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NASA
National Aeronautics and
Space Administration

A Mars 1984 Mission

Report of the

Mars Science Working Group

July 1977

A MARS 1984 MISSION

Recommendations

and

Summary Report

of the

Mars Science Working Group

INTRODUCTION

The Mars Science Working Group (MSWG) was formed at the request of NASA to provide the science rationale for post-Viking Mars exploration and to work with a group at the Jet Propulsion Laboratory that was studying the technical feasibility of a 1984 mission. Under the chairmanship of Thomas A. Mutch the committee has met four times in the first half of 1977 and has convened numerous sub-committee meetings to consider a wide range of scientific and technical issues.

This section (yellow pages) is a self-contained summary report with the committee recommendations. The full report, with a description of the MSWG's task, its membership and recommendations comprises the bulk of this document (white pages).

RECOMMENDATIONS OF THE MARS SCIENCE WORKING GROUP

SCIENCE OBJECTIVES

The Mars Science Working Group (MSWG) concludes that a 1984 mission to Mars should address the following objectives, all of which are attainable with the proposed orbiter-penetrator-rover mission design (no prioritization is implied by the order):

1) Characterize the internal structure and dynamics of the planet.

2) Characterize the chemistry and mineralogy of surface and near-surface materials on a global and regional scale.

3) Determine the chemistry and mineralogy of rock and soil samples, especially as related to the reactive surface chemistry observed by Viking.

4) Document geologic characteristics of major landforms, toward an understanding of current and past surface processes.

5) Determine the distribution and state of H_2O and other volatiles, toward an understanding of the chemical evolution of the regolith and atmosphere.

6) Characterize the global dynamics of the atmosphere.

7) Measure the planetary magnetic field and study the interaction of the upper atmosphere with the magnetic field, the solar radiation, and the solar wind.

SCIENCE INSTRUMENTS

The MSWG concludes that the 1984 mission goals could be achieved with the following instruments:

Orbiter: cameras, gamma ray spectrometer, reflectance spectrometer, radar altimeter, magnetometer, IR atmospheric sounder, plasma probe, UV spectrometer.

Rover: cameras, simple microscope, sample processor, element analyzer, X-ray diffractometer, reflectance spectrometer, mass spectrometer system (organic and inorganic), electrical sounder, active seismic experiment, 3-axis broad-band seismometer, magnetometer, meteorology station.

Penetrator: 3-axis seismometer, element analyzer, soil-water analyzer, atmospheric pressure sensor, photometer.

Entry: neutral mass spectrometer, retarding potential analyzer.

Preparatory to formal selection of instruments in response to an Announcement of Opportunity, we recommend that NASA vigorously pursue a program of instrument development.

OTHER CONCLUSIONS

Achievement of the objectives of this mission will contribute substantially to our understanding of the potentialities for life on Mars. By investigating the local physical and chemical environments, and by searching for organic compounds, the mission will shed light on the question of whether life could have arisen in the past, and will also address the possibility that living systems are still present. Furthermore, the anticipated data will add to our understanding of the reactive surface chemistry observed by Viking.

The sophisticated nature of the rover science payload reflects our guiding philosophy that the rover should be a self-contained scientific laboratory, capable of traversing at least 100 miles. Length of specific traverses will depend on the characteristics of the landing site and on real-time operational decisions regarding appropriate balance between travel and in situ analysis.

The MSWG concludes that all three vehicular elements -- orbiter, penetrator, and rover -- are essential to the accomplishment of mission goals as previously defined by the Space Science Board, and as determined by the MSWG. Deletion of any one vehicle will require a major reassessment of science instruments and operational strategy.

The MSWG adopts the premise that the 1984 mission is the next logical step in the exploration of Mars. At a future date (1990?) a sample return mission is envisioned by the Space Science Board. Although the 1984 mission stands independently of a subsequent sample return mission, the 1984 experiments will provide new information that will optimize strategy for returning samples. Planning for a Mars sample return should be carried out in coordinated fashion with the planning and conduct of the 1984 mission.

The MSWG recommends that continued attention be devoted to both the acquisition and analysis of data to support the 1984 mission. These data should include Viking orbiter images, infrared and radio occultation data, and ground-based radar observations.

SUMMARY REPORT

A MARS STRATEGY

At the time when the Viking mission was at a planning stage comparable to that of the presently considered mission, Mars was perceived to be a relatively simple planet, rather like the Moon, but with a thin atmosphere and some dynamic features that could be observed in telescopic images by acute observers. The Mariner 4, 6 and 7 data then in hand provided few hints of the highly varied surface features that we now know Mars to possess. Subsequently Mariner 9 data demonstrated that the planet has had a long and complex evolution, one that continues to this day: Mars is certainly intermediate in evolution between the Moon and the Earth.

The Viking experiment payload was chosen to emphasize biological investigations. The likelihood of there being life on Mars is somewhat diminshed as a result of the Viking experimental results but interest in the planet has, nevertheless, been considerably enhanced by the exciting observations that the Viking landers and orbiters have made. To cite only a few of the provocative determinations: soil samples contain highly reactive oxidizing materials; bulk chemistry of soil samples suggests uniformly weathered material; residual polar caps are composed of water ice; atmospheric rare gas and isotopic abundances suggest a former denser atmosphere; large channels, probably carved by water, score the surface.

Dynamic variations have been observed during the one-year course of the Viking mission: changes in atmospheric pressure related to the waxing and waning polar caps; diurnal and seasonal changes in atmospheric water vapor abundance; formation of near-surface fogs; tidal winds; generation of two global-scale dust storms and associated darkening of the skies at the landing sites.

Viking data have raised more questions than they have provided answers. This should come as no surprise. It is simplistic to assume that any complex environment can be completely understood in the wake of a few specific investigations carried out under constrained conditions. It would be equally simplistic to argue that any single mission in the future will answer all of the questions regarding the composition and evolution of Mars.

The Viking mission, by virtue of its sophisticated scientific yield, sets a pattern for subsequent missions. The questions before us now, many of which could not be addressed by the Viking experiments, are sufficiently complex and wide ranging that an ambitious strategy for the future is required. Small-scale missions, such as orbiters, or orbiters with hard landers are likely to be, by themselves, inadequate. Both with respect to scientific yield and exploratory context, they would be a step backward.

Viking has demonstrated the feasibility of operating sophisticated analytical laboratories on the surface of Mars. The next step is a rover that can operate in a variety of different environments. The capability to travel across the Martian terrain making a variety of scientific measurements is indeed the key to this mission. Coupled to a rover mission, orbiters and penetrators provide integrating value that they separately lack. We contend that the global reconnaissance carried out by the orbiters, the network science and limited characterization of otherwise inaccessible environments carried out by the penetrators, and the detailed study of local environments conducted by the rover provide complementary benefits. Elimination of any one of the three vehicular elements necessitates major reassessment of total mission science goals.

An orbiter/penetrator/rover mission is conceived as one element in a continuing program of Martian exploration. Scientifically important in its own right, such a mission is a required precursor to a sample return mission. We argue that it would be a mistake to move directly from Viking to sample return. Many important scientific questions can only be resolved by in situ investigations. Geophysics experiments -- seismic, magnetic, and thermal -- provide a good example. Although Viking apparently has not detected life, the possibility of unusual small-scale environments conducive to life, or at least protected from the oxidizing conditions documented by Viking, cannot be discounted.

It is obvious that the chemical and mineralogical techniques available in a terrestrial laboratory far exceed anything that can be delivered and operated remotely on the surface of Mars. Eventual sample return is, therefore, dictated. However, Viking data convey a note of caution. The most remarkable characteristic of Viking soil samples is the reactive surface chemistry. The clues to atmospheric-lithospheric interactions may reside in loosely-bound complexes or in interstitial gases. These chemical situations can be

effectively studied <u>in situ</u> but would be extraordinarily difficult to preserve in a returned sample, especially a sample that had undergone any disequilibrium sterilization.

In summary, we believe that continuing exploration of Mars promises a rich scientific yield in areas that are directly or indirectly related to an understanding of our own planet, Earth. We conclude that the program of Martian exploration is most effectively advanced by an orbiter/penetrator/rover mission in 1984.

THE MAJOR SCIENCE QUESTIONS

Internal Structure

Knowledge of the interior is essential for obtaining the bulk composition of Mars and establishing its origin. On the basis of geological, geochemical, and geophysical evidence it is reasonable to assume that Mars is a differentiated planet. Like Earth, it probably has a crust, mantle and core. However, the dimensions and densities of the core and mantle are presently unknown. Consequently, there is no way to determine composition and to develop a unique differentiation history. A direct determination of the size of the core by seismic methods will constrain the overall composition of the planet. Although there is a seismometer working on Mars at present, one instrument is insufficient to determine the internal structure. Seismometers deployed globally by penetrators, and locally by rovers, will provide a sensitive array that can acquire the needed data.

An array of four or more solidly emplaced seismometers will allow Martian quakes to be located and characterized. This information is vital in understanding the internal structure and the tectonic state of the planet. For example, measurements of quakes in the Tharsis region would speak to the issue of recent vulcanism and of long-term crustal adjustment to disequilibrium loads.

The strength and nature of the Martian magnetic field are still unknown. This stands out as a singular deficiency in our rapidly increasing inventory of knowledge regarding Mars. An important test would involve measurement of the magnetospheric field to determine whether it is primarily the result of dynamo influences, or induction. Such measurements can be carried out by complementary plasma probes and magnetometers carried on orbiters. Furthermore, it is essential that magnetometers be deployed on the surface using the rovers as a transporting device. Such magnetometers can be used to measure the response of the crust and upper mantle to the changing magnetic environment measured in orbit and can, thereby, provide information about the state of these regions.

Heat flow measurements are both unusually instructive and notoriously difficult to make. The flow of heat to the surface not only indicates the present thermal environment but permits reconstruction of thermal evolution. Direct measurement of the thermal gradient via sensors on penetrators or in drilled holes may be impractical. Alternately, the determination of a liquid-solid transition at the base of a near-surface permafrost layer by seismic and electrical profiling could characterize the temperature distribution in the upper crust. Such 'active' experiments can be performed by the combination of rover and deployed science station.

Global Geochemistry

Present chemical knowledge of Mars is restricted principally to measurements of apparent clay-rich weathering products at the two Viking landing sites. Telescopic measurements provide additional data, revealing major albedo variations and absorption features attributed to variable types and amounts of basalt-forming minerals. Further knowledge of the chemical composition of the various regions of Mars is essential to an understanding of crustal evolution. K, Th, and U abundances are particularly important as a petrologic signature and as a clue to the thermal environment at the time of accretion.

The 1984 strategy is to make a global geochemical survey from orbit with the use of a gamma ray spectrometer. The spectrometer will not only map the abundance of the radioactive elements K, Th and U, but also will map major elements such as O, Si, Fe, Mg, Ti, Al, and S. Particularly important are determinations of volatile elements H and C over the polar regions.

Reflectance spectroscopy is a technique of recently demonstrated merit for determination of mineral phases, particularly iron-rich silicates, and hydrated minerals.

Geomorphic Diversity

Viking orbiter pictures reveal numerous provocative landforms. Perhaps the most intriguing are sinuous and dendritic channels that may have been formed by surface flow of water. Peculiar ejecta deposits surrounding craters suggest fluidization by impact melting and release of subsurface ice. Volcanic

constructs and flows of varied morphology imply that volcanic eruptions of diverse composition have occured at a variety of times. Layered deposits are present in polar regions and are also exposed in equatorial canyons. In both cases they record a sequential history of events.

A 1984 orbiter can image the landscape with greater detail, permitting geochemical and morphological correlations. Of potentially even greater importance is the capability of a rover to traverse geologic units of different composition and age, examining samples and measuring their chemistry and mineralogy. This kind of traverse geology is a technique which has proven uniquely important in deciphering the Earth's history.

Chemistry and Mineralogy of Surface Samples

Although the available chemical analyses of the Martian regolith have been recast in terms of reasonable mineral constituents, many uncertainties and questions of composition and origin remain. The primary mineral composition of the crust is still in doubt. No data were obtained for concentration of elements of atomic number lower than magnesium. Therefore, we know little about the quantity of carbonates and nitrates. In a more general sense, the absence of any direct phase measurements makes mineralogical determination speculative. A major Viking determination was the pronounced surface reactivity of the Martian regolith. Organic compounds were found to decompose rapidly in contact with Martian soil; molecular oxygen was released, following addition of water; CO_2 was released slowly following wetting with aqueous solutions of organic compounds. There is little doubt that Martian surface materials are strongly oxidizing. A biologic explanation for the results appears unlikely but biologic effects cannot be definitively discounted.

The 1984 strategy is to use a rover as a platform for a sophisticated chemical/mineralogical laboratory. Preparatory to analysis, selective sample procurement and processing must be carried out. In particular, unweathered rock must be obtained either by crushing or by drilling. Variations in atmospheric-related alteration may be recorded in auger-procured samples of soil from a depth of a meter.

Chemical analyses improved over those obtained by Viking can be obtained by several candidate instruments using alpha, proton, x-ray and γ-ray spectroscopy. Mineralogical determinations dictate the inclusion of an x-ray diffractometer and a reflectance spectrometer.

Volatiles in the Soil

The volatile content of surface materials provides clues regarding accretion and outgassing history of the planet, lithospheric-atmospheric interactions, and possible storage and subsequent release of water. Viking lander mass spectrometer results indicate loosely bound water up to 1% in some soil samples, in agreement with spectroscopic estimates. Definition of volatile inventory, composition and bonding state is essential.

Volatiles can be detected by a variety of complementary techniques. An orbital gamma-ray spectrometer will map near-surface H and C concentrations. IR reflectance spectroscopy will measure the strength of H_2O and OH absorption bands in mineral phases. The state of volatiles in soils can be more directly measured by step-heating samples, with evolved gases fed into a mass spectrometer.

Sampling the regolith at depths of a meter or more is particularly important with respect to the detection of any H_2O present as ice in permanently frozen ground. Such sampling can be achieved using an auger on the rover and by including a small drill in the penetrator forebody.

The depth of permafrost can be determined by active seismic and electrical sounding techniques using the rover and deployed science stations.

Global Atmospheric Dynamics

Increased understanding of the dynamics of the Martian atmospheres can be expected to yield major dividends. The Martian atmosphere is especially useful because of its similarity to the Earth's atmosphere in such important properties as size, temperature regimes, atmospheric transparency, and rotation rate. The Martian atmosphere is subjected to thermal forcing and boundary

conditions that are only slightly different from the Earth's. Specific Martian planetological questions must also be addressed: the chemical stability of the atmosphere, the chemistry and dynamics of the upper atmosphere, and the history of escape from the top of the atmosphere.

The basic strategy for dealing with these questions is to obtain data on the distribution of the dynamically interesting parameters (vertical temperature profiles, pressure, optical opacity, water vapor concentration). The 1984 mission concept is nearly ideal: low circular polar and low-inclination orbits provide the opportunity to distinguish diurnal, longitudinal, topographic and synoptic variations in those quantities that can be remotely sensed, while the surface penetrator network allows distributed measurements of other key variables. Finally, the rover provides the opportunity for correlated surface measurements, using more complete instrumentation than can be carried by penetrators.

Upper Atmosphere Interactions

To understand Mars it is important to understand how the atmosphere has evolved. The amount of CO_2 and H_2O degassed from the Martian interior, as inferred from a comparison of the Martian and terrestrial abundances of ^{36}A, Kr, and Xe, is large relative to the amount of CO_2 and H_2O presently in the Martian atmosphere. The implication is that there are reservoirs of H_2O and CO_2 in the planet's crust. Examination of the amount of N_2 in the atmosphere, and the enrichment of ^{15}N compared to ^{14}N suggests that in the past the atmosphere was much more dense than it is presently. An analysis of the enrichment depends on adequate understanding of the way in which the temperature structure and the neutral and ionic composition of the upper atmosphere varies during the solar cycle. It is also necessary to understand how the solar wind interacts with the planetary ionosphere and upper atmosphere.

The Mars 1984 orbiter can answer the questions about the solar wind interaction by measuring plasma ion fluxes in such a way as to distinguish between solar wind ions (H^+) and ionosphere ions simultaneously with magnetic field measurements. The required direct sampling of the interaction region near 300 km and of the night-side magnetosphere, plasma tail or wake cavity can be readily achieved using initial elliptical orbits early in the mission.

Inclusion of an ultraviolet spectrometer on the 1984 orbiters along with entry vehicle _in situ_ measurements of the composition of the neutral and ionized atmospheres as well as the ion temperature will allow a calibration of data from Viking and from Mariners 4, 6, 7 and 9. Atmospheric and ionospheric data for a large range of solar conditions will thereby be made available for the construction of models of atmospheric escape processes. The improved 1984 orbiter coverage will also allow clear separation of diurnal, latitudinal, longitudinal, and solar activity-related variations.

THE BIOLOGY QUESTION

The on-going exploration of Mars must address the issue of biology. Although there does not appear to be active biology at the two Viking landing sites, there may be other localities with special environments conducive to life. Life-supportive aspects of the Martian environment must be defined in greater detail. The characterization of former environments, through stratigraphic and climatological studies, and even a search for fossil life, should be conducted.

The espoused mission provides clear continuity in the biology related search. The rover will explore multiple environments both in space and in time. The mass spectrometric analysis permits monitoring not only of volatiles but also organic compounds. With the use of gas reagents, coupled to mass spectrometer analysis, it should be possible to determine the reactive chemical states in the Martian soil that have been discovered by Viking. If there is in fact, an overlay of biologic and inorganic reactions, the two are separable with the multiple sample analysis available to the 1984 rover.

REDUCED MISSIONS

The MSWG was charged with the task of defining the science rationale for three mission options: (1) polar orbiter/rover/network science, (2) polar orbiter/rover, and (3) polar orbiter/network science. Because it early became clear that accomplishment of all major science goals required the first option, the MSWG has focused its attention on that mission. The MSWG anticipates that a significant number of major science goals may be met with the two latter optional mission designs. However, a major reassessment of science instruments and operational strategy would be necessary.

MISSION DESIGN

In December-January 1983-84, the Shuttle/IUS launches two spacecraft (each comprising an orbiter, a rover, and three penetrators) on the way to Mars, with encounter set for September-October 1984. Science payloads allocated for the "point design" mission are: 87 kg for the orbiter, 100 kg for the rover, and 4 kg for each penetrator.

Arrival time is close to Mars perihelion, which is a period of wide-spread dust storm activity. The penetrators are deployed a few days before encounter, but the rovers are expected to be held in orbit for up to several months until the storm activity has cleared. Initial, highly eccentric orbits will permit magnetospheric studies to be conducted.

After the landings, the orbits are circularized with one in a near-polar, 500-km orbit and the other in a low inclination, 1000-km orbit. The former provides excellent global coverage; the latter provides improved coverage of low latitudes, the ability to made diurnal observations, yet is high enough to provide several useful relay links to each rover every day. The polar orbiter is expected to supply the main communication links with the penetrators.

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SITE ACCESSIBILITY

For landing, the rovers will use the Viking soft-landing system augmented by a terminal hazard detector that moves the landing point away from boulders. The spacecraft in the low inclination orbit has access to a latitude band between 20°S and 20°N, while the other has access to a band between 30°N and 50°N. The landing latitudes must be selected before orbit insertion, as was the case for Viking. Both latitude bands contain sites of great scientific interest, including areas of channels and canyons.

The penetrators can be directed to a wide range of latitudes, from 87°S to 50°N. Access is not to a latitude band, however, but to a small circle centered about the approach asymptote. The exact hour of arrival dictates the longitude accessibility.

The rover landing ellipse is about 65 x 40 km, with the major axis along the track. Terrain heights must not exceed 5 km, referenced to a 6.1 mb pressure level. For the penetrators, the landing uncertainty is approximately a circle, 280 km in diameter.

ORBITER SCIENCE

Orbiting spacecraft, with a broad and integrated set of geophysical and geochemical sensors, are essential elements in the exploration of Mars. Studies of the planetary interior, surface, atmosphere and plasma environment all depend heavily on data acquired from orbit.

Payload

The orbiters in the point design are nadir-oriented and do not have a scan platform. A candidate science payload for the orbiter includes imaging systems, a gamma ray spectrometer, reflectance spectrometer, radar altimeter, IR atmospheric sounder, microwave radiometer, UV spectrometer, magnetometer and plasma probe. Instrument development benefits from various previous lunar, planetary and terrestrial experience and should present few important problems.

ROVER SCIENCE

The rovers will advance our understanding of Mars by making detailed geochemical and geophysical studies in regions selected to allow these mobile laboratories to sample key units of differing age and composition.

Payload

A candidate rover payload includes stereo imaging, a simple microscope, elemental and mineral phase analyzers, a mass spectrometer system, active seismic and electrical sounding experiments and a magnetometer. In addition, each rover carries a deployable science station that includes a broadband seismometer, a magnetometer, a thermal probe and a meteorology experiment. The station is an integral part of the active sounding experiments, and contains a high frequency seismometer and a 0.5 to 20 MHz transmitter.

Sample Acquisition and Processing

Effective sample procurement is a key to rover mission success. An improved manipulator, a rock drill, and an auger are necessary if fresh rock samples and soils are to be analyzed. The auger should be able to acquire samples autonomously and will serve to acquire samples from beneath the surface (to 1 meter) where the volatile component of the soils may be larger and where photochemical alteration may be reduced.

On-board sample processing should provide fractions that have been enriched in various mineral components through simple physical procedures, such as sieving and magnetic separation. The sample distribution system must be able to provide these fractions to several different instruments in commandable sequence.

PENETRATOR SCIENCE

Some of the science goals of the 1984 mission require a wide distribution of sensors across the planet. Small, hard-landing spacecraft provide the only economic means of providing such a network. Penetrators have not been used for planetary missions before, but provide a unique capability.

Payload

A candidate science payload would consist of seismometers, an element analyzer, and a water detector in the penetrator forebody, with a pressure sensor and visible light photometer on the after-body. Thermistors are deployed along the umbilicus to measure the temperature gradient. All of the instruments must be small, lightweight and must consume little power. In addition, they must be highly shock resistant. Instrumentation with these characteristics can be developed.

Sample Acquisition

Tests have shown that the material near the penetrators is highly modified by the penetration heating. To make a meaningful elemental analysis, a sample of unmodified regolith must be acquired. The use of a small drill to provide such access has been shown to be feasible. The sample must be delivered to both the elemental analyzer and to the water detector.

MISSION OPERATIONS

The Mars 1984 mission will generate much more data than the Viking mission and will demand substantially shorter response times. All this must be accomplished with a much smaller flight team. Clearly, significant technical and managerial advances must be made, building on the Viking experience. It is anticipated that site selection will be less time consuming because of our improved knowledge of the Martian surface, the advanced imaging, and the radar in the orbiter payload. Another asset is the demonstrated success of the Viking entry/landing system. The terminal hazard avoidance system will provide added confidence to the operation.

New spacecraft "architecture", using multiple microprocessors, each servicing a major spacecraft component, will permit selective updating for individual instruments without extensive coordination with other command sequences. Considerable autonomy built into the rover will allow it to traverse terrains without frequent operator intervention. Sample acquisition, manipulation and internal distribution will also be achieved with systems possessing considerable autonomy. The orbiter will be nadir pointing, sending back most data in real time. Imaging data will be recorded and replayed on a first-in/first-out basis, largely eliminating tape management problems.

Three different operational modes are envisioned for the rovers. In the site-investigation mode, an intensive science investigation will be carried out. All science, maneuverability and manipulative skills will be used in a flexible manner. The rovers will operate in this mode for less than half the mission. The survey-traverse mode requires a near-autonomous capability for both travel and science. Each day's travel will be in a series of segments toward a local destination, approximately 500 m away. The rover will autonomously locate hazards in each segment with a laser range finder or imaging system and will plot a path accordingly. Short range detectors on the rover will provide a backup capability to ensure that the vehicle stops if hazards are encountered. In this mode, preprogrammed science observations will be carried out at the end of traverse segments and at night. A third mode, the reconnaissance-traverse mode, is planned to maximize the daily rover traverse range. Science activity will be minimal, stops as infrequent as possible, and traverse may continue through the night.

Penetrator operations can be systematic and relatively unadaptive, although the capability for changing instrument modes will be available. When the orbits are circular, the penetrators can be interrogated one or more times each day, with science readout commanded by the orbiter. Before the landings take place, the orbiters will be in highly elliptical orbits and some penetrators may be inaccessible for interrogation. These can be placed in a quiescent mode, storing only deceleration and subsurface temperature data, limited meteorology and seismic data. Those penetrators that can be interrogated even before the orbit circularization takes place can acquire proportionally more data.

AN INTEGRATED MULTIPLE-MISSION STRATEGY

The 1984 mission should be viewed in the context of a long-range Mars exploration program, each event being part of an evolving saga. The current Viking missions are continuing to contribute important science data and can provide further information about potential 1984 landing sites and about weather conditions at the season of the landings. The Viking landers may still be operating at the actual time of the 1984 landings and could provide invaluable surface weather data.

The 1984 mission can, similarly, play an important role as a precursor to a 1990 sample return mission by providing a global geochemical survey, detailed information about potential landing sites, and even by collecting samples for return in 1990. Such sample collection would add immeasurably to the value of the 1990 mission and would serve to calibrate the entire 1984 rover data set.

A Mars 1984 Mission

Report of the

Mars Science Working Group

July 1977

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A MARS 1984 MISSION

MSWG TASK DESCRIPTION

AND

RECOMMENDATIONS

INTRODUCTION

THE TASK ASSIGNED TO THE MARS SCIENCE WORKING GROUP

The Mars Science Working Group (MSWG) was formed at the request of NASA to provide a science rationale for post-Viking Mars exploration and to work with a group at the Jet Propulsion Laboratory (JPL) that was studying the technical feasibility of a 1984 mission. The basic scientific context was provided by a letter dated 23 November 1976 from Dr. A. G. W. Cameron, Chairman of the Space Science Board (SSB), to Dr. J. C. Fletcher, Administrator of NASA. The relevant passage of the letter is as follows:

> "For Mars, the Board reaffirms its view that the return of unsterilized surface samples to Earth is the major long-term goal in the period 1986-1990. To better define the nature and state of Martian materials for intelligent selection for sample return, it is essential that precursor investigations explore the diversity of Martian terrains that are apparent on both global and local scales. To this end, measurements at single points of extreme planetary environments should be carried out as well as intensive local investigations in selected areas of 10-100 km in extent. These local investigations should explore terrain diversity with analytical techniques and manipulative skills much advanced from those used on Viking, but without attempting to duplicate an Earth laboratory. By extending the range and flexibility in choice of in situ measurements, the primary scientific objectives of understanding the current and past processes operating both at and near the surface of Mars and the structure and dynamics of its interior will be met."

Consistent with the SSB strategy, NASA directed JPL to undertake a design and cost analysis for a 1984 orbiter-penetrator-rover mission. The study project was initiated 1 January 1977. The first phase was to be completed by July 1977, providing cost and design data necessary for assessment of the mission as an approved new start in FY 1979.

A specific charter for the MSWG was proposed by NASA and, after discussion and some modification, was approved at the first MSWG meeting on 25 January 1977. The statement of function reads as follows:

a. Define the major science goals of a dual launch 1984 Mars Mission, on the assumption that this will be the only post-Viking but pre-sample-return mission to Mars. The nominal goal for a sample return mission in 1988.

b. Define the science rationale for three mission options: (1) polar orbiter/rover/network science: (2) polar orbiter/rover; and (3) polar orbiter/network science.

c. To accomplish the science goals, defined in (a) within the context of the mission options indicated in (b), define a typical set of scientific instruments for a rover, and consider the capabilities required of the rover itself (range, manipulative ability, etc.) to carry out the required scientific investigations.

d. To accomplish the science goals defined in (a), within the context of the mission options indicated in (b), define a typical set of scientific instruments for a polar orbiter. Consider the degree to which the experiment objectives can be met with non-circular orbits or limited surface coverage.

e. To accomplish the science goals defined in (a) within the context of the mission options indicated in (b), define a typical set of scientific instruments for potential penetrators, rough landers, and rover-deployable science packages. Establish limits on the numbers and distribution of such instruments to achieve the objectives of network science.

f. Interact with the spacecraft and mission design teams in order to assure optimization of these designs for scientific purposes, and supply advice as requested to NASA Headquarters on the scientific impact of various mission options.

The charter identifies three types of missions that might meet a significant fraction of science goals specified or implied in the 23 November 1976 letter from Dr. Cameron to Dr. Fletcher. These missions, in descending order of desirability are:

1)   Orbiter-rover-network

2)   Orbiter-rover

3)   Orbiter-network

Although there are, in theory, a diversity of vehicles that might deploy network science, the attention of the MSWG has been directed towards penetrators.

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Massachusetts Institute of Technology

Full committee meetings were held as follows:

24-25 January 1977	Caltech
9-11 March 1977	Jet Propulsion Laboratory
15-16 April 1977	NASA Goddard Space Flight Center
12-13 May 1977	Jet Propulsion Laboratory

The committee has performed much of its task through a number of sub-committees with chairmen as follows:

Geophysics	M. Nafi Toksoz
Geochemistry	Heindrich Holland
Rover	Arden Albee
Orbiter	James Arnold
Site Studies	Harold Masursky
Mission Analysis	Michael Malin
Integration	Michael Duke

These sub-committees have met frequently on an _ad hoc_ basis with their membership augmented by colleagues. We wish to acknowledge the generous donation of time, energy and enthusiasm by our colleagues on such occasions.

A meeting of the sub-committee chairmen, together with several other members of the committee, was held at JPL on 23-24 June 1977 to edit a draft of this report. Dr. Thomas Blackburn provided further editorial help that is gratefully acknowledged.

RECOMMENDATIONS OF THE MARS SCIENCE WORKING GROUP

SCIENCE OBJECTIVES

The Mars Science Working Group (MSWG) concludes that a 1984 mission to Mars should address the following objectives, all of which are attainable with the proposed orbiter-penetrator-rover mission design (no prioritization is implied by the order):

1) Characterize the internal structure and dynamics of the planet.

2) Characterize the chemistry and mineralogy of surface and near-surface materials on a global and regional scale.

3) Determine the chemistry and mineralogy of rock and soil samples, especially as related to the reactive surface chemistry observed by Viking.

4) Document geologic characteristics of major landforms, toward an understanding of current and past surface processes.

5) Determine the distribution and state of H_2O and other volatiles, toward an understanding of the chemical evolution of the regolith and atmosphere.

6) Characterize the global dynamics of the atmosphere.

7) Measure the planetary magnetic field, and study the interaction of the upper atmosphere with the magnetic field, the solar radiation, and the solar wind.

SCIENCE INSTRUMENTS

The MSWG concludes that the 1984 mission goals could be achieved with the following instruments:

Orbiter: cameras, gamma ray spectrometer, reflectance spectrometer, radar altimeter, magnetometer, IR atmospheric sounder, plasma probe, UV spectrometer.

Rover: cameras, simple microscope, sample processor, element analyzer, X-ray diffractometer, reflectance spectrometer, mass spectrometer system (organic and inorganic analysis), electrical sounder, active seismic experiment, 3-axis broad-band seismometer, magnetometer, meteorology station.

Penetrator: 3-axis seismometer, element analyzer, soil-water analyzer, atmospheric pressure sensor, photometer.

Entry: neutral mass spectrometer, retarding potential analyzer.

Preparatory to formal selection of instruments in response to an Announcement of Opportunity, we recommend that NASA vigorously pursue a program of instrument development.

OTHER CONCLUSIONS

Achievement of the objectives of this mission will contribute substantially to our understanding of the potentialities for life on Mars. By investigating the local physical and chemical environments, and by searching for organic compounds, the mission will shed light on the question of whether life could have arisen in the past, and will also address the possibility that living systems are still present. Furthermore, the anticipated data will add to our understanding of the reactive surface chemistry observed by Viking.

The sophisticated nature of the rover science payload reflects our guiding philosophy that the rover should be a self-contained scientific laboratory, capable of traversing at least 100 miles. Length of specific traverses will depend on the characteristics of the landing site and on real-time operational decisions regarding appropriate balance between travel and in situ analysis.

The MSWG concludes that all three vehicular elements -- orbiter, penetrator, and rover -- are essential to the accomplishment of mission goals as previously defined by the Space Science Board, and as determined by the MSWG. Deletion of any one vehicle will require a major reassessment of science instruments and operational strategy.

The MSWG adopts the premise that the 1984 mission is the next logical step in the exploration of Mars. At a future date (1990?) a sample return mission is envisioned by the Space Science Board. Although the 1984 mission stands independently of a subsequent sample return mission, the 1984 experiments will provide new information that will optimize strategy for returning samples. Planning for a Mars sample return should be carried out in coordinated fashion with the planning and conduct of the 1984 mission.

The MSWG recommends that continued attention be devoted to both the acquisition and analysis of data to support the 1984 mission. These data should include Viking orbiter images, infrared and radio occultation data, and ground-based radar observations.

A MARS 1984 MISSION

SCIENCE GOALS

SCIENCE GOALS

INTERNAL STRUCTURE

The ultimate objectives of the study of Mars include the determination of the origin, composition and evolutionary history of the planet. Knowledge of the present day structure and physical state of the planet's interior is needed so that this knowledge may be applied as a boundary condition for further investigations. Seismic, magnetic, gravity and heat flow measurements are the best methods available to obtain this knowledge. Seismic data will give information about the mode of operation of the thermal engine of the planet through its seismicity, about the structure from seismic velocities, and about composition and physical state, since seismic velocities and attenuation depend on these properties. Magnetic data of appropriate sensitivity will determine whether Mars has a magnetic field of internal origin that may be generated by a core dynamo. The variation of gravity indicates both the strength and dynamics of the planet and variations in its structure from place to place. The value of the heat flow is a critical constraint on thermal profile within the planet. The chemistry may be inferred from required heat source (K, U, Th) abundances.

Planetary Seismology

Question

What are the basic internal divisions of Mars? Is there a core? If so, what is its radius, composition, and state? What is the thickness and composition of the crust? If there are other major internal discontinuities, what are their locations and characters?

Present Status

On the basis of geological, geochemical, and geophysical evidence, it is reasonable to assume that Mars is a differentiated planet, with a crust, a mantle and a core. However, the available data are so limited that they neither confirm the existence of such layering nor establish the thickness of the crust

or the size of the core. Using the mean density, the moment of inertia factor, and plausible geochemical models, it is possible to calculate models of the interior, but these are highly non-unique. The radius of the core can be as small as one-third of the planet's radius if it is composed of pure iron, or more than one-half for an FeS composition. The mantle density and inferred composition vary greatly for these two models.

Question

What is the character of Martian seismicity (frequency, location, and magnitude of Martian seismic events)? Is Mars, like the Earth, a tectonically active planet (continuing its dynamic evolution), or is it quiescent and relatively static, like the Moon (long past its peak activity)?

Present Status

Two seismometers were delivered to Mars by the Viking mission. The instrument on Viking Lander 1 failed to uncage and has returned no useful data. The seismometer on Viking Lander 2 has operated successfully since the landing. It has provided and will continue to provide valuable information for planning the Mars '84 mission.

One of the first and most surprising results obtained from this seismometer is the low seismic noise level generated by Martian winds. In this respect, the Viking seismometer is not ideally sited, being on the top of a relatively compliant spacecraft which exposes a large surface area to wind forces. Nonetheless, the seismometer can be operated at maximum sensitivity most of the time. About half of the time, the noise level is below the detection limit of the instrument. At other times, when the wind speed is more than a few meters per second, some noise can be detected. On the basis of these measurements, it has been estimated that seismometers more sensitive than the Viking instrument by a factor of 10^3 can operate on Mars without being significantly affected by typical winds, if they are emplaced by penetrators or deployed in small, windshielded packages.

Thus far, only one possible Marsquake has been identified by the Viking seismometer. While it is hard to make definitive statements with a possible

statistical sample of one, some preliminary conclusions can be drawn. Mars is most probably less active seismically than the Earth. If Martian seismicity were similar to that of the Earth, several Marsquakes should have been detected by now. On the other hand, the seismic activity on Mars is probably greater than that of the Moon. Possible seismic sources on Mars are quakes, due to tectonic processes or relaxation of stress, and meteorite impacts. A comparative examination of the geologic features of Mars and Moon give strong evidence of more recent tectonic activity on Mars. In addition, the gravity anomalies on Mars, particularly the Tharsis Ridge, are larger than any on the Moon or even the Earth. Such large anomalies imply large stresses or strong tectonic forces to maintain the anomaly. As a result of these factors (large gravity anomalies, geologic features, size considerations) we would expect Mars to be seismically more active than the Moon. The single tentative marsquake thus far recorded is larger than all but three of the moonquakes detected by the ALSEP seismic network on the Moon. Yet ALSEP seismometers, with a much greater sensitivity than that of the Viking instrument, record about 2000 moonquakes per year. Thus seismometers of lunar sensitivity proposed here should detect many Marsquakes suitable for the investigation of the internal structure. With such high sensitivity instruments, meteorite impacts would also be detected thus providing an alternate source.

1984 Strategy

Acquisition of the needed data requires the deployment of a global network of seismic stations. This network should consist of:

1.   A widely dispersed array of four or more three-axis seismometers (station spacing on the order of 5000 km), and

2.   At least two three-axis, broadband seismic stations.

Each of these network components should be capable of operating at gains 10^2 to 10^3 times higher than that of the Viking instrument. The function of the dispersed array is to provide information for event location and the coverage necessary for the delineation of internal structure, primarily based on the analysis of short period signals. The function of the broadband stations is to provide the long period information (e.g., surface wave data) needed to define near surface structures and the structure (depth?) of internal discontinuities, as well as to supplement additional short period data.

We propose that a dispersed array of six seismometers be deployed by penetrators. A subset of three penetrators could be targeted for an area thought to be seismically active, such as the Tharsis ridge, thus establishing a regional network with a station spacing on the order of 500 km capable of detecting and locating events below the magnitude threshold of the global array. The other three penetrators would be targeted with greater (5000 km) spacing to fulfill the requirements for the global network. The two broadband seismic stations would be components of packages deployed by the two rovers. The seismometers contained in these packages would be much more sophisticated than the instruments aboard the penetrators, since they would not be subjected to the large deceleration associated with penetrator emplacement. These stations would be deployed as soon as possible after landing, to maximize the available recording time. With the external manipulation capability of the rover, it would probably be possible to set up the stations in an environment at least partially shielded from the wind.

The recording strategies will have to be carefully considered. Although the penetrators provide an excellent means for deploying a dispersed array of seismometers in buried sites with low noise levels, volumetric and power limitations will restrict the bit rate transmission capabilities of the system. Various data compaction schemes will be needed, including the ability to select and record interesting signals. Presumably, the data rate capabilities of the deployed stations will be greater and will allow continuous recording of ground motion.

Magnetic Measurements

Question

What is the strength and nature of the Martian magnetic field? Establishing the magnitude of the Martian magnetic field, characterizing its spatial variation and understanding its origin are important subjects not only for the study of Mars but for the comparative study of other terrestrial planets as well. Demonstration that the magnetic field is due to a dynamo would indicate that the planet is sufficiently evolved thermally to possess a convecting iron core.

Present Status

The strength, nature, even the existence of the Martian magnetic field are still unknown. Mariner 4 was the only U.S. spacecraft to carry a magnetometer and plasma probe to Mars, and it detected what appeared to be a bow shock. From these observations an upper limit ($M \simeq 2.4 \times 10^{22}$ Gauss cm^{-3}) was placed on the planetary dipole moment.

Three Soviet spacecraft (Mars 2, 3, 5) carried out magnetic field and plasma measurements. These measurements suggest the possibility that Mars has a small intrinsic magnetic field with a moment $M \simeq 2.5 \times 10^{22}$ Gauss cm^{-3} and a surface strength about 10^{-3} that of the Earth. These interpretations, however, are not unique. Because of the weak field, the bow shock is close to the surface of the planet and the post-shocked solar wind may be in physical contact with the ionosphere. It so, some or all of the magnetospheric field may be due to induction by the solar wind electric field.

1984 Strategy

An important test for the source of the Martian magnetic field comes from testing the magnetospheric field to determine whether it is primarily poloidal (implying a dynamo) or toroidal (implying an induced field). Such a determination can be made using low altitude orbital magnetometers and a network of surface deployed magnetometers. With the orbital magnetometer it is important to have a complementary plasma probe. Magnetometer and plasma measurements together would permit the internal field and solar wind interaction to be determined with detail and confidence.

Like seismology, the study of the Martian magnetic field will benefit greatly from measurements at a widely dispersed network of surface stations. It appears that the inclusion of a magnetometer on the after-body of the penetrators is possible but requires further study to assess the technical requirements. Magnetic measurements are easily corrupted by the stray magnetic fields such as those associated with other components within the penetrator. It is essential, therefore, that a magnetometer be included as a component of the surface packages deployed by the rover. The rover can easily emplace the magnetometer some distance (~15 m) from the main body of the package, thus isolating the sensor from stray fields.

With data from orbital surface magnetometers it is possible to determine the electrical conductivity profile in the crust and upper mantle of Mars. Such a conductivity profile is important for inferring temperatures and structure. A network of instruments, or a rover magnetometer, would provide important measurements on the magnetization history of the Martian crust.

Crustal Dynamics

Question

How does the thickness of the Martian crust vary across the planet? How important are internal dynamical processes in the maintenance of isostatically uncompensated regions?

Present Status

Mariner and Viking observations suggest that the Martian crust has had a long and varied history, with significant modifications of the face of the planet that established the variable surface morphology evident today. Observations of the gravity field demonstrate that this variability extends below the surface layers. The orbital gravity data suggest a variable crustal thickness over the planet. The elevated Tharsis region, where major volcanoes stand, is not isostatically compensated, implying the existence of large internal forces at depths of hundreds of kilometers. These forces presumably are either statically maintained by the strength and thickness of the Martian lithosphere or else are a manifestation of dynamical processes currently active within the Martian interior.

1984 Strategy

More gravity and altimetry data are needed from relatively low-altitude circular orbits. With these measurements our knowledge of the shape, internal mass distribution and dynamics of the planet could be significantly improved. By combining these data with one or two measurements of crustal thickness using seismic techniques, it may be possible to estimate with reasonable accuracy the crustal thickness almost anywhere on the planet.

Constraints on the low-order harmonic coefficients of the gravity field are obtained from the precise tracking of the orbiters. To obtain significant improvements over the results from the Mariner and Viking missions, the orbital configuration should consist of one circular, high-inclination orbit and one low-inclination orbit, each with as low a periapsis as possible. Considerable improvement in the resolution of the gravity field could be obtained by orbiter-orbiter tracking. The use of gravity gradiometers also seems promising in cases where low spacecraft altitudes can be achieved.

The determination of the shape of the planet complements the gravity field measurements and is critical for the interpretation of the gravity data in terms of dynamic mechanisms. Orbiter altimeters are necessary to obtain the required resolution of surface topography and should be given high priority.

Heat Flow

Question

What is the average heat flow at the surface of Mars? This is related to the quantity of heat producing (radioactive) elements originally incorporated in the planet and to the thermal evolution of the body. A measurement of average heat flow would place important and relatively sensitive constraints on models of the origin, composition and evolution of Mars.

Present Status

No relevant data are presently available.

1984 Strategy

Heat flow measurements are notoriously difficult to make, even under ideal conditions. To obtain the heat flow, estimates of both the thermal conductivity and the thermal gradient are necessary. The former can be obtained by monitoring the temporal decay of the thermal transient induced by the emplacement of a penetrator or by monitoring the seasonal variations of temperature at some depth relatively near the surface. Estimation of the steady-state thermal gradient, however, is much more difficult, since it is easily perturbed by the emplacement of a probe and seasonal or even secular temperature variations at the surface. Furthermore, even if accurate estimates of the local heat flux

at a one or more sites are available, the inference of the average heat flux rests on the assumption that these quantities are representative of the planet as a whole.

In spite of the general difficulty of the problem, measurements can be made which place constraints on possible temperature profiles within the planet. Constraints are provided by electrical conductivity measurements, seismic velocity profiles and the attenuation characteristics of seismic waves. For example, seismic evidence for a liquid-solid transition at, say, a core-mantle interface can establish a single but important point on a temperature curve. The determination of a liquid-solid transition within a near-surface permafrost layer by seismic and electrical conductivity profiling could pinpoint the melting interface and thus yield the near-surface thermal gradient. Even more indirect evidence such as the level of tectonic activity revealed by the size, frequency and distribution of seismic events could be an important indicator of the thermal state of a planetary interior.

Experiments to obtain heat flow information for Mars should be given high priority. Techniques include the deployment of a thermistor-instrumented probe by the rovers, the measurement of temperatures at intervals along the penetrator umbilicus and the measurement of subsurface temperatures using orbital microwave radiometry. As discussed above, data acquired by a seismic network are relevant to the problem and, as discussed in more detail in the section on Volatiles, active seismic and electromagnetic sounding of the regolith to determine the location of the melting interface should have high priority for the rover.

GLOBAL GEOCHEMISTRY

A knowledge of the chemical composition of the various regions of the Martian surface is essential to an understanding of its origin and evolution. Of all the major questions considered in this report, it is (with the possible exception of seismicity) the one about which we know least.

Questions

1) What are the major chemical components in Martian surface material, and what is their pattern of distribution?

2) What minerals can be observed on the Martian surface, and how does their distribution relate to that of the chemical components?

3) How do these distributions relate to geomorphology? For example, is the hemispheric contrast in terrain associated with chemical differences? What does this tell us about the roles of igneous processes, of meteoritic impact, and of the action of wind and water in the development of the present surface? Do the great shield volcanoes, for example, retain the composition characteristic of their igneous origin? If so, we may learn something about the nature of the differentiation process, and of the source material. As another example, do the ejecta blankets of the largest impact craters expose distinct material derived from depths of kilometers' below the surface? Are the extensive dune-fields distinct chemically and mineralogically? Do they show an enhanced abundance of SiO_2?

4) What is the distribution of hydrated minerals and of carbonates over the Martian surface? Are such mineral assemblages associated with regions of abundant channels?

5) Are there differences in composition observed by instruments with different characteristic penetration depths? Can these be tied to atmospheric transport of dust?

6) What is the distribution of near-surface H_2O with latitude and season?

7) <u>What are the average concentrations of the radioactive elements K, Th and U on the surface, and what is their distribution?</u> How do these relate to any data we may be able to obtain for heat flow?

Present Status

The Viking mission made a large number of important discoveries regarding the nature of surface materials on Mars. The bulk compositions of soils in the two landing sites were found to be very similar to each other and rather different from the composition of all likely igneous parent rocks on the planet. The high iron content and low aluminum content of the Martian soils is somewhat surprising, and is reminiscent of the composition of metalliferous sediments of the Eastern Pacific Ocean. The high sulphur content of the Martian regolith may well be due to the presence of sulphate minerals. The sulphur may be derived in part from the weathering of sulphide minerals and in part may be due to sulphur from the interior of the planet that has been brought to the surface as a constituent of volcanic gases and/or hydrothermal solutions.

The available chemical analyses of samples of Martian regolith have been recast in terms of reasonable mineral constituents. However, in the absence of mineralogical data, the proposed regolith mineralogy is quite speculative. No data were obtained for the concentration of elements of atomic number lower than magnesium. We therefore know little about the quantity of carbonates and nitrates in the Martian regolith except the approximate maximum of their sum. Clearly, much critical information regarding the regolith at the Viking landing sites is still missing, and the coverage of the planet as a whole is extremely incomplete. All of the attempts which were made during the Viking mission to obtain and analyze fresh rock samples were unsuccessful. We therefore know very little about the compositional range of unaltered Martian rocks.

Some very interesting ground-based spectroscopic observations have been made recently. There are significant differences in spectral shape between the bright and dark regions. The dark regions show stronger absorption features due to pyroxene. This may indicate a greater exposure of unaltered (or less altered) basaltic material in these regions. There is a tendency for the dark areas to be high and sloping, while the bright areas (like the two Viking sites) are generally low and flat.

1984 Strategy

The use of geochemical sensors on the two orbiting spacecraft can give us a quantum jump in knowledge and, we trust, understanding in this area, though we cannot hope for answers to all the questions posed above. The primary reliance, so far as we can see at present, will be on two instruments, the gamma-ray spectrometer and the reflectance spectrometer. In all these studies, the interaction of the surface science with orbital science is the true heart of the matter. Geochemical objectives of the rover and penetrator portions of the mission (discussed below) dovetail with those of the orbiter. Completeness of coverage on one hand is matched to direct, local observation on the other, in every aspect of the program.

The gamma ray spectrometer can give a map of the major elements (O, Si, Fe, Mg, Ti and, with less accuracy, Al and S), of the key volatile elements H (down to 0.2%, or 2% H_2O) and C (to 1%, or 10% $CaCO_3$), and of the radioactive elements K, Th and U. The linear resolution element is of the order of the altitude, nominally 500 km for Mars '84. This is sufficient to resolve the largest shield volcanoes, the polar caps, and other major named regions of Mars. The instrument requires long counting times for best accuracy. Hence the polar orbiting spacecraft will provide excellent coverage at high latitudes, but will be somewhat short of counting time in the equatorial regions. The lower-inclination orbit of the second spacecraft provides a good solution to this problem.

The mean depth of penetration of the characteristic gamma rays is on the order of 10-20 cm; hence this is the depth sampled. The thickness of the seasonal polar caps, and of subsurface H_2O layers, may be of this order, permitting direct observation of changes.

Reflectance spectroscopy and multispectral imaging systems have been developing rapidly in recent years. They have the ability to indicate the major mineral phases present, and in favorable cases (particularly pyroxene) to give useful information on their composition. The characteristic infrared bands of H_2O in hydrated minerals give important data on the presence and nature of hydrated mineral phases. The characteristic depth of penetration is that of visible and IR radiation (micrometers). Thus the dust in the atmosphere can

be examined, and transient features such as diurnal frost deposits and the plumes left by dust storms can be studied in detail.

There are other instruments which may give very useful information on surface chemistry. The measurement of neutron albedo, especially in an energy-sensitive mode, can show the presence of soil H_2O with high sensitivity, especially if done together with a gamma-ray experiment. Neutrons penetrate as much as one meter into the surface, so that somewhat deeper layers can be explored. There are also compositional possibilities in radar mapping. Measurement of the bulk density of the surface soil, perhaps by microwave observations, would complement the geochemical data. Thermal properties (heat flow measurements discussed above, and nighttime cooling rates) are also of great value.

K/U and Th/U ratios are diagnostic, respectively, of thermal partitioning of volatiles from refractory elements, and of the partitioning of two refractory elements by a process akin to weathering. The orbiting gamma-ray spectrometer should provide these ratios with sufficient precision to place Martian values in the context of known values for chondritic meteorites, the Moon, Earth, and Venus (Venera 8).

GEOLOGIC DIVERSITY

Diversity of surface form and composition presents puzzles in planetary history while, at the same time, holding the key to solving those puzzles by reference to large scale processes. Such diversity is the very basis for the science of geology. Mars, unlike the Moon and the half of Mercury's surface that has been observed by Mariner 10, exhibits a remarkable spectrum of geological provinces. This provides much of the motivation for exploring Mars in detail. Because the current questions flow directly from the unexpected richness of the Mariner 9 and Viking orbiter observations (recognizing, however, that our understanding of Martian geology stems from a synthesis of many kinds of data discussed in other sections), these observations are discussed before the questions that they generate are posed.

Present Status

The surface features of Mars, as recorded in many thousands of orbital images with resolutions typically between 100 m and 1 km, are morphologically diverse. Many different geologic processes and episodes were involved in forming these features. On a global scale the dichotomy between the northern and southern hemispheres is most striking. The northern hemisphere is one or two kilometers lower on average and reveals a heterogeneous surface that has, through volcanism and gradation, lost most evidence of its former, highly cratered appearance. The more elevated southern hemisphere, while much modified by volcanism and tectonism, still displays a high density of large craters that apparently date back to an early period of heavy meteoritic bombardment.

Although planet-wide tectonic activity is strikingly evident in the enormous equatorial canyon system and in faults that can be traced across half the globe, Mars does not show obvious indications of having passed through an evolutionary phase in which plate tectonism controlled surface development. Possibly as a result, volcanism on Mars has led to the construction of central volcanos whose scale dwarfs terrestrial examples. As on the Moon, large areas of the planet have been flooded by lava flows to form mare-like regions.

At the highest latitudes little-cratered layered units are present. These young units are probably aeolian in origin and the periodic deposition of material that is implied by the layering has excited much interest as a record of climate change. The effect of the atmosphere on surface morphology is also strikingly apparent in the vast "seas" of dunes that surround the northern (and probably the southern) polar region. Such dunes are also found elsewhere on the planet. Episodic deposition and stripping away of fine material is clearly shown by dramatic changes in surface reflectivity recorded in orbital images.

The discovery on Mars of channel-like features by Mariner 9 has provoked speculation and controversy. Martian fluviatile channels are of at least three types:

1. Broad channels originating in areas of collapsed terrain, believed by some to have been formed by the release of subsurface permafrost following melting (evidence for permafrost also is implied by different styles of impact ejecta blankets).

2. Intermediately-sized sinuous channels that head in canyons.

3. Dendritic networks that may record precipitation and run-off during earlier epochs when the atmosphere was denser and warmer.

Given such a complex surface and the limited available data it is not surprising that there are many controversial aspects to the interpretation of Martian surface evolution. Some major questions that arise are enumerated below.

Questions

1. What is the time sequence of Martian impact events? Is the meteroid flux similar to the lunar flux?

2. What is the tectonic history? Can the faulting episodes be dated by crater counts? Are the faults still active? Are there still seismic events?

3. Are there regional geochemical differences that correlate with volcanic style? Are the lowland and upland lava flows similar in age and composition?

4. <u>Are the central volcanic vents of different ages and composition?</u> Is there a simple relationship between composition and height of the volcanoes?

5. <u>Are the channels fluvial, and are they of many different ages and types?</u> Are the channels related to local geothermal heating or do they record planetwide interglacial climates? Do different stratigraphic units record varying environmental conditions?

6. <u>Are the collapsed terrains due to melting of subsurface permafrost?</u> Are they related to planetwide warm episodes?

7. <u>Are the aeolian deposits all of one age or are they spread out in time?</u> Is there more than one episode of polar deposition?

8. <u>Are there ancient mass wasting deposits or are they all of young age?</u> Are these deposits related to climatic changes?

1984 Strategy

The above questions will be answered only by the synthesis of the results of many types of investigation. The various elements of the 1984 mission provide the ability to make global surveys from orbit, in situ measurements at a dispersed number of sites using penetrators, and intensive observations along selected traverses using the rovers. Such traverse studies will be a unique capability of the rovers and could allow the classical stratigraphic mode of geological study to be applied to another planet. Example traverses, described in a later section, indicate that the rovers will be able to visit numerous sites of geological interest during a two year mission. Crossing units of different age and composition, the rovers will collect and analyze samples and will acquire detailed images of local areas to provide the necessary context. Further supporting data will be acquired by the orbiter experiments - chemistry, imaging and radar. There can be little doubt that the synthesis of these data will allow major advances to be made in understanding Martian geological questions.

With only two landers many types of terrain will not be visited by the 1984 rovers. Many of the above questions must therefore be addressed principally through data gathered from orbit. Measurements of elemental composition on a

regional scale coupled with high resolution imaging and mineral phase data will prove powerful tools. The orbital techniques will be greatly enhanced by ground truth calibration supplied by rover experiments.

CHEMISTRY AND MINERALOGY OF SURFACE SAMPLES

Although the recent past has seen a dramatic growth in our ability to determine chemical composition by remote sensing, inherent limitations in this art - especially those of sensitivity and spatial resolution - require that the Martian surface be accessible to chemical and mineralogical examination in situ.

A number of important chemical and mineralogical questions have been addressed by the Viking mission. Some have been answered fairly con-vincingly, others not at all. The following five questions seem to us to deserve particular attention, in part because they are major, in part because they can be addressed directly by the Mars '84 mission as outlined in this report.

Question

Has there been large scale differentiation on Mars?

Present Status

The answer to this question has a profound bearing on our understanding of the evolution of the planet. Although the evidence discussed in this report (volatiles inventory, volcanism, evidence of some rock alteration, fluvial events, magnetic measurements) indicates at least some differentiation, evidence for the extent of this process is equivocal or lacking. The data required for a convincing answer will come in part from geophysical, in part from geochemical measurements.

1984 Strategy

The required geochemical data consist of analyses of fresh igneous rocks from several parts of the planet. The Mars '84 rovers should be equipped with sample acquisition and with analytical equipment to obtain and analyze fresh rock samples. The proposed range of the rovers should allow us to sample a variety of geologically different terrains in two widely separated parts of the planet. The proposed analytical equipment for the penetrators should add

single analyses of material at some depth below the surface in a number of other, widely separated areas. Together, the analytical data base should go far toward defining the chemical diversity of rock types on the surface of the planet.

Question

What is the inventory and distribution of volatiles on Mars?

Present Status

The quantity and distribution of volatiles in the Martian atmosphere is now quite well defined. The distribution of volatiles in the ice caps is less well known; very little is known about the distribution of volatiles in the regolith and in the lithosphere.

1984 Strategy

For a variety of reasons the polar regions are unattractive targets for rover missions. Combined physical and chemical measurements can, however, define the abundance and distribution of volatiles along feasible rover traverses. Analytical equipment which can determine the concentration of the majority of the elements, including those of atomic number 1 through 11, will, of course, be vital. Instruments for defining the mineralogy of near-surface samples will also be essential. X-ray diffractometers, reflectance spectrometers, and differential scanning calorimeters - especially if the latter are connected to a direct inlet mass spectrometer system - are particularly promising candidate instruments for mineralogical analysis. The presence of a drill or auger will be very helpful, but it seems likely that shallow geophysical measurements will be required to determine whether an ice table is present within the rover traverse areas and, if so, at what depth below the surface. The presence of a first rate camera system may turn out to be important in defining the distribution and morphology of volatile-rich phases.

Nothing is known about the presence of evaporite horizons on Mars. On Earth, evaporites account for major portions of the terrestrial inventory of

chlorine and sulfur. The possibility of finding such horizons in the walls of the Valles Marineris is intriguing, and adds one more reason to the many others for visiting that part of the planet.

Question

What are the major weathering processes on Mars and what are their products?

Present Status

The curious chemical composition and the pronounced surface reactivity of the regolith in the two Viking landing sites raise a number of important questions regarding the origin and properties of the regolith as a whole. The composition of the analyzed soil samples at the two Viking landing sites is unlike that of any terrestrial igneous rocks. On Earth iron and aluminum tend to concentrate in oxidizing surface environments, whereas in the Martian soils the two elements seem to have been separated. If these soils have been derived by the weathering of igneous rocks at the surface of the planet, then either the parent rocks were strikingly nonterrestrial in composition or extensive element separation took place during the formation of the soils in the two landing sites. Unusual processes must be called upon to provide the necessary separation.

1984 Strategy

The difficulty of accounting for the composition of Martian soils may be resolved if they are not the products of weathering but of hydrothermal activity. The similarity of the composition of the regolith to that of metalliferous sediments in the Eastern Pacific Ocean suggests that some of the regolith may be the residue of hydrothermal solutions derived from the subsurface of the planet. It should be possible to test this idea by determining the concentration in Martian soils of elements that are strongly enriched in the products of hydrothermal activity. Manganese, copper, nickel, zinc, and barium would be particularly useful.

The Viking X-ray fluorescence unit is only able to set an upper limit of two percent on the manganese content of Martian soil. The proposed Mars '84 orbital gamma ray spectrometer will have a detection limit for manganese of 0.2 percent, and the proposed rover instruments should be able to determine the concentration of other minor and critical elements whose presence would suggest that hydrothermal processes have played an important role in the development of the Martian regolith.

The presence and zonation of weathering crusts on Martian rocks may shed light on the nature of Martian weathering processes. The mineralogy of the regolith itself will also yield important clues, and together with terrestrial simulations of Martian weathering, may prove helpful in deciding whether the Martian regolith is a product of surface weathering under present-day conditions or under some different, ancient conditions, or whether the origin of the regolith is to be sought in subsurface, high-temperature processes.

The origin of the surface reactivity of Martian soils should certainly be addressed by the Mars '84 mission. The reaction of Martian soil with a series of gaseous reagents can be automated for repetitive measurements, and the gaseous products of such reactions can be analyzed readily by means of existing mass spectrometric technology. The temperature of the reaction chamber can be controlled to yield maximum information regarding reaction kinetics, and the behavior of stable isotope labeled reagent gases and their reaction products can be monitored by the mass spectrometer. The effectiveness of such measurements presupposes a body of experimental data derived from appropriate experiments on Earth prior to the mission. Such experiments are now being planned; the results should be in hand well before the final planning stages for Mars '84.

The nature of highly oxidized surface phases could also be defined, perhaps more directly, by electron spectroscopy (ESCA or Auger). No flight models of such equipment are currently available, but proposals for their development are in hand, and the techniques seem sufficiently powerful to warrant a study of their suitability for the analysis of Martian soils and of the feasibility of constructing a flight model.

Question

Is there and/or has there ever been life on Mars?

Present Status

This question was the major driving force behind the Viking mission. The Viking answer has been equivocal, but more negative than otherwise.

One of the major discoveries of the Viking mission was the pronounced surface reactivity of the Martian regolith. Organic compounds were found to be decomposed rapidly in contact with Martian soil; molecular oxygen was released rapidly when water was added to Martian soil samples with aqueous solutions of organic compounds. There is no doubt that the Martian soil samples in both Viking Lander sites contain one or more highly reactive oxidizing materials. Superoxides formed at the surface of mineral grains are likely candidates, but little is known about the nature and origin of these compounds. Although the results of the Viking Biology Experiments are most readily explained in terms of the inorganic surface chemistry of Martian soil, the results do not rule out the possibility of some biologic effects. The very stringent upper limit set by the Viking GCMS data on the quantity of organic compounds in samples of Martian regolith from the Viking landing sites makes a biologic explanation for the results of the Biology Experiments rather unattractive. The existence of past and present life on the planet as a whole cannot, however, be ruled out.

1984 Strategy

The odds given by various scientists for the existence of life on Mars today vary considerably, but they are usually small. It is therefore reasonable to assign higher priority in Mars '84 to the exploration of geophysical and geochemical questions rather than to the continuing search for life, but the mission should surely be equipped with some life-detection equipment. Cameras serve this purpose, but only in part. The analytical equipment required for a variety of geochemical purposes should be able to single out rock units and areas of regolith containing unusual quantities of carbon, and the mass spectrometer

should be available to detect the presence of unusual quantities of organic compounds and to discriminate between organic matter associated with carbonaceous meteorites and indigenous organic compounds.

A more active experiment might involve the insertion of a probe into the regolith or the placement of a bell jar on the surface, and the monitoring of the composition of soil air for one or more diurnal cycles, perhaps during the course of several Martian seasons by means of the mass spectrometer. The same experiment could be modified to include the injection of gases into the soil to determine in situ the reaction of Martian soil and/or organisms with a variety of compounds. As a minimum the results of such measurements would supplement the data obtained from experiments on regolith samples brought into the rover analytical train. At best the measurements could confirm the presence of living organisms within the Martian regolith.

Question

What is the age of surface rocks and soils?

Present status

The establishment of a firm lunar chronology was one of the major accomplishments of the Apollo program. An absolute Martian chronology still remains to be constructed. Crater counts have established the relative age of various surface features, but the history of cratering intensity is not well enough known to permit a great deal of confidence in conversions of crater densities to absolute ages.

1984 Strategy

A knowledge of the absolute age of the most recent volcanism, of the "stream" channels, and of the major canyons is an essential ingredient in developing models for the evolution of the planet, its surface, and its atmosphere. The determination of precise ages will almost certainly have to wait until Martian rocks and soils are returned to Earth. It should, however, be possible to obtain approximate K/Ar ages during the Mars '84 mission. The proposed analytical equipment should be able to measure the potassium content of rocks and soils with sufficient accuracy; the mass spectrometer should be able to

measure the quantity and isotopic composition of argon released by heating such samples; K/Ar ratios of sufficient accuracy should therefore be obtainable to set meaningful lower limits to the age of critical events in the history of the planet. A traverse in the Valles Marineris, for instance, could give minimum ages for what appears to be a very thick section of largely volcanic rocks. At best these K/Ar measurements could be used to calibrate the crater-count chronology and to serve as a starting point for the later, more precise and detailed dating of returned Martian samples.

DISTRIBUTION AND STATE OF H_2O AND OTHER VOLATILES

Many of the key processes that occur during the history of a planet result in diagnostic elemental enrichments or depletions which are determined by the relative volatility of constituents. These processes include planetary accretion and differentiation. A careful assay of the entire volatile inventory which has been degassed from a planet is one of the most effective means of inferring both the bulk volatile content of a planet (which reflects the initial conditions of condensation and accretion), and the extent and timing of its degassing (which reflect its energetic and dynamic history). Once released, the volatiles may interact with the primary igneous rocks on the surface. The sequence of phase assemblages that result provides a dramatic record of changes in the delicate physical and chemical conditions which have prevailed at the planet's surface. In addition, a planet's degassed volatiles are highly vulnerable to - and hence highly diagnostic of - the interaction of the planet with its space environment, including atmospheric sweeping and loss processes.

Planetary surface volatiles also constitute a major link between life and abiotic environment. This is so because the chemical evolution of planetary surface volatiles is, along with the thermal environment, one of the most crucial aspects determining the suitability of the abiotic environment for the origin and subsequent support of life. Therefore an effective means of evaluating the surface environment as a habitat for life is to study the degassing history and geochemical fate of its surface volatiles, based in turn, on their present distribution.

Questions

1)   What is the present abundance and distribution of H_2O and other volatile constituents in the Martian regolith, caps and atmosphere?

2)   What does this distribution tell us about the evolution of the Martian atmosphere and the history of the near-surface environment?

3)   What does this distribution tell us about the degassing history, thermal history and composition of the Martian interior?

Present Status

Although optimized largely to facilitate the search for evidence of life on Mars, the Viking 1976 mission nonetheless provided major advances in our knowledge of the distribution and history of Martian volatiles. Viking orbiter imaging provided outstanding evidence that the channels observed by Mariner 9 were members of a large complex and diverse population. Huge winding channels were revealed. Some of these appeared to contain contoured "islands" in midstream and similarly contoured banks. In some cases the channels appeared to originate from huge collapse features, supporting the contention that the channels were formed by H_2O originally trapped below the surface as ground ice. The abundance of H_2O in the atmospheric column was measured with high spatial resolution, and results indicated that in some areas the atmosphere was saturated with H_2O near the ground. The data further suggested that H_2O might have a much lower scale height than CO_2. Viking orbital images confirmed that diurnal ice fogs formed locally in many low-lying areas. The GCMS on the lander heated soil samples rapidly to ~200°C and then to ~500°C. Although the instrument design was optimized for measurement of organic molecules, H_2O contents ranging up to ~1% were indicated, in full harmony with earlier earth-based observations of H_2O average topsoil concentrations of 0.3 - 3.0% (based on whole disc 3 μm observations from high altitude aircraft). The chemical and multispectral reflectance data, limited as they were to elements heavier than Na, and providing no direct mineralogy, nevertheless were consistent with volatile-altered minerals.

Thus most Viking data support the suggestion that a large volatile inventory is hidden in the Martian regolith, as had been proposed on the basis of earlier laboratory and theoretical studies. However, the atmospheric analyses performed by the Viking entry and landed mass spectrometers - especially the rare gas analyses - appear to place stringent limits on the possible "hidden" volatile inventory. The elemental abundances of ^{36}Ar, Kr and Xe suggest that if the rare gas: H_2O ratios were similar to those of the Earth's surface volatile inventory then only a few tens of meters of H_2O (averaged over the planet), and vastly lower amounts of CO_2, N_2 and other volatiles could have been supplied to the Martian surface. In view of the large H_2O inventory apparently suggested

by channel formation, there may be some need to "decouple" H_2O, CO_2 and other volatiles from the rare gases. Several suggestions have been made, including several mechanisms of preferential loss of rare gases to space. None of these is fully satisfactory, since all seem to require a loss mechanism that does not alter the $Ne:{}^{36}Ar:Kr:Xe$ ratios.

Some loss of atmospheric constituents to space does seem to have occurred, as evidenced by ^{15}N enrichment of about 70%. Also, inerts (N is quasi-inert relative to O_2) seem more susceptible to this mechanism than O_2 which seems to have a large atmosphere-exchangeable reservoir somewhere in the regolith and which shows an ^{18}O enrichment of <2%.

1984 Strategy

The 1984 mission, because of its combined orbiter/rover/penetrator systems, presents a unique opportunity for a coordinated and geologically-oriented approach to the problem of the origin and evolution of Martian volatiles. The following experiments can all contribute significantly to our understanding in this area.

Orbiters and Entry Vehicles

A γ-ray experiment can provide not only general elemental composition maps, but low resolution maps of the H and C distribution in the surface material as well. The experiment can be sensitive to about the 0.2% level for H and the 1% level for C. It can, in conjunction with other data, help map hydrated phase distribution and adsorbed H_2O and CO_2, H_2O ice, CO_2 ice, and clathrate distributions in both space and time.

An IR reflectance spectrometer can produce high-spectral resolution, moderate-spatial resolution maps of mineral distribution. Not all mineral species are easily identified by these techniques, but many of the most significant ones are. The 1.4 μm, 1.9 μm and 3.0 μm H_2O bands provide a triple check means for mapping the bound H_2O and OH distribution. Other spectral characteristics allow maps to be made of the distribution of weathering products vs. exposed igneous source rocks, of the state of oxidation of the surface, etc.

The combined results of the plasma probe, the magnetometer and the UV photometer on the orbiters plus the neutral mass spectrometer and retarding potential analyzer on the entry vehicle will allow quantitative modeling of the interaction of the space particulate and radiation environment with the uppermost atmosphere. This, in turn, will allow identification of the mechanisms by which various volatile constituents are being (or have been) lost from the atmosphere — regolith volatile system to space and the rates at which these processes occur.

Imaging will allow further definition of channel origin(s) and ages(s), and will provide new evidence relating to the distribution of ground ice and the possible genetic relationship between these two phenomena. The dynamics of exchange of H_2O and CO_2 with the surface on a daily and seasonal time scale will also be elucidated.

Rovers

Analyses of soil by the central mass spectrometer system can be done in such a way as to provide a complete spectrum of gases effused by heating. This will involve slow heating (not flash heating) and a direct input of gases from the soil to the mass spectrometer. An assay of hydrated phases, nitrates, carbonates, sulfates, unknown surface oxidants, etc., will be possible.

These measurements will be enhanced by concurrent calorimetric data from the oven which will provide data on enthalpic changes (even in 1 mg components) corresponding to each of the effused gas peaks plus some data on phase transition not involving volatile effusion. Release of volatiles by introduction of reactive vapors was described above (Chemistry and Mineralogy of Surface Samples).

To sample the properties of the Martian regolith below the zone directly accessible to the rover (about one meter depth), "active" geophysical methods are useful; i.e., techniques which use artificial rather than natural sources of energy. Two complementary experiments are possible using the rover and its deployed station:

(1) Active seismic experiment. Sources (e.g., explosive pellets) deployed by the rover are used to generate signals recorded by

high-frequency seismometers at the deployed station and aboard the rover. By spacing the shots at increasing distances, a profile of seismic wave velocity versus depth can be obtained.

(2) Active electromagnetic experiment. A transmitter aboard the rover generates an electromagnetic signal which is received at the deployed station. The interference between the direct-wave and the wave refracted through the ground can be used to estimate the dielectrical properties of the regolith. By repeating the experiment at increasing spacings, a profile of the electrical conductivity of the regolith can be derived.

These two experiments together represent the best method for determining the existence of an ice-water transition within the regolith. The electromagnetic experiment is sensitive to the presence of water, whereas the seismic experiment is sensitive to the presence of ice.

A reflectance spectrometer on the rover should allow small-domain qualitative identification of a portion of the mineralogical assemblage, including any concentrations of volatile-rich phases in the scene. An example would be detection of hydrated iron oxides, carbonates, sulfates or clay minerals. The unique contributions are twofold: First, this instrument can provide direct (although incomplete) information on mineralogy in an imaging context, which allows relating of mineralogy to in-situ geometry or texture, allowing conclusions about mineral genesis to be drawn; and, second, this instrument is an enormous convenience as a survey instrument for spotting concentrations of unusual mineralogical domains for sample acquisition and later detailed analysis by analytical instruments which are far more sophisticated.

An X-ray diffractometer will identify major volatile-containing phases in the soil. Properly designed, the instrument can be effective for clay minerals, despite their high d-spacing. Moreover, some mineral separation is desirable prior to analysis, which extends the sensitivity for relatively minor phases.

Penetrators

Penetrators can sample the subsurface, which should have different volatile-related properties than the rover-accessible surface because of the effectiveness of the summer insolation in modifying hard-frozen permafrost.

A soil "P_2O_5" water analysis experiment could provide at least semi-quantitative assay of the H_2O content of the separate possible major H_2O containing lattices (including ice) in the regolith at depths below the seasonal "thermal wave" at each of six sites. This is an essential "planetary volatile inventory" measurement which is not pre-empted by sample return. A simple instrument could provide simultaneous slow heating, effused H_2O analyses coupled with calorimetric data. That would provide a complete assay of H_2O at all possible mineralogical sites.

The afterbody of the penetrator will experience an acceleration of 17, 000 - 20, 000 G. However, an atmospheric H_2O (or "humidity") device has survived such acceleration in tests. Such near-to-ground P_{H2O} measurements are crucial to complement "maps" of the H_2O in the total atmospheric column. Ground-level P_{H2O} measurements over a long period of time could provide crucial information as to the life profile of H_2O molecules in the atmosphere, the dynamic exchange of H_2O between the atmosphere and the top centimeter or two, and top meter or two of topsoil on a diurnal and seasonal timescale respectively. These data will have crucial meteorological and biological implications.

GLOBAL ATMOSPHERIC DYNAMICS

Just as the study of geologic and tectonic processes on other planets broadens our understanding of those processes and adds new insights and perspective to terrestrial geology and tectonophysics, increased understanding of the dynamics of other planetary atmospheres can be expected to yield major dividends in the field of geophysical or planetary fluid dynamics. The Martian atmosphere is especially useful in such comparisons because of its similarity to the Earth's atmosphere in such important properties as size, temperature regimes, atmospheric transparency, and rotation rate. The central problem of geophysical fluid dynamics is to determine the dependence of the flow of rotating differentially heated fluids, oceans or atmospheres, on their thermal forcing and boundary conditions. The Martian atmosphere is subjected to thermal forcing and boundary conditions that are only modestly different from the Earth's, at least when contrasted either to conditions on other planets or to conditions obtainable in the laboratory. Martian atmospheric observations could shed light on a number of fundamental problem areas. There are questions concerning the dynamics of the lower atmosphere, the chemical stability of the atmosphere, dominant mechanisms in the upper atmosphere, and the history of escape from the top of the atmosphere.

Question

How do the distribution and intensity of transient eddies depend on the boundary conditions and on the thermal forcing? Baroclinic and barotropic instabilities produce transient eddies in the Earth's atmosphere and in laboratory experiments. Although the theory of infinitesimal unstable disturbances is well developed, the full life cycle and the large amplitude stages of these disturbances are not amenable to analytic treatments, and observations of the seasonal and spatial distribution of eddies under Martian conditions would be of great interest. Although baroclinic eddies are expected theoretically in some regions and during some seasons, the conditions under which they could develop would differ in important respects on Mars from those on Earth. These include: different static stability, different planetary scale, absence of latent heat release on Mars (as well as stronger thermal damping) and stronger topographic influence.

Question

How is the transport of heat and angular momentum related to the zonally averaged temperature and momentum distributions? This question is of fundamental importance in climate theory since the development of "closure schemes" for relating the eddy transports to mean conditions depends on its solution. Martian observations of the distribution of zonally averaged temperature and observations of surface easterly and westerly winds, which are indicative of source and sink regions for atmospheric angular momentum, together with observations of the distribution of eddies would shed light on this important question.

Question

How do topographically forced disturbances depend on atmospheric structure and on the topographic characteristics? Complementing the transient eddies in climate theory are the stationary disturbances produced directly by the kinematic effects of topography or indirectly by thermal effects induced by the topography. Such features as the Bermuda and Pacific highs, the Siberian high, and the Aleutian and Icelandic lows are quasi-stationary features produced directly or indirectly by terrestrial topography. Similar features are expected on Mars as a result of the influence of Hellas, Chryse, the Tharsis Ridge, and other large topographic entities. Topographically forced disturbances in the Earth's atmosphere often amplify with height and, in some cases, they can interact with the mean flow to produce dramatic changes in the latter. Major winter warmings of the terrestrial stratosphere, such as occured in the winter of 1976-77, apparently result from such an interaction. It would be valuable to know whether similar phenomena occur on Mars.

Question

How does the planetwide circulation vary in response to the thermal forcing? This general question concerns the zonally averaged temperature and wind distributions, the major quasi-stationary non-zonal features of the circulation, and also the diurnal variations of wind and temperature, the atmospheric tides. On Mars, there are particularly large variations in the thermal drive associated with diurnal and seasonal changes, as well as with absorption of

solar radiation by variable amounts of dust in the atmosphere. The dynamics associated with condensation of about one third of the atmosphere each year at the polar caps may involve a circulation pattern unique to Mars.

Question

What is the rate of vertical mixing; how does this affect the stability of the CO_2 atmosphere? The chemical composition of the atmosphere is believed to be stabilized by catalytic reactions between dissociation products of H_2O and those of CO_2, but the relative importance of reactions in the atmosphere compared with reactions occurring at the surface is a matter of debate. The alternative chemical models are quite sensitive to the rate of vertical mixing below 45 km. Vertical mixing in this region is probably caused by the large-scale circulation but is not quantitatively well determined.

Question

What is the rate of transport of surface material by the wind? The modification of the surface by aeolian erosion, and the movement of fine-grained materials over the surface are obviously major factors determining the surface features and the distribution of materials on the surface. Much of the fine material appears to be moved in great dust storms of nearly planetary scale. Determination of the mass transport rate would allow estimation of the time scale associated with dune features and layered terrain. Since direct measure of the aeolian transport rate appears very difficult, it would be valuable to identify the conditions under which dust can be raised, and the mechanisms responsible for the generation, growth, and decay of dust storms on all scales.

Question

What are the processes that control the height of the turbopause and circulation in the thermosphere? The dynamics of the upper atmosphere pose a different class of problems. The height of the turbopause influences the separation of escaping isotopes of oxygen and nitrogen. The turbopause height is determined by turbulent mixing, which, in turn, is believed to be generated by tides or internal gravity waves propagating upward from the lower atmosphere.

The circulation of the thermosphere, its response to solar ultraviolet radiation, to charged particle fluxes, and to upward flux of energy of wave disturbances generated in the lower atmosphere strongly influences the population at the escape critical level. These are important factors in the history of volatiles on Mars, as well as important questions in comparative planetology.

Present Status

Spacecraft missions have provided the body of data relevant to Mars atmospheric dynamics. The infrared interferometer (IRIS) experiment on Mariner 9 and radio occultation experiments on both Mariner 9 and Viking have provided vertical temperature profiles. Surface wind, temperature and pressure measurements are being obtained at the two Viking landing sites. The two Viking entry experiments together with data from a stellar occultation observed from Earth have provided evidence of dynamical activity in the Martian upper atmosphere. The distribution and optical properties of atmospheric dust have been observed by orbiting spacecraft, with Viking lander measurements providing quantitative information on dust particle properties and opacity. The Viking water detecting spectrometer (MAWD) has mapped diurnal and seasonal variations in total water column, and the Viking infrared radiometer (IRTM) has added additional data on horizontal temperature variations. The Mariner 9 ultraviolet spectrometer (UVS) measurements of airflow features in the upper atmosphere and of ozone absorption in the polar lower atmosphere have helped to identify the processes occurring in these regions.

The remote sensing temperature measurements have revealed the strong latitudinal and seasonal variations in temperature and in the static stability. They have also shown that the atmospheric temperature distribution is very sensitive to atmospheric opacity, the consequent absorption of sunlight by dust, and diurnal temperature variations in increased radiation coupling. The sensitivity of the dynamics to dust load is particularly significant since the Viking observations have shown that the dust opacity is substantial much of the time. The surface meteorological observations have demonstrated that topographically controlled wind systems and global tides are both important components of the global circulation. Large seasonal pressure variations associated with carbon dioxide condensation and sublimation in the polar cap regions as well as

smaller variations associated with meteorological changes have been identified.
The Viking IRTM has found anomalously low temperatures over both the winter
polar caps, and one interpretation is that the carbon dioxide is depleted over
the polar cap with respect to nitrogen and argon as a consequence of the con-
densation process. Such a depletion would have interesting dynamical conse-
quences. The UVS ozone determinations provide some additional evidence con-
cerning polar processes, indicating considerable day-to-day variability in
abundance of the ozone controlling factor, water vapor.

Although considerable progress has been made, our knowledge of the
dynamical properties of the Mars atmosphere remains very incomplete. This
is chiefly because orbital and operational constraints have precluded systematic
coverage. Although indications of a large diurnal temperature variation during
extremely dusty conditions are evident in the Mariner 9 data, it is generally
impossible to sort out the influence of latitude, longitude, diurnal, seasonal,
synoptic, and dust-related variations. The ability to separate these influences
is a prerequisite to advancing our understanding of the dynamics. Coverage of
the planet with the Viking IRTM has been more systematic than with the other
remote sensing techniques, but the very important vertical structure is not
resolved in these measurements. Similarly, the MAWD data do not provide
information on the vertical distribution of water or on the water vapor pressure
at the surface. The UVS data provide information on physical processes and
their variability, but these processes are complex, and unambiguous interpre-
tation of this large body of data requires direct comparison of ultraviolet airglow
measurements with in situ measurements. Additional factors which must be
sorted out in the upper atmosphere are the variations depending on solar ultra-
violet irradiance or on energetic charged particle fluxes; both of these have
major solar cycle components.

1984 Strategy

The basic strategy for dealing with the questions raised above is to obtain
sufficient data on the distributions of the dynamically interesting quantities
that the several contributions to variability can be sorted out. This does not
require the informational detail from which synoptic weather maps could be

constructed, but it does require systematic coverage of a number of key variables. The 1984 mission, configured primarily to meet other objectives, is nearly ideal for this purpose as well. The low circular polar and low-inclination orbits provide the opportunity to distinguish diurnal, longitudinal, topographic, and synoptic variations in those quantities which can be remotely sensed, while the surface penetrator network allows distributed measurements of other key variables. Finally, the soft-lander/rover component of the mission provides the opportunity for correlated surface measurements which can aid in the interpretation of the relatively simple network instrumentation.

The following group of interrelated measurements is needed to take best advantage of this unique opportunity.

Global Vertical Temperature Profile

An IR measurement of approximately 8 distinct temperature weighting functions, well-distributed below 40 km, would provide the necessary temperature coverage. With the two orbits under consideration, it would be possible to separate all contributions to the variability, provided that independent measurements of dust opacity are also obtained. Temperature distributions are important in their own right, but they also yield geostrophic thermal winds. These provide a first approximation to the real wind, and they can also be used as a first step in obtaining improved wind approximations. The geostrophic approximation is not applicable to the diurnally varying component of winds, but techniques are also available for deducing these tidal winds from the temperature variation field.

Surface Network Pressure Measurements

A survey of surface pressure measurements would allow the following problems to be addressed: (i) identification of the principal tidal modes and determination of their amplitudes. These measurements would be supplemented by the orbiter measurements of diurnal temperature variations. (ii) Determination of the regional and seasonal distribution of synoptic variability. The Viking stations provide some information on this, but the array coverage could lead to

a much more complete and unambiguous determination of the regional distribution. Supplemented by orbital measurements of temperature, this bears directly on the problem of transient eddies. (iii) <u>Coarse regional coverage of the distribution of quasi-stationary highs and lows and of geostrophic zonal winds</u>. Again, these measurements are complementary to orbiter temperature determinations. Determination of the largest scale variations of the surface pressure and vertical temperature allows fairly complete specification of winds at the same scale. Success of this part of the experiment depends on determining the height of the pressure sensors with respect to the local reference aereoid with complementary radar altimeter and orbital gravity measurements. The Viking results indicate each of the three goals of the pressure measurement experiment is a reasonable one in terms of achievable instrument accuracies.

Surface Network Optical Measurements

The dynamical information obtained from the orbiter atmospheric temperature measurement and from the surface pressure measurements should be accompanied by a quantitative measure of the atmospheric dust load. This could be accomplished by an array of optical sensors which quantitatively determine atmospheric opacity and also distinguish dust from condensate aerosols. Dispersal of the array over the penetrator network and on the roving vehicles would be ideal in order to provide as much information as possible on the spatial distribution of aerosols. However, sensors on the rovers alone would be of some value. These observations could be supplemented by low resolution orbiter imaging data in order to provide qualitative data on aerosol distribution. The combined aerosol and dynamical data from orbiter thermal sounders, surface pressure and optical networks, and orbiter imaging should be adequate to definitively relate dust content and circulation intensity, and would provide the information necessary to resolve outstanding questions concerning the origin, evolution, and decay of planetwide dust storms.

Surface Meteorological Stations

In order to make maximum use of synoptic pressure fluctuation data it would be extremely valuable to have a number of more complete meteorological

stations measuring wind speed and direction and ambient temperature. Correlation of these data with pressure fluctuation data would greatly assist in determining the nature of the disturbances producing the fluctuations. For example, it would make it possible to identify frontal passages, high or low pressure cells passing on the poleward or equatorward side of the station, etc. The complete set of measurements would also refine our knowledge of boundary layer characteristics and or local or regional topographic wind systems. In addition, wind speed measurements are essential to determination of saltation threshold winds, and hence to gaining a complete understanding of the dust transport problem. Meteorological instrumentation should be deployed with each roving vehicle geophysical instrument package. It would be desirable to obtain such measurements at the penetrator array sites as well.

Surface Humidity Measurements

To supplement the Viking measurements which yielded column water vapor measurements, a deployed array of atmospheric water vapor sensors would be of great value. By coupling the information on large scale atmospheric motions obtained with the instruments described above with surface humidity measurements deployed over a well distributed network and also with the Viking MAWD water abundance measurements, it should be possible to delineate major features of the diurnal and seasonal water vapor sources and sinks.

INTERACTION OF THE UPPER ATMOSPHERE WITH THE MAGNETIC FIELD, SOLAR RADIATION, AND THE SOLAR WIND

To understand Mars it is important to understand how the atmosphere has evolved to reach its present state. The absolute amount of CO_2 and H_2O degassed from Mars that is implied by a comparison of the Martian and terrestrial abundances of ^{36}A, Kr, and Xe is large relative to the quantity of CO_2 and H_2O presently in the Martian atmosphere. The implication (see above) is that there are reservoirs of H_2O and CO_2 in the planet's crust. Examination of the amount of N_2 in the atmosphere, and the enrichment of ^{15}N compared to ^{14}N suggests that in the past the atmosphere was much more dense than it is presently. N can escape from the exosphere because of kinetic energy supplied to it there by dissociative processes such as:

$$e + N_2^+ \longrightarrow N + N + K.E.$$

$$h\nu + N_2 \longrightarrow N + N + K.E.$$

$$e + N_2 \longrightarrow N + N + e + K.E.$$
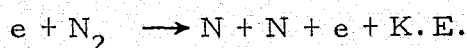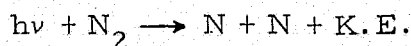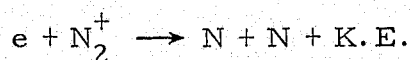
Enrichment occurs because of gravitational separation in the thermosphere that causes the ratio of ^{14}N to ^{15}N at the base of the exosphere to be larger than in the mixed atmosphere. Similar processes also permit CO, C, and O to escape but isotopic enrichment of these volatiles would not be as great as in the case of nitrogen if they are in contact with a sizeable reservoir and N_2 is not. The analysis of the amount of enrichment implied by the presently measured $^{15}N/^{14}N$ ratio and the model of atmospheric evolution that can be inferred depends on an adequate understanding of the way in which the temperature structure and the neutral and ionic composition of the upper atmosphere varies during the solar cycle. It is also necessary to understand how the solar wind interacts with the planetary ionosphere and upper atmosphere; i.e., how the loss of atmospheric ions due to solar wind ablation compares with loss effects from other processes; how the bombardment by solar wind ions can provide gaseous constituents within the upper atmosphere; how the solar wind

energy deposition, heat flux and ionization effects compare with those provided
by solar radiation; and how the local magnetic field (which may be associated
with a permanent planetary field, or a piled-up interplanetary field) controls
the local dynamics of the wind-atmosphere interaction.

The night-side solar wind interaction must also be analyzed because the
magnetosphere, the plasma tail or the wake cavity may be associated with a
reservoir of plasma and energetic ionizing particles that can serve to maintain
the night-side ionosphere, and can provide substorm-like activity, as in the
magnetospheres of Earth and Mercury.

Question

What is the form of the solar wind interaction with the upper atmosphere
and ionosphere?

Present Status

As was discussed in the section on internal structure the plasma probe
and magnetometer on Mariner 4 which passed within 3.9 planetary radii of the
center of Mars detected what appeared to be a bow shock. From indications
that the wind interaction occurred close to the Martian surface an upper limit
of 2.4×10^{22} Gauss-cm^3 was placed on the planetary dipole moment. The
Soviet satellites, Mars 2, 3, and 5, all carried plasma probes and magnetom-
eters. They observed novel interaction phenomena at the interface between
the upper atmosphere and the solar wind. However, none of these measure-
ments has been complete enough to provide a definitive answer to the question
posed above.

In fact, none of the Soviet spacecraft directly sampled the region where
the solar wind interacts with the upper atmosphere, the ionosphere, or the
planetary magnetic field. While they did penetrate the bow shock and established
that the "obstacle" altitude was about 300 km above the Martian surface near
noon, they did not actually penetrate this obstacle region.

Because of the orderly pattern of the magnetic field observed at the
flanks of the planet the Soviets concluded that Mars has an intrinsic field with

a moment of 2.5×10^{22} Gauss-cm^3. However, this pattern could simply be an aspect of sheath flow around a nonmagnetic obstacle. Plasma probes on the Soviet Mars missions have given conflicting results and so are of no help in distinguishing between these alternatives.

The entry science data obtained on the Viking missions indicate a high altitude energy source which is not solar ultraviolet radiation but may well be the result of direct solar wind input into the upper atmosphere.

Thus there is not yet any conclusive evidence bearing on the questions of whether Mars has an intrinsic magnetic field, or how the solar wind interacts with the upper atmosphere and the ionosphere.

1984 Strategy

The Mars 1984 orbiter can answer the question posed here if it measures plasma ion fluxes, in such a way as to distinguish between solar wind ions (H^+) and ionosphere ions, simultaneously with the magnetic field. Direct sampling must be made for a reasonable length of time in the interaction region near 300 km. To establish the characteristics of the night-side magnetosphere, plasma tail or wake cavity measurements also must be made on the night-side at distances of 5 to 7 Mars radii for several orbits.

Question

What are the major atmospheric escape processes? How are they affected by variations in the thermal structure and composition of the upper atmosphere and ionosphere? How have these processes affected atmospheric evolution?

Present Status

Prior to the Viking missions our information concerning the upper atmosphere and the ionosphere of Mars had been obtained by Mariner 4, 6, 7, and 9 utilizing two techniques: radio occultation determination of electron density profiles and remote sensing ultraviolet spectroscopy. The results obtained for the exospheric temperature inferred from the plasma scale height and from models for the excitation processes leading to the observed airglow spectra, are summarized below:

Mission	Date	$F_{10.7}$	H (plasma)	T_x (from plasma)	T_x (UV)
Mariner 4	1965	78	29 km	270°K	
Mariner 6	1969	148	45 km	445°K	
Mariner 7		148	49 km	450°K	350°K
Mariner 9	1971	115	39 km	350°K	325°K

where $F_{10.7}$ is the solar decametric flux in appropriate units, H (plasma) is the topside ionospheric scale height, and T_x is the exospheric temperature. The observed exospheric temperatures T_x are only about half those predicted using early estimates of the solar UV heating efficiency. They may differ by an even larger factor if solar fluxes are multiplied by a factor of 3 to achieve consistency with the observed magnitude of electron densities. The very low abundance of atomic oxygen and CO inferred from a study of the UV resonance radiation of these species emitted by the atmosphere and the low thermal escape flux of hydrogen determined by an analysis of H Lyman-α observations imply a very effective eddy transport in the upper atmosphere.

Data concerning the neutral and ionic composition and temperature of the upper atmosphere on the Viking mission were obtained from two "vertical" in situ sets of probe measurements performed by mass spectrometers and retarding potential analyzers on the entry vehicle. The results, for solar conditions similar to those of Mariner 4 but with Mars at aphelion, were totally unexpected. The temperature of the upper atmosphere was very low, $160 - 220^\circ$K, and exhibited wholesale wave structure unlike the smooth variations inferred from the results obtained by earlier probes. The results, in fact, suggest that in the summer of 1976, solar radiation was not as important in heating the upper atmosphere as internal gravity waves transporting mechanical energy from the lower to the upper atmosphere. Calculations leading to estimates for escape fluxes of N, C, O, and H are based on the 1976 atmospheric structure. Data obtained for different solar conditions may force a modification of the conclusions based on these special conditions. Furthermore, there may be important escape processes not yet taken into account. In the case of Earth, the conversion of thermal H atoms to fast atoms as a result of charge

exchange with hot H^+ ions in the plasmasphere seems to be the dominant contributor to the escape of hydrogen. Adequate information concerning the composition, density, and the interaction of the solar wind with the atmosphere may modify the present models of atmospheric escape.

1984 Strategy

Our experience in studying the upper atmosphere of the Earth demonstrates that it would be shortsighted to base models of the atmosphere on results obtained from two vertical probes made under very special conditions such as obtained during the 1976 Viking landings. The Viking Orbiter did not carry a limb scanning ultraviolet spectrometer that would have permitted a direct comparison with the entry science composition data. Inclusion of such a spectrometer on the 1984 orbiters along with entry vehicle in situ measurements of the composition of the neutral and ionized atmospheres as well as the ion temperature will allow such a calibration. It will then be possible to relate the Mariner 4, 6, 7, and 9 data obtained in 1965, 1969, and 1971 with remote sensing techniques to the measurements made on Viking in 1976 and those made in 1984. Thus, atmospheric and ionospheric data for a large range of solar conditions will be available for the construction of models of atmospheric excape processes. The improved 1984 orbiter coverage will also allow clear separation of diurnal, latitudinal, longitudinal, and solar activity-related variations.

A MARS 1984 MISSION

MISSION DESIGN

MISSION DESIGN

MISSION DESIGN

THE POINT DESIGN CONCEPT

When a multi-vehicle mission is first considered, there is a virtually unlimited number of design options. Ideally, it would be logical to consider each option in detail, and then consider the inter-relationships of all candidate sets of options. However, there are neither resources nor time for such an ambitious undertaking. An important constraint has been the requirement for the JPL study group to present a detailed cost analysis to NASA review committees by July 1977. The credibility of this cost analysis will be an important factor in the decision regarding a mission start in FY 79. Obviously, no cost analysis will survive scrutiny unless it is related to specific hardware and mission events.

We have determined that the achievement of all the science goals for the mission requires data from each of the three systems -- orbiter, rover and penetrator. Further, a sound mission design based on these is feasible. Therefore, we have focussed our efforts on this "all-up" option for which the JPL "point design" has been developed. This point design is made up of a mission design and designs for each of the systems that meets the mission requirements. In the point design, both hardware and software are identified and described adequately to determine their cost.

The point design is a candidate mission in which, for the most part, available options are resolved in favor of a particular choice. Predictably, the MSWG has felt uncomfortable working in this framework. At our very first meeting, we were confronted with requests to make choices concerning launch strategies, trajectory strategies, instrument selection, mission operations modes, etc. Nonetheless, we recognize the necessity to provide our best estimates in order that cost and feasibility analyses can move forward.

We wish to underscore the fact that the point design is not necessarily the final design. This distinction should be kept prominently in mind as one reads subsequent sections of this report in which we discuss such topics as science instrument payloads. We have not selected certain instruments, nor

should our failure to mention other instruments be construed as rejection. The selection of instruments will be made, quite properly, more than a year from now in response to an Announcement of Opportunity for a flight mission. At that time, we would be delighted to discover that our complement of instruments has been replaced with a different set, if it should represent better capabilities than ours.

GETTING TO MARS

Introduction

Prior mission experience has demonstrated that severe constraints are placed on the scientific capability of missions by spacecraft weight, fuel availability, and trajectory/orbit geometries. These factors are inter-related in ways that are not always obvious.

In this section we demonstrate, on the basis of a reasonably detailed study, that a Mars 1984 orbiter/rover/penetrator mission is practical in terms of weight, fuel and trajectory/orbit constraints. Clearly, the mission plan will be modified and, it is hoped, improved in the future. We seek here only to establish that an acceptable mission has been identified.

Spacecraft Characteristics

As currently proposed, the Mars 1984 missions commence with two Shuttle launches in late December 1983 and January 1984, with arrival at Mars slightly over 9 months later. Each spacecraft consists of an orbiter, a landing system carrying a rover, and three penetrators. A two-stage, solid/liquid propellant rocket is used to insert the spacecraft into Mars orbit. Table 3-1 lists the major masses, including contingencies (i.e., allowance for unexpected growth in spacecraft systems), that fit within the performance capabilities of the Space Shuttle and its Intermediate Upper Stage (IUS). Nominal values are the best estimates; contingencies are estimates based on past experience. The total "allocated" mass must not exceed the Shuttle/IUS capability.

Mission Summary

This section summarizes the overall mission operations plan from launch through landing. Figure 3-1 shows a timeline for the plan, with significant events marked.

Table 3-1. Mars 1984 System Weights, kg
(Based on S/C-2 Fully Loaded)

	NOMINAL	CONTINGENCY	ALLOCATED
ORBITER	*3683	97	3780
Orbiter without propulsion	597	60	
Liquid stage & propellants	*1354	29	
Solid stage & propellants	1732	8	
LAUNCH VEHICLE/SPACECRAFT ADAPTER	88	5	93
LANDER/ROVER	1210	43	1253
Rover	414	27	441
Deployable science	50		50
Lander (incl. entry science)	673	16	689
Adapter & misc. structure	73		73
PENETRATORS	214	18	232
3 penetrators	114		
Decelerators	50		
Launch tubes	22		
Retrorockets	22		
Misc. structure	6		
TOTAL	*5195	173	**5358

* Orbiter liquid stage nominal wt based on propulsion sized for allocated
  system wts.

** Expected Shuttle/IUS capability = 5385 kg for maximum energy condition
   (C_3 =11.03 km^2/sec^2 on 1/2/84) during S/C-2 launch period.
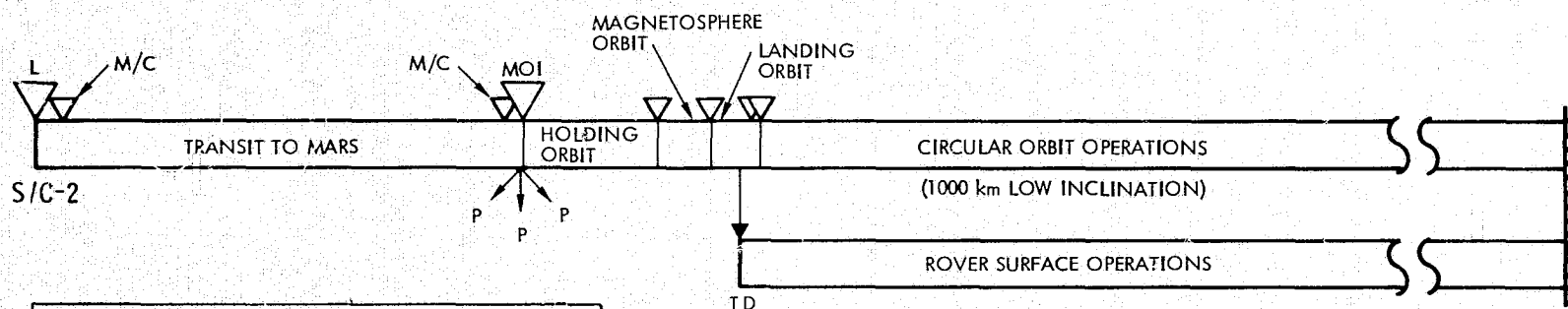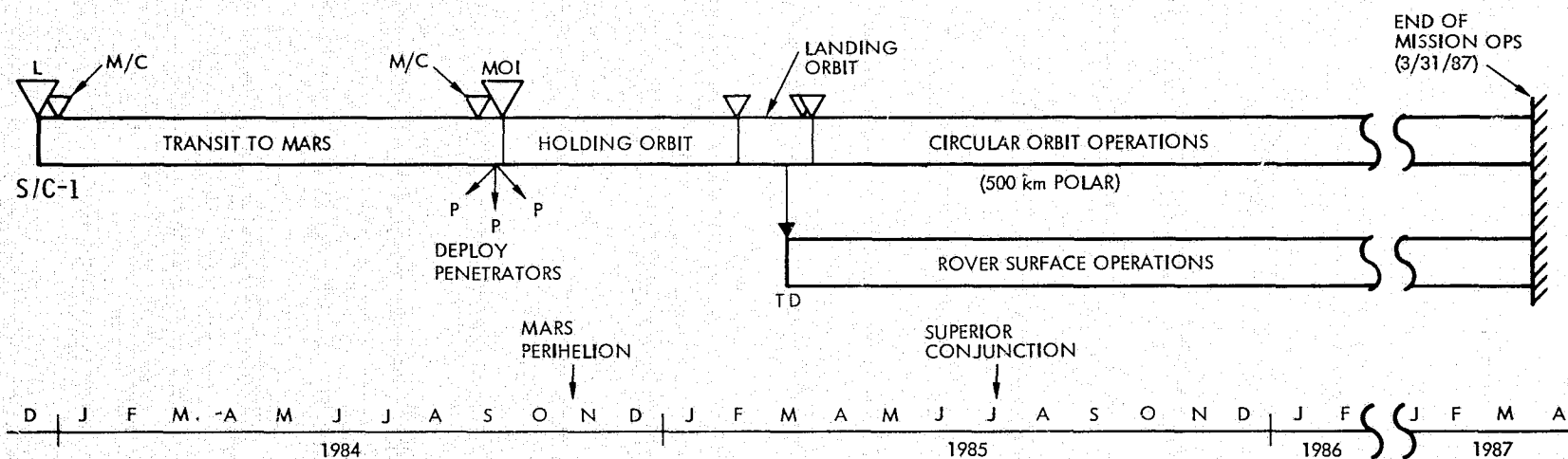
Figure 3-1. Typical Mars 1984 Timeline.

Launch to Encounter

Two spacecraft are launched by the Shuttle/IUS twin stage into a circular shuttle parking orbit during the December 1983 to January 1984 period. Each spacecraft consists of an orbiter, a landing system carrying a rover, and 3 penetrators. The launch opportunity period is about 28 days. The assumed minimum separation between launches is 7 days. After separating from the Shuttle, and after some nominal wait in orbit, the IUS injects the spacecraft into Type II interplanetary trajectories (heliocentric transfer angle between 180° and 360°) requiring about 9 months transit time (Figure 3-2). Near-Earth and Mars-approach midcourse maneuvers are executed to remove launch injection errors ($3\sigma \sim 15$ m/sec) and to achieve final approach targeting. The penetrators are deployed during approach about 2 days before Mars orbit insertion. The time of arrival of the approach trajectory is selected for the desired longitude of penetrator impact points. Spacecraft arrival occurs during September or October 1984. The interval between the arrival of the two spacecraft will be approximately 14 to 26 days, depending on the actual launch dates. Spacecraft arrival occurs about a month before Mars perihelion and 9 months before conjunction with the sun.

Penetrator Latitude Accessibility

The penetrators will impact in an annular ring centered on the hyperbolic approach velocity vectors (Figure 3-3). The limits of this ring are defined by the range of acceptable atmospheric entry angles. These limits are -10° to avoid skip-out and -15° to avoid overheating of the decelerator. The resulting annular ring is between 67 and 77° from the approach velocity vector. This corresponds to Mars latitudes of 50°N to 87°S for the early launch (as shown in Figure 3-4) and 38°N to 75°S for the late launch. The central longitude of the ring can be varied by a full 360° by controlling the time of arrival during a Sol (a Martian day). Once an arrival time is selected for a spacecraft, the associated three penetrators have a fixed ring in which the impact will occur.

MOI and Initial Orbit

A Mars orbit insertion (MOI) maneuver is performed to place the spacecraft in an initial elliptical capture orbit. The nominal initial orbit has a

SUPERIOR CONJUNCTION (7/18/85)

SPRING EQUINOX

6/20/85

4/21/85

$L_S = 0°$

MARS ORBIT

8/19/85

340°

2/20/85

1/1/84

320°

LAUNCH PERIOD (12/19/83 – 1/15/84)

60°

300°

10/18/85

10/27/84

80°

EARTH AT ARRIVAL

280°

12/22/84

3/1/84

SUN

12/17/85

100°

EARTH ORBIT

8/28/84

4/30/84

260°

PERIHELION (11/8/84)

120°

2/15/86

6/29/84

240°

10/23/84

140°

220°

ARRIVAL PERIOD (9/25/84 – 10/18/84)

EARLY S/C TRAJECTORY

LATE S/C TRAJECTORY

160°

4/16/86

8/24/84

6/15/86

L_S = HELIOCENTRIC ANGLE OF MARS IN ITS ORBIT MEASURED FROM THE SPRING EQUINOX

Figure 3-2.   Mars 1984 Type II Trajectory.

TRAJECTORY CORRIDOR FOR
ACCEPTABLE ENTRY FLIGHT
PATH ANGLES

APPROACH
VECTOR

EQUATOR

DECLINATION OF
APPROACH VECTOR

LOCUS OF LANDING
SITES IS A RING
CENTERED ON
APPROACH VECTOR
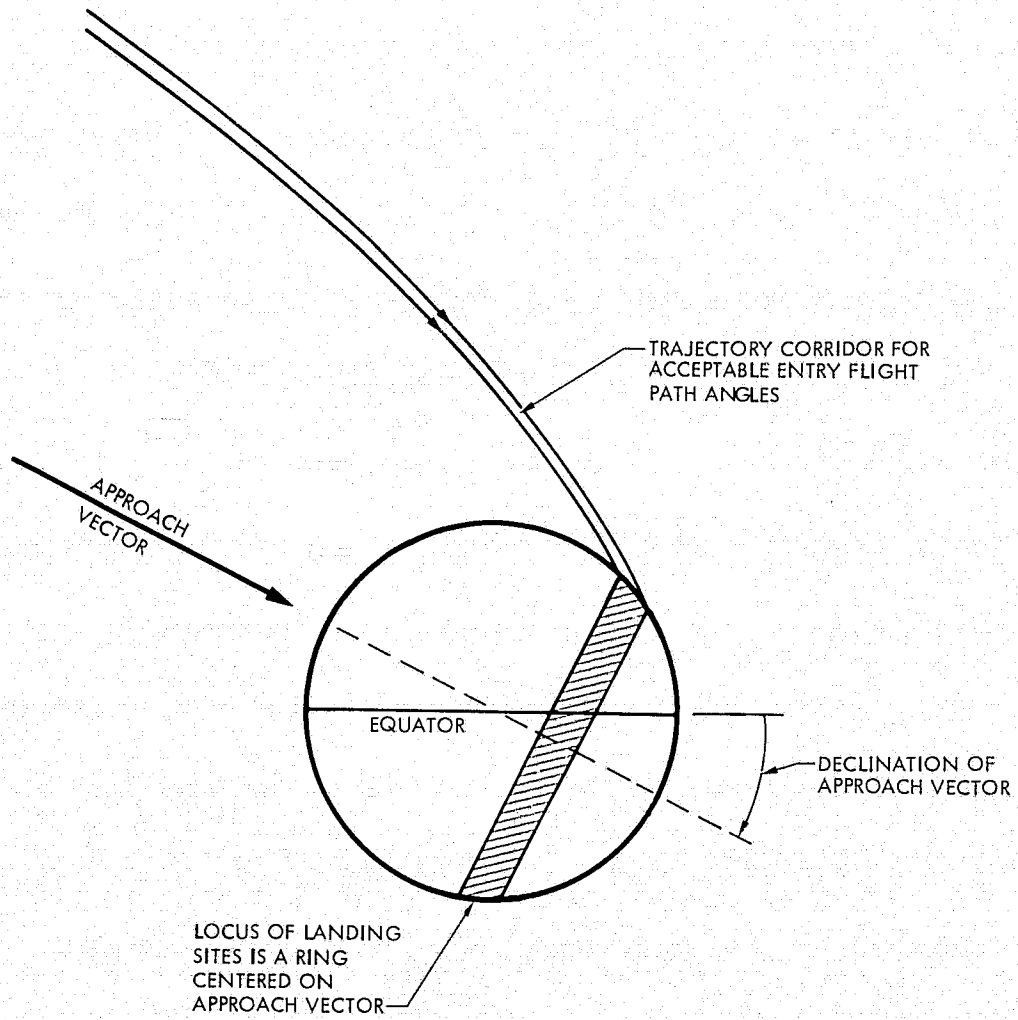
Figure 3-3. Penetrator Site Accessibility.

ARRIVAL
DECL = 28°

65S
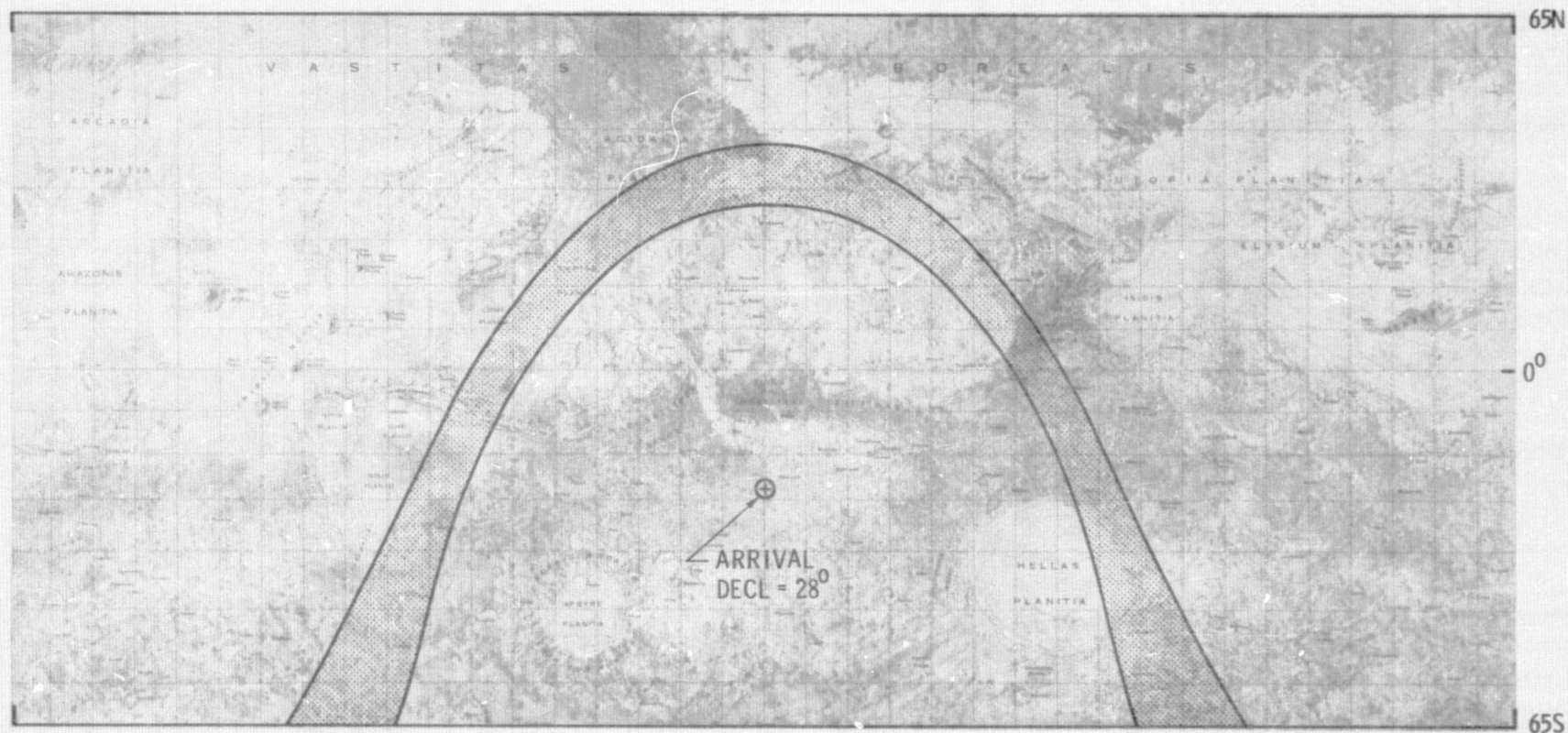
NOTES: 1) MAX SOUTH ACCESSIBILITY = -86° LAT
2) LONGITUDE OF LANDING LOCI CAN BE SELECTED BY CHOICE OF S/C ARRIVAL TIME

3-11

Figure 3-4. Penetrator Site Accessibility (Early Launch/Arrival).

500-km periapsis altitude and a period equal to 5 Mars days (5 Sols). The apoapsis altitude will be 112,000 km. One of the spacecraft is targeted for an initial orbit with near-polar inclination to support a landing either at a moderate north or far south latitude. The other spacecraft is inserted into an initial orbit with low inclination (~30 to 50°) for an equatorial zone landing. The insertion maneuver consists of two parts. First, the solid stage reduces the spacecraft velocity to near capture; the liquid-fueled engines then complete the maneuver.

The 5-Sol initial orbit serves as a "holding" orbit from which Mars atmospheric conditions can be assessed before the start of operations required for landing. Current Viking data indicate that the start of site certification observations may be delayed a few months since the surface is apt to be obscured by dust.

Preseparation Operations

The 5-Sol initial orbit period is reduced to a 1-Sol synchronous orbit to support site certification and lander/rover separation for landing. A minimum of about one month is required from the start of site certification to separation, based on the estimated data required to certify a site within a candidate region. Figure 3-5 shows the pre- and post-separation mission profile.

The low-inclination orbiter makes measurements in the magnetosphere bow wave and tail while in elliptical orbit. The orbit periapsis should be lowered to ~300 km to measure the bow wave, and the tail should be measured from an altitude of at least 3 Mars radii (~10,000 km). The opportunity to make these measurements will occur about 2 to 4 months after arrival, when the Sun line crosses the plane of the orbit (also causing orbiter eclipses that are of ~4 hr duration).

Separation to Landing

Separation occurs from the nominal 500 x 33,000 km (1-Sol) synchronous orbit. The landing system uses Viking subsystems (de-orbit propulsion, aero-shell, parachute and terminal propulsion) with minimum modification, resulting in a basic landing trajectory similar to Viking. Some changes in the landing

ALT, KM: 500 X 112,200   500 X 33,500   500 X 500
PERIOD: 5 SOLS   1 SOL   2.0 HR

| HOLDING ORBIT | LANDING ORBIT | CIRCULAR ORBIT OPS |

S/C-1
(HI INCL)

SITE CERT

| ROVER CHECKOUT | SCIENCE SURVEY & DSP DEPLOY |

TD

12/1   12/31   1/30   3/1   3/31   4/30

1984   1985

ALT, KM: 500 X 112,200   300 X 33,700   500 X 33,500   1000 X 1000
PERIOD: 5 SOLS   1 SOL   1 SOL   2.46 HR

PERIOD MAINTENANCE MANEUVERS (AS REQ'D)

| HOLDING ORBIT | MAGNETO ORBIT | LANDING ORBIT | CIRCULAR ORBIT OPERATIONS |

S/C-2
(LO INCL)

SUN-LINE CROSSING OF ORBIT PLANE (MAX SUN OCCULATION)

SITE CERT

| ROVER CHECKOUT | SCIENCE SURVEY & DSP DEPLOY | TRAVERSE |

TD

ASSUMPTIONS

• EARLY LAUNCH/ARRIVAL
• 30-day SEPARATION BETWEEN LANDINGS
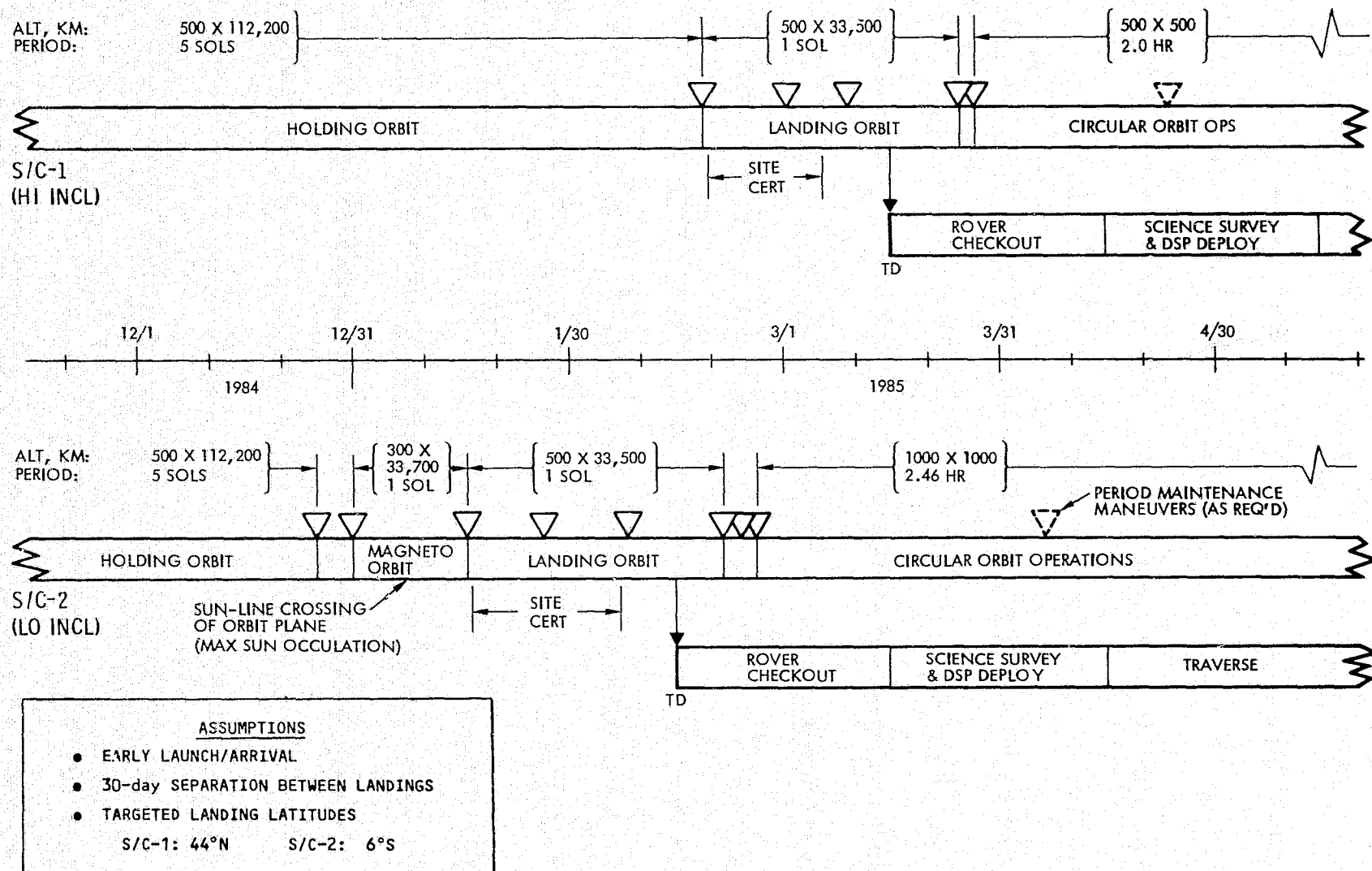• TARGETED LANDING LATITUDES
  S/C-1: 44°N   S/C-2: 6°S

Figure 3-5. Typical Presep/Postsep Mission Profile.

trajectory parameters have occurred because of the lower periapsis landing
orbit and heavier separated weight. The nominal landing location is about 16° of
central angle in advance of periapsis. Lander crossrange targeting capability
is $\pm 2^{\circ}$; downrange capability is $\pm 1^{\circ}$. The estimated overall 3σ landing error
ellipse capability is 40 x 65 km (major axis along track) assuming post-Viking
error source reductions. Terrain height capability is about 5 km maximum
above the 6.1 mbar reference (not including map error). A terminal site selec-
tion system operates during approximately the final 1000 m of descent to avoid
small-scale landing hazards.

The orbiter separates the biobase/adapter within the first few revolutions
after landing.

Post Landing

After the landing, the low-inclination orbit is circularized to a final
orbit with about 1000 km altitude (10 revs/Sol) to provide prime relay support
for the landed spacecraft and science mapping of the equatorial zone. A small
plane-change maneuver may be executed before circularization to achieve the
most desirable final orbit inclination for overall relay support.

After the landing from the high-inclination orbit, a small plane-change
maneuver is executed, if required, to achieve polar or near-polar inclination.
The orbit is then circularized to a final one with 500 km altitude (12 revs/Sol)
for science mapping.

The final orbits can be chosen to provide an integral number of revs
per Mars day so the orbiter ground tracks will approximately retrace them-
selves each Mars day. The precise period is selected to achieve a small drift,
on the order of 10 km/Sol at the equator, to permit high-resolution continguous
mapping.

Orbiter ΔV Capability and Landing Site Accessibility

The point design system weights are summarized in Table 3-1. The
approach velocity, V_{∞}, is minimum for an early trajectory and the required
ΔV budget is presented in Table 3-2.

The estimated postseparation ΔV capability is compared with the ΔV budgets in Figure 3-6. The term "offloading" is used to describe the reduction of propellant to achieve early launching of the first spacecraft. The spacecraft must be off-loaded because a greater launch energy (C_3) is required. At the same time, less propellant is needed because of the lower planetary approach velocity associated with the early arrival at Mars.

The high-inclination ΔV budget (Table 3-2) provides 125 m/sec capability for a small inclination change and/or apsidal rotation. This capability allows landing site accessibility in the northern or southern latitude bands shown in Table 3-3. The accessible range of landing sites tends to be farther north for early arrivals because the declination of the approach velocity vector is less negative. The data of Figure 3-6 indicate that early launches could provide extra ΔV capability, which could be used to increase the range of latitude accessibility.

The low-inclination ΔV budget allows for latitude accessibility between about 20°S and 20°N by selecting the initial inclination between about 30 to 50° and making a small plane change for the final orbit inclination to enhance relay support.

Once orbit insertion has been executed, landing is restricted to the narrow latitude band defined by the nominal angle of 16° before periapsis and the small amount of lander downrange and crossrange targeting capability. Because of the oblateness of Mars, the orbit will rotate with time in its plane about Mars' center, thus changing the accessible landing longitude. The rate of rotation or drift in periapsis is dependent on orbit inclination. The initial "holding" orbit is selected with a 5-Sol period to limit periapsis rotation before commiting to the 1-Sol orbit for preseparation operations and landing.

Mission Constraints - Trajectory & Propulsion

From the standpoint of spacecraft weight and propulsion systems, the 1984 Mars launch opportunity represents the most constrained trajectory of the 1980's.

Owing to mass constraints dictated by this opportunity, the overall performance is "tight". Use of a two-stage Mars orbit insertion motor (one solid

Table 3-2. ΔV Budget for Mars 1984 Mission

Event	ΔV, m/sec
I. PRESEPARATION	1641
Midcourse Corrections	25
MOI (500 km x 5 Sol)	1414*
Trims	50
Reduce Orbit From 500 km x 5 Sol to 500 km x 1 Sol	152
II. POSTSEPARATION	1355
Plane Change	125
Circularize to 500km	1155
Trims in Final Orbit	75
TOTAL	2996

*Max. required - 1/15/84

Table 3-3. Landing Site Latitude Accessibility, Based on a Mission
Plan With a Scheduled Landing on ~3/1/85
(~3-1/2 Months After Perihelion)

• Lo-Inclination Mission	20S to 20N
• Hi-Inclination Mission	
S/C-1 Launched first day	44N to 57N*; 74S to 81S
S/C-1 Last day	39N to 57N*; 74S*
S/C-2 First day	32N to 57N*; 74S*to 80S
S/C-2 Last day	34N to 57N*
*Restricted by assumed minimum sun elevation of 15° required for landing	
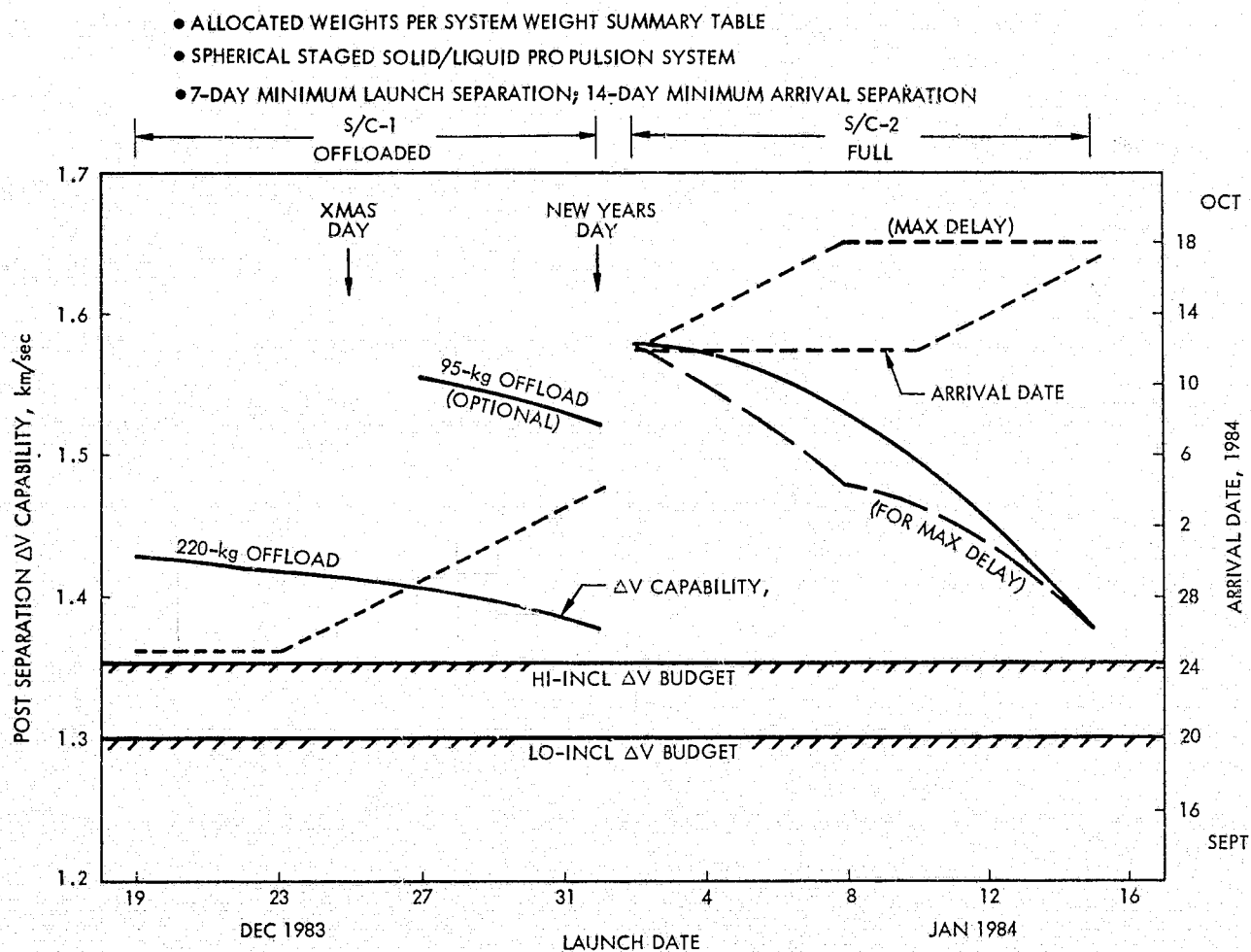
Figure 3-6.   Post Separation ΔV Capability vs Launch Date.

stage to provide primary insertion impulse, and a liquid propellant motor to provide for all other impulse requirements) has been incorporated into the point design to provide adequate performance. Several options to further increase the payload/performance for the Mars 1984 orbiter/rover/penetrator mission are under consideration. These include:

1. The use of high energy, advanced fuels that can survive extended periods in space (i.e., space storable) in the orbiter propulsion system improves performance by 1000 m/sec post-separation ΔV, or, equivalently, ~400 kg in final orbit.

2. Reduced launch window duration gains about 12 m/sec for each day sacrificed.

3. Elliptical orbit for the spaceshuttle Earth parking and trans-Mars insertion gains approximately 175 m/sec in ΔV or 65 kg.

4. Instead of using a Type II interplanetary trajectory (heliocentric transfer angles between 180 and 360°), a long duration (29 mos) trajectory termed Type IV (transfer angle ~540°) provides nearly 1300 m/sec ΔV or 700 kg increase in performance.

SITE SELECTION AND CERTIFICATION

Rover

When the spacecraft arrives at Mars it will be necessary to insert it into a preselected orbit based on the selection of landing sites from Viking and Mariner 9 photographs, infrared data and ground based radar observations. Certification of sites can be carried out by the orbital instruments, particularly the high resolution imaging system and the radar altimeter. Imaging resolution of 6 m/line pair should allow examination of at least the central portion of the landing ellipse to characterize the terrain roughness. Stereoscopic images and radar altimetry should allow determination of slopes and evaluation of their effect on rover mobility. Finally, a re-evaluation of imaging and other orbital data can confirm the science interest of the site. It may not be possible to accumulate enough counts to use the gamma ray spectrometer to determine chemical variation and to evaluate science interest before committing to a landing. Site selection and certification not only involves study of the landing point itself, but also of the area that will be traversed. The landing ellipse should be in an area of low hazard and the traverse area should be free of slopes (including cliffs) and block fields that would be impossible for the rover to negotiate. At the same time, the variety of geologic features should be sufficient to warrant choice as a site.

Images now in hand allow evaluation of site safety and scientific interest based on monoscopic 80 to 200 m/line pair resolution pictures. It should be possible to acquire 16 m/line pair resolution photographs and stereoscopic photographs at about 80 to 200 m/line pair resolution of a few potential sites during the Viking extended mission. Radar data, now on hand, together with data that can be acquired at future oppositions, can be applied to candidate sites located between 25°N and 25°S. Elevations and radar scattering to determine local slopes and roughness will be valuable in site evaluation.

The nominal 3σ landing ellipse for Viking was 300 x 100 km. We are using an ellipse 65 x 40 km in our current landing site search. Three factors contribute to the landing errors:

1.   Map errors and pole location ~ 20 km semi major axis

2.   Deorbit execution errors ~ 20 km semi major axis

3.   Entry and descent uncertainty ~ 15 km semi major axis

All three are under study and the errors should decrease.

It is anticipated that the ellipse may decrease to 40 x 20 km, which is a closer match to the clear areas in the candidate landing sites that we have examined. In addition, a terminal descent hazard avoidance system will be incorporated to avoid small craters or other local terrain hazards.

Penetrators

Since the penetrators will be targeted from the approach trajectory (before MOI), no information important to impact-site selection will be collected during the Mars 1984 mission. The sites must therefore be chosen on the basis of data gained from the Mariner, Viking and the USSR Mars missions. The constraints on site latitude and longitude imposed by celestial mechanics are discussed in the section on "Getting to Mars." Additional criteria to be considered are: elevation between -1 and +10 km to assure proper impact speed; wind and terrain, discussed later in this section; and impact-error ellipses in addition to the scientific issues of importance as noted below.

The error ellipse for penetrator impact is primarily a function of the trajectory error (about 30 km [3σ] in the targeting plane), and the pointing and propulsive errors at deployment from the orbiter. The pointing control of the penetrator at deployment is provided by the orbiter to an accuracy of about $\pm 0.25°$ (3σ). The propulsive maneuver (presently about 80 m/sec) is provided by the penetrator system with a solid propellant. Velocity errors are about $\pm 1\%$ (3σ). The resultant impact errors, taking into account optimal targeting strategies, are approximately circular with a radius of 140 km.

Survivability

In all phases of the Mars 1984 mission, the issue of survivability of each vehicle can be raised. The threats confronting the orbiter and rover are fairly well defined by the Viking experience; such is not the case for penetrators. The very novelty of the penetrator and the abruptness with which it is emplaced raise questions that must be answered by extensive testing and analysis. One feature that complicates emplacement is the impact angle of attack resulting from horizontal winds in the lower few kilometers of descent. If the wind is less than about 10% of the descent speed of approximately 150 m/sec, the induced angle of attack will be about 6° or less. Experimental data indicate that the point-design penetrator will perform properly. The response to stronger winds must be determined by large-scale experiments.

Another uncertainty of landing on Mars is the probability of landing in a boulder-strewn field. No quantitative data exist to show in detail what the penetrator response to a glancing blow on the side of an exposed boulder will be, and numerical analysis is unlikely to yield understanding. The very limited testing done with a prototype penetrator at Amboy, California showed no effect of impact on exposed rocks. Two penetrators passed through highly irregular targets (one layer lava flows and the other a boulder-sand mixture), although the structure of one penetrator was bent slightly as a result of side loads. These hazards to the penetrator and its payload must be assessed in realistic experimental studies so that workable designs can be evolved and qualified.

Other challenges to penetrator integrity are posed by high speed deployment of the umbilical cable during emplacement, a process achieved in military missile systems; survival in a poorly predicted and widely varied thermal environment; and endurance through the rigors of high and rapidly changing deceleration at impact. These threats will be treated using technical approaches that have succeeded in a variety of recent technical programs for military and space applications; no new technical developments are anticipated.

SCIENCE PAYLOADS

Introduction

In this section we review some possible science payloads for the three
vehicles: orbiter, penetrator, and rover. Our intention is not to designate
specific measurements or instruments but rather to demonstrate that a rich
science return is possible within reasonable mission hardware constraints.

Development of flight instruments still requires much effort; even the
concepts are not well in hand for some rover and penetrator instruments.
Instruments of particular concern are sample procurement devices, sample
processing devices, X-ray diffractometers, reflectance spectrometers
and simple microscopes. These deficiencies are partly offset by NASA's pro-
gram of instrument development which will involve work by many potential
investigators during fiscal 1977 and 1978, prior to the Announcement of Oppor-
tunity. Even so, detailed study of candidate instruments must be closely coordi-
nated and monitored.

Orbiter

A polar orbiter with a broad and integrated set of geophysical and geo-
chemical sensors is an essential element in the exploration of Mars, or in fact
of any planet. Table 3-4 describes in outline an example of such a payload of
science instruments for the orbiters. The recent study of the Terrestrial Bodies
Science Working Group (TBSWG), which has been available to us in draft form,
gives a detailed analysis of scientific objectives, of candidate science instru-
ments, and of the important interactions among them and with the rover and
penetrator portions of the mission. We will quote liberally from it in our own
text.

The central strength of the polar orbiting component of the Mars '84 mis-
sion is completeness of coverage. The example of Mariner 4, which led
scientists to an erroneous view of the general nature of the planetary surface,
because it covered only a limited region, should be reminder enough of the need
for complete coverage.

The sample set of instruments which we have chosen (Table 3-4) addresses the nature of the planet at four levels: the interior, the surface, the atmosphere, and the surrounding plasma field.

In a sense, all studies have some bearing on the interior, since the surface and atmosphere arose at the start from processes occurring in the interior, and have continued to show their influence (in the building of volcanoes and in the degassing of ^{40}Ar, for example). The orbital experiments which most directly bear on interior processes are those which study the magnetic and gravitational fields. If a heat flow experiment is possible, it will give direct evidence on the content and distribution of radioactive elements in the interior. The seismic data from the surface portions of the mission will tie these experiments together to give a first-order picture of the solid body.

The planetary surface has been formed (1) by igneous processes, the melting and differentiation of large masses of rocks, (2) by impact, producing the prominent large and small craters, and (3) by sedimentary processes, in which wind, and at some time water modified and redistributed surface materials. To understand these processes even in broad outline, we need information on the chemical and mineral compositions associated with the surprising variety of terrain types seen in the Mariner and Viking photographs. A gamma ray spectrometer experiment can provide maps of the major elements, and of the radioactive elements, on a resolution scale of several hundred kilometers. Reflectance spectroscopy and multispectral imaging can provide information on the abundance, composition, and distribution of certain major minerals on a much finer scale. Both experiments can give us new insight into the distribution and quantity of volatiles, particularly H_2O, on the Martian surface. An imaging system capable of substantially higher performance than the Viking one is necessary for geological studies. These experiments interact strongly with those on the rover. The result of the Mars '84 mission will be a quantum advance over our present level of knowledge of the processes affecting the Martian surface.

The infrared and limb-scanning ultraviolet sensor systems will give us additional information about the state of the Martian atmosphere, its vertical structure, its dust content, and the nature of upper atmospheric processes. The magnetometer and plasma probe should enable us, with a suitable mission plan, to gain sufficient information about the Martian interaction with the solar

Table 3-4. Orbiter Instrument Characteristics.

INSTRUMENT	MEASUREMENT	PROTOTYPE	RESOLUTION PER ELEMENT AT 500 Km ALTITUDE	MASS	POWER	VOLUME	DATA RATE	BER MAXIMUM	COMMENT
GAMMA RAY SPECTROMETER	LOW RESOLUTION ELEMENT COMPOSITION Th, K, U, Fe, Mg, Ti, Al, Ca, Na, Si, O H-RICH COMPOUNDS	APOLLO, LPO	500 km	13 kg	10 W	50 × 45 × 40 cm	4 Kbs	5×10^{-5}	LOCATED ON BOOM ($\geq$ 2m) ~100 sec INTEGRATION PER RESOLUTION ELEMENT/DAY OP T ~ 120°K
REFLECTANCE SPECTROMETER	MINERALOGY, COMPOSITION, SOIL MATURITY (PERCENT AGGLUTINATES)	EARTH TELESCOPES LPO	2.5 (0.3° FOV)	13	10	54 × 20 × 19	10.4	10^{-4}	400 CHANNELS 0.35-4μ ~4 samp/sec/CHANNEL OP T ~ -50°C
CAMERA 10 mm f.1	GEOLOGY, ATMOSPHERIC DYNAMICS, MINERALOGY GEODETIC NETWORK	EARTH TELESCOPES JOP	0.75 (60° FOV)	7	10	15 × 15 × 40	850	10^{-3}	800 × 800 CCD MULTISPECTRAL IMAGING 0.3 -1.1μ OP T. ~ -50°C
200 mm f.1	GEOLOGY, ATMOSPHERIC DYNAMICS	EARTH TELESCOPES, JOP, VOYAGER	0.0375 (3° FOV)	9	10	20 × 20 × 55	850	10^{-3}	
1500 mm f.1	GEOLOGY, ROVER SEQUENCING	EARTH TELESCOPES, JOP, VOYAGER	0.005 (0.5° FOV)	8	10	25 × 25 × 98	2500	10^{-3}	1 ms SHUTTER SPEED
RADAR ALTIMETER	PLANETARY SHAPE, ELEVATIONS, RMS SLOPES BULK DENSITY OF NEAR SURFACE MATERIAL DIELECTRIC CONSTANT	EARTH ORBIT, PIONEER VENUS	12.0 (1.5° CTR BEAM)	10	20	120 × 120 × 5 (ANTENNA) 120 × 60 × 10 (ELECTRONICS)	0.8	5×10^{-5}	COMBINED WITH MICROWAVE ANTENNA 20m RANGE RESOLUTION 1-2m GOAL, 2-20 cm λ
IR MULTI CHANNEL RADIOMETER	SURFACE TEMPERATURE, ATMOSPHERIC DYNAMICS SURFACE PRESSURE	NIMBUS, PIONEER VENUS	9 (1 × 1° FOV)	7	4	25 × 25 × 17	0.12	10^{-4}	9 CHANNEL 2.5 -60 16 cm TELESCOPE
UV SPECTROMETER	ATMOSPHERIC PRESSURE, OZONE CONCENTRATION UPPER ATMOSPHERE STRUCTURE, ATOMIC HYDROGEN DISTRIBUTION	MARINER 9, PIONEER VENUS JOP	2 × 5 (SLIT FOV) 2 × 16	3.5	4	36 × 15 × 14	0.2	5×10^{-4}	0.11 - 0.34 LIMB SCANNING VIA MIRRORS
MAGNETOMETER	INTRINSIC MAGNETIC FIELD, IONOSPHERE-SOLAR WIND INTERACTION, MAGNETOSPHERE, DIURNAL VARIATIONS	PIONEER VENUS, LPO, VOYAGER	NA	2.2	1.7	22 × 11 × 15 (ELECTRONICS) 7.5 × 5 × 5 (SENSOR	0.3	10^{-4}	$\geq$5m BOOM 0.1 γ MEASUREMENT
PLASMA PROBE	ION ENERGY DISTRIBUTION, PHOTOIONIZATION HEAT TRANSFER FROM SOLAR WIND TO ATMOSPHERE	MJS, PIONEER VENUS JOP, PLS	NA	6	7	14 × 17 × 23 (ELECTRONICS) 21 × 21 × 10 (DETECTORS)	0.1	10^{-4}	
MICROWAVE RADIOMETER	SUBSURFACE DIURNAL AND SEASONAL TEMPERATURE VARIATIONS, THERMAL AND ELECTRICAL PARAMETERS, PERMIFROST, HEATFLOW	LPO, EARTH ORBIT	125	15	12	120 × 60 × 10 (ELECTRONICS)	0.06	10^{-3}	USES RADAR ALTIMETER ANTENNA 2-20 cm WAVELENGTH
GRAVITY	GRAVITY ANOMALIES, PLANETARY FIGURE	MARINER 9, VIKING	500	EXISTING S-X BAND TRANSPONDER			TRACKING 3-6 DAY PERIODS	10^{-3}	NO ADDITIONAL WEIGHT POWER, etc. 3-SPECIAL TRACKING PERIODS OF ORBITAL WALKS
OCULTATION	SIGNAL VARIATION DUE TO PASSAGE THROUGH MARTIAN IONOSPHERE, ATMOSPHERE, AND OCCULTING BY PLANET	MARINER 9, VIKING		EXISTING S-X BAND TRANSPONDER			TRACKING 3-6 DAY PERIODS	10^{-3}	NO ADDITIONAL WEIGHT POWER, ect. 3-SPECIAL TRACKING PERIODS OF ORBITAL WALKS

wind and the solar magnetic field, to resolve the puzzling differences between present U.S. and Soviet results.

The following section includes excerpts from the draft of the TBSWG report on Mars.

Geochemistry

The presence of the Martian atmosphere limits elemental abundance measurement techniques to gamma ray spectroscopy. Mineral phase information can be acquired remotely by reflectance spectroscopy. Instrumentation to perform both functions has been defined for the LPO mission and it is anticipated that similar experiments will be readily developed for a Mars mission.

Elemental composition mapping can be performed for a variety of important elements at Mars. Mapping of the naturally radioactive elements K, Th and U is relatively uncomplicated since the gamma-rays are produced directly by the elements and no modeling assumptions concerning excitation are needed to infer elemental concentrations. Only the knowledge of atmospheric column density to ~10% is required to correct for atmospheric absorption. Current models, combined with Viking data and real time atmospheric data from this mission will easily satisfy this requirement. A particularly significant result of this class of measurements is the K/U ratio, which is related to the degree of planet-wide differentiation and the enhancement or depletion of volatile elements during and since planet formation.

Another set of elements can be detected through neutron capture and scattering interactions with atmospheric and surface material. These include O, Fe, Si, Mg, H, Al, Ti, S and possibly C and Gd, in approximate order of detectability at expected levels. Qualitative analysis of these elements is relatively straightforward since these elements produce characteristic spectral signatures which can be unraveled using procedures and calibration data developed for the Apollo orbital gamma-ray analysis. Quantitative analysis is more complex even for relative abundance values since the excitation depends on the neutron energy spectrum which can be modified by the atmosphere and hydrogen concentrations.

Whereas the Apollo gamma-ray mapping was accomplished using NaI detectors, recent developments with large germanium crystals have led to the expectation that detectors with much greater spectral resolution will be available for future missions. Such detectors, which require cooling (passive) to about $140^{\circ}K$, will provide a great improvement in the sensitivity and precision with which various elements can be detected. The spatial resolution with which elemental data can be acquired is a function of the instrument field of view and is roughly equal numerically to the spacecraft altitude. This, however, is a limiting resolution and depends upon the accumulation of adequate counting time. Sensitivity depends on the square root of this time. Given the large number of 500 km and 1000 km resolution elements over the surface it is anticipated that the spectrometer will operate in an uncollimated mode (in principle, collimation can increase spatial resoltuion, but only if adequate counting time is available). Table 3-5 describes the detection sensitivity of the experiment for a number of important elements.

Analysis of the spectral characteristics of reflected solar radiation to infer mineralogical and compositional information about planetary surfaces has been developed as a useful remote-sensing tool over the past few years. Generally, compositional information comes from three basic features in reflectance spectra: (1) Charge transition bands due to transitions in the d-shell electrons of transition metal ions in crystal lattices. The best known of these are the bands near 1.0 μm due to Fe^{2+} in pyroxenes. (2) Charge transfer bands where electrons are exchanged among ions in a material. These are generally less diagnostic of detailed mineralogy than transition bands but are frequently useful in determining concentrations of transition metal ions or oxidation state. (3) Vibrational bands, usually due to H_2O, OH, SO_4, CO_3 etc. in minerals. These bands are analogous to molecular absorption bands in the infrared spectra of gases and are relatively sharp and diagnostic when present. Mars appears from ground-based spectra to exhibit all of these classes of spectral features and is thus a very promising target for the application of these techniques.

With the two orbits chosen for the point design there should be little difficulty achieving excellent illumination conditions for data acquisition. The principal difficulties confronting the experiment are atmospheric obscurations and the blanketing effects of ubiquitous fine surface material.

Table 3-5. Uncollimated Orbital γ-ray* Instrument Sensitivity**

		1000 km		500 Km	
Orbital Altitude (circular):					
Resolution Element:		1000 x 1000 Km		500 x 500 Km	
Region:		Equatorial	Polar	Equatorial	Polar
Revolutions/Sol:		10	10	12	12
Observation time per element per year***		16.7 hr	297 hr	4.24 hr	178 hr
Element	Apollo II (Basalt)				
Th ppm	2.1	0.42	0.05	0.86	0.084
U ppm	0.55	0.25	0.03	0.52	0.056
K %	0.12	0.025	0.004	0.06	0.006
Fe %	12	0.75	0.10	1.67	0.16
Ti %	5	0.33	0.04	0.69	0.07
Si %	20	2.5	0.37	6.34	0.62
O %	42	3.3	0.44	7.5	0.73
Al %	7.1	7.5	0.98	--	1.6
Mg %	4.6	3.2	0.40	--	0.67
Ca %	8.6	--	1.5	--	2.5
C %	(30)	3.2	0.40	6.9	0.67
H %	(5)	0.42	0.05	0.92	0.09
Na %	0.3	2.5	0.37	--	0.62
Mn %	0.2	0.58	0.08	--	0.13
Ni %	0.024	0.42	0.05	--	0.08
S %	0.1	2.5	0.34	--	0.56
Cl %	0.003	0.09	0.012	--	0.02

*Germanium Detector
**3σ
***Polar Orbit @ 10 Km/Sol Equatorial Drift Rate

Magnetic Field and Plasma

For the investigation of the planetary magnetic field and the solar wind interaction with the planet the orbiters require a magnetometer and a plasma probe in their payloads. To sample the wind-planet interaction directly it is necessary for the orbits to have low periapses (300-500 km) and to make measurements in the plasma tail or wake cavity an elliptical orbit with an apoapsis at 5-7 R_{Mars} is needed at the beginning of the mission.

The magnetometer experiment is not expected to place strong requirements on the magnetic cleanliness of the orbiters if a dual sensor approach similar to Voyager is adopted. A boom of about 5 m length is needed. A sensitivity of 0.1γ is both adequate and feasible. The plasma probe must be capable of distinguishing between plasma ions of solar wind origin (e. g., H^+) and those which must ultimately come from the planetary atmosphere and ionosphere (e. g., 0^+). Such a probe can be straightforwardly derived from existing instruments.

Gravity and Figure

Determination of the higher degree harmonics of the Mars gravitational field is an important geophysical objective because it will place constraints on crustal thickness and strength. Doppler tracking of the orbiter can accomplish these goals; gravity gradiometer systems also show promise of being able to perform sensitive gravity surveys from orbit, although none have been flown on planetary spacecraft to date. Because gradiometry has better response to high spatial frequencies in the gravity field and Doppler tracking to low frequencies, the two methods used together would, in principle, produce a superior survey. Effective spatial resolution of the measurements is numerically approximately equal to the orbital altitude.

The 500 km circular polar orbit for the 1984 mission promises to provide data of significantly higher resolution over the whole planet than has been previously available. The circular geometry of the orbit, however, presents some difficulties for orbit determination in comparison with the tracking of spacecraft in highly elliptical orbits as in the past. More study is needed in this area to properly understand the implications of the 1984 orbital geometries for gravity field measurements. Likewise further study is required to assess the potential

science advantages and engineering implications of providing orbiter-orbiter-rover telemetry links for tracking purposes.

No matter how the gravity field is measured, accurate altimetry is required to make maximum geophysical use of the data. Altimetry is used to correct the important effects of topography on the gravity field, allowing the effects due to density variations to be modeled. Figure measurements seem most readily to be made using a radar altimeter as proposed for the LPO mission. The greater altitude of the two orbiters makes the Martian task more difficult and additional studies are required to define the optimum radar system for the orbiters. In addition it is anticipated that the radar experiment can also provide surface roughness measurements that will be important for landing site certification.

Meteorology and Upper Atmosphere

A magnetometer and plasma probe will make important measurements for understanding the interaction of the solar wind with, and escape mechanisms from, the upper atmosphere. Other orbiter instrumentation required for meteorology and upper atmosphere studies includes an IR multi-channel radiometer providing about 8 distinct temperature weighting functions, well distributed below 40 km and a UV spectrometer. Instruments from which the required experiments could be derived already exist. Several IR instrument designs are available, including limb-scanning instruments. Because the point design orbiters are nadir-viewing, any instruments observing the limb would need some provision for scanning their field of view across the limb. Cooling of IR detectors may be required. The thermal environment of the detectors relative to the complex, changing geometry of the spacecraft with respect to the sun remains to be analyzed.

Imaging

An orbiter imaging capability is required for site certification (including dust storm monitoring), rover traverse planning, geological mapping and meteorological studies. The high resolution required for several of these studies necessitates the use of high sensitivity sensors and long focal-length optics. In practical terms this appears to mean using CCD sensors and a 1 - 2 meter focal

length telescope offering about 10 m/line pair resolution at 500 km altitude. While the use of line-array CCD sensors is possible from the circular orbits it is recognized that the spacecraft will also be in elliptical orbits and it seems likely that the use of area-array CCD's will offer greater flexibility.

Limitations of onboard data storage and telemetry downlink bandwidth imply that the areal coverage at such high resolutions will be greatly constrained. The example payload includes a camera with shorter focal length (200 mm) optics to acquire broader coverage, but with spatial resolution (70 m/line pair at 500 km) that compares favorably with that used for Viking landing site certification. In addition a very wide angle ($\approx 60^\circ$ field of view) camera appears necessary if synoptic data are to be acquired from the circular orbits for meteorological studies.

Provision for multi-spectral imaging at least in the medium and wide angle cameras, is highly desirable both for discriminating of condensate and dust clouds and for mineral phase mapping. The mineral identification achieved by reflectance spectroscopy would be extended in coverage and correlated with morphological characteristics by the multispectral imaging data.

In principle the orbiter and rover imaging systems could use similar (or even identical) electronics and also have their data processed by the same ground system. The data processing system could be that used by other flight projects and commonality of hardware and software could provide numerous benefits, particularly in the area of cost.

Rover

The rover will require a variety of "skills" in order to answer the many outstanding questions about the rocks, surface materials and processes on Mars. These science skills for the rover are summarized in Table 3-6. Possible instruments are briefly reviewed in Table 3-7 and 3-8. Figure 3-7 depicts the rover. In the following sections we comment selectively on some of the more critical science components.

Table 3-6. Rover - Necessary Science Skills

Quantitative imaging	• long range to close up • multi-spectral • stereoscopic
Sample procurement	• selective rock or soil • preprogrammed rock or soil • unweathered rock - 10 cm (?) • deep soil - 1 m (?) • scoop/rake/sieve/drill/hammer/lever/wedge/cracker/chipper
Sample processing and distribution	• fractionate sample by physical properties -- crusher/magnetic separator/sieves/heat/leach/dust/splitter-holder • flexible sequencing of preparation and distribution
Elemental analysis	• accurate and precise • major and critical minor elements
Mineral phase analysis	• positive identification • abundance in mixtures
"Molecular" analysis	• volatiles/organics/anion complexes • atmosphere analysis • soil and rock analysis • stepwise heating • gas reactions
Microscopy	• multi-spectral • fabric and texture • composition, size, shape of particulates • surface features and coatings on grains • grain surface reactivity • biological activity
Sample return study	• test reactivity of soil with packaging materials • test for gas release and pressure buildup
Traverse geophysics	• seismic profile - regolith thickness • electrical conductivity - permafrost thickness • magnetic profile - near-surface structure • gravity profile • topographic mapping
Transport deployable packages	• seismometer • magnetometer • metereology - pressure/temperature/wind velocity and direction • heat flow/near-surface temperature profile • u. v. -visible photometer

Table 3-7. Rover Instrument Characteristics.

INSTRUMENT	MEASUREMENT	PROTOTYPE	RESOLUTION	MASS	POWER	VOLUME	DATA RATE	BER	COMMENTS
MASS SPECTROMETER-CHEMISTRY	SOIL CHEMISTRY, ATMOSPHERIC ANALYSES	VIKING GCMS		25 kg	35 W – atm 100 W – SOIL	33 x 33 x 33 cm	500 kb/15 min 30 mb/3 hr	5×10^{-4}	ONE MEASUREMENT EVERY 10-20 days
REFLECTANCE SPECTROMETER	IDENTIFICATION OF MINERALS AND THEIR ABUNDANCE	LPO		6	5	27 x 20 x 19	200 bps	5×10^{-5}	10^7 bits/SOL 0.4 – 50
STEREO IMAGING EXPERIMENT	ROVER RECONNAISANCE, ROCK DISTRIBUTION, TERRAIN ANALYSES, METEOROLOGY	UNDER DEVELOPMENT (JOP CCD)	50	8 PER CAMERA	10 PER CAMERA	40 x 20 x 20 (PER CAMERA)	3×10^7 bits/day	10^{-3}	800 x 800 PIXEL FORMAT COOLING –50°C ZOOM LENS
GAMMA RAY SPECTROMETER	ELEMENT ANALYSIS, WATER DETECTION	APOLLO		2 (ROVER) 2.5 (DEPLOYED)	0.8 1.3	15 x 7 x 7 15 x 10 x 10	1.4×10^7 bits/ANALYSIS 4 kbs/hr	10^{-5}	
X-RAY DIFFRACTOMETER	IDENTIFY MINERAL PHASES	SURVEYOR, JPL BREADBOARD SEVERAL DESIGNS		8	15	30 x 30 x 33	2.4×10^5 bits/10 min	5×10^{-5}	1000 ELEMENTS/DIFFRACTION PATTERN
ALPHA-PROTON-X-RAY SPECTROMETER	ELEMENT ANALYSIS	SURVEYOR	0.5%	2	1.2	12 x 8 x 7	10^4 bits/12 hr	10^{-4}	
MICROSCOPE	GRAIN PROPERTIES OF SAMPLE, MINERAL IDENTIFICATION AND ABUNDANCE	UNDER DEVELOPMENT (CCD)		1 (HEAD + OPTICS) 0.3 (ELECTRONICS)	10	8.5 x 3.5 x 3.5 10 x 12 x 5	2×10^7 bits/day	10^{-3}	USES PREPARED SAMPLES
SOIL SOUNDING	REGOLITH ICE vs WATER, SUBSURFACE DISCONTINUITIES	TERRESTRIAL GEOLOGY		0.5 (ANTENNA) 1.5 (RECEIVER) 1.0 (DATA PROCESSOR)	5	15 x 15 x 15	5 kb/min ONCE PER HOUR	10^{-2}	
UV PHOTOMETER	SOLAR FLUX, METEOROLOGY	CONCEPTUAL		4	5	25 x 25 x 30	0.5 kbps	10^{-4}	2 CHANNEL 0.11-0.3 , 0.3-0.8 INTEGRATING SPHERE FASTRE–EBERT SPECTROMETER INFREQUENT MEASUREMENT
RADIO	RANGING FOR RELATIVITY, EPHEMERIS IMPROVEMENT POLE PRECESSION, ASTEROID MASS DETERMINATION	VIKING	NA	0.3 5 (DESIRED)	0.1 2.0 (DESIRED)	20 x 10 x 5 20 x 20 x 25 (DESIRED)	1 DOPPLER, RANGING MEASUREMENT/MINUTE	10^{-3}	30 min/day THROUGHOUT MISSION
SAMPLE COLLECTION-MANIPULATION AND PREPARATION	PREPARE SAMPLES BY SIZE FOR VARIOUS INSTRUMENTS	NONE	NA	8	25	30 x 30 x 50	TBD	TBD	
SOIL SAMPLER (AUGER)	SAMPLE PROCUREMENT TO 1 METER DEPTH	TERRESTRIAL APPLICATIONS	NA	5	30	15 x 15 x 100	TBD	TBD	AUTONOMOUS OPERATION NIGHT TIME USE
ROCK DRILL	OBTAIN UNWEATHERED MATERIAL FROM ROCKS	TERRESTRIAL APPLICATIONS	NA	6	60	10 x 10 x 50	TBD	TBD	1/2 in. DRILL
METEOROLOGY	ATMOSPHERIC PRESSURE AND TEMPERATURE	VIKING	NA	2.5 TOTAL 68 kg	1	TBD	TBD	10^{-4}	
MAGNETOMETER	PERMANENT AND INDUCED MAGNETIC FIELDS	VOYAGER, MARINER 10	NA	2	1	5 x 5 x 1 SENSOR 8 x 4 x 4 ELECTRONICS	0.1 kbps	10^{-4}	REQUIRES BOOM OR DEPLOYMENT
THUMPER OR EXPLOSIVES FOR ACTIVE SEISMOMETRY	ACTIVE SEISMOMETRY	CONCEPTUAL	NA	< 10 kg	NA	TBD	NA	NA	1 kg CHARGE (TNT) NEEDED AT 1 km

3-1-33

Table 3-8. Rover Potential Instrument Characteristics.

INSTRUMENT	MEASUREMENT	PROTOTYPE	RESOLUTION	MASS	POWER	VOLUME	DATA RATE	BER	COMMENTS
X-RAY DIFFRACTION/X-RAY FLUORESCENCE – USING THERMO-LUMINESCENT DOSIMETERS	MINERAL PHASE IDENTIFICATION ELEMENT IDENTIFICATION Na THROUGH Ti	COMMERCIAL COMPONENTS	14 to 2Å INTERPLANAR SPACING	0.5 kg	1 W	25 x 25 x 3 cm	8 bps	10^{-3}	ONE SAMPLE PER DAY (10^4 bits/ANALYSIS) 800 ELEMENTS DIFFRACTION
SCANNING ELECTRON MICROSCOPE WITH ENERGY DISPERSIVE ANALYSER	CHEMICAL ANALYSES OF INDIVIDUAL GRAINS OF PARTICULATE MATERIAL, IMAGING	UNDER DEVELOPMENT	≤0.1μ	10	30	TBD	TBD	TBD	
X-RAY FLUORESCENCE SPECTROMETER	CHEMICAL COMPOSITIONS IN SURVEY MODE (WITHOUT REQUIRING SAMPLE)	VIKING	TBD	2.5	2	5 x 5 x 15	110 kb/45 min 18 kb/13 min 18 kb/5 min	TBD	LOCATED ON BOOM
ELECTROLYTIC FREE SOIL AND ATMOSPHERIC WATER DETECTOR	MEASURE BOTH ATMOSPHERIC AND FREE SOIL WATER	UNDER DEVELOPMENT FOR PENETRATOR	ppm	0.1	0.01	0.5 x 0.5 x 5	TBD	TBD	
SCANNING CALORIMETER	MEASURE WATER EVOLVED FROM SURFACE SAMPLE	UNDER DEVELOPMENT	ppm	5	10	TBD	TBD	TBD	
UNIFIED BIOLOGY INSTRUMENT	ORGANICS DETECTION	UNDER DEVELOPMENT		20	30	TBD	TBD	TBD	

RELAY ANTENNA

EARTH COMMUNICATIONS ANTENNA (STEERABLE)

OPTICS PORTS & STROBE

SELENIDE RTG (SHIELD REMOVED)

IMAGING/LASER RANGE FINDER MAST (2)

SAMPLE INLETS

MANIPULATOR

CHASSIS

HAZARD DETECTORS
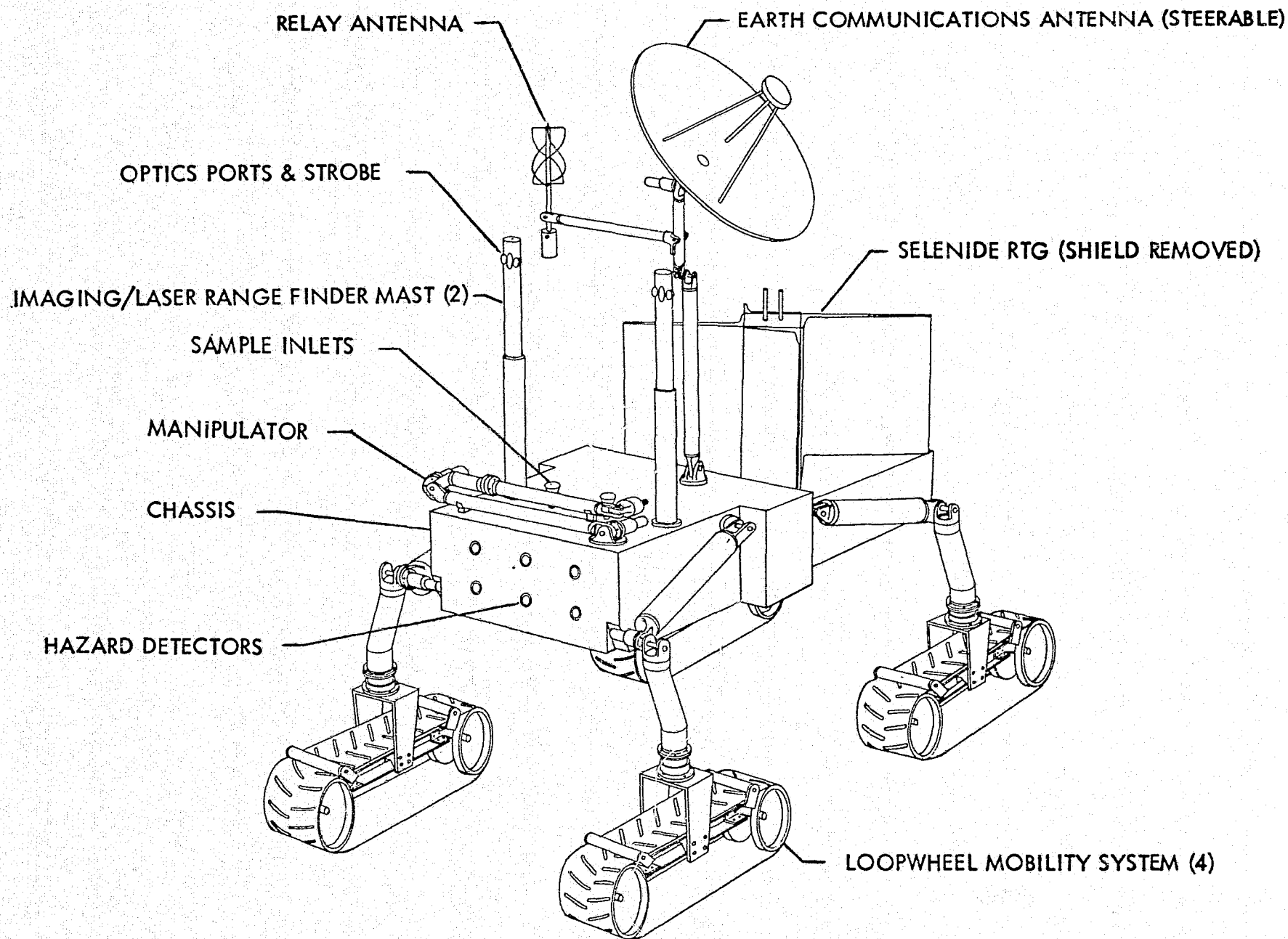
LOOPWHEEL MOBILITY SYSTEM (4)

Figure 3-7. Rover Configuration.

Quantitative Imaging

The term quantitative imaging comes close to describing what a geologist does in the field -- the geologist obtains multi-spectral, stereoscopic images at a variety of scales and resolutions, processes them, and interprets them by comparison to images derived from previous experience. In the traverse modes the rover will only be able to return to Earth for processing and interpretation a small fraction of the number of images that a geologist would normally utilize in the field and much thought must be given to ways to maximize the science return from these images. Consider a number of examples: 1) At the end of each day the rover will obtain a stereoscopic panorama with a wide baseline. Although chiefly for guidance purposes these must also be efficiently utilized to direct the image return for the next day's traverse. 2) The rover guidance system will have the capability to recognize and locate boulders in order to avoid them. Such information should also be used to instruct the cameras to obtain close-up images of those boulders close to the rover's path. 3) The imaging system must be designed to permit rapid utilization of the pictures without the need for extensive computer processing. Since the cameras will have a fixed separation (i.e., stereo-baseline), it may be desirable to construct an analogue device for quantitative viewing of stereo pairs. The present design has a separation of the cameras of ~0.6 m; this should be analyzed to see if a slightly greater separation would be important. 4) Framing CCD cameras have been included in the tentative design, primarily for processing compatibility with orbital pictures. Other types of cameras may offer certain advantages and assessment of the best imaging system should be continued. Other types of cameras may offer distinct advantages in obtaining spectroscopic data on particular objects.

In conclusion, it must be continually kept in mind that quantitative imaging is one of the prime functions of the rover and should be accorded very high priority.

Sample Procurement

Effective sample procurement is an important key to the success of the rover mission. An improved Viking-type manipulator, capable of providing soil samples and small rock fragments, is required during the Site Intensive Mode of Investigation (See later section on Mission Operation.). It is important that samples of unweathered rock be delivered to the analytical instruments. Moreover, since more than half of the mission will be spent in the Traverse Mode in order to achieve the desired range it is important to have a means of obtaining samples autonomously during this time.

There exist almost no data on which to base objectives for the depth of drilling necessary to obtain unweathered material from a boulder or outcrop, to penetrate below the superficially altered soil, or to reach permafrost. Sampling depths up to 1 meter appear practical. The necessity to reach greater depths would introduce extraordinary hardware difficulties.

Some guidelines for sample procurement are as follows:

1) There must be a manipulator at least as advanced as Viking's, for the Site Intensive Mode of study.

2) There must be a means of obtaining samples during the Traverse Mode. Preferably this would be an autonomous repetitive device, operating during the "halt" portion of the travel cycle. Alternatively, it could involve operation of the manipulator during the night halt and storage of samples for study during the day.

3) There should be a soil drill or auger capable of obtaining soil samples from a depth of up to one meter. It is believed that such an auger can also serve as the autonomous sampler during the "halt" portion of the travel cycle.

4) There should be a rock drill (rotary percussion) capable of drilling into and obtaining samples of rock from a depth of up to 25 cm. It should be capable of obtaining at least 10 such samples without changing drill bits. It is desirable that drilling not be confined to vertical holes, but that drilling into the side of large boulders or outcrops should also be feasible.

Sample Processing and Distribution

The procurement, processing and distribution of samples on the rover should be accomplished by an integrated system that services all instruments. Low-abundance phases, defined as those present in amounts less than or close to the limit of detection by X-ray diffraction of the bulk regolith sample, are likely to have great genetic significance. The regolith will probably consist of grains of a number of different mineral phases, differing in distribution according to size, density, magnetic susceptibility and other physical properties. A large proportion of these grains could be of high-temperature igneous origin, but may well be coated with fine grained minerals, such as clays, Fe-oxides, sulphates and carbonates, that formed by reaction with the atmosphere. It seems possible, therefore, that X-ray diffraction analyses of bulk Martian regolith samples will only provide identifications for the more abundant minerals of igneous origin, even in the circumstance that each grain had a thin coating of clay and/or Fe-oxide.

Since minerals differ in physical properties, simple physical processes will tend to produce fractions containing quite different proportions of the minerals. Judging by terrestrial examples, wind action may provide a high degree of sorting within adjacent thin layers. If so, sampling at different depths and places could provide substantial variation in mineral abundances.

However, it cannot be assumed that the natural variation will be sufficient to identify critical minerals. On-board sample processing should provide fractions, which have been enriched in various mineral components by means of simple physical procedures such as sieving and magnetic separation. Clearly it makes sense to study separately the 3-7% of magnetic material found by Viking. The sample distribution system must be able to provide these fractions (or splits of them) to several different instruments in commandable sequence. Such flexibility in processing and distribution will make it possible to determine the amount and composition of all phases in a total bulk sample.

For each sample split, instrumental analysis will determine: 1) the mass abundance of a number of elements by chemical analysis; 2) the approximate mass abundance of the major mineral phases by X-ray diffraction or by spectrometry; 3) the approximate elemental composition of most phases by correlation of X-ray

and spectral data with chemical composition; and 4) the volume or mass of the split. Additional constraints will be provided by the stoichiometry of the identified phases and by "normal" assemblage arguments. A least squares solution of the mass balance equations for the sample splits and the bulk sample can solve for the abundance and composition of all phases in the total bulk sample -- even for phases not directly detectable in the bulk sample.

A conceptual approach to achieving such analytical flexibility can be outlined. Samples may be procured under direction by the manipulator or the drill or automonously by an auger. These samples will be sorted at entry into fines (<1mm), fragments (>1mm), and coarse rejects (>25mm). The sample processing is assumed to include a crusher, a sieve stack (2 sieves and pan), a magnetic separator, and a splitter-holder. Sample splits of known mass or volume must be delivered to the various instruments for analysis. Thus, it is necessary that the entrance and exit ports of all instruments be accessible to the sample distribution system. Only the first few samples and subsequent unusual samples will require complete processing, since early studies should pinpoint the key measurements. Various analytical sequences would be pre-programmed for autonomous operation. A conceptual sample distribution system, which provides for maximum flexibility of instrument placement and analytical sequencing, consists of a sample cup, mounted on an extendable arm, which is attached to a vertical tower, which moves on a track -- thus providing full access to all instruments. Direct sample delivery by the manipulator to a port on top of the rover could be provided for some instruments and is probably necessary for the "molecular" analyser to control organic contamination.

Few of the specific suggestions herein are singular requirements. However, careful thought must be given to sample processing and distribution if the rover is to attack successfully the important mineralogic and chemical problems of the regolith and of the rocks.

Elemental Analysis

Accurate and precise analyses for major and certain critical minor elements is an essential skill for rover science. This goal is best accomplished by an instrument with radioactive sources and detectors for several simultaneous detection modes: alpha, proton, X-ray, and gamma ray. In general alpha and

proton detection is best for lighter elements, X-ray for heavier elements, and gamma ray for the radioactive elements, U, Th, and K. Major limitations are imposed by the requirement for heat sterilization and by the desirability for cooled detectors. Both limitations are being challenged by the development of new detectors, but cooling of detectors may still be necessary to achieve the desired accuracy and precision. Simultaneous multi-channel counting is absolutely necessary in order to obtain complete elemental analyses in a reasonble time.

In such instruments the actual radioactive sources and detectors are relatively small and light. Thus, it is practical to have several detectors utilizing the same electronics package. One instrument would be on the internal sample train and would probably be cooled for higher quality analyses. One or more detectors could be deployable at the end of a cable, either autonomously or by the manipulator. These auxiliary detectors would not be cooled, but would provide semi-quantitative analyses for many elements. They would provide a very useful tool for discriminating features such as surface stains or coatings that cannot be sampled effectively for analysis within the rover.

A list of desired sensitivities and accuracies for various elements is shown in Table 3-9. These are adequate, for example, to draw clear distinction between major classes of lunar and terrestrial basalts and among the major meteorite classes. These sensitivities and accuracies are at or near those obtainable in a conventional geochemistry laboratory using the same basic instrumental methods that could be placed in a rover (α, p, X-ray, and gamma ray spectroscopy). Similar results could be obtained with potential flight instruments, although for some trace elements the sensitivities are about an order of magnitude better than present capabilities.

Mineral Phase Analysis

Bulk elemental analyses of rocks and soil samples can provide significant constraints on the origin of a planetary body, how it evolved to its present state, and its surface and near-surface processes. However, identification of particular mineral phases and assemblages of phases provide much more stringent constraints on the nature of the rock, the pressure and temperature of origin,

Table 3-9.   Desired 4σ Sensitivities for Chemical Analyses

The suggested values are equal to the difference between two measurements whose 2 sigma error bars just touch. For the trace and minor elements these values are also essentially the effective detection limits. For higher concentrations of trace elements more realistic sensitivities are four sigma differences equal to 30% of the amount present. Numerically the desired accuracies are equal to the sensitivities and indicate two sigma errors on single concentration measurements.

Element	Desired four sigma sensitivity (wt %)
H(as H_2O)	0.4
C	0.2
N	0.2
O	0.8
F	0.1
Na	0.2
Mg	0.6
Al	0.6
Si	1.0
P	0.4
S	0.02
Cl	0.02
K	0.02
Ca	0.4
Sc	0.0005
Ti	0.2
V	0.0005
Cr	0.02
Mn	0.02
Fe	0.4
Ni	0.002
Cu	0.002
Zn	0.002
Br	0.002
Rb	0.0005
Sr	0.0005
Y	0.0005
Zr	0.0005
Ba	0.0002
Ce	0.0005
Lu	0.00005
Pb	0.0005
U	0.00005
Th	0.00005

the fugacity of volatile species, the likely minor element content, the state of hydration and oxidation, etc. Identification of a low abundance phases in a soil mixture may have great genetic significance.

There is no single simple instrument that provides both a positive identification and the relative abundance of all phases in mixtures. The spacings between the various planes of atoms within the crystal structure yields a characteristic X-ray diffraction pattern for a mineral whereas the particular details of the chemistry and the atomic groupings yield a characteristic absorption spectrum for a mineral. Thus the two methods provide complementary data which can provide mineral identification, some indication of the chemical composition of a phase, and an estimate of relative phase abundances in a mixture. X-ray diffraction, as commonly used by geoscientists, involves extensive sample preparation and is rather insensitive to low abundance phases in mixtures. Absorption spectra are less widely used by geoscientists and little experience is available to define detectability limits and to decipher mixtures. However, spectroscopy in the 0.4-50 μm region is particularly diagnostic for salts, carbonates, sulphates, oxides, ices, etc., is useful in all three modes of rover operation, and will complement and extend orbital spectral mapping. In theory a single spectrometer could provide: 1) reflectance and transmission spectra on bulk rock and soil samples being studies within the rover, 2) reflectance spectra on the soil surface beneath the rover during a traverse, 3) reflectance spectra and multispectral imaging of individual grains through a microscope, 4) reflectance spectra of rock surfaces on nearby boulders, 5) reflectance spectra of outcrop and soil surfaces in the near-distance and 6) multispectral imaging with the main cameras. It may not be practical to perform all these functions with a single instrument, but it is clear that an integrated approach should be taken to the use of spectral measurements. Although discussed here under mineral phase analysis, spectroscopy is also an important contributor to the "quantitative imaging," "molecular analysis," and "microscopy" science skills.

Molecular Analysis

Analysis for volatile elements, organic compounds, and anion complexes is a necessary complement to elemental analysis and mineral phase

identification. A mass spectrometer system, derived from that used on Viking, can provide such analyses for multiple samples of Martian soil, rock, and atmosphere. Other suggested instruments, in general, are more complex or less comprehensive. The "system" should provide for: 1) direct introduction of soil samples, bypassing the sample train, so as to identify volatile ices, 2) controlled stepwise heating to assist in the identification of phases containing volatile complexes, 3) gas reaction cells to study the surface reactivity discovered by Viking, and possibly 4) high-temperature heating or total chemical reaction so that qualitative K-Ar ages can be measured for glassy or fine-grained volcanic rocks.

It might prove desirable to measure some of the volatiles _in situ_. This might be accomplished by lowering a combined heating coil and trap to the surface and piping the evolved gases to the mass spectrometer.

Microscopy

Microscopy could logically be grouped with the quantitative imaging capability; close-up imaging provides much of a field geologist's basic data. The fabric and texture of a rock provides key information on its origin; the size distribution, shape, and surface features on grains from a regolith provide information on planetary surface processes, including impact phenomena and mechanical or chemical interaction with an atmosphere. In its simplest form, the addition of an auxiliary lens system to the main rover cameras would provide multispectral, close-range pictures of the surfaces of boulders, outcrops, regolith, and peculiar features or coatings on their surfaces. A microscope within the rover could provide higher-magnification, multispectral, stereoscopic images of dispersed grains under controlled lighting conditions. This could be achieved by an optic train to the main rover cameras or, probably more practically, by a lens-equipped CCD imager with color wheel, sharing the electronics of the main cameras. Use of a facsimile camera would make it possible to direct the output from a single grain into the spectrometer, thereby helping to identify the individual mineral grains. Microscopic examination may be very useful in determining whether stains or coatings on boulders or fragments are of biological orgin.

Sample Return Study

A goal for the Mars '84 mission is preparation for a sample return mission. The apparent surface reactivity of Martian soil discovered by Viking and the volatile content must be considered in the design of sealed containers for sample return. The "molecular" analysis system should answer these questions, but a direct test of a container might be desirable.

At some time in the future it seems probable that the rover will be revisited. Thus simple monitors should be placed on the rover to record very long-term radiation and particle fluxes, cumulative erosion by wind storms, etc. In addition, rock samples from various places along the traverse can be stowed and carried after the deployable packages are emplaced. No packaging would be necessary and they could be identified at some later date if they are photographed before stowage.

Traverse Geophysics

The prime objective for traverse geophysics is to extend our knowledge on the inventory of Martian volatiles and on the Martian regolith. The key measurements include: 1) depth to bed rock, 2) regolith density, 3) depth to permafrost, if it exists and 4) depth to the "zero" degree melting isotherm. These can be obtained by combining data from an active seismic sounder, and an electrical conductivity sounder.

A magnetic and/or a gravity profile can provide some information on the subsurface geologic structure. Under particular circumstances a magnetic profile could provide some insight into the magnetic history of the planet.

Transport Deployable Science Stations

A deployable package, like the lunar ALSEP stations, can provide valuable long-term monitoring of geophysical and meteorological phenomena. The penetrators can provide a global network of relatively simple instruments whereas a deployable station could contain more versatile instruments -- for example a broad-band, 3-axis seismometer or a more complete meteorology station. A 20 km triangular net of three such broad-band, 3-axis seismometers can

provide important constraints on global seismicity, although it cannot replace the global network of penetrators. A measurement of heat flow is probably not practical, but a simple probe to measure the near-surface temperature profile seems useful and practical.

The meteorology capability provided by the deployed station should be more substantial than that on the penetrators. Viking lander capabilities (pressure, temperature, wind direction and speed) should be augmented by the addition of a hygrometer to measure atmospheric humidity. The station or the rover should also be equipped with a photometer able to measure the intensity of sunlight at visible and UV wavelengths. Viking lander and orbiter imaging data indicate that low level water ice fogs form at night. Measurements of atmospheric water vapor levels after sunset and after dawn would address the problem of the transfer of water between atmosphere and surface. Photometric data would have similar value and would also serve to monitor quantitatively the atmosphere's changing aerosol burden.

Penetrator

The penetrators are key elements in achieving the network science goals of the 1984 mission. These goals require a wide distribution of sensors across the planet. The seismic experiment and the meteorology experiment are especially affected by the geometry of the arrays. A determination of the internal structure of Mars is not likely to be achieved using seismometers deployed from two rovers only. Studies of the magnetic field of Mars and of subsurface chemistry, including an analysis of volatiles, benefit greatly from wide dispersal. In principle, a measurement of heat flow could be made by the penetrators although this is difficult.

Possible instrumentation for the penetrators is reviewed in Table 3-10, which illustrates a representative suite of instruments in terms of mass and power constraints. The masses of suggested penetrator instruments are notably small in comparison with those proposed for the other 1984 vehicles. We remain somewhat uneasy about potential growth of these figures for both mass and power. If such growth occurs the payload diversity of the penetrators may diminish significantly. However, a good quality seismometer must be maintained in the payload since a determination of planetary structure is a science goal of especially high priority.

Table 3-10. Penetrator Instrument Characteristics.

INSTRUMENT	MEASUREMENT	PROTOTYPE	RESOLUTION	MASS	POWER	VOLUME	DATA RATE	BER	COMMENT
MAGNETOMETER	PERMANENT AND INDUCED MAGNETIC FIELD AT SURFACE	UNDER DEVELOPMENT	0.02 γ · DC to 0.02 Hz	0.4	45 mW	300 cm^3 $-4 \times 4 \times 19$ cm	1.6 bps	10^{-3}	ONE MEASUREMENT EVERY 50 sec OF 30 bits (3–10 bit wds) + 4th WORD EVERY 6 min. ORIENTATION TO WITHIN 0.2° OF PLANET VECTORS
ELECTROLYTIC FREE SOIL WATER DETECTOR	FREE WATER IN SOIL SAMPLE	UNDER DEVELOPMENT	ppm	0.1	5 mW	0.3 × 0.3 × 5	TBD	TBD	
SOIL SAMPLER AND PROCESSOR	OBTAINS SAMPLE AND HEATS WHILE EXPOSED TO VARIOUS INSTRUMENTS	UNDER DEVELOPMENT	NA	2.0	500 J/cm^3	4 × 4 × 4	TBD	TBD	
SEISMOMETER	MAJOR SEISMIC EVENTS	UNDER DEVELOPMENT	<60 Hz	0.6	0.1 W	8 × 8 × 25	TBD	10^{-4}	TWO AXES 3×10^6 BITS/DAY
ALPHA PARTICLE INSTRUMENT	ELEMENT IDENTIFICATION	UNDER DEVELOPMENT	0.5% BY AI...	0.4	0.1 W	6 × 6 × 8	TBD	TBD	
METEOROLOGY	PRESSURE, TEMPERATURE WIND VELOCITY AND DIRECTION HUMIDITY	UNDER DEVELOPMENT	NA	0.3	75 mW	6.7 × 6.7 × 6.7	1.0 bps	TBD	
HEAT FLOW	TEMPERATURE GRADIENTS	UNDER DEVELOPMENT	NA	0.065	1 mW	4 × 4 × 4	2.0 bps	TBD	
ACCELEROMETER	REGOLITH STRUCTURE	UNDER DEVELOPMENT	NA	0.025	30 mW	3 × 3 × 3	20 kbps	TBD	
PHOTOMETER	ATMOSPHERIC TRANSMISSION	UNDER DEVELOPMENT	NA	0.018	20 mW	3 × 3 × 3	0.06 bps	TBD	

Seismology

Penetrator seismometers will benefit greatly from the subsurface emplacement that protects them from wind noise and diurnal temperature variations and allows operation at the highest possible gains. The use of a very small, simple and rugged bubble tiltmeter for the horizontal-axis measurements is promising. We have been assured that an appropriate vertical axis seismometer can be selected from a number of candidate designs. Instrument resolution should be 10^{-8}g over a range 0.01-5 Hz for all axes. The necessary leveling capability remains to be demonstrated within the particular constraints of shock, volume, etc., imposed by the penetrators, although stepping motors have survived shock tests without damage. The seismometers will be the principal data volume gatherer among the penetrator instruments. Because of power and, hence, telemetry limitations the penetrators have a data storage capability which is barely adequate for the seismometer experiment. There is little promise that this may improve and we are concerned that the seismometer experiment not be compromised to meet other penetrator science goals. Data compression may be required for the seismic experiment.

Meteorology

The after-body of the penetrator remains at the surface and a suitably distributed array of penetrators can, therefore, provide a capability for global meteorology studies as previously described. The development of suitable pressure (0.01 mb resolution, 3-12 mb range), humidity, (1 ppm H_2O, 6-600 ppm range) and temperature (0.1°K resolution, 130-300°K range) sensors to meet the severe demands of penetrator aft-body emplacement appears to present no special difficulty. On the other hand, we feel that the difficulty of providing a wind-vector measurement capability is incommensurate with the importance of the data. (The same remark can be applied to an imaging capability whose importance is diminished in the context of a mission that also includes rovers.) A scalar wind speed measurement, while of modest value, might be justified.

A simple after-body visible-light photometer equipped with multiple slits would be highly desirable for meteorological purposes as it would allow the monitoring of atmospheric opacity. We believe that further work is needed to

adequately define this instrument, which may also be used for the determination of penetrator orientation where 1° azimuth and elevation resolution is required within the accessible hemisphere.

Chemistry

The deployment of a simple drill (1-4 cm) for sample acquisition appears feasible to avoid the chemical alteration of the material close to the penetrator (within 1 mm, or so). A small, high quality instrument to measure elemental composition also appears quite feasible. The requirements on this instrument are indicated in Table 3-10. The analysis of water evolved from heated samples is possible using either P_2O_5 or piezo-electric devices. We have some concern that the complete instrument (sample procurement, heater, sensor) may prove to be more complex than we presently recognize. However, the importance of the measurements, and the difficulty of acquiring the data in any other way, persuade us that this experiment, if feasible, would significantly enhance the total penetrator science return.

Heat Flow

Both the importance and extreme difficulty of making a heat flow measurement have been discussed in the Science Goals section. The deep emplacement of the penetrator, possibly below the depth of seasonal temperature variations, is a major advantage of this approach while the site modification and RTG heating are serious disadvantages. The problem of long term temporal changes in surface albedo is one that is common to all attempts at measuring heat flow.

The penetrator concept that has been discussed most recently deploys thermistors (required resolution $0.05^{o}K$, $170-230^{o}K$ range) along thin wires that are drawn from the center of a number of wire coils as the probe is emplaced. This approach is elegant but as yet untested in realistic circumstances. We have some concern that the deployment of the thermistor cables may interfere with the deployment of the main umbilicus. We support this concept of making a highly important measurement only if there is assurance that it will impose no risk to other experiments more certain of providing interpretable data.

MISSION OPERATIONS

Introduction

Although mission operations may not attract as much attention as cost and hardware, operational capability is one of the more important elements in a successful mission -- especially a complex mission. Viking mission operations were tremendously complicated, requiring substantial financial, computer, and personnel resources. Even so, it generally took a week or more to prepare, certify, and transmit a routine command. It was also necessary to prioritize processing of data returned to Earth. Low-priority data were often inaccessible for periods of several days or more.

In general, the Mars 1984 mission will involve significantly more data than Viking and will demand much shorter response times. It is likely that this must be accomplished with a smaller flight team and financial resources no greater than those available to Viking. In the following paragraphs we look at specific problems which arose during the Viking mission and discuss these in light of expected improvements in the 1984 mission operations system.

Viking landing site certification was an exhausting task for several reasons. A successful landing on Mars had never been previously accomplished. Many assumptions regarding the Martian environment were being tested for the first time. Many spacecraft systems were being utilized for the first time. The landing site terrain was demonstrably more rugged in Viking orbiter pictures than in Mariner pictures. The uncertainty of lander targeting required certification of terrain safety within a large ellipse, approximately 260 km by 100 km.

With respect to these concerns the 1984 mission will be using essentially the same entry and landing vehicle already certified by Viking. Further, a great deal of the Martian surface has now been photographed from orbit at high resolution. Included are several areas included as potential landing sites in 1984. Pictures from the surface illustrate roughness at the scale of rover operation. Targeting uncertainty for the 1984 landings is anticipated to be reduced to the range of 65 km x 40 km. In addition an image dissector hazard analysis device on the entry/landing system will bias the landing towards relatively smooth regions in the final kilometer of the descent.

Viking used a single computer onboard the lander to operate all spacecraft components. This caused complications in preparing and uplinking new command loads as no instrument could be updated without potentially endangering all other components. A long series of meetings and on-lab computer runs, proceeded even the simplest of changes.

The 1984 mission will utilize multiple microprocessors, one servicing each major spacecraft component and science instrument. Resulting autonomy will permit selective updating of individual instruments without extensive coordination with other command sequences.

Viking used a tape recorder on-board each lander to record all science data. Serious problems of tape management resulted and planning for each tape load took a week or more. For the 1984 mission as presently planned, with a single 10^8 bubble memory on each rover and with intermittent orbiter overflights, data management requires careful planning: even with a 50 kbps link there is still a narrow funnel constraining data flow from the Martian surface to Earth. Data compression of rover images can partially relieve the constraint, but further study is needed to arrive at a satisfactory data management scheme.

Viking operations were limited by capability to send commands from Earth to the spacecraft: a link once every second day to the orbiters and daily to the landers. A full evaluation of the 1984 uplink situation remains to be made, but a substantially greater uplink capability is available due to greater Earth-orbiter-rover link bandwidths, more frequent overflights and greater on-board computer capacity. At the same time, rover operations will be more complex than those of a fixed lander so that the 1984 uplink constraint is still one of uncertain dimension.

Viking lander direct links to Earth were generally 250 or 500 bps. Relay links to the orbiter tape recorder were at 16 kbps with replay to Earth at 4 kbps. The 1984 rover data will be relayed directly to Earth via the orbiter at 50 kbps without intermediate storage on the orbiter. (See Figure 3-8 showing the link options.) Viking was constrained to lander-orbiter relay links of approximately 20 minutes as each orbiter passed overhead. The 1984 situation is similar except that there will be several links each day. The orbiter data may be returned at up to 150 kbps. Non-imaging data will be returned in real time, and imaging data will first be recorded. A "first in, first out" strategy will greatly simplify orbiter tape management.
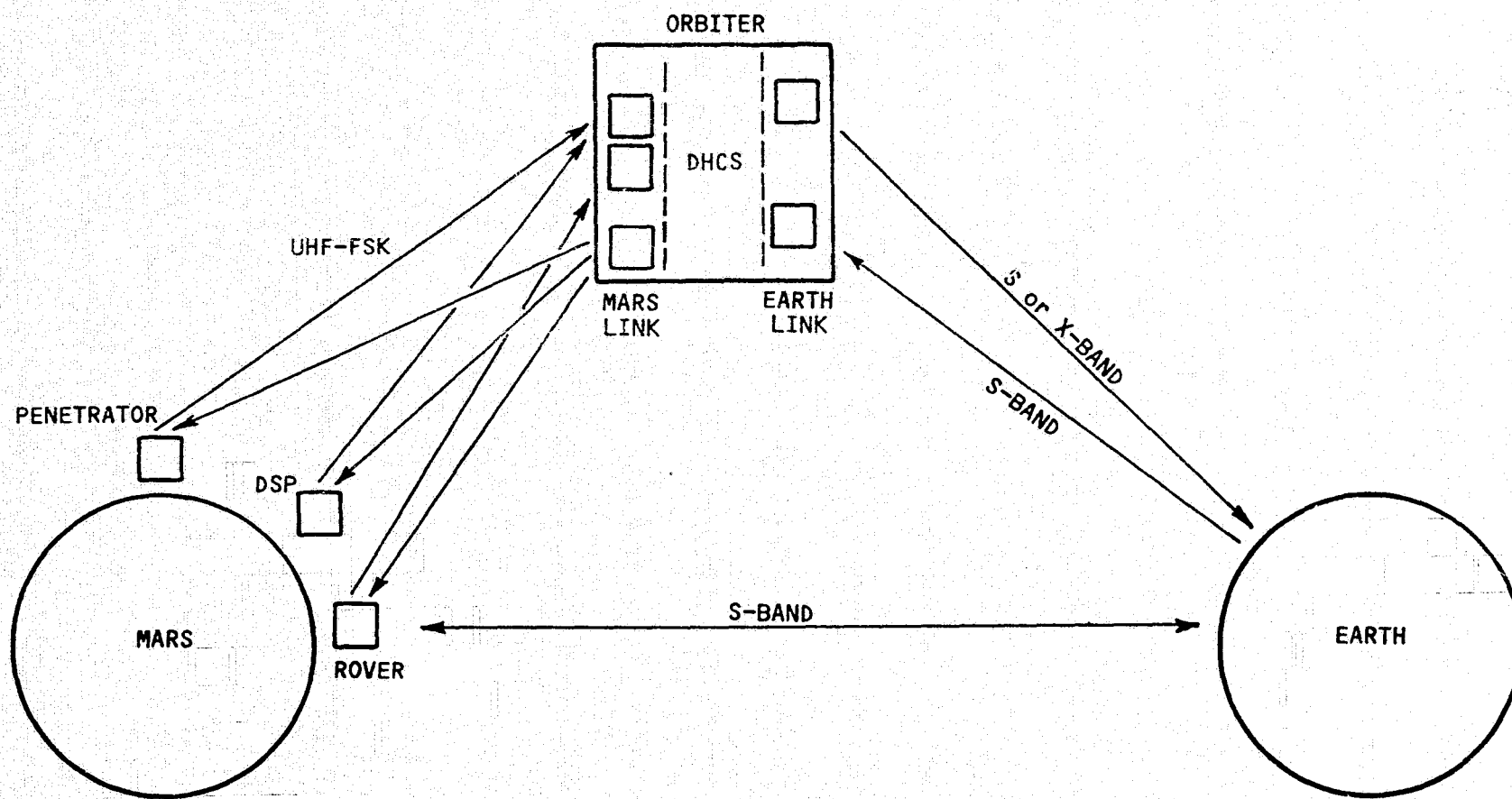
Figure 3-8. Mars 1984 Link Options

Viking decision-making involved many groups and individuals. In particular, most decisions had to be substantively reviewed and approved by directorate heads and by the Project Manager. The proposed decision-making chain for the 1984 mission minimizes this pyramidal structure and assumes independent decisions at intermediate organizational levels. Viking experience during the extended mission suggests the value of this approach. The Viking spacecraft are carrying out sequences of difficulty comparable to those in the primary mission, even though the flight team has been numerically reduced and the personnel interactions are more informal.

Viking clearly showed that current computing facilities and command and data processing software were not efficient. Early attention was not given to overall systems design. Pioneering efforts always involve a real-time learning exercise, and this was experienced by Viking. It is expected that the 1984 mission will profit from the Viking experience and that a knowledgeable systems approach to computer utilization will streamline uplink and downlink data processing. In addition, it is a design goal to utilize off-lab computer facilities, especially in the case of individual investigators who have developed their own programs for data reduction.

Viking involved intensive effort for a period of approximately six months. Following the primary mission, day-to-day involvement by some flight team elements -- particularly scientists -- has dropped off sharply. The primary reason is that other professional commitments have required attention. The 1984 mission will involve intensive effort for two years or more. Maintaining a fine edge on day-to-day operational decisions for that long period of time is a matter that has not been considered in any detail.

Perhaps the single most important issue in mission operations is flexibility, or adaptability. On one hand, adaptability is often advertised -- and rightly so -- as the key ingredient in successful completion of a complex mission. On the other hand, exercising an adaptive mission plan introduces complexity and requires substantial resources.

Mission operations will probably be simplified by two new features. One is the utilization of block telemetry formating. The other is the mechanization of a distributed data handling and control subsystem. Block telemetry formating removes the strong dependence between instrument sequencing and data handling.

A distributed system complements this easing of constraints by making it practical for an individual experimenter to exercise more direct control over his instrument's operation. If we assume that high-level sequencing control is exercised by the central processor according to fixed "skeletal" sequences, there can be very nearly direct control by an experimenter of his instrument's operating parameters and data acquisition sequences. In the ground system only the system constraints imposed by the skeletal sequence, plus instrument safety constraints, need to be considered. On the orbiter, non-imaging instrument modes could easily be altered without system effects, as long as data blocks are available at specified times. Orbiter imaging could be controlled even to the time of shuttering, if an adaptive central coordination of image recording were built into the skeletal sequence. Individual instrument flexibility would be less on the rover, due to more complex coordination required of physical activities: roving, manipulating, camera articulation, sample acquisition, sample preparation, etc. However, the key again is the design of the high-level skeletal sequences. Considerable experiment flexibility and direct control are possible here, too.

The mode of operation of the rovers differs significantly from that used for the only remote, automated rover mission to date: the U.S.S.R. Lunakhod. This spacecraft was driven by operators using television data. The Earth-Mars light-time is sufficiently long to entirely prohibit such an approach, even if it were deemed desirable. Some form of machine intelligence is clearly required to perform the functions listed above. The use of laser range finder data to allow a vehicle to navigate obstacles in a laboratory and to locate and retrieve objects has been demonstrated. In the former case the location of obstacles and of hidden areas is determined from the laser data and a terrain map is generated for on-board path planning. Turn and move commands are then generated and executed. A similar capability is also possible using stereo imaging data. With some limitations, this has been demonstrated also. The principal development required, for either approach, is software to allow satisfactory operation in a natural landscape characterised by varying slopes. Translating the prototype hardware and software into a system that can be used flexibly and safely on Mars is recognised to be a substantial development task, but one that does not differ in kind from many others needed for this mission.

Automated sample manipulation is also required for the 1984 mission. Laser and imaging data can be used to locate and characterize (size and center-of-mass) rocks. Complex manipulator motions needed to retrieve rocks can be determined by software using these data and such a capability has been demonstrated. Recent improvements include the addition of proximity sensors to the pincers to provide more sensitive gripping of objects. Using such a system the scientist may arrange to acquire a sample by transmitting to the rover little more than the picture element location of the object within a rover image. Desired developments include replacement of simple pincers with a three finger claw and, interchangeably, with a scoop and a drill.

While recognizing that machine intelligence is in its infancy, we are encouraged by the development that has taken place to date and believe that the capability needed for the 1984 mission is achievable in the time available. Early activity in this area clearly must have high priority, however, if the potential is to be realised.

In summary, the MSWG believes that the mission operations plan for 1984 is reasonable. However, we are apprehensive. It would appear that radical new approaches are required to problems of data handling. Viking emphasized system centralization. It might be advisable to decentralize much of the 1984 activity so that experimenters can communicate with the spacecraft more-or-less directly. A great deal of data processing might be done most effectively at off-lab facilities.

Clearly, these problems -- and related problems -- are not thoroughly understood at the present time. The ambitious plans for mission operations remain to be certified.

Orbiter Operations

The orbiters have three basic functions:

1. Site certification for the rover/lander

2. Global and regional studies of the Martian surface, atmosphere and plasma environment

3. Relaying information from the lander spacecraft (rover/landers and penetrators) to Earth.

All of these functions carry with them one or more required or preferred orbits. One of the spacecraft will be placed in an orbit with a high, near-polar inclination to permit global mapping and to permit lander access to nonequatorial regions. Sites between either approximately 35-40°N and 57°N or ~60°S to 80°S can be reached from this orbit, depending or whether periapsis is in the northern or southern hemispheres. The second spacecraft will be placed in a low inclination (~30°) orbit to permit lander access to equatorial sites and to allow for a study of the solar wind-plasma interaction.

As currently proposed, arrival at Mars occurs just prior to Martian southern summer solstice/perihelion, which is historically a period of intense dust storm and north polar hood activity. This may necessitate an extended delay in Mars orbit prior to deployment of the rovers and initiation of global mapping from orbit.

Current Viking data indicate that the start of site certification observations is likely to be delayed a few months owing to obscuration of the surface by haze or dust around perihelion. A 5-Sol initial orbit serves as a "holding" orbit which will limit periapsis rotation before commiting to a 1-Sol orbit for site certification and landing operations. In order to support magnetospheric sampling, the low inclination equatorial orbit is shifted to a low periapsis (≤ 300 km), 1-Sol orbit that passes through the magnetic tail at an altitude of at least 10,000 km. The plane of this orbit must also cross the Sun-Mars line during the period of data collection, as will happen 2 to 4 months after arrival.

Following completion of these studies (a few weeks) this orbiter is shifted to a 500 km periapsis by 1-Sol elliptical orbit to support site certification for the equatorial rover. The high inclination orbiter is moved directly from the

initial 500 km periapsis by 5-Sol orbit to the 500 km periapsis by 1-Sol orbit used for site certification. Following site certification and landing of its rover, the equatorial orbiter is placed in a 1,000 km circular orbit with a 2.46 hr. period where it will perform science mapping of the equatorial zone and act as the primary communication link for both rovers. Lower altitude orbits provide too little relay link time.

After the landing of the "high latitude" rover the polar orbiter is shifted to a 500 km circular orbit with a 2-hour period and science mapping is initiated with the goal being global coverage. The polar orbiter will probably serve as the principal relay link for all penetrators. The final orbits can be chosen to provide an integral number of revolutions per Mars day so that the orbiter ground tracks will approximately retrace themselves each Martian day. The precise period is selected to achieve a small drift, on the order of 10 km/Sol at the equator, to permit high-resolution contiguous mapping by the optical instruments and the radar altimeter. Initially, however, it may be desirable to have the ground tracks repeat precisely so that, for a period of a few months, the gamma spectrometer can observe a limited part of the planet and, thereby, build-up useful statistics. This conservative approach ensures that, even if an orbiter fails to survive for the planned two years, high spatial resolution composition data will have been acquired for part of Mars.

Orbiter science operations are expected to be highly repetitive with most instruments acquiring data continuously and sending it to Earth in real time without tape recording. Imaging data, however, are acquired at a rate that is many times too great for real time transmission and will, therefore, be recorded. The imaging science planning will represent the greatest perturbation of the systematic orbiter science operations. At present one tape load of images (about 80 frames) is planned for acquisition and transmission each day (a much greater rate is possible, however, for site certification and for other selected periods of intensive imaging science). These images will be divided between geological mapping and atmospheric monitoring in a flexible manner. Both imaging activities can be undertaken systematically (e.g., mapping can occur at the same time each Sol while contiguous coverage is acquired over some area of interest) and need not represent a major burden on the mission operations system. Recorded data will be replayed on a first in/first out basis, generally with a complete tape load being recorded and replayed each day.

The relay of data from the 10 landed vehicles (2 rovers, 2 rover-deployed stations, and 6 penetrators), some of which may be interrogated several times each day, will clearly require careful planning. It is expected that the low inclination orbiter will be able to service both rovers several times each day so that a relay link of about 80 minutes duration can be maintained. The high inclination orbiter has a lower altitude and, therefore, provide relay links of shorter duration. This orbiter can, however, provide a relay to almost any point on the planet and will probably be the prime link with the penetrators, since these will be globally distributed.

The availability of the Deep Space Network to support the 1984 Mars mission will clearly be a major consideration affecting mission operations. In order to minimize dependence on the most powerful and, therefore, most tightly scheduled DSN dishes, the orbiter communications system has been sized to allow downlinks to the 34 m dishes for most of the mission. During periods when the Earth-Mars distance is greatest, the 64 m dishes will be required, such support being negotiated in the normal manner.

During certain phases of the mission the orbiters will be eclipsed by Mars on each revolution for a time that may be as much as 40% of the orbital period. During eclipses orbiter power is supplied by a battery which must be recharged during the part of each orbit that the spacecraft is in sunlight. The solar panels and battery are sized accordingly. In principle the orbiters could be powered by RTG's like the rovers and penetrators, thereby eliminating any effects due to eclipses. It appears, however that this would be a more expensive approach and the effect of radiation from the RTG's is likely to detract greatly from the gamma ray spectrometer measurements. It is expected that little data can be usefully gathered by this experiment until the penetrator and rover (with their RTG power sources) are deployed from each spacecraft.

Rover Operations

The 1984 rovers will be substantial vehicles carrying complex instrumentation designed for both site-intensive investigations and for survey science during a two year mission that will involve a total traverse of over 100 km and visits to a variety of geologically interesting areas. Several different operational modes are required for the rover and its capabilities must be planned to take advantage of these different modes. Three modes are presently envisaged:

1. Site Investigation Mode

    -   Intensive investigation of a scientifically interesting site.

    -   Full maneuverability and manipulative ability can be utilized for earth-directed sample procurement and processing.

    -   All science skills may be utilized with flexible sequencing.

2. Survey Traverse Mode

    -   Near-autonomous capability is required for both travel and science - the route and sequencing is updated daily.

    -   Operates in a "halt-sense-think-travel-halt" cycle with a mean path of ~30-40 m; mean cycle time of ~50 mins., and a travel rate of ~1.5 m/min. At each programmed halt, the rover acquires laser range finder data for use in modifying its path.

    -   Preprogrammed science observations are primarily restricted to the halt portion of the cycle, to brief pre-programmed stops, and to night halts.

    -   Manipulator will not be used.

    -   Autonomous state could be terminated by hazard or science "alarms."

3. Reconnaissance Traverse Mode

    -   Minimize site-to-site travel time.

    -   Terrain conditions permit long mean path at top speed (~93 m/hr).

- Minimize the number and length of science stops.

- Travel during night.

The point design mission plan assumes that in the Survey Traverse Mode (~300 m/day) the rover will require about 2/3 of the mission time in order to cover more than 100 km. Additional time in the Site Investigation Mode or more than 130 km of travel distance would require compensating travel in the Reconnaissance Traverse Mode.

A timeline for a typical survey traverse mode day is shown in Figure 3-9. The timeline begins at the close of the Martian day with the rover transmitting to the orbiter. The data include science and engineering and stereo images required for the planning of the next traverse day. The data are processed at JPL and placed into mass storage. The stereo images are converted to hard-copy prints and passed to the Rover Mobility Team which is responsible for determining the commands necessary for updating the rover's on-board path planner. In addition, the data are made available to an image processing system via the mass storage system as are laser data. The Mobility Team accesses the imaging computer through a keyboard console located in the mission support area. By means of a stereo viewing system the local Martian scene is displayed for the operator allowing him to develop a traverse plan. Other data which are used to formulate the plan are soil characteristics, orbiter images, slope information and rover imaging data. A traverse plan consists of coordinates for the traverse steps which provide the rover with an obstacle-free path for the initial step(s) and the best discernible path for the remaining steps.

The step coordinates are converted into commands and, together with other commands necessary for the rover's planned daily activity, are transmitted to the orbiter at the appropriate time. The orbiter stores the commands until the relay link with the rover is established, at which time the commands are relayed to the rover.

The rover is now ready to begin another survey traverse mode day. By utilizing the command information and by use of its on-board logic and hazard

TIME REQUIRED, SOL

ACTIVITY	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

ON MARS

TRAVERSE IMAGING

ORBITER OVERFLIGHT

TRAVERSE DATA DUMP

SCIENCE DATA DUMP

SURVEY TRAVERSE SEGMENTS

COMMANDS RELAYED FROM ORBITER TO ROVER

ON EARTH

ROVER TRAVERSE IMAGING DATA ANALYSIS

ROVER PATH SELECTION
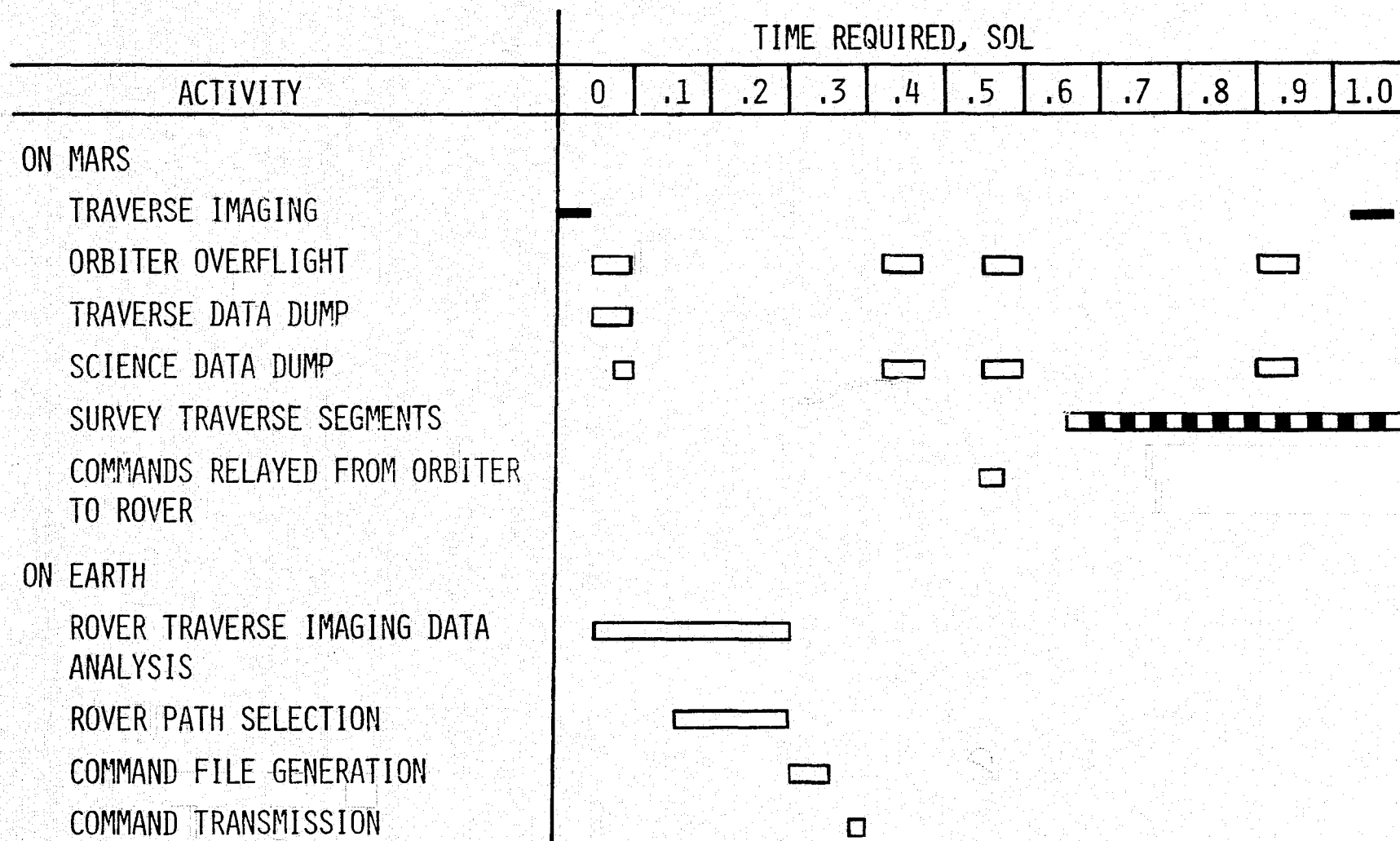
COMMAND FILE GENERATION

COMMAND TRANSMISSION

Figure 3-9. Typical Survey Traverse Day Plan.

avoidance equipment, the rover proceeds across the Martian terrain. At the completion of each step the rover, by means of image data or laser range data or both, modifies the next traverse step based on local knowledge. In addition, the planned survey science data are gathered and stored in the data storage subsystem. The data gathering, planning and traverse step make up a traverse segment. A timeline of a traverse segment is shown in Figure 3-10. Should the rover encounter any obstacles that it cannot by-pass using its onboard logic, it executes a stored emergency sequence and awaits ground assistance.

At the completion of the planned steps for the day the rover takes the stereo images and laser range data required for the next traverse day's planning and awaits the orbiter overflight for the relay event which will start the planning cycle once again.
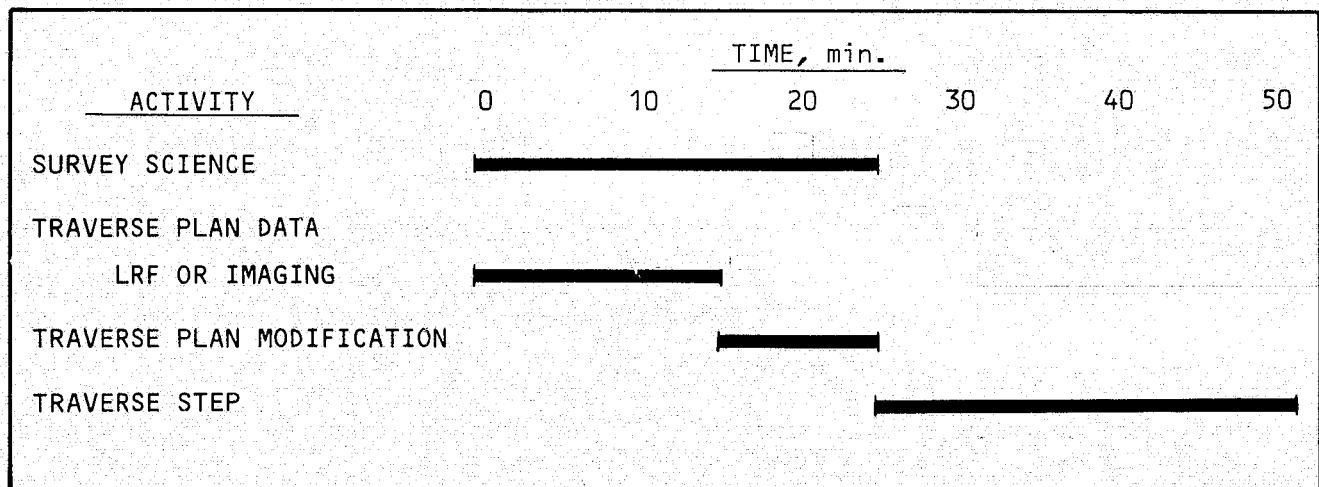

Figure 3-10. Typical Survey Traverse Segment.

Penetrator Operations

Since the long-term operations are those which the penetrator performs most effectively and are most significant from the standpoint of geophysics, this mode will be treated first. The point-design mission calls for the orbiters to remain in 5-day-period orbits for up to six months following orbit insertion; during this time, a sharply different mode of operation is required of the penetrator in order to retrieve the most important geophysical data. These special operations are described following the long-term routine operations.

During the last 18 months of the point-design mission (i.e., after the orbiters have been placed in circular orbits) the penetrators' routine operating mode concentrates on seismic, magnetic and meterological observations. Early in this period, however, a few days are devoted to geochemical and bound-water studies.

Routine Penetrator Operations

Following circularization of the orbits at low altitude, the polar orbiter will be able to contact each penetrator once and perhaps twice per Sol; the other orbiter (inclination approximately 30 degrees) will be able to contact all penetrators between 30 degrees north and 30 degrees south once or more each Sol. With routine communications established, the penetrators can achieve their full scientific potential.

As the orbiter approaches the penetrator site, the penetrator receiver is turned on according to a timed command transmitted during the previous session. As the orbiter moves into communications range it addresses the penetrator; the penetrator acknowledges the call, whereupon the orbiter transmits a sequence of commands to update the penetrator clock, reset instrument modes and sensitivities, and read-out stored data. The penetrator then acknowledges the commands, transmits the stored data, and resumes the desired data collection.

Highly interactive (Earth/penetrator) activities, such as for soil sampling and elemental analysis, will be conducted as needed at intervals of a few sols. Routine measurements of the various phenomena of scientific interest (temperatures, pressure, insolation, magnetic field, etc.) will be recorded in a format

3-62

fixed for that period; seismic phenomena will be recorded in compressed form on a routine basis or in detailed form during significant events.

Simultaneous Penetrator Operations

Since the array of penetrators and deployable science packages (DSP) on Mars is to include a local network of at least three stations in a triangular pattern with sides on the order of 100's of kilometers, it will be necessary that the orbiter be capable of receiving multiple data streams simultaneously. It appears that this capability can be provided by the receiver proposed for use in the Jupiter Orbiter Probe program. Each penetrator would be assigned a part of the receiver's bandwidth; all commands from the orbiter to the fixed ground stations, penetrators and DSP's, will be at one frequency so that each must recognize its own address code.

Limited Communication Operations

During the six months immediately after emplacement, all of the penetrators must operate for at least five-day periods between communication sessions with the orbiter. This reduced frequency results from the necessity to wait out the Mars perihelion dust storm period as well as the desire to have elliptical orbits (polar and inclined) for detailed study of the interaction of Mars' atmosphere and magnetosphere with the solar wind. Those penetrators near the respective orbiter periapses will have access to the orbiters. Some penetrators will be targeted to less accessible locations, so that protracted periods of autonomous operation (perhaps as long as six months) may be required. For such a case the penetrator will be programmed to concentrate primarily on those scientific observations which cannot be postponed to later parts of the mission, and secondarily on regularly scheduled observations of phenomena of global importance.

More specifically the accelerometer data recorded during implantation will be stored, followed by recording (at ever-increasing intervals) of the temperature measurements for the heat flow experiment. The necessity for storing deceleration data is clear; the urgency of starting the heat flow measurements lies in the need to determine the short-term effect of implantation and to pursue

the determination of average pre-impact soil temperatures before the long-term thermal dissipation of the RTG influences the nearby soil. Even rather detailed measurements of these two phenomena will use only a small fraction of the penetrator's memory so that provision can be made for the collection of further data. One strong candidate for regularly scheduled measurements of global significance is the collection of meteorological observations, e.g., pressure, temperature, wind, humidity, and solar extinction. A most interesting part of Mars' weather and its major effect on surface features occurs near Mars' perihelion. Global, in situ observations, during two dust-storm periods (one at the beginning and one at the end of the mission) represent an unparalleled opportunity. Magnetic data also contend for collection to correlate with the magnetometer and plasma data collected aboard the orbiters during their six month exospheric mapping.

Analysis of long-term seismic data from the global and local networks is the prime goal of the penetrator operation. Achievement of that goal must be postponed, in this mode, to permit acquisition of the previously described data unique to the time period of several weeks after impact. While these data will fill most of the penetrator's 1.5 million bit memory, the remainder may be devoted to seismicity (e.g., frequency of events or recording a major event). It may be found desirable to record other phenomena during this period (e.g., background moisture levels in the penetrator).

At some time after implantation, the penetrator's command receiver will be turned on periodically in a duty cycle which, while within an acceptable power budget, will guarantee acquiring the orbiter/penetrator downlink during the first low-altitude pass on which the orbiter attempts communication. When the link is established, the penetrator will respond and the orbiter will then transmit the desired commands for data read-out and changes of penetrator status. The penetrator may be programmed to "recycle" the waiting-period data for transmission at a second opportunity to permit scrutiny by the scientists before the memory is devoted to new data, obtained via the routine operation strategy.

ROVER TRAVERSE SITE STUDIES

Introduction

Five regions have been studied intensively using Viking data. Four other sites had been studied previously, using Mariner 9 data, and are documented in informal U.S.G.S. reports. Summary descriptions of two sites in the Candor and Capri regions (figure 3-11) are included in this report to illustrate that a variety of geologic problems can be investigated within the constraints of the point design mission. A landing ellipse 60 by 40 km, aligned with long axis along the spacecraft ground track, was used in this study and the assumption made that the landing was at the center of the ellipse.

Intensive-study sites along the traverse are marked and between these points the rover operates in one of the two traverse modes in which science data is gathered in an autonomous mode. Although the point design was based on a traverse distance of about 150 km in one Mars year, at the studied landing areas the planned traverses indicated the value of travelling closer to 200 km. The illustrated traverses also include rover paths for distances of 400 km, to show the full range of possible rock types and geological problems attainable in an extended mission.

Both the Candor and the Capri areas were imaged by the Viking orbiters at slant ranges of more than 3000 km. Because the periapsis altitudes of the orbiters have been lowered and the periapsis latitudes are moving south these regions can be observed with much better resolution in the coming year. Multicolor and stereoscopic imaging of these and other regions are possible also. Such data will be very important since the landing latitude must be selected before orbit insertion. Final site selection and certification will be carried out from orbit in 1984.

Capri Chasma Region

This proposed landing site lies on the north rim of the great equatorial canyon system. The rock units include ancient, heavily-cratered Mars uplands; less-ancient lava flows that partially bury these rocks; younger lava flows and lava channels; and fluviatile channels and deposits. This highly
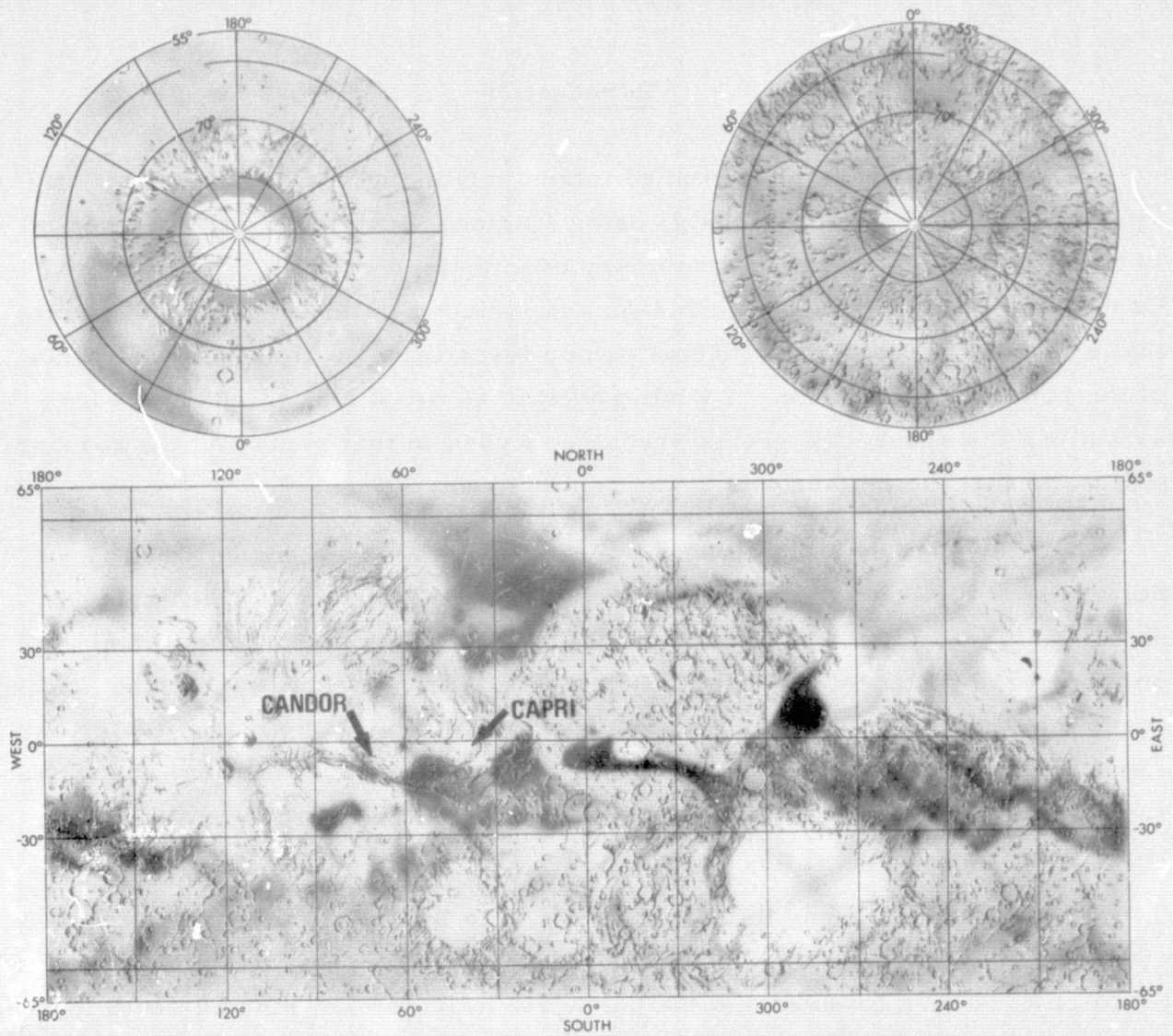
CAPRI: 1.0°S   41.8°W

CANDOR: 5.7°S   74.9°W

Figure 3-11.   Examples of Rover Missions.

varied terrain has areas that appear to be smooth in Viking pictures. Sharp, strong radar returns have been interpreted to indicate smooth terrain at the lander scale. The abundant crater ejecta should allow sampling and analysis of ancient- and intermediate-age rock units that will make possible comparison with similar ancient rocks on the Moon and Earth. There may be significant alteration at various soil horizons or organic material may have been formed and preserved during earlier climatic episodes. Intensive sampling of crater ejecta and fluviatile channel deposits should permit analysis of the maximum variety of rocks in the minimum distance. (See Figure 3-12 and 3-13.)

Figure 3-12.   Photomosaic of Capri Site.

TRAVERSE OF CAPRI SITE

STATION	DISTANCE- KM	UNIT	MATERIALS TO BE SAMPLED
1	5	PLC	LANDING SITE ON CRATERED PLATEAU; BASALTIC? WITH THICK REGOLITH
2	10	PLC	CRATERED PLATEAU NW OF LAVA CHANNEL
3	16	LC	FLOOR AND WALL OF LAVA CHANNEL
4	20	PLC	CRATER AND LAVA CHANNEL
5	36	LC	LAVA CHANNEL
6	44	LC/PLC	LAVA CHANNEL AND CRATERED PLATEAU
7	46	SC	SECONDARY CRATER CLUSTER
8	48	PLC	SAME AS STATION #1
9 (UNDER ARROW)	55	PLC	CRATERED PLATEAU; POSSIBLY SOME C_1
10	65	C_1	RIM OF C_1 CRATER
11	70	PLC	CRATERED PLATEAU IN BREECHED RIM OF C_1 CRATER
12	75	C_1	SAME AS STATION 10
13	84	PLC	RIM CREST OF C_2 CRATER
14	100	PLC	CRATERED PLATEAU
15	132	CRL_3	CRL_3 FROM LARGE C_3 CRATER
16	135	C_4	CR_4 FROM YOUNG CRATER; POSSIBLY SOME CRL_3
17	142	CRL_3	LOBATE EJECTA FROM C_3 CRATER
18	148	CR_3	HUMMOCKY RIM FROM LARGE CRATER SE OF LANDING ELLIPSE
19	155	CRL_3	SAME AS STATION 17
20	160	CRL_3	LOBATE EJECTA FROM CRATER SE OF LANDING ELLIPSE
21, 21A	165	CRL_3	LOBATE FLOW EJECTA NORTH OF STATION 20
22	170	PLC	CRATERED PLATEAU AND REGOLITH
23,23A,23B	186	CR_1	RIM OF C_1 CRATER
24	200	PLC	SAME AS 22
25	212	PLC	CRATER RIM CREST FROM FLOODED, PARTIALLY BURIED DOUBLET CRATER
26	225	PLC/CHF	CRATERED PLATEAU NEAR GRADATIONAL CONTACT WITH CHANNEL FLOOR (CHF)
27, 28	230-235	CHF	CHANNEL FLOOR MATERIAL
29	240	CHF	CHANNEL FLOOR NEAR CONTACT WITH CHAOTIC/KNOBBY TERRAIN (KK)
30	245	KT	CHAOTIC TERRAIN/KNOBBY
31,32	250-260	CHF	CHANNEL FLOOR MATERIAL
33	265	PLC/CHT	GRADATIONAL CONTACT BETWEEN CRATERED PLATEAU AND CHANNEL FLOOR
34	275	C_3	RIM OF C_3 CRATER
35,36	320	PLC	CRATERED PLATEAU
37	350	CRL_2	SUBDUED LOBATE EJECTA FROM C_2 CRATER NORTH OF LAVA CHANNEL
38	365	CR_1	RIM OF C_1 LARGE CRATER AND C_2
39	375	CHW	WALL MATERIAL FROM NORTH WALL OF CHANNEL
40,41,42	378-395	CHF	CHANNEL FLOOR
43	400	CHW	WALL FROM SOUTH WALL OF CHANNEL
44	405	PLCR	ROUGH CRATERED PLATEAU; MAY BE RELATED TO CHANNEL FORMATION OR EJECTA FROM LARGE C_2

LC   LAVA CHANNEL - MATERI
DEPRESSIONS SHOWS CON
(UNITS CHW, CHF) SMAL
COMPOSITION, FILLING

CHF   CHANNEL FLOOR MATERIA
CHAOTIC MATERIAL (UNI
THAT HAVE BEEN ERODED

CHFD   CHANNEL FLOOR DISTURB
IN COLLAPSED AREA OF
INTERPRETATION: AREA
ATION; MAY HAVE BEEN

KT   KNOBBY/CHAOTIC MATERI
CHANNEL, CONSIST OF F
BASALTIC FLOWS, THAT

PLCR   CRATERED PLATEAU MATE
SURFACE ARE RADIAL TO
UNCLEAR, MAY BE RESUL
FORMATION OF LARGE CH

PLC   CRATERED PLATEAU MATE
SURFACE SMOOTH TO GEN
ANCIENT CRATERED TERR

CHW   CHANNEL WALL MATERIAL
CHW   CANYON WALL MATERIAL
BEDDED FLOWS AND POSS
CAPRI CHASMA TO SOUTH

C_4 FRESH CRATER MATERIA
HAVE SHARP WALL TERR

C_3 SLIGHTLY DEGRADED MA
CRATERS ARE BOWL-SHA

C_2 MODERATELY DEGRADED
HUMMOCKY FLOORS,

C_1 DEGRADED CRATER MATE
BY CRATERED PLATEAU

SC   SECONDARY CRATERS --
DEGRADED.

CAPRI - EXPLANATION

LC — **LAVA CHANNEL - MATERIAL** -- Occur as material of elongate sinuous to nearly straight depressions. Head of longest depressions shows complex, braided morphology. Longest depression has northeasterly trend like that of large channel; (units CHW, CHF) smaller depressions trend N-S. INTERPRETATION: Lava flow materials, probably basaltic in composition, filling lava channels or collapsed lava tubes.

CHF — **CHANNEL FLOOR MATERIAL** -- Forms lineated or braided, rough surface of channel floor; some areas covered by knobby/chaotic material (unit KT) INTERPRETATION: Fragmented volcanic flows materials, possibly basaltic in composition, that have been eroded and oxidized by widespread, voluminous flow of water.

CHFD — **CHANNEL FLOOR DISTURBED MATERIAL:** -- Occur as relatively smooth floor material associated with knobby/chaotic unit (KT) in collapsed area of channel floor (unit CHF). INTERPRETATION: Area of channel floor material (unit CHF). INTERPRETATION: Area of channel floor material (unit CHF) that collapsed at time of knobby/chaotic (unit KT) formation; may have been caused by underground sapping of permafrost.

KT — **KNOBBY/CHAOTIC MATERIAL** -- Occur as three crudely circular areas of extremely rough, hummocky material within large channel, consist of rounded rectilinear blocks. INTERPRETATION: Cratered plateau (unit PLC) materials probably basaltic flows, that have collapsed from removal of underlying permafrost and/or from sapping of canyon walls.

PLCR — **CRATERED PLATEAU MATERIAL; ROUGH** -- Occur as slightly roughened surface on south rim of large channel; lineations on surface are radial to large C_2 crater north of canyon and normal to lineations on channel floor. INTERPRETATION: Unclear, may be result of erosion by ejecta from large C_2 crater north of canyon; alternatively may be connected with formation of large channel (units CHW, CHF, KT).

PLC — **CRATERED PLATEAU MATERIAL** -- Forms major surface area of map as inter crater plains between crater material (C_1-C_4). Surface smooth to gently rolling, forms floor of all C_1 craters. INTERPRETATION: May be lava flows covering ancient cratered terrain; alternatively, may be fluidized impact ejecta.

CHW — **CHANNEL WALL MATERIAL** -- Forms steep, smooth slopes

CHW — **CANYON WALL MATERIAL** -- In canyon and channel walls and extends to channel or canyon floor. INTERPRETATION: Interbedded flows and possible pyroclastics underlying the crater plateau surface (unit PLC). One resistant layer in Capri Chasma to south of map area suggests at least two types of material are present.

CRATER MATERIAL

C_4 — **FRESH CRATER MATERIAL** -- Small, very fresh appearing craters; all have well defined ejecta blankets; larger craters have sharp wall terrain, smaller craters bowl-shaped.

C_3 — **SLIGHTLY DEGRADED MATERIAL** -- Forms small and moderate sized crater with fresh, sharp rims and terraces. Small craters are bowl-shaped; large craters have hummocky or lobate ejecta blankets.

C_2 — **MODERATELY DEGRADED CRATER MATERIAL** -- Forms low, hummocky rims; ejecta subdued or covered; most craters have hummocky floors.

C_1 — **DEGRADED CRATER MATERIAL** -- Forms craters with subdued, narrow, continuous to discontinuous rims; most are filled by cratered plateau materials. Ejecta blanket mostly covered or absent.

SC — **SECONDARY CRATERS** -- Individual or clusters of elongate or open ended craters; floors shallow; rims sharp to degraded.

OM LARGE C_2

USGS

44°

0°

-1°

-2°

-3°

-44°

cr_1

c_3

plc

chw

Kt

SC

c_3

SC

c_4

SC

c_2

contact-dashed where indefinite

fault-bar on downthrown side

graben-dot in trough

mare ridge
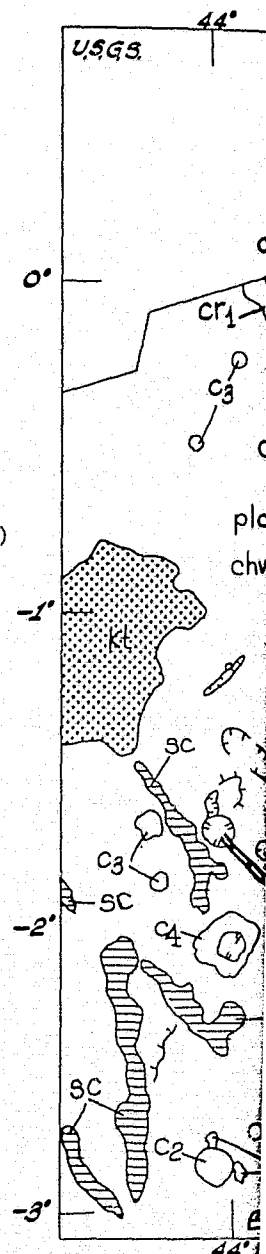
FOLDOUT FRAME
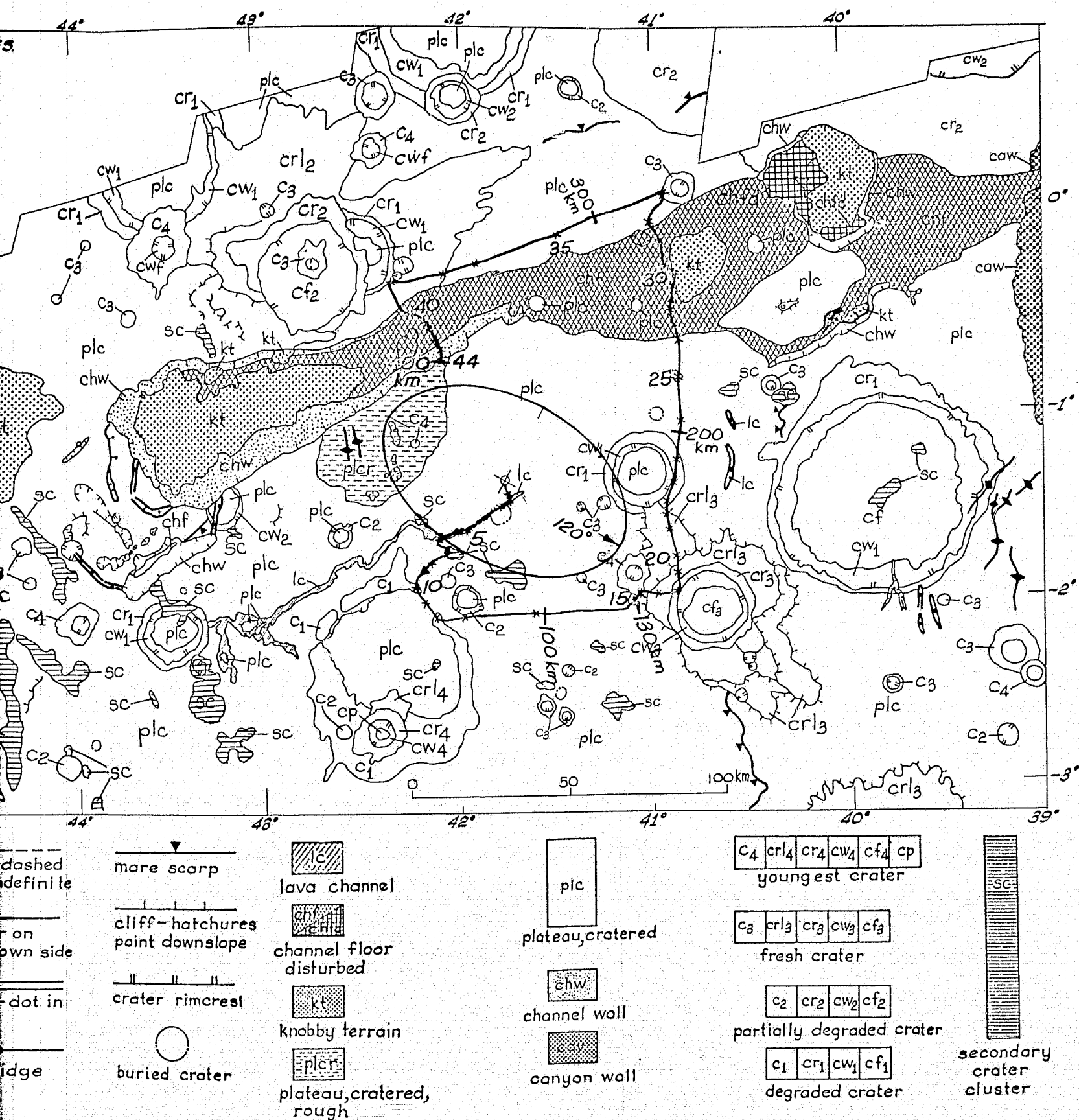
Figure 3-13. Geologic Map of Capri Site on Mars

(Proposed Rover Traverse-1984)

FOLDOUT FRAME

Legend:

dashed definite

r on own side

dot in

idge

▼ mare scarp

cliff-hatchures point downslope

crater rimcrest

buried crater

lc — lava channel

chf / chf — channel floor disturbed

kt — knobby terrain

plcr — plateau, cratered, rough

plc — plateau, cratered

chw — channel wall

caw — canyon wall

c_4	crl_4	cr_4	cw_4	cf_4	cp

youngest crater

c_3	crl_3	cr_3	cw_3	cf_3

fresh crater

c_2	cr_2	cw_2	cf_2

partially degraded crater

c_1	cr_1	cw_1	cf_1

degraded crater

sc — secondary crater cluster

scale: 50   100km

Candor Chasma Region

This proposed landing site and rover traverse lies in one of the branch canyons of the great equatorial system that lies along the Mars equator. This site most closely resembles a traverse of the rocks displayed in the Grand Canyon of Arizona. Two groups of rocks are exposed in the canyon walls and floor. The upper sequence along the canyon rim is composed of resistant, thickly layered rocks - possibly lava flows with interbedded volcanic ejecta. The lower sequence that crops out in buttes and mesas and on the floor is thinly layered and well bedded. These rocks too, may be volcanic in origin, but in addition, may have been reworked by wind or water to resemble sedimentary layering. In all, more than four kilometers in thickness of rocks can be traversed and analyzed. The composition, age and environmental conditions during their deposition may have been very different. These differences may be discernable by alteration products, soil and/or organic material buried and preserved by later rock units. Quite ancient crystal rocks may be exposed in the canyon bottom. Young lava flows, according to crater counts, are exposed on the plateau surface. It is not possible to discriminate yet whether the layered sequence in the canyon bottom is a filling of younger rocks or older rocks that pre-date the rimrock lava flows. (See Figure 3-14 and 3-15.)

Figure 3-14. Photomosaic of Candor Site.

Dd   DARK DEPOSITS -- MATERIALS WITH LOW ALBEDO THAT TRANSECT AND OVER
DIFFUSE OUTLINES. OCCURS MOSTLY IN LOW AREAS. MAPPED ONLY WHERE
AEOLIAN DEBRIS OF RELATIVELY RECENT ORIGIN.

Sc   SLUMP DEPOSITS - CHAOTIC -- MASSES OF CHAOTIC MATERIALS AT THE BA
DEPOSITS INCORPORATING MOSTLY CANYON WALL MATERIAL (CW) WITH SOME

Su   SLUMP DEPOSITS, UNDIFFERENTIATED -- FAN SHAPED OR TONGUE SHAPED D
LINEAR SURFACE TEXTURE. INTERPRETATION: LANDSLIDE DEPOSITS INCO

Lc   LAYERED DEPOSITS, CAPROCK -- FORMS UPPER LAYER OF STRATIFIED DEPO
CANYON. UPPER SURFACE FLAT AND FEATURELESS EXCEPT FOR SPARSE CRA
THE TOP OF OR WITHIN A LAYERED SEQUENCE THAT POST-DATES THE CANYO
(INTERBEDDED TUFFS AND FLOWS) OF FLUVIATILE OR LACUSTRINE SEDIMEN

Lu   LAYERED DEPOSITS, UNDIFFERENTIATED -- SAME AS Lu, BUT EXCLUDES CA

Cc   CANYON CAPROCK -- FORMS FLAT, SPARSELY CRATERED FAULTED SURFACE I
LAVA PLAIN OR EROSION SURFACE.

Cw   CANYON WALL DEPOSITS -- MATERIALS THAT FORM THE WALLS OF THE CANY
BIFURCATING SPURS ON CANYON WALLS AND INTERVENING TALUS. INTERPR
COMPRISING LAVA FLOWS, POSSIBLY BASALTIC IN COMPOSITION AND INTER

Cf   CANYON FLOOR DEPOSITS -- FORMS FLAT FLOOR OF CANYON WHERE SEDIMEN
ON ANCIENT CRATERED MEGAREGOLITH.

STATION	DISTANCE - KM	UNIT	
1-2	10	Cf	CANYON FLOOR DEPOSITS; EXHUME CRATERED TERRAIN.
3	15	Sc	SLUMP DEPOSIT, CHAOTIC; LANDS MATERIAL (CW) AND LAYERED DEP
4-6	30-50	Lu	LAYERED DEPOSITS, UNDIFFERENT MATERIAL. MAY INCLUDE WIND A MATERIALS WHICH MAY BE MORE S
7-10	52-60	Cw	CANYON WALL DEPOSITS; MATERIA MATERIALS, INCLUDING BASALTIC
11-18	62-85	Lu	LAYERED DEPOSITS UNDIFFERENTI
19-26	90-112	Lu	LAYERED DEPOSITS, UNDIFFERENT
27	118	Cf	CANYON FLOOR DEPOSIT; SEE STA
28	125	Sc	SLUMP DEPOSITS; SEE STATION
29	132	Cf	CANYON FLOOR DEPOSITS; SEE ST
30, 31	145-148	Dd	DARK DEPOSITS, LOW ALBEDO MAT
32	150	Cf	CANYON FLOOR DEPOSIT; SEE STA
33-50	160-275	Lu	LAYERED DEPOSITS UNDIFFERENTI
51-53	280-285	Cw	CANYON WALL DEPOSITS; SEE STA
54, 55	290-300	Cc	CANYON CAPROCK DEPOSITS; OLD OR FLUVIATILE DEPOSITS FROM

FOLDOUT FRAME !
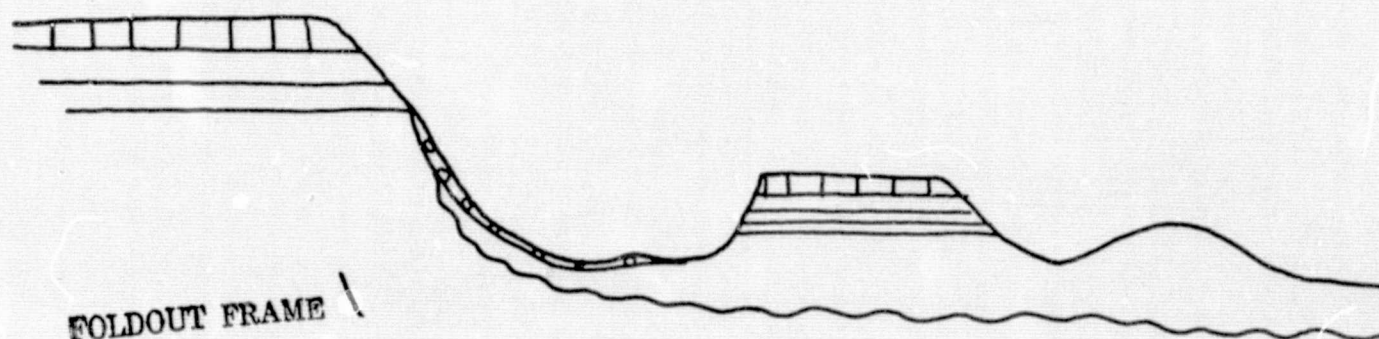
VALLEY FILL-YOUNG SEQUENCE

CANDOR - EXPLANATION

THAT TRANSECT AND OVERLIE ALL OTHER UNITS. DEPOSITS HERE IRREGULAR,
AS. MAPPED ONLY WHERE EXTENSIVE DEPOSITS. INTERPRETATION: PROBABLY

TIC MATERIALS AT THE BASE OF CANYON WALLS. INTERPRETATION: LANDSLIDE
MATERIAL (Cw) WITH SOME LAYERED DEPOSITS (Lu).
APED OR TONGUE SHAPED DEPOSITS OF MATERIALS COMMONLY WITH A MARKED
LANDSLIDE DEPOSITS INCORPORATING MOSTLY LAYERED MATERIALS OF UNIT Lu.
AYER OF STRATIFIED DEPOSITS WITH FORM "MESA" LIKE FEATURES WITHIN THE
S EXCEPT FOR SPARSE CRATERS. INTERPRETATION: MORE RESISTANT LAYER AT
AT POST-DATES THE CANYON AND PARTIALLY FILLS IT. LAYERS MAY BE VOLCANIC
E OR LACUSTRINE SEDIMENTS.
AS Lu, BUT EXCLUDES CAPROCK.
TERED FAULTED SURFACE INTO WHICH CANYON IS CUT. INTERPRETATION: OLD

M THE WALLS OF THE CANYON. LAYERS VISIBLE AT TOP OF SECTION. FORMS
RVENING TALUS. INTERPRETATION: SUCCESSION OF VOLCANIC DEPOSITS,
N COMPOSITION AND INTERBEDDED PYROCLASTIC DEPOSITS.
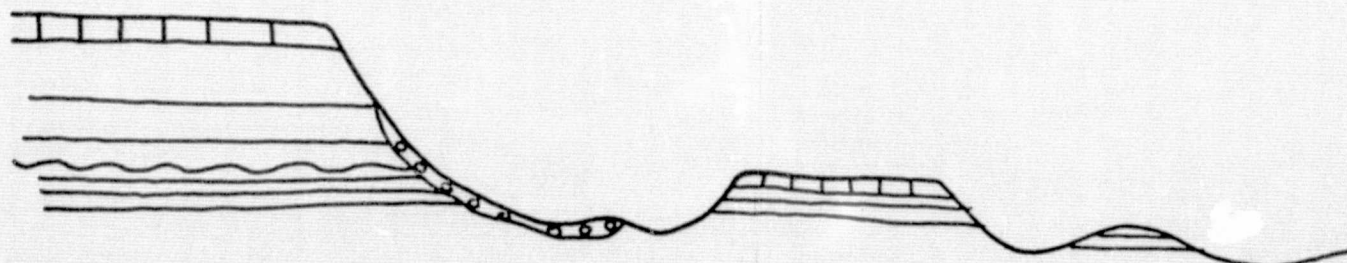OF CANYON WHERE SEDIMENTS ABSENT. INTERPRETATION: EXHUMED LAVA PLAIN
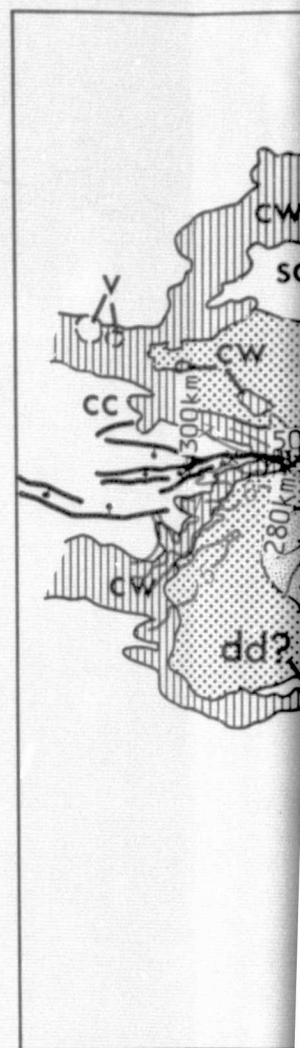
TRAVERSE OF CANDOR SITE

MATERIALS TO BE SAMPLED

N FLOOR DEPOSITS; EXHUMED LAVA PLAIN; MAY INCLUDE EXPOSURE OF ANCIENT
RED TERRAIN.
DEPOSIT, CHAOTIC; LANDSLIDE DEPOSITS WITH INCORPORATED CANYON WALL
IAL (Cw) AND LAYERED DEPOSITS (Lu)
ED DEPOSITS, UNDIFFERENTIATED; STRATIFIED DEPOSITS WITHOUT CAPROCK
IAL. MAY INCLUDE WIND AND/OR WATER REWORKED PYROCLASTIC VOLCANIC
IALS WHICH MAY BE MORE SILICIC THAN THE LAVA FLOWS.
N WALL DEPOSITS; MATERIALS THAT FORM WALLS OF CANYON; POSSIBLY VOLCANIC
IALS, INCLUDING BASALTIC LAVA FLOWS AND INTERBEDDED PYROCLASTIC DEPOSITS.
ED DEPOSITS UNDIFFERENTIATED; SEE STATIONS 4-6.
ED DEPOSITS, UNDIFFERENTIATED; SEE STATIONS 4-6.
N FLOOR DEPOSIT; SEE STATIONS 1-2.
DEPOSITS; SEE STATION 3.
N FLOOR DEPOSITS; SEE STATION 1-2.
DEPOSITS, LOW ALBEDO MATERIAL; AEOLIAN DEBRIS.
N FLOOR DEPOSIT; SEE STATION 1-2.
ED DEPOSITS UNDIFFERENTIATED; SEE STATIONS 19-26.
N WALL DEPOSITS; SEE STATIONS 7-10
N CAPROCK DEPOSITS; OLD LAVA PLAIN OR EROSION SURFACE COVERED BY AEOLIAN
UVIATILE DEPOSITS FROM EARLIER EPISODES OF DOWNCUTTING.

OLD   SEQUENCE
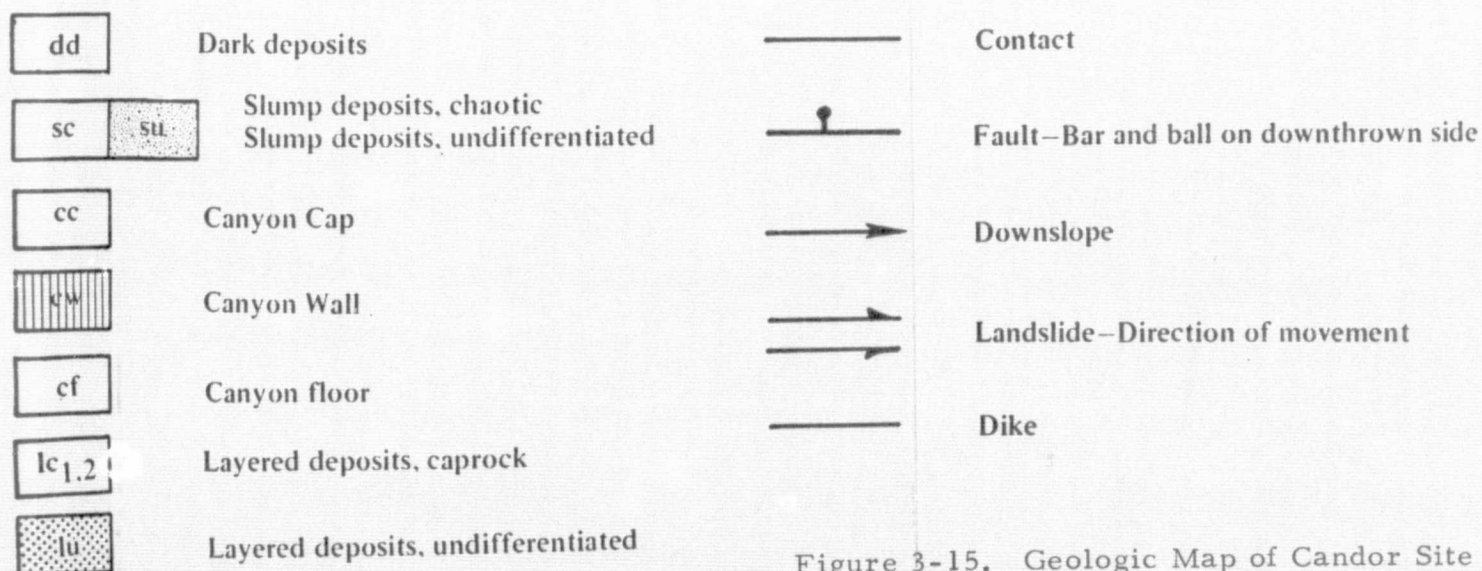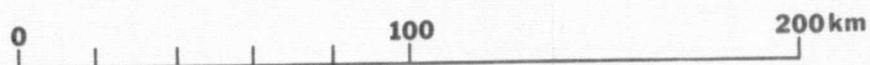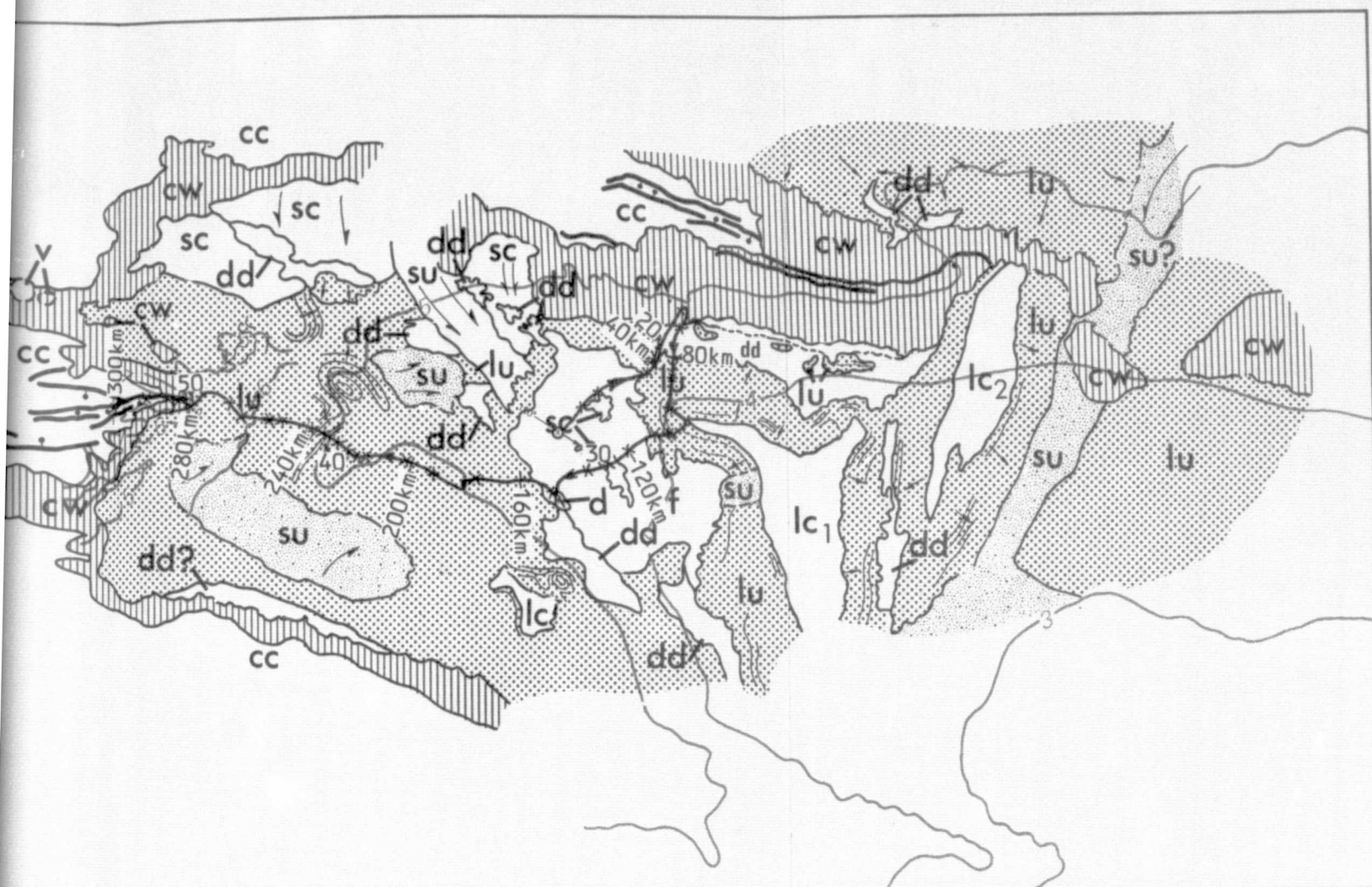
Figure 3-15. Geologic Map of Candor Site on Mars
(Proposed Rover Traverse-1984)

Legend:

dd	Dark deposits
sc / su	Slump deposits, chaotic / Slump deposits, undifferentiated
cc	Canyon Cap
cw	Canyon Wall
cf	Canyon floor
lc₁,₂	Layered deposits, caprock
lu	Layered deposits, undifferentiated

Contact

Fault—Bar and ball on downthrown side

Downslope

Landslide—Direction of movement

Dike

AN INTEGRATED MULTIPLE-MISSION STRATEGY

The Martian environment is the most Earth-like of all the other planets and this, coupled with relative accessibility, has established Mars as the focus of NASA's planetary exploration program. Systematically, one mission has led to the next in a continuing saga that has both science merit and wide public appeal. Just as the Mariner 6, 7 and 9 missions provided a science rationale, an engineering model and also detailed landing site data for Viking, so Viking will provide a similar basis for a Mars 1984 mission.

The contribution that Viking can make is not yet completed since all four spacecraft continue to operate. Orbital imaging data (both high resolution and synoptic, multispectral images) are being returned at an undiminished rate and will allow an assessment of both science value and surface roughness of potential 1984 sites. The Viking orbiters and landers have already imaged and made meteorological measurements during two global-scale dust storms around perihelion (reassuringly, the measured surface wind velocities were not unduly great at either northern site -- the skies at the sites were evidently darkened by material carried aloft from the south). The Viking landers may actually still be returning data at the time the 1984 spacecraft arrive at Mars and could provide wind data that might allow the landing date to be moved forward, reducing the planned period of delay in orbit. Furthermore, the landers could add two more sites to the meteorology network.

Planetary quarantine requirements are important for all Mars missions since the lowest permissible orbital altitudes are constrained and heat sterilization adds cost and risk to lander development. Such sterilization also prohibits the use of certain components and instrument detectors. The Viking data on the surface environment will allow a re-evaluation of planetary quarantine requirements and, possibly, an easing of constraints. Looking further ahead in the Mars exploration program, the next step after the 1984 mission is recognized to be a Mars Sample Return (MSR) Mission. As with the lunar samples the talents of the worldwide scientific community can be brought to bear using the latest techniques (even ones yet to be invented). Delicate and complex procedures can be employed to provide an absolute chronology for Martian events, definitively tying together terrestrial, lunar and Martian history. Samples can be minutely dissected and both their principal and trace

mineral constituents analyzed in depth. The 1984 orbiters will make a geo-chemical survey of Mars for the selection of 1990 MSR landing sites. The science potential of such a powerful mission can only be realized if the returned samples have been rationally selected from a broad area containing a variety of units. Both mobility and advanced manipulative skills will be needed to collect the samples, a technology developed for the 1984 rovers. Although ambitious in concept, we believe that consideration should be given to using the 1984 rovers to collect the samples for later return. The great advantage is that the 1984 mission will have the time and opportunity to study many samples and retain a critical selection. This could much simplify the later mission. Clearly, a rendezvous technique, perhaps based on a homing transponder, would need to be incorporated in the 1984 rovers. Both the MSR and the 1984 mission would be enormously enhanced by this interaction as the calibration of the 1984 data set would allow the complete reassessment of the earlier data.

The 1984 mission could have further implications for an MSR mission. The integrity of the samples, for both geological and biological analyses, can only be preserved if they do not undergo heat sterilization as a part of a quaran-tine procedure. Therefore, other elaborate quarantine procedures are envisaged, implying great cost and complexity. In spite of extensive quarantine precautions there still may be vocal opposition to the return of Martian samples if no more data than that of Viking are available to define the extent of the problem. The 1984 mission promises to provide a much improved definition of the Martian environment, both at and below the surface. Moreover, the observations will be made over a much broader area, providing much greater confidence in the general validity of the data. The 1984 data can, if no organics are detected, allay contamination fears and can also assist in the specification of appropriate quarantine levels.

On these grounds, we believe that the mission outlined in this report not only promises to significantly advance our understanding of Mars, and the solar system in general, but also that the mission fits logically into the uniquely exciting Mars exploration program.

COST AND SCHEDULE

Cost estimates for the 1984 Mars Mission have been prepared for submission to NASA by JPL and Ames Research Center staff assigned to this preproject activity. The example science payloads developed by the MSWG were used to develop the systems requirements. The experiment costs along with the systems costs were estimated using several costing methods. It should be emphasized that the cost estimating and review process is a preproject activity under the cognizance of JPL with ARC support and not a function of the MSWG. The process has been conducted in parallel with the MSWG study.

The resulting costs from this effort are clearly of interest to the members of the MSWG since the members have opinions regarding the value of the proposed scientific investigations and the resulting mission cost. The preproject team imposed a number of constraints upon the design definition activities in an effort to provide the lowest reasonable cost. The estimate costs were reviewed in detail by a NASA Headquarters Cost Review Committee on 23 June 1977 and development risk assessments in their findings have been included. A second review took place on 15 July 1977. The constraints to provide low costs include but are not limited to the following:

1. Maximum application of NASA standard subsystems and components.

2. Required use of existing flight qualified designs that meet system requirements.

3. Planning of mission operations to be conducted over at least a two year period of Mars surface operations. One or two day delays to recover from unexpected situations represent a small portion of the planned mission when compared to the standard 60-90 day Viking prime mission surface operations.

4. Significant application of the proposed NASA standard unified distributed data system using standard microprocessors to interface with each instrument; this concept allows for more flexible action by each investigation team.

The schedule for the 1984 Mars Mission is shown on Figures 3-16 and 3-17. The project is planned as a new project start for FY 1979. Several items of significance to science are listed on lines 8 and 9 of Figure 3-16. Funds have
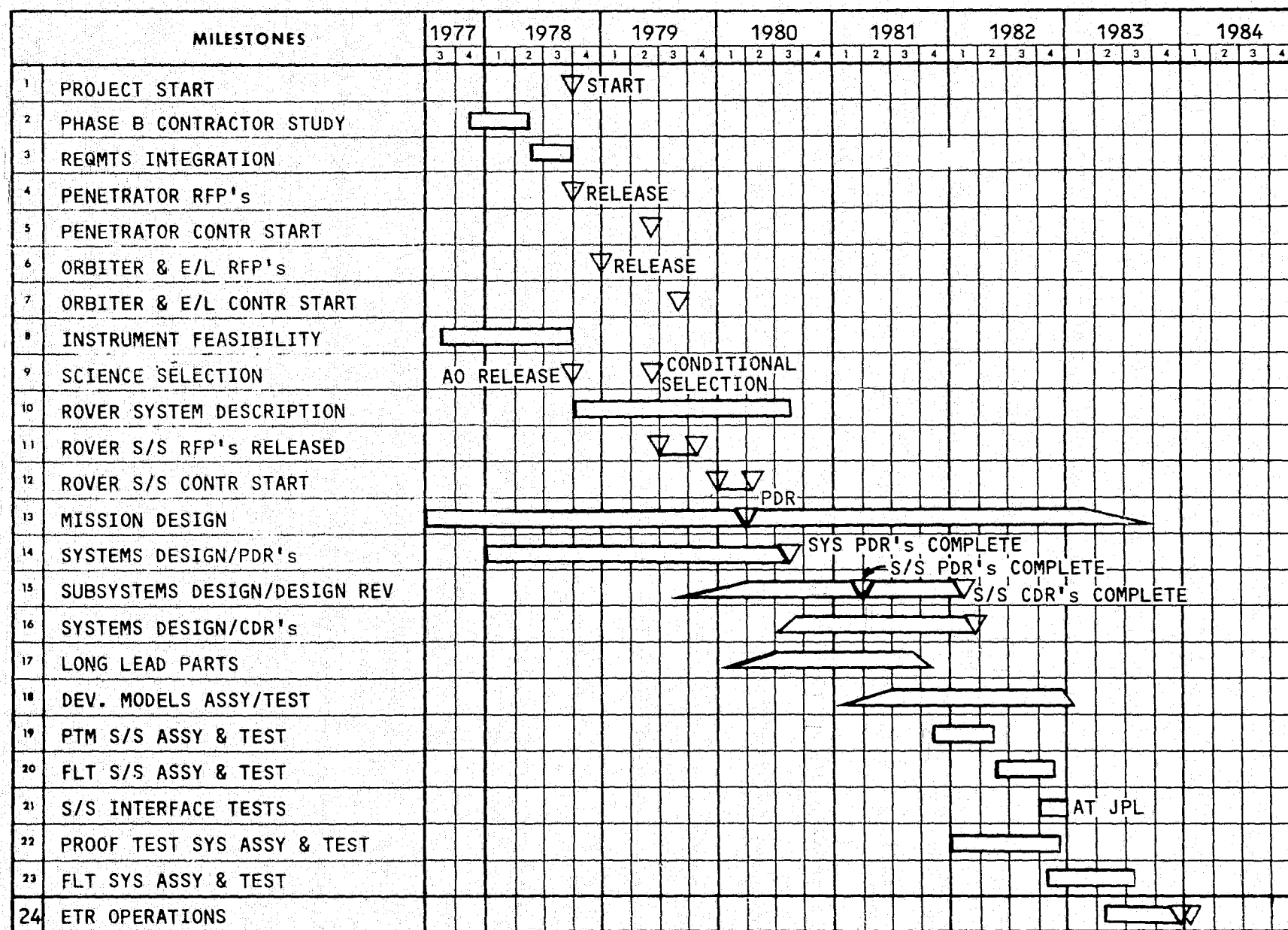
Figure 3-16. Mars 1984 Mission Master Schedule.

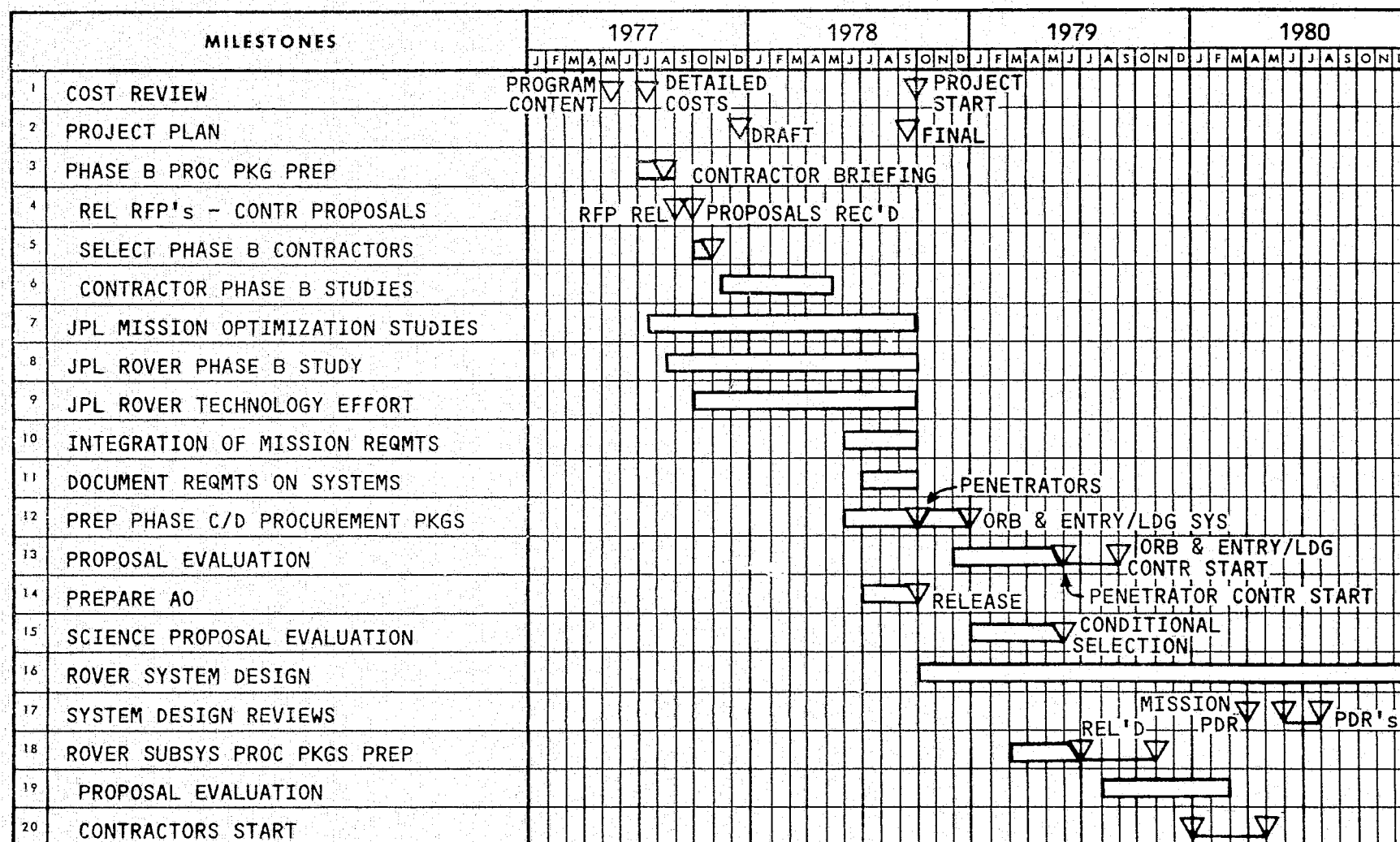| MILESTONES	1977	1978	1979	1980
	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D
1 COST REVIEW	PROGRAM ▽ ▽ DETAILED CONTENT COSTS		▽ PROJECT START	
2 PROJECT PLAN		▽ DRAFT	▽ FINAL	
3 PHASE B PROC PKG PREP	▽ CONTRACTOR BRIEFING			
4 REL RFP's – CONTR PROPOSALS	RFP REL ▽ PROPOSALS REC'D			
5 SELECT PHASE B CONTRACTORS	▽			
6 CONTRACTOR PHASE B STUDIES				
7 JPL MISSION OPTIMIZATION STUDIES				
8 JPL ROVER PHASE B STUDY				
9 JPL ROVER TECHNOLOGY EFFORT				
10 INTEGRATION OF MISSION REQMTS				
11 DOCUMENT REQMTS ON SYSTEMS		PENETRATORS		
12 PREP PHASE C/D PROCUREMENT PKGS		▽ ▽ ORB & ENTRY/LDG SYS		
13 PROPOSAL EVALUATION			▽ ▽ ORB & ENTRY/LDG CONTR START	
14 PREPARE AO		▽ RELEASE	PENETRATOR CONTR START	
15 SCIENCE PROPOSAL EVALUATION			▽ CONDITIONAL SELECTION	
16 ROVER SYSTEM DESIGN				
17 SYSTEM DESIGN REVIEWS			MISSION ▽ ▽ ▽ PDR's REL'D PDR	
18 ROVER SUBSYS PROC PKGS PREP			▽ ▽	
19 PROPOSAL EVALUATION				
20 CONTRACTORS START			▽ ▽	

Figure 3-17.   Mars 1984 Project Initiation Schedule.

been allocated to support feasibility demonstration of potential experiments prior to the time that the Announcement of Opportunity is released in October 1978. As a result it is hoped that more effective advanced instruments will be proposed for the 1984 Mars Mission. Following selection of experimenters for the mission, a Science Steering Group will be formed made up of the team leaders and principal investigators to provide science guidance to the Project.