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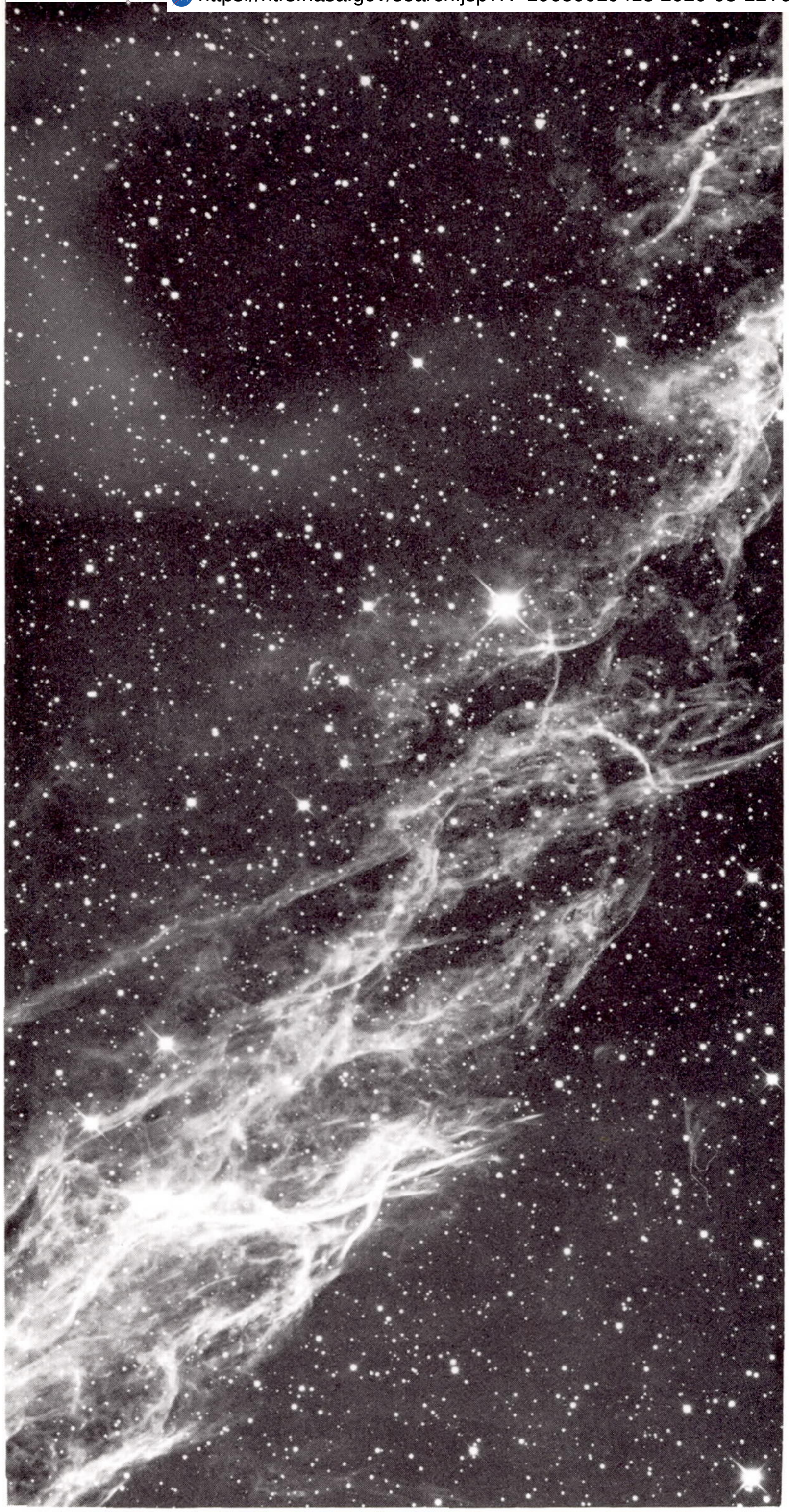

Report No. P-23

A PRELIMINARY EVALUATION OF THE APPLICABILITY OF SURFACE SAMPLING TO MARS EXPLORATION

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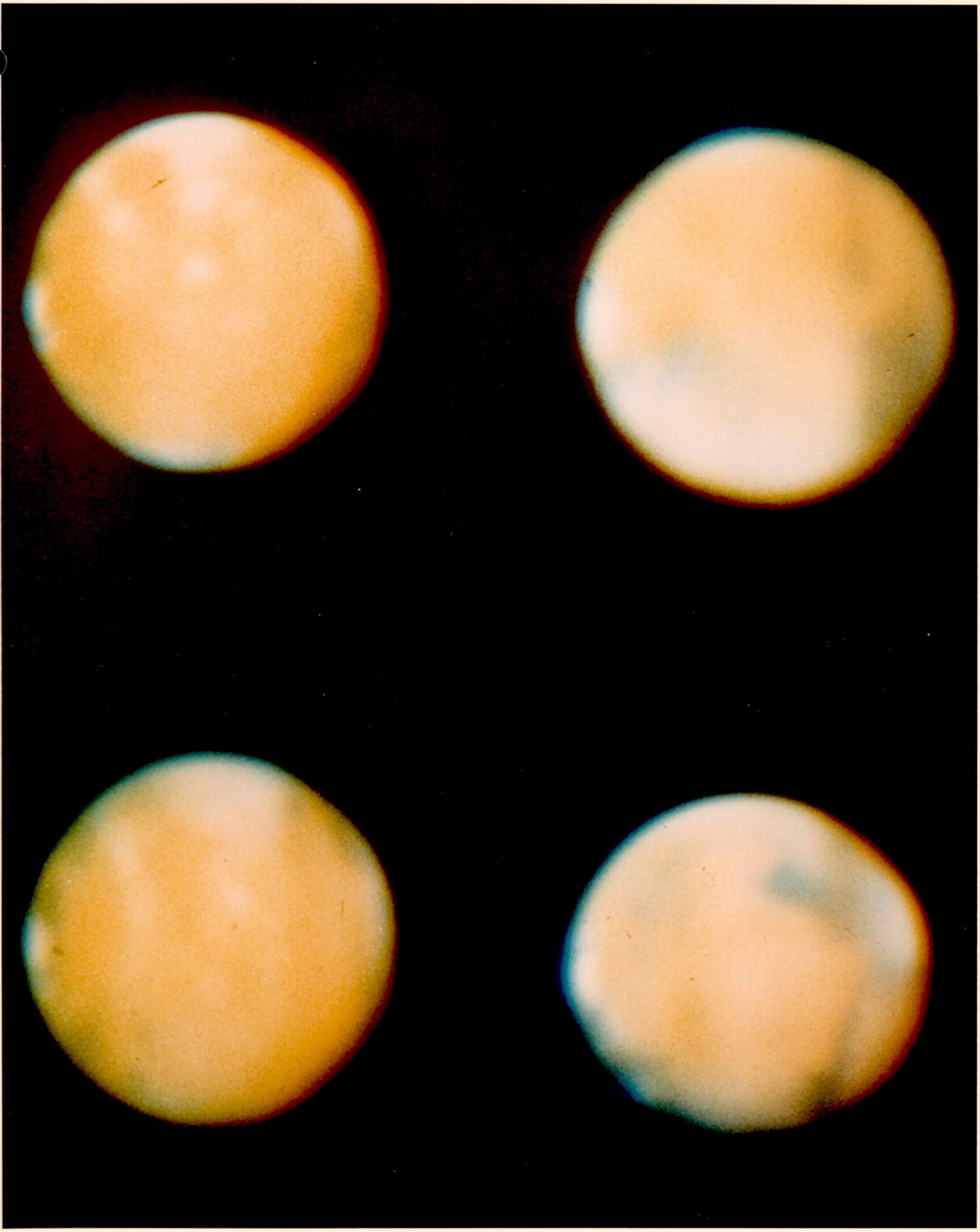
Chicago, Illinois 60616

FRONTISPIECE

Photographs of Mars were taken with the Lunar and Planetary Laboratory, 61 in. telescope at the University of Arizona. The time of year on Mars is midsummer in the northern hemisphere. Each successive photograph shows the planet after it had rotated approximately 90 degrees; thus, the entire surface of Mars is shown in the sequence. The number of clouds visible at the limbs of the planet and across the disk are characteristics of an aphelic opposition.



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A PRELIMINARY EVALUATION OF THE APPLICABILITY OF SURFACE SAMPLING TO MARS EXPLORATION

by

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Physics Research Division

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ABSTRACT

This report presents a preliminary evaluation of the applicability of surface sampling to the total exploration of Mars. The primary purposes were to identify the value of sampling as an investigation technique, to define the constraints imposed upon sampling by the objectives, and to assess the value of samples from a single landing site.

The overall conclusions of this report are the following:

(1) Sampling, in general, is a valuable investigating technique for obtaining information for the accomplishment of certain exploration objectives;
(2) The disciplines most dependent on sampling as an exploration technique are geology and biology;
(3) Samples at a single site on the Martian surface apply to the majority of objectives, but only to a very limited extent;
(4) Samples at a single site will provide much more information with regard to characterizing the general nature of the Martian surface than in determining specific properties of Mars.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the following persons for their contributions to this study: Mr. Clint Stone and Dr. Alan Binder of IIT Research Institute, Dr. Martin Molloy of NASA Headquarters and Dr. John T. Dockery who initiated the ideas in Appendix 2.

Report No. P-23

A PRELIMINARY EVALUATION OF THE APPLICABILITY OF SURFACE SAMPLING TO MARS EXPLORATION

SUMMARY

This report presents a preliminary evaluation of the applicability of surface sampling to the total exploration of Mars. The primary purposes were to identify the value of sampling as an investigation technique, to define the constraints imposed upon sampling by the objectives, and to assess the value of samples from a single landing site. Sampling, as used in this study, is defined as the process of obtaining samples of the Martian surface or near-surface rocks or rock materials at several surface sites. A sample is considered as one or more specimens of material taken at a single surface site on the Martian surface. The present state of the art of surface sampling as applied to planetary bodies is rather primitive, especially when considering unmanned automated systems. Consequently, we have not attempted to determine whether or not the samples should be returned to Earth for analysis.

There is, at present, a lack of knowledge of even the general crustal nature of Mars. A fairly extensive literature search for surface models of Mars was made during the initial phase of this study. Many of the models were based on spectroscopic and visual telescopic observations, while others were based solely on Earth considerations (i.e., mineral types and their abundances). The surface models were used in conjunction

with the Martian exploration objectives stated by the Space Science Board, as the basis for the overall scientific objectives for Mars. These objectives were considered in five categories: Record of Life, Physical Constitution, Active Processes, Chemical Composition, and History of Events in Martian Rocks. The objectives were each broken down into "attributes" which identify the properties of the planet and which must be measured in order to satisfy the objectives. A total of 110 attributes were developed. The measurement techniques which could be applied to each of the attributes were identified and included surface sampling, remote sensing, photographic mapping, topographic mapping, surface geophysical sensing, atmospheric sampling, and surface geological mapping. The usefulness of sampling was then evaluated in view of all the applicable techniques for all of the objectives and attributes.

The four major conclusions of this report are the following:

(1) Sampling, in general, is a valuable investigating technique for obtaining information for the accomplishment of certain exploration objectives;
(2) The disciplines most dependent on sampling as an exploration technique are geology and biology;
(3) Samples at a single site on the Martian surface apply to the majority of objectives, but only to a very limited extent;
(4) Samples at a single site will provide much more information with regard to characterizing the general nature of the Martian surface than in determining specific properties of Mars.

In order for sampling to be of maximum value when used as an exploration technique, sampling must be carried out in such a manner as to provide samples adequate, both in number and type, for understanding the overall nature of Mars. However, due to the remoteness of the planet and the inherent problems in obtaining proper samples, especially with unmanned automated systems, it will be difficult to investigate certain problems by samples alone. For example, in the investigation of structural features, such as folds and faults, by sampling, it is essential that samples be obtained at certain locations with respect to the feature under investigation and the the orientation of key samples be known to within a few degrees. Other investigating techniques, both orbital and surface, are in some cases much more applicable to investigating certain properties of the surface and subsurface than is sampling. This can come about as a result of either the difficulty of obtaining certain types of samples or because other techniques may be much more expedient for obtaining the desired information.

The average values of surface sampling for the accomplishment of the exploration objectives are shown in the summary table which follows. These values were taken as averages from the values presented in Table 9. All the objectives, regardless of whether or not sampling is applicable, are represented in the summary table.

Summary Table

AVERAGE VALUES OF SAMPLING/SINGLE SAMPLE TO OBJECTIVES

Objective Categories	Objectives	Average Value of Sampling	Average Value of Single Sample
Record of Life	Evidence of extinct life	High	Very low
	Presence of living matter	High-Medium	Very low
	Prebiotic matter	High	Very low
Physical Constitution	Physical properties of planet	Very low	Very low-No value
	Geophysical properties of planet	Very low	No value
	Atmospheric properties of planet	No value	No value
	Structural properties-land forms	Medium	No value
	Physical properties of rocks	High	Very low
	Structural properties of rocks	High-Medium	Very low
	Geophysical properties of materials	Medium	Very low
Active Processes	Abiological activity	High	Very low
	Seismic activity	Very low	Very low-No value
	Erosion, deposition & transportation	Medium	Very low
	Processes responsible for land forms	High-Medium	Very low-No value
	Nuclear processes	Low	Very low-No value
Chemical Compositions	Chemical composition of materials	High	Very low
	Chemical composition of atmosphere	No value	No value
	Composition of surficial fluids	High	Very low
	Macromolecular distribution	High	Very low
	Cosmic or other foreign material	Medium	Very low
	Surficial water distribution	High	Very low
History of Events Recorded in Martian Rocks	Age of Martian materials	High	Very low-No value
	Stratigraphic sequence of rocks	High	Very low-No value
	Relationship of structural features	High-Medium	Very low-No value
	Remnant magnetism	High	Low
Overall Value of Sampling		Medium	Very low

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF TABLES

LIST OF FIGURES

Report No. P-23

A PRELIMINARY EVALUATION OF THE APPLICABILITY OF SURFACE SAMPLING TO MARS EXPLORATION

1. INTRODUCTION

A wide range of investigation techniques will be utilized in the scientific exploration of the solar system. The technique which will probably place the most extensive demands on spacecraft subsystems and their advanced technological development is sampling. Almost equally demanding, however, will be the subsequent analysis of sampled material be it *in situ*, in a space laboratory, or back in an Earth laboratory. The purpose of this study is (1) to define the scientific value of surface and subsurface sampling as a technique in the exploration of the planet Mars, (2) to define the constraints that the scientific objectives impose on sampling and sampling missions, and (3) to assess the comparative value of a single surface sample in accomplishing the scientific objectives of exploration.

Sampling, as used in this study, is defined as the process of obtaining samples of the Martian surface or near-surface rocks or rock materials at several surface sites. A sample is considered as one or more specimens of material taken at a single surface site on the Martian surface.

One of the key problems in planning for the exploration of any planetary body is to assess the relative value of the various investigative techniques which can possibly be utilized during an exploration program. Seven different types of techniques which are applicable to planetary exploration have been considered in this study. They are: surface material sampling, remote sensing, photographic mapping, topographic mapping, surface geophysical sensing, atmospheric sampling, and surface geological mapping. It seems rather obvious that since no single exploration technique is adequate for the total exploration of a planet, that a combination of techniques will be essential. However, since this study is primarily concerned with the value of surface sampling to the total exploration of Mars, only sampling is treated here in any depth. The other techniques are discussed only to the extent required to show their relative applicability to the objectives.

The present state of the art of surface sampling as applied to planetary bodies is rather primitive, especially when considering unmanned automated systems. Consequently, we have not attempted to determine whether the samples should be returned to Earth for analysis or not. For the purpose of this study, it is assumed that analytical techniques will be available for extracting the required information from the samples.

The major problem in the study has been the lack of knowledge of even the general crustal nature of Mars. A fairly extensive literature search for surface models of Mars was made during the initial phase of this study. Many of the models were based on spectroscopic and visual telescopic observations, while others were based solely on Earth considerations (i.e., mineral types and their abundances). Various investigators have treated the problem of possible surface conditions of Mars. Those hypothesized surface conditions which were considered pertinent to this study are presented in Section 2.

An evaluation of surface material sampling as an exploration technique was undertaken by considering the Mars exploration objectives, the objective related attributes*, the techniques required to measure the attributes, and the value of sampling to individual attributes. This information is presented in Section 3. The next phase was to define the constraints imposed by the objectives upon sampling. These constraints are presented in Section 4. The final phase of work of this study is presented in Section 5 and deals primarily with the evaluation of sampling (as a technique) and of a sample from a single site in the investigation of Mars.

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*Attributes are properties of the planet which can be measured. The data obtained on the attributes are then related, by theory, hypothesis, or extrapolation, to the scientific objectives.

2. GENERAL DESCRIPTION AND PRESENT KNOWLEDGE OF THE MARTIAN SURFACE

The surface of Mars, when viewed through a telescope, appears to consist of three distinctively different types of materials. They appear as light ocher colored areas, dark areas, and white polar caps.

The light areas make up about three-fourths of the Martian surface and have been interpreted to be desert-like in nature with limonite being responsible for the ocher coloring. The remaining one-fourth of the Martian surface constitutes the dark areas. The polar caps are ephemeral and, therefore, are not considered as being part of the surface. One of the most confusing aspects in regard to the dark Martian surface areas is that they appear to change in size and degree of darkness. These changes are seasonal and have been attributed to such things as response of vegetation, material changes due to humidity, and/or sand and dust particles being transported by prevailing winds. Most of the dark areas become darker during the Martian spring and are, for the most part, confined to ± 30 degrees from the equator, although they are most prominent in the southern region of the planet.

2.1 Light Areas - Hypotheses

The light areas of the Martian surface historically have been described as deserts, with limonite as the major constituent. This model of the surface is based upon polarimetric, spectroscopic, color, and albedo measurements, all of which are consistent with the presence of limonite. The various surface models which have been proposed are summarized in Table 1.

Van Tassel and Salisbury (1964) reviewed the evidence for limonite as the major mineral constituent within the light areas. They concluded, on the basis of laboratory experiments, that the evidence for vast amounts of limonite, particularly from the midinfrared spectroscopic evidence, was not conclusive; and that from geological considerations, the major solid constituents of any planet should be both abundant and resistant to abrasion.

A more recent consideration in regard to the limonite hypothesis made by Salisbury (1966) is that it is very difficult, based on geologic considerations, to account for the great abundance of hydrated iron oxide on Mars. Although iron is present in a large number of minerals on the Earth, it would seem that the predominant minerals on Mars should be those same ones which make up the Earth's crust (i.e., silicon and aluminum). He further stated that the mean density of Mars (3.9) as compared to that of the Earth (5.5) does not provide for a great quantity of iron, which is necessary to account for vast amounts of limonite. Presumably, this takes into consideration the possibility of Mars not being structurally differentiated as is the Earth.

According to Rea (1965), in the Martian atmosphere the settling out time required after a dust storm could segregate the fine, easily pulverized limonite particles from the coarser

Table 1

HYPOTHESIZED SURFACE CONDITIONS OF LIGHT AREAS

Surface Type	Possible Surface Condition	Reference
Sand Deserts	The light areas are chains of desert and dunes analogous to those found on Earth in such desert countries as Africa, Arabia, Libya, etc.	Salisbury (1966)
Silicates	Based on laboratory experiments of Earth materials and on geological considerations, the light areas are for the most part made up of silicates.	Van Tassel & Salisbury (1964)
Silica and Limonite	Light areas consist of both silicates and limonite which have been pulverized leaving coarse grained silicate sands with fine particles of limonite. The settling out after dust storms produces a concentration of limonite at the surface.	Rea (1965)
Ferric Oxides	Based on spectroscopic data, these light areas appear to be, at least down to the depth observed, largely composed of ferric oxide minerals.	Sagan et al. (1965); Draper et al. (1964)
Weathered Igneous Rocks	Based on spectroscopic measurement, there seems to be some support that the light areas consist of certain weathered igneous rocks.	Binder & Cruikshank (1964)
Silicates and Hydrated Iron Oxides	During the early history of Mars, there was an atmosphere capable of altering the form and chemical composition of the crustal material which caused the separation of iron from crustal materials. Thus, the hydrated iron oxides could constitute some minor percentage of the surface materials.	Van Tassel & Salisbury (1964)

Table 1 (Cont'd)

Surface Type	Possible Surface Condition	Reference
Silicates (20%)	Based on observed gray-body emission from Mars, the interpretation has been made that less than 20 percent of silicates make up the Martian light surface materials.	Sinton & Strong (1960)
Fine Dust	The light areas consist of finely divided materials. This is based on optical thickness measurements of the yellow clouds.	Koval and Morozkenko (1962)
Limonite Dust	The continents of Mars are covered everywhere by an erosion mantle of loose, soft, floury silt, consisting of either dust-like particles of pure limonite, or of some other particles intensely colored by that material.	Sharonov (1961)
Topography	The boundaries between the dark and light areas appear to suggest fairly sharp topographic changes, with the transition occurring within a few miles.	Kuiper (1955)

silicates. This would result in the preferential deposition of the limonite particles as the top surface. Spectroscopic data obtained by Sagan et al. (1965) have added some support to the limonite theory. Total reflection spectrophotometric analysis of limonite and hematite in the near-infrared has led them to conclude that the light areas, at least down to the depth observed at infrared frequencies, are composed largely of ferric oxide minerals. A similar conclusion was made by Draper et al. (1964). Binder and Cruikshank (1964) reported that similar spectroscopic measurements suggest that the limonite was possibly derived from weathered igneous rocks.

Van Tassel and Salisbury (1964) suggested that during one period of time early in Martian history, there existed an atmosphere capable of altering the form and chemical composition of the crustal materials through chemical weathering. If this were the case, it would be possible to separate the iron from crustal materials. Thus, the hydrated iron oxides could constitute some minor percentages of the surface materials.

Sinton and Strong (1960) observed gray-body emission from Mars, which they interpreted as an indication that less than 20 percent of silicates exist on the Martian surface. A significant point to consider is that Van Tassel and Salisbury have shown in their experiments that finely divided materials other than limonite also could have produced the results shown by Sinton and Strong's observations. In support of the finely divided materials or dust concept, Koval and Morozkenko (1962) defended it on the basis of optical thickness of the yellow clouds.

Sharonov (1961) has made a preliminary lithologic interpretation of the Martian surface material by the use of photometric and colorimetric information. His interpretations are based on two assumptions: the Martian mantle consists of the same major minerals as does the mantle of the Earth; and, the color characteristics of Martian minerals are the same as those on the Earth. However, Sharonov also pointed out the possibility that these two assumptions are not justified, since Mars may have minerals completely unlike those found on the Earth, and that the color of minerals are quite variable and dependent upon environment.

In the study, Sharonov evaluated several types of materials that are present at the Earth's surface which possibly could be responsible also for the ocher color on Mars. Of the samples evaluated, the only variety which displayed sufficient similarity in color and lightness to the Martian surface was what he called earthy limonite. He noted that Dollfus, based on his polarimetric work, concluded that of all the terrestrial materials investigated, only powdered limonite exhibited complete similarity with the observed surface data of Mars. Sharonov (1961) concludes that, based on the results of his study of various materials and the results of Dollfus' study, the following hypothesis should be considered: "The continents of Mars are covered everywhere by an erosion mantle which is a layer of loose, soft, floury silt, consisting either of dust-like particles of pure limonite, or some other particles intensely colored by that mineral."

It would appear that all of the hypotheses regarding the nature of the light areas presented here, could be satisfied by a limonite coating of silicate particles and/or limonite dust at the surface. In either case, the limonite is probably a minor constituent which produces the ocher coloring.

2.2 Dark Areas - Hypotheses

There have been as many or more hypotheses regarding the nature of the dark areas on Mars as those which concern the much larger light areas. This has been because of the observed changes which seem to follow a seasonal pattern. These hypotheses are summarized in Table 2.

Kuiper (1955) has pointed out that the boundaries between the dark and light areas appear to be quite sharp, with the transition occurring within a distance of a few miles. Such evidence suggests that the control is due primarily to changes in the surface relief (topography) rather than by some of the other suggested causes such as vegetation or changes in materials. Kuiper seems to have overstated the degree to which transition occurs between the light and dark areas since the best telescopic resolution of the Martian surface is of the order of 30 miles. It is possible that the migration of sand by means of the prevailing winds could be the key process responsible for the changes in size and shade.

Table 2

HYPOTHESIZED SURFACE CONDITIONS OF DARK AREAS

Surface Type	Possible Surface Condition	Reference
Lava Flows	The dark areas of the Martian surface are lava fields that are quite smooth and are seasonally swept free of dust by prevailing winds.	Kuiper (1955)
Volcanic Ash	The dark areas are caused by volcanic ash being blown down from active volcanos.	McLaughlin (1954)
Variation in Particle Sizes	Variation in brightness might be due solely to variation in particle size, with areas covered by larger particles being darker and lessening in darkness as the particles get smaller.	Rea (1965)
White Clouds	Isolated white clouds frequently form over bright areas adjacent to the dark areas. They align themselves along the edges of the topographically high dark areas and remain stationary for extended periods.	Wells (1965)
Dust Storms	The temporary dark areas follow the occurrence of severe dust storms.	Slipher (1962)
Vegetation	The origin of dark areas are caused by vegetation growth during specific seasons.	Slipher (1962); Sinton (1958); Dollfus (1961)
Plateaus	The dark areas are wind-swept plateaus.	Kuiper (1955)

Kuiper (1955) also suggested that the dark areas of Mars may be lava fields that are quite smooth, and which seasonally are swept free of dust by prevailing winds.

A volcanic hypothesis also was suggested by McLaughlin (1954). However, his hypothesis proposes that the dark areas are caused by volcanic ash blown downwind from active volcanos. Salisbury (1966) contended that such a hypothesis would be difficult to use in explaining seasonal volcanic rejuvenation. Kuiper (1955) has pointed out also that the volcanic activity would add continuously large amounts of water vapor to the atmosphere: this does not agree with the low water content of the Martian atmosphere. Also, IR observations of the maria (Binder and Cruikshank, 1966) indicate that the spectrophotometric properties of the maria do not match those of either basaltic flows or basaltic volcanic ash. On the other hand, Urey (1956) concluded that it cannot be demonstrated that water vapor added by volcanic activity could not be removed by escaping into space, hydration of surface materials, or absorption by vegetation.

Rea (1965) proposed that the variations in lightness might be due solely to variations in particle size, with areas covered by larger particles being darker, and lessening in darkness as the particles get smaller.

Wells (1965) reported that isolated white clouds frequently form over the light areas adjacent to the dark areas. He said that such clouds align themselves along the edges of the topographically high dark areas and remain stationary for extended periods of time.

Slipher (1962) suggested that the temporary dark areas follow the occurrence of severe dust storms.

The vegetation hypothesis also has received much attention through the years. This hypothesis states that the origin of dark areas is caused by the growth of vegetation during specific seasons. Slipher (1962), Dollfus (1961) and Sinton (1958) have supported the vegetation theory. Rea (1963) attacked the vegetation hypothesis on the basis that the Martian surface temperature within the dark areas never reaches 0°C, and consequently, the temporary darkening of light areas is difficult to explain as being the result of vegetation.

2.3 Surface Conditions Detected by Mariner IV Photographs

The photographs taken by Mariner IV have shed new light on the topographic surface conditions on Mars, and they should clear up some of the confusion about the planetary surface. These photographs have shown clearly that parts of the Martian surface are very similar in appearance to the lunar highlands. This indicates that the Martian surface has undergone processes - primarily cratering - similar to those of the moon. Also, the subdued character of the craters indicates that erosional processes are, or have been, present. However, the existence of large numbers of craters indicates that erosion has not been nearly as active as it has on Earth.

Salisbury (1966) suggested that if there has been a scarcity of water on Mars, it is unlikely that the surface materials could be composed largely of limonite. He further stated that if one were to accept Sagan's et al. (1965) conclusion that there was once a high-humidity tropical environment on Mars, it would be difficult to justify a limonite-rich soil surviving the subsequent cratering processes, since impact craters, 15 to 20 km in diameter and 1- to 2-km deep, suggest a considerable excavation and mixing of the crust. Even though Rea (1965) stated that the impact crater ejecta would be sorted, Salisbury believes that the average crustal composition, due to the low density of Mars, would be something less than 25-percent iron.

If the conclusion is drawn from the Mariner-IV photographs that limonite is unlikely to be present in very large quantities, it is necessary then to justify or explain the visible and near-infrared spectroscopic data. According to Salisbury, upon close examination of the experimental data, the spectroscopic data _per se_ are not inconsistent with those that one obtains from volcanic rocks that have ferric oxide impurities. Sagan et al. (1965), however, rejected this possibility on the basis of polarimetric work conducted by Dollfus (1961). Dollfus found that the polarized phase curve of silicates does not resemble the data taken of Mars. Rea and O'Leary (1965), however, have shown that the polarimetric data are consistent with several types of rocks including at least one type of lava, if the polarization effects of an atmospheric aerosol mixture are taken into account.

3. MARS EXPLORATION

The Space Science Board stated during its 1965 conference on planetary science, "The geology of Mars is particularly important because Mars may be expected to have paralleled the Earth somewhat closely in origin and development." In the context of this statement, we would add that not only should the detection of similarities between the two planets be important, but also any significant differences should be equally important in solving problems related to planetary origins and relationships.

There are many pressing questions concerning the planet Mars which must be answered before much can be learned about its relationship to other planets and the universe, its origin, history of development, and the processes which have modified its interior and surface. Many of the questions which should be answered during the exploration of Mars have been defined and compiled by the Space Science Board (SSB 1965). The SSB grouped these questions into six categories. They are presented for reference in Appendix 1 of this report.

In planning for the exploration of a planetary body it is much more meaningful to define the applicability of measurement techniques by consideration of the quantities that have to be measured (designated as attributes in this study) rather than by consideration of the more abstract exploration questions or objectives. However, to develop a logical exploration program it is essential to begin with a set of objectives which may be in the form of questions or statements and from which one can derive measurable attributes. Investigation techniques can then be evaluated in terms of how well they measure the attributes. For the purposes of this study, Martian exploration has been considered under the following categories:

1. Record of Life
2. Physical Constitution
3. Active Processes
4. Chemical Compositions
5. History of Events

These five categories and the related objectives were, for the most part, taken from the SSB's consideration of the exploration of Mars in their Space Science Research Report of 1965. However, some modifications were made in order to state them in such a way as to provide categories which would facilitate for a more complete listing of objectives. For example, the SSB's listing of categories included exobiology and differentiation. We feel that exobiology should be replaced with the Record of Life, since biology implies presently living matter rather than the complete record, past and present. Also, the differentiation of the planet can logically be considered as part of the Physical Properties of the planet.

A brief description of the purpose of each of the above categories is presented in the following subsections along with Tables 3 through 7, which present the various exploration objectives, the related attributes, and the applicability of sampling to these attributes. The investigation of these attributes is considered necessary in order to completely accomplish the objectives listed under the five categories. The techniques which can be used to investigate the many attributes considered in this section are designated as follows:

Surface Sampling (S)

As previously defined, sampling is the technique of taking rock or rock material samples of the surface or near-surface of Mars.

Remote Sensing (RS)

Remote sensing includes all measurements of the electromagnetic spectrum made remotely.

Geophysical Surveying (GS)

This includes all the physical measurements made at the surface of Mars.

Geological Mapping (GM)

This is used in the context of conventional Earth type geological mapping (i.e., rock outcrops, dip and strike of beds, etc.).

Photographic Mapping (PM)

Photographic mapping indicates the measurement of the visible part of the electromagnetic spectrum from a remote distance. This technique is used solely to get the appearance of the surface and surface features. Photographic mapping as used in this report does not imply stereoplotting for topography, as topographic mapping is considered separately.

Atmospheric Sampling (AS)

Atmospheric sampling applies to the whole atmosphere from just above the surface to the exosphere. It is treated distinctly from surface sampling even though the latter may well include some of the atmosphere.

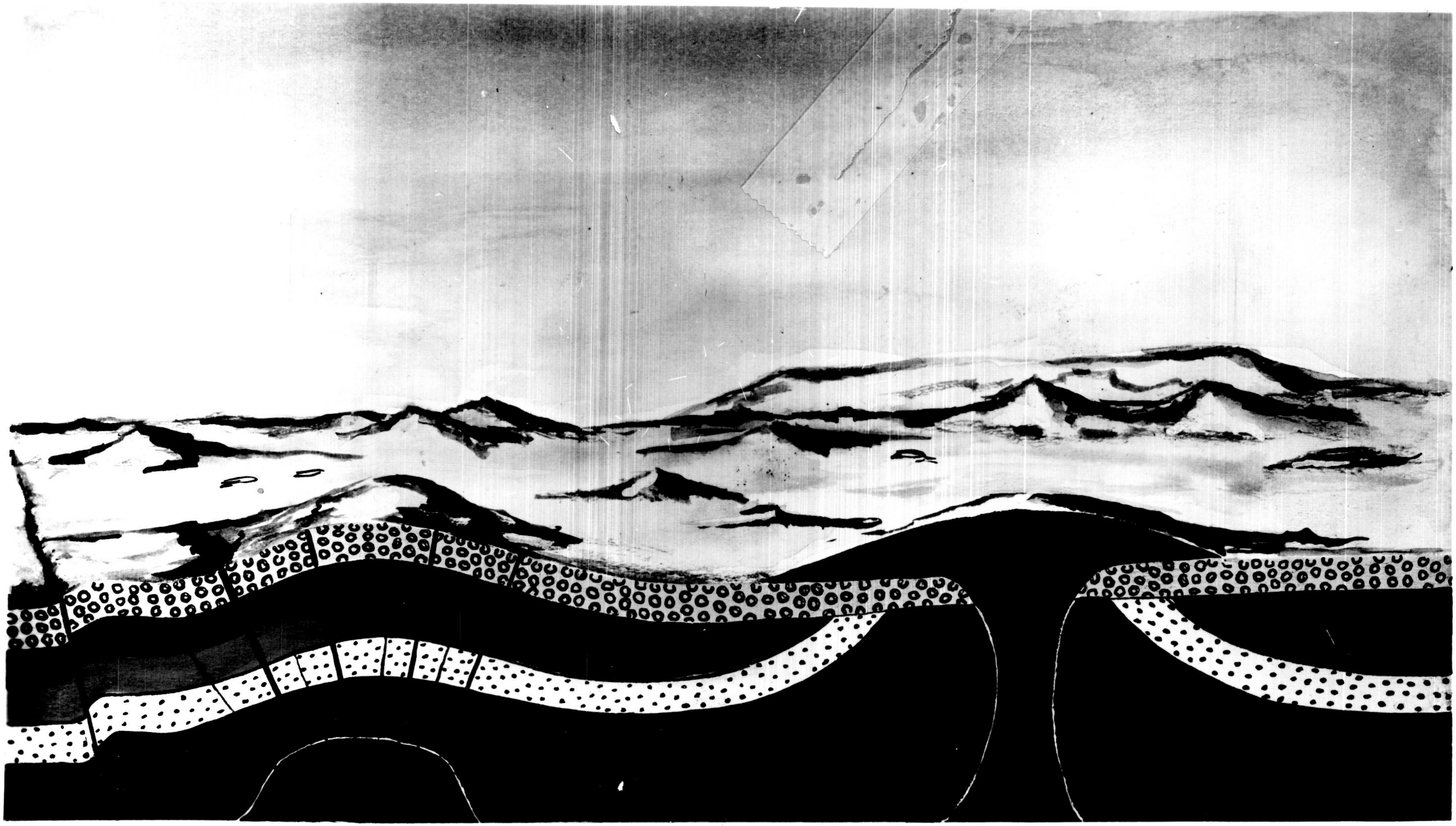
Topographic Mapping (TM)

Topographic mapping is the mapping of surface elevations from orbit or on the surface. This includes plain table type surface mapping, and/or altimetry and photography from orbit.

Since we are concerned primarily with the applicability and value of sampling it is always listed prior to any other applicable techniques. No consideration has been given to the priority of all techniques as applicable to individual attributes.

Figures 1 and 2 which follow present some of the possible structural features which might be expected on or very near the Martian surface; Figure 3 presents possible surface appearances (morphology) which may be a direct indication of subsurface structure; and Figure 4 presents some structural properties of rock units which when determined will provide information on material and structural formation, rock modifications since formation, and processes responsible for the rock formation and modifications

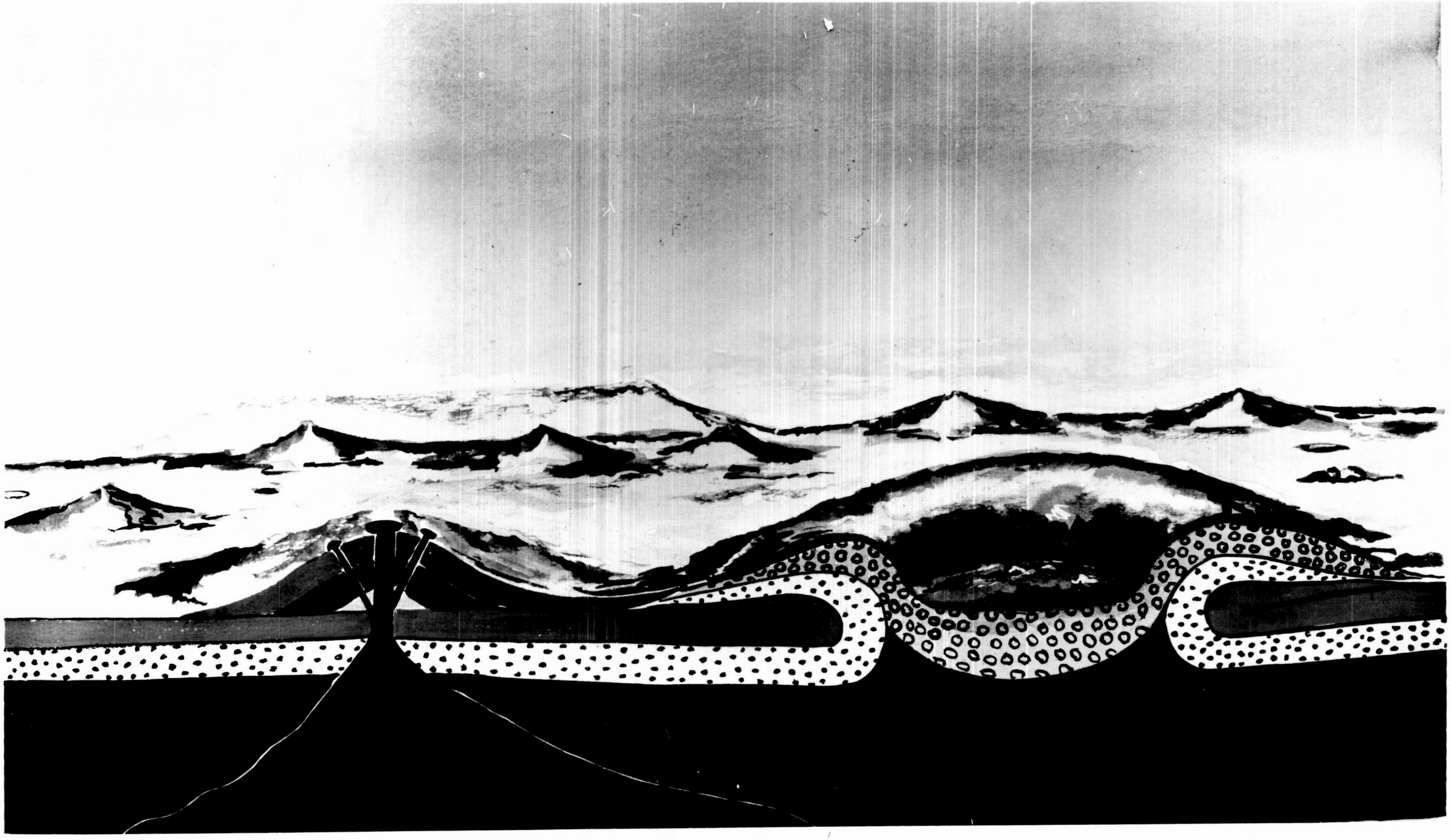
The properties portrayed in Figures 1, 2, 3, and 4 are presented to demonstrate the kinds of geological attributes which must be investigated either by sampling or other techniques during the exploration of Mars in order to understand the origin and evolution of the planet. The attributes in these figures represent only a small portion of the total



This diagram illustrates some of the possible surface and subsurface features which might be expected to exist at or very near the Martian surface. Shown are, from left to right, a normal fault with surface expression, an instrusion (batholith) with fractures radiating upward to the surface, and with overlying folded strata, a surface stratigraphic contact, an extrusion which formed a dome, subsurface bedding, and local surface topography in the background.

Figure 1

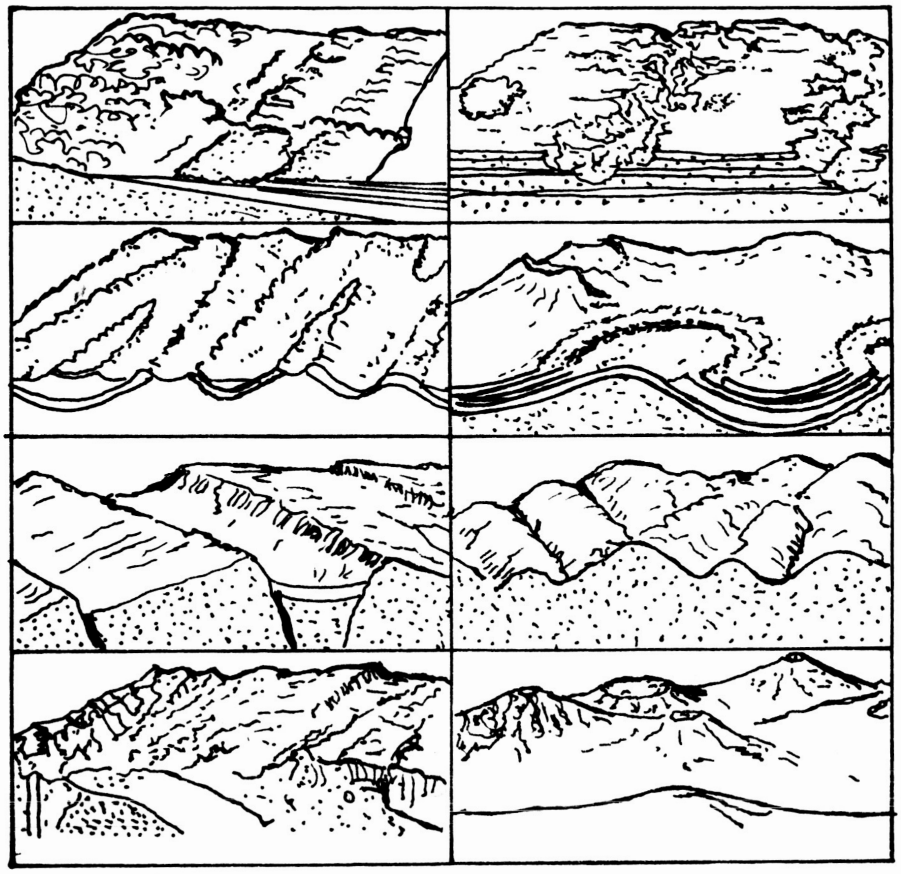
SOME POSSIBLE MARTIAN SURFACE AND SUBSURFACE FEATURES



This diagram illustrates some of the possible surface and subsurface features which might be expected to exist at or very near the Martian surface. They are, from left to right, a composite volcano with side vents, local strata, a stratigraphic contact between the volcanic material and ejecta material, an impact crater with folded rim spectra, fracture zone below the crater floor, and local surface topography.

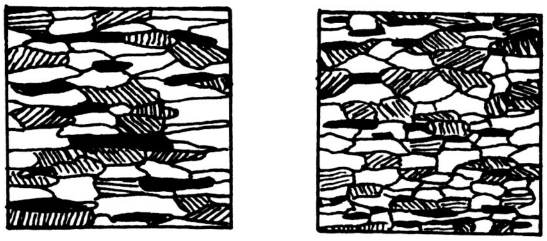
Figure 2

SOME POSSIBLE MARTIAN SURFACE AND SUBSURFACE FEATURES

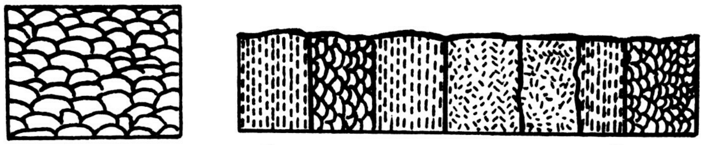


Shown are some of the possible surface appearances as a result of structure and lithology. (After McLaughlin 1954)

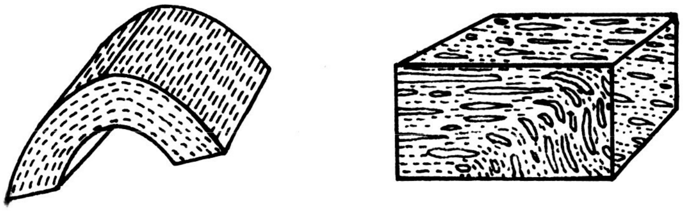
Figure 3 SURFACE MORPHOLOGY

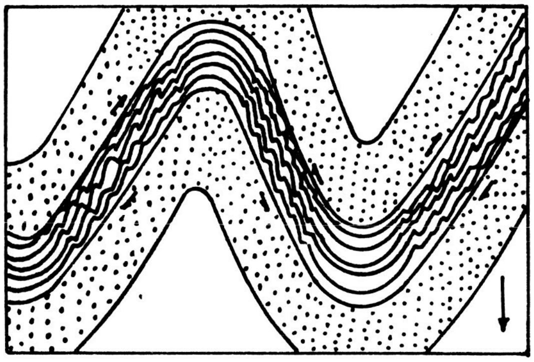

Platy Minerals Platy Minerals

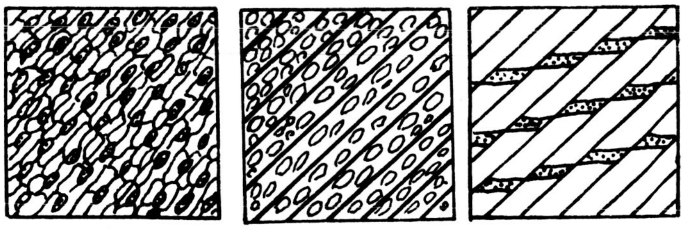
Foliation: minerals are platy and lie parallel to one another. Primary foliation forms during the crystallization of a magma.


Lava Lava Lava

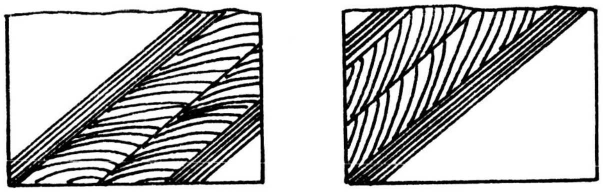
Vesiculars: are void spaces within a rock (lava) and are formed by escaping gas.

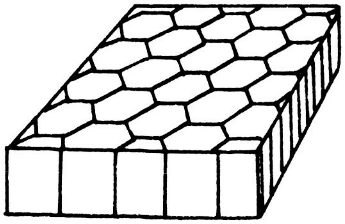

Lineation is the linear arrangement of minerals and is in general related to the major structure.


Drag Folds: can be used to determine the top, the dip, and the strike of beds.


Normal Cleavage Fracture Cleavage Slip Cleavage

Cleavage: the parallel arrangement of platy minerals in general formed by rock flowage.


Cross Bedding: can be used to distinguish the top from the bottom and the origin of most wind deposited and some water deposited materials.


Columnar Jointing: Indicates shrinkage

Shown are some of the structural properties of rocks which can be used to interpret the nature, origin and modification of rocks and structural features. (after Billings 1954)

Figure 4 ROCK STRUCTURE

considered in this study. Particularly important but less amenable to graphic presentation are the biological attributes.

3.1 Record of Life

The determination of the Record of Life implies the detection of various families and species of past and present living matter, along with certain chemical compounds which may possibly be the results of biological activity or of decayed flora or fauna.

In order to determine the record of life it is essential that the exploration program be conducted in such a way that evidence, if present, can be detected on extinct life forms, and on any prebiotic materials which could possibly be conducive to future life. This, then, indicates that there are basically three different objectives which should be accomplished in order to determine adequately the record of life: (1) evidence of extinct life, (2) presence of living matter, and (3) prebiotic materials. These objectives are presented in Table 3 along with related attributes which should be thoroughly investigated, and the exploration techniques applicable to investigating the attributes.

Each of the three above listed objectives are discussed below in more detail.

3.1.1 Evidence of Extinct Life

Evidence of extinct life as preserved in rocks or rock forming materials in the form of fossils includes both flora and fauna life forms. There is also additional evidence

Table 3

RECORD OF LIFE

Objectives	Attributes	Investigating Technique
Evidence of Extinct Life	Fossils	S
	Hydrocarbons	S, RS
	Molecular fossils	S
Presence of Living Matter	Biochemistry	S, RS
	Metabolism	S
	Reproduction	S
	Movement	S
	Growth	S
	Morphology	S
Prebiotic Materials	Complex organic chemistry	S

Key: S = Sampling
RS - Remote Sensing

which may possibly be the by-product of decomposition after death; this includes the presence of hydrocarbon compounds and molecular fossils. Such evidence should not be considered as conclusively demonstrating a biota. For instance, on the Earth it has not been proved that hydrocarbons can be identified as being formed by organic or inorganic processes.

Past life forms may be preserved in the form of altered and unaltered soft parts, altered and unaltered hard parts, and imprints or traces. The preservation of life forms in the above ways is known as fossilization. Fossilization of organic remains generally requires quick burial in a protective medium and, in most cases, some kind of hard parts, such as a shell or skeleton. This is not always the case, since imprints or trails can be preserved which give direct evidence of the type life form which left them. For example, a worm could leave a trail in mud which is subsequently buried and preserved. The preservation of fossils in rocks on the Earth is valuable in that life forms and their evolutionary development can be determined by their position in the stratigraphic column. Certain species of fossils which appear only during a specific period of geologic time (index fossils) are valuable in correlating deposits containing them, and for determining relative geologic ages.

In the search for fossils, samples should be taken of both consolidated and unconsolidated materials at the surface and in the subsurface. Fossils are generally found in sedimentary type materials which were at one time unconsolidated, but have since become consolidated due to cementation and pressure as more material was deposited upon them. These materials may be buried below the surface or they may have been reexposed by folding, faulting and/or erosion. If the materials have been reexposed they are most likely to have been subjected to weathering or erosion, or both; in this case the material will again become unconsolidated.

The origin, accumulation, and migration of hydrocarbons are not well understood, but they are known to exist in Earth rocks throughout the geologic column. Therefore, they may be found in all types of rocks and materials at the surface or in the subsurface of Mars. Hydrocarbons are usually associated with features which create traps for them to accumulate. However, they sometimes migrate to the surface through porous and permeable rocks which are tilted and exposed at the surface, or through faults or fractures.

Molecular fossils may also be found in most any type material with the exception of most igneous rocks. They may be detected in materials at the surface or in the subsurface, much the same way as fossils are.

Samples should be taken at several locations on the planet within each type of surface and should be related to surface features which can be identified in advance as those likely to provide unambiguous data. The samples for fossils and molecular fossils should be taken at a sufficient number of surface locations to provide confidence in the data on their existence or nonexistence.. Even on the Earth there is a significant probability of finding no fossil evidence in any given sample. However, it should not be necessary to examine a large area around a landing site unless there are several different types of rocks present. This is not likely since the different types of surface materials are most probably well mixed and distributed.

On the other hand, the exploration of hydrocarbons will require the investigation of specific types of features and materials which are most likely to contain hydrocarbons. The general scarcity of hydrocarbons in surface materials on the Earth may make surface sampling almost useless. Deep drilling may be required if the first few samples yield no sign of hydrocarbons. Several samples should be obtained from the local area since hydrocarbon seeps may be quite localized.

3.1.2 Presence of Living Matter

The presence of living matter, as used here, implies the detection of life forms living at the time of sampling. The detection of living matter is especially important for understanding to what extent life has evolved, if it has, and in what form. The investigation of life forms will be, for the most part, accomplished by sampling the surface. One possible indicator of life is the presence of biochemicals, which if detected will provide information on the complex molecules required for all living matter. Other possible indicators which could indicate life include metabolism, movement, and growth. These properties, if detected, may not prove that life does exist since they may possibly be exhibited by non-living things. However, the two properties which will be direct evidence of living matter are reproduction and the complex morphology of higher orders of life. Therefore, the attributes which must be investigated to determine if there is evidence for life on Mars are as follows: (1) biochemistry, (2) metabolism, (3) reproduction, (4) growth, (5) movement, and (6) morphology. Biochemistry, growth, and movement could conceivably be detected by means other than sampling. Even for these attributes, sampling is considered to be the best technique.

Living matter may be found in consolidated or unconsolidated material and is generally restricted on Earth to the first few meters of the surface. However, when considering the Earth as a model, it is most likely that life forms will be most prolific on or within the unconsolidated materials although some life forms such as lichen are found attached to igneous rocks. Since life forms may prove to be quite scarce and widely distributed over the Martian surface, it is felt that many samples should be taken.

Also, since living matter and particularly micro-organisms are not likely to be restricted to a specific point on the surface, there is no need to take samples over a large area at a landing site. The sites chosen for detecting the presence of living matter should emphasize the light and dark areas since the polar regions are considered to be too cold to support living matter. The number of sites required for the above listed attributes are essentially the same as they are for detecting fossils.

3.1.3 Prebiotic Materials

The final objective which must be accomplished to determine the Record of Life is "Prebiotic Materials." Materials which may be prebiotic can be detected through the investigation of complex organic chemicals. The detection of complex organic chemical compounds does not indicate past life, but rather implies that an active and complex chemistry has been or is operating. The attribute indicative of prebiotic materials is complex organic chemicals. Complex organic chemicals may be found in both consolidated and unconsolidated materials. They may be present anywhere in the stratigraphic column. Samples should be taken within the light and dark areas of the Martian surface at approximately the same number of sites as for the detection of life.

3.2 Physical Constitution

Physical constitution is used in a broad sense in this study and encompasses those properties of the planet and atmosphere which basically are physical, geophysical, and structural in nature. Based on this consideration the objectives for the physical constitution of the planet are as follows: (1) physical properties of the planet, (2) geophysical properties of the planet, (3) atmospheric properties of the planet, (4) structural properties of the surface and land forms, (5) physical properties of surface and near-surface materials, (6) structural properties of surface and near-surface materials, and (7) geophysical properties of surface and near-surface materials. Each of these objectives must be accomplished through a number of attributes in order to fulfill the requirements for understanding the physical nature of Mars.

The many attributes which must be investigated to accomplish the above objectives are presented in Table 4 with the investigating techniques applicable to each attribute.

3.2.1 Physical Properties of the Planet

The physical properties of the planet include those properties which are characteristic of the entire body and can be used in describing the basic or overall nature of the planet. Such properties are designated attributes and include the following: (1) the planet's shape, (2) internal differentiation, (3) density distribution, (4) mass distribution, and (5) topography. The investigation of these attributes should provide the necessary information required to understand the overall physical characteristics of Mars. Most of the information on physical properties is best obtained from geophysical techniques. The applicability of sampling to investigating the above listed attributes is restricted to the internal differentiation of Mars. However, sampling is of limited

Table 4

PHYSICAL CONSTITUTION

Objectives	Key Attributes	Investigating Techniques
1. Physical Properties of the Planet	Figure of planet (geoid)	RS,PM,GS
	Differentiation	S,GS,RS
	Density distribution	RS,CS
	Mass distribution	RS,GS,TM
	Topography	TM
	Librations	RS
2. Geophysical Properties of the Planet	Magnetic field	S,RS,GS
	Gravity field	RS,GS
	Seismic waves	GS
	Thermal regime	RS,GS
	Elasticity	RS,GS
	Rigidity	RS,GS
3. Atmospheric Properties	Wind profile	RS,AS
	Synoptic meteorology	PM,RS
	Temperature profile	RS,AS
	Energy balance	RS,AS
	Density profile	AS
	Pressure profile	AS
	Dust particles	RS,AS
	Humidity	AS
4. Structural Properties of Land Forms	Folds	S,PM,RS,GS,GM
	Faults	S,PM,RS,GS,GM
	Intrusions	S,GS,GM
	Extrusions	S,PM,RS,GM
	Beds	S,PM,RS,GS,GM
	Unconformities	S,GS,GM
	Fractures	S,GS,GM
5. Physical Properties of Surface Materials	Consolidation	S,RS
	Grain sizes	S,GM
	Porosity	S,RS,GS
	Permeability	S,GS
	Density	S,GS
	Hardness	S,GS
	Thickness	S,GS,GM

Table 4 (Cont'd)

Objectives	Key Attributes	Investigating Techniques
6. Structural Properties of Materials	Foliations	S,GM
	Lineations	S,GS
	Cleavage plains	S
	Joints	S,GS
	Tectonites	S
	Vesicles	S,GM
	Dragfolds	S,GM
	Beds	S,GM
7. Geophysical Properties of Materials	Thermal conductivity	S,GS
	Elasticity	S
	Electrical conductivity	S,GS
	Magnetic permeability	S
	Magnetic susceptibility	S
	Albedo-reflectance	S,RM
	Emissivity	S,RM
	Acoustic velocity	S,GS

Key: S = Surface Sampling
RS = Remote Sensing
GS = Geophysical Surveying
GM = Geological Mapping
PM = Photographic Mapping
AS = Atmospheric Sampling
TM = Topographic Mapping

value to this attribute if only surface of near-surface samples can be obtained. The samples obtained are classified according to their mineralogy and petrology, and, therefore, by mode of origin (i.e., igneous, volcanic, sedimentary, etc.). It should be possible then to infer whether there has been differentiation or not. For example, if volcanic and granitic rocks are abundant on the surface, this would imply a greater amount of differentiation than it would if basaltic rocks are the most abundant.

Samples should be taken of both consolidated and unconsolidated materials at the surface and in the subsurface since it is possible to have unconsolidated materials in the subsurface if there is no mechanism available for cementing loose rock materials. The number and location of sites are restricted by the probable distribution of rock types and the ice coverage of the polar regions. The light and dark areas should be sufficient to determine the basic nature of surface and near-surface materials of Mars.

3.2.2 Geophysical Properties of the Planet

The geophysical properties of the planet include properties which when measured will determine the nature of the dynamical forces inherent within Mars. The attributes of the geophysical properties are: (1) magnetic field, (2) gravity field, (3) seismic activity, (4) thermal regime, and (5) the planetary elasticity and rigidity. An investigation of these attributes is important in understanding the dynamic forces responsible for the present physical state of Mars. The geophysical properties of Mars are similar to the physical properties because most of them will, for the most part, require geophysical measurements. The only exception is magnetic fields.

It will be important to determine if Mars exhibited a magnetic field in the past which was markedly different from its present very small field. The magnetic field can be determined, in part, by sampling consolidated materials of the surface and subsurface at a limited number of sites. However, precise orientation of the samples must be known, since magnetic field directions are recorded within the rock. The magnetic susceptibility and permeability of the specific rock determines to what extent the planetary field strength will be recorded. Rock magnetic field measurements may be required for remnant fields (paleomagnetism) or if the present field is too low to be measured uniquely. There is no requirement to take large numbers of samples at the landing sites as the magnetic field should stay fairly constant over a localized area and the type of rocks will most probably be locally uniform. Sampling can only provide a limited amount of information on the overall nature of the magnetic field. One reason for this is that there may be several remnant magnetic fields in any sample.

3.2.3 Atmospheric Properties

The physical properties of the atmosphere include the following attributes: (1) wind profile, (2) synoptic meteorology, (3) temperature profile, (4) energy balance, (5) density profile, (6) pressure profile, (7) dust particles, and (8) humidity. A knowledge of these will help determine the evolutionary trend of the planet and the present energy with regard to exogenic and endogenic processes. However, the atmospheric properties are not considered to be surface sample applicable in the context of the definition of sampling as used in this study. Therefore, sampling is not designated as an investigation technique. It is conceivable, however, that samples of the atmosphere may well be included when samples are taken of surface materials if the sample containers are adequately sealed. Atmospheric sampling is considered an entirely different investigating technique than surface sampling.

3.2.4 Structural Properties

A knowledge of the nature of the structural properties of land forms is important in order to understand, by deduction, what processes were active during specific periods of the Martian geologic history, what processes are presently acting upon and within Mars, and to determine the present structural nature of the surface and near-subsurface. This can be accomplished in part through the investigation of the structural properties and relationships of features such as: (1) folds, (2) faults, (3) intrusions, (4) extrusions, (5) beds, (6) unconformities, and (7) fractures. Therefore, these general types of features, separate or in combination, are considered to be the attributes which must be investigated in order to accomplish the "Structural Properties of Land Forms" objective.

The investigating technique of sampling is applicable to all of the above listed attributes to varying degrees. In most cases, however, other techniques are much more applicable than is sampling. The applicability of sampling and the other techniques are shown in Table 4. The above attributes, in most cases, may be investigated separately or in combination with one another. The first four and the last attributes as listed above require that samples be taken of consolidated materials from both the surface and the subsurface. The other two attributes (beds and unconformities) require samples of both consolidated and unconsolidated materials from the surface and subsurface. The basic difference being that beds and unconformities can consist of both types of materials and the others can only be apparent in consolidated materials.

Samples should be taken in such a way as to permit both local (over several hundred meters) and regional (over tens of kilometers) coverage if possible for the first four attributes (i.e., folds, faults, intrusions, and extrusions) since they may be either local or regional in size. The other three attributes (beds, unconformities, and fractures) require local sampling since they can be readily investigated within a relatively small area. The number of sites required for each attribute should be relatively small since feature types generally can be detected remotely prior to site selection. The sites should be restricted to the Martian surface where there are distinct feature types exposed at the surface.

3.2.5 Physical Properties of Materials

The physical properties of surface materials are important in providing information with regard to the genesis of the materials, the processes acting upon the material during and subsequent to their formation, and the environment during formation, and, in many cases, the rate of deposition. The physical properties are also quite valuable in assisting in the interpretation of various types of geophysical data. The attributes relating to physical properties of materials are: (1) consolidation, (2) grain sizes, (3) porosity, (4) permeability, (5) density, (6) hardness, and (7) thickness. Sampling techniques are applicable to all of these attributes.

An investigation of the above attributes should be made of all types of materials on or beneath the Martian surface. Samples should be taken of consolidated as well as unconsolidated materials, since both types have characteristic physical properties. Sampling should be included for surface materials within the light and dark areas of Mars and as near the polar ice as possible, especially during the summer. Several sites will probably be required in order to sample a sufficient number of rock or material types to permit a reasonably good idea of the basic physical nature of Martian surface materials.

3.2.6 Structural Properties of Materials

The structural properties of materials can for all practical purposes be considered as the spatial relation of units that comprise a rock. The investigation of structural properties is essential in determining past rock movements, rock deformation, and geneses of sedimentary and igneous rocks. The most important attributes relating to rock structure are: (1) foliations, (2) lineations, (3) cleavage planes, (4) joints, (5) tectonites, (6) vesicles, (7) dragfolds, and (8) beds.

Sampling is applicable to all of the above listed attributes. Geologic mapping is also applicable to all but two of the attributes as indicated in Table 4. The exceptions are cleavage plains and tectonites.

The investigation of the structural attributes are restricted to consolidated rocks since, almost by definition, unconsolidated materials do not usually exhibit any structure. Samples should be taken of all consolidated materials at or near the surface. Much like the physical-property attributes, to determine the structural nature of rocks, several sites within the light and dark areas will be required.

3.2.7 Geophysical Properties of Surface Materials

The attributes which are considered important to understanding the geophysical nature of materials are: (1) thermal conductivity, (2) elasticity, (3) electrical conductivity, (4) magnetic permeability and susceptibility, (5) albedo, (6) emissivity, and (7) acoustic velocity.

Samples of the Martian materials should provide much of the information required. However, as shown in Table 4, other investigating techniques can also provide geophysical data on Martial materials, and, in some cases, probably much better than can sampling. The very nature of the geophysical properties of materials creates a somewhat more mixed situation with regard to measurement techniques and to the complexity of investigating the above attributes. There are some attributes which require both consolidated and unconsolidated samples of the surface and subsurface materials (i.e., thermal and electrical conductivity, and acoustic velocity), while there are other attributes which require only consolidated samples of surface and subsurface materials (i.e., elasticity, and magnetic susceptibility and permeability). There are also additional attributes which require both consolidated and unconsolidated samples of only the surface materials (i.e., albedo-reflectance and emissivity). These differences are discussed in Section 4.

The investigation of geophysical properties of Martian rock materials can be concentrated in the light and dark areas.

Several sites will be required to determine the general nature of the geophysical properties of the Martian surface materials.

3.3 Active Processes

Active processes, as used in this study, means those processes acting upon or within a planet which are presently operating. This includes (1) abiological chemical activity, (2) seismic activity, (3) erosional, depositional and transportational processes, (4) processes responsible for forming and modifying land forms, and (5) nuclear processes. These are considered, therefore, to be the objectives related to Active Processes.

A thorough investigation of the above types of processes is of primary importance in attempting to understand the origin and development of Mars. It is also of importance in assessing the geologic time and mechanisms required for the formation and modification of certain types of features by active processes, for example, the time required to form a mountain range (period at orogeny) and the time required to reduce a mountain range to peneplain level. Information of this type provides the means necessary to extrapolate geologic conditions and activities back to earlier geologic periods. The active processes are presented in Table 5 and are discussed in the following subsections.

Table 5

ACTIVE PROCESSES

	Objectives	Key Attributes	Investigating Techniques
1.	Abiological Activity	Carbon, hydrogen, oxygen reactions	S,RS
2.	Seismic Activity	Quakes (seismic waves)	GS
		Meteoritic impacts	S,GS,GM
		Volcanic explosions	S,RS,GS,GM
		Microseismic activity	GS
3.	Erosional, Depositional & Transportational Processes	Wind activity	S,PM,AS
		Temperature fluctuations	GS,AS
		Slumping	S,PM,GM
		Soil creep	GM
		Wedging	GS
		Fluid	S,PM,GM
		Volcanic activity	S,RS,GS,GM
		Meteoritic impacts	S,GS,GM
		Chemical Reactions	S
4.	Processes Responsible for Forming & Modifying Land Forms	Igneous activity	S,PM,RS,GS,GM
		Folding	S,RS,GS,GM
		Faulting	S,RS,GS,GM
		Subsidence	S,RS,GS,GM
		Meteoritic impacts	S,GS,GM
		Wind activity	S,PM,GM
		Fluidization	S,PM,GM
5.	Nuclear Processes	Cosmic ray flux	GS
		Cosmic ray spectra	GS
		Radiation level	GS
		Rock radioactivity	S,GS

Key:
S = Surface Sampling
RS = Remote Sensing
GS = Geophysical Surveying
GM = Geological Mapping
PM = Photographic Mapping
AS = Atmospheric Sampling

3.3.1 Abiological Chemical Activity

The abiological chemical activity of interest includes the chemical reactions which could possibly be associated with or involving biologically significant materials, but not necessarily indicative of biological processes. This includes organic chemical reactions and changes in the concentration or distribution by nonbiological processes. Also included are reactions involving hydrogen and oxygen, and possibly the formation of such compounds as amino acids, proteins, and enzymes. Reactions involving such elements as those above are of importance in determining the presence of active organic chemical processes of biological significance. The attributes which should be investigated in order to evaluate possible activity are, carbon, hydrogen, and oxygen reactions. Sampling will be useful in determining whether Mars is supporting a present organic chemical activity which is now biological.

The existence of activity should not be restricted to any one type of material (and, therefore, samples should be taken of both consolidated and unconsolidated materials). However sampling should be limited to the near surface since this is where chemical changes will probably be most active. If present abiological activity does exist on the surface of Mars, it should be rather widespread and not restricted to small isolated areas. Therefore, only a few sites widely distributed should be adequate for the detection of this type activity from samples.

3.3.2 Seismic Activity

Seismic activity is usually defined as quake activity which results from the rapid movement of large blocks of rocks, particularly along a line of fault. We have for the sake of completeness included other types of seismic activity which also generate shock waves. They are (1) quakes, (2) meteoritic impacts, (3) volcanic explosions, and (4) microseisms. All these are considered to be important for understanding all the processes which might be responsible for seismic activity upon and within Mars. The above processes, therefore, have been designated as the attributes of seismic activity.

The presence and level (magnitude and rate of occurrence) of seismic-quake and volcanic-explosion activity detectable at the surface are indicative of the stress buildup within a planetary body. They are considered, therefore, to be important keys in determining the planet's thermal and tectonic history.

Meteoritic impact and microseismic activity, on the other hand, are important in that they provide pertinent information regarding the level of activity of external and surface activity. Microseisms are the low-frequency activities generated by such things as landslides, wind, etc. Of the different types of processes responsible for seismic activity, only meteoritic impacts and volcanic explosions can be readily determined by sampling. Sampling by itself, however, will not give the complete picture of present activity since samples must be taken of materials already laid down. In order to determine if both meteoritic and seismic activity are presently active on Mars, it is necessary to sample surface materials which will permit an interpretation as to the mechanism responsible for its existence. In the case of meteoritic activity, samples should be taken of unconsolidated material around what would appear to be a meteoritic impact feature. On the other hand, both consolidated and unconsolidated material should be sampled of features which appear to be of volcanic origin. Unconsolidated volcanic material is derived from subsurface explosions and is known as pyroclastic material. The consolidated material is formed from molten material pouring out of a surface vent or fracture and is in the form of lava. Surface samples should be required at only a small number of sites, if the sites are selected with respect to specific types of features which appear to be indicative of these two types of activity. Sampling should also be restricted to the Martian surface areas where relatively young rock or rock materials appear to be exposed.

3.3.3 Erosional, Depositional, and Transportational Processes

These processes are those which are responsible for wearing down, moving, and redepositing materials which make up the outer portion of the planet. The sum of the processes responsible for wearing down or reducing the height of landmasses and landforms has been termed denudation. This, in many cases, would include the same processes which transport and deposit materials. The difference being in the final results at a specific location, e.g., if water is eroding at a certain location it is an erosion agent, whereas, if it is depositing at a certain location, it is a depositional agent as well as being the transportational agent between the two locations.

The processes which make up the above three categories are as follows: (1) wind, (2) temperature fluctuations, (3) slumping, (4) soil creep, (5) wedging, (6) fluidization, (7) volcanism, (8) meteoritic impacts and (9) chemical reactions. The activity of these processes can be determined, in general, by several investigating techniques, of which sampling is one. Sampling is not directly applicable to temperature fluctuations, soil creep, and wedging. These processes must be determined by other means as indicated in Table 5. The other processes are sample applicable in that inferences can be made with regard to their type from the properties recorded within the rocks or materials. The investigation of the above attributes which are sample applicable are restricted, for the most part, to sampling surface unconsolidated materials with the exception of volcanism. Both types of samples are required for volcanism since lava and pyroclastic materials may be deposited and transported by volcanic activity. The other attributes are only detected in unconsolidated materials.

Only a few sites will be required for each of the attributes providing adequate sites can be selected remotely in advance. Sampling should be restricted to the light and dark regions for all the attributes. Samples should also be obtained adjacent to the polar caps and along the wave of darkening, especially during the spring.

3.3.4 Processes Responsible for Forming and Modifying Land Forms

The effects of volcanism, erosion, deposition, impacts, etc. on the surface and near subsurface are very important in understanding the types of processes responsible for the evolutionary changes of the planet. The identification of the processes responsible for the surface structure of a planet indicates the present and past level of endogenic and exogenic activity. For example, if the subdued topography of the Martian craters is found to be due to water erosion, this would directly indicate the presence of a hydrosphere during the history of Mars, although only small traces of water have been detected at the surface recently. The attributes which should be investigated in order to provide sufficient information to accomplish the objectives listed are: (1) igneous materials, (2) folds, (3) faults, (4) subsidence, (5) meteoritic impact materials (6) winds, and (7) fluids.

Since it is difficult to measure processes responsible for forming and modifying land forms, it is necessary to deduce the information required through morphology (shape and appearance), structure, and petrology of features. Thus, through investigation of the shape, structure, nature and associated materials of features, it is possible to determine the type of formation and modification processes which have been active in the past or present. This is not the only way of determining the type and magnitude of active processes, however, since several processes expend part of their energy in such a way as to easily be detected by physical measurements. Various techniques may be used separately or in combination. These are indicated in Table 5.

The use of sampling to investigate the above attributes is similar to that described for the attributes listed under erosion, depositional and transportational processes, in that there is a mixture of requirement for consolidated and unconsolidated materials from both the surface and subsurface materials. However, there are some differences since there are some additional processes which must be inferred from samples that are not included in the previous description. They are folding, faulting, and subsidence. Sampling these attributes requires samples of consolidated materials of both the surface and subsurface materials. These requirements are based on the consideration that only the consolidated materials record the movement involved and that much of the required information is recorded in materials below the surface. Only a small number of sites should be required to fulfill the requirements for the attributes in this group.

3.3.5 Nuclear Processes

Nuclear processes can be determined through an evaluation of the isotopic abundances and ratios. The ratios and abundances are indicative of the kind and extent of fractionation that has occurred during the history of the planet. This is accomplished in conjunction with radioactive dating. The identification and the determination of the abundances of isotopes will also help to evaluate the level of past and present cosmic activity.

The attributes which relate to the nuclear processes are: (1) cosmic ray flux, (2) cosmic ray spectra, (3) radiation level, and (4) rock radioactivity. Of these, sampling is only applicable to rock radioactivity. The other attributes are determined by geophysical sensing. Samples should be obtained from both the surface and subsurface and of consolidated and unconsolidated materials, as radioactive elements are likely to be in both types of materials. The number of sites required to determine if radioactive elements are present within the Martian surface rocks should be small since radioactive elements would be expected to be widespread (it is the typically high concentrations of these elements which are usually confined to localized areas on the Earth).

3.4 Chemical Composition

The chemical composition is used here in the broadest sense. It includes not only the chemical composition of Martian rock materials, but also the composition of the atmosphere. The composition of both are of utmost importance for understanding the present and past environmental conditions and for understanding the past evolutionary history of Mars.

Some major problems which possibly could be solved from a knowledge of the chemical composition are the relationship of Mars to the Earth, any parallel in development, and their relationship to other terrestrial planets within the solar system. It is essential also in making comparisons between the times of any major events recorded in the rocks of both planets.

In general, a knowledge of the chemical (i.e., elemental, isotopic, and mineralogical) composition of the Martian surface, and how it varies over the surface, will assist in making interpretations regarding the development and modification of the planet during recordable periods of geologic time. For example, if the upper region of the planet is abundant in the lighter elements, such as silica and alumina, there would appear to be a similarity in development between Mars and the Earth.

While the identification of certain chemical elements provides information on the evolutionary development of the planets, the identification of certain other chemicals and chemical compounds will provide valuable information on the probability or nonprobability of past or present living matter. Also, the detection of certain chemical compounds will assist in evaluating the accumulation of foreign elements (i.e., solar, cosmic, and meteoritic) during a given period of geologic time. The objectives which should be accomplished in order to determine the chemical composition of Mars are: (1) chemical composition of materials, (2) chemical composition of the atmosphere, (3) composition of surficial fluids, (4) macromolecular distribution, (5) cosmic or other extra-Martian materials, and (6) surficial water distribution. These objectives, the attributes which must be investigated, and the techniques applicable to investigating individual attributes are shown in Table 6. In order to extrapolate the chemical composition to the interior and over the planet's surface there is a definite requirement for surface geophysical and remote sensing measurements and atmospheric sampling. The only objective to which surface sampling is not of value is the chemical composition of the atmosphere. In most cases, in order for remote sensing to be of any value, ground truth is required through sampling. Once ground truth is acquired remote sensing can be utilized to extrapolate chemical properties over the planet's entire surface.

Table 6

CHEMICAL COMPOSITION

Objectives	Key Attributes	Investigating Techniques
1. Chemical Composition of Materials	Elemental composition Mineralogical composition Isotopic composition Macromolecular distribution	S,RS S,RS S,RS,GS S,RS
2. Chemical Composition of the Atmosphere	Molecular identification Molecular distribution	RS,AS AS
3. Composition of Surficial Fluids	Liquid constituents	S,RS
4. Macromolecular Distributions	Organic/proto-organic molecules	S,RS
5. Cosmic or Other Extra-Martian Material	Mineralogical identification	S,RS
6. Surficial Water Distribution	Adsorbed water Free water Ice Permafrost Hydrated water Absorbed water	S,RS S,RS,GS S,PM,RS,GS S,GS S S,RS,GS

Key: S = Surface Sampling
RS = Remote Sensing
GS = Geophysical Surveying
PM = Photographic Mapping
AS = Atmospheric Sampling

3.4.1 Chemical Composition of Materials

The lithology and/or mineralogy of a planetary surface is a direct function of the rock forming process which has been active during the history of the planet. The presence of granite rocks in a planetary crust indicates a high degree of differentiation both in the upper mantle and crustal regions, whereas the presence of large quantities of basaltic rocks indicates a low degree of differentiation. The presence of sedimentary rocks indicates the activity of erosion, solution, and depositional processes. The composition of surface materials is given directly by determining the surface petrology and mineralogy and can be accomplished through the investigation of the following attributes of chemical composition: (1) elemental composition, (2) mineralogical composition, and (3) isotopic composition.

Sampling materials is one of the best proven methods of determining the chemical composition. However, it is not the only technique, since sensors (both remote and *in situ*) have been developed which can provide information on the chemical composition of minerals. Consolidated and unconsolidated samples should be taken of surface and subsurface Martian materials in order to get an indication of the chemical nature of the crustal material. A good first approximation of the chemical composition of Martian materials should be possible from a moderate number of well selected sites within the light and dark surface areas. The polar regions where covered by ice caps, should be excluded since it may be difficult to sample rock materials under the ice.

3.4.2 Chemical Composition of the Atmosphere

The identification of the chemical elements which make up the Martian atmosphere, their relative abundances, and their distributions will provide much of the information required to determine its origin and evolution, interaction with the Martian surface, and energy exchanges with the Sun. This type of information will also be of great importance in helping to obtain a better insight into the origin and evolution of our own atmosphere.

The attributes which should be investigated with regard to the chemical composition of the Martian atmosphere are (1) molecular identification, (2) percentage abundances, and (3) molecular distribution.

Surface sampling is not directly applicable to the attributes as such. If, however, surface samples are taken in such a way as to preserve the atmospheric constituents, it would be valuable for the atmosphere very near the Martian surface. Otherwise atmospheric sampling and remote sensing are the only techniques applicable.

3.4.3 Composition of Surficial Fluids

The nature of surficial fluids on Mars may vary drastically from those found on Earth or any other planet, if in fact they exist at all. The fluids will most probably have changed in composition throughout geologic time. The materials which are dissolved in the liquids are indicative of at least part of the types of processes which have been active on the surface. Also, materials can be deposited through biological processes, evaporation, or chemical methods to produce certain lithologic rock units.

The existence and composition of surficial fluids on Mars or any other planet can best be determined with a combination of surface sampling and remote sensing (see Table 6).

The exploration for surface fluids should be carried out over the entire planet (i.e., polar, light, and dark areas). However, samples should only be taken of unconsolidated surface materials since for this objective we are only concerned with the fluids which are in relatively free form at the Martian surface. A small number of sites should be sufficient, providing the sites are selected on the basis of orbital data.

3.4.4 Macromolecular Distribution

The macromolecules are the nonpolymerized molecules of very high molecular weight and of great structural complexity (e.g., nucleic acids, peptides, proteins, etc.). The existence of complex macromolecules are especially of interest since they are a prerequisite to any biological process or activity. The attributes for determining the distribution of macromolecules are: (1) organic molecular distribution, and (2) proto-organic molecular distribution.

There are two techniques which appear to be applicable to investigating the two attributes of macromolecular distribution.

These are sampling and remote sensing. Remote sensing is the most attractive since vast portions of the planetary surface can be covered in a relatively short period of time. However, sampling will most probably be essential in order to clearly identify the nature of the molecules. Since the macromolecular distribution is likely to be widely distributed about the planet, samples should be taken at only a small number of sites of both consolidated and unconsolidated materials. Sampling should be restricted to the immediate surface material since it is most likely to be concentrated within the first meter or two.

3.4.5 Cosmic or Other Extra-Martian Materials

The accumulation of extra-Martian materials on the Martian surface, such as meteorite material, should provide valuable information in determining the type and degree of activity during present as well as past periods of time. This is important for understanding the processes involved in changing the nature of the Martian surface throughout geologic time.

The only way to identify clearly the existence of foreign material is by examining the mineralogy of the surface materials. Therefore, the measurement attribute for the objective of extra-Martian material is mineralogical identification. Again, like the two preceding objectives, there is a possibility of utilizing both sampling and remote sensing for this attribute. Sampling is an important investigating technique for mineralogical identification. The detection of foreign materials on the surface of Mars should require only a few sites carefully selected about the entire planetary surface. The polar caps may prove to be exceptionally good for detecting cosmic materials, as are the polar regions on Earth. Other foreign materials will most probably be more abundant around impact crater structures. Consolidated and unconsolidated samples should be obtained with emphasis on the very near surface and surface material.

3.4.6 Surficial Water Distribution

The surficial water content of the Martian crust is important for many reasons. The primary reasons are related to geological, biological, and meteorological considerations. This includes water in the following forms: (1) absorbed, (2) free, (3) ice, (4) permafrost, (5) hydrated, and (6) adsorbed. These forms are therefore considered to be the attributes for investigation.

There are several investigating techniques which could possibly be utilized for investigating the above attributes (see Table 6). However, sampling is probably the most important of those listed.

Free water, ice, and permafrost are not necessarily associated with rock materials and, therefore, the consolidated and unconsolidated type materials do not apply. However, if these forms of water are detected from orbit or from the surface, samples should be taken. Since we are primarily concerned with the distribution and forms of water under this objective, the other three forms (i.e., adsorbed, hydrated, and absorbed) will require that material samples taken of the Martian surface be analyzed to determine if there is water in the sample and if so, in what form or forms does it exist. In the case of the latter types, samples should be taken of consolidated and unconsolidated materials. A modest number of sites should suffice to provide a reasonably good idea of the distribution of water about the planet.

3.5 History of Events Recorded in Martian Rocks

It must first be realized that the history of a planet, especially in the geologic sense, encompasses many different facets of many scientific disciplines. It is not possible to treat the different disciplines as separate entities with regard to history. For example, one cannot conceive of examining the petrographic rock properties without also considering the processes responsible for the rock formation, its relationship to the local stratigraphic column, the environment in which it was formed, and possibly the living organisms which existed at the time of formation. All of these parameters, and more, must be integrated with respect to one another and with time, in order to get a reasonably clear picture of the past planetary history.

To establish local stratigraphic columns, investigate structural features, and determine the relationships between structural features and rock units, the investigation of the early history of Mars will probably require long spacecraft stay times and deep drilling techniques.

However, it is possible to obtain a good deal of information through surface exploration techniques, provided that they are properly carried out. The normal procedure for conducting surface geological or geophysical investigations is first to obtain a topographic base map of the general area to be examined. This can be accomplished from either aerial photography or surface surveying. Once the base map is completed, an exploration program is set up to determine both the local and regional geology. Samples are taken at the various outcroppings with the attitude (dip and strike) of the strata recorded. In the case of Mars, especially during unmanned missions, the attitude of the strata should be determined by recording the orientation of the sample.

If several key features (structural and stratigraphic) are investigated in the above manner, it should be possible to get some general idea of the past history of events which occurred on Mars. This, then, would provide valuable information on some of the more fundamental questions regarding the processes which had been modifying the upper region of the planet's surface during later geologic periods.

The objectives which should be accomplished to get a fairly clear picture of the major events which have taken place during Martian history are: (1) age of Martian materials, (2) stratigraphic sequence of rock units, (3) relationship of structural features, and (4) remnant magnetism.

There is only one attribute listed under the History of Events objective to which sampling is not applicable, and that is morphology, which should be determined primarily by photographic mapping (see Table 7). Other indicated techniques can be utilized in the same way as they are for chemical properties, i.e., by extrapolating data over the planet's surface. The only attribute where remote sensing techniques are not used in support of sampling is for detection of remnant magnetic fields. Martian surface rocks must be sampled in order to determine this property.

The above listed objectives are presented along with related attributes and investigating techniques in Table 7.

3.5.1 Age of Martian Materials

The determination of relative and absolute ages of rock units will provide the means for unraveling the past geologic history of Mars through the technique of stratigraphy. Stratigraphy is basically the establishment of stratigraphic columns or chronological sequence of events and environmental changes as recorded in rocks which make up the stratigraphic column. Through the use of stratigraphy, rock units can be traced over short and long distances giving both the local and regional conditions. Through age determination of rock units from radioactive isotopes and their relative position with

Table 7

HISTORY OF EVENTS

Objectives	Key Attributes	Investigating Techniques
1. Age of Martian Material	Radioactivity	S,RS,GS
	Relationship of rock units	S,RS,GS,GM
2. Stratigraphic Sequence of Rock Units	Superposition of rocks	S,RS,GS,GM
	Radioactive ages	S,RS,GS
	Stratigraphic contacts	S,RS,GS,GM
	Petrographic classification	S,RS,GS,GM
3. Relationship of Structural Features	Bedding	S,RS,GS,GM
	Stratigraphic contacts	S,RS,GS,GM
	Attitude of strata	S,GS,GM
	Morphology	PM
	Petrology	S,RS,GS,GM
4. Remnant Magnetism	Rock magnetic fields	S

Key: S = Surface Sampling
RS = Remote Sensing
GS = Geophysical Surveying
GM = Geological Mapping
PM = Photographic Mapping

respect to one another it is possible to determine the approximate time of formation of the rocks.

The attributes which must be investigated with respect to the age of Martian materials are (1) radioactivity, and (2) the relationship of rock units. Absolute age determinations of materials are restricted to consolidated rocks which contain radioactive elements. On the other hand, relative ages of many rock units can be determined for both unconsolidated and consolidated materials by their position within the local stratigraphic column. Therefore, samples for both absolute and relative age determinations should be taken of surface and subsurface materials at several locations within the light and dark surface areas of Mars. If this is done properly, a good deal of information regarding the approximate ages of surface and near-surface material can be obtained.

3.5.2 Stratigraphic Sequence of Rock Units

The stratigraphic sequence of rock units is better known as the stratigraphic column at a particular location. However, due to possible local disturbances in the past there may be situations where the strata have been overturned, tilted, or sheared. The study of rock strata provides information on the conditions of their deposition, their character, and distribution. The attributes which must be investigated to accomplish the determination of the general stratigraphic column are: (1) superposition of rocks, (2) radioactive ages, (3) stratigraphic contacts, and (4) petrographic classification.

Sampling is applicable to investigating all the above attributes as are other techniques much the same as they are for the preceding objective. However, the stratigraphic sequence of rock units at any one location will require many samples of subsurface materials if there are not sufficient outcrops within the general region to permit extrapolation from the surface to the subsurface. Also, to permit the establishment of a stratigraphic column the dip and strike of the outcropping rock units must be known. For a general knowledge of the stratigraphic sequence of Martian rocks we are confining ourselves to the large rock types which are exposed or very near the surface. If consolidated and unconsolidated samples are obtained at a moderate number of surface sites, it should be possible to get a fairly good idea of the stratigraphic nature of the crustal region of Mars. The samples should also be restricted to the light and dark areas of the surface where outcrops are available for sampling.

3.5.3 Relationship of Structural Features

A major part of the history of a planet is probably recorded in the rocks which make up the first few kilometers of its crustal region. The crustal region can logically be thought of as different types of materials and structural features, both being formed and modified by processes which were active sometime during its history. Therefore, one of the important aspects of Martian exploration is the investigation of the relationship of structural features as determined by their position in the stratigraphic column.

The relationship between structural features is determined through the investigation of such attributes as (1) bedding, (2) stratigraphic contacts, (3) attitude of strata, (4) morphology, and (5) petrology. Sampling is applicable to all the above attributes with the exception of morphology. Morphology which is the appearance of land or structural features can only be determined by photographic mapping techniques. The other attributes can also be determined by techniques other than sampling as indicated in Table 7. Samples should be taken of both consolidated and unconsolidated materials of the surface and subsurface, with the exception of the attitude of strata. This is determined by sampling consolidated materials and recording the orientation with respect to some reference point. To determine the relationship between two structural features it should only be necessary to sample a small number of carefully selected sites. Since visible structural features are restricted to the exposed Martian surface the sites should be located only in the light and dark areas.

3.5.4 Remnant Magnetism

Through the detection of remnant magnetic fields as recorded in igneous rocks, it is possible to determine a great deal about the changes in direction of the planet's magnetic field or changes in general direction of masses of rock.

This is important in studying reversals in the magnetic field as a function of time and to studying the migration of fairly large masses of rock. It is fairly obvious that the attribute which must be investigated with respect to accomplishing the remnant magnetism objective is rock magnetic fields. The most appropriate investigating technique is sampling and it is essential that the orientation of the samples be known accurately.

Sampling again should be restricted to the light and dark areas of the Martian surface, with samples obtained from only consolidated materials of the surface and subsurface.

As indicated under the investivation of magnetic fields, the only rocks which record magnetic fields are those which have magnetic susceptibility and permeability.

4. SAMPLING CONSTRAINTS IMPOSED BY OBJECTIVES

The scientific objectives of Martian exploration impose a number of constraints upon surface material sampling. Those constraints which are considered of major importance are presented in Table 8. Such constraints are always inherent in any sampling program - the constraints are, of course, dependent upon the objectives, the sampling system, type sample desired, and the basic nature of the crustal region of the planetary body under investigation.

In many cases the sampling requirements for any one attribute will satisfy the sampling requirements for a number of other attributes, i.e., there is a great deal of commonality between many attributes as far as sampling requirements are considered. Therefore, when conducting an exploration program by sampling, it will not be necessary to obtain samples of as many sites as might seem to be indicated when considering the number of attributes individually.

Table 8 presents the various exploration objectives and the related attributes for the cases where sampling was found to be applicable in Section 3. The constraints imposed upon sampling by the objectives are presented in the third through the ninth columns. The estimated relative values for sampling (multiple sites) and for single samples (single site) to accomplish the objectives are presented in columns 10 and 11.

Table 8

SAMPLING CONSTRAINTS IMPOSED BY OBJECTIVES

	(1) Objectives	(2) Attributes	(3) Type Sample	(4) Sampling Depth	(5) Area Coverage	(6) Minimum Number of Sites	(7) Site Selection Accuracy	(8) Area Type	(9) Seasonal Consideration	(10) Value of Sampling	(11) Value of Single Samples
Record of Life	Evidence of Extinct Life	Fossils	C & UC	S & SS	Point	20-30	± 2 km	L & D	No	High	Very low
		Hydrocarbons	C & UC	S & SS	Local	8-10	± 100 m	L & D	No	High	No value
		Molecular fossils	C & UC	S & SS	Point	20-30	± 2 km	L & D	No	High	Very low
	Presence of Living Matter	Biochemistry	C & UC	S	Point	20-30	± 2 km	L & D	No	High	Very low
		Metabolism	C & UC	S	Point	20-30	± 2 km	L & D	No	Medium	No value
		Reproduction	C & UC	S	Point	20-30	± 2 km	L & D	No	Medium	No value
		Movement	C & UC	S	Point	20-30	± 2 km	L & D	No	Medium	No value
		Growth	C & UC	S	Point	20-30	± 2 km	L & D	No	High	Very low
		Morphology	C & UC	S	Point	20-30	± 2 km	L & D	No	High	Very low
	Prebiotic Material	Complex organic chemistry	C & UC	S	Point	20-30	± 2 km	L & D	No	High	Very low
Physical Constitution	Physical Properties of the Planet	Differentiation	C & UC	S & SS	Point	4-8	± 2 km	L & D	No	Low	Very low
	Geophysical Properties of the Planet	Magnetic field	C	S & SS	Point	2-4	± 2 km	L & D	No	Low	Very low
	Atmospheric Properties	Sampling Not Applicable									

Key: C & UC = Consolidated and unconsolidated
S & SS = Surface and subsurface
P,L&D = Polar, light and dark areas

Table 8 (Cont'd)

	(1) Objectives	(2) Attributes	(3) Type Sample	(4) Sampling Depth	(5) Area Coverage	(6) Minimum Number of Sites	(7) Site Selection Accuracy	(8) Area Type	(9) Seasonal Consideration	(10) Value of Sampling	(11) Value of Single Samples
Physical Constitution	Structural Properties of Land Forms	Folds	C	S & SS	Local & regional	2-4	± 100 m	L & D	No	Medium	No value
		Faults	C	S & SS	Local & regional	2-4	± 100 m	L & D	No	Medium	No value
		Intrusions	C	S & SS	Local & regional	2-4	± 100 m	L & D	No	High	No value
		Extrusions	C	S	Local & regional	2-4	± 100 m	L & D	No	High	Very low
		Beds	C & UC	S & SS	Local	2-4	± 100 m	L & D	No	Medium	No value
		Unconformities	C & UC	S & SS	Local	2-4	± 100 m	L & D	No	Low	No value
		Fractures	C	S & SS	Local	2-4	± 100 m	L & D	No	Medium	No value
	Physical Properties of Surface Materials	Consolidation	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	High	Low
		Grain sizes	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	High	Low
		Porosity	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Permeability	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Density	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Hardness	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Thickness	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	Medium	No value
	Structural Properties of Surface Rock Materials	Foliations	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Lineations	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Clevage plains	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Joints	C	S & SS	Local	8-10	± 2 km	L & D	No	Medium	No value
		Tectonites	C	S & SS	Local	8-10	± 2 km	L & D	No	Medium	No value
		Vesiculars	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Dragfolds	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Beds	C	S & SS	Local	8-10	± 2 km	L & D	No	Medium	No value

Table 8 (Cont'd)

	(1) Objectives	(2) Attributes	(3) Type Sample	(4) Sampling Depth	(5) Area Coverage	(6) Minimum Number of Sites	(7) Site Selection Accuracy	(8) Area Type	(9) Seasonal Consideration	(10) Value of Sampling	(11) Value of Single Samples
Physical Constitution	Geophysical Properties of Materials	Thermal conductivity	C & UC	S & SS	Local	8-10	± 2 km	L & D	Yes (all)	High	Very low
		Elasticity	C	S & SS	Local	8-10	± 2 km	L & D	No	Medium	Very low
		Electrical conductivity	C & UC	S & SS	Local	8-10	± 2 km	L & D	Yes (all)	Medium	Very low
		Magnetic susceptibility	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Magnetic permeability	C	S & SS	Local	8-10	± 2 km	L & D	No	High	Very low
		Albedo reflectance	C & UC	S	Local	8-10	± 2 km	L & D	Yes (all)	Low	Very low
		Emissivity	C & UC	S	Local	8-10	± 2 km	L & D	Yes (all)	Low	Very low
		Acoustic velocity	C & UC	S & SS	Local	8-10	± 2 km	L & D	No	Low	Very low
	Abiological Activity	Carbon, hydrogen, oxygen reactions	C & UC	S	Point	3-6	± 2 km	P,L&D	No	High	Very low
Active Processes	Seismic Activity	Meteoritic impact	UC	S	Local	2-4	± 2 km	L & D	No	Low	Very low
		Volcanic explosions	C & UC	S	Local	2-4	± 2 km	L & D	No	Low	Very low
	Erosional, Depositional & Transportational Processes	Wind activity	UC	S	Local	2-4	± 100 m	L & D	Yes (all)	Medium	Very low
		Slumping	UC	S	Local	2-4	± 100 m	L & D	Yes (Spring)	Medium	Very low
		Fluidization	UC	S	Local	3-6	± 100 m	P,L&D	Yes (Spring)	Medium	Very low
		Volcanic activity	C & UC	S	Local	2-4	± 100 m	L & D	No	High	Very low
		Micrometeoritic impact	UC	S	Local	2-4	± 100 m	L & D	No	High	Very low
		Chemical Reactions	UC	S	Local	2-4	± 100 m	L & D	No	High	Very low

Table 8 (Cont'd)

	(1) Objective	(2) Attributes	(3) Type Sample	(4) Sampling Depth	(5) Area Coverage	(6) Minimum Number of Sites	(7) Site Selection Accuracy	(8) Area Type	(9) Seasonal Consideration	(10) Value of Sampling	(11) Value of Single Samples
Active Processes	Processes Responsible for Forming & Modifying Land Forms	Igneous activity	C & UC	S & SS	Local	2-4	± 100 m	L & D	No	High	Very low
		Folding	C	S & SS	Local	2-4	± 100 m	L & D	No	Medium	No value
		Faulting	C	S & SS	Local	2-4	± 100 m	L & D	No	Medium	No value
		Subsidence	C	S & SS	Local	2-4	± 100 m	L & D	No	Low	No value
		Meteoritic impact	UC	S	Local	2-4	± 100 m	L & D	No	High	Very low
		Wind activity	UC	S	Local	2-4	± 100 m	L & D	Yes (all)	Medium	Very low
		Fluidization	UC	S	Local	3-6	± 100 m	P, L&D	Yes (Spring)	Medium	Very low
	Nuclear Processes	Rock radioactivity	C & UC	S & SS	Local	4-8	± 2 km	L & D	No	Medium	Very low
Chemical Composition	Chemical Composition of Surface Materials	Elemental composition	C & UC	S & SS	Local & regional	8-10	± 2 km	L & D	No	High	Very low
		Mineralogical composition	C & UC	S & SS	Local & regional	8-10	± 2 km	L & D	No	High	Very low
		Isotopic composition	C & UC	S & SS	Local & regional	8-10	± 2 km	L & D	No	High	Very low
	Chemical Composition of the Atmosphere	Sampling Not Applicable									
	Composition of Surficial Fluids	Liquid constituents	C & UC	S	Local	20-30	± 2 km	P, L&D	Yes (all)	High	Very low
	Macromolecular Distribution	Organic/protoorganic compounds	C & UC	S	Local	20-30	± 2 km	P, L&D	Yes (all)	High	Very low
	Cosmic or Other Extra-Martian Materials	Mineralogical identification	C & UC	S	Local	4-8	± 2 km	P, L&D	No	Medium	Very low

Table 8 (Cont'd)

	(1) Objectives	(2) Attributes	(3) Type Sample	(4) Sampling Depth	(5) Area Coverage	(6) Number of Sites	(7) Site Selection Accuracy	(8) Area Type	(9) Seasonal Consideration	(10) Value of Sampling	(11) Value of Single Samples
Chemical Composition	Surficial Water Distribution	Adsorbed H_2O	C & UC	S	Local	8-10	± 100 m	P, L&D	No	High	Very low
		Free H_2O	N/A	S	Local	8-10	± 100 m	P, L&D	Yes (all)	High	Very low
		Ice	N/A	S	Local	8-10	± 100 m	P, L&D	Yes (Winter)	High	Very low
		Permafrost	N/A	S	Local	8-10	± 100 m	P, L&D	Yes	High	Very low
		Hydrated H_2O	C & UC	S	Local	8-10	± 100 m	P, L&D	No	High	Very low
		Absorbed H_2O	C & UC	S	Local	8-10	± 100 m	P, L&D	Yes (all)	High	Very low
History of Events	Age of Martian Materials	Radioactivity	C	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	Very low
		Relationship of rock units	C & UC	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	No value
	Stratigraphic Sequence of Rock Units	Superposition of rock units	C & UC	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	No value
		Radioactive ages	C	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	No value
		Stratigraphic contacts	C & UC	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	No value
		Rock types	C	S & SS	Local & regional	8-10	± 100 m	L & D	No	High	Very low
	Relationship of Structural Features	Bedding	C & UC	S & SS	Local & regional	2-4	± 100 m	L & D	No	Medium	No value
		Stratigraphic contacts	C & UC	S & SS	Local & regional	2-4	± 100 m	L & D	No	High	No value
		Attitude of strata	C	S & SS	Local & regional	2-4	± 100 m	L & D	No	Medium	No value
		Rock types	C & UC	S & SS	Local & regional	2-4	± 100 m	L & D	No	High	Very low
	Remnant Magnetism	Rock magnetic fields	C	S & SS	Local	4-8	± 2 km	L & D	No	High	Low

The constraints vary somewhat from objective to objective and from attribute to attribute. The entries in Table 8 have, been derived, to a large extent, from the discussion of individual objectives in Section 3. Since it would be repetitive to attempt to justify each of the entries in this table, entry by entry, we will only attempt to give the general rationale for each column. The number of samples required at a given site is dependent, to some extent, upon the sample type (i.e., consolidated and unconsolidated) and the depth requirements. However, there are other requirements which must be taken into consideration. For example, it is rather obvious that to delineate the nature of a structural feature both surface and subsurface samples are required. For some features three or four samples may be adequate, but for others many more would be required. Therefore, we have not attempted to specify the number of samples required at each site but have simply assumed that the appropriate number will be obtained.

The following subsections discuss each of the major constraints listed in Table 8.

4.1 Type Sample

Column 3, "Type Sample," indicates whether there is a requirement for consolidated, unconsolidated, or both types of samples. These are shown by the symbols "C" for consolidated and "UC" for unconsolidated. As is indicated in this column, there is a mixture of sample type requirements. Those attributes which require both consolidated and unconsolidated samples are restricted to those properties (whether they be biological, geological, geophysical, etc.) which exhibit themselves in all types of materials. The detection of fossils is a good example of the requirement for both consolidated and unconsolidated materials. Fossils may be preserved in material which was once unconconsolidated but has subsequently become consolidated, or they may be present in material which has become unconsolidated due to erosion and/or weathering. Alternatively, a remnant magnetic field can only be recorded in consolidated rocks, while the presently active processes of wind erosion and deposition can only be recorded in unconsolidated material. Past wind deposition can be detected however by cross bedding characteristics in rocks which were once consolidated but have subsequently become consolidated.

4.2 Sample Depth

Sampling depth requirements appear in column 4 and only indicate the need for surface (designated by "S") and/or subsurface (designated as "SS") samples. In the context of this report, surface indicates the first meter or two, and subsurface indicates from two meters down to about ten meters or more below the surface. Most of the attributes require that samples be obtained from both the surface and subsurface. However, several attributes require only surface samples. There seems to be no situation which requires only subsurface samples. However this is somewhat deceptive since there is the likelihood that the first few meters of the surface is blanketed with unconsolidated material leaving very little exposed consolidated rock. Since we do not know the actual conditions of the Martian surface at this time, we shall assume that there are both types of materials within any given landing site.

Those attributes which require both surface and subsurface samples include those features and processes which are not dependent upon external conditions, but are rather more internal in nature or are preserved in surface and subsurface materials. For example, a fold which is usually produced by internal processes is recorded in the strata at the surface as well as the subsurface. Similarly, those attributes which are confined to only surface materials are generally produced by processes in the surface materials or externally. This generalization does have exceptions, however. For example, meteoritic impacts penetrate the surface and subsurface to produce features and material characteristics which can be detected in both the surface and subsurface rocks.

4.3 Area Coverage

The area coverage requirement is presented (column 5) primarily to indicate to what extent data are required about the landing sites. There are three designations used to describe the site area coverage required per attribute. They are point, local, and regional.

Point coverage indicates that there is no requirement for samples beyond the immediate area of the point of landing, i.e., within a few meters of the spacecraft. This is based on the considerations that if the attribute is not at the landing point it is not likely to be present within the general area, and that there is no requirement to extrapolate the data beyond the one point. A good example of this would be in the case of magnetic fields and a consolidated sample. A sample is taken of the rock to determine the direction and possibly the strength of the Martian paleomagnetic field at the point of landing. This should be adequate for this attribute since the likelihood of different rock units being in the general area is low. There is also no immediate need to extrapolate the data beyond this point since the magnetic field is not likely to vary a great deal within the general area.

The local-coverage designation implies that there is a need to take samples beyond the immediate point of landing possibly out to several hundred meters, and that there is possibly a need to extrapolate data to a local scale to permit a reasonable interpretation of the attribute. For example, the exploration for hydrocarbons requires that samples be taken of the local area around the feature which they are likely to be associated with.

Finally, the regional coverage requirement is quite similar to the local coverage, but differs in that there is a definite need to sample a much larger area around the landing site, which would provide data necessary to interpret regional distribution or condition. For example, to investigate the structural nature of large features it would probably be necessary to take samples over an area of some hundred of square kilometers in order to get the general trend of the rock units within the area.

4.4 Minimum Number of Sites

The number of sites required, as designated in column 6 are based on several considerations, depending, of course, upon the attribute under investigation. The considerations are: (1) likely distribution, (2) probable concentration, (3) the possible types of land forms, and (4) the three basic types of Martian surfaces (i.e., polar, light, and dark). The minimum number of sites per attribute include 2-4, 3-6, 4-8, 8-10, and 20-30.

The numbers 2-4 indicate a requirement for one to two sites of a particular type feature and of materials associated with a particular feature. As an example, to determine the structural properties of land forms caused by faulting (i.e., grabens, horsts, clifts, etc.) a minimum of two such features should be examined to determine the processes (from the associated material) responsible for forming particular classes of land forms.

The 3 - 6 site requirement indicates that there is a need to sample materials at one to two sites in each of the three different types of surfaces (i.e., polar, light, and dark). An example is the investigation of fluidization. Since fluids may be a process in all three types of areas, each area type should be sampled at least once to determine the extent of present activity.

The 4 - 8 site requirement is based on the need to examine the nature of materials in only the light and dark areas. Rock radioactivity is a good example. Since rocks are believed to be exposed in the light and dark areas, samples should be taken at two to four sites within each of these areas for a total of four to eight sites. This number of sites should be adequate to determine the general radioactive content of the materials which make up these two types of surfaces.

The requirement for 8 - 10 sites is based on the consideration that, in order to get a fairly good idea of the nature and distribution of chemical elements, physical properties, rock types, rock sequence, and rock ages, it is necessary to sample at least four to five sites within both the light and dark areas. This does not mean to imply that the rock units on the Martian surface can be mapped from samples alone from this number of sites. However, with adequate orbital coverage and carefully selected sites, it should be possible to get a first approximation of the distribution of the major types of rock units which make up these areas.

The 20-30 site requirements are imposed when planet-wide attributes are being investigated and where it is necessary to characterize the planet from the sample measurements. The biological attributes are good examples.

4.5 Site Selection Accuracy

The accuracy to which the sampling sites should be located for investigating specific attributes are based on localized surface conditions and distribution of the phenomenon under investigation. We have designated two accuracy requirements: ± 2 kilometers, and ± 100 meters.

The ± 2 kilometers indicates that the attribute is probably not localized or associated with a particular type of surface feature or material. For example, the presence of living matter, if it exists, is probably widespread and not concentrated at any particular location on the Martian surface. It may, however, be almost absent or very sparse within certain areas much as it is on Earth.

The ± 100 meter accuracy indicates that the attribute is localized in nature or requires localized investigation in order to adequately provide sufficient data to permit an interpretation. Examples are structural features and hydrocarbons. Structural features require localized investigation in order to delineate their structural properties while the investigation of hydrocarbons requires a localized investigation since they are usually concentrated at features which are indicative of their accumulation.

4.6 Area Type

As previously indicated, in dealing with site requirements for the exploration of Mars, we must also, at the same point in time, take into consideration the three basically different types of Martian surfaces, i.e., the polar, light, and dark areas. These are the types of Martian surfaces as seen through the telescope. Since the Mariner IV photographic mission detected no differences between the light and dark areas of Mars, it is difficult to conclude whether the differences are produced as a result of physical, chemical, or biological phenomenon. Since, at this time, we do not know the nature of the differences between the light and dark areas, we must treat them as if they were two completely different types of surfaces for the purpose of this study. The requirement to select sites within these areas for sampling is shown in column 8. The area type requirement is indicated by the following: "P" for polar, "L" for light, and "D" for dark.

4.7 Seasonal Considerations

Column 9 indicates whether there are any seasonal requirements which might be of benefit during the investigation of a particular attribute. As can readily be seen, there are only a few attributes which have seasonal requirements. This is as expected since most of the attributes change on a time scale much larger than a season. Those attributes which vary somewhat with the seasons are directly related to meteorological changes, such as fluids, winds, and solar illumination. For example, the wind activity at a particular location on the Martian surface may have an almost negligible effect on changing surface conditions during a particular season, but substantial effect during another season. The same situation holds true for fluid activity.

The seasonal requirements are indicated by a "no" if there is none and by a "yes" if there is a requirement. If there is a seasonal requirement, the "yes" is further modified by the particular season, if there is a requirement to sample during all seasons (i.e., spring, summer, fall, or winter) an "all" is included.

4.8 Value of Sampling/Sample

Columns 10 and 11 give the estimated values of sampling as a technique and of single samples to each attribute, respectively. The value of sampling (i.e., samples taken at numerous sites) as an exploration technique in the exploration of Mars ranges from high to low since only those attributes for which sampling is applicable are included in Table 8. The method used in determining the value of sampling has been subjective but took three things into consideration. These are: (1) whether sampling is the only applicable technique, (2) whether sampling is the best technique to investigate a specific attribute, and (3) the effectiveness of other techniques which can be used to investigate a particular attribute. It should be pointed out that it is only sampling and not the other techniques which are being evaluated.

In contrast to the value of sampling, the value of single samples (i.e., point samples taken at one surface site) have a value range from low to no value. In the case of a single sample, the no value is shown since sampling may be of value to an attribute while at the same time a single sample is of essentially no value. In deriving the value of single samples to the various attributes, the minimum number of sites required and the probability of obtaining data on a particular attribute from one sample were also considered.

It may not be obvious why the value of multiple samples for some attributes can be high, while the value of a single sample can be low or even of no value. A couple of examples may serve to clarify this to some extent. The first example is the case of detecting fossils under the objective "Evidence of Extinct Life." Here sampling is essentially the only technique which is of value and it can provide a large measure of the required data; therefore, sampling is of high value to this attribute. At the same time, however, the likelihood of a single sample containing fossils and providing information must from Earth experience be considered very remote. The second example is for determining the superposition of rock units. The superposition of rock units is found under the objective "Stratigraphic Sequence of Rocks." Here again sampling is of high value in determining the rock sequence of a planet, but at the same time a single sample is of no value since there are no other samples available from other locations to permit extrapolation of data. One sample just is not sufficient to determine the superposition of rock units. Based on considerations such as these, the values assigned for a single sample to the attributes were founded on the premise that all samples will be obtained from surface sites most appropriate to the attributes under investigation.

5. VALUE SUMMARY OF SAMPLING AND OF A SINGLE SAMPLE TO TOTAL EXPLORATION

This section summarizes the value of sampling and the value of a single sample to investigating all the listed attributes and are presented in Table 9.

The value of sampling to individual attributes is shown in the first column to the right of the attributes while the value of samples at a single site are shown in the last column. There are five possible value ratings for sampling and a sample in terms of its applicability to the listed attributes if we include the no value rating. They are: high, medium, low, very low, and no value. In actuality there are only three ratings which have been found to apply to a single sample, they are low, very low, and no value.

Since no attempt has been made to rank-order the objectives or attributes in terms of their importance to Martian exploration, we will assume, that all the objectives and attributes are equally important for the purposes of determining the value of sampling in the context of this report. We recognize that, in fact, this is not the true situation.

The evaluation of sampling is directed at total Mars exploration in contrast to just sample-applicable objectives and attributes as was the case in Section 4. According to Table 9 there are 49 attributes for which sampling has high value, 24 which have medium value, nince which have low value, and 28 for which

Table 9

VALUE SUMMARY OF MULTIPLE SAMPLES VS. SINGLE SAMPLE TO TOTAL EXPLORATION

	Objectives	Attributes	Multiple Sample vs. Single Sample	
			Value of Sampling	Value of Single Sample
Record of Life	Evidence of extinct life	Fossils	High	Very low
		Hydrocarbons	High	No value
		Molecular fossils	High	Very low
	Presence of living matter	Biochemistry	High	Very low
		Metabolism	Medium	No value
		Reproduction	Medium	No value
		Movement	Medium	No value
		Growth	High	Very low
		Morphology	High	Very low
	Prebiotic material	Complex organic chemistry	High	Very low
Physical Constitution	Physical properties of the planet	Figure of planet	No value	No value
		Differentiation	Low	Very low
		Density distribution	No value	No value
		Mass distribution	No value	No value
		Topography	No value	No value
		Librations	No value	No value
	Geophysical properties of the planet	Magnetic field	Low	Very low
		Gravity field	No value	No value
		Seismic waves	No value	No value
		Thermal regime	No value	No value
		Elasticity	No value	No value
		Rigidity	No value	No value
	Atmospheric properties of the planet	Wind profile	No value	No value
		Synoptic meteorology	No value	No value
		Temperature profile	No value	No value
		Energy balance	No value	No value
		Density profile	No value	No value
		Pressure profile	No value	No value
		Dust particles	No value	No value
		Humidity	No value	No value
	Structural properties of land forms	Folds	Medium	No value
		Faults	Medium	No value
		Intrusions	High	No value
		Extrusions	High	Very low
		Beds	Medium	No value
		Unconformities	Low	No value
		Fractures	Medium	No value

Table 9 (Cont'd)

			Multiple Sample vs. Single Sample	
	Objectives	Attributes	Value of Sampling	Value of Single Samples
Physical Constitution (Cont'd)	Physical properties of surface materials	Consolidation	High	Low
		Grain sizes	High	Low
		Porosity	High	Very low
		Permeability	High	Very low
		Density	High	Very low
		Hardness	High	Very low
		Thickness	Medium	No value
	Structural properties of materials	Foliations	High	Very low
		Lineations	High	Very low
		Clevage plains	High	Very low
		Joints	Medium	No value
		Tectonites	Medium	No value
		Vesicles	High	Very low
		Dragfolds	High	Very low
		Beds	Medium	No value
	Geophysical properties of materials	Thermal conductivity	High	Very low
		Elasticity	Medium	Very low
		Electrical conductivity	Medium	Very low
		Magnetic permeability	High	Very low
		Magnetic susceptibility	High	Very low
		Albedo reflectance	Low	Very low
		Emissivity	Low	Very low
		Acoustic velocity	Low	Very low
Active Processes	Abiological activity	Carbon, hydrogen, oxygen react.	High	Very low
	Seismic activity	Quakes	No value	No value
		Meteoritic impacts	Low	Very low
		Volcanic explosions	Low	Very low
		Microseisms	No value	No value
	Erosional, depositional and transportational processes	Wind	Medium	Very low
		Temperature fluctuations	No value	No value
		Slumping	Medium	Very low
		Soil creep	No value	No value
		Wedging	No value	No value
		Fluid	Medium	Very low
		Volcanism	High	Very low
		Meteoritic	High	Very low
		Chemical Reactions	High	Very low

Table 9 (Cont'd)

	Objectives	Attributes	Multiple Sample vs. Single Sample	
			Value of Sampling	Value of Single Sample
Active Processes (Cont'd)	Processes responsible for forming and modifying land forms	Igneous materials	High	Low
		Folds	Medium	No value
		Faults	Medium	No value
		Subsidence	Low	No value
		Meteoritic materials	High	Very low
		Winds	Medium	Very low
		Fluids	Medium	Very low
	Nuclear processes	Cosmic ray flux	No value	No value
		Radiation level	No value	No value
		Rock radioactivity	Medium	Very low
Chemical Composition	Chemical composition of materials	Elemental composition	High	Very low
		Mineralogical composit.	High	Very low
		Isotopic composition	High	Verv low
	Chemical composition of the atmosphere	Molecular identification	No value	No value
		Molecular distribution	No value	No value
	Composition of ~~surficial fluids~~	Liquid constituents	High	Low
	Macromolecular distribution	Organic/protorganic molecules	High	Very low
	Cosmic or other extra Martian materials	Mineralogical identification	Medium	Very low
	Surficial water distribution	Adsorbed water	High	Very low
		Free water	High	Very low
		Ice	High	Very low
		Permafrost	High	Very low
		Hydrated water	High	Very low
		Absorbed water	High	Very low
History of Events	Age of Martian materials	Radioactivity	High	Very low
		Relationship of rock units	High	No value

Table 9 (Cont'd)

	Objectives	Attributes	Multiple Sample vs. Single Sample	
			Value of Sampling	Value of Single Sample
History of Events (Cont)	Stratigraphic sequence of rock units	Superposition of rocks Radioactive ages Stratigraphic contacts Petrography classification	High High High High	No value No value No value Very low
	Relationship of structural features	Bedding Stratigraphic contacts Attitude of strata Morphology Rock types	Medium High Medium No value High	No value No value No value No value Very low
	Remnant magnetism	Rock magnetic fields	High	Low

sampling has no value. We can see from this that by including all attributes the average value of sampling for total Martian exploration is somewhat lower than is indicated in Section 4 where only the sample-applicable attributes were treated. This is due primarily to the fact that there are 28 attributes for which sampling is not applicable and which have not been taken into consideration in Section 4. The values for sampling do not, as previously indicated, take into account the best possible mixing of all investigating techniques which could conceivably be used for the exploration of Mars. Therefore, the value of sampling to those attributes for which other techniques are also applicable may be somewhat lower than is indicated herein. We have also assumed that all samples will be taken at locations most favorable to the individual attributes in our evaluation of the worth of sampling.

The value of a single sample as compared to that of sampling, is of very low value to the exploration of Mars. In fact, according to our analysis indicated in Table 9, it would appear that a single sample is of very low to almost no value. There are 58 attributes for which a single sample could provide some information, and 52 for which a single sample will provide essentially nothing. Therefore, considering the fact that only 58 of the 110 attributes have very low value and none have a value higher than low, we can conclude that even if the sample was obtained at a location where all of the attributes were present, the best possible value for a single sample would be of very low value. However, since we know that it is impossible to find all of the attributes at one site the actual value would be even lower than is indicated.

6. CONCLUSIONS

The major conclusions of this study are:

(1) Sampling is, in general, a valuable investigation technique for obtaining information on Mars.

(2) The disciplines most dependent on sampling for investigating Mars are geology and biology.

(3) Samples at a single point site on Mars apply to the majority of objectives but only to a very limited extent in each case.

(4) Samples at a single site will do more to indicate further sample requirements than to characterize the properties of Mars itself.

The present study should be regarded as a first step in the evaluation of investigation techniques in the exploration of Mars. The listed objectives should be reviewed to ensure their completeness for total exploration. The applicability of all investigation techniques should be revised with particular emphasis on the interrelationships between them. The sampling constraints included in Section 4 have been restricted to planetological constraints. As important, if not more so, are the constraints which will be imposed by the objectives on sampling missions and on the treatment of the samples during acquisition, storage, and analysis. Appendix 2 has been attached to this report since it represents the type of detailed considerations which probably should be included in any further studies. Appendix 2 also discusses the mass and volume requirements for a Martian sample as related to disciplines and sub-disciplines.

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Appendix 1

SCIENTIFIC QUESTIONS IN THE EXPLORATION OF MARS

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Appendix 1

SCIENTIFIC QUESTIONS IN THE EXPLORATION OF MARS*

The major scientific questions to be asked in the exploration of Mars can be grouped under six main headings:

Exobiology

Is there or has there ever been life of any kind of Mars? What is the chemistry of this life? How is it adapted to an environment quite different from that on Earth? What is the past environment from which it evolved and what is the evolutionary sequence of life forms? On the other hand, there may be no life at all, either extant or extinct, in which case the problem is to search for proto-organic materials. The biological aspects of the exploration of Mars already have been discussed in some detail in the report of a Space Science Board group under the title "Biology and Exploration of Mars" (published by NAS-NRC, April 1965, 19 pp.) to which reference should be made.

Differentiation

Is Mars differentiated into a core, mantle, and crust and are there areal as well as vertical differences? If

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*Space Research Directions for the Future, Report of a study by the Space Science Board, Woods Hole, Massachusetts, 1965.

differentiated, then is the process still functioning or is this a feature accomplished during the original accretion of the planet or by subsequent radioactive heating and chemical processes? The prime requirements are refinements in determination of mass, shape, and movements of inertia, coupled with natural or active seismic exploration and heat flow measurements.

Activity

Is Mars now, or has it ever been, an active planet from a seismic, volcanic, and tectonic point of view? The answer will necessitate search for present and past tectonic patterns; investigation of types and classes of folding, faulting, mountains, and craters; determination of seismic activity, heat flow, magnetic field, and many other standard geophysical parameters. The combination of these data with similar data about the Earth will provide a powerful couple for understanding the internal driving forces of both planets.

Composition

What is the physical, chemical, and mineralogical composition of Mars? Did Mars come from the same chemical crucible as did the Earth, and what physical and chemical processes have operated to modify its original constitution? The answers will require analysis of volcanic rocks, atmosphere, sediments, any volcanic gases, and determination of some of the isotopic ratios. Of considerable importance is the role of water, possibly in fossil oceans, in these processes as compared with its major role in development of Earth's geochemical character.

History

What has been the history of Mars? The time scale and sequence of major events on the planet must come from the rock record of those events. This means crude reconnaissance geological mapping by a variety of remote image devices to work out the sequence of superposition of the various strata and their relationship to major events in the planet's history. Coupled with this must be an understanding of the interactions of the dominant surficial processes of erosion, transport, and deposition. This time sequence must eventually be keyed into absolute ages, first by estimation of rate processes and eventually by radioactive age dating of some samples.

Atmospheric Dynamics

What is the character of the general circulation of the Martian atmosphere? Is it in the symmetric or the wave regime, and does the regime change with season? If in the wave regime, what is the characteristic wave - number, amplitude, phase speed, and internal structure of the waves? What is the relation of this large-scale circulation to the thermal structure and to the cloud forms and violet layer on Mars? What nonhydrostatic or mesoscale circulations are present in the Martian atmosphere? What is the character of the surface boundary layer? How do the boundary layer motions, the mesoscale motions, and the general circulation interact to raise dust particles from the surface and to transport the suspended dust and wind-blown sand? How do these various scales of motion affect the transport of water vapor within the atmosphere, especially the cross-equatorial transport, with the corresponding geographical and seasonal variation of the flux of water vapor across the air-ground interface? The answers to these questions, which can be obtained from theory combined with observations from instrumented orbiters and entry probes, will increase our knowledge of the dynamics of planetary atmospheres and provide essential information for many aspects of the biology and surface geology of Mars.

Appendix 2

MASS AND VOLUMETRIC CONSIDERATIONS FOR A SAMPLE RETURN

Appendix 2

MASS AND VOLUMETRIC CONSIDERATIONS FOR A SAMPLE RETURN

A serious problem connected with sample return is establishing some sound rationale for establishing acceptable bounds on mass and volume for the collected sample. One method of establishing a sample size is to total the minimum sample requirements of parties interested in Martian sample analysis.

Such a number can then be compared with mass and volume constraints which may arise from purely technical/engineering constraints. Such a comparison can illuminate the degree to which the engineering constrained sample package fulfills the requirements of the experimenters. If compromises in mass and volume must be affected, it may also provide a means for establishing which groups of experimenters will suffer the most and which will suffer the least. A still further utility is the identification of which disciplines make the most serious mass and volume constraints upon the package.

While the bulk of our study does not constrain the package, but asks only that the sample package fulfill a scientific objective irrespective of mass and volume, we still find it useful to connect the utility of the sample (expressed in mass and volume) with scaling numbers useful in preliminary design studies.

The roster of scientific disciplines and branches published by the National Science Foundation (and periodically updated) serves as a source listing for interested parties to the AMSR. The roster in question, while possibly excluding some disciplines, is thought to be the most complete list of its kind in existence. We went through the listing calling every conceivable discipline, group, and branch that might have some interest in a Mars sample return. Such a listing expressed in terms of their mass and volume requirements for their laboratory analysis must surely give some order of magnitude estimate, if not an absolute upper bound, on the usefulness of a Mars sample return with a given specific mass and volume.

Of the two items, mass and volume, we shall first treat mass. When the limit on mass has been established, we shall then compute upper and lower bounds on volume. Limits on volume are taken from recent estimates of the density of bright and dark areas on Mars as respectively 1 gm per cc and 2.5 gm per cc.

In arriving at the sample size requirements for the subdisciplines listed by the NSF, we attempted to establish an order of magnitude estimate of the smallest sample which could be handled by the groups using regular analysis techniques. First it was thought that spectroscopists could work with samples on the order of 100 micrograms, whereas people interested in stratigraphic composition would require samples of the order of tens of grams. We nominally assigned to each subdiscipline 10 assays from the return sample, each weighing the bare minimum mass. This number 10 is somewhat arbitrary in that this is a lower bound. However, as the analysis develops, it will be shown below that this number in many cases could be increased to 100 without significant increases in the total sample size. It must be remembered that the use of 10 random assays from the sample, say for microchemical analysis, implies a statistical analytical distribution of the return sample, rather than a continuous distribution. It remains the function of the body of the report, in which are discussed detailed scientific objectives, to determine whether this statistical distribution is adequate to the task. In summing the requirements of individual disciplines using a statistical analysis of the return sample, we also sidestep the question of priority, which is implicit in the assignment of all or a large portion of the return sample to a particular discipline or subdiscipline.

We also sidestep a more subtle problem, namely, that in preparing samples for use by several parties, we may be able to accomplish certain tasks that, for instance, require sectioning of the samples. We also do not consider the overlap of measurements which are made on the bulk sample, such as reflectivities or acoustical transmission properties, but which do not affect the sample integrity for purposes of further analysis. For example, we may make microchemical analysis or nuclear counting analysis for radioactivity levels.

In the accompanying Table 2-1, we have listed the major fields which are chemistry, physics, astronomy, geology, all biological sciences, and some aspects of engineering. A few miscellaneous areas such as archeology and photogrammetry were also considered, but these affect the whole sample. In the first column of the table is the subspecialty, e.g., under Chemistry, analytical. The next column contains the branch of the discipline, and finally the last two columns contain respectively the quantity q, in fractions of a gram, and the quantity (nominally set at 10). To be specific we choose the example of analytical chemistry and the biochemical analysis where we have set the quantity at 1 milligram and taken 10 assays. We assume that a complete biochemical analysis will be done on each 1 milligram sample. It is quite clear that we could go to 10 or 100 milligrams in this particular case, without adding a great deal of weight to the sample. The increase would be from 10 milligrams to a total of 100 or 1000 milligrams, which is still only a single gram for biochemistry. At the end of each subspecialty we have totaled our lower estimate of mass for the disciplines contained. In a few cases, namely botany and ecology, no detailed breakdown is given, but a sample of 10 grams is arbitrarily assigned to that discipline.

What has emerged from this breakdown are three broadly based mass categories. The mass categories concern themselves with microstructure of microchemical analysis, with microscopic properties and/or bulk parameters, and a category which requires large samples because they depend on distribution of materials for analysis. By far the largest category is the first, namely microchemical or microstructure analysis. A somewhat smaller group of disciplines fall into the second category, namely microscopic samples up to the order of 10 grams; only a very few disciplines, primarily geological disciplines, fall into the third category. This division by mass has implication for various degraded modes of sample return which are discussed elsewhere. The connection is the following. Those items which depend on microchemical structure of microchemical analysis in general tend to be independent of the orientation and condition of the return sample, providing it is not pyrolyzed. Bulk properties are likewise, to a certain extent, independent of rough handling. However, those which depend on geological inferences about distribution in bulk samples (to the order of a kilogram) are definitely degraded if subjected to rough handling or heat damage. This puts these samples in the same special handling category as biological samples. Since biology is presumed to be paramount, we can assume that samples in all categories in the ideal case, will receive adequate handling. However, it is worthwhile to note what can be salvaged should portions of the mission go awry.

The totals we have reached on the total mass are of the order of 250 grams exclusive of geology. Geology adds an additional 250 grams, bringing the total to 500 grams, or slightly over one pound. This analysis has arrived, then, at a number which agrees with the study conducted on the AMSR (Niehoff 1967) mission in which one pound of sample was used as an approximate scaling factor. A somewhat more generous allowance for chemical analysis and geology, which depends on distribution of structure, raises the total to no more than 1 kilogram. To a first approximation this is within the framework of the previously mentioned AMSR feasibility study.

Since certainly there will be fewer groups than we have listed in the accompanying table, we may then take it as a working hypothesis that a 250 to 500 gram sample will be adequate to satisfy most disciplines. The problem of auxiliary samples to which some discussion exists elsewhere,is not addressed by our current discussion. There, additional single constraints establish the package. For instance, a biological control need not be more than 1 to 10 grams since it serves only as a source for innoculant. Likewise, control samples for chemical analysis need only be in the 1 to 10 gram range.

Coarse samples are in a somewhat different class than those that we have discussed, where the tacit assumption has been made that the sample was unconsolidated, or at most, loosely consolidated.

Taking the number of 500 grams as some sort of working hypothesis, we then can estimate volumetric constraints as follows. For the 2.5-gm-per-cc estimate (a figure characteristic of terrestrial rocks), we arrive at a volume of 200 cc. This is a lower bound. Using the figure of 1 gm per cc (a figure characteristic of silt or dry sand), we arrive at 500 cc. This is an upper bound. Of course the presence of a few rocks or stones in an otherwise unconsolidated sample changes this picture. However, we seek here only to establish upper and lower limits.

Table 2-1

PARTIAL LIST OF INTERESTED DISCIPLINES IN MARTIAN SAMPLES

(From National Register of the NSF)-
Related to Sample

Major Field	Sub-specialities	Branch	Q	No.
Chemistry	Analytical	X-ray diffraction	1 mg	10
		Biochemical	1 mg	10
		Microchemical	.1 mg	10
		Mass spectroscopy	.1 mg	10
		Gas analysis	1 mg	10
		Chromatographic	1 mg	10
		Spectroscopy	.1 mg	10
				43 mg
	Inorganic	Atomic structure	1 mg	10
		Radio chemistry	1 mg	10
		Nonmineral products	1 mg	10
		Reaction kinetics	1 mg	10
		Various families in periodic table	1 mg	10
		Solvent theory	.1 mg	10
				32 mg
	Organic	Agricultural chemicals	1 mg	10
		Alkaloids	1 mg	10
		Amino acids/proteins	1 mg	10
		Stereochemicals	1 mg	10
		Reaction-mechanisms	.1 mg	10
		Phosphorous compounds	1 mg	10
		Carbohydrates	1 mg	10
		Ring compounds	1 mg	10
		Aliphatic chemicals	1 mg	10
		Heterocyclics	1 mg	10
				9.2 mg
Physics	Acoustics	Ultrasonics	1 g	1
		Electrocoustics	1 g	1
				1 g

Table 2-1 (Cont'd)

Major Field	Sub-specialities	Branch	Q	No.
Physics	Atomic and molecular	Mass spectroscopy	10μg	10
		Atomic structure	100μg	10
		Atomic mass/abundance	100μg	10
		Spectra	100μg	10
		Surface effects	100 mg	5
				.5 mg
	Electro-magnetism	Electron microscopy	10 mg	1
		Magnetism	1 g	1
				1 g
	Elementary particle	Cosmic ray intensities	10μg	10
	Mechanics	Elasticity	1 g	5
		Friction	1 g	5
		High pressure	1 g	5
		Impact	1 g	5
				20 g
	Nuclear	Nuclear spectroscopy	100μg	10
		Nuclear reactions	100μg	10
		Radiation effects	100μg	10
		Radiation properties	100μg	10
				>.5 mg
	Optics			
		IR	100mg	5
		Interferometry	100mg	5
				1.0g
	Fluids	Aerosols	1g	
		Viscosity	1g	
		Rheology	1g	
				3g
	Solid State	Crystallography	1g	3
		Dielectronics	1g	3
		Thermal Conduction	1g	3
		Surface Structure	1g	3
		Optical Properties	1g	3

Table 2-1 (Cont'd)

Major Field	Sub-specialities	Branch	Q	No.
Physics	Solid State	Luminescense	1g	3
		Photoelectric	1g	3
				21g
	Thermal	Calorimetry	1g	3
		Thermal Properties	1g	3
				6g
	Other	Standards/Units	10g	
Astronomy	Cosmology			
Geological Type	Atmosphere	Composition	10g	
	Dynamics	Planetary Atmosphere	10g	
		Radiation	1μg	
		Turbulence/Dif.	10g	
		Thermodynamics	1g	
				12g
	Climatology	Biodimatology	10g	
		μ Bioclimatology	10g	
		Paleo Bioclimatology	10g	
				30g
	Special Areas	Agricultural	10g	
		Polar		
				10g
	Geochemistry	Cosmochemistry	1μ	10
		General Inorganic	1μg	10
		Geochronology	1μg	10
		Mineral Syntheses/ Stability	100μg	10
		Organic Geo.	100μg	10
				3.2g
	Geology	Mineral	100g	3
		Geomorphology	100g	3
		Crystallography	50g	3
		Petrography	50g	3
		Stratigraphy	100g	3
		Structural	100g	3
				500g

Table 2-1 (Cont'd)

Major Field	Sub-specialities	Branch	Q	No.
Geological Type	Paleontology	μ-paleontology	10g	10
		Paleobotany	10g	10
		Palynotogy	10g	10
		General	10g	10
				109
	Geophysics	Heat Flow	1g	5
		Physical Properties	1g	5
				10g
	Geography	Physical	1g	5
		Biogeography	1g	5
				10g
	Hydrology	Evaporation/Transpiration	.1g	10
		Ground H_2O	.1g	10
		Soil Moisture	.1g	10
		Snow, Ice, permafrost	.1g	10
				4g
Biology	Botany		1g	10
				10g
	Entomology	Taxonomy	1g	
				1g
	Genetics	μ-organisms	1g	10
		plant		
				10g
	Immunology	Anti-body formation	1mg	10
		Cell Culture	1mg	10
		Infection	1mg	10
		Vaccines	1mg	10
				40mg
	Micro Biology	Antibiotics	1mg	10
		Bacteriology	1mg	10
		Cytology	1mg	10
		Metabolism	1mg	10
				40mg

Table 2-1 (Cont'd)

Major Field	Sub-specialities	Branch	Q	No.
Biology	Microbiology	Microbinal process	1 mg	10
		Mycology	1 mg	10
		Parasitology	1 mg	10
		Protozoology	1 mg	10
		Toxonomy	1 mg	10
				50 mg
	Nutrition	Amino/peptides/ proteins	1 mg	10
		Energy metabolism	1 mg	10
		Enzymes	1 mg	10
		Lipids	1 mg	10
		Minerals (trace)	1 mg	10
		Nutrients (per se)	1 mg	10
		Vitamins	1 mg	10
				70 mg
	Pharmacology	Biochemical	1 mg	10
		Drug metabolism	1 mg	10
				20 mg
	Phytaphotology	Bacterial	1 mg	10
		Fungal	1 mg	10
		Host resistance	1 mg	10
				30 mg
	Virology		1 mg	10
				100 mg
	Zoology	Cytology	10 mg	10
		Parasitology	10 mg	10
		Protozoology	10 mg	10
				300 mg
	Agronomy	Seeds	.1 g	10
		Micro-organisms	1 mg	10
		Plant growth regulators	1 mg	10
				1.29 mg

Table 2-1 (Cont'd)

Major Field	Sub-specialities	Branch	Q	No.
Interdisciplinary Specialities	Biochemistry		.1 mg	10
				10-50 mg
	Biophysics		10 mg	
	Physical chemistry	Chemical kinetics	.1 mg	10
		Electrochemistry	.1 mg	10
		Salts	.1 mg	10
		Phase study	.1 mg	10
		Polymer	.1 mg	10
		Radiatives	.1 mg	10
		Surface chemistry	10 mg	5
				10.6 mg
	Soil	Soil chemistry	1 mg	10
		Soil bacteriology	1 mg	10
		Soil genis	1 mg	10
		Soil mechanics	1 g	10
		Soil mineralogy	1 g	10
				20.3 g