VIKING SITE SELECTION

AND CERTIFICATION

CASE FILE
COPY

NASA

National Aeronautics
and Space Administration

VIKING SITE SELECTION

AND CERTIFICATION

Harold Masursky
U.S. Department of the Interior
Geological Survey
Flagstaff , Arizona

and

Norman L. Crabill
Langley Research Center
Hampton, Virginia

Page intentionally left blank

Page intentionally left blank

PREFACE

The landing site selection and certification effort for the successful National Aeronautics and Space Administration Viking Mission to Mars is reviewed from the premission phase through the acquisition of data and decisions during mission operations and the immediate postlanding evaluation. The utility and limitations of the orbital television and infrared data and ground-based radar observation of candidate and actual landing sites are evaluated. These observations could statistically minimize the hazards but could not define hazards and potential scientific return at the scale of the spacecraft. Additional instruments and types of observations which would have been useful and will be necessary to support future lander missions to Mars include higher resolution cameras, radar altimeters, and terrain hazard avoidance capability in the landing system. The principal hazard is the presence of blocks that might damage the lander; only very high resolution images will adequately record their presence.

A Viking Landing Site Working Group was convened in early 1972 to evolve site selection criteria that would meet mission capabilities and constraints. The group met intermittently from 1972 to early 1976 and consisted of 15 to 20 Viking scientists, systems analysts, designers, and project planners from various government, educational, and industrial facilities. Members of the group included A. Thomas Young, Chairman, NASA Langley Research Center; William A. Baum, Lowell Observatory; Geoffrey Briggs, Jet Propulsion Laboratory; Norman L. Crabill, NASA Langley Research Center; C. Barney Farmer, Jet Propulsion Laboratory; Noel Hinners, NASA Headquarters; Hugh H. Kieffer, University of California at Los Angeles; Joshua Lederberg, Stanford University; Conway B. Leovy, University of Washington; Harold Masursky, United States Geological Survey; Thomas A. Mutch, Brown University; Tobias Owen, State University of New York; James Porter, Martin Marietta Corporation (now Martin Marietta Aerospace); Carl Sagan, Cornell University; Gerald A. Soffen, NASA Langley Research Center; and Bradford A. Smith, University of Arizona. During mission operations, this group was expanded to include members of the Viking Flight Team who were responsible for the day-to-day conduct of mission operations; the group was redesignated as the Landing Site Staff (LSS) with Harold Masursky as Chairman and Norman L. Crabill as Deputy. The LSS met almost daily to consider all problems involved in the day-to-day acquisition, reduction, analysis, and interpretation of data as well as decision making.

An ad hoc geologic mapping group that supplemented the Viking Landing Site Working Group included Harold Masursky, Joseph M. Boyce, Michael H. Carr, George W. Colton, Carroll Ann Hodges, John F. McCauley, Daniel J. Milton, Henry J. Moore, Elliot C. Morris, David H. Scott, Laurence A. Soderblom, Desiree Elizabeth Stuart-Alexander, Newell J. Trask, Alta S. Walker, Mareta N. West, Donald E. Wilhelms, Terrence S. Kreidler, Charles E. Meyer,

Kenneth S. Murray, Joseph T. O'Connor, James Pettengill, Richard J. Pike, all of the United States Geological Survey; Thomas A. Mutch, Brown University; and R. Stephen Saunders, Jet Propulsion Laboratory. This group performed geologic mapping and terrain analyses of the many sites considered and made recommendations to the Landing Site Working Group.

CONTENTS

INTRODUCTION

In the summer of 1976, the United States successfully landed two spacecraft (landers) on the surface of Mars. This effort began when the Viking Project of the ˙National Aeronautics and Space Administration received formal authorization in 1969; the launches were originally scheduled for mid-1973, with arrivals planned for early 1974. The project goals and methods for this launch opportunity are described in reference 1. Early in 1970, the launch date was changed for budgetary reasons to the period between August and October 1975. Trip times for these launch dates increased up to a year, resulting in arrivals at Mars from June through September 1976; this schedule held with minor perturbations during the actual mission. This paper presents a brief account of how the sites were selected and certified and also includes suggestions based on this experience that might be applied to future missions.

ABBREVIATIONS AND SYMBOLS

D	block size
GCMS	gas chromatograph mass spectrometer
h	altitude
IR	infrared
IRTM	infrared thermal mapper
IRU	inertial reference unit
JPL	Jet Propulsion Laboratory
MAWD	Mars atmospheric water detector
MEM	Mars Engineering Model
max	maximum
min	minimum
PDT	Pacific daylight time

RA	radar altimeter
sol	Mars solar day
T	temperature
TD	touchdown
TDLR	terminal descent and landing radar
UAMS	upper atmosphere mass spectrometer
UV	ultraviolet
V	wind magnitude
VO	Viking orbiter
VIS	visual imaging system
VL	Viking lander
VL-1	Viking lander 1
VL-2	Viking lander 2
ρ	density
ρ_s	surface density

SITE SELECTION

Primary and Secondary Sites

It was obvious from the onset of the project that Viking would require many radical changes from mission design concepts of previous missions; thus, the mission strategy and site selection policies were formulated early. Plans called for two spacecraft, each consisting of an orbiter and a lander, that would provide complementary data concerning Mars and perform complementary functions as well as providing redundancy. The final site certification strategy would depend largely on knowledge acquired from Earth-based radar reflectivity observations obtained between 1969 and 1973 and on the results of data obtained by the 1969 and 1971 Mariner Missions. There was time to study thoroughly the Mariner 9 data and incorporate the results of these studies into site selection. The Viking orbiter data

would have to be worked essentially in real time; this accelerated schedule was possible only because of the experience gained from analysis of the Mars data available from the Mariner Missions.

One prime landing area and one secondary landing area at the same latitude were to be preselected for the first lander in a low-elevation region of Mars between 30° south and 30° north latitude. Targeting of the first spacecraft was planned such that the first lander could utilize the prime site at the earliest practical time after the site was certified. If the prime area proved unsatisfactory, the secondary area would be examined. Selection of the landing site for the second lander would be based on operational information obtained by the first lander during entry and while on the surface and on orbital reconnaissance data obtained by either the first or the second orbiter, depending on arrival and separation times.

The project strategy was modified only once, in 1973, when the zone of interest for possible second mission landing sites was expanded to include the area between 30° north and 75° north latitude where biologists thought the higher atmospheric water content might enhance biological activity. No hardware design changes were planned to provide this additional capability. Selection of the landing sites depended on interaction among various mission capabilities and constraints, including such factors as lander safety, system capabilities, and scientific objectives.

By September 1972, the Landing Site Working Group had formulated the criteria for selecting candidate landing sites. The most important criteria were safety for the lander and anticipated scientific return. The site had to be low enough to provide maximum atmospheric aerodynamic braking to slow the lander so that it could land safely; the site also had to be warm and wet enough to optimize chances for biological activity. Earth-based radar measurements, where available, were required to show reflectivity values greater than 5 to 7 percent and root-mean-square surface slope values less than 3.5° to 4°; such measurements would indicate that the area was smooth and hard enough to allow landing safely. The site pairs (a prime site and a backup site for each lander) were to be located far enough apart to prevent radio interference between orbiters and landers during periods of simultaneous relay link transmission; the two sites within each pair were to be far enough apart to optimize the probability that if a local storm interfered with one site, the other would be unaffected. Direct links from each lander to Earth were to have 2.5 hours separation; simultaneous tracking of both landers should be possible for 0.5 hour per day. Either orbiter was to be able to provide relay communication support for either lander. The first orbiter was to be able to conduct reconnaissance studies of the second landing site and both backup sites. Dual coverage of the sites by Earth tracking stations was to be available the first few days of the landed mission. Other factors, such as required orbital roll orientation for surface observations, attainable Sun elevation angle, occurrence of Earth and Sun occultations, and visibility of the polar regions from orbit were also considered. At a September 1972 meeting of the Landing Site Working Group, 10 preliminary candidate sites that met these criteria were identified within the ±30° latitude limits. (See fig. 1.)
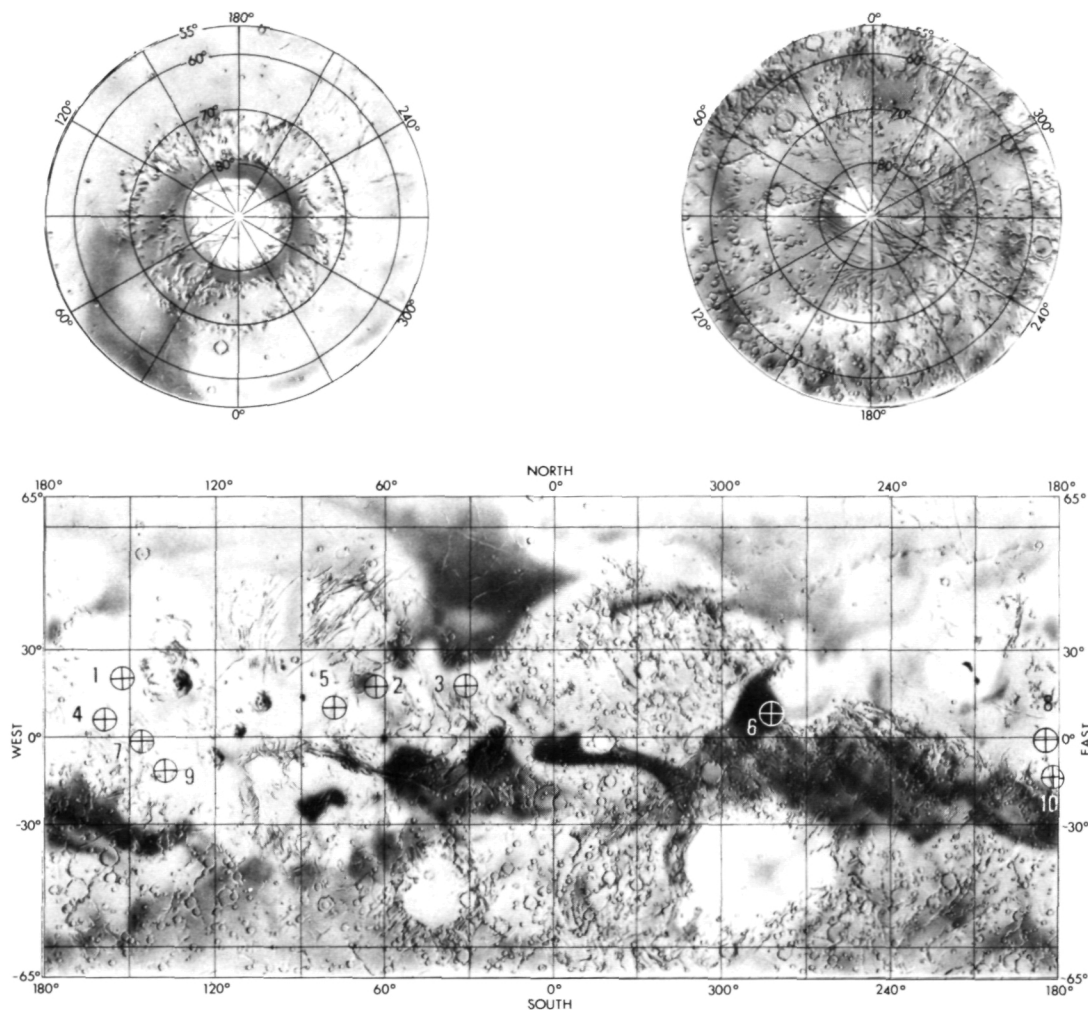
Figure 1.- Central latitudes of Mars showing original 10 candidate landing
selected by Landing Site Working Group in September 1972.

At another meeting in December 1972, the Landing Site Working Group considered the data obtained by Mariner 9 (1971) imaging; the results of infrared, ultraviolet, and water-vapor mapping; cloud studies provided by Lowell Observatory; and geologic and terrain analyses provided by the U.S. Geological Survey (ref. 2); these analyses were based on data provided by all the Mariner 9 experimenters and intensive study by an ad hoc group of geologists. From these data, site 3, "Chryse," was designated the prime landing site for the A mission; site 10, "Apollinares," the prime site for the B mission; site 9, "Memnonia," the backup site for the B mission; and a site at 20° north and 250° west, tentative backup site for the A mission (ref. 2). Mission designations A and B were changed to 1 and 2, respectively, after launch. The Chryse site was located in a low-plains area where four long water-related channels debouch onto Chryse Planitia. Because large quantities of water were inferred to have existed there in the past, the site was considered to represent a reasonable place to

4

search for existing or fossil life forms. Rocks, eroded from the headwaters area of the Martian highlands, rounded by stream erosion, and deposited at the Chryse site, were also a target for study by the lander instruments.

Radar data obtained in 1967 at the Haystack and Goldstone facilities indicated areas of both high and low reflectivity in Chryse Planitia. The prime landing dispersion ellipse was placed as close to the mountain front as possible (fig. 2). The size of the ellipse was decreased from ±300 kilometers in length in 1972 to ±120 kilometers in 1976. Additional ellipses were placed farther downstream to avoid possible boulders that had eroded from the stream bed and washed into the plains close to the highland border. The scablands of Washington and Oregon in the Pacific northwest were studied as a terrestrial analogue (ref. 3). The backup for the A prime site was located where radar observations indicated a smooth site with high surface densities (ref. 4).
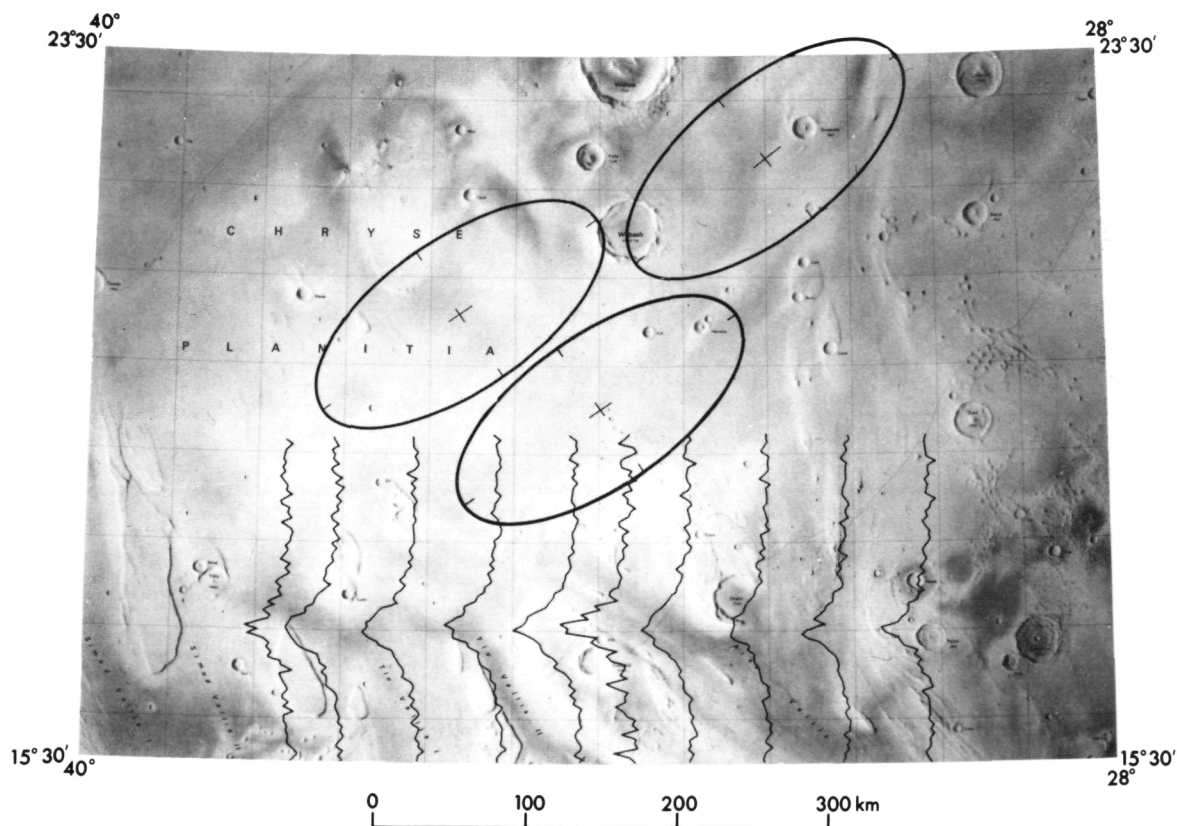

Figure 2.- Premission map of A1 (Chryse) site with landing ellipses and radar spectra of area obtained by Arecibo antenna.

Apollinares (site 10) was chosen for the original B prime site because the atmospheric water content was relatively high for an equatorial site (fig. 3) and the elevation was low. In addition, the site was located in a smooth plain near a large volcanic complex; the formation of these plains was thought to represent a fundamental geologic process. The backup site, Memnonia (site 9), was at the same latitude but in a different geological context; that is, the rocks probably are ancient, heavily cratered continental crust rather than younger lava flows.
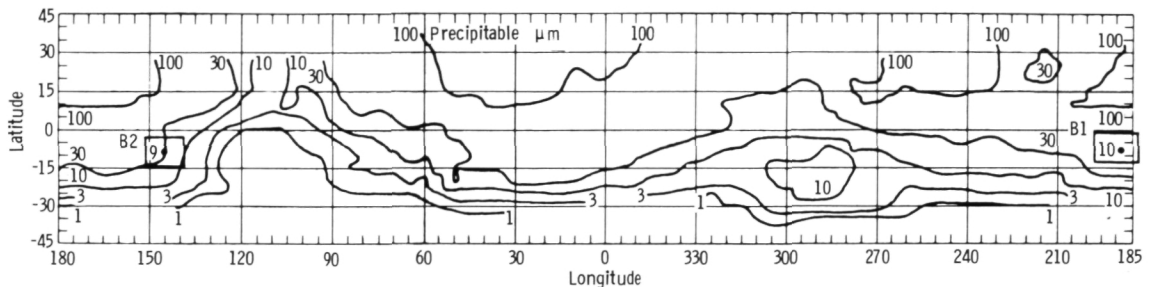

Figure 3.- Distribution of Mars atmospheric water vapor content from Mariner 1971 data.

As early as July 1972, the members of the Biology Team (ref. 5), particularly Joshua Lederberg, had shown a strong interest in sites at latitudes as far north as 75° where they believed there would be a greater likelihood of finding evidence of biological activity because of the increased atmospheric and surface water content. Also, Klaus Biemann, Molecular Analysis Team Leader (ref. 5), proposed that organic materials might be cold trapped along the margins of the polar cap and that the gas chromatograph mass spectrometer might therefore have a better chance of detecting organic compounds. Landing in the north polar region was deemed to be technically possible although some additional risk, cost, and impact to the schedule might be involved. Accordingly, the Landing Site Working Group devised a strategy in December 1972 for a possible polar landing mission that would target the B lander for a landing at a high northern latitude following a successful landing of the A lander in the equatorial zone.

In February 1973, several candidate polar sites north of 60° north were selected for study. These sites were rejected later when the Biology Team decided that any site north of 60° might be too cold for terrestrial-like organisms to reproduce. However, the Biology Team continued to favor a landing site between 40° and 55° north where surface temperatures reach at least 260 kelvins and where biologically available water might exist. C. B. Farmer, Water Vapor Mapping Team Leader, had concluded in 1973 that liquid water could be expected to occur most frequently at low elevations in latitudes on the poleward side of the subsolar point during the period around the summer solstice and that the concentration and availability of water might be large enough there to meet the requirements for the occurrence of terrestrial-like organisms. In an informal communication in November 1975, Farmer considered that these conditions were adequately met in the 40° to 55° north latitude region. Farmer's conclusions were published just before the arrival of Viking 1 at Mars (ref. 6). Scanty topographic data available for that latitude band suggested that the elevation was at or below the zero Mars datum. In addition, the backup site A2 at 20° north and 252° west was made final at this meeting.

The Landing Site Working Group considered seven "northern" sites at a meeting held in April 1973 (ref. 7). At that meeting, Harold Masursky, speaking about the work done by an ad hoc geologic mapping group, reported that, based on available Mariner 9 photographs, the site at 44° north appeared to be safer than sites at 51° or 55° north (ref. 7); biologists in the Landing Site Working Group favored the sites at 55° north where biological conditions were considered optimum. Sites 16 (Cydonia) and 17 (Alba) were finally selected as the prime and backup sites for the second (B) mission (fig. 4); they represented a compromise between the biologically more desirable sites at 55° north and the sites south of 30° north latitude where more photographs and radar data were available. The final locations selected for the premission A (prime, A1; backup, A2) and B (prime, B1; backup, B2) landing sites are shown in figure 4; a detailed map of the prime B site is shown in figure 5.
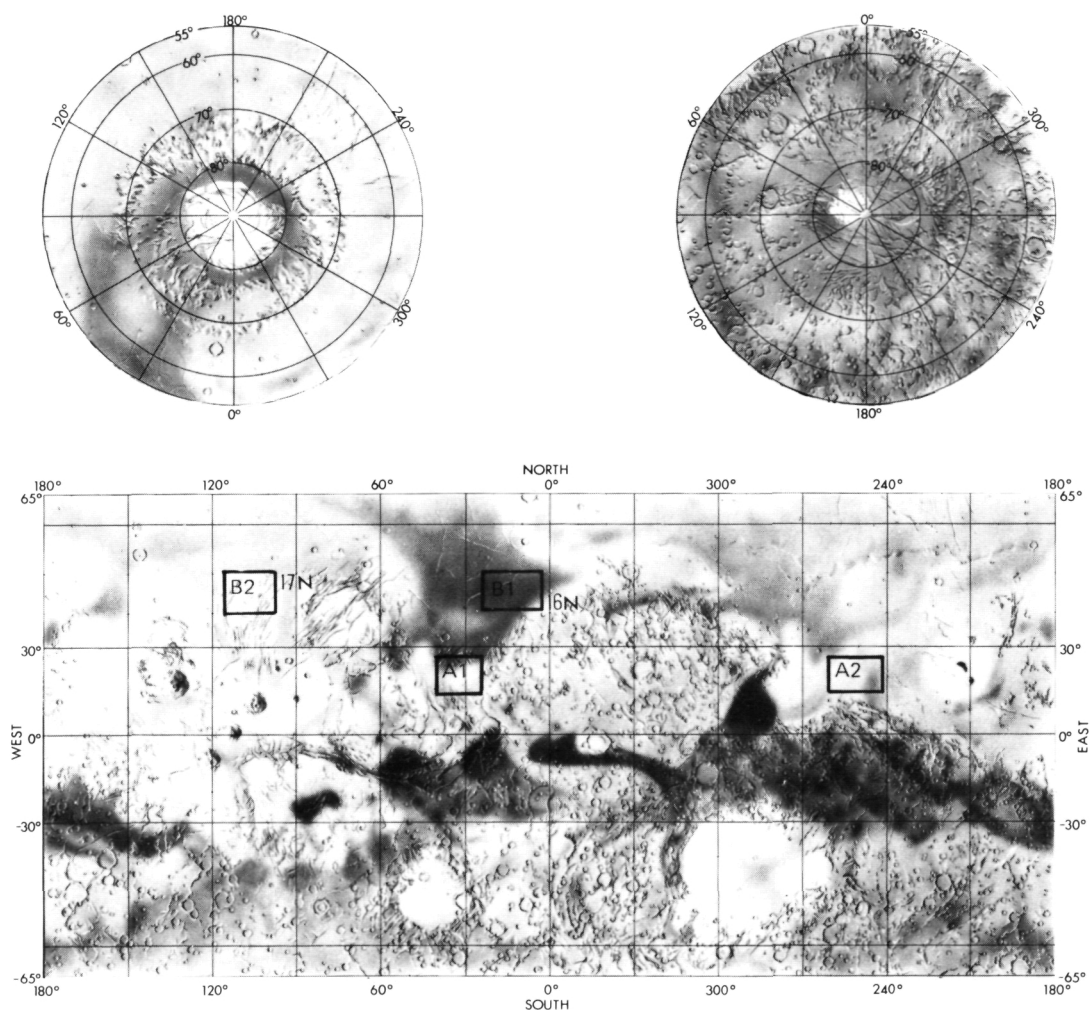

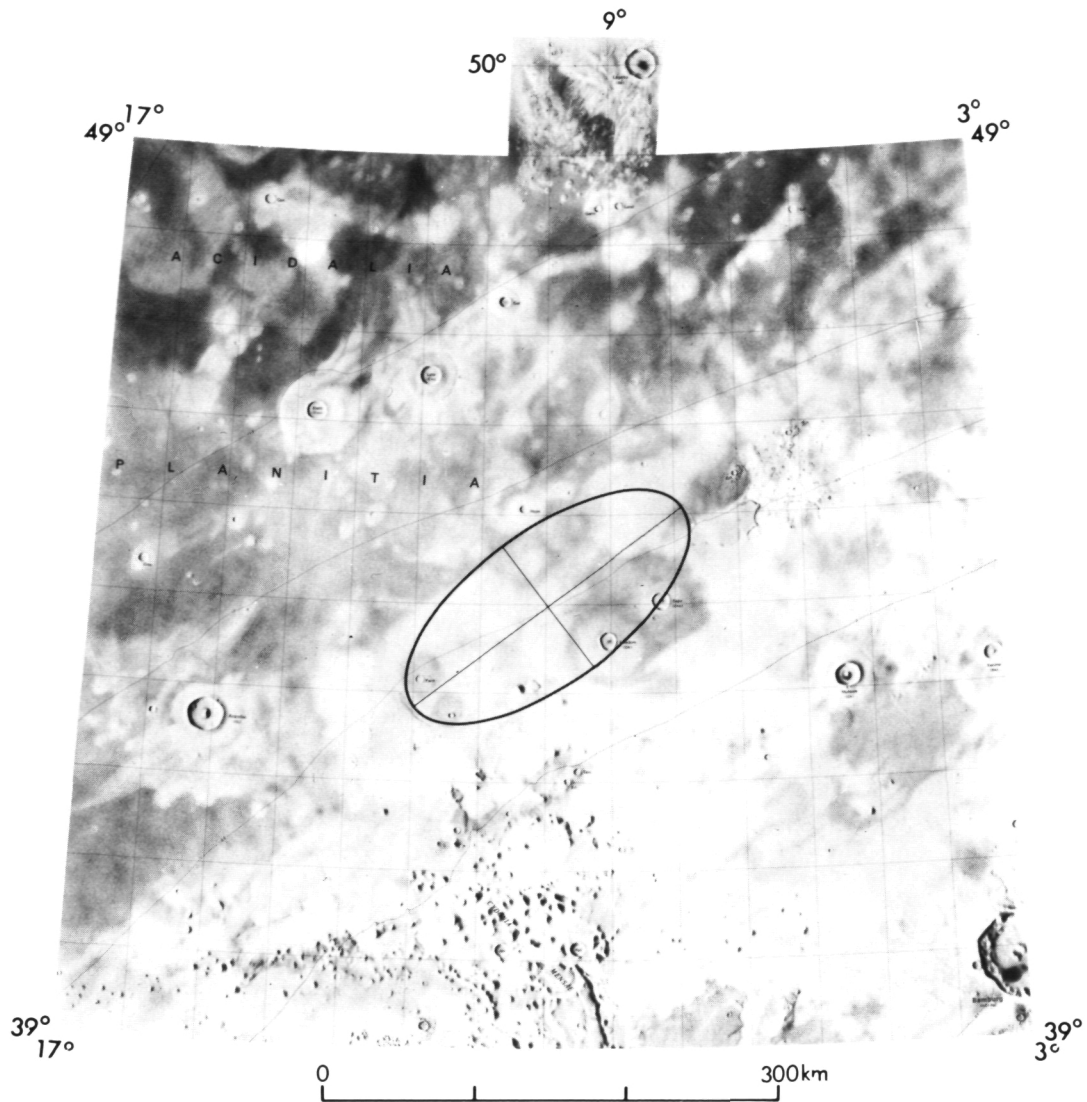Figure 4.- Final preselected Viking 1 landing sites for A and B missions.

Figure 5.- Premission map of B1 (Cydonia) site with landing ellipse.

Design of the A mission began in April 1973, with Chryse designated the A1 site and Cydonia designated the B1 site. The premission design phase was essentially completed in March 1975 when the Preliminary Mission Design Mission Summary was released for project use.

Alternate Sites

Although the primary landing sites had been selected and trajectory designs planned for both missions, the Landing Site Working Group became concerned because radar data were ambiguous at the Chryse (A1) site and impossible to obtain at the northern latitudes of the

Cydonia (B1) site. In early 1975, the Working Group selected an alternate equatorial area that was deemed safe from radar data as well as Mariner 9 imaging. The second (B) mission would be targeted to a site in this region if the landing for mission A were unsuccessful. Accordingly, additional Earth-based radar observations of the equatorial latitude band were planned for the 1975-76 observing opportunity with the JPL Goldstone X-band (3.8-centimeter wavelength) antenna and the Arecibo (Puerto Rico) S-band (12.5-centimeter wavelength) antennas; surface elevations, root-mean-square slope, roughness reflectivity, and possibly density and/or dielectric constant values would be determined from the observed backscatter characteristics. (See ref. 8.) The range of accessible Martian latitudes for this time interval is shown in figure 6.

Three smooth areas large enough to accommodate a Viking dispersion ellipse (100 by 240 kilometers) were selected as alternate candidate sites (designated C1, C2, and C3) based on detailed studies of Mariner 9 photographs and geologic and topographic maps. (See fig. 7.) Equipment downtime at both radar facilities prevented acquisition of some of the planned coverage. Nevertheless, enough data were obtained to identify one acceptable area, Capri (C1), and two possible backup areas, Meridiani (C2) and Schiaparelli (C3); all three areas were located at about 5° south latitude. Several other promising areas were rejected because the reflectivity values were low and surface slope values were excessively high. In particular, radar echoes from sites 8, 10, others in the Apollinaries area, and site 9 (Memnonia) were weak to nonexistent. Such weak echoes were interpreted to indicate a rougher surface or a material with a very low bulk density. The C1 and C2 sites were finally selected in March 1976, based on the good correlation between the radar and Mariner 9 pictures. However, there continued to be a question about the acceptability of the C1 (Capri) site altitude. Additional Goldstone radar ranging observations were made at the end of March 1976. Unpublished analysis of these data by Myles Standish of JPL indicated that the site altitude was acceptable in all but the most extreme "stacked worst case" of landing subsystem performance tolerance buildup. The C1 (Capri) site map is shown as figure 8. Detailed mission designs were not prepared for these alternate sites because of the press of mission operations and training at that time; only the basic trajectories were defined for a second mission landing at these sites. These alternate sites were not used because the first landing was successful and because the MAWD measurements had shown a higher water content in the atmosphere of the 44° north latitude band than had been anticipated. An intense review and discussion of the B and C sites photographed by the first orbiter did take place at the time of the mission B approach to Mars. The final decision, made after the Viking 1 landing and before the Viking 2 orbit insertion, was to land in the 44° north latitude band, as had been planned, because of the successful first landing and the larger amounts of water vapor in the northern zone indicated by MAWD measurements.
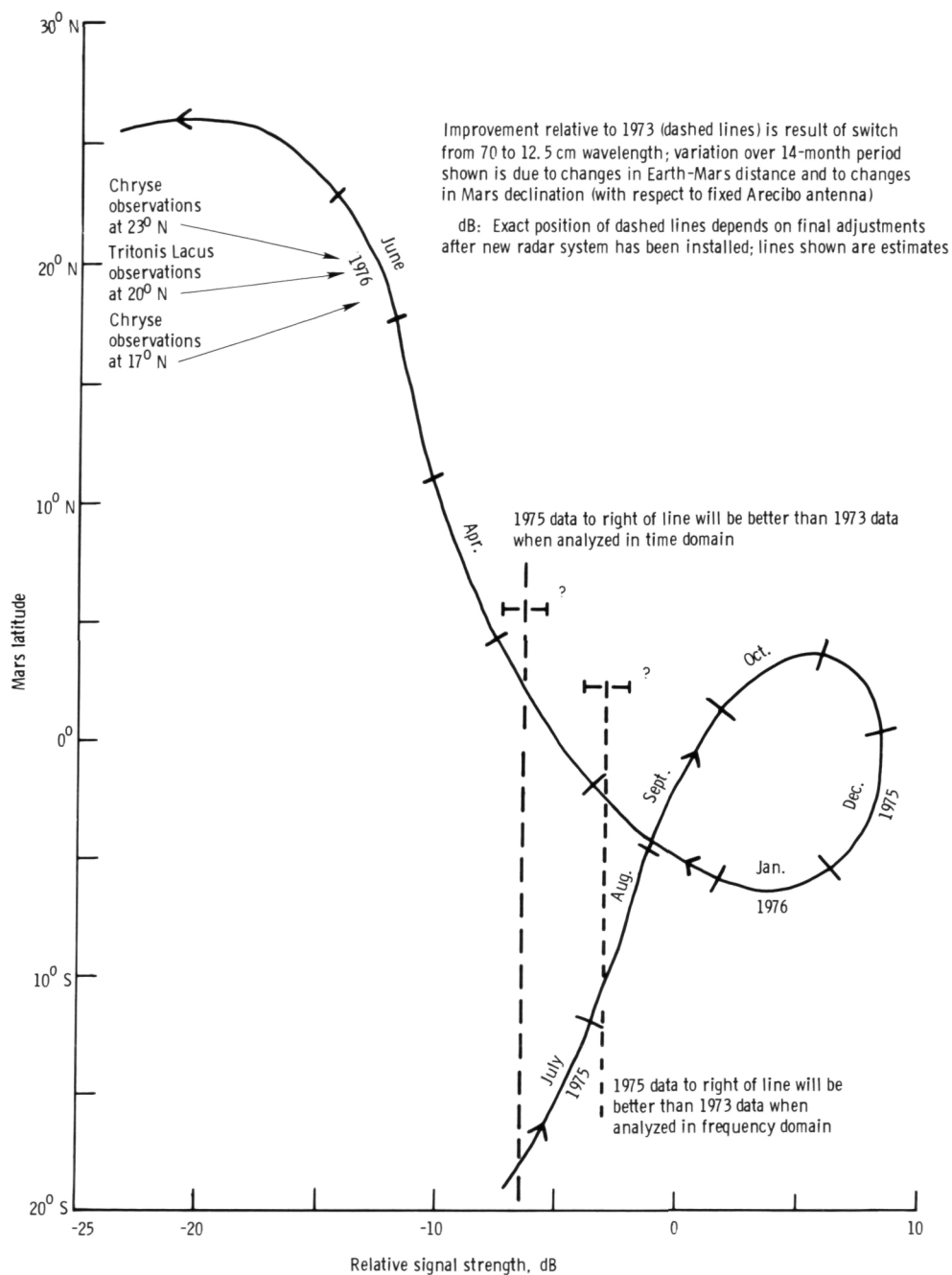
Figure 6.- Expected signal strength at Arecibo for Mars observations in 1975 and 1976.
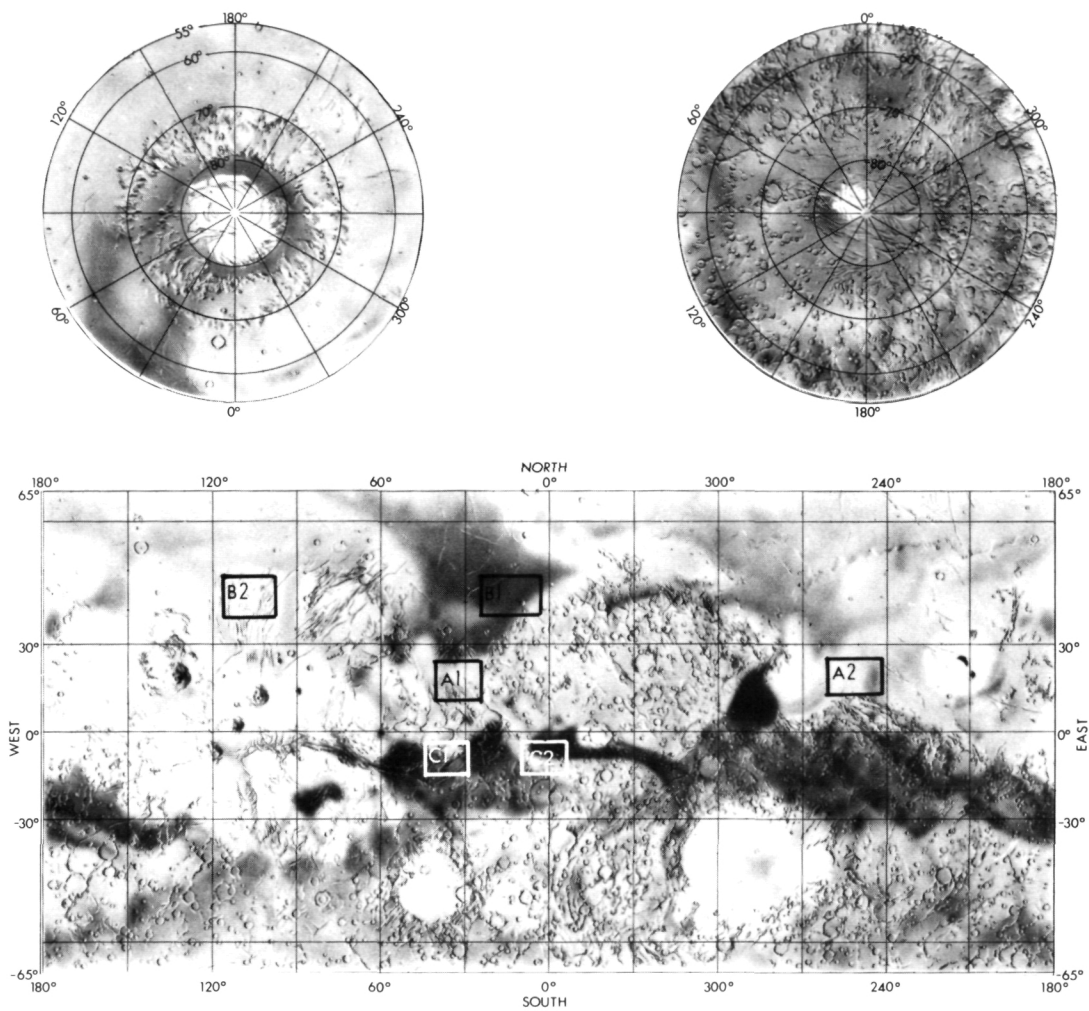
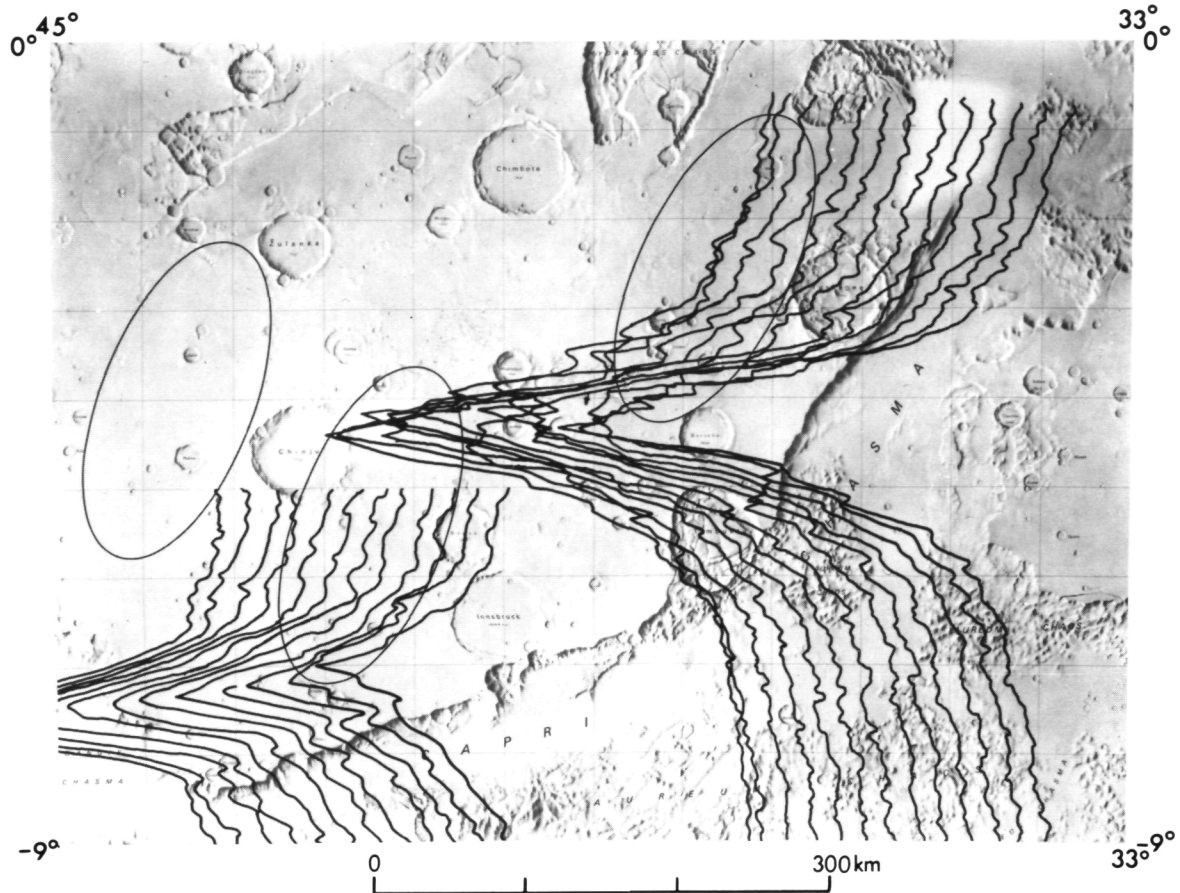Figure 7.- Final premission selections for Viking 1 landing sites.

11

Figure 8.- Premission map of C3 (Capri) site with possible landing ellipses.

SITE CERTIFICATION

Planning

Even though the primary and secondary sites had been selected, the job of site certification was far from completed. Both Earth-based and orbital instruments would gather much additional information during the 2 years that remained before the first spacecraft landed. Also, before the second landing would be attempted, data obtained by instruments on the first lander, during entry and after landing, would be used to confirm or modify the information which both Earth-based and orbital instruments had obtained concerning the physical and chemical characteristics of the site. Planned Earth-based observations included radar observations of the A1, A2, C1, C2, and C3 sites by the Goldstone and Arecibo facilities and "Mars Patrol" observations (telescopic, photographic, and polarization studies of Mars by a world-girdling array of observatories). Planned orbital observations included photographs and measurements of surface temperatures and atmospheric water vapor concentrations. Planned entry observations included measurements of atmospheric pressure, temperature, density and composition, wind velocities, and variations in these measurements

12

with altitude. Planned landed observations included surface pictures to determine terrain slope and rock sizes at spacecraft scale; meteorological measurements of temperature, pressure, and wind velocities; and estimates of surface properties that would be derived from studies of footpad penetration and surface sampler activities. The complete set of site-related properties to be estimated and the importance and approximate quantitative surface criteria (where applicable) for these factors are shown in table I.

The primary tool for determining surface characteristics would be visual inspection of the monoscopic mosaics and stereoscopic pairs of orbital photographs of the site area. Each site would be subdivided into geologic units, deduced from crater density determinations derived from photographs of the surface at landing site 1 and other stratigraphic clues obtained by photogeologic interpretation; the physical properties of each geologic unit would be estimated by comparing similar data obtained for lunar and terrestrial analogue areas. The results would then be collated on overlay maps showing geological and physical properties. Other overlays that would be prepared and used in these analyses included (1) surface elevation contours and measurements of slopes and roughness, derived from photogrammetric analyses of stereoscopic photographs of the landing site area, and approximate site elevations derived from the studies of stereoscopic photographs; (2) qualitative surface slope measurements derived from photometric analyses of VIS pictures of the area; (3) surface temperature plots from IRTM observations which permitted estimates of grain size from thermal inertia calculations; (4) water vapor concentration plots from MAWD observations and possible estimates of altitude of the water vapor layer if the concentrations were greater than 30 precipitable micrometers of water; (5) estimates of root-mean-square surface slopes and radar reflectivity from the Doppler radar spectra at X- and S-bands; (6) estimates of surface density from radar reflectivity measurements; (7) surface slope estimates down to a scale length of approximately 500 meters from the television stereoscopic images; and (8) extrapolation of slopes to the 3-meter spacecraft scale in dune fields and in craters in order to compare the characteristics of Martian and terrestrial dune fields and crater studies (ref. 7). None of the available techniques could provide clear indications of unsafe surface conditions at the scale of the lander except possibly the radar data which theoretically could measure surface roughness at slope lengths with a range of 3 to 20 meters; however, the radar was known to be insensitive to block abundances — the greatest hazard to the lander. The imaging could be used only to infer block abundances in the vicinity of impact craters derived from studies of analogous terrestrial and lunar craters. The resolution of the imaging system would only allow identification of blocks that were about 300 times larger than a block considered dangerous to the lander safety. In general, however, the techniques for site certification would depend on inferences drawn from terrestrial and lunar analogues and extrapolation of data obtained by orbiting instruments to geologic units mapped from visual imaging.

The only atmospheric properties that could be estimated before landing were dust storms observed by the imaging system, winds inferred from cloud motions or albedo changes observed by the imaging system, atmospheric temperature variation from 15 to 30 kilometers above the surface inferred from infrared thermal measurements, and a limiting surface pressure derived from MAWD observations. Entry results of atmospheric pressure, density,

TABLE I.- VIKING SITE CERTIFICATION PARAMETERS

Property	A1 or A2 before landing	A1 or A2 after landing	B1 or B2 before landing	Significance	Parameter
Surface					
Location	VIS – landmark recognition	VL-1 imagery landmark resection correlation with VIS imagery	VIS – landmark recognition	Landing ellipse size	
Altitude	Earth radar VIS stereo	VL-1 transponder tracking	VIS stereo	Entry vehicle parachute performance	<4.25 km above Mars datum
Temperature	IRTM	IRTM	IRTM	Lander operating environment Length of lander activity cycle	
Geology	VIS – visual impression	VL imagery – visual impression	VIS – visual impression		
Slopes	Earth radar VIS stereo	VIS stereo VL imagery	VIS stereo	Prevention of TD tumbling	<19°
Protuberances	VIS – visual impression	VL-1 imagery	VIS – visual impression	Prevention of lander bottom plate penetration	<22 cm
Density, grain size, and cohesion	Earth-based radar VIS – visual impression	VL-1 TD dynamics Imagery of foot pads	VIS – visual impression	Surface sampler operations, lander TD penetration, and shock load	1200 to 1920 kg/m3
Radar reflectivity	Earth-based radar	Gross RA TDLR performance		Prevention of lander terminal guidance system losing lock	>1%
Atmospheric					
Density and temperature as functions of altitude	MAWD – surface pressure (gross) IRTM – T as function of h (15 to 30 km)	Entry measurements (IRU)	MAWD – surface pressure (gross) VL-1 results mapped to 44° north latitude IRTM – temperature as function of altitude	Entry vehicle performance	
Composition	None	UAMS entry results GCMS landed results	VL-1 results mapped to 44° north latitude	Unknown gases during entry performance lander GCMS analysis	<15 to 20% argon to preserve GCMS experiment integrity
Dust storms	VIS – hazes, clouds albedo IRTM – thermal inversions	VL-1 imagery	VIS – hazes, clouds IRTM – inversions		
Winds	VIS – cloud motion, albedo changes	VL-1 meteorology	VL-1 results mapped to 44° north latitude	Entry trajectory performance, lander stability and imagery capability, wind loads on sampler boom	

temperature, and winds as functions of altitude from the first entry would be extrapolated to the second landing site and landing time for the second lander, taking into account the change in landing site location and season of the Martian year.

Mission Operations

Viking 1 mission operation activities during site certification have been briefly documented in reference 9. In addition, the use of Earth-based radar in the search for the VL-1 site is described in reference 10; some of the orbiter imaging results obtained during the in-orbit phase of the VL-1 site certification are given in reference 11; and the corresponding MAWD and IRTM results are given in references 12 and 13. Preliminary postlanding results are given in reference 14 for the composition and structure of the Martian atmosphere from the VL-1 entry experiment. The ground truth measurements of surface meteorology, chemistry, geomorphology, and physical properties are given in references 15, 16, and 17. Events are described in reference 18. As these reports indicate, whereas science objectives could have been met, the preselected landing site (fig. 2) was rejected when photographs taken from orbit showed evidence of intense fluvial dissection and other possibly hazardous features (such as, wind stripping and volcanic features) at both the A1 site and 200 kilometers farther downstream to the northwest (fig. 9). Radar reflectivity values obtained near the time of the nominal landing date also were low in this area (fig. 2). The search then ranged many hundreds of kilometers away from this area in an attempt to find a site which minimized these features. The nearest possible safe location was thought to be the central part of the Chryse basin (at -3 kilometers, Mars datum) situated about 500 to 1000 kilometers northwest of the original site (fig. 10). Presumably this basin acted as a trap for the outflow from the large stream complex where the lessened stream gradient was thought to have caused deposition rather than dissection like that seen on terrestrial desert playas. In order to verify this hypothesis, additional photographic coverage was obtained of the Chryse basin, northwest from the original A1 site, on revolutions 10, 20, and 22 (fig. 10). At the same time, additional Arecibo S-band Doppler spectra were obtained over these locations. The reflection coefficient at 43.75° west (A1NW site, eastern ellipse) was 3.1 percent; this anomalously low value disqualified the site. The site selection team then moved the nominal ellipse west to 48° west (western ellipse) where the higher reflection coefficient value of 8.2 percent at 48.25° west indicated a smoother and, therefore, safer area. Discussions of the radar characteristics and geology of these areas are given in references 10 and 11.

The VL-1 was finally targeted for a site at 22.4° north aerocentric and 47.5° west, west of the center of the Chryse basin, part way up the western slope of the basin. Photographs of the region resemble those of lunar mare regions where wrinkle ridges also are prominent. This area was chosen because there were a minimal number of impact craters and, therefore, a minimal number of blocks that might be hazardous to the lander; radar data showed intermediate reflectivity values of about 8 percent, a value close to the Mars average. A smooth area with a minimum of large impact craters at 23.4° north and 43.4° west (site A1NW) at the center of the basin was rejected because the observed radar reflectivity fell to about 5 percent there. This radar
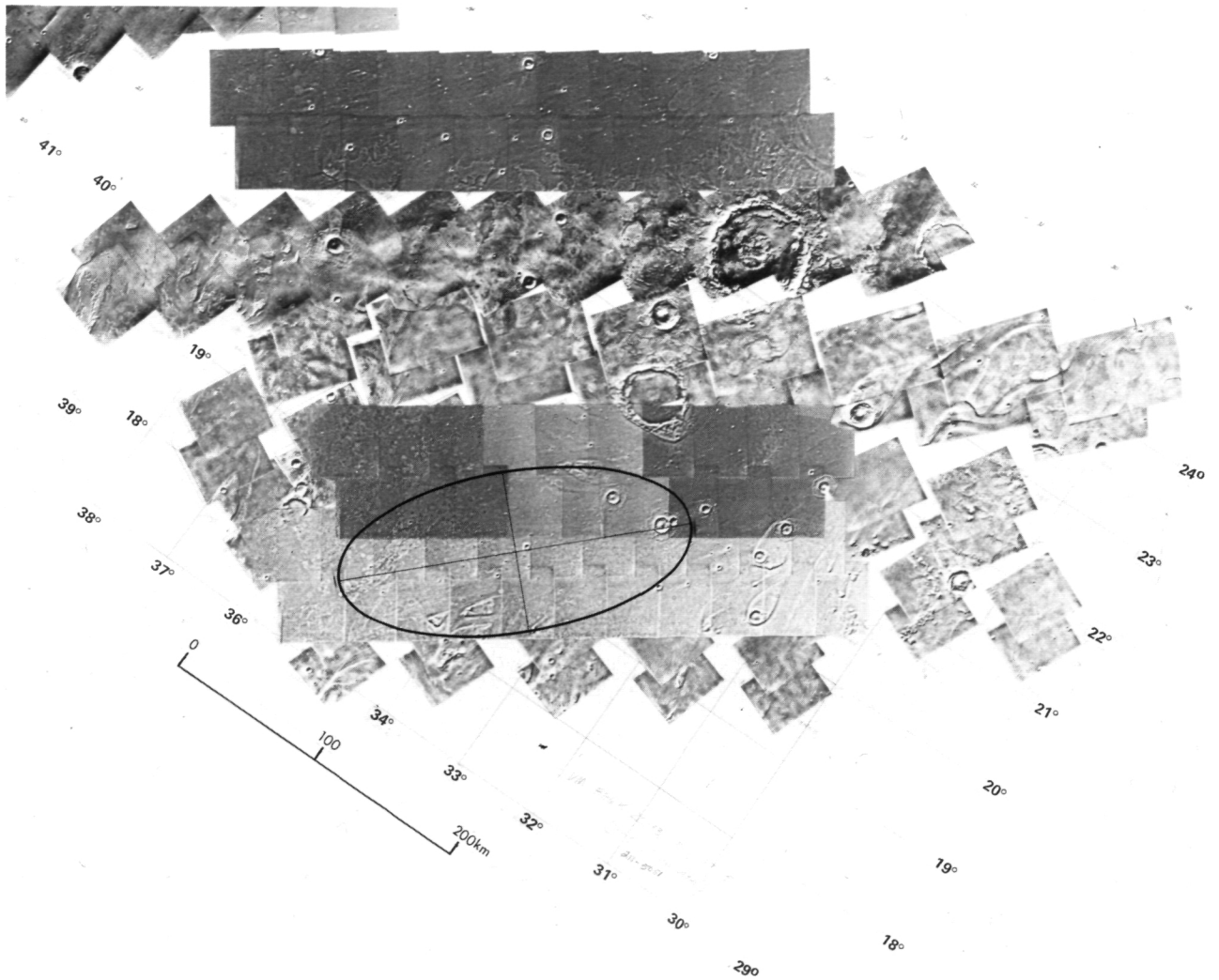
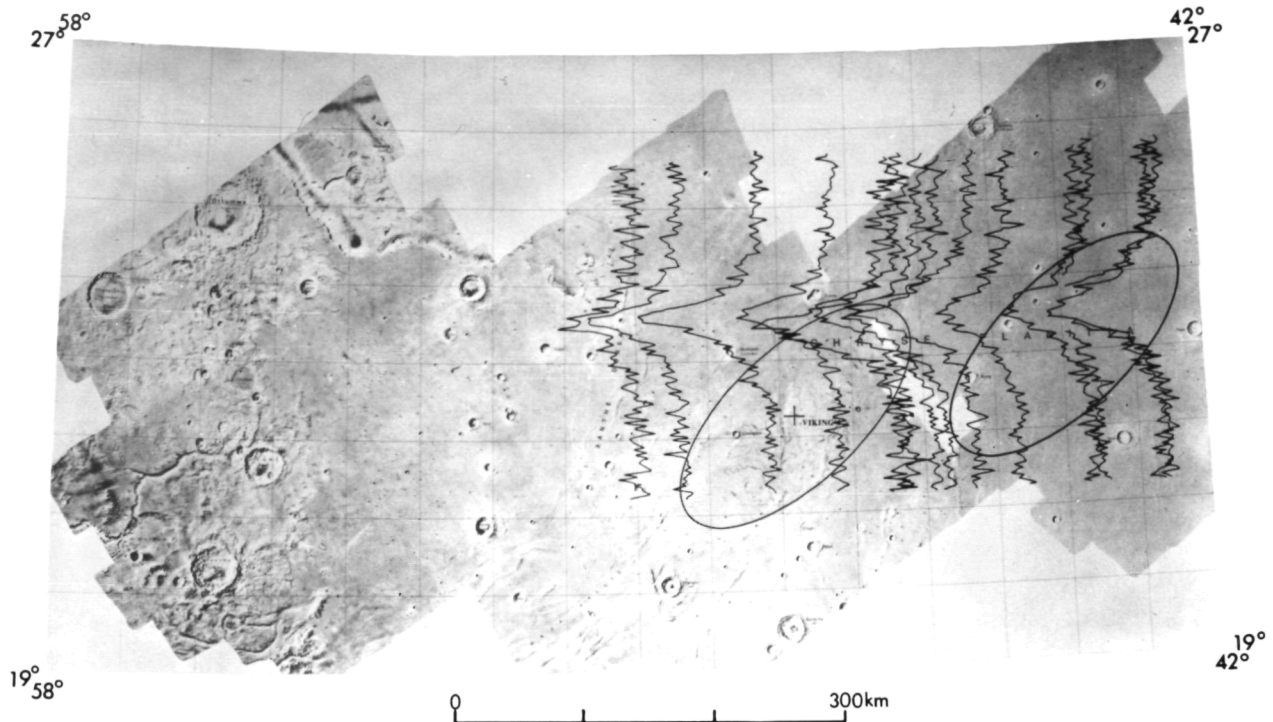Figure 9.- Photomosaic of A1 (Chryse) site.

Figure 10.- Photomosaic of western Chryse region of Mars with radar spectra obtained on July 5, 1976, at 23.2° north.

anomaly is shown in figure 10. Similar lower radar reflectivities were observed in terrestrial dune and playa areas (U.S. Geological Survey interpretation of data obtained from Charles Elachi of the Jet Propulsion Laboratory). The mare-like surface west of this area shown in the Viking orbiter images resembled the well understood lunar mare areas so that surface properties could be extrapolated to the scale of the lander; radar data for the lunar mare areas and the Martian surface were also similar but not identical. The details of the radar signatures involved quasi-specular and diffuse echoes; polarized and unpolarized returns were still being actively investigated and debated. The landing point therefore was a compromise between the best and worst images and best and worst radar reflectivities. Landing was successfully accomplished on July 20, 1976, at 5:12 a.m. PDT (Earth-received time) at 22.272° north aerocentric and 47.94° ± 0.2° west. Figure 11 is a controlled photomosaic of the Viking landing site area; the original scale of the map was 1:250 000.

Much important information was obtained when the entry and immediate postlanded data returns were reviewed. The structure of the atmosphere, as revealed by the entry experiment, was shown to be well within the design models; therefore, less constraining models could be used for the design of the second entry (fig. 12). The lander imaging (fig. 13) shows a depression approximately 100 meters away with rocks in the foreground; observed block size frequency distributions are given in figure 14. Results from terrestrial and lunar crater studies suggest that the blocks are ejecta from a 100-meter-diameter crater; alternatively, some may be locally derived bedrock blocks from areas where the eolian deposits have been
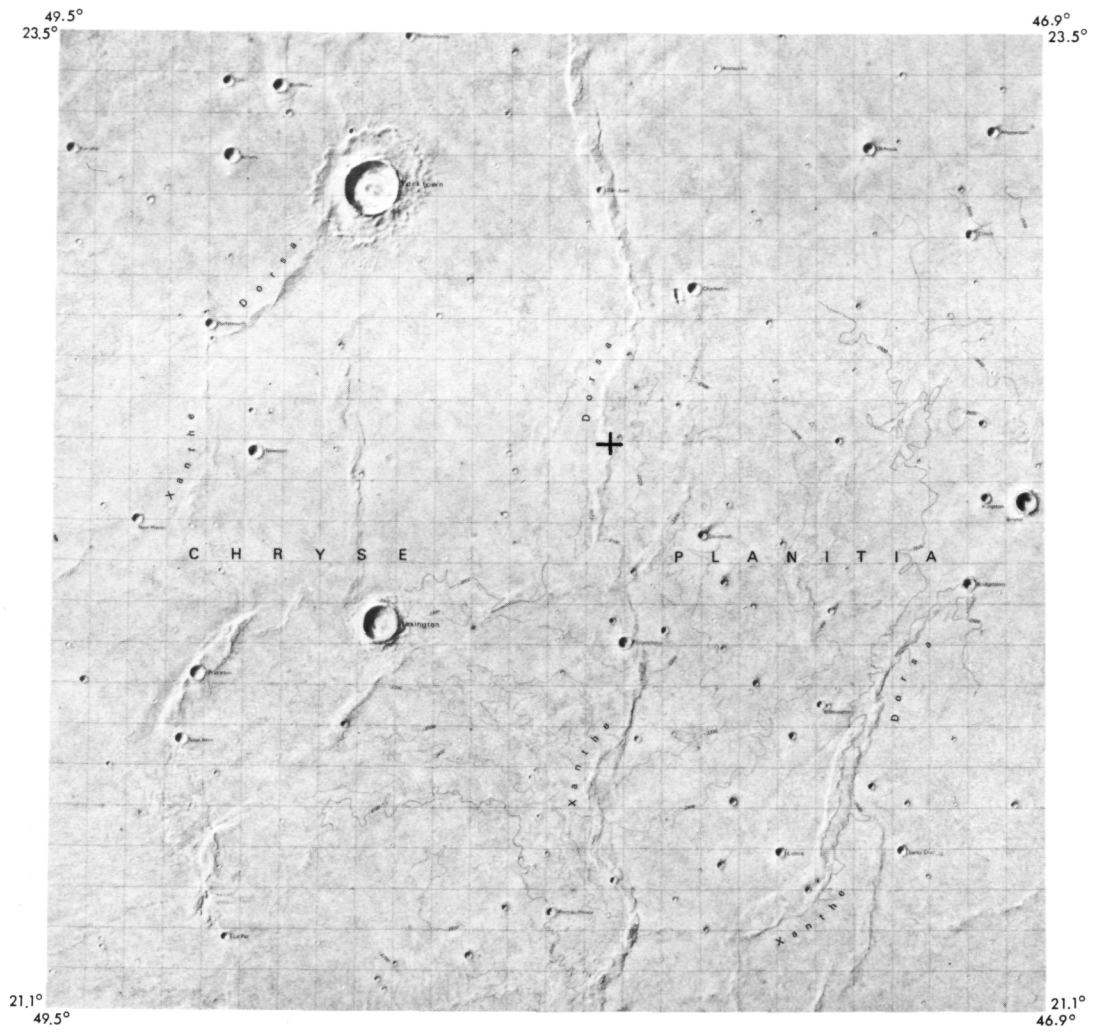
17

Figure 11.- Controlled photomosaic of Yorktown region of Mars. VL-1 landing site is shown by +.
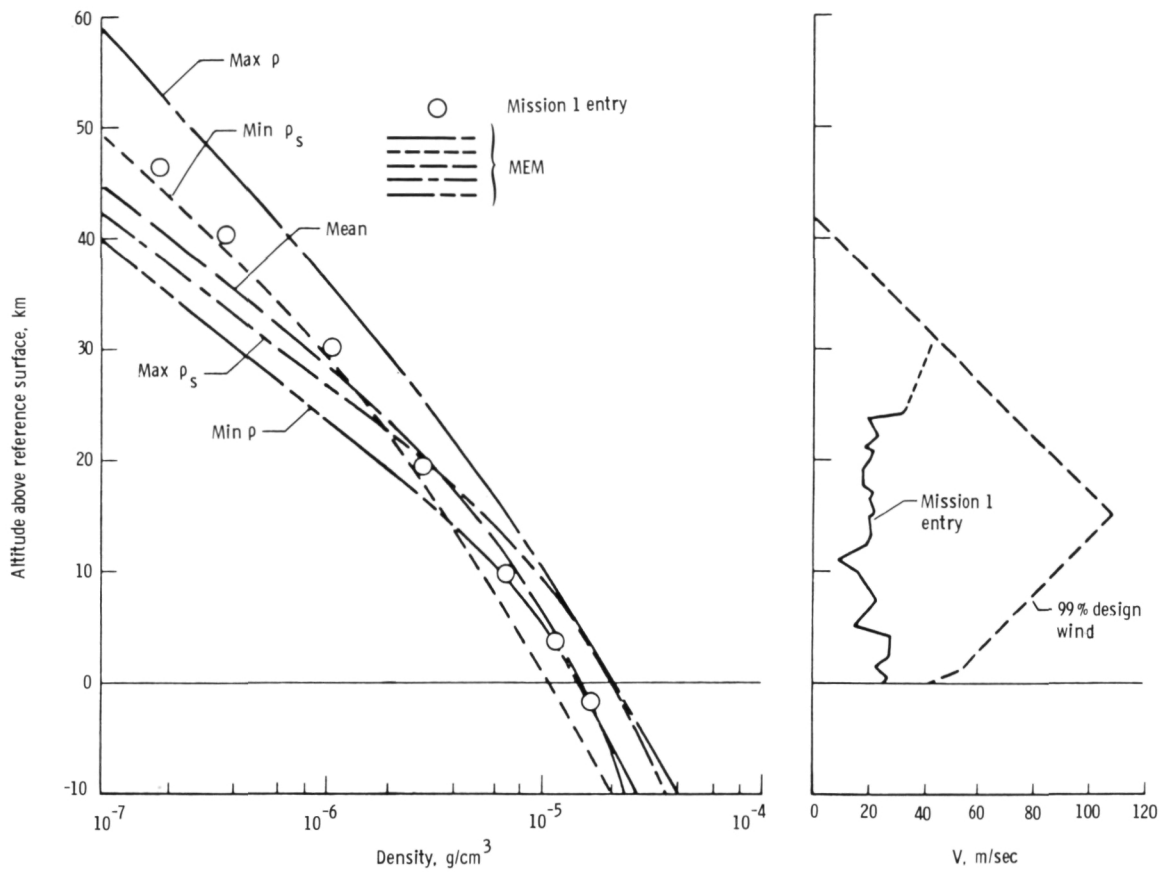
Figure 12.- Measured atmospheric parameters and comparison with design values.
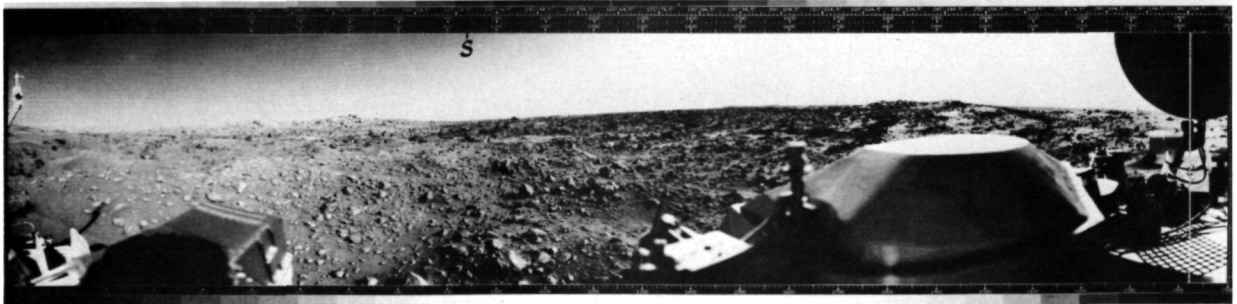

Figure 13.- Low-resolution panorama of Martian landscape taken on sol 0. Viking Lander 1.
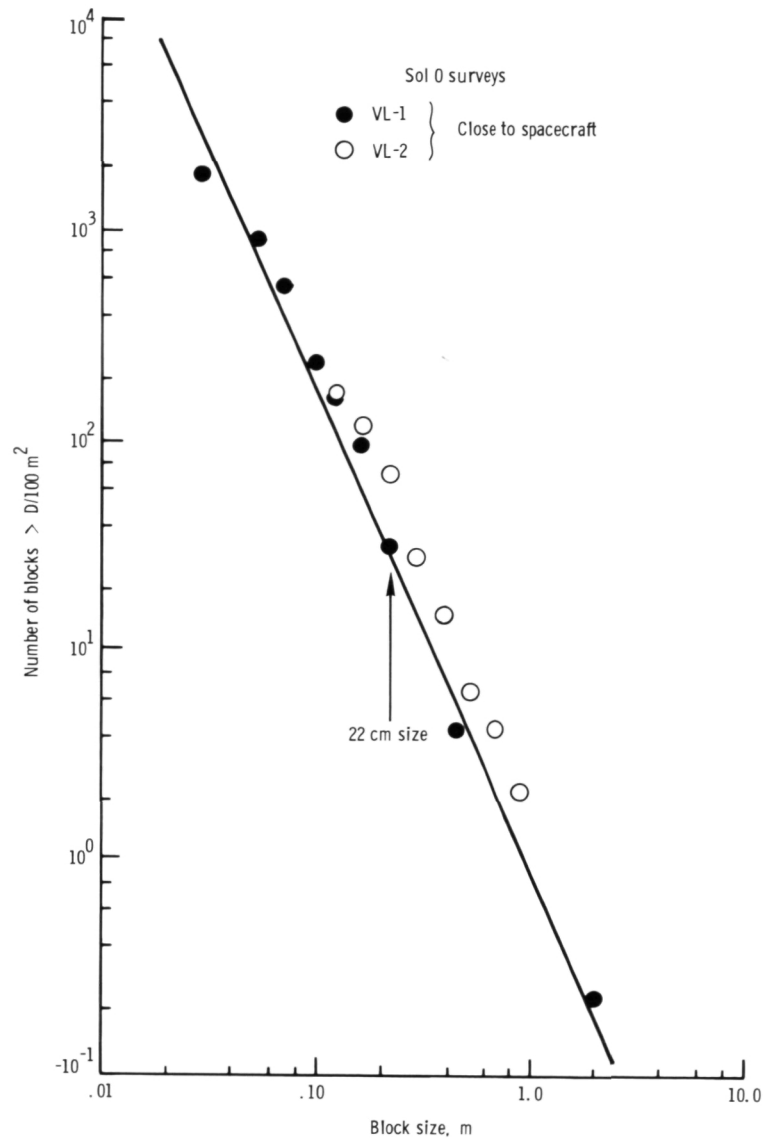
Figure 14.- Viking 1 and 2 sites near-field block size frequency distribution.

stripped. Two percent of the surface is estimated to be covered by blocks greater than 22 centimeters high; approximately 25 percent of the area accessible to the surface sampler was judged to be unsuitable for sample collection because of rocks.

It was not possible to determine whether the landing site actually had water-laid deposits beneath its surface because eolian material appears to have partially covered and then been partially stripped from the area (fig. 13). The left side of the panorama shown in figure 13, where part of the surface sampler is visible, faces east on Mars. The right edge is north. The sky is brighter in the direction of the setting sun. Some of the irregularities on the skyline, particularly the one to the southeast, may be parts of the raised rims of impact craters. A shallow depression occurs in the foreground just to the right of center and may

be a shallow 3-meter-diameter impact crater, possibly a secondary crater. At this resolution an object 6 meters in size subtends one picture element at the nominal horizon. The bedrock outcrops that might be of this origin were far out of reach of the sampler arm. Nor was it possible, with the Viking orbiter image resolution at 1500-kilometer periapsis elevation, to delineate the hazardous block populations shown in the lander photographs. Higher resolution images are needed to determine such local hazards and to interpret the processes that formed the rocks seen at the landing site.

In retrospect, several pertinent observations about the use of the available instruments can be made. The orbiter imaging photographs were used to determine nearness to large impact craters and the inferred associated blocks; nearness to craters less than 100 meters in diameter could not be determined with this camera from this orbital altitude. Determination of surface roughness by orbital observation depends on both the actual distribution of roughness and the response of the instrument. It is quite possible to have surfaces that appear rough in the orbiter images but smooth in the lander images or smooth in the orbiter images but rough in the lander images. In the Lunar Orbiter and Apollo Programs, small blocks and slopes were observed on the Moon by flying appropriate focal-length cameras with ultra high resolution film at sufficiently low altitudes. Although Earth-based radar data could be used to avoid areas where reflectivity values were low and root-mean-square slope values were high, these data could not absolutely certify the absence of hazardous blocks. The Earth-based radar could be used to obtain depolarized echoes on Mars to help interpret block abundances at a site. Later attempts to obtain depolarized echoes of the site (needed to resolve block frequency) were unsuccessful. It was also difficult to verify block size and frequency on the Moon from Earth-based radar (refs. 19, 20, and 21) although depolarized echoes were more easily obtained there and were used for interpretations of block frequencies (refs. 22 and 23). Infrared observations of the proposed landing sites under predawn and noontime conditions might have helped to resolve the nature of the radar anomaly at the A1NW site (23.4° north and 43.4° west); however, this would have required orbit changes. Time constraints and uncertainty about the applicability of the results ruled out any orbit changes. The most direct method for determining block populations would be a much higher resolution (about 1 meter as was used for lunar site certification) imaging system supported by IR and radar observations. A radar altimeter for confirming the actual elevation would also be useful.

Mission operations for certifying the VL-2 site have been reported in detail in reference 24; only the highlights are reviewed here.

The search for the second Viking landing site began a week after the first spacecraft was inserted into orbit on June 19, 1976. On June 28 and 29, the B1 and C1 sites (figs. 4 and 7), respectively, were photographed by the first Viking orbiter; results of these efforts are shown in figures 15 and 16. Once again, the Martian terrain was shown to be unexpectedly rough at the B1 site. The latitudes between 40° and 60° north had appeared, from Mariner 9 photography, to be dominantly composed of lava flows, overlain in some areas by a windblown mantle; it was hoped that the windblown deposit would cover hazardous blocks.

Photographs of the B1 site (fig. 15) showed a surface that was rougher than had been expected from high-resolution Mariner frames of the area and rougher than the premission A1 site. Most of an overlying mantle of wind-deposited material had been stripped away, exposing large-scale polygonally fractured bedrock and irregular lava flows; abundant secondary craters gave evidence of a formidable impact history. Photographs were then taken east and west of the B1 site and to the northeast above the 50° latitude band (fig. 15) where the eolian mantle was inferred to be more continuous (ref. 25). Remnants of a mantle are seen in several locations (fig. 15), but the mantled areas were too small (approximately 60 kilometers) to accommodate a Viking landing ellipse.
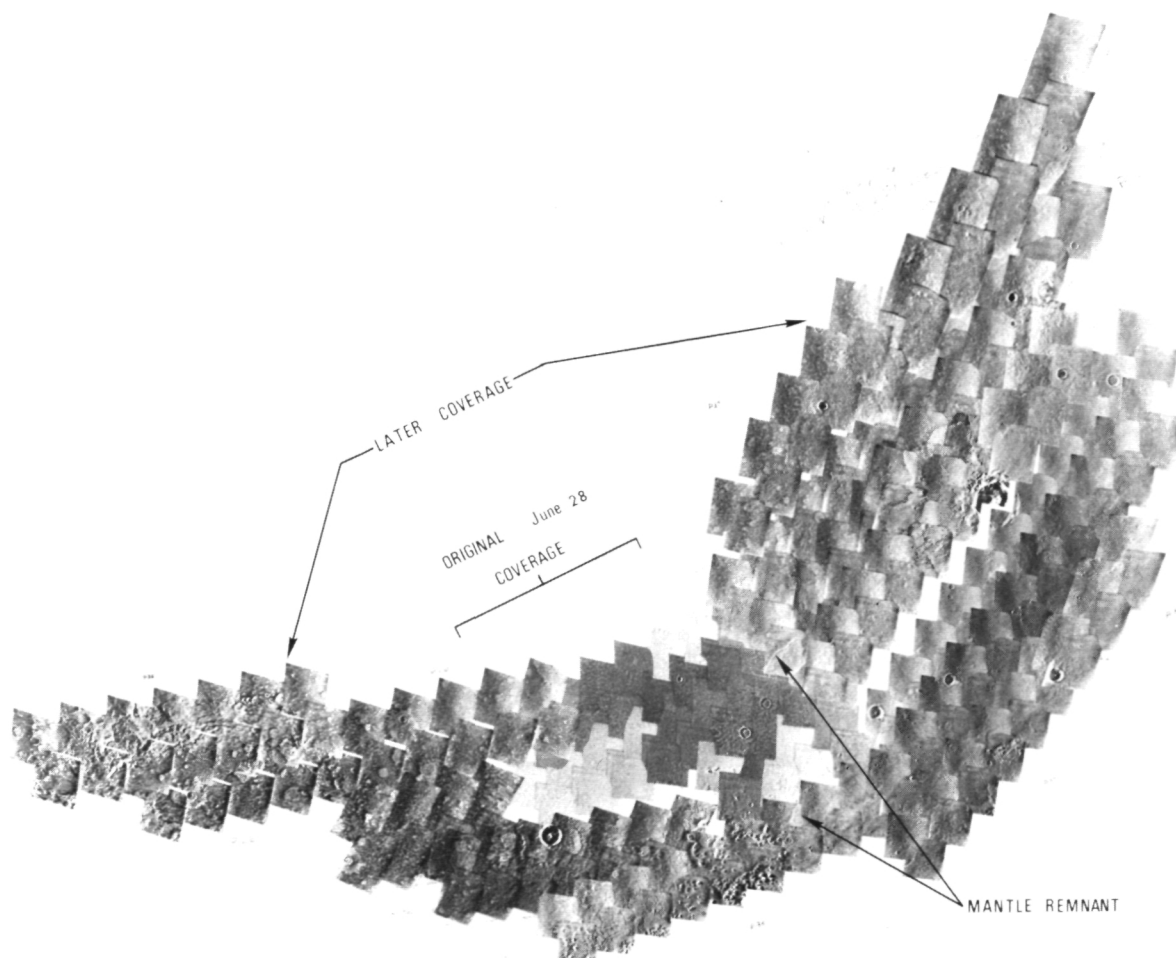

Figure 15.- Photomosaic of area surrounding B1 site.

The subdued appearance of the large craters and the lack of any sharp features at the C1 site (fig. 16) appeared more promising; the surface of this area was interpreted as being partially overlain by a windblown mantle a few meters thick overlying lava flows that covered the ancient heavily cratered terrain. This interpretation was consistent with the radar observations obtained in January to March 1976 which indicated that the surface was

smooth with very small root-mean-square slope values; infrared data and Mariner 9 pictures were also consistent with this interpretation.
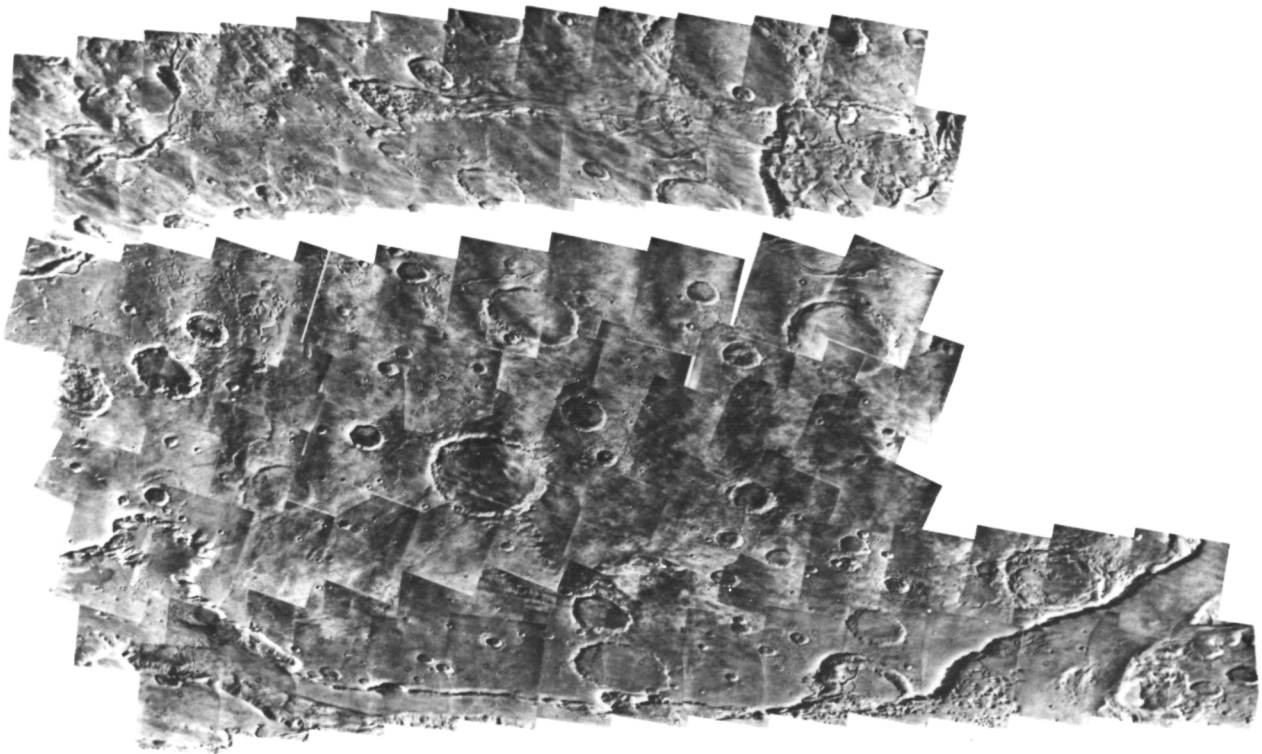

Figure 16.- Photomosaic of area surrounding C1 site.

The successful landing of Viking 1 on July 20, 1976, presented the project with a "happy" dilemma: Should the second lander be targeted to the 40° to 50° north latitude region as planned, despite the inhospitable terrain seen at the B1 site, or should it be targeted to the C1 site where the landing might be safer but where less atmospheric water had been measured? Orbital atmospheric water measurements (ref. 12), such as those obtained from Earth-based instruments, continued to indicate an increase in measured water vapor with increasing latitude and decreasing elevation. Thus, the C1 site was judged to be a poor choice because it was even drier than the VL-1 site, and it was feared the dryness would have an adverse effect on the possibilities of finding biological activity there; this was not an unanimous view, however. Some scientists, including Vance I. Oyama of the Biology Team, believed that the results of chemical tests obtained by VL-1 favored selection of the more southerly C1 site; they believed that the ubiquitous solar ultraviolet effect would cause little change in the surface oxidizing potential between the VL-1 site and the 44° latitude band but that warmer conditions at the C1 site might enhance the possibilities for biological activity so that the resulting higher thermal activity might decrease the soil oxidizing potential. However, the former view prevailed, and on July 17 a decision was made to insert Viking 2 into an orbit that would permit landing at about 44° north latitude even though a safe landing site had not been defined. A latitude change capability of at least -5° to $+5^O$ could be obtained

through use of orbital apsidal rotation due to the favorable navigation experience for the second mission. Attention was then focused on alternative longitudes within the 40° to 50° north latitude band; the coverage obtained is shown in figure 17. While Viking orbiter 1
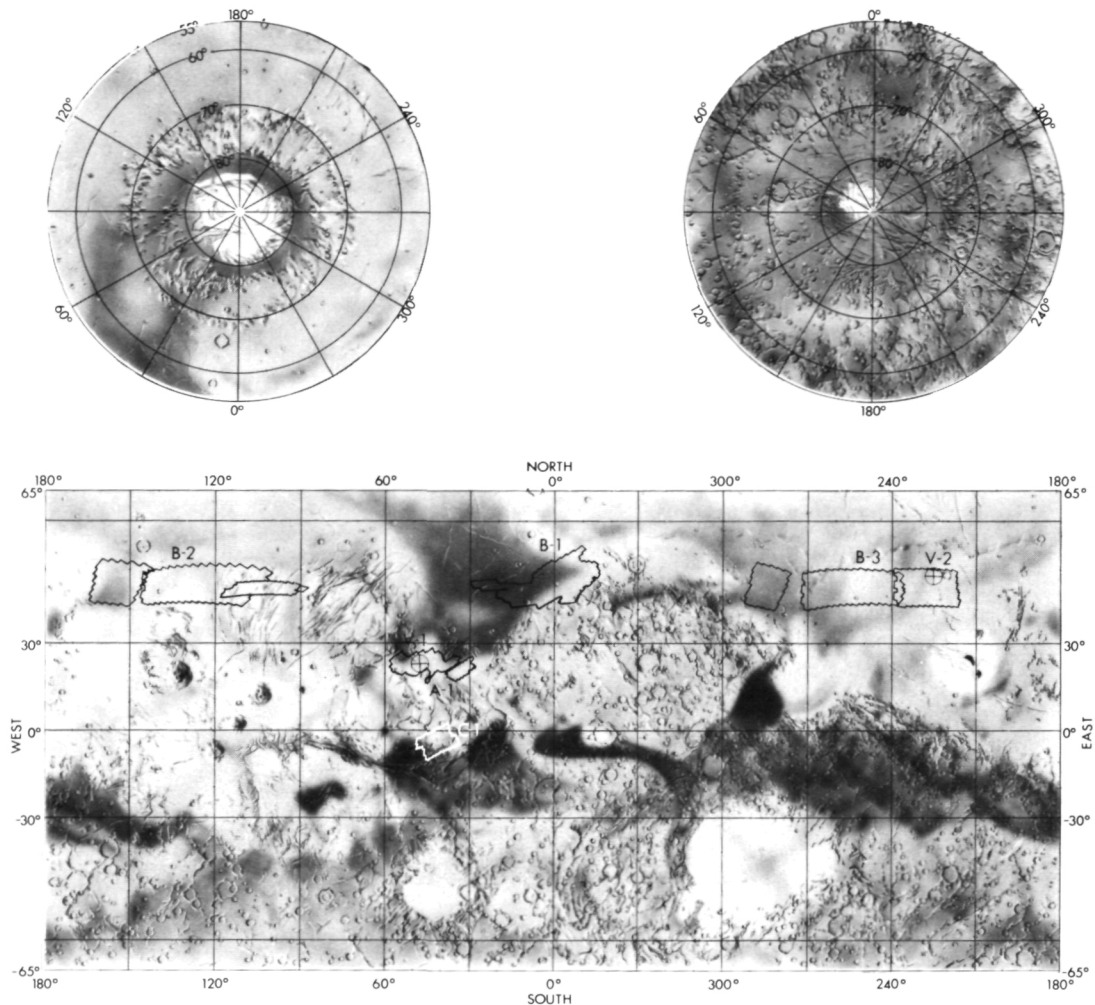

Figure 17.- Viking 1 and 2 photographic coverage of B1 and B2 areas obtained
for site certification.

continued to search the B1 area, the second orbiter would search the B2 site and the newly designated B3 area located at approximately 44° north and 110° east; the associated mission operations timeline is shown in figure 18. The original plan provided four options for landing at different places and times; however, by August 16 it was apparent that the resulting operational workload had become too great. The B1 and B2 options were eliminated and the B3 option became the prime objective in the nominal timeline even though it had not yet been observed. If results warranted, the other options could be reexamined at a later appropriate time.
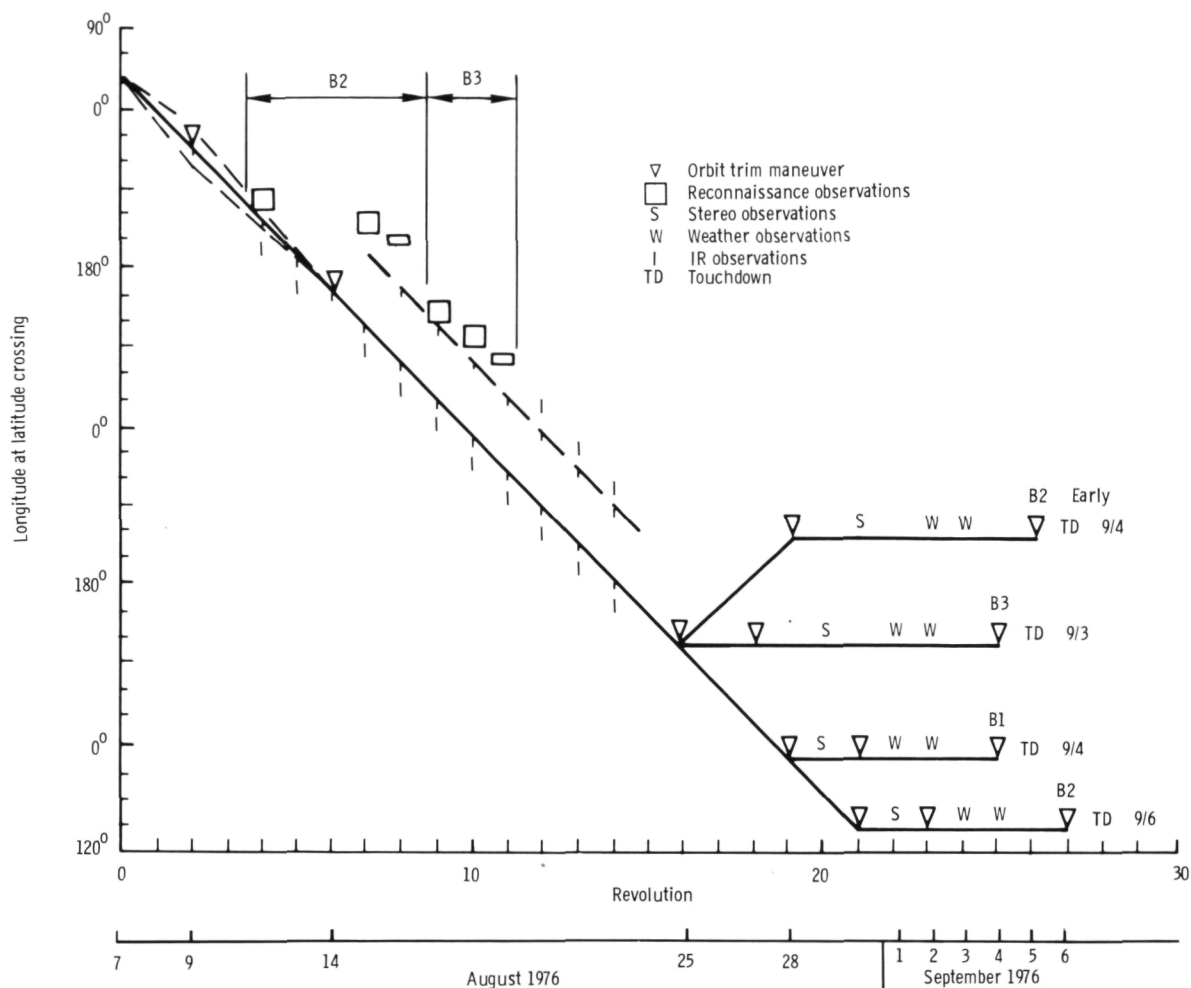
Figure 18.- Viking 2 timeline showing types of observations to be obtained during 4-week period before planned VL-2 touchdown.

Photographs of the B2 area were obtained on revolutions 7 and 8 and of the B3 area on revolutions 9, 10, and 11; the photocalibration test on revolution 4 was also targeted to Alba Patera, the B2 area. These photographs showed that the Alba Patera site contained extremely rough volcanic rock; therefore, the area farther west (B2 west) was investigated. Figure 19 is a photomosaic of the B2 site coverage and figure 20 is a controlled photomosaic of the B3 area; tentative locations for landing sites are marked by ellipses. The Viking orbiter cameras showed a much more complex and hazardous surface in these areas than was apparent from the smooth plains shown by the lower resolution and poorer discrimination Mariner 9 photography. Viking photographs showed multiple eolian mantles that appear to have been deposited and then partially eroded during several cycles. At the 200-meter identification resolution of the orbital images (40-meter pixels (picture elements)), separating areas that had been blanketed from those that had been stripped was difficult. In addition, the older mantles appeared to have abundant secondary craters from impact craters formed on them. Detailed analyses of these areas are given in reference 24.
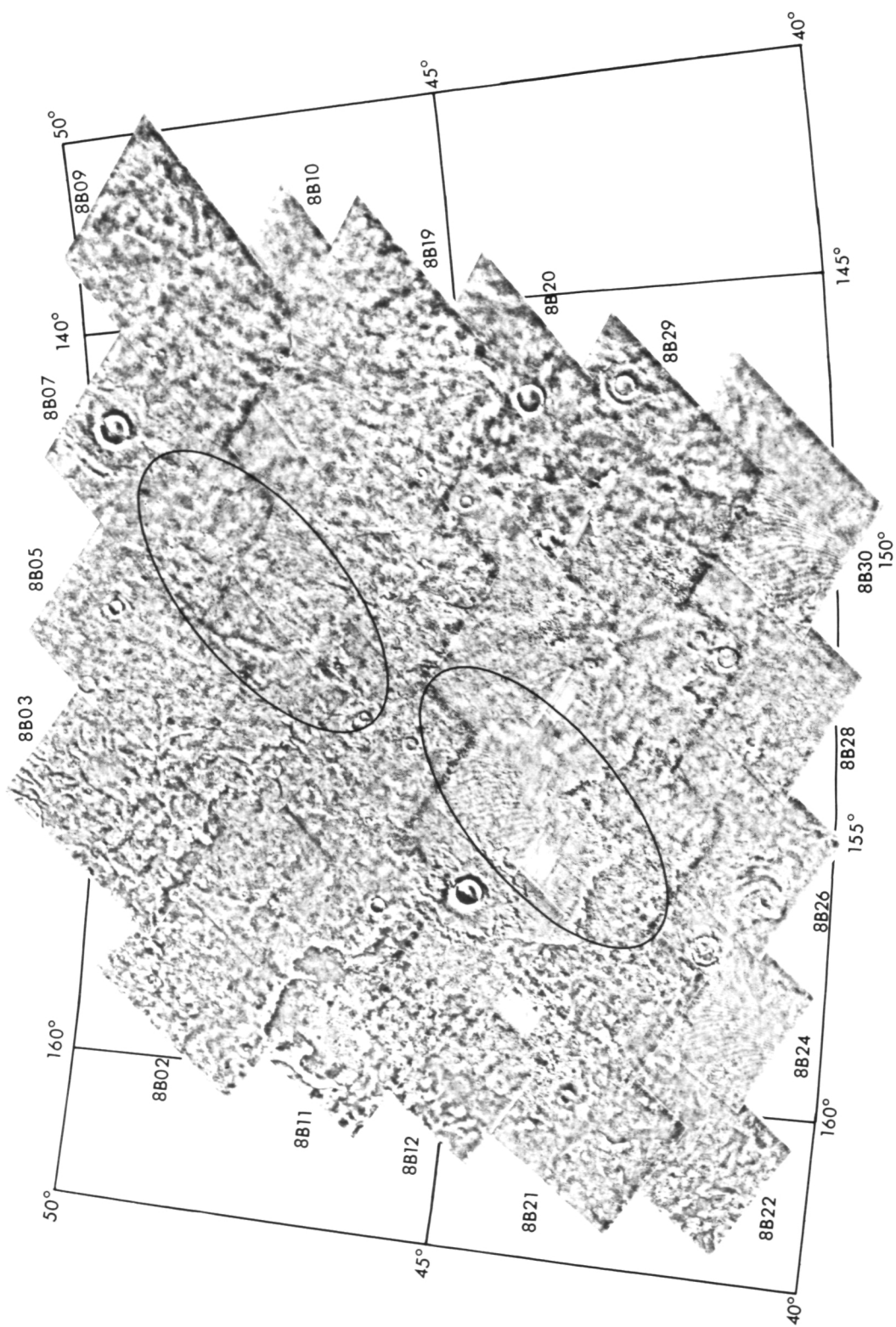
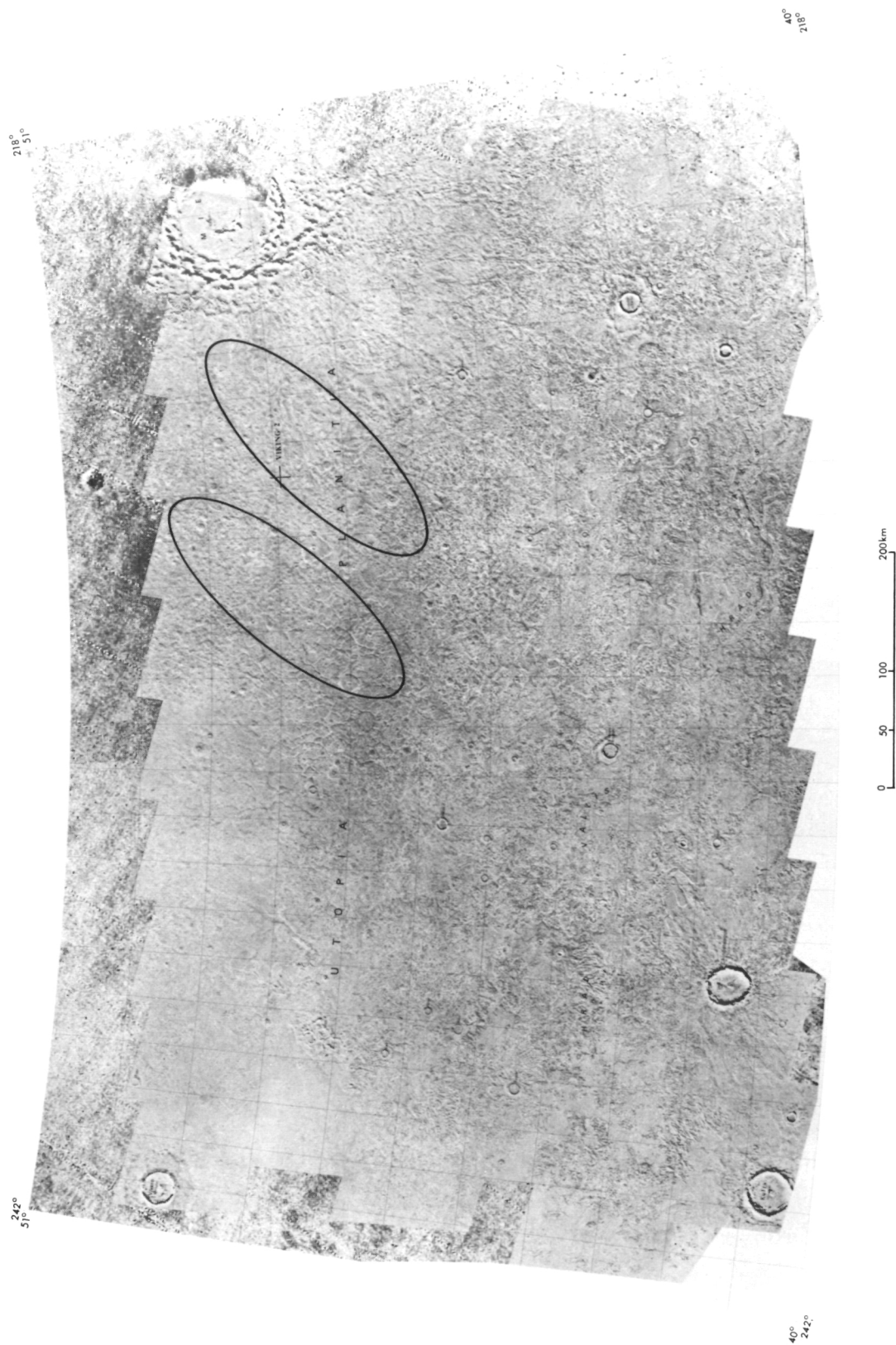Figure 19.- Photomosaic showing candidate sites in B2 west region.

Figure 20.- Controlled photomosaic of Utopia region of Mars. Approximate position of VL-2 is shown by +.

27

Many factors were considered before the final choice between the two sites was made. The most important areas of conflict concerned safety to the lander, the expected scientific return, and the relative complexity of operations planning for the two sites. The textured terrain visible in the ellipse areas of figure 21 was judged by some geologists to be dunes that ranged in thickness from 10 to 30 meters. There was some concern, however, that the amount of obscurely textured terrain within the lander dispersion area (only about 60 percent) did not provide a high enough margin of safety. Also, there was no way to judge the thickness of the cover that did not have the dune shape and might therefore represent deflation hollows like those that were abundantly displayed in the areas to the east, west, and south of the site. The dunes in the B2 site were clearer and larger and did not have interspersed
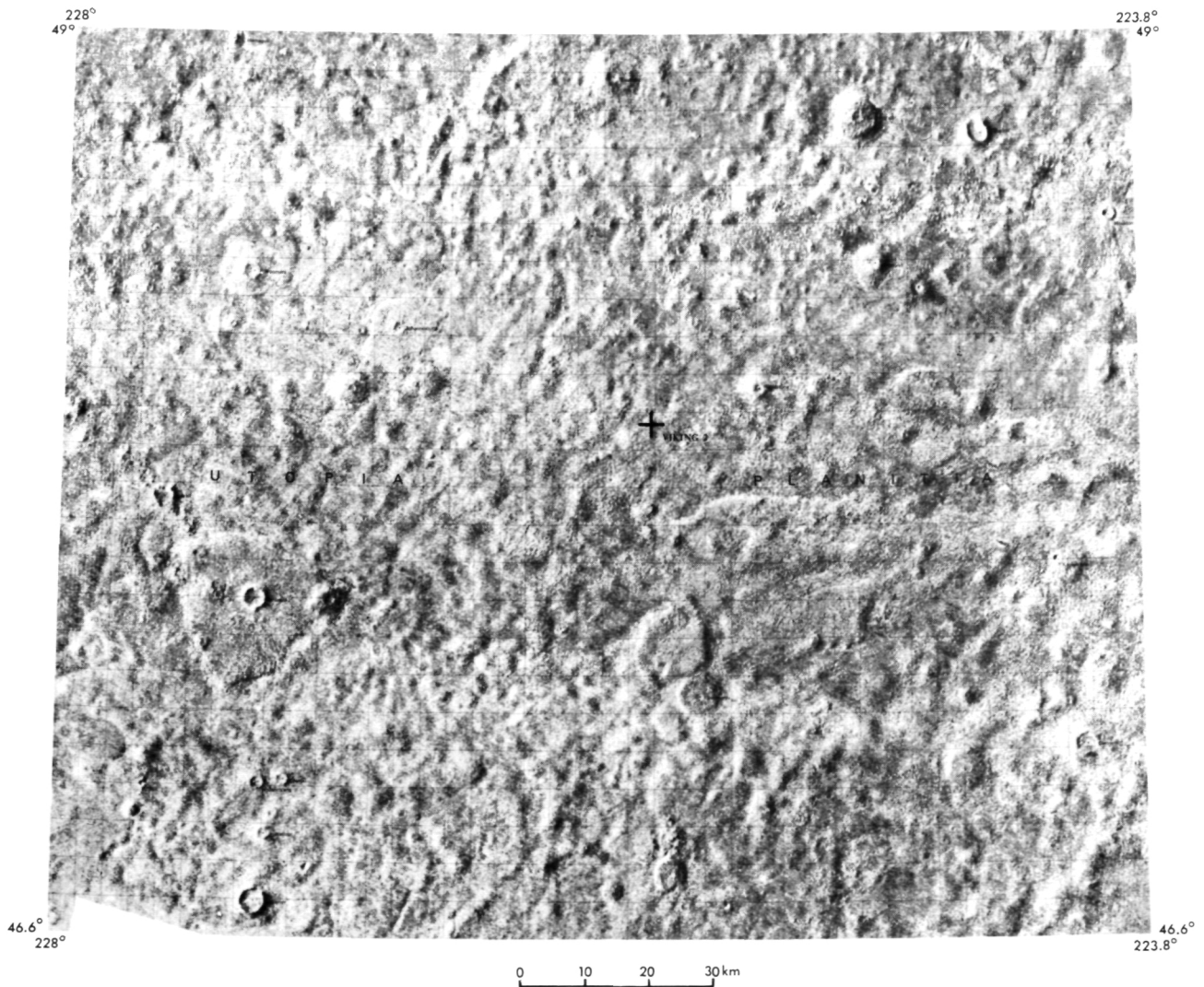

Figure 21.- Controlled photomosaic of Canberra region of Mars. Approximate position of VL-2 is shown by +.

28

deflation hollows. In addition, there was some question of whether the large blocks from the large impact crater Mie near the B3 site would be adequately covered by the smaller dunes in the B3 area. In contrast, the small blocks from small craters observed in the B2 site would probably be adequately covered by the larger dunes in that area. Although the B2 region was thought to be slightly warmer and wetter than the B3 site, the differences were not judged to be critical. The decision to target to 44° north had already provided a major scientific gain; only a small additional gain would be provided by landing at the B2 site rather than at the B3 site. The effort to maintain parallel options for a landing at the B2 or the B3 site had been dropped earlier; operational complexity would be minimized if the nominal mission plan to land somewhere within the B3 region were followed. Although the safety and science factors slightly favored the B2 site, they were not judged to be significant enough to warrant the 3-day delay and additional operational complexities that would be required to land at the B2 site; therefore, the B3 site was selected as the landing site for Viking lander 2.

Viking lander 2 landed successfully on Mars on September 3, 1976, at 3:58 p.m. PDT (Earth-received time); figure 21 is a controlled photomosaic of the landing site. As the initial lander imaging panorama (fig. 22) came in, it became obvious that the site was dominated, not by dunes, but by blocks; approximately twice as many blocks that were potentially hazardous to the lander were seen as were visible at the first site (fig. 13). However, as the horizon profile shows the area to be remarkably smooth and flat, some geologists think that the lander came down in a deflation hollow from which 3 to 10 meters of material had been removed. Deflation hollows had been predicted by some in the prelanding debates based on the presence of larger distinct deflation hollows northeast of the landing point. The eolian fine-grained (silt and clay size) material interspersed among the boulders which was sampled at the VL-2 site is closely similar chemically to the material sampled at the VL-1 site; therefore, a thorough homogenization of the fine-grained wind-transported material is indicated. It is not possible to determine from the available data whether the material in the large dunes at the proposed site is actually coarser sand-size material which might differ in composition from the silt and clay found at the VL-1 and VL-2 sites.
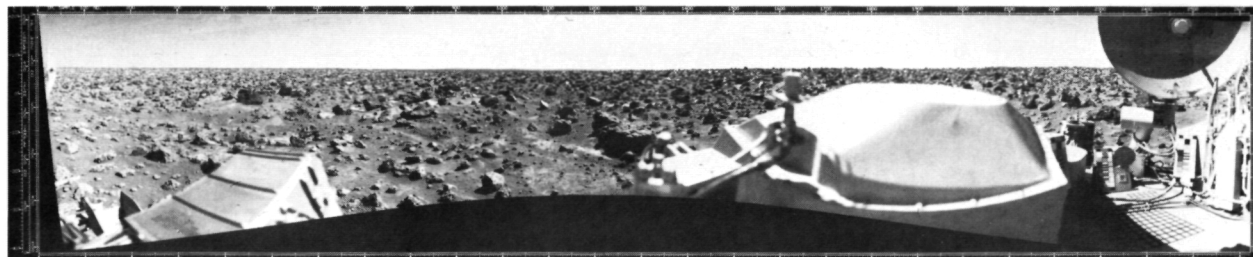

Figure 22.- Low-resolution panorama of Martian landscape taken by VL-2.

IMPLICATIONS FOR FUTURE MISSIONS

Postlanding analyses of deorbit and entry systems performance indicate that the VO orbit can be readily positioned so as to negate the need for any significant cross ranging and that the VL accelerometer can be calibrated more accurately than expected. These results simplify the problems in landings. Realistically, the 99-percent dispersion ellipse could be reduced from ±120 by 50 kilometers to ±40 by 20 kilometers or even to a 20-kilometer circle with the aid of landmark tracking from orbit before landing. This kind of capability would have permitted landing in smooth parts of the B1 region or at other scientifically attractive targets. On future missions, if the nominal landing ellipse is smaller, the lander should be targeted to a small, safe area; then, the roving vehicle could traverse more difficult terrain to observe the scientifically more rewarding areas. The difficulty of correlating the photographs obtained from orbit with the lander images highlights the need for higher resolution photography for such purposes as site certification and/or rover traverse planning. Resolutions close to the scale of the lander (1 to 3 meters) will be urgently needed for any future mission. Coverage at lower altitudes were obtained of the VL-1 and VL-2 sites with the present orbiters to close the resolution gap and to permit more positive identification of the geological domain of each lander. The scan platform was used to obtain image motion compensation, so that an 8-meter resolution for a 300-km altitude was achieved. The chemical analyses at the two sites showed that the composition, including the oxidizable components in the soil, were similar. The small pebbles in the sites may be poorly consolidated clods; solid rocks were not acquired. Some differences existed between the sites. The VL-2 site showed small grooves filled with fine-grained material that indicated a deflation history; a plethora of blocks that appeared to be volcanic in origin because of their vesicular character and an absence of bedrock were also shown. In contrast the VL-1 site photograph showed a greater variety of rock types and possible outcrops of bedrock.

More effective correlation of the IR with the VIS might have been obtained if more time had been available to do the detailed mission design and carry out observations before landing. Perhaps future missions should utilize preselected regions rather than pinpointed sites; this would permit enough time in the schedule for all planned data to be collected and analyzed before critical decisions have to be made.

If the search for life is continued in future missions to Mars, the problem of how to negate the oxidizing effect of the surface chemistry will again have to be faced. A landing site should either be planned for latitudes north of 75° north latitude or south of 75° south latitude, where water is more abundant and the temperature colder, or an equatorial site chosen where water is less abundant but thermal activity, which might result in a less oxidized soil, is greater. A profitable addition to such missions would be a two focal-length orbital camera experiment that could provide both 1- to 3-meter resolution of samples and global views for synoptic meteorology. Of course, such mapping tools as a gamma-ray spectrometer, colorimetric mapping and spectrometry, magnetometry, UV photometry, IR radiometry, and microwave radiometry would help define attractive science targets. Orbital radar would allow candidate sites located at almost any latitude to be screened for desired

surface parameters of elevation and roughness. If a landing site were chosen within 1000 kilometers of either of the present sites, the direction of the movement of atmospheric pressure waves around the planet could be detected (provided that either of the present landers' meteorological experiments were still working). Terminal phase hazard avoidance radar and guidance should be reconsidered as a means of improving landing success probability in areas of high relief and apparent contrast. The Viking orbital instruments might be able to define oases where temperature, pressure, water content, and imaging data indicate more promising areas to examine for possible life forms. Plans for future missions must be developed so that, after the most interesting sites are selected, the spacecraft can land nearby in safe areas and traverse the scientifically critical areas with a system which provides mobility. In this way, the most effective planetary studies could be accomplished. Much more scientifically interesting targets that exhibit a wide range of planetologic processes and histories were defined by Viking orbital data during the extended mission. For example, a mission that included a rover could sample rocks and soil from layered deposits in canyons and channel walls; these samples might preserve evidence of past periods when climatic conditions were more hospitable. Soil properties might provide clues to atmospheric and temperature conditions in earlier times or even contain organic material. Analyses of these samples would provide important data concerning the relations between vulcanism and channeling from which the early history of Mars could be deduced.

CONCLUDING OBSERVATIONS

In retrospect, it is obvious that the two Viking landings on the surface of Mars involved some elements of luck because possible hazards appeared only a few meters from each of the landers. Therefore, in future missions, more complete data that would decrease the hazards and enhance the scientific return should be obtained to increase the chance for successful lander, rover, and sample-return missions.

REFERENCES

1. Martin, James S., Jr.; Bowen, Fred W., Jr.; Brummer, Edmund A.; Crabill, Norman L.; Kingsland, Louis, Jr.; Newcomb, John F.; Soffen, Gerald A.; Taback, Israel; Wolfe, Allen E.; and Young, A. Thomas: 1973 Viking Voyage to Mars. Astronaut. & Aeronaut., vol. 7, no. 11, Nov. 1969, pp. 30-59.

2. Masursky, Harold; and Strobell, Mary H.: Geologic Maps and Terrain Analysis Data for Viking Mars '75 Landing Sites Considered in December 1972. Interagency Rep.: Astrogeology 59, Open-File Rep. 76-431, Geol. Surv., U.S. Dep. Inter., 1976.

3. Baker, V. R.: Paleohydrology and Sedimentology of Lake Missoula Flooding in Eastern Washington. Geol. Soc. of America Spec. Paper No. 144, 1973.

4. Carpenter, R. L.: 1967 Radar Observations of Mars. Supporting Research and Advanced Development, Space Programs Sum. 37-48, Vol. III (Contract NAS7-100), Jet Propul. Lab., California Inst. Technol., Dec. 31, 1967, pp. 157-160. (Available as NASA CR-93204.)

5. Soffen, Gerald A.: The Viking Project. J. Geophys. Res., vol. 82, no. 28, Sept. 30, 1977, pp. 3959-3970.

6. Farmer, Crofton B.: Liquid Water on Mars. Icarus, vol. 28, no. 2, June 1976, pp. 279-289.

7. Masursky, Harold; and Strobell, Mary H.: Geologic Maps and Terrain Analysis Data for Viking Mars '75 Landing Sites Considered in February and April 1973. Interagency Rep.: Astrogeology 60, Open-File Rep. 76-432, Geol. Surv., U.S. Dep. Inter., 1976.

8. Lipa, Belinda; and Tyler, G. Leonard: Surface Slope Probabilities From the Spectra of Weak Radar Echoes: Application to Mars. Icarus, vol. 28, no. 2, June 1976, pp. 301-306.

9. Masursky, H.; and Crabill, N. L.: The Viking Landing Sites: Selection and Certification. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 809-812.

10. Tyler, G. L.; Campbell, D. B.; Downs, G. S.; Green, R. R.; and Moore, Henry J.: Radar Characteristics of Viking 1 Landing Sites. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 812-815.

11. Carr, Michael H.; Masursky, Harold; Baum, William A.; Blasius, Karl R.; Briggs, Geoffrey A.; Cutts, James A.; Duxbury, Thomas; Greeley, Ronald; Guest, John E.; Smith, Bradford A.; Soderblom, Laurence A.; Veverka, Joseph; and Wellman, John B.: Preliminary Results From the Viking Orbiter Imaging Experiment. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 766-776.

12. Farmer, Crofton B.; Davies, Donald W.; and LaPorte, Daniel D.: Viking: Mars Atmospheric Water Vapor Mapping Experiment — Preliminary Report of Results. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 776-780.

13. Kieffer, Hugh H.; Chase, Stillman C., Jr.; Miner, Ellis D.; Palluconi, Frank Don; Münch, Guido; Neugebauer, Gerry; and Martin, Terry Z.: Infrared Thermal Mapping of the Martian Surface and Atmosphere: First Results. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 780-786.

14. Nier, A. O.; Hanson, W. B.; Seiff, A.; McElroy, M. B.; Spencer, N. W.; Duckett, R. J.; Knight, T. C. D.; and Cook, W. S.: Composition and Structure of the Martian Atmosphere: Preliminary Results from Viking 1. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 786-788.

15. Hess, S. L.; Henry, R. M.; Leovy, C. B.; Ryan, J. A.; Tillman, J. E.; Chamberlain, T. E.; Cole, H. L.; Dutton, R. G.; Greene, G. C.; Simon, W. E.; and Mitchell, J. L.: Preliminary Meteorological Results on Mars From the Viking 1 Lander. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 788-791.

16. Mutch, Thomas A.; Binder, Alan B.; Huck, Friedrich O.; Levinthal, Elliott C.; Liebes, Sidney, Jr.; Morris, Elliot C.; Patterson, William R.; Pollack, James B.; Sagan, Carl; and Taylor, Glenn R.: The Surface of Mars: The View From the Viking 1 Lander. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 791-801.

17. Shorthill, Richard V.; Hutton, Robert E.; Moore, Henry J., II; Scott, Ronald F.; and Spitzer, Cary R.: Physical Properties of the Martian Surface From the Viking 1 Lander: Preliminary Results. Science, vol. 193, no. 4255, Aug. 27, 1976, pp. 805-809.

18. Biemann, Hans-Peter: The Vikings of '76. Publ. by the author (175 Brattle Street, Cambridge, MA 02138), c.1977.

19. Moore, H. J.; and Zisk, S. H.: Calibration of Radar Data From Apollo 17 and Other Mission Results. Apollo 17 — Preliminary Science Report, NASA SP-330, 1973, pp. 33-10 — 33-17.

20. Moore, H. J.; Tyler, G. L.; Boyce, J. M.; Shorthill, R. W.; Thompson, T. W.; Walker, A. S.; Wilhelms, D. E.; Wu, S. S. C.; and Zisk, S. H.: Correlation of Photogeology and Remote Sensing Data Along the Apollo 14 Bistatic-Radar Ground Track. Part I — A Working Compendium. Interagency Rep.: Astrogeology 75, Open-File Rep. 75-284, Geol. Surv., U.S. Dep. Inter., 1975.

21. Moore, H. J.; Tyler, G. L.; Boyce, J. M.; Shorthill, R. W.; Thompson, T. W.; Wilhelms, D. E.; Wu, S. S. C.; and Zisk, S. H.: Correlation of Photogeology and Remote Sensing Data Along the Apollo 14, 15, and 16 Bistatic-Radar Ground Tracks. Part II — A Working Compendium. Interagency Rep.: Astrogeology 80, Open-File Rep. 76-298, Geol. Surv., U.S. Dep. Inter., 1976.

22. Thompson, T. W.; Masursky, H.; Shorthill, R. W.; Tyler, G. L.; and Zisk, S. H.: A Comparison of Infrared, Radar, and Geologic Mapping of Lunar Craters. Moon, vol. 10, no. 1, May 1974, pp. 87-117.

23. Pettengill, G. H.; and Thompson, T. W.: A Radar Study of the Lunar Crater Tycho at 3.8-cm and 70-cm Wavelengths. Icarus, vol. 8, no. 3, May 1968, pp. 457-471.

24. Masursky, H.; and Crabill, N. L.: Search for the Viking 2 Landing Site. Science, vol. 194, no. 4260, Oct. 1, 1976, pp. 62-68.

25. Soderblom, L. A.; Condit, C. D.; West, R. A.; Herman, B. M.; and Kriedler, T. J.: Martian Planetwide Crater Distributions: Implications for Geologic History and Surface Processes. Icarus, vol. 22, no. 3, July 1974, pp. 239-263.

34

National Aeronautics and
Space Administration

Washington, D.C.
20546

SPECIAL FOURTH CLASS MAIL
BOOK

U.S.MAIL

NASA