. There were similar debates over radar analysis, the fate of the Soviet Mars landers, and other topics. Hal Masursky gave the group additional cause for concern when he pointed out that the visual impressions of Mars had been constantly changing from the beginning of the mapping mission. For example, features were just now becoming visible on the floor of the region called Hellas as the dust in the atmosphere dissipated. He expected his whole outlook on landing sites to alter by February when the skies would be clearer and orbital photographs more revealing. Jerry Soffen ranked the experiments proposed for Viking, giving the search for life the highest priority, which meant that water or evidence of water in the past would give a region good marks as a landing spot. And there were other considerations:

- The geoscience investigation should be made in areas of heterogeneous and differentiated characters.

- The meteorology investigation should be in locally smooth areas.
- Entry science preferably should have one mission in the northern hemisphere.
- The sites should be selected so that orbiter science has favorable viewing conditions.

Regardless of their interests, the specialists all had to work within an established "landing site strategy": The Viking sites would be selected using Mariner and Earth-based data, with a primary and a backup site for each lander. The preselected Mission A primary site would be examined by the Viking orbiter's science instruments before the first landing, to make sure there were no surface changes or atmospheric hazards. If the site was certified, the lander would be committed to it; if not, the backup site would be the next choice. If results from the Mission A orbiter and lander supported the preselected Mission B sites, certification would be made in the same way as for Mission A, but spacecraft B could be retargeted to a new area if data indicated the need. A new site would be certified by orbiter instruments, although certification would be more complicated because the site would not have been studied intensively beforehand.

On 5 August, "with maps, overlays, theories and opinions abounding," each interest group was given an hour to indicate its primary choices for landing regions. Two stood out—15°N, and 0° to 10°S longitude. *Viking 1* would be targeted for the north; *Viking 2* would be sent south. Before the end of September, the eight regions chosen would be examined in detail.[41]

Before the working group adjourned that day, it placed a conference telephone call to Joshua Lederberg of the biology team. Professor of genetics at the Stanford University School of Medicine, Nobel Laureate, and long-term supporter of Mars exploration, Lederberg carried considerable influence. He restated the biologists' desire to land at low, wet places, preferably near river basin deltas, but he raised another possibility. Why couldn't Viking land far north, 65° or higher, touching down where the polar cap had recently retreated? He had originally expressed the desire to go north in a handwritten memo to Howie Robins in June, believing the zone between 30°S and 30°N to be too restrictive. "I am about to leave the U.S. for about a week; but on my return will prepare a statement of dismay (for the record). *Biology* is assertedly a prime goal of Viking. The [Mariner] 71 *data* surprised us by indicating that Mars' H_2O is principally poleward. Yet here is the box we are in for Viking '75: to be choosing 'optimal' landing sites *within* the least promising zone."[42] Since many members of the working group responded favorably to Lederberg's proposal to go farther north, Tom Young had his mission planners look into the engineering constraints. Jim Martin subsequently authorized Martin Marietta and JPL to make a limited study to determine what would be involved in landing between 65° and 80°N, but Young advised the landing site working group they would "approach this subject with caution and much reservation."[43]

The 28 September 1972 landing site working group session at Langley was well attended. After Soffen introduced new member Noel Hinners of the Apollo Lunar Explorations Office at NASA Headquarters and Jim Porter briefed the group on engineering constraints, Young addressed the key topic: Should they try to land a craft near the north polar region of Mars? His answer was no. It could be done, but the risks to the landing craft did not seem to justify the potential gains. Equally significant, not only would it cost between $2 million and $20 million more depending on hardware changes, it would also slow the project's schedule. Young believed the combined increase in money and time was bad news, but he was ready with a detailed reply to the scientists' grumblings. First, landing in the north polar region was technically feasible, an important consideration for future missions. And second, the Viking Project Office understood the high scientific interest in the far north. But third, studies indicated high-risk or high-cost schedule impact because additional communications equipment would have to be developed to ensure adequate links between the orbiter and the lander. With a fixed launch date, the risk was just too high. Because of a November 1976 solar conjunction—Mars would be out of view from Earth—a delay in launching the spacecraft would cut into the prime cycle of science data gathering. All factors considered, Viking 75 would not try to land closer to the northern polar region. John Naugle also restated the budget limitations, firmly reminding the scientists that no additional money would be made available. Information gathered by *Mariner 9* regarding the polar regions would have to be filed away for use on some future mission to Mars. Considerably more discussion ensued about sites in the 30°S to 30°N latitude range, as each member of the working group had the opportunity to indicate his preferences. At the conclusion of the meeting, they recommended 10 sites.

Table 48
Candidate Landing Sites Selected August 1972

Mission A			Mission B		
No.	Latitude	Longitude	No.	Latitude	Longitude
1	20°N	158°	7	2°S	148°
2*	20°N	77°	8	2°S	186°
3	19.5°N	34°	9	9°S	144°
4	12°N	158°	10	9°S	181°
5	12°N	77°			
6	12°N	267°			

*Denotes lower priority.

The group's next step was to review these candidates and select one primary and one backup site for each mission at the next meeting, scheduled for 4 December 1972 at Orlando, Florida.[44] But it was not that simple. On 19 October, Tom Young telexed 20 members of the landing site working group; Hal Masursky and William Baum of the Planetary Research Center, Lowell Observatory, had recommended changes in the 10 sites.

Table 49
Changes in Candidate Landing Sites, October 1972

Site No.	28 September Locations		Masursky Recommendations	
	Latitude	Longitude	Latitude	Longitude
1	20.0°N	158°	21°N	157°
2	20.0°N	77°	19°N	65°
3	19.5°N	34°	No Change	
4	12.0°N	158°	8°N	163°
5	12.0°N	77°	10°N	80°
6	12.0°N	267°	10°N	269°
7	2.0°S	148°	No Change	
8	2.0°S	186°	No Change	
9	9.0°S	144°	9°S	141°
10	9.0°S	181°	No Change	

The alterations had been proposed so the Viking team could get maximum Mariner B-frame high-resolution pictures. Tom Young polled the working group by telephone on the 20th—15 had no objections; Barney Farmer, Richard Goldstein, Jim Porter, and Toby Owen had specific comments; and Al Binder could not be reached. Changes like these would become part of the routine process of landing a spacecraft on the surface of another planet, and this was just the beginning.[45]

Polar Option Revisited

By the time the landing site working group next met, in December 1972, *Mariner 9* had completed its mission and Joshua Lederberg had thumped on the desk of NASA Administrator James C. Fletcher. On 27 October when *Mariner 9* used the last of its attitude control propellant, a command was sent from JPL's Mariner Mission Control that shut down the spacecraft's transmitters. Despite initial setbacks, the mission had mapped the entire planet, permitting Viking scientists to gather far more images of candidate landing zones than they had originally anticipated. The infrared and ultraviolet instruments aboard Mariner had also observed large portions of the planet. As the data were being analyzed in November, Lederberg met with Fletcher and Naugle to express the scientists' concern that the polar region was not being given a fair chance because the "engineers"—Lederberg's shorthand for the project management—had not done their homework earlier and examined the polar regions for possible landing zones. The upshot of his arguments was the decision by Fletcher, in consultation with George M. Low, his deputy, and Naugle, to hold in abeyance any final action on a polar region landing until they had heard from all the science team leaders.[46]

Armed with the latest in a growing series of maps based on *Mariner 9* data, the landing site team met 4-5 December at Martin Marietta's Orlando facility to pick the primary and secondary landing sites for *Viking 1* and *2*. When Tom Young opened the session, he admitted that the question of a polar landing site had not yet been resolved, but the working group would go ahead with the original task of naming the landing sites in the equatorial band. In turn, John Naugle commented briefly on the strategy for a polar landing mission: "Send Mission A to the equatorial zone and target Mission B for the polar regions. Then if A succeeds, allow B to continue to the polar landing site, but if A fails, retarget B to an equatorial site." The Viking Project Office would provide a work plan and cost estimate to NASA Headquarters by 15 January 1973. Young responded that the ground rules would be kept open but no hardware changes would be made yet. If a decision was made to go to the pole, a fifth and sixth site should be selected; that is, a primary and secondary site in the polar region. NASA intended to hold a press conference in late December to announce the landing targets, and Young wanted any decisions reached by the working group before then withheld until the briefing.

The December 1972 announcement was not made; it was 7 May before any decision was made public. Between the December 1972 and the April 1973 sessions of the landing site working group, there was a great deal of argument, debate, or spinning of wheels—depending on one's perspective. Unanimity over where to land was difficult to achieve. During the 4 December dialogue, which lasted some 12 hours, only one site was selected. The group agreed that the primary site for the first lander would be at Chryse, 19.5°N longitude, 34° latitude. On the fifth, after another lengthy discussion, site 10 from the list, Apollinares, 9°S, 181°, was picked as the prime target for the second lander; site 9, Memnonia, 9°S, 144°, would be the backup. A secondary target for the first lander was not selected, because of concern over the strength of the surface at site 1 (21°N, 157°) and because site 2 (19°N, 65°) had undesirable elevation characteristics.[47]

A backup target for *Viking 1* and the question of going further north continued to be nagging problems into the early months of 1973. An ad hoc group* for identifying north polar region sites for review by the working group met 14 December at Stanford University. Five sites were proposed.

*N. L. Crabill, J. A. Cutts, C. B. Farmer, J. Lederberg, H. Masursky, L. Soderblom, G. A. Soffen, and A. T. Young.

Table 50
Polar Landing Sites Proposed December 1972

Site No.	Latitude	Longitude
12	73°N	350°
13	74°N	225°
14	63°N	0°
15	63°N	85°
16	63°N	160°

During the next several weeks, each of the science team leaders indicated his group's thoughts on the polar landing, as Jerry Soffen had requested during a December Science Steering Group meeting.[48]

Mike Carr was one of the first scientists to express his opinion: "In general the Orbiter Imaging Team has conflicting responses." On one hand, team members were enthusiastic about a polar landing coupled with a successful equatorial touchdown, because of the potential benefits to lander science. But on the other, they were apprehensive about the impact of such a landing on the orbiter imaging experiment. If the orbiter was used to support a lander in the polar regions, the craft could not be employed to photograph other areas of the planet as planned, because the orbiter's path would have to be altered considerably to accommodate a polar site. Carr said, "We are unable at this time to adequately, confidently assess some of the implications of a polar landing because of inadequate study of the problem."

Carr was also concerned that landing one spacecraft so far north would curtail the two "walks" around the planet, during which the orbiter would photograph Martian features at higher resolution. Four years would have passed since *Mariner 9* did the same; to lose this comparative photography would reduce measurably the understanding of the processes at work shaping the planet's features. If there were great pressure to go north, "the disadvantages could be tolerated if the Lander were to go to a site that exhibits uniquely polar phenomena *ie* one that is at least as far north as 75°. We would be very reluctant to accept these substantial disadvantages for a site at 65°N, which is not likely to be significantly different geologically from an equatorial site."[49]

Physical properties investigator Richard W. Shorthill said that he had discussed the "north polar site" with his team, and it had not favored the proposal. From the start, this group had considered safety to be the prime requirement for a Viking landing site. "Considering the present state of knowledge we cannot support a North polar landing." There was no radar coverage of the polar regions—"*no* information on surface roughness at the scale of the spacecraft, *no* information on the mechanical properties of the surface materials." Mariner imagery of the polar regions had been either ambiguous or too obscured by dust for a reliable evaluation. He went on:

> We believe that soils with excessive amounts of water or ice are incompatible with the Viking lander surface sampler system as well as the GCMS [gas chromatograph mass spectrometer] experiment. The behavior of soil with intersticial ice in a Martian environment [is] poorly understood. One could visualize a sublimation process that yields a porous under dense surface material more than 40 cm thick. On the other hand the surface could be wind swept yielding a rock like surface composed of soil and ice.

Furthermore, the safe landing of the first spacecraft at the equator would not ensure that vehicle's longevity on the surface. The team believed that the second lander should also be sent to a relatively safe place. Shorthill also looked at the question of money. He was strongly opposed to cutting back on science funding to provide changes in the lander and orbiter so that they might operate in the polar region. "Any new funds NASA might make available for design changes required for polar operations could better be used to increase mission success in areas where previous cutbacks have reduced the chances of success"—areas such as testing, mission planning, team activities, and continued assessment of the surface properties of the equatorial landing sites.

After first evaluating the polar proposal on its scientific merits, Seymour L. Hess of the meteorology team had subsequently developed reservations. He found it "incredible that a project with such severe financial problems has accepted the addition of a thirteenth experiment and now seems to be about to swallow an additional major cost for the polar option." He also believed that the polar site proposal would be bad for the entire project. "One of the major sources of our troubles is that NASA has been extremely ambitious in the total amount of science it is scheduling in comparison to its fiscal resources. To add this new ambition is, in my opinion, fiscal recklessness."[50]

Harold P. Klein, biology team leader, had another point of view. Klein told Soffen that the biology team had once again reviewed the polar versus equatorial site question at its 11 December meeting and regarded the presence of water as "the most critical parameter in the search for life on Mars." After listening to all the facts and opinions, the team believed that liquid water would be less likely on the equatorial regions than in areas closer to the poles. "We are not, of course, assured that the polar regions will afford opportunities for the production of water under or near the ice caps, but we feel that these regions afford a significantly better prospect for this than the more equatorial zones." Therefore, Klein reported that his team strongly supported the proposition that at least one landing be made in the polar region.[51]

Tim Mutch made a personal response. He had written one letter to Soffen that was a "dispassionate, scientific-engineering analysis," which came to a slightly negative to neutral conclusion on the polar landing proposal. After thinking about what he had written, Mutch concluded that he had probably missed the real issue: "The point is that Viking is an

The landing site working group on 8 February 1973 debates the choice of targets on Mars for Viking landers. In a voting process on one proposal are (above, left to right) Richard Young, Harold Klein, Henry Moore, William Baum, Noel Hinners, Harold Masursky, and Walter Jakobowski. At left, Norman Crabill and Masursky discuss pros and cons. From left below, Carl Sagan, Tobias Owen, Terry Gamber of Martin Marietta, and Barney Farmer consider arguments for a proposed site.

2. The Mission "B" landing sites, if NASA decides that the sites will be in the North Polar Region, be:

Primary	Site 12	73.0°N	350.0°W
Backup	Site 13	73.5°N	221.5°W

3. The Mission "B" landing sites, if the sites are in the equatorial region, be:

Primary	Site 10	9.0°S	181.0°W
Backup	Site 9	9.0°S	144.0°W

While approving the A sites for the first lander, the Science Steering Group could not come to an agreement over the second lander's destination. Several members of the group still wanted additional information regarding which areas had the highest probability of containing water in liquid form. In a joint memo to the steering group, Soffen and Young noted that any additional delays would have "a significant impact on the Viking mission design schedule and other Viking planning"; completion of the recommendation by 1 April was extremely important.[55]

As the delays mounted, the Viking management grew restive. Some unknown person suggested that when ultimately chosen the Mission B site should be called "Crisis Continuum," but at higher levels that sense of levity was not shared. On 20 February, John Naugle reported to Administrator Fletcher that the polar latitude site issue had still not been resolved. In reviewing the problem, Naugle went over the "presence of water" issue that was dividing the scientists. "It appears that the regions most recently studied by the Viking Landing Site Working Group may not be good sites from the point of view of availability of *liquid* water because of low temperatures, even though large amounts of water ice are known to exist." Furthermore, *Mariner 9* data being analyzed suggested that the optimum

Viking landing site working group discussions continue on 8 February 1973, with (left to right) Michael Carr, Gerald Soffen and Thomas Young at the table, Robert Hargraves, Burt Lightner, Arlen Carter, and Priestley Toulmin (back to the camera).

sites for water availability might be around 55° north. Naugle added that this region had not yet been studied in detail by the landing site specialists. The possibility of water and the geographical differences between the polar and equatorial zones were the two reasons some of the scientists favored landing in the northern latitudes. Naugle said that the Office of Space Science saw sufficient justification, in recommendations from a majority of the landing site working group to plan for a polar landing. "If we do decide to do a polar mission, we have a majority decision . . . to recommend a site at 73°N to you." Liquid water was the nagging question. Where were they most likely to find it? Naugle promised the administrator a recommendation by early April. On the following day, 22 February, Fletcher returned a copy of Naugle's memo with a terse, handwritten message in the margin:[56]

> John N—
> I have two questions.
> (1) Does Lederberg (& his committee) agree that the chances of life are best at 73°?
> (2) Does liquid water have to exist *now* or could it have existed once, for life "signatures" to be detected?
> From my own point of view, the main reason to consider polar landings was to increase the probability of finding life, not to study vastly different geological regions.
>
> JCF

The biologists would commit themselves only to the statement that the chances of finding life "are highest wherever liquid water is present for at least transient periods." As for Fletcher's second question, Naugle reported:

> For an active biota to exist, liquid water must exist at least transiently. Biological "signatures" (e.g., organic molecules) can exist if liquid water was ever present and life existed in the distant (millions of years) past. The difficulty here will be in determining whether the organic molecules detected are the product of biological processes or nonbiological (or prebiological) processes. Viking will detect organic matter, but may not be able to clearly distinguish between biological and nonbiological types. We have newly developed techniques available in the laboratory now . . . but such sophisticated analyses will have to wait for post-Viking or return sample missions.

A special meeting had been held 28 February to consider the question of possible locations for liquid water on the Red Planet. Naugle summarized the results of the "water hole tiger team's" session for Fletcher. No one could say positively that there was any locale on Mars where liquid water could be found. "This does not preclude the possibility for liquid water; it simply means that based on what we know now about the surface of Mars, we cannot determine where liquid water may exist even in transient form." Therefore, it was not realistic to select any site using only the liquid water argument. In the absence of a firm consensus among the biologists, Naugle had to report that he was not much closer to a recommendation than before.

He told Fletcher that he would have the necessary information following the next meeting of the landing site working group.[57]

Destinations Determined

The big day was 2 April, and Tom Young wasted no time in laying down the ground rules for this important meeting of the landing site working group. Selection of Viking targets "should be based upon the best knowledge that we have today." In choosing a backup for the second lander, Young wanted the group to assume that the first one had made a successful touchdown. Finally, site selection should be based only on scientific, cost, schedule, and risk considerations—not on policy constraints.[58]

While Naugle and Fletcher were puzzling over a polar landing site, the Viking scientists were changing their minds about the north. The more they talked about liquid water at higher latitudes, the more they thought about the low temperatures they would find there. Could they expect living organisms to survive during the transient appearance of liquid water as that compound passed from the solid to the vapor form or vice versa? Biologist Wolf Vishniac had looked into that question during February but had not turned up any evidence to support the belief that bacteria could grow or survive at temperatures much below -12°C.[59] Studies made with the *Mariner 9* infrared interferometer spectrometer had disclosed surface temperatures ranging from -123°C at the north polar region to +2°C near the equator.[60] The search for unfrozen, active life forms in the northern latitudes on Mars seemed unrealistic.

On 2 April, Lederberg conceded that 73°N no longer appeared to be a rational goal. Now the biologists were seeking a region where condensation might be anticipated that reached a temperature as high as -13°C—they wanted to land between 40° and 55°N. Long hours of discussion followed, during which the working group voted not once but several times on where to send the Viking spacecraft. Site 3 (19.5°N, 34°) was selected as the primary target for the first lander, and site 11 (20°N, 252°) was chosen as the backup. The group narrowed the second mission to two candidates, 16 and 17, but remained undecided over which should be the primary target. The Science Steering Group subsequently made that decision, recommending number 16 (44.3°N, 10°) as the Mission B primary site and number 17 (44.2°N, 110°) as the backup.[61]

Looking back on the ordeal of choosing sites for Viking, Tom Young used the word "traumatic" to describe the process. "We really thought that we were embarking on a reasonably simple task. . . ." But it had been very difficult to focus all the engineering and scientific issues on each specific site; "everytime we thought we [had] it, we would find another problem. . . ." One of the complicating factors had been the continuous stream of new knowledge about Mars. Their immediate need for information had forced them to take a quicker and harder look at the recent *Mariner 9* and Earth-based data than they would have under normal conditions. And each new piece of data changed the Martian picture as the specialists tried to select their targets.[62]

Hal Masursky, who had worked with Lunar Orbiter, Surveyor, Apollo, and earlier Mariner missions, thought the lengthy debate over landing sites had been not only useful but essential. However, he thought that the biologists and organic chemists had not thought through the landing site question; they had had to be educated about the nature of the planet and the spacecraft's capabilities. According to Masursky, some of the scientists developed many of their ideas as the debates went along, and they were forced to analyze quickly new facts at the table. The photogeologist recalled that while Tom Young and Jim Martin had kept pressing the working group for timely decisions, the managers had obviously understood the need for extended debate and had never tried to stifle interchange of ideas. Young and Martin, despite all kinds of external pressure, had managed to protect the scientific integrity of the landing site working group.[63]

Results of the landing site search were made public on 7 May 1973. John Naugle announced that a valley near the mouth of the six-kilometer-deep "Martian Grand Canyon" was the target for the first lander. Known as Chryse, the region had been named for the classical land of gold or saffron of which the Greeks had written. If all went well, Naugle told the assembled press corps, the first Viking would be set down on or about the Fourth of July 1976. The backup to the Chryse site was Tritonis Lacus, Lake of Triton, named for the legendary river in Tunisia visited by Jason and the Argonauts. The second Viking was targeted for Cydonia, named for a town in Crete, with Alba, the White Region, as backup. Soffen told the press that NASA hoped *Viking 1* would be heading for a very safe but interesting target. The scientists had decided early that the first site should be sought in the northern hemisphere (because it would be Martian summer there), at the lowest elevation possible (higher atmospheric pressure and better chance of water in some form), on the flattest, least obstructed region they could find (for landing safety and weather observations). But the second mission had been a different story. The biologists wanted water, and after much debate and study they hoped to find it in the 40° to 55° north latitudes. Their Mission B sites were just above 44°.

But what about these specific sites? What were they really like? Hal Masursky spoke to this point. From the *Mariner 9* photographs, he could demonstrate that about 50 percent of the planet was pockmarked with large craters not unlike the southern highlands of the moon. "We think this is the ancient crust of Mars that was differentiated very early . . . and continued to be bombarded by cosmic debris. . . ." Large basins on the planet recorded that epoch. The largest basin, Hellas, was nearly twice the size of the Mare Imbrium, a giant lunar crater 676 kilometers in diameter. To the north, the planet appeared to be smoother and younger, and scientifically more interesting. Chryse was at the point where a number of "stream" channels appeared to empty onto a plain (Chryse Planitia). Essentially featureless in the Mariner A-frame photographs, there was reason to believe that the area was covered by fine wind-borne materials. The photogeologists believed that there was a likelihood of finding fossil water* in this region, since highland materials would have been deposited here during earlier epochs of water-caused erosion. According to Masursky, "It looks like . . . the Mars environment has been different enough so that there was surface flowage of enormous amounts of water . . . into this great northern basin, and our landing site is at the mouth of that great channel system." The B site, Cydonia, combined the greatest chance of atmospheric water with a low, smooth plain. Masursky thought that this was an optimal landing target. Whereas the first area saw the drainage of the highlands and would likely provide soil samples representing transported highlands materials, the second site, near a large volcanic complex, was covered with basalt flows partly blanketed by wind-blown debris. "We think this combination of sites gives us the best possibility of fossil and present water, and our best samples to test the evolution of the planet."[64]

Selection of the Viking landing sites based on the data available in 1973 was only a first step toward ensuring safe havens for the spacecraft on Mars, and the Viking scientists recognized that additional data should be obtained from Earth-based radar observations and Viking orbital photography. Still, the work of the landing site working group provided the foundation for subsequent debate about the safety of the two Viking landers. The second phase of the landing site story focuses on the certification of the chosen sites, a process that started in May 1973 and was still going on hours before the landers were released for descent to the Red Planet. As is so often true of first steps, site selection was the initiation to a more bewildering process—landing site certification.

---

*Stream channels are equivalent to fossils in that they are evidence that water once existed.