N87-17768

PLANETARY SCIENCE QUESTIONS FOR THE MANNED EXPLORATION OF MARS

Douglas P. Blanchard
NASA Johnson Space Center
Houston, TX

ABSTRACT

A major goal of a manned Mars mission is to explore the planet and to investigate scientific questions for which the intensive study of Mars is essential. The systematic exploration of planets has been outlined by the National Academy of Science. The nearest analogy to the manned Mars mission is the Apollo program and manned missions to the Moon, but the analogy is limited. The case is argued here that Mars may have to be explored far more systematically than was the pre-Apollo Moon to provide the detailed information necessary if we plan to use any of the resources available on Mars. Viking missions provided a wealth of information, yet there are great gaps in our fundamental knowledge of essential facts such as the properties of Martian surface materials and their interaction with the atmosphere. Building on a strong data base of precursor missions, human exploration will allow great leaps in our understanding of the Martian environment and geologic history and its evolutionary role in the solar system.

INTRODUCTION

The exploration of the planets is among the most exciting and challenging endeavors of science and the human curiosity. The ability to send spacecraft to other bodies of the solar system is a recent development in human history. Surely the astronomers of many centuries ago would be envious of our opportunities.

A major stated goal of a manned Mars mission is to explore the planet and to investigate scientific questions for which the intensive study of Mars is essential. The orderly exploration of the solar system proceeds within a logical framework which has been carefully debated and is well documented.[1,2,3,4] But, that logical plan for the orderly exploration of the Moon and the planets and their moons can be disrupted by external events and budgetary contingencies. Still, for whatever the reason we are allowed to follow our fancy to Mars, the fundamental scientific problems and questions should be kept in the forefront of our planning. This mission is an integral part of the overall strategy for the study of Mars, building on the knowledge from preceding missions and forming the foundation for subsequent missions.

This paper will look at the logical plan for planetary exploration and compare that to a sketch of the exploration of the moon which culminated in the landing of twelve men on the Moon's surface. It will look at what we have learned from previous missions to Mars and discuss some of the specific scientific priorities for the exploration and study of Mars.

THE PLANETARY EXPLORATION MODEL

> The primary scientific goals in exploring the solar system are to determine the composition, structure, and environment of the planets and their satellites in order to define the present morphology and dynamics of the solar system and with the purpose of making major steps in understanding the processes by which planets formed from the solar nebula and how they evolved with time and how the appearance of life in the solar system is related to the chemical history of the system. The investigation of the interplanetary and interstellar medium is considered an intrinsic part of such an endeavor.
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> Space Science Board 1975[1]

Models for the exploration of the planets have been presented by the SSB (Space Science Board of the National Academy of Sciences)[1,3] and Complex Committee on Planetary and Lunar Exploration[2] of the Space Science Board. The models identify three stages in the unmanned exploration of any planetary body: (1) Reconnaissance stage of flyby and hard lander missions; (2) Exploration stage of orbiter and entry probe missions; and (3) Intensive study stage of soft landers and sample returns. Missions involving humans represent a special case of intensive study as well as an advanced stage in themselves.

The solar system exploration strategy as stated by the SSB[1] follows the principle that the overall exploration of the solar system should advance more or less evenly for all of the planets, sending "reconnaissance" missions to all of the planets before we move into the "exploration" and "intensive study" of any of them. The principle is admittedly tempered by the technical difficulty of even the most rudimentary mission to distant outer planets. Consequently, the plan calls for advancing the exploration of selected inner planets while continuing the reconnaissance of the outer planets. A manned mission to Mars is a significant anomoly to this orderly exploration plan. The decision to undertake this mission will be made on many considerations in addition to purely scientific issues.

MANNED PLANETARY EXPLORATION BASED ON THE LUNAR EXPERIENCE

Human events and budgets affect the orderly course of planetary exploration. The Apollo program of lunar exploration is an example in which political events strongly influenced both the objectives and the pace. It is likely that the commitment to send humans to explore Mars will have much in common with the commitment to send humans to explore the Moon. It may be fruitful to examine the lunar exploration experience for lessons that can be applied to the manned mission to Mars.

The race to the Moon was conducted by the U.S. and U.S.S.R. along roughly equivalent developmental paths (Tables 1 and 2). Both programs progressed through the reconnaissance phase using flybys and hard landers, and through the exploration phase with orbiters and soft landers. Finally, the U.S.S.R. returned samples with three automated landers, and the U.S. returned samples and explored the Moon with six landing teams.

The exploration stage of lunar science was truncated by the political urgency to land men on the Moon before 1970. As a result, we still do not have high quality global maps nor do we have global mineralogical and chemical data. In some respects we have more complete global coverage of Mars than we do of the Moon because of the extended coverage of Mariner 9 and the two Viking orbiters. Only now, with attention returning to the Moon and with a lunar base a possibility, is a more systematic exploration of the whole Moon getting started with the proposed Lunar Geochemical Observer (LGO).

There are important lessons to be learned from the Apollo experience. Scientifically and developmentally, the Apollo missions were an anamoly. As long as the Apollo missions were totally self-sufficient and the objectives of the missions were primarily engineering objectives, there was little need for more detailed exploration. A lunar base will not be a totally self-sufficient system. It will need to use some of the resources available on the Moon. As a result, there is a need to resume the detailed global exploration of the Moon with LGO and to follow with

TABLE 1

PROFILE OF LUNAR EXPLORATION

YEAR	MISSION	FLYBY	HARD LANDING	ORBITER	SOFT LANDING	RETURN	MANNED FLYBY/ ORBITER	MANNED LANDING	COMMENTS
1959	Luna (2)	1	1						
o									
o									
o									
1964	Ranger (1)		1						
1965	Ranger (2)		2						
	Zond (1)	1							
1966	Luna (5)			3	2				
	Lunar Orbiter (2)			2					
	Surveyor (1)				1				
1967	Explorer (1)			1					
	Lunar Orbiter (3)			3					
	Surveyor (1)				2				
1968	Apollo (1)						1		
	Surveyor (1)				1				
	Zond (1)	1				X			
1969	Apollo (3)			1			1	2	
	Zond (1)			1		X			
1970	Apollo (1)						1		
	Luna (2)				2	X			One Rover
1971	Apollo (2)							2	One Rover
	Luna (1)			1					
1972	Apollo (2)							2	Both Rovers
	Luna (1)				1	X			
1973	Luna (1)				1				Rover
o									
o									
o									
1976	Luna (2)				1	X			
o									
o									
o									
199X	LGO								

TABLE 2

PROFILE OF MARTIAN EXPLORATION

YEAR	MISSION	FLYBY	HARD LANDING	ORBITER	SOFT LANDING	RETURN	MANNED FLYBY/ ORBITER	MANNED LANDING	COMMENTS
1965	Mariner	1							
o									
o									
o									
1969	Mariner	2							
o									
o									
o									
1971	Mariner			1					
	Mars (2)		2	2					Landers Failed Orbiters Failed
o									
o									
o									
1973	Mars (4)			4	1				One Orbiter Failed One Lander Missed
o									
o									
o									

1992	MGCO			X					
1996?	Sample Return				X	X			
?	Russian Mars Probe			?	?	X	X ?		
o									
o									
o									
?	Manned Mars Mission			X	X	X	X	X	

intensive study of selected areas, with possibly automated sample returns.

The exploration phase for Mars may have to be far more systematic and thorough than was the pre-Apollo exploration of the Moon. The thoroughness of the prelanding exploration will depend on the extent to which the proposed manned Mars mission will use systems that depend on being recharged using locally available resources on the Martian surface. The Mars manned exploration scenario is made somewhat simpler if it can regenerate at least some of its simpler systems at Mars. To enable any such simplification, we will need a detailed knowledge of the Martian surface and certain knowledge of the regions of Mars that will have proven resource potential. The pace of Martian exploration may be somewhat slower than was possible for the Moon because of the infrequent opportunities and the technical difficulty. Nevertheless, as evidenced by Mariner and Viking orbiters, well planned capable precursor missions such as those planned for the observer class missions of the planetary exploration program can add immensely to our knowledge base.

OUR PRESENT KNOWLEDGE OF MARS

The reconnaissance stage of the exploration of Mars was accomplished by the Mariner flyby missions of the 1960's and Mariner 9 Mars orbiter in 1971. After several unsuccessful Russian attempts to visit the planet, the U.S. continued systematic exploration with the Viking landers and orbiters in the late 1970's. With the data from these exploratory missions, our understanding has progressed to the level to support the beginning of the detailed exploration of the planet.

With Viking, a more intensive investigation of Mars began. It was discovered that there are only very low levels of hydrocarbons and no direct evidence of life(4) (Table 3). The tenuous atmosphere is depleted in nitrogen and generally enriched in the heavy isotopic species of the atmospheric gases. We have only the simplest idea of the composition of the materials on the Martian surface(5) (Table 4). The polar caps appear to have permanent water ice and seasonal carbon dioxide ice. Water, while present in the atmosphere, is present only in small amounts. A major scientific question is the evolution and fate of the Martian atmosphere and the history of the volatiles(5) (Table 5).

TABLE 3

VIKING MARS SCIENCE HIGHLIGHTS

-- No definite evidence for biological activity in soil, despite unusual chemical reactions produced in life detection experiments.

-- Surface rocks resemble basalt; surface chemistry resembles altered basalt.

-- Polar cap in North made largely of water ice, with lesser amounts of solid carbon dioxide.

-- Isotope ratios of carbon and oxygen in the atmosphere resemble those in the Earth's atmosphere.

-- Loss of nitrogen to space has produced isotopic ratios on Mars that are different than those on Earth; the heavy isotope of nitrogen (^{15}N) has been preferentially retained.

-- Abundant erosional channels on surface suggest that Mars could have had a denser atmosphere in the past and may have had liquid water on its surface.

-- Noble gas abundances (Ar and Ne) suggest that Mars has a lower volatile content than either Venus or Earth.

-- Red color on the surface is due to oxidized iron.

-- Soil is fine grained and cohesive, like firm sand or soil on Earth.

-- Water compounds and sulfur compounds are present in soil.

-- Small-scale land forms formed by aeolian (wind) processes.

-- Typical surface temperatures range from about -84^{o} C at night to -29^{o} C in the afternoon.

-- Surface pressure of the atmosphere (only 0.8 percent of the Earth's) varies seasonally in accordance with the sublimation of the polar caps.

-- Martian moons (Phobos and Deimos) are grooved, indicating that incipient fracturing has occurred; they are heavily cratered and may be captured asteroids.

TABLE 4

COMPOSITION OF MARTIAN SURFACE MATERIALS[5]

	CHRYSE FINES	CHRYSE DURICRUST	CHRYSE DURICRUST	UTOPIA FINES	ESTIMATED ABSOLUTE ERRORS
SiO_2	44.7	44.5	43.9	42.8	5.3
Al_2O_3	5.7	n/a	5.5	n/a	1.7
Fe_2O_3	18.2	18.0	18.7	20.3	2.9
MgO	8.3	n/a	8.6	n/a	4.1
CaO	5.6	5.3	5.6	5.0	1.1
K_2O	<0.3	<0.3	<0.3	<0.3	
TiO_2	0.9	0.9	0.9	1.0	0.3
SO_3	7.7	9.5	9.5	6.5	1.2
Cl	0.7	0.8	0.9	0.6	0.3
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SUM	91.8	n/a	93.6	n/a	

TABLE 5

COMPOSITION OF ATMOSPHERE AT MARTIAN SURFACE[5]

Carbon dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon monoxide	0.07%
Water vapor	0.03%
Neon	2.5 ppm
Krypton	0.3 ppm
Xenon	0.08 ppm
Ozone	0.03 ppm

ISOTOPE RATIOS

RATIO	EARTH	MARS
C^{12}/C^{13}	89	90
O^{16}/O^{18}	499	500
N^{14}/N^{15}	277	165
Ar^{40}/Ar^{36}	292	3000
Xe^{129}/Xe^{132}	0.97	2.5

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MARS SCIENCE GOALS AND PRIORITIES

COMPLEX(2) divides the strategies for the exploration of the inner planets into two groups, one for bodies without atmospheres and one for bodies with atmospheres. Their recommendation was to make the triad of planets with atmospheres the focus of the exploration attention in the period of 1977-1987.

The three planets Earth, Venus, and Mars were seen by COMPLEX to represent a "natural experiment in planetary evolution." The first experiment produced Earth with its abundant volatiles and free water in the oceans and atmosphere. Water on the Earth plays a central role in the morphology of the planet and in the origin and sustenance of life. The second experiment produced Venus. Venus has been nearly completely degassed but has very little water in its atmosphere. Presumably, many of the light volatiles, including water, have been lost to the intense heating that characterizes the Venus surface. Mars is the product of the third experiment. Mars has lost much of its atmosphere but has not been thoroughly degassed as a planet. Substantial amounts of liquid water have clearly played a role in the formation of the surface morphology of the Martian surface, yet no liquid water is known to exist on the surface today (and probably none has been on the surface since very early in the planet's evolution). Is Venus a more thoroughly evolved Earth? Has Mars been cut short in its evolution and does it still retain the potential to develop into an Earth-like planet that in some future era may also be hospitable to life?

The science objectives for the study of Mars in the post-Viking era are primarily geological and geophysical. With the first order knowledge that present life on Mars is unlikely, the objectives for further study are defined by the need for primary information about the planet Mars and its atmosphere which is essential to understand its place in the evolution of the solar system. This same information is important in the debate over the probability of past life on Mars. After the Earth, Mars is the next-most-likely planet for the support of life. Although the essential elements for life are present, no proof of present life has been forthcoming.

Careful studies of the surface materials and the evidence therein for interactions between the atmosphere and the Martian surface may prove extremely valuable for understanding the evolution of the Martian atmosphere. Precise dating of the surface rocks and soils will allow the major geologic processes to be put into chronological sequence. Stratigraphy of carefully recovered cores and samples from layered deposits will give insight into the more recent effects of geological processes and the nature of the processes themselves.

A list of science objectives has been assembled by the Solar System Exploration Committee (SSEC)[4] for the exploration of Mars. The list (Table 6) defines the basic science tasks on Mars. Many of the tasks require global perspective and are appropriate for precursor orbiters and soft landers. Other tasks are clearly appropriate for and could benefit greatly from the human presence on the surface of Mars. The missions to Mars defined for the NASA Core Program of Planetary Missions address the objectives for global exploration of Mars. Mars Geochemical Climatological Orbiter (MGCO) will gather data on the global chemistry and the global atmospheric circulation. The Mars Aeronomy mission will explore the intricacies of the upper atmosphere and its interaction with the solar wind. The Mars Network Mission will collect fundamental geophysical information on the planet as well as surveying the composition of surface material and taking meteorological data using multiple penetrators and their surface stations.

Clearly, the intensive study of the local materials is the area of science most greatly aided by the presence of human explorers. The global scale objectives are best done with orbiting instruments and observers, but they too are greatly aided by having "ground truth" established for them by human explorers.

CONCLUSIONS

Comparison of the Apollo and manned Mars missions leads to the conclusion that their analogy is a limited one. We will need to do a far more thorough exploration of Mars at a global level and intensive study at a local level before we launch a manned mission than was done for the Apollo missions. The chief discriminator is the need to depend on any of the Martian resources as an essential element of the manned Mars mission plan. While there is a good start in uncovering the mysteries of Mars, there are many fundamental pieces of information that are lacking, especially concerning the exact nature of the surface materials and their

TABLE 6

PRIMARY SCIENCE OBJECTIVES FOR THE EXPLORATION OF MARS[4]

-- Characterize the internal structure, dynamics, and physical state of the planet.

-- Characterize the chemical composition and mineralogy of surface and near surface materials on a regional and global scale.

-- Determine the interaction of the atmosphere and the regolith.

-- Determine the chemical composition, distribution, and transport of compounds that relate to the formation and chemical evolution of the atmosphere.

-- Determine the quantity of polar ice and estimate the quantity of permafrost.

-- Characterize the dynamics of the atmosphere at a global scale.

-- Characterize the planetary magnetic field and its interaction with the upper atmosphere and the solar wind.

-- Characterize the processes that have produced the landforms of the planet.

-- Determine the extent of organic chemical and biological evolution of Mars and explain how the history of the planet constrains these evolutionary processes.

-- Search for evidence of the signature of the early atmosphere in the ancient sediments.

interaction with the atmosphere. Manned exploration of Mars will be most helpful for the detailed understanding of these phenomena at various local areas of Mars.

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