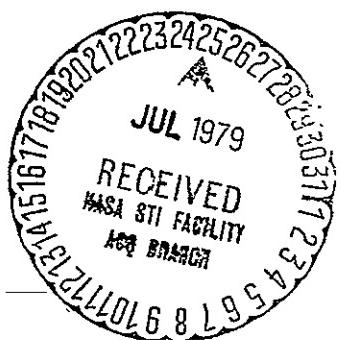NASA Technical Memorandum 58213

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March 1979

NASA

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston. Texas 77058

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PREFACE

The National Aeronautics and Space Administration at the present
time is considering the options available for further Mars exploration
following the successful Viking missions. It is imperative that
separate types of missions in a Mars exploration strategy are evaluated ·
as to their unique or complementary roles in the overall exploration
objectives. While acknowledging the indispensable role of other mission
types in obtaining information, it is concluded that the sample return
mission provides the maximum scientific return obtainable. In this
report the data sets necessary for characterizing Mars are considered.
If further analysis of surface samples is .to be made, the best
available method is for the analysis of the Martian samples to be
carried out in terrestrial laboratories.

In January 1977, the Lunar and Planetary Sciences Division at the
Johnson Space Center began to examine the scientific rationale and
requirements for a Mars Surface Sample Return. The experience gained
from the analysis and study of the returned lunar samples must be
incorporated into the science requirements and engineering design for
the sample return mission. The report was assembled and written by
Donald D. Bogard, Michael B. Duke, Everett K. Gibson, John W. Minear,
Larry E. Nyquist, and William C. Phinney with inputs from personnel
within the Lunar and Planetary Sciences Division and the Lunar Science
Institute.

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I. Introduction

Mars has been shown by successful Mariner and Viking missions to be an exceedingly complex planet, although its developmental history appears less complex than that of the Earth. No set of missions that can be flown to Mars in the next 10-20 years will answer all first-order scientific questions about the planet, and each mission probably will raise many more detailed questions than are answered. However, enough information is available to begin to identify the basic questions posed in the Martian context and their manner of solution. Possible missions include orbiters, in situ surface measurements (soft landers, rovers and/or penetrators), sample returns, and eventually, manned exploration (1,2). Each type of mission has a potential role in exploration of the planet. The purpose of this document is to present the case for return of a Martian sample to Earth for study.

Sample studies play an essential and unique role in developing an understanding of the formation and subsequent history of any planet. Studies on samples returned to the Earth are unique with respect to the capabilities of remote missions in that they (1) can be performed with state-of-the-art technology at the time the samples return or at any future time, unconstrained by weight or volume limitations; the sensitivity, precision, and scope of laboratory analysis is constantly improving; (2) involve the broadest range of scientific disciplines and the international scientific community; (3) permit iterative, imaginative experiments whose designs can be rapidly modified as the experimental

results are obtained; (4) allow separation and concentration of phases, based on the specific properties of the samples; (5) permit many different analyses on the same sample; and (6) permit the deferral of experiments if better analytical technology or understanding is necessary. The confidence placed in laboratory sample analysis is greater than for landed remote instruments due to higher analytical precision and because of greater control of experimental parameters, greater sensitivity, and multiple analysis by several laboratories (3). For Mars, sample studies will provide essential information on the chemical and physical processes by which the planet accreted, became internally differentiated, developed complex surface features, evolved a modest atmosphere, and possibly experienced biological activity (4).

The search for life, apparently unsuccessful in the Viking missions, can be carried out more comprehensively with returned samples (5). Returned samples would allow the search for present, past or fossilized organisms to be conducted with the greatest sensitivity and resolution available. Determination of the absolute chronology of the planet's development is dependent on sample studies. Sample studies, coupled with geophysical studies of the current physical and thermal state of the planet, promise the best opportunity to move significantly beyond the surface information obtained from Mariner and Viking missions toward the characterization of the planet as a solid body (6).

In the next decade it will be technologically feasible to return samples from Mars (7-10). A Mars Surface Sample Return (MSSR) mission will be a major milestone in our exploration of the solar system -- the first pieces of another planet -- equivalent scientifically to the major step in understanding the Moon and solar system that resulted from the study of the first lunar samples. It will allow concepts of the further

exploration and utilization of Mars to be developed, based on firmly established data. As did the Apollo program, MSSR will reach another benchmark in technological achievement and will demonstrate the continuing leadership of U.S. efforts in space. It will lay the foundation for manned exploration of Mars, which could occur within the next 25 years.

On Earth, MSSR will stimulate research in planetary processes, analytical technology, and the biological sciences. As in the case of the lunar samples, an immensely broad and sophisticated set of scientific investigations will be brought to bear on the samples. International scientific cooperation will be promoted by participation of scientists from many nations. If other nations acquire samples of their own, the opportunity for U.S. scientists to participate in their study will be increased. The anticipation of the sample return and its study will have major impact on the lay public as well, in part because of the prospect of finding alien life forms in the samples, in part because of inherent interest in whether other planets are similar to or very different from Earth, and in part because of the possibility that future habitation and resource utilization will be closer.

The importance of MSSR to science and its high public interest will make it a particularly visible mission which requires careful definition and management (5). As Viking results are better understood and as the engineering alternatives become more clearly defined, refinement of the mission objectives will be possible. Because of the long lead time required for the development of portions of the system, especially those portions dealing with biological containment, it is necessary to begin the processes of intensively studying alternatives and developing engineering concepts as soon as possible (5,6,11-15). These engineering efforts will require continuous interaction with the scientific community in order to maintain the highest quality scientific capability within the cost, weight, power, and other constraints.

II. Mars Science Objectives

The study of Mars should lead us toward major new insights into the processes by which planets formed; the effects of initial temperatures, pressures, and compositions on the subsequent internal evolution of the planet; the time history of internal activity that led to the evolution of its current internal structure, surface features, and the atmosphere; the degree to which impact of meteoritic or asteroidal material may have determined planetary composition and crustal structure; the interaction of solar and galactic radiation with the atmosphere and surface materials of the planet and their role in determining atmospheric evolution; the history and dynamics of the atmosphere and hydrosphere and their relationship with the surface and internal processes of the planet; the nature of the environments in which organic evolution can be sustained; and the resulting biological evolution of the Martian surface. In this endeavor we will learn by direct study of the planet and its materials, by comparison to the Earth, Moon, and other planets, and by laboratory studies that tie together observation and theory (1,16,17).

Some of the questions in principal areas of concern that must be addressed in order to understand the formation and evolution of Mars are:

1. Formation

What is the chemical composition of the planet? How does that relate to the initial location of Mars in the evolving solar system? What were the heat sources that provided the energy for internal activity and differentiation? When did the planet accrete with respect to the formation of other planets and the meteorites? Was the planet "cold" or "hot" when accretion was complete?

2. Structure

What is the current internal structure of the planet? What are the compositions and mass of the Martian core, mantle, and crust? When did the internal differentiation occur? Is the magnetic field related to an internal dynamo? What redistribution of energy sources occurred during differentiation? What is the current and past seismicity of the planet? What are the orbital dynamics of the planet? What can be said about the history of Mars' moons?

3. Crustal and Mantle Evolution

What is the history of crustal evolution and volcanic activity? How has mantle composition evolved through time? What are the compositions of crustal and volcanic rocks? How thoroughly outgassed is Mars? What are the controlling oxidation/reduction reactions in the Martian interior and how have they affected the composition of crustal and volcanic materials? Have there been episodic periods of volcanic activity, or has volcanism been continuous? From what depth were Martian volcanic rocks derived? Did plate motions on Mars ever play a major role in the crustal tectonics as on Earth?

4. Planet Morphology

What are the origins of the principal landforms of the planet? What are the relative roles of volcanism and tectonic processes in the development of surficial features of the planet? What is the history of meteoriti influx on the Martian surface and how has it changed over geologic time? How does the meteoritic cratering rate on Mars compare to that on the Moon or Mercury? Has the composition of impacting objects changed with time? Is the composition of meteorites landing on Mars different from

those impacting the Earth? How does impact metamorphism modify indigenous. Martian materials petrologically? What has been the role of impact in generation of mountains and basins or the ancient cratered units? Can crater densities be used to determine relative ages of surface features reliably? Has water or wind blown dust been the chief erosional agent operating on the surface? Do the canyons result from erosion or from subsidence due to withdrawal of volatiles or lava? What is the relationship of Mars' moons to the planet, to asteroids or meteorites?

5. Atmosphere

What are the origin, evolution and history, structure, and dynamics of the Martian atmosphere? Are primordial gases retained, or are all gases derived from volcanic, crustal, or interior outgassing? What effect does solar corpuscular and electromagnetic radiation have on the composition of the atmosphere? How are volatile materials distributed between the crust, regolith, poles, and atmosphere? Can mass balances for atmospheric constituents (H_2O, CO_2, N_2, noble gases, others) be derived? What are the rates of exchange of volatiles between the various reservoirs including the polar caps? Have substantial amounts of volatiles been lost from the planet? What are the controlling factors for atmospheric dynamics, including wind patterns, dust storms, polar cap growth and recession, and cloud formation? Are there records of greatly differing atmospheric compositions, pressures, or dynamics in the past? Has liquid water been stable at or near the surface in the past?

6. Surface Chemistry and Regolith Formation

What chemical and physical processes determine the composition of the boundary layer between the lithosphere and atmosphere? What part does meteorite impact play in the generation of the regolith? What are the

types and rates of mechanical and chemical weathering processes active at the surface? Do they depend on atmospheric photochemical effects? Do they vary in different locations; have they been different in the past? Do they depend on fresh inputs of chemical reactants from volcanic processes? What transport, depositional, and lithification processes are presently active or were active in the past? What is the role of adsorbed water in reaction and lithification? What is the fate of organic compounds at the Martian surface?

7. Life

Are there viable lifeforms, and if so, what are their characteristics? Were there any in the past, and if so, when? What were the characteristics of past life if it existed? What are the environments in which Martian biological activity may have existed in the past or does exist today? What organic compounds are stable in those environments? Are organic compounds produced or destroyed by abiogenic means?

III. Current Knowledge of Mars

Mars is the fourth planet from the Sun, roughly 40-50 million miles
from Earth at closest approach, and similar enough to Earth that it may
provide significant insights into the evolution of the Earth as well as
the other terrestrial planets. Our current state of knowledge consists
of limited whole-body information obtained by astronomical and spacecraft
observation, a vast amount of surface morphologic information obtained by
Mariner and Viking imagery, and detailed information on atmospheric
composition and dynamics and surface temperatures obtained by Viking.
The Viking landers have provided preliminary information on surface
composition and potential mineralogy as well as limits on the complex
organic chemistry, biological activity, and possibilities for life. Too few
significant seismic events have been detected to permit an understand-
ing of the internal structure of the planet. In general, our ability to
answer questions posed in Chapter II varies significantly, depending on
the progress made with previous experiments. Many atmospheric and surface
properties of the planet, including a relative, but not absolute, chronology
of surface features, appear to be rather well characterized, whereas the
data pertaining to formation, internal structure, petrology, chemistry,
differentiation history, regolith formation, and absolute chronology are
virtually nonexistent. Although no conclusive evidence of the present existence
of life has been provided by Viking, it cannot be assumed that Martian life
is nonexistent or never existed on the basis of current data (18,19).

1. Formation

The density of Mars is 3.9 gm/cm^3, intermediate to that of the Earth
and the Moon. This is generally interpreted as signifying a different

chemical form and concentration of iron in the bulk planet than in the Earth. The abundance of volatiles in the Martian atmosphere indicates that substantially more volatiles were trapped during planetary accretion than can be demonstrated for the Moon. With the exception of sulfur, which may have been concentrated by secondary processes, the Viking geochemical analyses do not show Mars to be richer than the Earth in moderately volatile elements such as potassium. Mars still has significant quantities of water, however, in contrast to the Moon which appears never to have had any water. Very little else is known that is pertinent to the questions of planetary formation, besides the knowledge that sufficient heat was present or subsequently generated to permit volcanism through a currently undetermined period of the planet's history (18,19).

2. Structure

Indirect evidence suggests that the structure of Mars includes a core, mantle, and crust. The moment of inertia is suggestive of the presence of a core and thermal history calculations suggest that the interior is molten Fe-Ni, possibly with substantial FeS. The intrinsic magnetic field is small, with a dipole moment of less than 10^{-4} that of the Earth; however, it is not known whether the field is due to the presence of a core dynamo. Speculations on the nature of the mantle and crust are based on surface morphologic features, which include an intensely cratered ancient terrain similar morphologically to that of the Moon, which is known to be a differentiated crust, and evidence for internal volcanism, probably derived from the Martian mantle. Gravity field determinations indicate that relatively old features (Hellas, Isidis, Thaumasia) are generally in isostatic equilibrium; relatively young

features (Tharsis, Chryse, and Amazonis basins) are not in isostatic equilibrium (19,21). At the present time, there is no significant seismic evidence on the internal structure, and evidence from the single operational Viking seismometer suggests that the planet is less active seismically than the Earth (16,18,19).

3. Crustal and Mantle Evolution

Several periods of volcanic activity are indicated in imagery of the planet obtained by Mariner and Viking missions; however, the absolute chronology is unknown. Interpretations of the absolute age of the youngest volcanic features range from a few hundred million years to 2.5 billion years (21). This range of interpretations is equivalent to the differences between an Earth-like history of continuing volcanism and a Moon-like history of very early volcanism with an ancient cutoff of internal activity.

Morphology of the volcanic forms suggests fluid lavas, probably basaltic, to more viscous lavas capable of building large domes, which may also be within the range of terrestrial basalt in composition. The composition of the ancient highlands is totally unknown. The Viking chemical analyses have been interpreted as representing a mixture of altered basic rocks (clays) with smaller amounts of carbonates, sulfates, and ferric iron minerals. However, the alteration and mixing represented by the soil samples thus far analyzed precludes the identification of any rock type. Vesicular rocks observed on the Martian surface may be volcanic, impact breccias, or may just appear to be vesicular, due to weathering and erosion. Although substantial outgassing of the Martian interior is believed to be responsible for the present atmosphere, and the surface materials appear to be rich in oxide and hydrous phases, the oxidation

state of the crust and mantle and the volatile contents of interior materials are undetermined. This data is crucial for comparative planetology, and the subject is currently a major area of research in terrestrial geoscience (17, 18, 19).

4. Planet Morphology

Mariner and Viking imagery have revealed a wide range of surface features, from which most of the current detailed questions on planetary evolution are derived.

Several distinct geologic provinces were identified on Mars from Mariner data. There is a striking hemispheric asymmetry along a great circle inclined at about 20° to the equator between the higher southern cratered terrain and the lower northern, relatively uncratered plains. The four physiographic provinces of Mars include: (a) polar units composed of permanent ice, layered deposits, and etched plains; (b) volcanic units composed of shields, domes, cones, plains that lack some volcanic features, and cratered plains that resemble lunar maria; (c) modified units composed of hummocky terrain with chaotic, fretted, and knobby features, channel deposits, undivided plains and grooved terrains; and (d) ancient units composed of cratered terrain with undivided, densely to moderately cratered uplands (most ancient of all surfaces) and mountainous terrain with rugged basin margin material -- probably eroded basin ejecta (19).

Impact craters on the Martian surface indicate a continuous bombardment of the planet by meteoroidal material. Studies at present have dealt only with crater morphology; at least one class of impact craters, in which lobate flows occur in the ejecta blanket, is different from that observed on the Moon or in terrestrial craters. This crater morphology

may represent the result of impact into volatile-rich or permafrost-rich zones. The presence of volatiles in the surface materials is likely to provide quite different types of impactites on Mars from those found on the Moon; however, there are no pertinent data at this time on the nature of Martian impactites, or on the nature of the impacting bodies, nor on their absolute flux through time (18,19).

The relative ages of surface features are established by superposition and by observations of impact crater densities. The improved imagery obtained by Viking is providing much improvement in relative age determinations. However, the determination of absolute ages rests on calibration of the meteoroid flux in the vicinity of Mars. The meteoroid flux is presumed to have declined rapidly during the early history of the planet, based on analogy with the Moon. Absolute age determinations are very sensitive to the assumptions made about the rate of change of the flux, which presently is in dispute, and to any differences in flux between Mars and the Moon. These uncertainties have led to widely divergent opinions of the absolute age of Martian surface features. The only way of unambiguously calibrating the meteoroid flux on Mars and the Moon is to obtain absolute (isotopic) ages of rocks that can be related to surfaces of known crater density (17-19).

- Mariner and Viking orbital photography has revealed channels and has stimulated a variety of ideas about the history of the planet's surface and atmosphere. Several different classes of channels are present, chiefly in the equatorial regions. Broad channels originate in chaotic terrain and flow northward towards the lower plains; accompanying them are sinuous channels with tributaries, braided floors, and streamlined islands. Finely

textured networks of branching channels occur throughout a planet-wide
belt just south of the equator. Formation of these channels may have
involved the flow of surface or subsurface water; however, at the present
stage of Martian evolution, liquid water is not stable at the Martian
surface. The existence of liquid water on the surface may be possible
with only a slightly higher planetary atmospheric pressure or large
concentrations of dissolved salts in the water. Catastrophic melting
of permafrost, rapid release of dammed lakes, and rainfall have been
suggested as causes of the erosion. Any of these would require large dif-
ferences in the Mars surface environment in the past. One type of channel
originates in craters and becomes narrower downstream rather than wider
as do the other types. Closely resembling terrestrial and lunar lava
channels, this type probably involves the channelized flow of molten
rock (18).

Aeolian activity on Mars has been clearly documented by telescopic
observation and Mariner 9 was able to follow the dispersal of the 1971
dust storm. The bright surface markings on Mars are relatively constant
whereas the dark markings show highly variable changes at all temporal
and areal scales. Observations of the markings over a period of time indi-
cate that they are produced by aeolian erosion and deposition of
sediment materials. Wind velocities necessary to move sediment in the
tenuous Martian atmosphere are of the order of tens of meters per second.
Small particles moving with these high velocities may be effective erosional agents.
Infrared spectral reflectance data indicate that the surface dust is highly
oxidized and widely distributed, but most prominent in the bright areas (19).

The polar regions of Mars are covered by thinly layered deposits,

possibly composed of material brought down by polar snow (or frost). The deposits are eroded and redeposited in the two aeolian polar mantles that thin towards the equator. The equatorial regions between 30°N and 30°S apparently have been extensively eroded to supply the material of the polar and mid-latitude aeolian mantles. Viking imagery is providing important detailed information on the sequence of erosional/depositional events in the polar regions; however, the period of time represented by these features is not known (18,19).

5. Atmosphere

Viking has provided detailed compositional and isotopic information on the Martian atmosphere, planetary temperature determinations, atmospheric structure at two points of entry and imaging data pertinent to atmospheric dynamics. The Martian atmospheric pressure is less than one percent that of Earth's. The atmosphere is predominantly CO_2 (95%) with about 2-3% N_2, 2% Ar, and less than 1% other components, including O_2. The $^{40}Ar/^{36}Ar$ ratio is 2750 ± 500, $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios have been measured to be within a few percent of terrestrial values, and the $^{15}N/^{14}N$ ratio is about 75% greater than the terrestrial value. These data suggest that the outgassing of Mars is only about 1/100 that of the Earth. Substantial quantities of gases have apparently been lost from the atmosphere by evaporation from the planet and by incorporation into the regolith. Indeed, much larger amounts of CO_2 (as carbonates) and water are likely to be retained in Mars surface materials than reside in the atmosphere (18).

Observations from the Viking atmospheric water vapor mapping instrument show very little water vapor in the Mars atmosphere in the southern

hemisphere (0 to 3 precipitable micrometers) with a gradual increase across the equator to northern latitudes where it is summer. Maximum amounts between 20 and 30 micrometers have been observed to date. Strong repetitive diurnal cycling between the solid and vapor phases has been observed. It is believed that at some sites the water vapor lies close to the Martian surface and is most probably in saturation equilibrium with a surface haze or fog throughout much of the day. Evidence for a permanent polar cap composed of water ice has been obtained from temperature estimates made by the Viking broad spectral observations and from higher partial pressure of water vapor near the northern pole (18).

Past variations in the atmospheric pressure, composition, and surface temperatures would be implied if the large erosional features observed on Mars are fluvial in origin. The absolute ages, and to some extent the relative ages, of the epochs of apparent fluvial erosion have not been determined. The Viking data show the surface material to be oxidized, hydrated, and to contain bound CO_2. The interchange of volatiles between the atmosphere and regolith may be of major importance in the evolution of the atmosphere (18).

6. Surface Chemistry and Regolith Formation

Viking landers have confirmed orbital observations that dust and sand-sized material, formed by a combination of mechanical and chemical weathering processes, are abundant on the surface.

Photographs of the Martian surface at the Viking 1 site on the western slopes of Chryse Planitia reveal a boulder-strewn and reddish desert, with distant eminences -- some of which may be the rims of impact craters -- surrounded by a pink sky. Photographs from Viking 2 located in the Utopia

region of Mars also reveal a boulder-strewn and reddish desert-like terrain.
The Viking 2 site is probably located on the ejecta blanket of Mie crater.
At both surface locations blocky and angular rocks are apparent. There is
a finer-grained, lower-albedo matrix material between the rocks that is
reminiscent of a desert armour or pavement in which the fine-grained
particles have been removed by aeolian processes, leaving behind coarser
material similar to gravel. The terrain around both landers contains an
impressive abundance of blocks of many sizes and shapes. Some of the
blocks are coarsely granular, possibly breccias formed by impact processes,
while other blocks are pitted and vesicular and resemble fragments from a
basaltic flow. Rocks with unusual forms are also present and may be the
result of various weathering processes such as frost shattering, spalling,
and aeolian sandblasting. Evidence of aeolian activities are dunes, lag
gravels, and scour marks associated with wind action (18).

The first chemical analyses of the Martian surface suggest that the
regolith is a mixture of primary silicates, secondary silicates, non-
silicate phases, and their weathering and alteration products. The
composition of the soil at two widely separated sites was determined to
be very similar, suggesting that surface dust on the planet is thoroughly
mixed on a planet-wide scale. No compositional data for the lithologies
of larger rocks have been obtained by Viking to date (18).

The sophisticated "life-detection" experiments carried by Viking
have demonstrated that the surface soil is chemically reactive, though
apparently not because of organic processes. Various hypotheses based
on data on the atmospheric composition and the radiation environment at
the Martian surface currently are being tested in the laboratory to place
constraints on the chemical processes active at the surface. These models

will be limited until the mineralogy of the volcanic and metamorphic materials that crop out at the surface have been determined (18,19).

7. Life

At the present time, Mars is the principal target for exobiological searches in the solar system. All other objects, with the possible exception of Titan and certain regions of the Jovian atmosphere, appear to be excluded as possible habitats of life, owing either to the lack of an atmosphere or to temperature regimes that are incompatible with complex organic chemistry. The Viking biology investigations consist of the following three experiments: 1) labeled release experiment which looks for signs of metabolism, 2) pyrolytic release experiment which looks for microorganisms that function by photosynthesis or chemotrophy, or organic response to chemicals, and 3) gas exchange experiment which searches for living organisms by measuring changes in the gases in a closed environment. All the biology experiments give positive responses, but the data has been interpreted as reflecting only unusual surface chemistry. The molecular analysis experiment (gas chromatograph-mass spectrometer) failed to find any organic molecules at either Viking landing site down to the level of 10^{-9} parts by weight. The experiment produced data that indicated only low temperature inorganic phases were present in the regolith.

The failure to positively detect life at the two Viking landing sites does not rule out the existence of life on the planet, which may be limited in its geographic distribution or to special environments. The remote Viking experiments were not designed to test for fossil evidence of life (18,19).

IV. EXPLORATION STRATEGY

The strategy for the further exploration of Mars should attempt to optimize science return within the constraints of technical capabilities and costs. The diversity of scientific questions which remain to be addressed make the selection of an optimum strategy complex, and eventually must lead to a prioritization of scientific objectives. Exploration strategy must address the types of data that can and must be provided by the various candidate missions of orbiters, penetrators, soft landers, mobile surface laboratories, and sample return. A strategy must also consider whether there exist strong scientific arguments for a particular sequence of missions (1).

If only a single mission could be flown to a planet, a well planned and flexible sample return mission would be the most likely to provide the widest diversity of information to the broadest spectrum of scientific disciplines of any mission. The Space Science Board of the National Academy of Sciences recommended in 1974 that "Mars Surface Sample Return (MSSR) be adopted as a long-term goal and that an early start be made on research and development into a verifiable system of sample isolation" (1). This position has been adopted also by other groups considering Martian exploration (4).

The experience with analyses of returned lunar samples is a measure of what one could expect to learn about Mars through laboratory investigations of returned Mars materials. The analysis of returned lunar samples has completely transformed our concepts of how the Moon formed and what its subsequent history has been. Our present knowledge of the timing of events that led to the Moon's present configuration, the evolution of the

crust, the bulk and trace element geochemistry and how it differs from that of the Earth have all been derived from examination of returned samples. The degree to which this understanding could have been achieved solely by remote analysis is a matter of some conjecture, but there is ample reason to be skeptical. Having lunar samples in hand allowed the complete analytical and intellectual capability of the scientific community to focus on the problem of the Moon's evolution. Instead of having a small, predetermined set of analytical techniques applied to the samples, the approach could be both all-encompassing and flexible, the analytical emphasis shifting as the meaning of each set of results became better appreciated. There is no reason to believe that these enormous advantages of returned samples should be any less for Mars. Indeed, the apparently more complex history of Mars enhances the importance of the kind of comprehensive examination that a returned sample allows. This is not to demean the value of remote analysis.. It is hoped that the Mars exploration program will take cognizance of all potentially available data relevant to composition, physical state and geologic context of the Martian surface and the site from which the samples will be collected (6).

1. Data Obtainable from Various Missions

    a. Orbital Science

Many types of whole-body data are best obtained from orbit.. Among these are global maps of surface features, magnetic and gravitational fields, surface infrared emission and reflection data, and chemical data by gamma ray spectrometry, as well as some types of atmospheric data (4). At the present state of exploration of Mars considerable imagery of the surface is available, although higher resolution would be helpful in some

areas. Maps of the magnetic field have not been obtained and are essen-
tial for understanding the origin of the global field. The gravity
field of Mars has been mapped by Viking; however, higher resolution
gravity maps and altimetry are desirable to allow the crustal mass dis-
tribution to be determined. Surface infrared emission has been mapped
by Viking. Multispectral imaging and reflectance spectroscopy could
provide important data on the distribution of surface materials. However,
these spectra may be dominated by dust and are likely to give evidence
primarily on the distribution of oxidized components and surface dust.
So also may the gamma-ray spectrometry be limited in usefulness, as the
first-order effects will be related to the distribution of dust, which
is suspected now on the basis of Viking to be similar in composition all
over the planet. Increases in surface spectral resolution to analyze
dust-free areas would be useful here. Orbital platforms could improve
our understanding of the composition of the upper atmosphere and of the
interaction of the solar wind and UV irradiation with the atmosphere.
Such data would be far advanced in detail with respect to other knowledge
of the planet (4).

b. Surface Science

(1) In situ sensing networks.

One class of surface experiments depends on one or more active
stations operating over a significant period of time (e.g., a Martian
year) and measuring the distribution of a given property either spatially or
temporally (22). The principal candidate experiments are: (a) a seismographic
net, which would be fundamental to an understanding of the planet's interior;
(b) a meteorological network, which could provide a basis for detailing the

dynamics of the Martian atmosphere with considerable exactness; (c) a surface magnetometer net, which could be used to define variations in the planetary magnetic field and be correlated with an orbital magnetometer in studies of the interaction of the solar wind with the planet; (d) heat flow measurements, which would provide fundamental information on the thermal properties of the planet; (e) additional measurements of atmospheric composition; and (f) near-surface water sensors, which may be required to study the interchange of volatiles between the regolith and the atmosphere and to search for life. The above geophysical and meteorological properties are fundamental and have high priority in any exploration strategy. Only for meteorology and atmospheric composition is there presently substantial data. Measurements of soil moisture have not yet been made.

To varying degrees, the above geophysical and meteorological experiments could conceivably be conducted with either penetrators or soft landers. The practical utilization of these sensing instruments in hard landers on planetary surfaces has yet to be demonstrated. Penetrators, however, appear to offer the potential advantages of low relative cost and the ability to implant a planetary network from a single mission (22). Establishment of sensing networks by soft landers and/or mobile surface laboratories involves much more complex missions and would undoubtedly be done in conjunction with additional geochemical and geological analyses of the Martian surface.

(2) Analysis of surface materials.

The types of analyses which would be conducted on Martian surface samples and the kinds of fundamental scientific problems addressed by the

resulting data are numerous and diverse. Sample analyses may be carried
out either on returned Mars surface materials or remotely on the surface
of Mars. Such analyses include chemical and isotopic composition,
mineralogy, texture, physical properties, age determinations, and others
(4,6). Table 1 gives a detailed list of problems to be studied via samples.
This table also indicates that other types of data will be required ultimately
to solve problems of planetwide dimensions and to answer questions bearing on
the geophysical properties of Mars. The principal message of this table is that,
although sample studies will not alone provide unique answers to all
questions, they will provide hard data pertinent to the most fundamental
questions of planetary origin and evolution.

Table 1. Data Required to Answer Fundamental Questions about Mars.

1. What were the physical properties and chemical composition of the hypothesized solar nebula when the material of Mars condensed and accreted? What was the state of the planet during the later stages of accretion?

Current State of Knowledge	Approaches through Sample Studies	Approaches through Other Data
Density of planet, relatively low compared to Earth, suggests lower iron content. Volatiles present, but no evidence that volatile inventory greater than the Earth's.	Constrain the bulk composition of planet by analyzing for those elements and isotopes that give evidence of inhomogeneities in nebular composition and accretion temperatures (e.g., O-isotopes; volatile/refractory element ratios such as K/U), and limit internal major element composition.	Determine present heat flow to limit thermal models of the planet.
		Extend K/U determination over entire planet by remote sensing.
	Determine mineralogy, petrology, chemical composition, and age of early crustal rocks to distinguish between internal and external sources of material and energy for early differentiation (e.g., examine for extinct radioactivity, and formation and model ages).	Extend sensitivity and accuracy of in situ analysis.
	Analysis of anomalies left by decay of short-lived radioactive isotopes to provide evidence for pre-accretion conditions and time scales.	
	Study volatile budget of planet by analysis of rocks and soil for H, C, O, N, noble gas content and isotopic composition. Analyze atmospheric sample for noble gas isotopes, to determine initial composition and differentiation history of planet.	
	Search for fossil fission tracks from decay of extinct radionuclides.	

2. What is the state of planetary differentiation involving major separations into core/mantle/crust/atmosphere? When did this differentiation occur? What were the differentiation processes in the crust and upper mantle and what was their time scale? What is the present state of the planet's interior?

Current State of Knowledge	Approaches through Sample Studies	Approaches through Other Data
Weak magnetic field and moment of inertia suggest presence of core; ancient cratered terrain may be analogous to lunar highlands, representing differentiated crust. Atmosphere is evolved (not primordial gas mixture. Volcanic landforms indicate extended period of surface evolution due to internal processes. Time scale is known only in relative sense for major units; absolute time scale is unknown.	Determination of petrology, composition and oxidation state of mantle and crust by chemical analysis of crustal rocks, including rocks derived by melting of the interior. Trends of fractionation can be used to determine differentiation mechanisms.	Seismic investigation of the planet to determine internal properties, presence of core, mantle and crust, current seismic activity.

Determination of age of crustal formation by isotopic analysis (Rb-Sr, Nd-Sm, K-Ar, etc.) of ancient rocks and history of volcanic activity and mantle evolution by isotope analysis of volcanic rocks of different ages and areal extents.

Determine history of mantle differentiation by Sr, Pb, Nd-Sm isotope studies and rare earth element distributions in crustal and volcanic rocks.

Determine siderophile and chalcophile element abundances in crustal rocks to limit differentiation processes in the crust and separation of core and mantle.

Compare experimental determinations of composition of coexisting minerals to obtain temperature, pressure of derivation of volcanic liquids

Determine H_2O, CO_2, O_2 and other volatiles in crustal rocks to help define degree of outgassing. Use O and S isotopes in mineral pairs to determine temperatures of formation or metamorphism.

Determine remanent magnetization of rocks of known age to determine history of planetary magnetic field.

Measure at various temperatures and pressures seismic velocity, electrical conductivity, density, thermal conductivity, and heat production for rock and soils samples to compare with seismic, electrical, magnetic, gravity, and heat flow data from instruments either on the surface or in orbit.

Remote sensing studies to determine relative ages of units (crater density or degradation, superposition), to be tied to absolute chronology of volcanic units.

Determine current heat flow, evidence for thermal development of planet.

Study of gravity field to determine isostatic state and mass distribution in crust.

Study magnetic field intensity and variations to develop models for source of field.

3. What are the physical and chemical processes presently acting on the surface of the planet? How did they differ in the past? How did they interact with internal processes?

Current State of Knowledge

Abundant photographic evidence of past volcanic activity and aqueous erosion. Photographic evidence of aeolian transport (and erosion?) processes and atmospheric exchange of volatiles (polar caps). Continuous meteoritic bombardment. Minor cosmic ray interactions with surface due to atmospheric shielding. Surface materials do not have composition of primary igneous rocks, are rich in S, contain significant water and CO_2, and are chemically reactive. Regolithic material compacted into "duricrust".

Approaches through Sample Studies

Establish absolute chronology of volcanic and major impact events by isotopic methods to provide calibration for relative age determinations of surface features and processes.

Physical, morphologic, chemical, mineralogical, and isotopic measurements of the physical and chemical weathering products of rocks and soil to determine current and past atmosphere interactions and temperatures of reaction (O, C, S isotopes).

Determine absolute (isotopic) ages of meteorite impact craters to form basis for crater modification rates.

Petrologic, geochemical studies of impact metamorphosed rock and regolithic material of various ages may provide information on past regolith compositions and weathering processes.

Study chalcophile and siderophile trace elements in soil and rock fragments for evidence of meteoritic material; calibrate meteorite flux in past by isotopic age measurements on breccias from different cratered units.

Determine nature of adsorbed gas species.

Identify minerals due to precipitation from aqueous phase or evaporation.

Measure cosmic-ray-induced activity or particle tracks in rocks and soil to determine exposure, mixing times, depositional dynamics. |

Determine cause of reactivity of surface material observed by Viking by chemical, mineralogical analysis.

Determine nature and mode of formation of "duricrust".

See also studies related to atmosphere evolution (4).

Approaches through Other Data

Photogeology (orbital/surface) study of landforms and stratigraphy to suggest dynamic processes and to determine relative chronology of surface features and processes.

Orbital measurements (electromagnetic, etc.) to determine amount and depth of permafrost.

Surface bore holes at selected spots to determine depth to permafrost, water distribution with depth.

Dynamic meteorology at surface to measure intensity and effectiveness of winds as erosive/depositional agents.

4. What is the origin and history of the atmosphere?

Current State of Knowledge	Approaches through Sample Studies	Approaches through Other Data
Gross composition determined; evidence of isotopic fractionation of N, suggests escape mechanism. Polar terrain appears layered. Some surface features appear to be due to erosion by liquid water, which is unstable at present. Atmosphere is dynamic, as shown by dust storms, cloud formation, growth and recession of polar caps.	Determination of abundances and isotopic composition of H, C, N, O, S, and rare gases in volcanic rocks give evidence for outgassing of interior. High precision noble gas isotope studies necessary to define early history of atmospheric and loss processes (Xe-isotopes) amount of outgassing (Ar^{40}). Analysis of weathering products for CO_2, H_2O, and other volatiles provide information on regolithic reservoir of volatiles and residence times. Dynamic chemistry of regolith materials in present and possible past atmospheric conditions necessary to extrapolate atmosphere-regolith interactions. Studies (morphological, chemical, mineralogical) for evidence of aqueous deposition of erosion of Martian rocks. Studies of ancient surface materials for indications of greater atmospheric interactions in past. Search for Xe isotopic patterns which are evidence of extinct short-lived isotopes, fission of long-lived and extinct isotopes of U and Pu, and mixing effects of various reservoirs of gas.	Imaging of secular and seasonal changes in polar regions to give better understanding of cyclic variation of atmosphere. Surface measurements of atmosphere composition with higher precision than Viking. Orbital measurements of P, T, H_2O, O_3, H profiles in atmosphere, solar particles and fields measurements, necessary to assess stability of atmosphere. Measure extent and composition of polar caps by remote sensing and in situ analysis. Determine volume of regolith by remote sensing, active seismic, electromagnetic sounding, to determine size reservoir of volatiles and total volatile budget.

5. Martian life: Does it exist now or did it ever exist?

Current State of Knowledge	Approaches through Sample Studies	Approaches through Other Data
Viking biology experiments ambiguous. Viking GC-MS analyses indicates indigenous complex organic concentrations less than one part in 10^{-9} by weight. Atmospheric constituents permissive. Active surface degradation of organics probable. Past atmospheric conditions may have been more conducive to life.	Search for present, past, or fossilized organisms with the greatest sensitivity and resolution available. Study nature of organic matter, if any. Determine carbon species, abundances and isotopic composition in rocks and soils to understand carbon cycle and nature of any biological contribution. Similar studies for H, O, N, S, P are also important. Tests of fundamental principles (life mechanisms, chemistry, structure), if organisms are discovered. Necessary to understand Mars surface chemistry before predictions of best environments, present or past, for life can be made.	Search for life and/or organic matter remotely with a predetermined set of experiments. Remote search for suitable environments for life. Remote search for favorable environments for preservation of organic material.

2. Strategy for Collection of Surface Samples

Regardless of the method by which Martian samples are collected and analyzed, whether by a roving laboratory, a sample return mission, or any other system, there are some basic considerations that cannot be overlooked. Proper analysis of any Martian sample will provide important new knowledge and understanding of Mars, but no single sample will solve either all of the Martian problems or any one problem completely (1,17). On the other hand, an unlimited number of samples is not a feasible objective in terms of the operational capability of a rover or the cost of numerous sample return missions. It is necessary, therefore, to define a strategy that maximizes the probability of selecting samples that answer the widest diversity of fundamental questions within operational and budgetary constraints (1,2). This strategy must include evaluation of: (a) the criteria for site selection, (b) the nature of an adequate sample, and (c) the degree of mobility required by the sampling device.

a. Site Selection

Site selection based on the characterization and explanation of specific surface features (e.g., lobate ejecta patterns) rather than on solution of basic planetological problems (e.g., the origin of Martian volcanic rocks) seems to be advocated by some investigators. Such a strategy generally cannot answer most of the planet-wide questions asked in Chapter 2. All of the lunar landing missions were oriented toward planet-wide problems, rather than placing high priority on the elucidation of specific surface features, such as the lunar sinuous rilles. Even

Apollo 15, landing adjacent to the Hadley Rille, was primarily directed towards returning a diversity of samples, which could provide information on broad internal and external processes of the Moon. Evidence pertinent to the origin of the rille was an objective of lower rank.

Several basic geologic units have been outlined on a first-order geologic-terrain map of Mars (21). Plausible interpretations of the origins and relative ages for such units should form the basis for our selection of optimum sites for sampling, but we must expect and allow that some of those interpretations, as in the Apollo experience, will turn out to be incorrect. The major processes that are presumed to have formed the basic geologic units are (a) early crustal formation, in which external impact and internal processes interacted to form material now preserved in the ancient cratered terrain, (b) flooding of vast regions, probably by basaltic lava, to form a series of plains units (some of these may turn out to consist of impact debris), (c) more recent volcanism that formed volcanic constructs and additional volcanic plains, (d) transport and deposition by wind, ice and water to form channels and the layered units around the polar caps (17-19).

Rocks from the ancient cratered terrain unit are expected to consist of a mixture of impact-generated breccias, impact melts, and volcanic and metamorphic rocks. From these we expect to learn about the petrologic and geochemical evolution of the Martian crust; to deduce the time of formation of the Martian crust; to place limits on the composition of the planet, its mantle and core; to develop the early impact history of the planet; to constrain the nature of an early atmosphere or hydrosphere; and to compile the characteristics of impacting asteroidal material (17).

Rocks from the volcanic units are expected to represent igneous activity of many different compositions and ages. From geochemical, petrologic and age studies of these rocks we expect to be able to decipher the thermal history of the mantle, the extent of its chemical differentiation, and the processes involved in near surface chemical fractionation. Moreover, we can place limits on the bulk composition of the planet; determine fundamental properties of that portion of the solar nebula from which Mars accreted; determine the age of extrusion of lavas at the surface which may permit the calibration of the relative age scale based on crater density; and establish the nature of volcanic gases which contributed to the atmosphere (21).

Rocks from the polar units are expected to represent a series of sedimentary strata. Currently, there is no evidence that endogenetic processes have led to different subsurface material at the poles; rather, the rocks from the polar regions are expected to be important in recording past atmosphere-surface interactions and may be important to biological studies (18).

The basic geologic units have been modified in several ways by important crustal or surface processes to produce canyons, channels, chaotic terrains, fretted terrains, hummocky terrains, etc. Some of these modifications may enhance sample selection because the associated erosion and deposition may have brought otherwise inaccessible sample materials within the reach of a sampling device. Major areas of sedimentation may provide the best chance of detecting evidence for past life. Any Martian site visited will contain a selection of wind-blown and impact-derived debris, which increase the probability of sampling distant as well as

local materials. Sampling near recent impact craters enhances the probability of obtaining material from the local subsurface in the form of small rock fragments (6,17).

At all landing sites samples of atmospheric gases and soil volatiles should provide evidence for atmosphere/surface interactions, extent of planetary degassing, and degree of retention of primordial gases.

On the basis of these concepts, several sites may be identified as candidates for sampling. From a practical point of view, we should (1) identify more candidate sites than we expect to visit, (2) make the best interpretation of their geology based on existing data, (3) identify gaps where extended Viking imagery can improve interpretation, (4) define precursor information that could be useful in improving the interpretation, and (5) wait as long as operational planning requirements will allow before selecting the final landing sites in order to be sure that all pertinent data has been evaluated.

A few potential landing sites are characterized in Table 2. The extension and elaboration of this table is an important immediate goal for a team of experts, including both the Viking photo team and sample-oriented investigators. The use of extended Viking imagery requirements to support sample return mission planning makes this an urgent task.

    b. Nature of Sample

Any mission designed for sample analysis is expected to be able to collect enough samples of soil, rocks and atmosphere to adequately characterize each sampling site (6). The nature of an adequate sample has been well-established through extensive experience with terrestrial sampling procedures, from the results of carefully planned sampling of Apollo

Table 2. Some Potential Sample Collecting Sites.

Site Description	Prime Mission Objectives[1]	Secondary Mission Objectives[2]
Flank of young volcanic con-struct, near boundary of cratered plains.	Geochemistry, petrology, age of young volcanism; weathering processes; aeolian transport; atmospheric studies.	Geochemistry, petrology, age of volcanic plains; impact crater on plains unit.
Bottom of Coprates Canyon; near contact of cratered plains, and ancient cratered terrain, at landslide or talus slope.	Geochemistry, petrology, age of old plains volcanism; geochemistry, petrology, age of ancient cratered terrain. Depositional processes on canyon floor; weathering; history of volatiles, water, atmospheric studies.	Mechanisms of canyon formation landslide mechanics; dune material; relict knobs.
Volcanic plains filling major uplands basin, near mountains.	Geochemistry, petrology, age of volcanics filling basin, depositional processes and products in intermontane basins, atmospheric studies.	Petrology, geochemistry of ancient cratered uplands; age of basin forma-tion; meteorite impact features.
Ancient cratered highlands; near base of ancient impact crater cut by gullies.	Geochemistry, petrology, age of crustal materials; erosional and depositional processes; presence of water; atmospheric studies.	
Ancient river delta.	Paleo-life.	History of sedimentary processes.

[1]All prime objectives can be met by samples collected within 5 km of landing site.
[2]All secondary objectives certainly can be accomplished within 25 km of landing site.

landing sites, and from the very detailed planning of allocations of the Russian Luna samples along with knowledge of their shortcomings. The nature of an adequate sample for Mars can be developed from our limited knowledge of the Martian surface characteristics provided by the Mariner and Viking Missions. In areas that contain various-sized particles of transported clastic debris such as characterizes most of the Earth's surface, all of the Moon's surface and apparently most of Mar's surface, there is a need for many types of analyses on many types of samples. For each sample-collection site soils from the surface and several subsurface levels must be analyzed for size, shape, petrology, major elements, trace elements, radiation effects, isotopes, surface features, fossils, and organic compounds. Furthermore, these analyses should be carried out on more than one size fraction of each soil. In particular the 4 to 10 mm size fraction provides fragments large enough for several types of analyses, and allows characterization of the source materials and alterations of the materials. Statistical studies of this fraction have proven very effective and require hundreds of fragments. Rock fragments larger than a centimeter allow analyses for several petrologic characteristics, major elements, trace elements, isotopes, radiation effects, and remanent magnetism. Tens of rocks of this type are necessary for adequate interpretation of each site. The principal samples and their recommended means of collection are as follows.

Soil Samples

Viking has provided evidence that the Martian soil is complex and probably consists of rock fragments; mineral fragments broken from the rocks; weathering products of the primary materials, including oxidized, hydrated and possibly carbonated minerals; and possibly evaporite minerals from local solution and redeposition (18). The primary erosive agents are wind, meteorite-impact, and possibly water. The action of the wind may winnow dust from some areas, leaving primarily coarser debris that has been moved around by impact or water, and may deposit mostly fine material elsewhere. Photographic and meteorological evidence indicates that surficial movement of dust is currently very active, compared to the rates of the other soil-transport processes.

The requirements for sampling the possible range of soil types seems to be (1) ability to sample both surface and subsurface materials, and (2) ability to document surface features partly to support interpretations of erosional vs. depositional features and partly to select the samples more intelligently.

Two extremes for surface conditions can be defined: (1) A site where active aeolian deposition of fine soil has occurred recently. In this case, simple scoop samples are likely to be sufficient. (2) A site where deflation has left a paved soil. In this case, surface pavement and subsurface material may be collected by a scoop/trencher tool. At present the uncertainty concerning distribution of windblown dust makes it impossible to argue strongly that short core samples (100 cm) will be essential to define a stratigraphic record extending past recent dust storms. Cored samples, however, may be important in locating favorable environments for the preservation of biological materials, and may be able to drill into permafrost horizons.

Rock Samples

The definition of a rock has been extended by the lunar program to include individual fragments larger than 4 mm. Individual igneous rocks as small as 4 mm diameter have been studied successfully by a wide variety of techniques including petrology, chemistry and age analyses. Thus, a sieving mechanism to sort fragments larger than 4 mm from the soil is the simplest rock sampling tool (6). Rocks in the size range up to several centimeters can be collected with the soil sampler. Rocks larger than 3-4 centimeters begin to exceed the optimum size for geochemical/petrological studies; if the total sample return is very limited, the return will be optimized if a great variety of smaller rocks is returned. Although larger rocks of many varieties are abundant at the Viking landing sites, it is quite likely that smaller fragments of the same rocks abound in the soil despite the fact that Viking appears to have been unable to obtain samples that were not soil clods (18). A crusher to discriminate against soil clods may be desirable. The capability of chipping a large rock is considered highly desirable for the adequate collection of rock samples.

The above considerations suggest that a sampling device similar to that of Viking, but upgraded to provide coring and chipping capability, is optimum for collection of soils and rocks. This sampling device, associated with the Viking-type imaging system, allows

(1) Location, limited description and documentation of shape and orientation of samples to be collected.

(2) Collection of surface and subsurface soils; i.e., trenching.

(3) Sieving of >4 mm "rocks" from soil.

(4) Chipping and collection of chips from larger rocks.

(5) Collection of a short core.

(6) Loading into appropriate sample canisters.

(7) Documentation of post-sampling configuration.

(8) Aid in verifying collection of sample.

In addition, an imaging system must be used for establishing the general geological context of the landing site. Surface imagery contributes to our understanding of the morphological features, such as erosional channels, wind-blown deposits, stratigraphy, etc.; all of these data are essential in the interpretation of the origins of the variety of samples that are to be analyzed.

Atmosphere Sample

Analyses of the Martian atmosphere should have a relatively high priority in approaches to many of the basic planetary questions about Mars. Although informative data on Mars atmospheric composition have already been obtained by the Viking mission, a number of important parameters have not yet been precisely measured, and several of these cannot be measured by Viking instrumentation to the required precision (18). In situ analyses have already approximately determined the proportions of the major atmospheric constituents, and more precise measurements of this kind may reveal important trends in these constituents such as seasonal variations due to thermal buffering effects of the Martian polar caps. Alternatively, returned samples of Martian atmosphere should also be considered in that isotopic compositions can be measured to a precision of parts per thousand or less in present laboratory instruments (16,17).

There are three basic ways to collect and return a sample of the Martian atmosphere. The third technique is the most complex but offers the greatest scientific return.

(1) An atmosphere sample returned in the free volume of the sample return container would be the simplest method, but would yield the smallest atmospheric sample.

(2) An ambient atmosphere sample returned in a separate, sealed container would yield a somewhat larger sample, but still would permit only a limited number of analyses. Serious consideration must be given also to contamination of the gas sample by container leaks and exchange reactions. Table 3 indicates the contamination levels ($\sim$0.1% for N, O, Ne, and Xe) which would occur in a one liter atmosphere sample allowed to leak for 10 days in the Earth's atmosphere. Highly reliable vacuum seals are required and the returned atmospheric sample container should be placed in a noncontaminating environment as soon as possible. Effects of the Mars atmospheric sample leaking into space during the long space flight are generally less serious. However, some common metals also contain H and C which could exchange with the atmosphere sample and alter its chemical and isotopic composition.

(3) An atmospheric sample could also be concentrated in some manner to greatly increase its mass per unit volume. Many gases, including H_2O, CO_2, Ar, Kr, Xe are readily adsorbed at cryogenic temperatures on charcoal, zeolites, etc. Hydrogen may be reversibly adsorbed into several metals. Several chemically active gases (H_2O, CO_2, SO_2, etc.) undergo chemical reaction with or are adsorbed by a variety of materials. An ion pumping technique could concentrate many species into a previously

Table 3. Mars atmospheric compositions and potential contamination effects.

Gas	Mars atmosphere composition according to Viking I		Earth atmosphere contamination (cm^3STP) for 10^{-9} cm^3STP/sec, leak rate for 10 days
	Proportion	cm^3STP/liter volume	
CO_2	95%	7.3	---
N_2	2-3%	.15-.23	$7x10^{-4}$
Ar	1-2%	.07-.15	$9x10^{-6}$
O_2	0.1-0.4%	.007-.03	$2x10^{-4}$
Ne	<10 ppm	$<8x10^{-5}$	$2x10^{-8}$
Xe	$\sim$0.02 ppm	$\sim1x10^{-7}$	$8x10^{-11}$

Mean pressure = 7.65 mbar

degassed metal substrate. The greatest difficulty with these methods would be prevention of isotopic fractionation and exchange reactions between the atmospheric gases and the materials used in their concentration. An alternative technique could be physical pumping of Mars atmosphere into a closed volume, i.e., compression. If the pressure inside an atmosphere container could be increased to that of the Earth's atmosphere (about 1 bar) the amount of gas returned could be increased two orders of magnitude. Compression also offers the advantage that the chemistry and relative proportions of gaseous species would not be seriously altered nor contaminated by introduced materials, nor would the effects of container leaks be as serious.

The above considerations suggest that a sampling device similar to that of Viking, but upgraded to provide coring and chipping capability in addition to an atmospheric sampler, would provide a basic capability for collecting essential Martian samples. The given sample masses would apply to samples being returned to Earth. The numbers and dimensions of samples, however, are necessary to characterize any sampling site and would apply for any type of mission. For an immobile leader with short-range sampling mobility, we would recommend the following types of samples:

a. Selection of 1 to 3 cm rocks, either raked or individually scooped from surface or chipped from larger rocks; minimum of 30 rocks or a total mass of 400 grams.

b. Two bulk soils of 50 to 100 grams from subsurface (preferably from below 20 cm), one for biology and one for geosciences.

c. Sieved fraction of 4 to 10 mm fragments from subsurface soils, minimum of 100 grams (300 to 600 fragments).

d. Core sample one meter in length and 2 cm diameter for a total mass of 500 grams of soil.

e. Several surface and subsurface soil samples of 10 to 25 grams each from various locations around lander.

f. Atmospheric sample -- compression may be required to increase sample mass.

An associated Viking-type imaging system would allow location, limited description, and documentation of shape and orientation of samples to be collected. Furthermore, it would allow documentation of post-sampling configuration and aid in verifying collection of samples.

In addition, an imaging system would be useful for establishing the general geological context of the landing site. Surface imagery contributes to our understanding of the morphological features, such as erosional channels, wind-blown deposits, stratigraphy, etc., all of which are essential in the interpretation of the origins of the variety of samples that are to be analyzed.

c. Mobility

The least amount of mobility for sampling is offered by a lander that simply scoops a sample at the base of the vehicle and places the sample either in a container for return to Earth or in an analytical instrument on board the spacecraft. Further degrees of mobility can be classified into three ranges:

(1) Short range mobility of a few meters to tens of meters in the vicinity of the lander to aid in selecting the proper samples from the local materials. This capability might consist of an arm that could extend up to a few meters from the vehicle and provide for scooping, raking, chipping, trenching, and coring. Alternatively, this might be accomplished by means of a tethered sampling unit that could extend for a few tens of meters and accomplish the same tasks.

(2) Intermediate range mobility of a few tens of meters to a

few kilometers to circumvent uncertainties in either the ability to land at a specific target or the resolution of the imagery. This capability might be achieved by either a mobile lander or a deployable vehicle that conducts sampling activities and returns samples to the lander.

(3) Long range mobility of up to hundreds, or less likely, thousands of kilometers to reach several predetermined but widely separated targets or to search for targets of opportunity. This capability might be achieved by a highly mobile lander or an elaborate deployable vehicle.

A lander with short range mobility could provide a general sample from a major geologic unit. Natural surface-transport processes involving wind, water, and cratering are expected to provide a variety of fragments at most locations as is the case on the Earth and Moon. The fragments should represent several rock types in the local geologic unit and would quite likely include rocks from other units (16,17).

A lander with intermediate range mobility, on first thought, could be landed near a specific target such as the boundary between two units with the potential of sampling both units. On second thought, however, the definition of a major boundary between units cannot be sharply determined geologically to within 1 or 2 km, the resolution of the imagery is, at best, a few hundred meters, and the landing trajectory cannot predict the landing site to within several kilometers. Thus, the possibility of landing within 10 km of the boundary is unlikely and the use of intermediate mobility for the purpose of sampling specific targets seems impractical. Nevertheless, natural surface-transport processes should provide a greater variety of fragments near the boundaries of such targets than would be present farther out in the middle of a unit. Intermediate mobility would allow the opportunity to search for samples of

optimum benefit within an area below the resolution of present imagery. It would also allow circumvention of local unresolved impediments to sampling such as extended outcrops or dunes.

A lander with long range mobility potentially could sample several major units. Considering that a lander with short to intermediate mobility near the boundary of two units should collect numerous samples from both units, long range mobility seems most appropriate for sampling a minimum of three units requiring traverses of at least several tens of kilometers. The search for interesting targets of opportunity is not easy to plan or discuss. The location of such targets and the significance of the data resulting from their investigation runs the usual risks of a game of chance.

Short and intermediate range mobilities are probably adaptable to either sample return or analytical lander types of missions. Relative aspects of cost, technological development, and scientific return should be considered for each case. Long range mobility would probably require on-board analytical capability and must be evaluated against multiple landings in terms of cost, technological development, and scientific return.

3. Sequence of Missions

The concept of a phased sequence of missions of increasing complexity is proper from an engineering point of view; however, in assessing the interrelation of scientific data sets obtainable from different classes of missions, no firm requirements can presently be established for the sequence of missions. The major points in question are:

a. Should further orbital analyses be carried out before a sample return mission? For some types of orbital data such as magnetic and

gravity fields and interaction of solar particles and fields within the upper atmosphere, the orbital data and sample return data are acquired largely independent of each other, and one data set is not a prerequisite for obtaining the other. On the other hand, orbital data such as multi-spectral imaging and reflectance spectroscopy bears directly on data obtained through returned sample analyses, and the question must be addressed. It appears that the inherent resolution of the geochemical mapping of Mars is rather poor compared to the scale of complexity of the planet and is hampered by the wide distribution of wind-blown surface dust. Thus, further orbital geochemical mapping may not provide significant new data on which to base landing site selection for sample return. Orbital geochemical mapping will be useful to extend sample data beyond the immediate region sampled, and to obtain an overview of the major surface units. However, such geochemical mapping may precede or follow the sample return mission, or comprise a part of it. For optimization of the sample return mission, imagery of better resolution than that obtained by Viking is required for the immediate vicinity of the sites sampled, in order to correctly understand the geological context of the samples. Until there exists a better definition of the requirements of a sample return mission and of the capabilities of future imagery and geochemical mapping, it is not possible to fully assess the necessity for a prior orbital mission.

b. Are there interrelations between geophysical measurements and the sample return missions? Although it is possible that a sample return site would be selected on the basis of geophysical data (a gravity anomaly, or a seismically active region), such selection is not a first-order

criterion. Prime sites for sample return will be based on imagery, both for geological content and for mission safety. The geophysical measurements provide a generally decoupled set and could be made prior to, concurrent with, or after a sample return mission. The same can generally be said for meteorological measurements, with the exception that moisture analyses may constitute an important criterion for site selection in the search for life.

c. Are further in situ analyses of surface materials a necessary precursor to sample return? It has not been shown that a preselection of samples for return to Earth, based on in situ analysis, can be carried out effectively at the present stage of Martian exploration. Any single analytical technique (e.g., rock chemistry) may not be able to distinguish between rocks of rather different origin (impactite vs. basalt; deep seated vs.extrusive basalt),and the practical combination of several analytical techniques on the same sample has not been demonstrated. Microscopic capabilities would be essential to a combined analytical device; however, sample preparation for adequate microscopic resolution has not been demonstrated. A surface rover with onboard analysis capabilities could undoubtedly be designed which would have the capability of seeking out special geological or biological environments. However, the above problems associated with precise analytical capabilities apply equally well to rovers. As already discussed, a roving vehicle could collect samples for a return mission, and an optimum sample return mission probably will have limited mobility. Roving laboratories probably are necessary tools for the long term in planetary exploration for some planets where sample return is not feasible. However, for Mars,

where both types of missions are feasible; the best combination of sample return and rover mission may be to use the sample return mission as a means of sharpening the "eyes" of a subsequent roving laboratory to extract maximum information from the surface experiments.

V. SAMPLE ANALYSIS: AT MARS OR IN TERRESTRIAL LABORATORIES?

A major issue to be resolved in planning the further scientific exploration of Mars concerns which types of sample analyses should be performed at Mars and which must be performed on a returned sample in terrestrial laboratories. The controversies concern tradeoffs between the capabilities of multiple hard landers, multiple soft landers, mobile surface laboratories, and sample return missions. Multiple soft landers (e.g., Viking) and mobile surface laboratories are alternate means of conducting many of the same experiments. The basic question is whether the data obtainable from additional post-Viking experiments that could be performed on the Martian surface justifies complex surface analysis missions if returned samples are planned. This question is particularly germane if funding for Mars exploration is so limited that only a sample return or an additional surface analysis mission, but not both, could be carried out in the foreseeable future. The next section addresses this point.

The rationale for analyses at Mars includes: (i) it has been demonstrated by Viking that certain types of analyses can be adequately performed at Mars; technological advances should make additional types of analyses possible; (ii) the possibility exists that certain features of the samples may disappear or be compromised by sample collection and return; (iii) analysis at Mars presents no danger of back contamination of the Earth. When analysis at Mars is coupled with mobility on the Martian surface this list is augmented by (iv) it may be possible to sample a large number of separated locales in a cost-effective manner, and (v) it may be possible to find and sample unique environments (e.g., life sustaining environments) by imaging, sampling, feeding back information, and moving closer.

The rationale for returning samples for analysis in terrestrial laboratories includes (i) the variety of techniques which can be used for sample preparation prior to analysis is immensely increased; (ii) maximum flexibility exists for the design of new experiments or modification of sample preparation on receipt of ambiguous results; (iii) the instrumentation and analyses are not constrained by factors extraneous to obtaining the best scientific results; consequently, the inherent quality of analysis is higher; (iv) it is almost inconceivable that certain types of analyses can be performed remotely; a sample return permits utilization of the full range of analyses and of yet undiscovered means of analysis. Since mobility can be envisioned for a sample return mission as well as for analyses at the Martian surface, item (iv) above can also be applied here. Item (v) above requires imaging and some sampling and analysis capability with mobility. However, it could be argued that selection of the proper parameter(s) to use for homing in on the goal is unlikely without extensive characterization of the Martian surface materials. Such characterization might best come via examination of a returned sample prior to the search for unique environments.

The issues involved in further sample analysis at Mars versus returned sample analysis are elaborated below.

1. Sample Preparation

Analytical instruments can produce accurate and meaningful data only when samples have been adequately prepared for analysis. Many years of work have been devoted to the development of proper techniques for preparation of samples in order to avoid contamination, to enhance sensitivity, and generally to overcome ambiguous results. For most analyses, the preparation of samples is rather complex and delicate, perhaps more so than the analyses themselves. A few examples of preparation procedures are outlined to illustrate the nature of the problem.

To perform standard combined mineralogic and textural descriptions with a polarizing petrographic microscope employing both transmitted and reflected light optics, a polished thin section must be prepared (20). These sections consist of thin slices of rock (or soil grains mounted in epoxy) that are ground to a 30-micrometer thickness, highly polished on at least one surface, and mounted on a transparent glass slide.

To perform major-element analyses of individual minerals by normal electron microprobe procedures, one must commence with a polished thin section as discussed above and then deposit a thin conducting coating, usually of carbon, over the polished surface.

To perform any type of meaningful chemical or isotopic analysis, one must first select the proper type of sample depending on what is to be studied; i.e., fresh unaltered material, weathered material, alteration products, etc. (20).

To perform X-ray fluorescence analyses of major elements that are precise enough to be meaningful, the samples must be crushed, fused with a proper flux, and placed in a mount such that the surface of the sample is smooth and flat.

To perform isotopic analyses for determination of crystallization ages of rocks, the preferred method requires separation of individual minerals or other phases from a given rock. The first step, therefore, is to utilize polished thin sections and the petrographic microscope to eliminate altered or weathered samples, to determine which phases to separate, and to determine the grain size of appropriate phases. After crushing to the appropriate grain size, the phases are separated by any of a number of techniques including magnetics, hand-picking, and heavy liquids. This is an iterative procedure requiring repeated evaluation by the analyst. The separated phases are then ready for chemical processing to separate the chemical fractions needed for isotopic analysis. Following the chemical separations, the sample is ready for

isotopic analysis. Even for isotopic analyses of whole rocks, one must first select the least altered and weathered samples. Then after crushing, the altered and weathered fragments must be removed and, following that, chemical processing still must precede the isotopic analysis.

To perform scanning electron microscopy, the preparation can range from simply mounting a sample and coating it with gold, carbon, or some other conductive material to making a polished thin section, then ion-etching the surface to produce micrometer-scale relief, and finally depositing a conducting coating.

From the above examples, it is clear that the preparation of samples for analysis in general requires rather elaborate equipment and sequencing and often requires evaluation and interaction by the analyst. Without such preparation, the precision and accuracy of an analysis, as well as its interpretation, is often at best ambiguous and at worst meaningless.

It is clear that those analyses best suited for remote performance at Mars are those requiring the least sample preparation. Thus, analysis of the Martian atmosphere was one of the most successful Viking experiments (18). Some sample preparation was used for some of the atmospheric analyses. However, even for these experiments, the isotopic composition of trace constituents could have been obtained with greater certainty if greater flexibility in sample preparation had been possible so that interferences could have been eliminated and the trace constituents more highly concentrated. Minimum sample preparation was possible for the inorganic analysis of Viking soil so that not only was the analysis of much lower intrinsic accuracy than that obtainable in the laboratory but an additional ambiguity exists in simply knowing what was analyzed (18). Although it could be argued that extensive research and development could result in improved sample preparation for a Mars lander, the tradeoffs between development of automated techniques for a

lander and utilization of the present standard laboratory techniques on a sample return must be carefully evaluated. Some types of sample preparations, such as those described above for determination of the crystallization ages of rocks, will be impossible to automate.

2. Variety of Analyses

A century of geologic and meteoritic investigations and nearly a decade of lunar investigations have clearly demonstrated that the most successful endeavors are characterized by a variety of analyses (20). This same period also has demonstrated that the converse is true; that is, individual analyses taken by themselves commonly yield erroneous or ambiguous interpretations. To illustrate the meaning of these statements, we can consider the simple illustration of the study of a rock from the surface.

Let us assume that orbital imagery of the surface has shown the presence of morphologic features characteristic of basaltic volcanic flows. If the major elements in a chemical analysis of a rock from this part of the surface display a typical basaltic composition, have we really learned anything more about the planet than was gained from the imagery? The answer to this would appear to be "very little". What then, are the major problems that we must consider to glean useful planetary information from this apparently basaltic rock? First, we must consider whether this rock represents the composition of a melt that formed at some depth within the planet. In other words, can near-surface chemical fractionation or contamination be ruled out, and, if not, what is the nature of the contamination or fractionation? Second, if we are confident that the composition of the rock allows determination of the original melt at

depth, then we must relate this composition to the internal composition of the planet. In other words, does this composition represent a total melt or a partial melt from an internal unit of the planet? Third, if we are confident of the melting and compositional relations then we must determine the associated temperature and depth conditions at which the melt originated. Fourth, we must now associate the composition, temperature, and depth relationships with the age of the rock to determine the time of planetary evolution at which these conditions existed.

It is possible, therefore, to gain significant information about the chemical, thermal, and physical evolution of a planet from this rock. To do so, however, requires evaluation of the several problems mentioned above. The data required to solve these problems comes from a combination of mineralogy, texture, major element chemistry of the minerals, major element chemistry of the whole rock, trace element chemistry of the whole rock, isotopic analysis of the whole rock, isotopic analyses of individual minerals, experimental work at high temperatures and pressures, seismic results, heat flow measurements and orbital imagery (16, 17). To evaluate these problems the necessary data would normally be obtained from petrographic microscopy, electron microprobe analysis, more than one type of mass spectrometry, X-ray fluorescence, neutron activation analysis, high temperature-high pressure furnaces, seismometers, temperature-conductivity measurements, and orbital imaging systems.

If only one set of data, such as the major element chemical composition, were utilized without being combined with data on mineralogy, texture and trace elements it might not be possible to recognize effects of near-surface fractionation or contamination. In such a case, one could easily

arrive at erroneous conclusions about the internal composition of the planet.

Although the problems were listed above in four steps, this listing is not meant to imply that there must be a rigid sequence of analyses and interpretations. All of the data are interrelated and many will bear on problems other than the origin of basalt. The need for data from many analytical techniques is mandatory if the basic questions of planetary science are to be solved. This multiplicity of analytical systems must be evaluated carefully for any future exploration plans if meaningful data are to be produced (17).

3. Analytical Instrumentation

It seems rather clear that analytical instruments which are constrained only by scientific considerations can be made superior to those which must also meet the power and weight constraints for remote operation on a distant planet. The key issue appears to be whether the latter can be made good enough to return satisfactory information. The prospects that technological developments can yield a variety of miniaturized, automated instruments which perform analytical functions at an acceptable level are brighter than the prospects of automating sample preparation which often requires analyst interaction. Indeed, considerable progress has already been made and such miniaturized analysers will be invaluable for obtaining some information from planetary objects for which sample return is not feasible. However, in considering the strategy for the scientific exploration of Mars, the tradeoffs between development of miniaturized instruments and use of standard laboratory instruments must be carefully evaluated for each type of data required. As an example,

consider the search for microfossils by scanning electron microscopy. If appropriate samples were available, a scientist at any one of several laboratories could do a preliminary examination by optical microscopy (which might in itself yield the answer), concentrate phases to be studied depending on the preliminary examination, and then do a systematic search essentially assured of a definitive answer for that sample. On the other hand, an automated SEM on Mars (if it could be successfully developed) would not have the benefit of proper sample preparation and would be searching for the proverbial "needle in a haystack." This same instrument probably could yield very useful results concerning the morphology and composition of soil particles of nonbiogenic origin, however. General rules for remote instrumentation are thus difficult to formulate and defend. However, the number of important problems which are routinely approachable by standard laboratory techniques, but which are difficult or impossible to do remotely, makes returned sample plus laboratory analysis an attractive option for Mars.

To illustrate the disparity between results obtainable in the laboratory and those obtained with remotely operated instruments, one need only compare laboratory analyses of lunar samples to the Viking results. Table 4 compares inorganic chemical analyses by X-ray fluorescence spectrometry of two lunar soils, 10084 and 12070 (23), to that of two Martian soils, S1 and U1 (18). It should be recognized that the Martian analyses, particularly that of U1, are preliminary. Nevertheless, it is clear that data obtainable with a commercially available laboratory instrument in 1970 are superior both in quality and in number of elements measured to those obtained from Mars in 1976. This is not to belittle the technical achievements represented by the Viking instrument. In fact, much of the advantage enjoyed by the laboratory instrument can be traced back to proper sample preparation as mentioned earlier.

Table 4. Inorganic Chemical Analysis of Lunar and
Martian Soils by X-ray Fluorescence Spectrometry

Major Elements (%)	Lunar[a] soil 10084	Lunar[b] soil 12070	Martian[c] soil S1	Martian[c] soil U1
SiO_2	41.79	45.83	44.7±5.3	42.8
TiO_2	7.55	2.81	0.8±0.3	1.0
Al_2O_3	13.44	12.48	5.7±1.7	---
FeO	15.91	16.81	---	---
Fe_2O_3	---	---	18.2±2.9	20.3
MnO	0.21	0.23	---	---
MgO	7.66	10.18	8.3+4.2	---
CaO	12.14	10.45	5.6+1.1	5.0
Na_2O	0.43	0.43	---	---
K_2O	0.14	0.27	0.1±0.1	0.0
P_2O_5	0.13	0.31		
S	0.14	0.12		
SO_3	---	---	7.7+1.3	6.5
Cr_2O_3	0.27	0.30	---	---
Cl	---	---	0.7±0.3	0.6
Total	99.81	100.22	91.8	---

Trace Elements (ppm)				
Ba	134	350	---	---
Rb	2.96	6.33	≤ 30	≤ 30
Sr	164.8	143.3	60+30	100+40
Th	2.5	6.6	---	---
U	---	1.6	---	---
Zr	318	512	≤ 30	30+20
Nb	18	30	---	---
Y	9.9	111	70+30	50+30
La	21	29	---	---
Ce	58	62	---	---
Pr	10	---	---	---
Nd	33	---	---	---
V	36	91	---	---
Cr	1850	2080	---	---
Co	34	45	---	---
Ni	230	186	---	---
Cu	33	6	---	---
Zn	37	6	---	---
Ga	4	2.5	---	---

[a]Compston, W.; et al.: Proceedings of the Apollo 11 Lunar Science Conference, Vol. 2, 1970, pp. 1007-1027. Reference 23.

[b]Compston, W.; et al.: Proceedings of the 2nd Lunar Science Conference, Vol. 2, 1971, pp. 1471-1485. Reference 23.

[c]Baird et al.: Science 194, 1976, pp. 1288-1293. Reference 18.
Clark et al.: Science 194, 1976, pp. 1283-1288. Reference 18.

Table 4 also illustrates a more fundamental problem of remote analysis; i.e., the inability to resolve a soil mixture into end-member components. The Apollo 11 and 12 landing sites, like those of Vikings 1 and 2, were selected because they were "safe." Comparison of the major element data for the soils from the two Apollo sites would lead to the conclusion that the sites were similar, with the possible exception of TiO_2 contents. However, in reality, quite a different spectrum of rock compositions contribute to the soil at the two sites. The isolation and characterization of the components present in the soil at these two sites led to a number of far-reaching conclusions about the Moon. The volcanic rocks (mare basalts) primarily contributing to the soil were found to be of distinctly different types at each site and produced at different times in the Moon's evolutionary history. They recorded the details of processes that occurred at several stages in the evolution of the lunar mantle. Many anorthositic fragments were found in the Apollo 11 soil, leading to the hypothesis (later confirmed by orbital data) that the lunar crust was predominantly feldspathic in composition. Glasses of basaltic composition, but greatly enriched in trace elements, were abundant in the Apollo 12 soil. The hypothesis that they represented a basaltic rock type (called KREEP) was later confirmed. The Sr-isotopic composition of some soil fragments was found to be extremely primitive, and together with Rb-Sr model ages of $\sim 4.6 \times 10^9$ years for soils and rocks, showed the Moon to have undergone early chemical differentiation. Laboratory characterization of samples returned from two "safe" lunar landing sites already yielded great insight into the geological evolution of the Moon as a planet. In contrast, the remote inorganic analysis of Mars has led some to believe that the Martian surface is everywhere nearly the same (which might also be concluded about the Moon from the data in Table 4) and has left the inorganic analysis investigators with the zero-th order problem of identifying the components in the Martian soil.

Other Viking analyses also provide examples of how mission constraints on instrumentation and sample preparation limit the quality of analyses. By extending the capability of the gas chromatograph-mass spectrometer (GC-MS) on Viking to its limit, it has been possible to measure Kr and Xe in the Martian atmosphere (18). The $^{129}Xe/^{132}Xe$ ratio has been found to be significantly greater than that in the terrestrial atmosphere (2.5 +2/-1 on Mars compared to 0.98 on Earth). Other isotopic ratios are not reported, but ^{128}Xe and ^{130}Xe appear to be absent from the published spectrum, whereas ^{126}Xe and ^{124}Xe appear to be overabundant (18). One cubic centimeter of Martian air contains an amount of Xe comparable to that used to <u>calibrate</u> laboratory mass spectrometers used to measure the isotopic composition of Xe in meteorites and lunar samples to a precision of better than $\pm 1/2\%$. The difference between analysis of Xe in the laboratory and on Mars evidently stems from the need to operate the Viking mass spectrometer dynamically; i.e., with the vacuum pump connected and gas admitted via a molecular leak. This is presumably dictated by the requirement of analyzing chemically reactive gas species and the desire to minimize vacuum valves which require power and may fail. Laboratory analyses, on the other hand, can be made with the instrument "tuned" for maximum performance for each element and with the mass spectrometer isolated from the vacuum system for "static" analysis. This increases analytical sensitivity tremendously. Furthermore, interferences are removed by chemical and cryogenic preseparation of the element to be analyzed.

One of the more astounding findings about Mars has been the discovery of an enhanced $^{15}N/^{14}N$ ratio by both the upper atmosphere mass spectrometer and the gas chromatograph-mass spectrometer (18). The $^{15}N/^{14}N$ ratio had to be derived by stripping the CO contribution from the measured signals at masses 28 and 29 (N_2). At least in the case of the upper atmosphere mass spectrometer, the

corrections were >50% (18). Although in this case, the stripping could be done with reasonable certainty, more direct means are available to the laboratory analyst. The CO could either be quantitatively removed prior to the analysis or the N_2 peak could be mass-resolved. The latter could be achieved with an instrument of mass resolution of $M/\Delta M = 2500$. The mass resolution of the Viking upper atmosphere mass spectrometer is $M/\Delta M = 50$; that of the GC-MS is $M/\Delta M = 200$. Both instruments are operating close to theoretical limitation in this respect, a testimonial to the excellence of Viking technology. Because theoretical mass resolution is directly proportional to physical size, the only feasible way to obtain an order-of-magnitude increase in resolution is to increase the size of the instrument by an order of magnitude; i.e., back to that of a laboratory instrument. It is clear that the precision of measurement of $^{15}N/^{14}N$ could be much greater for a sample analyzed in a terrestrial laboratory than was possible on Mars.

Because of the large nitrogen isotopic effect, its scientific interpretation does not critically depend on the precision of measurements, and the foregoing discussion was meant partly to illustrate the direct relationship that can exist between instrument size and analytical capability. Isotopes of other light elements such as H, C, O, and S naturally fractionate as a result of chemical reactions (e.g., mineral equilibrium in a cooling newly formed rock) or phase changes (e.g., formation of water ice from vapor). On Earth, these isotopic variations seldom exceed a few percent (except in some biological systems), and important conclusions can be drawn from isotopic differences as small as 0.1% or less. Thus, nearly all the expected variations in the isotopic compositions of these elements in Martian surface materials is considerably less than the stated precision of Viking isotopic measurements of C, N, and O in the Martian atmosphere. Although it is conceivable that instrumentation could be developed for 0.1% isotopic measurements at Mars, it is probable that the significance of such measurements would always be clouded by interferences due to inadequate sample preparation.

In summary, although it appears possible to construct excellent, sophisticated instruments for remote operation on distant planets, the quality and quantity of data which they can deliver will always be severely constrained by considerations extraneous to the scientific objectives. The data obtained by remote analysis can never adequately substitute for that obtained on returned samples when sample return is possible.

4. Sampling Mobility

Mobility required on the Martian surface to achieve scientific objectives is a consideration for both sample return missions and for analyses at Mars. Mobility requirements for sample return have been discussed in more detail in Chapter IV. If long-range mobility ($\sim$100 km) is feasible, it could provide a cost-effective means of sampling several separated locales and/or geologic units irrespective of the means of sample analysis.

One unique feature of long-range surface mobility coupled with an extensively instrumented lander is the apparent possibility of searching out special environments. It is true that such a detailed search might be carried out with a landed laboratory, capable of selecting samples for biological analysis, for example, on the basis of some characteristic of the Martian soil (e.g., carbon content) or a favorable climatic environment. The presence of the oxidized, reactive Martian surface provides a major limitation to such a search; it is probable that biologically active samples only can be located below the layer of surficial dust and outside the highly irradiated surface layer (18). The thickness of the surficial layer and its typical residence time is unknown, so design of an appropriate drilling device cannot be well specified. Moreover, such a search would be predicated on the assumption that the proper scientific and analytical questions were being asked. For example, current "favorable" climatic conditions may

be irrelevant to finding where life might have existed in the past. This is a question second in scientific and philosophical importance only to the question of whether life exists today and appears to have a higher probability for a positive result. It is at least debatable whether the search for special environments utilizing real-time analytical feedback is realistic. It may be as effective to identify favorable target areas from orbit and sample them either directly or with a lander and intermediate mobility (~10 km), possibly with sample return.

Although not directly pertinent to the mode of sample analysis, it is worth considering whether long range surface mobility plus imaging should be considered as an end in itself. It has been suggested that this aspect of a mission would have immense attraction to the lay public. Although public opinion is a valid consideration in any endeavor utilizing public funds, this argument interjects nonscientific considerations which are difficult to evaluate. Whether the above suggestion concerning public reaction is valid is a matter of conjecture. It is relatively more certain that the public will inquire as to why a planet is visited after an initial visit. Photographs which are repetitive of those obtained with Viking, even if from "over the next hill" are unlikely to appear as strong justification. It is safe to assume that the public and its representatives have a strong aversion to large public expenditures which yield results which are ambiguous or contain no new information. It thus seems axiomatic that strong scientific rationale is the best public rationale. The science rationale can and should contain items of intrinsic interest to the public. If there is a realistic chance for a significant discovery "over the next hill," it is good science and good public relations to look there; if not, it is neither.

5. Logistics of Sampling and Analysis

Adequate characterization of any one site requires extensive sampling and analyses. Chapter IV, Section 2b contained a discussion on the nature of an adequate sample to properly characterize each sampling site. From that discussion it is clear that each site requires several types of analyses on each of several samples including several bulk soils, various size fractions of soil, and several tens of rocks. If the required variety of samples is to be collected and analyzed on the Martian surface, the Viking experience would suggest that the length of stay-time required at each sampling site would be on the order of months. It is assumed that the vehicle would remain at one site throughout this period because (a) many of the experiments might be too sensitive to carry out on a moving vehicle, (b) the available power and/or telemetry may be less than required for both analysis and mobility, and (c) resampling of certain materials may be necessary to overcome such problems as loss of sample or data, unusual or ambiguous results, or modification of experimental conditions. In order to evaluate such fundamental parameters as length of time required at a given site, overall power requirements, distance that can be traversed on the Martian surface, and telemetry requirements, there must be a thorough consideration of the various types of samples to be collected and the various types of analyses to be performed. These considerations must include (a) imagery requirements to develop an adequate sampling plan, (b) sequencing of sample collection, sieving, selection of specific fragments, and other preparation procedures, (c) power requirements for sample collection, sample preparation, analysis, spacecraft housekeeping and mobility, (d) the bit rates required for adequate telemetry of all of the above activities,

and (e) additional time and power that must be reserved for verification or modification of experiments that yield unusual or ambiguous results. Only with such data in hand can a valid comparison of cost and efficiency be made between capabilities to be developed for the Martian surface and those that we have already developed for the Earth and Moon.

6. Sample Degradation, Contamination, and Back Contamination

The surface materials of Mars have been shown to be chemically reactive, and it is suspected by some that the reactivity is maintained by the continued irradiation of the material or steady-state reaction with the atmosphere (18). Arguments have been made that these reactions would disappear if the samples were removed from their Martian surface environment for analysis on Earth. However, it appears likely that any first-order reactions could either be stimulated by reintroducing the samples into simulated Mars ambient conditions or reconstructing the original compounds by appropriate simulation experiments. Reproduction of the behavior of Martian soil observed in Viking analyses has been successful in terrestrial laboratory simulations, which demonstrates that unique properties of the Martian surface probably can be satisfactorily reproduced in the laboratory.

A potentially more extensive sample degradation could be caused if a returned sample were sterilized; however, much valuable scientific information could be expected to survive sterilization (6). Sterilization, sample contamination, and back contamination of the terrestrial biosphere are major issues which must be addressed in planning sample return. They are considered more fully in Chapter VII. Many of the issues involved are primarily technical ones which can be addressed from the backlog of experience already accumulated in handling special materials (lunar samples, special biological materials, radioactive materials).

The foregoing analysis suggests that the case for further in situ analysis at Mars is at best debatable. This is especially true in light of the immense capability and significance of data obtained on returned samples in laboratories on Earth.

VI. INTEGRITY AND PRESERVATION OF MARS SAMPLE

Once collected, the samples will be handled in a series of steps. The following section outlines principal areas of concern regarding the mechanisms of collection, containment, curation, and distribution that will protect the samples and make the best possible combinations of samples available for scientific study.

Independent of the nature and complexity of a Mars sample return mission, certain basic precautions are required to protect the sample's scientific value (3,6). Additional optional precautions, while not a requisite, would contribute greatly to the sample's scientific value and would rate high on a list of possibilities to be included in a sample return mission. Several of the optional precautions are closely tied to a complex mission involving multiple sampling. An outline of the more important sample precautions is given below. Similar discussions may be found in References 6, 10, and 15.

1. Protection against chemical contamination

a. Degassing of fuel and other volatiles from the landed spacecraft should be minimized or done in such a way as to avoid contamination of the surrounding soil with organic compounds.

b. The containment vessel and collection scoop should be constructed of materials which meet structural requirements yet do not readily abrade or contaminate the sample.

c. Containment vessel liners, retainers, pressure seals, and other devices in contact with the sample for long periods should meet even stricter contamination controls. The use of many sensitive elements

and compounds must be avoided and strict concentration limits for many additional elements should be set (6).

d. Precleaning and presterilization of Mars sample collection and containment devices should leave a minimum residue.

e. Isotope-exchange reactions should be minimized by avoiding certain materials and by avoiding elevated temperatures. Elements like H, C, O, Si, S, and N in Mars samples and atmosphere contain scientific information in their isotopic composition, which may be compromised by isotopic exchange reactions with the sample container (6).

2. Separate packaging and sealing of samples

a. In complex mission modes where samples of different types or locales are collected, the samples should be separately packaged and/or sealed. Among the possibilities are

(1) Separately sealed solid sample and atmosphere sample.

(2) Separately sealed solid samples for physical sciences and life sciences. Each sample could then have defined its own set of contamination and environmental requirements.

(3) Separately sealed fines and rock samples. Fines may contain large quantities of water, carbonates, or sulfates, which could react chemically with rock surfaces at relatively low temperatures.

(4) Separately packaged and labeled samples collected at different locales to retain and identify potentially different types of materials. This technique might consist of thin, flexible metal foil bags which separately contain different samples, but which are all packed into a single containment vessel.

b. Problems associated with collecting, breaking and storing a core sample. Among the possible problems are

(1) Loss of the stratigraphy within the core.

(2) Loss of sample during withdrawal of the core from the regolith.

(3) Loss of sample during separation of core into sections.

(4) Options if a large rock is encountered during coring operation.

3. Pressure seals and containment

a. The sealing mechanism of the containment vessels must be highly reliable even under possible dusty conditions and probably should have a minimum leak rate of 10^{-10} cm^3 STP/sec of any gas under a 1-atmosphere pressure differential. (See Chapter IV - atmosphere sample for further discussion.) A seal protector may have to be used during sample loading.

b. Of the four types of common vacuum seals -- crimping, heat seals with low melting metals--containment seals with soft gaskets (elastomers), and knife edge metal gasket (Au, Al, etc.) seals -- it is possible that only the latter will meet all requirements of leak rates, reliability, and contamination.

c. In case of an appreciable rise in temperature, considerable pressure may develop in the containment vessel. Some type of pressure monitoring or release mechanism may have to be included. For example, preliminary data from Viking indicate that, at 350° C, from 0.1% to 1% of a sample weight may be released as water vapor (18). For a 1-kilogram sample with a 1-liter free volume, this could produce 12 atmospheres

or 180 lb/in^2.

d. A mechanism for controlled withdrawal of gases from the returned sample containers must be provided.

4. Temperature control and monitoring during return

a. Strict control of the maximum temperature experienced by the sample should be maintained. If possible, the sample should remain at Mars ambient temperature. Elevated temperatures could have a variety of adverse effects, including failure of the vacuum seal, dehydration and degassing of volatile-rich materials, and increased rates of chemical reaction and isotopic exchange between sample and released gases or container materials. Precautions must be taken to prevent elevated temperatures around the container during lift-off and passage through the Martian atmosphere and upon return to Earth (7).

b. A reasonable upper temperature limit is probably the ambient soil temperature at time of sample collection, or at most, the maximum ambient temperature likely to have been experienced by the sample.

c. From a physical science point of view, much lower temperatures are preferable and there may be no strict lower limit (6).

d. Some mechanism of recording the temperature of the sample during return should be available. Mechanisms to alter spacecraft orientation and other devices (thermal radiators, etc.) to accomplish cooling should be included.

5. To minimize sample abrasion, some type of sample "keeper" should be included.

6. · Protection against excessive magnetic fields: The Earth's field would be the maximum allowable and any additional fields should be shielded

to protect any remnant magnetism the sample may possess.

7. Protection from and monitoring of radiation environment

a. Passive dosimeters to record the cumulative radiation environment during sample return are desired.

b. Shielding against low-energy solar flares is desirable. The maximum shielding required would be that naturally provided the sample by the Mars atmosphere (about 20 g/cm^2).

VII. QUARANTINE AND CURATION OF RETURNED SAMPLES

1. Quarantine and Life Detection

Since any material returned from Mars might contain Martian biological systems toxic to the terrestrial biosphere, there must be a quarantine program for the samples and spacecraft (5,15,24,25). The constraints placed on a sample return mission by the quarantine and life detection requirements are not trivial in design or cost, and they must be carefully evaluated in defining mission concepts. Major issues and approaches that must be considered in the mission plans are identified below. (For this document, the problem of protection of Mars from contamination is not considered, although Viking-like control mechanisms would be required to protect Mars.)

Inorganic chemical contamination of the Earth should not be an issue; nor should possible inorganic toxicity of Martian material. The Martian surface is an evolved planetary surface consisting of rocks and their degradation, oxidation, and hydration products (17,18). Dispersal of such material in the terrestrial environment should be no more dangerous than the deposition of fresh volcanic ash or the fall of a meteorite. It is possible that inorganic chemical compounds in the samples, especially highly soluble compounds, might be toxic to test samples when administered in relatively large quantities. This is of no concern because inorganic materials are easily contained.

The major problem of back contamination is the possibility of contaminating the Earth with a viable Martian micro-organism (5). At the same time, the study of such micro-organisms would be of paramount importance in understanding the origin, evolution, and distribution of

life. Thus, on one hand, the sample with the fewest Martian micro-organisms may be the safest to return, whereas the scientific interest would be greatest for a sample that returned the most viable micro-organisms. Viking results suggest that viable organisms are absent or at best present at very low levels at the two Viking landing sites; however, life forms may exist elsewhere and it must be taken as an operational constraint that any Martian sample will contain viable micro-organisms (18). Therefore, a quarantine protocol will be required (5).

A fundamental conflict occurs between life detection and quarantine in the case of sample sterilization (5,6). Although there is undoubtedly some set of conditions (for example, heating until all molecular bonds are broken) that will deactivate any Martian micro-organism, such sterilization also destroys the potential to study viable life forms. In addition, much of the value of a Martian sample for geosciences would be destroyed by sterilization (6). The hardiness of the unknown Martian micro-organisms is unknown and thus the degree of sterilization required is undetermined. The only completely dependable sterilization procedure based on chemical principles would be heating of the sample to unacceptably high temperatures. It appears that sterilization is not an alternative if the full scientific objectives of a sample return mission are to be achieved (6). Therefore, the principle on which quarantine must be based is containment; micro-organisms must not be introduced to the terrestrial biosphere (10,13,15,24).

When the sample has been subjected to a preliminary examination, it may prove possible to sterilize subsamples in such a manner that living organisms are destroyed while scientific value is preserved. For example, igneous rocks will suffer minimum damage when subjected to dry heat, whereas the same material might react strongly if heated in a closed

system along with hydrous phases such as clay minerals (6). Radiation sterilization may also be effective. If our basic assumption that the Martian samples will contain viable micro-organisms is correct, undoubtedly it will be necessary to learn how to kill those micro-organisms so that appropriate sterilization can be performed on all samples released from the containment facility. The design of appropriate facilities, procedures, and verification tests should be investigated.

The nature of the containment problem is illustrated by the following equation (26) which approximately describes the probability (P) that the Earth may become contaminated with a viable organism:

$P \simeq P_1 P_g [P_c P_s1 P_d + P_c1 P_s2 P_r] \leq E$, where E is some very small number

P_1 = Probability of a Martian organism existing at the landing site

P_g = Probability that the organism could survive in the terrestrial environment

P_c = Probability of contaminating the return equipment

P_s1 = Probability that the organisms can survive the return trip

P_d = Probability of organism escaping into terrestrial environment

P_c1 = Probability of collecting a sample with viable organisms

P_s2 = Probability that organisms can survive once returned to Earth

P_r = Probability of accidental release of the organism

Of the parameters above, only P_c, P_d and P_r are controllable by engineering; the others are parameters that must be determined by experiment or estimated from defendable models. For purposes of preliminary engineering design, these other parameters must all be assumed = 1. In that case, the above inequality requires $P_c \cdot P_d + P_c \cdot P_r < E$, which can be assured if each term in the sum is made $< E/2$.

The two portions of the equation within the brackets refer to the contamination external to the sample container and the portions internal to the sample container. The external contamination problem must be reduced primarily by engineering a series of barriers that insures that the device that enters the Earth's biosphere is not contaminated on its outer surface (7,11,13,15,26). The internal contamination problem must be solved by means of demonstrated containment capability and a testing protocol that reduces the probability of not detecting a viable life form before sample release to a very low level. The samples must be contained until P has been shown to be sufficiently small. The size of the permissible probability is crucial to an evaluation of the proposed mission but is certainly no larger than 10^{-6}.

It is possible to visualize the implications of the containment requirements for several types of sample return missions that have been proposed: (i) direct return from the Martian surface to the Earth's surface, (ii) return from Mars, by means of rendezvous and sample transfer in Mars orbit, then direct return to the Earth, or (iii) direct return from Mars to Earth orbit, then capture and examination with quarantine in an orbital laboratory, and (iv) return by means of Mars orbit rendezvous and capture by an Earth orbital laboratory (7-9).

The problem of providing containment is most severe for a direct return mission. This derives from three separate problems: (i) stripping, isolating, or sterilizing bioshields to leave the returning spacecraft free of external contamination is difficult to accomplish in a manner which excludes transfer of potential Mars organisms; (ii) the probability of accidental rupture or loss of the capsule on reentry is

fairly high; and (iii) the containment system (including the terrestrial facility) must be utilized for testing to show that the returned materials are harmless (12-15).

The Mars orbital rendezvous concept may increase the potential to minimize (i), because a physical transfer from one vehicle that has been exposed to Mars to another that has remained sterile provides a reduction of contamination approximately in proportion to the ratio of the surface area of the transferred canister to that of the contaminated Mars ascent vehicle (7). That ratio is rather small. The orbital rendezvous mission does not affect (ii) or (iii).

Testing of samples for biological activity on Mars or on the return voyage from Mars can reduce the probability that samples will be released to the biosphere before adequate testing is performed (5). The definition of Mars surface or spacecraft experiments and the reduction of probability of back contamination based on the results from those experiments requires study. However, the most conservative assumption, and the most exciting scientifically, is that the samples would be shown to contain viable organisms.

Capturing the returning vehicle in an Earth-orbiting space station can alter the probabilities in all three areas significantly. It provides the possibility to effect multiple transfers and sterilizations, it reduces the risk of accidental impact on the Earth, and it provides for the conduct of significant tests before samples are returned to the Earth . (unsterilized materials conceivably might never be brought to Earth, if viable micro-organisms were discovered). The availability of an orbiting laboratory may reduce the need for a containment facility on Earth, but that is not certain. It appears that the biological laboratory capability

being developed for the Shuttle Program could perhaps perform the same order of magnitude of quarantine testing as was done in the Lunar Receiving Laboratory.

The engineering feasibility of any of these alternate approaches has not been studied in detail. Until the acceptable probability of contamination, P, is defined, any of the four mission types must be considered viable candidates, because all can provide several orders of magnitude reduction of the probability of contamination.

If viable organisms exist, some concerns have been raised that they may die on the return trip. Maintaining micro-organisms at low temperatures (freezing) is conducive to the preservation of many terrestrial species, including some higher species, and dehydration reduces the risk of radiation damage. Temperatures are already low in the Martian ambient environment, and preservation of samples at those temperatures throughout the return mission is given high priority (15). This may interfere with proposed biological testing on the return trip, unless separate samples are collected for that purpose. At first inspection, it appears that the risk of damage to Martian organisms is small, compared to the difficulty of keeping organisms in a viable state throughout the return flight; however, this is a question that must be studied further.

The amount of sample required for quarantine testing in the lunar program was excessive in comparison to the amount that will be returned by planned Mars missions. In Apollo 11, 700 grams of material went to quarantine testing; this can be compared to a nominal Mars sample weight of 2-5 kgs. Procedures to characterize the Martian samples for biological purposes using less than 20 percent of the returned material

should be developed. Use of tissue cultures instead of injecting animals or plants as was done in the lunar program can greatly reduce sample requirements.

Any staffed terrestrial or orbital quarantine facility will have to provide absolute protection of the humans from the Martian material (1,5,8). The sample probably should be studied and stored in an atmosphere like that on Mars. The glove-box enclosures of the Lunar Receiving Laboratory allowed some accidental exposure of personnel to lunar material. If it appears unlikely that such a glove box system could be made sufficiently risk-free, an automated system should be considered (12). Because the sample size and configuration of the return canister will be fixed and limited in dimensions, an automated system for Martian sample return would possibly be small physically. Designs of possible facilities have been undertaken by the exobiology group at Ames (12).

The lunar sample quarantine procedures were directed by an Inter-agency Committee on Back Contamination, which consisted of representatives of the Departments of Agriculture and Interior, the Public Health Service and NASA (25). Since that time, governmental bodies with potential interest and authority to regulate introduction of biological materials to the United States have increased (e.g., the Environmental Protection Agency; National Institute of Health). Recent experiences in containment problems associated with recombinant DNA must be taken into account during the handling of Martian samples. A study should be initiated to determine the membership of an updated ICBC and begin to establish the framework for making quarantine decisions, as they directly affect mission design.

2. Quarantine and Curatorial Operations

Containment of the Mars samples from escape into the terrestrial biosphere or to where humans could be exposed is an essential requirement of quarantine (5,24,25). Protection of the samples from contamination or degradation through exposure to the Earth's atmospheric gases or airborne dust is also a prime requirement for chemical, physical, and biological research. The two requirements were never met simultaneously in the Lunar Receiving Laboratory during the Apollo missions, but solutions are essential for the Mars sample return mission.

Sample processing operations in the lunar program have been conducted in vacuum chambers and in nitrogen-filled cabinets penetrated by gloves to allow personnel to manipulate objects in the cabinets. These systems cannot totally prevent contamination in the event of rupture or leakage through the gloves. For early lunar missions, when biological containment was the overriding concern, enclosures were operated at negative pressure, so that any leakage would be inward and contamination from the samples would be contained (25). Following the end of quarantine, positively pressurized systems have been used, so that the leakage would be outward and outside contamination prevented from reaching the samples.

· For most early Martian sample studies, it appears necessary to maintain the samples under atmospheric conditions similar to those at the Martian surface (see Chapter III). It appears that to meet the proper requirements for atmospheric conditions, containment, and contamination control, a sealed system will be necessary, in which samples are manipulated by remote means (12). This approach, although technically feasible, requires careful study to preclude the possibility of contaminating

samples by the internal mechanisms that are required for sample manipulation (motors, screws, lubricants, etc.). Some basic requirements for the system will be

a. Ability to interface with the return canister. The canister will be sterile or its exterior will be contained. Any containment will have to be removed and the canister opened within the containment system. This interface must also include capability of sampling gases within the sample canister.

b. Ability to store subsamples without fear of cross-contamination. This requires the provision of internally sealable cubicles within the containment system.

c. Ability to move and manipulate samples within the system. This includes removal from and insertion into containers, movement between sections or cubicles, lifting, rotating, etc.

d. Ability to split samples. This includes capability of splitting, chipping, and sieving under ambient conditions.

e. Ability to weigh samples.

f. Ability to photograph and study samples under binocular microscopes.

g. Sterilization capability. In the initial stages of the lunar program, an attempt was made to interface rather sophisticated analytical equipment into the containment system. For many types of physical/chemical measurements, it is more reasonable to sterilize small amounts of materials that may then be removed from the containment system for analysis. However, this will not be feasible for all types of measurements and is dependent upon the method of sterilization (6). It is also necessary to sterilize any nonsample materials that must be removed from the containment system, including all exhausted gases (25).

· h. Interface with normal atmospheric chambers. For biological testing, most work probably will be done at ambient terrestrial conditions. Transfer mechanisms will be required (5,12).

i. Experimental chambers. Some experiments, especially biological, must be carried out behind the containment barrier. Special facilities will be required (5).

j. Packaging and sealing will be required for any samples transferred from the system.

k. If quarantine restrictions can be lifted, greater flexibility for sample handling and preparation will be possible; however, development of systems for handling materials behind containment barriers may be useful in defining better contamination control design.

If the sample sizes, containment, etc., are well defined prior to design of the facility, many of the design criteria can be more precisely stated. For example, the design of the system for handling a 5-kg sample may be quite different from that for a 100-kg sample.

3. Sample Curation and Study

The objective of the sample return mission is to make materials available for scientific study. Mechanisms for review of proposals, support of investigations, and allocations of samples similar to those used in the lunar program should be implemented. The creation and training of curatorial staff and the development of curatorial/quarantine facilities should be based on lunar experience. Significant lead times for this development are essential, especially with respect to providing guarantees against back contamination (5,24).

As with lunar samples, there will be a need to preserve some of the Martian material for study by future generations of scientists. This

. need should be recognized at the outset of design of any Martian sample curatorial facility. The design should include the capability of preserving some portion of returned Mars samples in a safe and contamination-free environment over long periods of time.

VIII. RECOMMENDATIONS

The Mars sample return mission should be adopted by NASA as a high-priority scientific expedition for the decade of the 1980's. Visibility should be given to the program, so that a team of scientists and engineers from NASA, universities, and private industry can begin to concentrate on the difficult development problems. The sample return mission supplies a valuable and unique data set in the scientific study of Mars. Sample return could be treated separately, independent of the decision as to when it should be flown. However, it is better to consider the data to be obtained from sample return in the context of data which must be obtained by other types of missions, so that an overall strategy of exploration can be formulated.

Even with a substantial lead time, it is clear that many items with long development times must be worked out well in advance of the mission launch date. Perhaps the most crucial is the sample quarantine system. A JPL study has identified crucial considerations for this area (15) which should be implemented as soon as possible, as funding permits. There is a clear possibility of useful interaction between technological advances required for the Mars quarantine system and current interest in protective systems for research.

Listed below are some specific areas of importance which require research and development efforts that can be initiated now.

1. Develop and analyze mission options for science content

A variety of mission options should be studied, including direct return or Mars orbital rendezvous transfer as the Mars to Earth options, and direct entry or capture in Earth orbit as the Earth return options.

Each of these differs in complexity, risks, and capability in terms of landed weight, ease of back contamination control, etc. The best option will maximize the probability of successfully accomplishing mission science requirements within the budget for the mission. This will involve tradeoffs between engineering, science, and quarantine constraints.

2. Develop systems for increased landing accuracy and landing safety

The accuracy with which a chosen landing site can be reached and the ability to avoid hazards on landing will govern the site selection strategy and the mobility requirements for the lander. Some of the more interesting scientific sites are apparently dangerous for present landing techniques. Improved accuracy and hazard avoidance will significantly increase the number of potential landing sites that can be selected. However, even samples returned from "safe" sites are apt to contain a wealth of scientific information.

3. Continue reduction and analysis of Viking and Mariner data to enhance landing site selection

The thorough evaluation of orbital imagery obtained by Mariner and Viking is necessary to provide the best basis for selecting landing sites and establishing the framework for interpretation of sample data.

4. Extend capability of surface sampling system

Concepts should be developed for a more versatile sampling system such as a modified Viking sample arm or a tethered sampling device. The desired capabilities include a rock chipper, a short core drilling device which could be used as a soil or rock borer, a trenching tool, a raking or sieving device. A rock chipper would have been highly useful on Viking; a rock crusher is not as important for sample return but is desirable for

in situ analysis and for discrimination of soil clods. The extended flexibility of sampling will be important for sample return as well as future planetary landers.

5. Develop mobility options

Mobility options range from tethered short-range rovers that are directed by the lander to totally autonomous long-range systems. The sampling and analysis capability of the various concepts should be investigated. It is extremely unlikely that either autonomous or joint lander-rover sample preparation and analysis systems (e.g., complete rover laboratory vs. rover capable of picking up large rocks, with sample preparation or analysis on lander) can produce the same range and quality of data obtainable from a returned sample.

6. Evaluate development of proper analytical capabilities

Sample analyses that lack proper selection and preparation of material, that have not been studied by a variety of analytical techniques, and that do not achieve the necessary sensitivity and precision are known to provide misinterpretations and/or ambiguous results. It is questionable, therefore, whether certain analyses should be carried out on the Martian surface if the prospect of a sample return is accepted. It is imperative that a very thorough and extensive evaluation be conducted of the cost, time, energy, and effort required to provide the proper selection, preparation, variety of analyses, sensitivity, and precision for remotely controlled analytical capabilities on Mars. These capabilities should then be compared with those that already exist in terrestrial laboratories.

7. Develop sample sealing, containment and monitoring systems

The sealing of sample containers on the surface of Mars and the preservation and verification of the required sample environments during

sample return require development of new technology. Sample canisters must be designed which can be sealed remotely to an acceptable gas leak rate. Canisters must be maintained at acceptable pressure and temperature (possibly Mars ambient). Pressure, temperature, radiation environment, and other parameters must be monitored during return. Different canister concepts to protect different types of samples (fines, core, rocks, atmosphere, etc.) need to be evaluated.

8. Develop receiving laboratory containment system and quarantine protocols

The concept, definition, and verification of the entire contamination and quarantine system requires early work. The potential requirement to maintain systems at Mars ambient conditions is a major difference with respect to previous technology for biological or radioactive material containment.

9. Continue support of state-of-the-art laboratory analytical capability

The amount of Martian material returned will be small compared to that returned from the Moon, and will be more complex. Under these conditions, high-sensitivity experiments on small subsamples will be required. Developments supported by the lunar program have revolutionized surface analysis and high-precision mass spectrometry techniques, among others, which are now being applied in many areas of science and technology. Similar developments and wide application of new techniques is a major objective of a supporting research program for MSSR.

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1. Report No. NASA TM 58213	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CONSIDERATION OF SAMPLE RETURN AND THE EXPLORATION STRATEGY FOR MARS		5. Report Date March 1979
		6. Performing Organization Code JSC-14864
7. Author(s) Donald D. Bogard, Michael B. Duke, Everett K. Gibson, John W. Minear, Larry E. Nyquist, and William C. Phinney		8. Performing Organization Report No.
		10. Work Unit No. 383-85-00-00-72
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

    This report sets forth the necessary data sets for characterizing Mars. If
further analyses of surface samples are to be made, the best available method is
for the analysis of the Martian samples to be conducted in terrestrial laboratories.
    The Lunar and Planetary Sciences Division at the Lyndon B. Johnson Space Center
has examined the scientific rationale and requirements for a Mars surface sample
return and has incorporated the experience gained from the analysis and study of the
returned lunar samples into the science requirements and engineering design for the
Mars sample return mission.

17. Key Words (Suggested by Author(s)) Mars sample Mars surface Planetary sample chemistry Sample return Planet morphology	18. Distribution Statement STAR Subject Category: 91 (Lunar and Planetary Exploration)

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 91	22. Price* $5.00