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Mars Sample Return: Site Selection and Sample Acquisition Study

Edited by:
Neil Nickle

November 1, 1980

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
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ABSTRACT

This document summarizes the results of studies in FY 79 by the Site Selection Team and the Sample Acquisition Team of the Mars Science Working Group.

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SECTION 1

INTRODUCTION

During FY 78, the objectives of the Mars Study Program at the Jet Propulsion Laboratory were to study various vehicle and mission options for the continued exploration of Mars, to estimate the cost of a "minimum" sample return mission, to synthesize the options and concepts into the program possibilities, and to present recommendations for the next Mars mission to the Planetary Program office. These objectives were met and the results are summarized in Ref. 1-1.

During these studies for a sample return mission, it became evident that to proceed with engineering design required specific scientific judgements on requirements that affected such items as power, weight, mobility, range, and stay time on Mars. Workshops were convened to answer four questions:

(1) Do we currently have enough data or do we require a precursor mission to select landing sites for a sample return mission that would ensure the acquisition of material from the most important geologic provinces of Mars?

(2) What surface mobility is required to ensure sample acquisition from these sites, considering the uncertainty in the location of the landing?

(3) Can rock samples be acquired by selection techniques or must they be acquired by drilling or related techniques?

(4) What mobility would be required at the two Viking sites to acquire adequate samples?

The Mars Science Working Group (Table 1-1) and other participants were divided into two teams of scientists familiar with Mars and planetary sampling techniques: the Site Selection Team and the Sample Acquisition Team. Their objective was to address the above questions using a number of intensive studies of specific sites and all relevant spacecraft and ground-based data.

Each team produced a number of reports related to its goals, and evaluation and team conclusions were accomplished by two joint-team workshops (see Table 1-2 for the workshop participants). The individual reports, most of which are JPL internal documents, are listed in Tables 1-3 and 1-4. The remainder of this report is a synthesis of the teams' conclusions.

The detailed reports are retained at the Jet Propulsion Laboratory. The reports should be reviewed when further consideration is given to a post-Viking mission to Mars.

Table 1-1. Members of the Mars Science Working Group

Member	Affiliation
Arden L. Albee, Chairman	Jet Propulsion Laboratory
John B. Adams	University of Washington
Raymond P. Arvidson	Washington University
Klaus Biemann	Massachusetts Institute of Technology
Geoffrey A. Briggs	NASA Headquarters
Thomas M. Donahue	Space Physics Research Laboratory
Michael E. Duke	NASA Johnson Space Center
Fraser P. Fanale	Jet Propulsion Laboratory
Ronald Greeley	Arizona State University
Robert B. Hargraves	Princeton University
Heindrich D. Holland	Harvard University
Norman H. Horowitz	California Institute of Technology
Norman J. Hubbard	NASA Johnson Space Center
Thomas H. Jordan	Scripps Institute of Oceanography
Hugh H. Kieffer	U.S. Geological Survey
Harold P. Klein	NASA Ames Research Center
Joshua Lederberg	Rockefeller University
Michael C. Malin	Jet Propulsion Laboratory
Harold Masursky	U.S. Geological Survey
John Minear	NASA Johnson Space Center
Thomas A. Mutch	Brown University
John Niehoff	Science Applications, Inc.
Carl B. Pilcher	University of Hawaii
Frederick L. Scarf	TRW, Inc.
Heindrich Schnoes	University of Wisconsin
Gerald A. Soffen	NASA Headquarters
James E. Tillman	University of Washington
M. Nafi Toksoz	Massachusetts Institute of Technology
J. L. Warner	NASA Johnson Space Center

Table 1-2. Workshop Participants

Member	Affiliation
J. B. Adams	University of Washington
A. L. Albee	Jet Propulsion Laboratory
R. P. Arvidson	Washington University
D. W. Davies	Jet Propulsion Laboratory
M. Duke	NASA Johnson Space Center
U. S. Clanton	NASA Johnson Space Center
R. Greeley	Arizona State University
E. A. King	University of Houston
H. Masursky	U.S. Geological Survey
J. Minear	NASA Johnson Space Center
H. J. Moore	U.S. Geological Survey
P. J. Mouginis - Mark	Brown University
T. A. Mutch	Brown University
N. L. Nickle	Jet Propulsion Laboratory
J. L. Warner	NASA Johnson Space Center

Table 1-3. Site Selection Team Reports

Author	Contribution
J. A. Cutts, K. R. Blasius, W. J. Roberts, and K. D. Pang Planetary Science Institute A. D. Howard University of Virginia	Detailed Reports of the Mars Sample Return Study Effort: Volume 1. Polar Site Analysis. Report No. 715-23
D. W. Davies JPL	"Results of the Study of Mars Sample Return Sites" (Section II of this report)
R. Greeley, A. W. Ward, A. R. Peterfreund, D. B. Snyder, and M. B. Womer Arizona State University	Detailed Reports of the Mars Sample Return Study Effort: Volume II. Arsia Mons West, A Young Volcanic Site and Chryse Planitia. Report No. 715-23
H. Masursky, A. L. Dial, M. E. Strobell, G. G. Schaber, M. H. Carr U. S. Geological Survey	Detailed Reports of the Mars Sample Return Study Effort: Volume IV: Tyrrhena Patera and Iapygia, Ancient Cratered Terrain, and Candor and Hebes Chasmata, Sequences of Layered Rocks. Report No. 715-23
P. J. Mouginis - Mark Brown University	Detailed Reports of the Mars Sample Return Study Effort: Volume III. A Young-Lavas Landing Site Northwest of the Volcano Apollinaris Patera and a Landing Site on the Ancient Terrain Southeast of the Schiaparelli Basin. Report No. 715-23

Table 1-4. Sample Acquisition Team Reports

Author	Contribution
R. Arvidson, E. Guinness, S. Lee, and E. Strickland Washington University	Detailed Reports of the Mars Sample Return Study Effort: Volume VII. The Presence and Abundance of Crystalline Rocks and Soil Types at the Sites of Viking Landers 1 and 2. Report No. 715-23
E. A. King University of Houston	Detailed Reports of the Mars Sample Return Study Effort: Volume V. Terrain Evaluation of the Martian Central Latitude Belt. Report No. 715-23
J. Minear, NASA-JSC	Co-Author, "Results of the Mars Sample Acquisition Study" (Section III of this report)
H. J. Moore III U.S. Geological Survey	Detailed Reports of the Mars Sample Return Study Effort: Volume VI. Rocks in the Sample Fields of Viking Landers 1 and 2. Report No. 715-23
T. Mutch, D. Grinspoon, P. Lucey, and E. Robinson Brown University	"Cumulative Size Frequency Distribution of Rocks Near Viking Landers 1 and 2" (Figure 3-3 of this report)
N. Nickle, JPL	Detailed Reports of the Mars Sample Return Study Effort: Volume VIII. Requirements for Monitoring the MSSR Samples. Report No. 715-23
J. L. Warner, NASA-JSC	Detailed Reports of the Mars Sample Return Study Effort: Volume IX. Instrumentation Required for Sample Selection. Report 715-23; Ibid., Volume X. A Returned Martian Sample; Co-Author, "Results of the Mars Sample Acquisition Team Study" (Section III of this report)

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SECTION II

RESULTS OF THE STUDY OF MARS SAMPLE RETURN SITES

D. W. Davies

Jet Propulsion Laboratory

To define the mobility requirements associated with a Mars sample return mission, and to assess whether viable sites can be chosen with presently available data, several candidate sample return sites have been studied in detail.

Participants were allowed to use all data available in selecting the best site to meet their objectives; in practice, however, only areas covered by high-resolution Viking images were considered. An additional factor in the choice of sites was the availability of high-resolution thermal and ground-based radar data. For each of the sites selected, detailed reports that discuss regional geology, site geology, site surface characteristics, rover requirements, and the adequacy of current data have been prepared (see Table 1-1). Figure 2-1 shows the location of the sites selected. Short summaries of these reports follow.

A. MARS SAMPLE RETURN MOBILITY REQUIREMENTS

The mobility required to assure (90% probability) acquisition of a sample of the desired type is very dependent on the sample type sought. In addition, for some sites, the mobility required is directly related to the number of obstacles in the area (i.e., the rover has to go only to the nearest obstacle for a sample). The easiest sample is a polar ice sample - landing ellipses (25 × 40 km semiaxis) can be placed in areas with essentially 100% ice cover, requiring no mobility. Of the nonpolar areas, the sampling of young volcanic material appears to be the easiest, basically because areas can be found where the material is expected to be either exposed, or to comprise the majority of any obstacles in the landing area. In this case, the rover need traverse long distances only if the surface is free of obstacles. The longest distance required is determined by the distance to the nearest identifiable (from orbital images) outcrop or crater. This distance turns out to be a few kilometers.

The most difficult unit to sample is ancient crustal material. Based on current photographic coverage, there are no sites where ancient crustal material is exposed, or even near the surface; the rover, therefore, must obtain samples of the ejecta from a large, fresh crater. Since these craters are sparse, and since the landing ellipse is tens of kilometers in extent, sampling the ancient crustal material results in the requirement of a rover traverse 10 to 20 km away from the lander over surfaces that could have many obstacles.

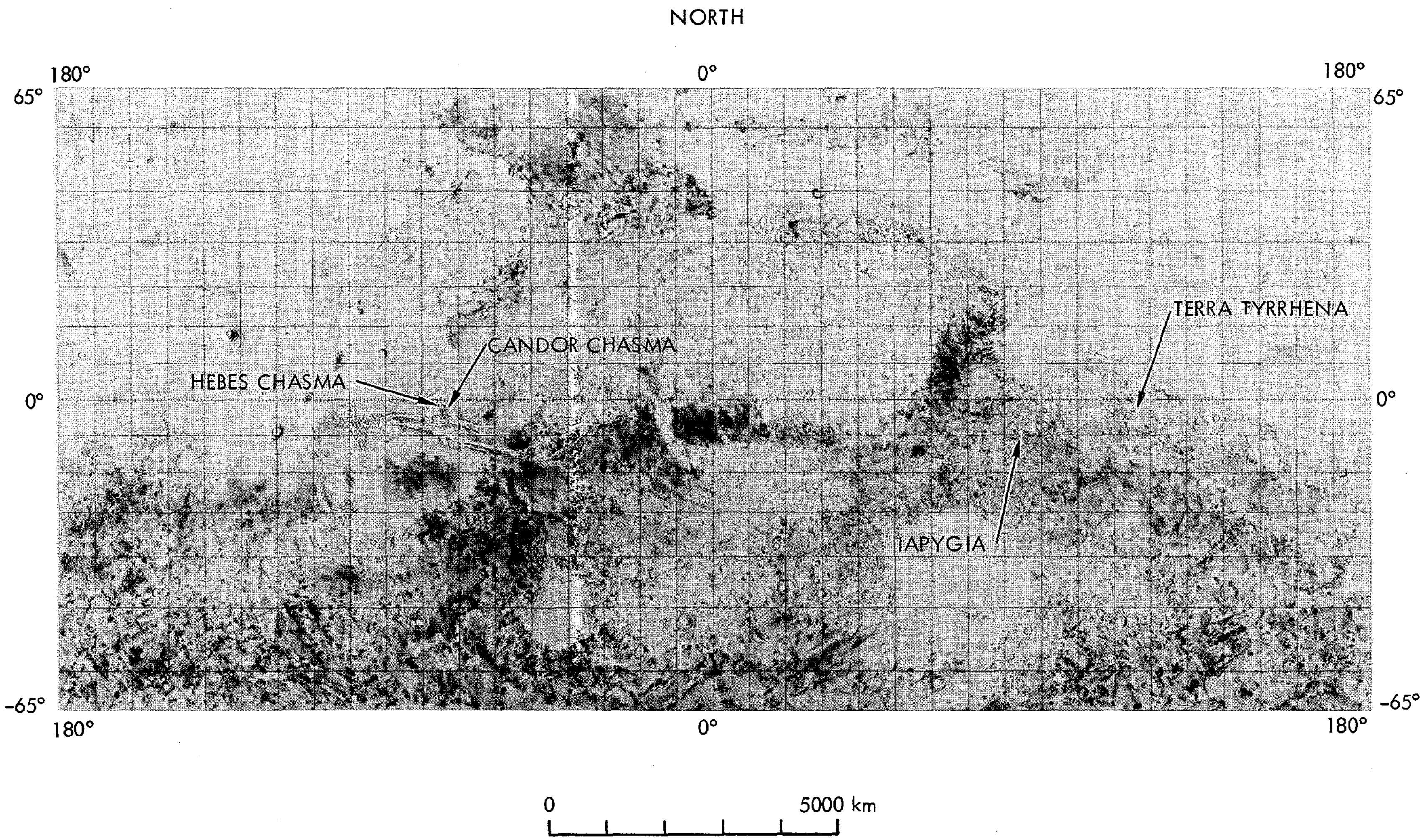

Figure 2-1. Proposed Rover Landing Sites (courtesy of U.S. Geological Survey, 1978)

As mentioned above, rover range at some sites is closely linked to the density of obstacles — large ranges may be required, but only if the area is free of obstacles. Since the performance of actual rovers, especially ones that require a lot of guidance from Earth, has the same characteristics, we define the mobility requirement for the sites in terms of both range required and density of obstacles. Figure 2-2 displays the types of sites studied in this range vs the mean free path ("mean free path" is the straight-line distance between obstructions). Location of terrain types on this figure is based upon the ability to locate a 50-km × 80-km landing ellipse in close proximity to the unit.

Rover performance depends, of course, on the rover design, but there are some general constraints that can be displayed on a plot similar to that of Figure 2-2 as shown in Figure 2-3. There are two straight-range (defined as the distance from the lander to rover) constraints. The first is on a tethered rover — the tether limits the range to about 100 m. Without a tether, the rover requires its own power system and telemetry to the lander. The other range constraint concerns the rover-lander telemetry link. With a range over about 3 km, communications with the lander must be replaced by two-way communications directly with Earth (or via the orbiter). This results in a large increase in rover mass and mission complexity. Teleoperated rovers can be used where few obstructions exist and relatively short daily traverses are required. As the obstructions increase in number, the requirement to traverse multiple mean free paths per day becomes necessary for increasing distance from the lander. Rovers operating in a region requiring more than one mean free path per day will need some form of autonomous operation capability.

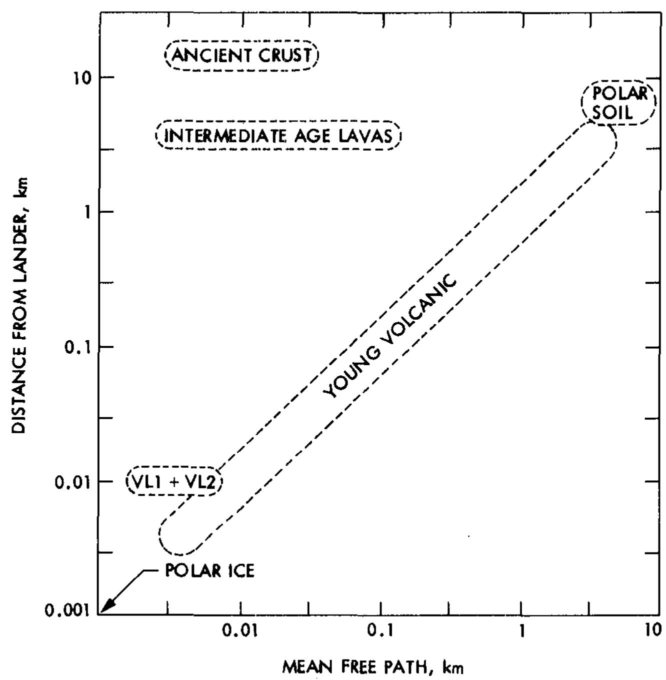

Figure 2-2. Mars Terrain Types as a Function of Mean Free Path and the Distance Between Rover and Lander

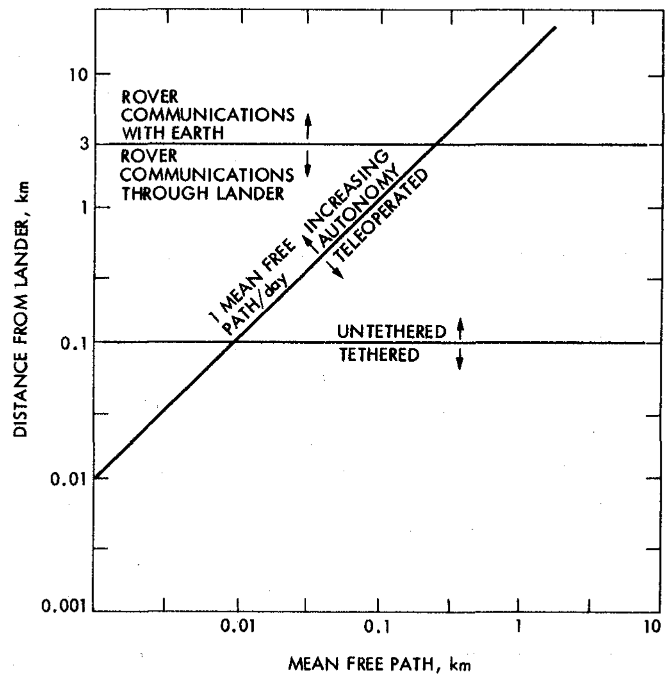

Figure 2-3. Rover Design Requirements as a Function of Mean Free Path and the Distance Between Rover and Lander

For a teleoperated rover, there is a constraint on range proportional to the mean free path. For a relatively dumb rover, one mean free path per day is a reasonable estimate of the rover's average speed. If a total of 30 days is allocated for travel time for a sample, a limit of 10 mean free paths results.

It can be seen from a comparison of the two figures that a tethered rover has too short an operating radius to perform the sampling job for most of the sites considered. A rover limited to a mobility of only 3 km by the rover-lander telemetry link would not have a large certainty of sampling some geologic terrain. Since further study may indicate a greater range for the rover-lander telemetry link, we do not strongly recommend a direct link to earth for a sample return mission. However, more extended rover missions will require a direct telemetry link.

B. ADEQUACY OF PRESENTLY AVAILABLE DATA

The data available appears to be "marginally adequate" to select sites. A young volcanic area was found, but the choice of sites was severely limited by the paucity of high-resolution (better than 50 meters) images. Data seems adequate for selection of a site in the north polar area. No really good sites were found (given the 25 $\times$ 40 km landing ellipse) to sample ancient crustal material. For most of the sample types studied, it is likely that the additional high-resolution coverage from the Viking extended Mission in 1979-80 will allow the selection of a site with significantly reduced mobility requirements.

Orbital infrared and ground-based radar and multispectral data were not a big factor in choosing the sites in this study. However, the understanding of the Viking infrared thermal mapper (IRTM) and ground-based radar data is currently increasing rapidly, and it is likely that these data types will be useful in site selection for the future.

This assessment of the adequacy of current data applies only to the requirements of selecting a site for the sample return mission. Obviously, more high-resolution orbital imaging, infrared, and even multispectral data are required to understand Martian geological processes; to the extent that this understanding allows selection of a better sample return site, they are valuable to Mars sample return.

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SECTION III

RESULTS OF THE MARS SAMPLE ACQUISITION STUDY

J.L. Warner and J. Minear

Lyndon B. Johnson Space Center

Mars program development activities in FY 78 were focused on a broad study of the scientific and vehicle options for Mars exploration. During these studies, it was recognized that several scientific requirements have critical implications for engineering design of a Mars sample return mission. Although these requirements have been addressed in general terms by various scientific groups, specific requirements that could be used by engineers in designing spacecraft are lacking. Also lacking are detailed documentation to substantiate the requirements. Consequently, small task groups were organized to address the several critical scientific requirements during FY 79. One of these groups was the Mars Sample Acquisition Team.

A. OBJECTIVES

The objectives of the team were to:

(1) Define the sample objectives for a mission to the surface of Mars.

(2) Evaluate the requirements for mobility and time in order to collect suitable samples to meet the sample objectives.

(3) Evaluate the requirements for acquisition of samples to meet the sampling objectives.

The major results in achieving the objectives follow:

(1) The prime sampling objective at each landing site is to collect fresh and weathered samples of the most abundant material types present in the vicinity of the lander.

(2) To achieve the prime sampling objective, mobility is required even if the sites are similar to the Viking landing sites, and the travel distances and times required are site dependent. Travel distances are measured in hundreds of meters and times in months.

(3) Because of the prime sampling objective and the natural conditions on Mars, tools capable of acquiring dense hard rocks, regolith, cohesionless materials, and the atmosphere are required.

Results of these evaluations, which are discussed below, are major determinants in the mobility, range, and sampling capability of a roving vehicle used in support of sample return.

B. BACKGROUND

The fundamental scientific value of returned samples has been recognized by every scientific advisory group that has considered Mars exploration. Earth-based laboratory analysis of returned samples is critical to the understanding of the chemical composition, mineralogy, chronology, atmospheric evolution, and organic evolution of the planet. Thus, a properly selected suite of samples of Mars materials will address in some respect all of these scientific disciplines of Martian exploration.

The proper sample suite of Mars materials is generally recognized to include unweathered igneous rocks, sedimentary rocks (if present), windblown dust (and dune material), chemically weathered regolith (duricrust), weathered rocks, and atmosphere. It is also recognized that samples from the permanent ice cap may be of high scientific value. Although the desirability of sampling the water—ice interface that may exist in the regolith is recognized, the difficulty of locating and sampling this interface generally is thought to preclude this as a specific sampling goal.

The Sample Acquisition Team therefore assumes that the basic sample suite consists of igneous rocks, sedimentary rocks (if present), regolith (weathered rocks, windblown dust, soil, subsurface samples), and atmosphere. With proper site selection (primarily avoiding dune fields larger than the mobility range of the sample rover), it is reasonable to assume that regolith and atmosphere can be collected anywhere. The critical item appears to be unweathered igneous rock. Consequently, the assessment of the ability to obtain unweathered igneous rock was taken as an indicator of the total sampling task.

> It must be emphasized that for a sample return mission, the collection of an igneous rock is not required for mission success.

Indeed, a collection from Mars that is limited to regolith, atmosphere, and sedimentary rocks will yield exceedingly interesting and important data concerning the development of Mars. Such a sample collection will yield the fundamental information indicated in Table 3-1. In this report, we focus on igneous rocks simply because we perceive the collection of unweathered igneous rocks to be the most difficult and most uncertain portion of the sample acquisition task.

Table 3-1. Contribution of Sample Suite to Scientific Objectives for Mars

Scientific Objective	Igneous Rock	Sedimentary Rocks	Regolith[a]	Atmosphere
Internal Structure	●			
Global Composition and Mineralogy	●	●	●	
Detailed Composition and Petrology	●	●	●	
Atmosphere Composition and Evolution; Atmosphere-Regolith Interaction	●	●	●	●
Atmosphere Dynamics				●
Magnetic Field	●			
Surface Geology	●	●	●	
Organic Chemistry	●	●	●	

[a]Regolith includes windblown dust.

C. APPROACH

The approach to the team's objectives was dictated by the resolution of the available data. Viking lander high-resolution frames and multispectral imaging data were used to estimate the size-number densities of rocks, the distance between rocks of specified sizes, the different types of abundant materials, and to broadly define the required sampling tools. Lander color pictures, high-resolution pictures, and physical property data provided a basis for evaluating the existence of igneous and other unweathered crystalline rocks as well as the compositional variety of rocks at the Viking sites. Sample traverses were developed for the Viking landing sites so as to sample the different types of materials. These traverses provided the basic data for estimating mobility range. The time required for sampling was estimated from Viking Surface Sampler operations on Mars.

In extrapolating the Lander results to other sites on Mars, the orbital imaging data was used with extreme caution because at orbital resolutions ($\sim$30 to 200 m) rocks are not visible; direct estimates of rock populations cannot be made from the Orbiter pictures. However, it may be possible that the combined use of orbital thermal inertial data, Earth-based reflectance spectra, Earth-based and orbital radar echoes, and the morphology and density of craters can provide a means of extending Viking Lander results to other sites of interest.

D. SAMPLING OBJECTIVES FOR A MARS MISSION

It is recognized that a Mars Sample Return Mission is to address the broad spectrum of endogenetic and biogenetic processes that have affected the planet's development, as well as those processes that are active on the surface of Mars today. To address a wide spectrum of processes, a wide spectrum of samples is required; therefore, the Mars Sample Acquisition Team recommends that the sampling objective for a sample return mission should be:

> The prime sampling requirement at each landing site is to collect samples of the most abundant material types present in the vicinity of the lander.

In the following paragraphs, we first indicate that there are a wide variety of material types, including rocks, in the vicinity of the Viking Landers and then discuss the existence of rocks at the sites and elsewhere on Mars. Because the Mars Sample Acquisition Team recognized that the most difficult sample to obtain might be unweathered igneous rock, the evidence for unweathered igneous rock is discussed in detail. We approach this task by discussing weathering on Mars, evidence for the existence of hard, dense (presumably igneous) rocks in distinction to consolidated regolith, evidence that would demonstrate that unweathered, hard, dense rocks at the landing sites are igneous, and that such rocks occur elsewhere on Mars.

1. Variety of Material Types on Mars

Evidence for the presence of a wide variety of material types at the Viking Landing sites is unequivocal (see, for examples, Refs. 3-1 through 3-4). The variety of materials that might be sampled at the site of Viking Lander 1 include (1) rocks (outcrops of light colored rocks, isolated light rocks, dark rocks, impact breccias, ventifacts, and layered rocks), which may be both igneous and sedimentary, and (2) poorly consolidated materials (duricrust, drift material, active dune material, small rocks, and a variety of "soils"). Similar results are obtained for the Viking Lander 2 site.

Viking Orbiter images and data on thermal inertias also demonstrate the existence of a wide variety of material types on Mars. In the Orbiter pictures, lava flows and other volcanic features can be seen, fresh impacts in a variety of Martian terrains have excavated materials from depth, and evidence for a variety of surface processes such as dune formation are observed. Evidence for catastrophic floods suggest water-laid sediments may be widespread in some localities. The wide range in thermal inertias implies a wide variety of material types.

2. Rocks on Mars

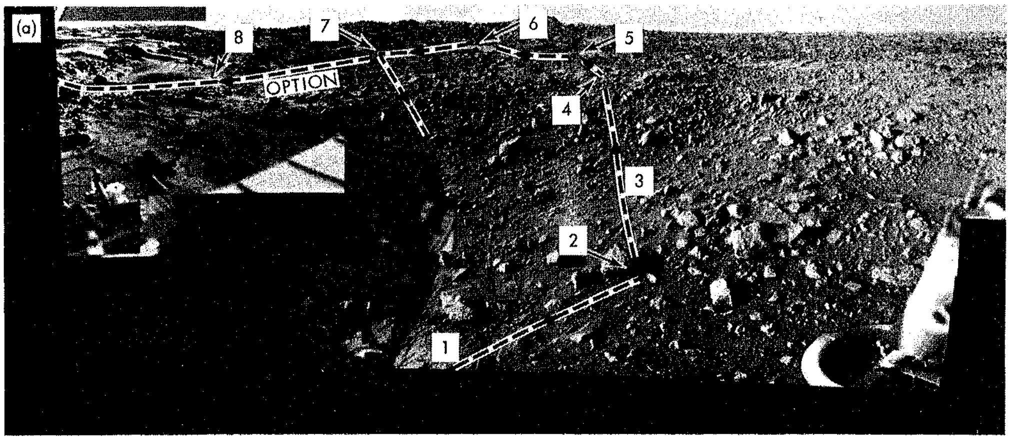
a. Weathering. It is clear that materials on the Martian surface have been weathered or altered to some extent due to a number of processes including the reaction of an atmosphere with surface materials. In this section, we evaluate the data in search of confidence that a significant portion of the materials on the Martian surface is not weathered. We review the evidence from Earth-based reflectance spectra and from Viking Lander color images.

Earth-based reflectance spectra of Mars have been obtained by Huguenin, et al. (Ref. 3-5). They find that most of Mars is covered by a mantle of high albedo, reddish dust that is remarkably uniform in composition. However, in several areas that have lower albedo, they have identified bands in their IR reflectance spectra that they identify with primary, igneous minerals that are not the products of weathering. These minerals include olivine, orthopyroxene, low-Ca clinopyroxene, high-Ca clinopyroxene, and oxide and glass phases that contain Fe^{++}. These observations suggest that there are large regions of Mars that contain unweathered materials common in igneous rocks at the surface.

Color-ratio images prepared from multispectral data obtained by the Lander cameras to investigate the possibility that unweathered materials are present at the Viking sites (Figure 3-1a, b, c, d) indicate that the rocks have a distinctly different spectral radiance than the soils, probably because of a distinct spectral reflectance signature (Ref. 3-4). Many rocks are bright enough to exhibit a subtle color change as the incidence, emission, and phase angles vary, indicating that a bright weathering coating, rather than darker mafic igneous minerals, dominates the spectral signatures. Most rocks smaller than 3 to 5 cm lose their distinct signature and in the ratio images are difficult to distinguish from duricrust fragments. As an example, compare the abundance of fragments in Figure 3-1a near the Lander with the dearth of discernible fragments in the ratio images of the same location.

Although small objects seen in the Viking pictures may be highly weathered or pieces of duricrust, larger rocks have only thin weathered coatings. Objects smaller than 5 cm have color-ratio signatures similar to the duricrust; those larger have distinct signatures. The bright weathering coating on many larger rocks must be thin because, as will be demonstrated below, rocks are harder than duricrust, and rock fabric and textures can be observed on some rocks.

A basic conclusion of this evaluation of weathering is that material samples should be obtained from the interior of rocks greater than 10 cm in diameter where the rocks will be unweathered.



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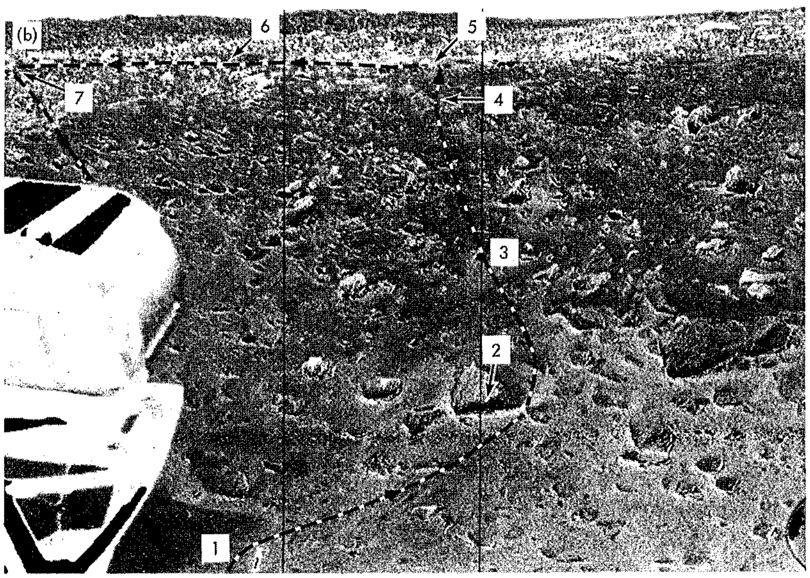
L1. C2. AM. Q1 + Q2



VIKING 1, CAMERA 2, CAMERA EVENT A168, SOL 28 COLOR.
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POS 150RAS 8BIT NL 512 NS 730 FILE 4
22-AUG-78 18 49 45 U.S.G.S. FLAGSTAFF IMAGE PROCESSING FACILITY

Figure 3-1. Viking Lander High-Resolution Mosaic and Color-Ratio Images Suggest that Crystalline Rocks and a Variety of Soil Types are Exposed at the Viking Lander Sites (Ref. 3-6): (a) High-Resolution Mosaic Showing an Abundance of Fragments Near Lander 1. Note How Few Fragments are Discernable in Parts (b), (c), and (d), Which are Color-Ratioed Images of the Same Location; (b) Blue/Red + Green Ratioed Image of Viking Lander 1 Site; (c) Green/Red + Blue Ratioed Image of Viking Lander 1 Site; (d) Red/Green + Blue Ratioed Image of Viking Lander 1 Site. A discussion of the traverse is contained in Ref. 3-6.

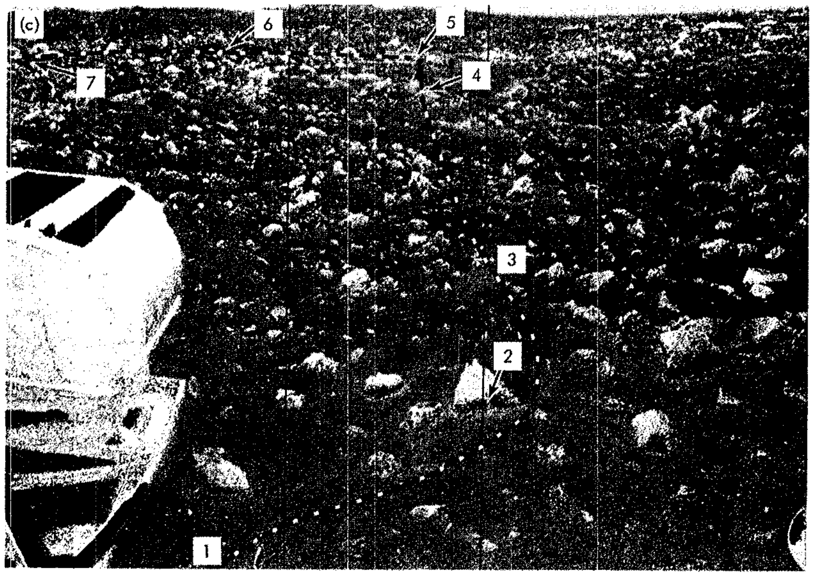

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Figure 3-1. (Continuation 1)

b. Hard, Dense Rocks on Mars. The chemical compositions of the large rocks of the Viking Lander sample fields are unknown because the Viking sampling subsystem was not capable of sampling indurated objects larger than 1.2 cm. Samples of both the fine fraction (<0.2 cm) and coarse fractions (0.2 to 1.2 cm) of materials are best interpreted as the product of weathered or altered igneous materials low in silica (Ref. 3-7). Estimated densities of individual clods or fragments (0.2 to 1.2 cm) acquired at the Viking Lander 1 site ranged between 1.2 and 2.0 g/cm^3. These densities are consistent with clods of soil, sedimentary rocks, and porous igneous rocks, but chemical analyses indicate they are clods of soil. The complex geometry of the X-ray fluorescent spectrometer sample chamber, uncertainties in the analytical procedures, and high values of comminutor motor currents allow the total sample to contain a significant fraction of hard, dense fragments at the Lander 1 site. No samples of the coarse fraction (0.2 to 1.2 cm) were acquired at the Lander 2 site because there is no indurated material in this size range.

Many other observations made by the Viking Lander imaging system bear on the question of the existence of hard, dense rocks on the surface of Mars. The most striking feature of the images from both Viking Landers is that the surface is strewn with rock-like objects. If these objects are hard, dense rocks, or even if some small fraction of these objects are such rocks, then at least at these two sites there is no problem with availability of hard, dense surface rocks. However, it is very difficult, if not impossible, to devise criteria for the unambiguous recognition of primary igneous rocks, as opposed to clods of weathering products and loess, cemented sedimentary rocks, and impact lithified detritus, from imaging data alone.

The general geology of the Viking 1 landing site was discussed by Binder, et al. (Ref. 3-1), who interpret much of the field of view to be immediately underlain by bedrock. This material is surely hard and dense. The general geology of the Viking 2 landing site has been discussed by Mutch, et al. (Ref. 3-2), who interpret the local terrain to be dominated by ejecta from the crater Mie. These ejecta blocks are also surely hard and dense.

The Viking Lander images reveal the presence of ventifacts produced by aeolian processes. Based on terrestrial experience, ventifacts are produced by aeolain processes acting on dense, hard, fine-grained rocks. Some rocks display pronounced chonchoidal fracture and regular planar fractures. These types of fractures are consistent with hard, dense rocks with a fine to microscopic grain-size.

Finally, there are experimental data that indicate that the surface rocks at the Viking Lander sites are hard. Hardness was derived from attempts to scratch rocks with the teeth on the scoop of the Viking sampling arm, and by the successful operations whereby rocks were pushed by the teeth of the sampling arm (Ref. 3-3). Based on the lack of observable scratches, chips, or other marks on the rocks, Moore et al., concluded that the tested rocks did not have weak, weathered rinds.

Results from other sources are consistent with the presence of rocks on Mars. The Viking Infrared Thermal Mapping (IRTM) experiment (Ref. 3-8), has produced a map of the thermal inertia values for a large portion of the Martian surface. These values are inferred from infrared measurements of surface temperatures as a function of time. Viking Orbiter pictures, which show abundant impact craters, suggest that it is reasonable to interpret the thermal inertia data in terms of relative area percent of exposed rock on the surface, although other interpretations are possible. In general, with only some very odd and unusual exceptions, rocks have high thermal inertias compared with dust and fragmental debris. Thermal inertia values (measured in units of 10^{-3} cal cm^{-2} $s^{-1/2}$ K^{-1}) for various regions of Mars range from 1 to more than 12. The planet appears to be bimodal with a major peak between 5-1/2 and 7-1/2, and a minor peak between 2-1/2 and 3-1/2. By contrast, values for bedrock regions on Earth are over 50. Reasonable models of the Martian surfaces based on Viking Lander and Orbiter pictures suggest that surfaces with thermal inertias more than about 3 should have substantial percentages of the surface area covered with dense rocks. Thus, the thermal inertia data give us confidence that at least some of the Martian surfaces have abundant surface rocks and that the weathering of the Martian surface has not been so effective as to have reduced all of the rocks to weathering products.

Additionally, the average radar reflection coefficient for Mars is high compared to the Moon and consistent with a relatively large population of rocks and the relatively large diffuse component of radar echoes is consistent with a rough, rocky surface.

> A basic conclusion of this evaluation is that the probability of sampling unweathered rocks on Mars appears to be very high.

c. Igneous Rocks on Mars. The only unambiguous identification that a given rock is igneous must rest on observations of that rock's texture and chemistry. Lacking such direct information, the following paragraphs outline the data that suggest that some of the rocks on the Mars surface are igneous.

There is some positive evidence that igneous rocks exist on the surface of Mars based on Viking Lander camera observations. Many rocks are pitted, especially at the Viking 2 Lander site. Although some workers have suggested that the pits are due to some type of erosion characteristic of arid climates, others "after considering all ways in which the deep pits have formed conclude that volcanic vesiculation is the most likely explanation" (Ref. 3-2). This conclusion is supported by observations that show (1) rocks equally pitted on all sides, a feature of volcanic vesicles and not expected if the pits are due to some weathering phenomenon, and (2) layering in rocks defined by differing concentrations of vesicles that are flattened and aligned parallel to the layering, a structure characteristic of volcanic rocks that contain vesicles and underwent flow after extrusion on the surface. Besides the vesicles, many rocks are banded and others display "crystalline" textures on fractured surfaces. Banding and crystalline texture are best explained by an igneous, volcanic rock, and not as the products of weathering or lithification of clastic debris.

Additional lines of evidence for the presence of igneous rocks on Mars are found in orbital pictures of its surface. In these pictures, lava flows and volcanic constructs are abundant. Fresh impact craters on these flows surely contain unweathered igneous rocks. Included in these landforms are the large volcanic edifices in the Tharsis and Elysium regions of Mars.

> The conclusion from this interpretation is that igneous rocks are present on Mars.

E. MOBILITY

Mobility for the acquisition of samples that meet the scientific objectives is required. Such a conclusion is based, chiefly, on observations and interpretations at the Viking landing sites where a variety of abundant materials, including igneous rocks, are found beyond the sample fields of the Viking Landers. The need for mobility is enforced on the weight of other data that imply that the abundance of rocks at the Viking sites may be unusually large. Thus, we conclude that a sample return mission must include a rover as a sampling device. The rover's chief function is as an aid to sample collection by providing the mobility necessary to collect a basic suite of materials that includes the most abundant material types present in the vicinity of the sampling site. As such, the rover should not be considered a scientific tool nor should its purpose be diluted by "add-on" science experiments. In this concept, the rover must travel until it reaches material to be collected. In the case that the Lander lands on a featureless plane and no appropriate material is present, the rover travels over free terrain until appropriate materials are encountered. As soon as rocks or some other obstruction is encountered, travel may end and sampling may begin.

The sample acquisition team approached the question of mobility range required for the sample acquisition rover by addressing the question of how far a rover would have to travel to make an adequate collection using the Viking landing sites as typical of Mars. The Viking landing sites were studied to determine the existing rock populations and the variety of material types. Model traverses were then generated to sample the most abundant material types at each landing site. The model traverses were expanded to include the possibility of each rover visiting several Viking-like sites. This discussion introduced boundary conditions imposed by available rover power, available time for the rover to operate on the Martian surface, and the mass of sample that the sample return system is capable of returning to Earth.

1. Rock Populations on Mars

The rocks (with diameters over 5 cm) in the sample fields of the Viking 1 and 2 Landers were mapped (Figure 3-2). There are distinct differences between the two sites: at Viking 2 there are more blocks over 10 cm in diameter, and there are fewer blocks less than 10 cm in diameter, relative to the Viking 1 site. These relations are displayed in the frequency distributions of blocks at the two landing sites (Figure 3-3). It is clear from the data in Figures 3-2 and 3-3 that at either Viking site there is an abundance of large and small blocks within a few meters from the spacecraft.

Several attempts were made to extrapolate the Viking landing site data to other portions of the Martian surface using the thermal inertia data obtained by the IRTM experiment. These models did not yield unique solutions. Thermal inertia is insensitive to small changes in the number density of rocks, and yet to adequately sample a region of Mars, only a small number of rocks is required.

A point that is often neglected is that crater ejecta blocks are present on Mars. Some rocks at the Viking Lander 2 site are interpreted to have come from Mie Crater. Some rocks at Viking Lander 1 may have been excavated from nearby small craters.

In extrapolating the rock populations measured at the Viking landing sites to other portions of Mars, it is interesting to note that rock distributions at two sites with demonstrably different geologic histories are essentially identical. This suggests either that the same process of rock production (e.g., impact crushing) is operative at both sites, or that different processes (e.g., impact crushing and physical-chemical weathering) produce similar distributions. As inadequate as our statistical base is — two small plots to characterize the entire planet — the similarity of the two sites lends some measure of confidence to regional extrapolations.

It is not obvious from these discussions how representative the Viking Lander sites are of the rest of the Martian surface in terms of rock populations, but Viking data on thermal inertias suggest the sites are nonrepresentative. However, even for a region of Mars that has an order-of-magnitude fewer rocks on the surface, there would be an abundance of rocks that are accessible to a rover that has a mobility range of as little as 10 m.

> Rock population on the surface of Mars (as observed at the Viking landing sites) does not appear to be a serious constraint on required mobility range for a sample acquisition rover.

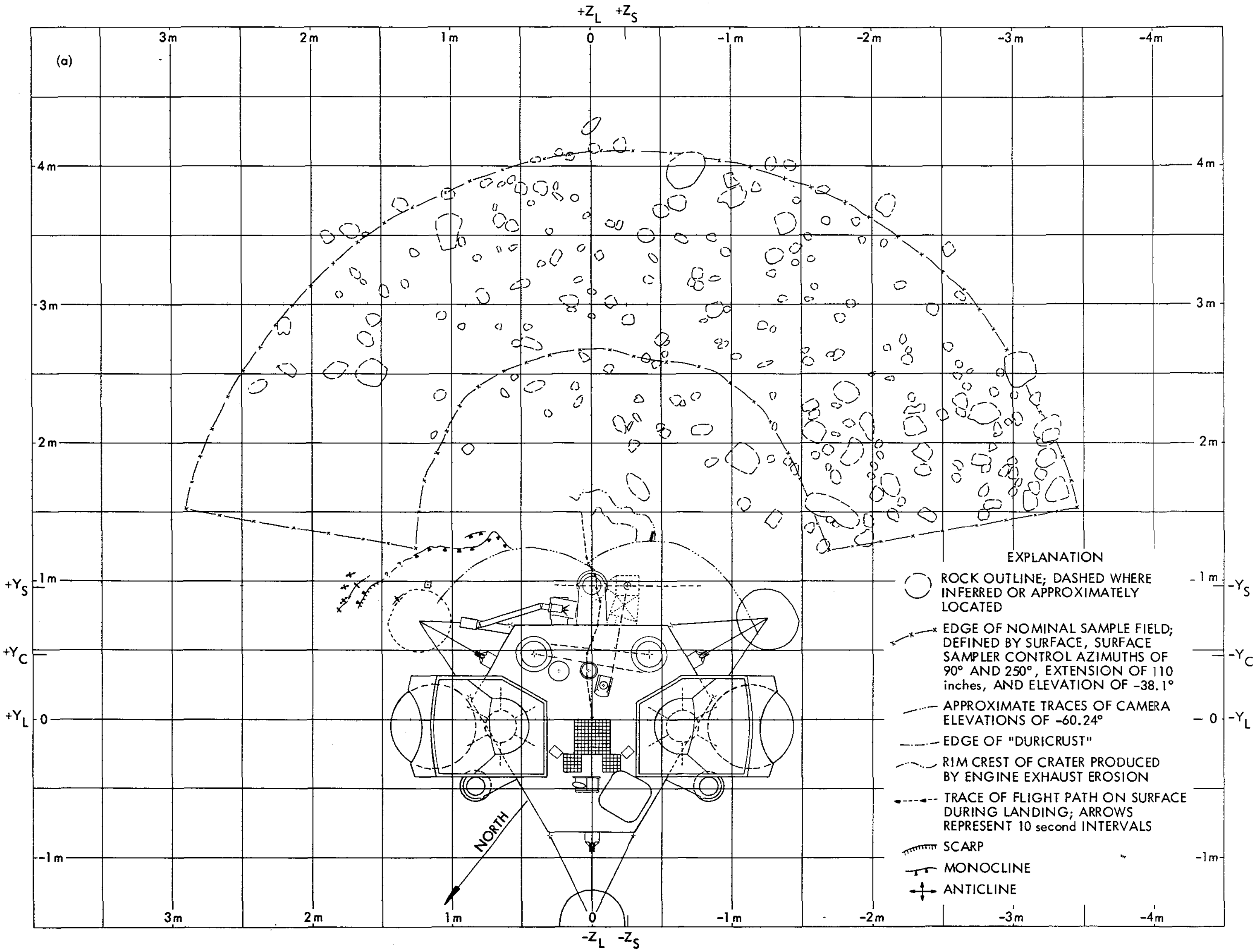

Figure 3-2. Generalized Working Maps of Sample Fields for (a) Viking Lander 1 and (b) Viking Lander 2 Showing Locations of Rocks 5 cm and Larger.

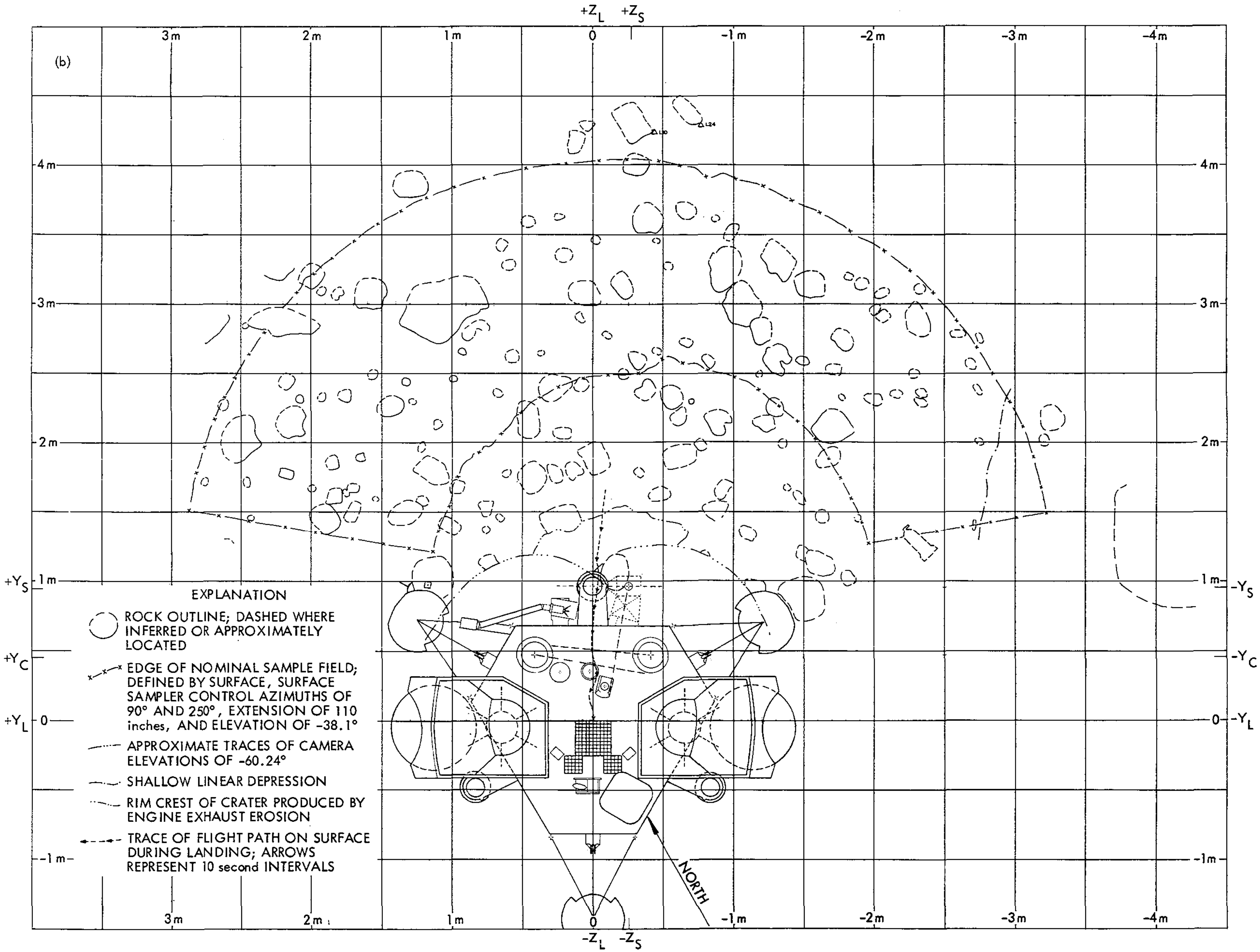

Figure 3-2. (Continuation 1)

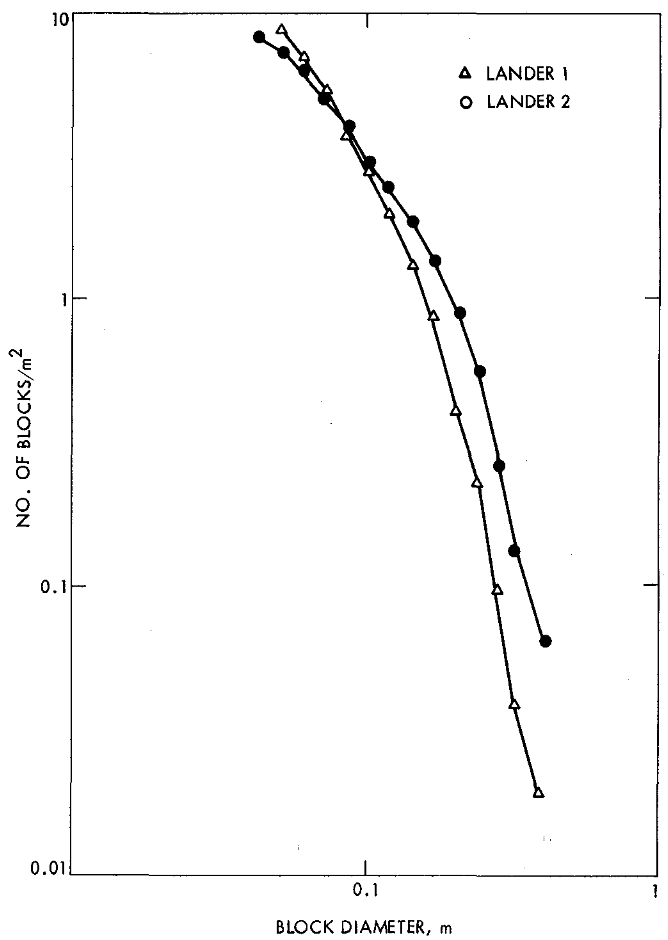

Figure 3-3. Cumulative Size Frequency Distribution of Rocks Near Viking Landers 1 and 2

2. Model Sample Collection Traverses at the Viking Lander Sites

Model traverses for sample collection were constructed for each Viking Lander site. These traverses were based on the objective of collecting all the abundant material types that were identified from the Lander camera system. The sample suite at each site consists of rocks, drift material, soils, fragments, and duricrust. As an example, the traverse designed by Moore for the Viking 1 site is shown in Figure 3-4 and described in Table 3-2. This traverse involves a total travel distance of less than 100 m. There are 11 rock samples, 6 soil and dune samples, and one duricrust sample. If the rocks and duricrust samples weigh 50 g each and the soil and dune samples weigh 150 g each, the samples collected on this traverse would weigh a total of 1.5 kg. To the above traverse must be added an atmosphere sample and a 1-m regolith sample. These two samples with their containers would weigh about 2.3 kg, yielding a total traverse weight of 3.8 kg.

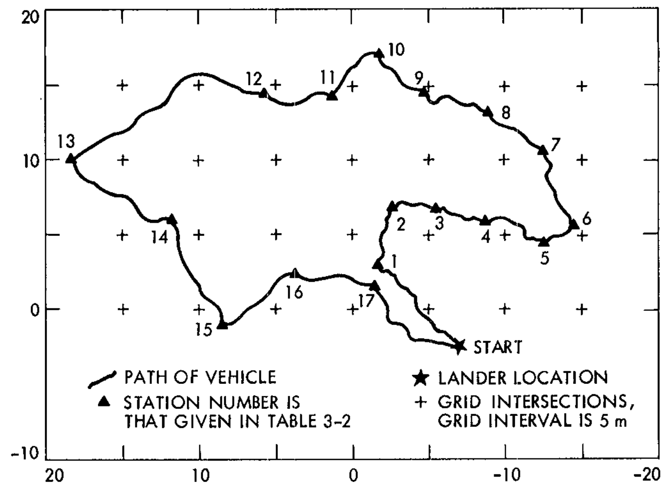

Figure 3-4. Hypothetical Sampling Traverse at the Viking Lander 1 Site

Based on the above analysis of a model traverse at a Viking-like site,

> The mobility range required of a sampling rover is on the order of 100 m. In addition, the above analysis indicates that the sample mass required to properly sample a Viking-like site is on the order of 4 kg.

3. The Relationships Between Sample Mass, Working Time on the Martian Surface, Spacecraft Power, and Traverse Distance

Rover mobility range is a function of the working time on the Mars surface, the available spacecraft power, and the mass of samples that the Earth-return vehicle can carry. It is obvious that the more time and power available, the further a rover can traverse. The relationship to sample mass is less obvious. The more time on the Martian surface, the longer the traverse will be, and the greater the mass of samples collected.

It has generally been assumed that one kilogram is an adequate amount of sample to collect and return. It has also been generally stated in engineering discussions that sample weights less than about 5 kg pose no additional problems to those related to returning 1 kg. The 1-kg estimate is based on an ideal sample that contains rocks, soil, and fragments on which many analyses may be performed. No account is taken of the need for a 1-m regolith core or of an atmosphere sample. No account is taken of the requirement to have redundant samples so that a large team of Earth-based researchers may study the returned material. No account is taken of the above traverse analysis that

Table 3-2. Materials Collected on Traverse at Viking Lander 1 Site

Station Number	Rock	Soil	Dune and Drift	Duricrust
1		Cloddy soil		
2	Outcrop			
3	Small rocks			
4	Outcrop			
5	Layered rock			
6	Dark rock			
7	Light rock			
8				Duricrust
9			Active dune	
10		Soil		
11	Pink rock		Light dune	
12	Layered rock			
13			Drift	
14	Breccia			
15	Largest rock			
16	Shocked rock			
17			Soil under rock	

indicates almost 4 kg are required to properly sample just one Viking-like site. No account is taken of the fact that a single rover will be able to sample several sites on a traverse, each site being about as complex as the model Viking-like site.

In view of these considerations,

> It is recommended that the returned sample mass from each lander site be at least 5 kg.

This mass includes a sleeve for the regolith core and the container for the atmosphere sample (estimated to weigh 1 kg).

The time required to traverse and sample was estimated from the Viking experience in surface sampler operations, including the task of pushing a rock. This should provide a conservative estimate because we can expect advances in the art of spacecraft command and control between Viking and a Mars Sample Return Mission. A five-day sampling time appears reasonable for data collection, data processing, sample selection, command sequencing, execution, verification, and documentation at each station. The time to move the approximately 10 m between stations is estimated at one day. Thus the total cycle for each station is 7 days. If there are 17 stations as indicated in the model traverse for the Viking-like site, then the surface operation time for that traverse is 17 weeks or 4 months. See Table 3-3 for estimated rover-sample timeline.

This analysis suggests that

> Sample collection time in a Viking-like site may take several months to complete.

Further, because the total operation time on the Martian surface is limited to approximately 8 months (Ref. 3-9), and because it takes about half of that time to properly sample one terrain type, the total 8 months will be utilized in the proper sampling of two or three terrain types of the complexity of a Viking-like site. From this analysis, it is concluded that the mission profile and mass carrying capacity of the Earth-return vehicle limit the effective required mobility range to that adequate to sample two or three terrain types.

F. SAMPLE COLLECTION HARDWARE

As noted previously, a returned mass of at least 5 kg is required to properly sample each landing site. A suite of hardware items is needed to collect these samples. These devices are used in several tasks - the selection of samples, the procurement of samples, and the handling of samples. The potential suite of devices that might be useful can expand to a very large number of items as each device acquires more specific functions. In this section a distinction is made between devices that are considered required and those that are highly desirable. Those devices that are merely desirable are not even listed.

Table 3-3. Estimated Rover-Sampler Timeline

Total Elapsed Time (Martian Days)	Sample Acquisition Cycle: Operation	Sample Acquisition Cycle: Days Required	Traverse Cycle: Operation	Traverse Cycle: Days Required
0		0		
	Data Received STA 1			
1		1		0
	Data Processed		Data Received (necessary data for traverse from STA 1 to STA 2)	
2		2		1
	Data Analyzed		Data Processed	
3		3		2
	Command & Sequence		Data Analyzed	
4		4		3
	Execute at STA 1			
5		5		4
	Ver., Doc., Accept.		Command & Sequence	
6		6		5
			Command	
7				6
			Execute 1-2 (actual traverse from STA 1 to STA 2)	
8		0		7
	Data Received STA 2		Verif.	
9		1		8 (0)
			Data Received (necessary data for traverse from STA 2 to STA 3)	
10		2		1
11		3		2
12		4		3
	Execute at STA 2			
13		5		4
	Ver., Doc., Accept.			
14		6		5
			Command	

Table 3-3. (Continuation 1)

Total Elapsed Time (Martian Days)	Sample Acquisition Cycle: Operation	Sample Acquisition Cycle: Days Required	Traverse Cycle: Operation	Traverse Cycle: Days Required
15				6
			Execute 2 - 3 (actual traverse from STA 2 to STA 3)	
16		0		7
	Data Received STA 3		Verif.	
17		1		0 (8)
			Data Received (necessary data for traverse from STA 3 to STA 4)	
18		2		1
19		3		2
20		4		3
	Execute at STA 3			
21		5		4
	Ver., Doc., Accept.			
22		6		5
			Command	
23				6
			Execute 3 - 4 (actual traverse from STA 3 to STA 4)	
24		0		7
25		1		8
26		2		
27		3		
28		4		
	Execute at STA 4			
29		5		
30		6		

(Number of cycles equivalent to number of sampling stations)

A drill-like device for obtaining cores from hard rock is required.

This device is required because of the need to: (1) obtain a sample that includes both weathering rind on a rock as well as unweathered material, (2) control the location of where a sample is obtained, (3) obtain samples with a uniform shape so that sample packaging is optimized, (4) obtain samples from both small objects (e.g., 10-cm rocks) to large objects (e.g., outcrops of meter-size boulders). The drill should obtain a sample core that is approximately 1 to 2 cm in diameter and 10-cm long. The drill must be mounted so that it can obtain a sample in a range of orientations (e.g., vertical, 45 deg to vertical, and horizontal) and directions (front, left, and right). This flexibility of the drill yields simpler operations than if the drill were fixed and the rover maneuvered. The drill mechanism, or associated hardware, must be able to hold the object being drilled in those cases where the object is small. The holding capability is probably required only for vertical drilling. (See Ref. 3-10 for a description of a device capable of satisfying the above requirements.)

A contingency sampling device is required.

This device must be a simple scoop and container with no complex operations. The device should be designed to operate even if it is the only device and it is mounted on the Lander spacecraft.

All other sampling devices should be mounted on the sampling rover. This eliminates the need to transport potential samples to the Earth-return spacecraft for selection and preparation.

A scoop with teeth, mounted on an arm of the sampling rover, is required.

This device is prime in collecting samples of soil, dune, and duricrust. The scoop is also used in conjunction with more complex sampling devices such as the drill. This device is essentially the Viking arm.

An atmosphere sample device is required.

This device must make a positive seal between the atmosphere sample and solid portions of the sample collected. This device may contain a subdevice that has the capability to concentrate a large mass of atmosphere in a small volume.

A device that will obtain a section of regolith one meter long is required.

This device may be a sampler arm and a scoop, or it may be a regolith drill. If it is a regolith drill, the drill may be combined with the rock drill described above.

An imaging device, mounted on the sampling rover, that has the capability of providing stereo images with millimeter resolution at a range of 2 m, and has the capability of providing some color or spectral data is required.

This device plays a central role in sample selection and in controlling sampling operations. The resolution and color/spectral data provide the prime data for sample selection. The stereo data provide the base on which specific sampling commands are designed.

A grasping device on a sampler arm on the sampling rover is highly desirable.

This device is used to hold and handle small rock and "bagged" soil samples, and to pick up small rocks and fragments.

Devices to measure the physical properties (such as hardness and density) of potential samples is highly desirable.

These types of measurements provide the second most important data for sample selection. These data also aid in designing the sampling operations. Hardness and density measurements may be derived as "free" data from other sampling devices such as the drill and the sampling arm and the scoop. This type of data was obtained in such a manner in the Surveyor project and in the Viking project. No special devices are required to satisfy this need.

An instrument that provides "reconnaissance" chemistry is highly desirable.

This device is used as a sample selection aid. As a sample selection aid, the device is most effective if mounted on a sampler arm so that the instrument can operate in various orientations and directions. A restricted set of elements is needed for the sample selection function. The aim is not to perform a scientific experiment; it is rather to distinguish rocks of similar appearance but different chemical positions. Therefore, high precision is not needed. The needed precision is such that basalt can be distinguished from andesite, tonalite from granodiorite, and quartzite from graywacke.

G. SUMMARY OF RECOMMENDATIONS AND CONCLUSIONS

1. Sample Objectives and Assumptions

(a) The prime sampling objective at each landing site is to obtain fresh and weathered samples of the most abundant material types in the vicinity of the lander.

(b) Unweathered materials are expected to be common on the Martian surface.

(c) Unweathered materials are expected to include both igneous and sedimentary rocks, which may occur in outcrops, talus, and ejecta from impact and volcanic craters.

2. Mobility

(a) A rover capable of acquiring samples is required to properly sample a Viking-like landing site.

(b) A sampling rover requires a mobility range of hundreds of meters to properly sample a Viking-like landing site as well as sites with fewer rocks at the surface.

(c) As the mobility range of a sampling rover increases, the required working time on the Martian surface and the mass of returned samples must also increase.

3. Sample Acquisition

(a) A returned mass of at least 5 kg is required to properly sample a Viking-like landing site and also to sample one adjacent, different terrain type.

(b) A drill capable of collecting cores from rocks 10 cm and larger is required to obtain fresh samples.

(c) A contingency sampling device is required.

(d) A sampling arm with scoop and teeth is required.

(e) An atmosphere sample is required.

(f) The acquisition of a sample of a 1-m section of regolith is required.

(g) A high-resolution imaging system with stereometric and color capabilities is required on the rover for sample selection purposes.

(h) A grasping arm on the rover may be desirable.

(i) The ability to obtain hardness and density of potential samples is desirable for sample selection purposes.

(j) An instrument to obtain reconnaissance chemistry is desirable for sample selection purposes.

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