N87-17762

EXOBIOLOGY ISSUES AND EXPERIMENTS AT A MARS BASE

Christopher P. McKay
NASA Ames Research Center
Moffett Field, CA

ABSTRACT

Research in Exobiology, the study of the origin, evolution and distribution of life in the universe, may be a major component of the science activities at a Mars Base. Exobiology activities would include: continuing the search for life on Mars; searching for evidence for ancient life from a warmer Martian past; research into the chemistry of the biogenic elements and their compounds; and other related activities. Mars provides a unique opportunity in Exobiology, both for immediate study and for long range and possibly large scale experimentation in planetary biology.

INTRODUCTION

The goal of Exobiology is to understand the origin, evolution, and distribution of life and life-related compounds on Earth and throughout the universe (DeVincenzi, 1984). To accomplish this goal, exobiological studies have been, and continue to be, carried out on missions to the other planets. Clearly Exobiology, as a scientific discipline, is inextricably tied to space and space missions.

Outside of the Earth, Mars has the most clement environment for biology in the solar system, and it naturally holds a particular fascination for exobiologists. It is not surprising that many opportunities for exobiological experiments exist within the context of a Mars Base. In fact, exobiology may be a major element of the Martian surface science activities conducted at a Base. However, a Mars base also focuses an important issue, of a fundamentally exobiological nature: the search for indigenous life on Mars. There will be strong pressure to conduct the search before humans land.

Humans add a new and vigorous dimension to the exploration of the surface of Mars, particularly in exobiology. For example, the presence of humans would ensure much better site selection and sample acquisition for exobiology investigations.

Equally important, the quality and quantity of scientific observation would be enormously increased.

The issues and opportunities for exobiology on Mars are discussed in this paper and the unique capabilities provided by humans on the surface are considered. The biological results of the Viking missions to Mars are briefly reviewed. The wealth of information obtained from the Viking missions generated a new set of questions and new lines of inquiry regarding exobiology and the question of the existence of life on Mars.

VIKING

In addition to the lander cameras, which would show the presence of any obvious macroscopic life-forms, the Viking landers contained three experiments specifically designed to search for indications of life on Mars:

1) The Gas Exchange Experiment (Oyama and Berdahl, 1977), designed to determine if martian life could metabolize and exchange gaseous products in the presence of a nutrient solution.
2) The Labeled Release Experiment (Levin and Straat,1977), which sought to detect life by the release of radioactively labeled carbon initially incorporated into organic compounds in a nutrient solution.
3) The Pyrolytic Release Experiment (Horowitz and Hobby, 1977), based on the assumption that martian life would have the capability to incorporate radioactively labeled carbon dioxide in the presence of sunlight (photosynthesis).

The results of all three experiments showed definite signs of chemical activity, but this was probably non-biological in origin (Horowitz, 1977; Klein, 1978, Mazur et al., 1978). In addition, the negative results of the Gas-Chromatograph/Mass-Spectrometer (GCMS) search for organic compounds places severe restrictions on the probability of life on Mars. The GCMS failed to detect organic material at levels less than parts per billion for heavy organics and parts per million for lighter ones (Biemann et al., 1977). It is relevant to note that these concentrations are considerably lower than would be found on the lunar surface. The conclusion seems to be that organics are not created but are actually destroyed on the surface of Mars. This is a strong indication that there is no life in the sands of Mars. The similarity of the elemental composition between the two Viking lander sites may be an indication that the top layers of martian regolith is a aeolian mantle of sand that has been reworked repeatedly (Carr, 1981). The Viking landers sampled in this mantle and conditions at greater depths may be different.

While in general finding no indication of the existence of life on Mars, the equivocal results of the biology experiments and the detection of all the elements necessary to support Earth-type life has led to much speculation concerning martian biology (Friedmann and Ocampo, 1976; Foster et al., 1978; Clark, 1979; Kuhn et al., 1979).

The properties of the Martian environment which seem most unfavorable to the sustenance of life are:

1) The general scarcity of water
2) The cold temperatures and extreme temperature variations which occur both diurnally and seasonally
3) Penetration to the surface of ultraviolet radiation between 190 and 300 nm and particle radiation
4) The apparent presence of strong oxidants in the soil
5) The low atmospheric pressure and, as a direct result, the exclusion of liquid water as an equilibrium state
6) The low concentration of nitrogen in the atmosphere and the apparent absence of nitrogen, in any form, in the top-regolith

With the possible exception of the final point, all of the unfavorable aspects of the Martian environment have sufficient variations such that any one of them can be eliminated by suitable site selection. Neither the Viking 1 nor the Viking 2 lander site was chosen based on this consideration.

CONTINUING THE SEARCH FOR LIFE

While the Viking missions gave us valuable insight into the biological potential on Mars, a more extensive search for extant Martian life forms needs to be done. The discovery of an indigenous Martian biota would profoundly effect the planning for a human presence on the planet's surface. An important question integral to any plans for a Mars Base program is: What steps and precursor missions should be undertaken to continue the search for life on Mars before humans land on the surface.

In approaching this question we must realize that the absence of life cannot be conclusively demonstrated by robotic missions, and possibly not by human biologists on the surface. The possibility that life could exist in an undiscovered cryptic niche will continually plague those who desire absolute answers from biology. The resolution of this dilemma will have to be in a two-step process. First, defining the biological impact of a localized human presence on Mars, and then determining what level of search is required to insure that any undiscovered cryptic Martian community of organisms is sufficiently well hidden that it is unlikely to be affected by such a presence.

Clearly, this approach points toward the necessity to understand the strategies of terrestrial organisms that occur in cryptic niches. As part of NASA's exobiological research effort, work in this area has been conducted with respect to the crypto-endolithic microbial communities of the Antarctic dry valleys (Friedmann, 1982; McKay and Friedmann, 1985). Studies of groups of organisms which grow in small depressions on glaciers, termed cryoconite holes, are also applicable (Wharton et al., 1985). Do these represent analogs for life in the present polar caps of Mars? Many other examples of cryptic life can certainly be found that would be applicable. By examining these communities on Earth we may be able to determine the relationship between the cryptic nature of a microhabitat and its degree of isolation from the environment. Often the very reason the organisms are in a cryptic niche is to isolate themselves from adverse environmental conditions. The more isolated a martian biological community is, the less likely it is to be affected by a human base.

The problem of searching for life on Mars with a rover or other sampling device is primarily centered around how to select the sample. It is probable that the development of artificial intelligence systems could result in a rover with the skills to navigate in rough terrain as well as a rudimentary form of biological and geological decision-making. The search for hidden life may require such sophistication, and preliminary studies should be started in the near future.

Once humans have landed, the search for extant life forms will certainly continue. Life is unique in that it is so diverse that it can only be loosely defined in terms of a set of attributes, rather than as a chemical or physical entity. Thus, human intelligence and the ability to make decisions, on the spot, could be critical for the recognition of Martian life forms, particularly as the search extends into environments beyond our terrestrial experience.

EARLY MARS

In looking at the profile of Mars drawn by the Viking results, it is hard to find any evidence that extant life forms exist on such a small, cold, dry planet. However, there is considerable evidence that at some time in the past, conditions on Mars were quite different. Large valley networks and outflow channels attest to the fact that copious amounts of liquid water once flowed on the martian surface (e.g. Carr, 1981). This in turn implies that the surface temperature was considerably warmer than it is today with concomitant high pressures. Some of these fluvial features occur in terrain that is heavily cratered, indicating that this warmer climatic regime probably dates back over four billion years (e.g. Carr, 1981).

This view is supported by theoretical considerations which suggest that during the first million years after the formation of Mars and Earth, the surface conditions of both planets were similar. During this time period, the atmospheric composition and pressure on these planets was determined primarily by outgassing of juvenile material and the surface may have been dominated by the processes of crust formation (e.g. Pollack and Yung, 1980). In fact, Earth, Venus and Mars may have all undergone initial periods of outgassing and crust formation that resulted in similar surface conditions on all three of the terrestrial planets. We know from the fossil record that life on Earth evolved and reached a fair degree of biological sophistication in the first 800 million years. The time interval was probably much shorter, but the absence of a suitable fossil record prevents that determination. It is entirely possible, then, that life also arose on Venus and Mars during an early clement epoch on these planets. Subsequent planetary evolution, however, seems to have favored only the Earth. The record of the origin and early evolution of life on Earth, and certainly on Venus, has been obscured by extensive surface erosion, while on Mars the situation is quite different and large fractions of the surface date back to this early time period (Carr, 1981). Hence, it is entirely possible that while no life exists on Mars today, it holds the best record of the chemical and biological events that led to the origin of life.

There are many areas in which a search for microfossils of an ancient martian biota could be conducted. One such area would be the valley networks that lace the ancient terrain and the bottoms of the outflow channels. Interesting lake sediments may exist on the floors of some of the martian equatorial canyons (Lucchitta and Ferguson, 1983). McKay et al. (1985) have shown that, similar to the Antarctic dry valley lakes, paleolakes on Mars could have extensive liquid water under a relatively thin ice cover, even under current cold martian conditions. Clearly, studies of these sediment beds, on site, by interdisciplinary teams of scientists could yield detailed information on past Martian biota.

THE BIOGENIC ELEMENTS

In addition to the search for life and past life, a goal of exobiology on Mars will certainly be to study the distribution and evolution of the biogenic elements (C,H,N,O,P,S) and compounds (e.g. water, carbon dioxide). The cycling of these elements is key to the sustenance of a biosphere. Even in the absence of life, studies of these cycles will provide a point of comparison and contrast for the biogeochemical cycles of these elements on Earth.

Information on the global scale cycling of the biogenic elements can be collected, to a large extent, by robotic observer spacecraft. It is the collection of more specific information on fine scale gradients, isotopic variations, and elemental ratios that would be greatly facilitated by a human presence. Such detailed studies might be required in areas with interesting mineralogy or salt composition. Interesting mineral phases, such as clay, may play an active role in processing the biogenic elements and compounds. Areas of rich salt concentration may be sites of enhanced water activity (Huguenin, et al., 1979). The study of this natural cycling of biogenic material would be useful in establishing the role of abiotic synthesis in the origin of life on Earth.

Planetary evolution and the interaction of global reservoirs of volatiles is an area of interest for the study of the evolution of life on planetary surfaces. If life did originate on Mars and subsequently became extinct, this event may be associated with changes in the cycling of the biogenic elements. Evidence for such changes may still be present in terms of the detailed elemental and isotopic structure of the layered terrain. Relatively recent information on the global cycles of carbon dioxide and water on Mars may be obtained from studies of the polar laminated terrain.

DISCUSSION

As one of the four main goals of planetary exploration through the year 2000, the Solar System Exploration Committee included the following, "Understand the relationship between the physical and chemical evolution of the solar system and the appearance of life" (SSEC, 1982). Studies of the surface of Mars can contribute to this goal. Many of the key research areas are dependent upon a human presence and a continually operated Mars Base.

Specific areas in which exobiological investigations on Mars would greatly benefit from, and possibly require, a human presence include:

1) Search for extant life
2) Search for evidence of ancient life
3) Examination of the chemistry of the biogenic elements and their compounds
4) Study the environmental parameters associated with each of the above
5) In situ exobiology experiments.

Exobiological investigations on Mars that would benefit from, but not require, a human presence include:

1) Observational Exobiology (e.g. studies of biogenic elements in the interstellar medium via VLBI techniques)
2) Interplanetary and interstellar dust collection for studies of the biogenic elements in primordial matter

In addition, a human base on Mars could serve as a springboard for exobiological research in the outer solar system. The research into the adaptive strategies of terrestrial organisms and an extensive understanding of the geochemical cycles on Mars may also lay the foundation for large scale exobiological experiments on Mars investigating the prospects for planetary ecosynthesis (Averner and MacElroy, 1976). It is the human component of the Mars Research Base that motivates these long term goals.

REFERENCES

1. Averner, M.M and R.D. MacElroy (1976) On the habitability of Mars: an approach to planetary ecosynthesis. NASA Spec. Publ. 414.
2. Biemann, K., J. Oro, P. Toulmin, III, L.E. Orgel, A.O. Nier, D.M. Anderson, P.G. Simmonds, D. Flory, A.V. Diaz, D.R. Rusbhneck, J.E. Biller, and A.L. LaFleur (1977) The search for organic substances and inorganic volatile compounds in the surface of Mars. J. Geophys. Res. 82, 4641-4658.
3. Carr, M. (1981) The Surface of Mars. Yale Univ. Press, New Haven, Conn.
4. Clark, B.C. (1979) Solar-driven chemical energy source for a martian biota. Origins of Life 9, 241-249.
5. De Vincenzi, D.L. (1984) NASA's exobiology program. Origins of Life 93-799.
6. Friedmann, E.I. and R. Ocampo (1972) Endolithic blue-green algae in the dry valleys: Primary producers in the Antarctic cold desert ecosystem. Science 193, 1247-1249.
7. Friedmann, E.I. (1982) Endolithic microorganisms in the Antarctic cold desert. Science 215, 1045-1053.
8. Foster, T.L., L. Winans, R.C. Casey, and L.E. Kirschner (1978) Response of terrestrial microoganisms to a simulated martian environment. Appl. Eviron. Microbiol. 35, 730-737.
9. Horowitz, N.H. (1977) The search for life on Mars. Scientific American, November 1977, 52-61.
10. Horowitz, N.H. and G.L. Hobby (1977) Viking on Mars: The carbon assimilation experiments. J. Geophys. Res. 82, 4659-4662.
11. Huguenin, R.L., K.J. Miller, and W.S. Harwood (1979) Frost-weathering on Mars: Experimental evidence for peroxide formation. J. Mole. Evol. 14, 103-132.
12. Klein, H.P. (1978) The Viking biological experiments in Mars. Icarus 34, 666-674.

13. Kuhn, W.R., S.R. Rogers, R.D. MacElroy (1979) The response of selected terrestrial organisms to the martian environment: A modeling study. Icarus 37, 336-346.

14. Levin, G.V. and P.A. Straat (1977) Recent results from the Viking Labeled Release Experiment on Mars. J. Geophys. Res. 82, 4663-4667.

15. Lucchitta, B.K. and H.M. Ferguson (1983) Chryse basin channels: Low gradients and ponded flows. J. Geophys. Res. 88, 553-568.

16. Mazur, P., E.S. Barghoorn, H.O. Halvorson, T.H. Jukes, I.R. Kaplan and L. Margulis (1978) Biological implications of the Viking mission to Mars. Space Sci. Rev. 22, 3-34.

17. McKay, C.P. and E.I. Friedmann (1985) The cryptoendolithic microbial environment in the Antarctic cold desert: Temperature variations in nature. Polar Biol. 4, 19-25.

18. McKay, C.P., G.D. Clow, R.A. Wharton, Jr., and S.W. Squyres (1985) Thickness of ice on perennially frozen lakes. Nature 313, 561-562.

19. Oyama, V.I. and B.J. Berdahl (1977) The Viking gas exchange experiment results from Chryse and Utopia surface samples. J. Geophys. Res. 82, 4669-4676.

20. Pollack, J.B. and Y. L. Yung (1980) Origin and evolution of planetary atmospheres. Ann. Rev. Earth Planet. Sci. 8, 425-487.

21. Solar System Exploration Committee (1983) Planetary Exploration Through the Year 2000. U.S. Government Printing Office, Washington, D.C.

22. Wharton, R.A., Jr., C.P. McKay, G.M. Simmons, Jr., and B.C. Parker (1985) Cryoconite holes on glaciers. Biosci 35, 499-503.