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Mars after the Viking Missions: Is Life Still Possible?

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The results of the biology and organic chemistry experiments carried aboard the Viking landers seem to rule out the possibility of life on Mars. However, we present a possible model of Martian ecology which is based on the premise that Martian life could be endolithic, and thus missed by the Viking biology experiments. This model is based, in part, on the endolithic microbiota found in the dry valleys of Antarctica. In addition, we combine our model with a previously described model which suggests that Mars may go through ice ages and periods of relatively mild climate. © 1991 Academic Press, Inc.

INTRODUCTION

Since humans first viewed Mars through primitive telescopes, we have been fascinated by the red planet. In the heyday of pulp science fiction, hundreds to thousands of stories were written about the possible forms of life on Mars—usually hostile invaders with three eyes and dangling antennae or the like.

As science replaced science fiction, the speculated Martians appeared more benign. Microbes and higher plants became the most likely candidates as inhabitants of Mars (Vishniac *et al.* 1966). However, during the Viking program, no life was found (Huguenin 1982, Klein 1977, McKay 1986). The purpose of this paper is to review some of the conclusions drawn from the Viking program, to evaluate the possibility of life on Mars, and to provide a hypothetical model of Martian ecology which fits the currently known conditions on Mars.

THE MARTIAN ENVIRONMENT

Mars is a cold, dry planet with a very thin atmosphere. At the Viking landing sites in the Northern hemispheres, the daily high temperature rarely rose ~~about~~ above 245 K (Hess *et al.* 1977). However, in the equatorial region (−20° to +45° latitude), temperatures above 245 K occur routinely for most of the year (Ditteon 1982). Global dust storms cause much lower temperatures in the Southern hemisphere (Martin 1981). The temperature at the surface occasionally rose above 273 K at the Viking Lander 2 site (Moore *et al.* 1977). Surface temperatures exceed 273 K at midday during the summer between −70° and +30° latitude (Anderson *et al.* 1973, Carr and Schaber 1977).

The Martian atmosphere is very thin with a mean ambient pressure between 600 and 1000 Pascals (Pa) (Hess *et al.* 1977, Niver and Hess 1982). For comparison, Earth's mean atmospheric pressure is approximately 101,000 Pa. Mars' atmosphere consists mainly of carbon dioxide with small amounts of nitrogen, argon, and oxygen (Table I; Owen *et al.* 1977). Water vapor makes up only 0.03% of the atmosphere, but this small amount is often the saturation level for water, indicated by occasional ground ice fogs, ice haze, frost, and water clouds (Ditteon 1982, Farmer *et al.* 1977, Spitzer 1980). Because the Martian atmosphere has such a low pressure, the combination of temperature and pressure are usually below the triple point of water. Thus, liquid water is unstable on Mars. However, since the pressure at the surface and within the "soil" may occasionally exceed the triple point, liquid water may be stable for short times in localized areas (Moore *et al.* 1977).

Most of Mars' water is apparently locked up in the polar caps and in permafrost. Contrary to pre-Viking beliefs, the Martian polar caps consist mainly of water ice, not frozen carbon dioxide (Farmer *et al.* 1977, Moore 1977). Exposed ground ice would be stable at latitudes higher than 40°. At lower latitudes, ground ice would sublime into the atmosphere, but buried permafrost could still exist (Carr and Schaber 1977). Polygonal surfaces photographed by the Viking Orbiters offer possible evidence

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TABLE I
Composition of the Martian Lower Atmosphere

Component	Proportion
Carbon Dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon Monoxide	0.07%
Water Vapor	0.03% (varies)
Neon	2.5 ppm
Krypton	0.3 ppm
Xenon	0.08 ppm
Ozone	0.03 ppm

Note. Adapted from Owen *et al.* (1977).

of Martian permafrost (see Carr and Schaber 1977, and Spitzer 1980 for photos). The polygons observed by Viking are similar in shape to those found in terrestrial tundra environments, but the Martian polygons are on the order of 100 times larger than their terrestrial analogs. Water in the form of permafrost is estimated to penetrate to depths of several kilometers into the surface of Mars (Carr 1987, Carr and Schaber 1977).

In addition to water, the Martian surface and atmosphere also contain all of the major elements necessary for life (C, H, O, N, P, S), and other trace elements (Clark *et al.* 1982, Singer 1982, Toulmin *et al.* 1976, 1977). Most of the surface components are believed to be in an oxidized state (Toulmin *et al.* 1977).

VIKING BIOLOGY RESULTS

The Viking landers performed four different experiments which addressed the question of life on Mars (Table II): organic analysis, carbon assimilation/pyrolytic release, labeled release, and gas exchange experiments. Each of the experiments was designed to show the presence or absence of some form of biological activity. Additionally, the Vikings' cameras were used to search for signs of life.

TABLE II
The Viking Biological Experiments

Experiment	Purpose
Organic analysis	Search for organic materials in the Martian soil
C Assimilation/ pyrolytic release	Detect the synthesis of organic materials in the Martian soil
Labeled release	Detect heterotrophic respiration of ^{14}C-labeled nutrient broth
Gas exchange	Differentiate between biological and nonbiological gas production

The organic analysis experiment (Biemann 1979, Biemann *et al.* 1977) detected water and carbon dioxide, but no organic substances could be found at a precision of ng/g for large molecules and μg/g for small molecules. The data from carbon assimilation/pyrolytic release experiment (Horowitz *et al.* 1977) showed that carbon fixation occurred in the Martian soil under conditions similar to the ambient environment. Also, carbon fixation was inhibited, but not completely obliterated by heating the incubation vessel to 175°C for 3 hr prior to the experiment. At first, these results appeared to support the hypothesis of life on Mars, but the retention of some carbon-fixing activity after the 175° preincubation either precluded biogenic carbon fixation (Horowitz *et al.* 1977) or indicated that some other processes occurred as well. The labeled release experiment showed CO_2 production after the injection of ^{14}C-labeled nutrient broth into Martian soil samples. Furthermore, CO_2 production was reduced when the samples were heated to 50°C prior to nutrient injection, and did not occur when the sample was heated to 160°C for 3 hr. These results were consistent with biological respiration (Levin and Straat 1977). The gas exchange experiment's primary objective was to differentiate between biological and nonbiological production of gases. Repeated addition of water should cause decreased production of gases from physical or chemical phenomena (e.g., adsorption), whereas biological systems should produce steady or increasing amounts of gases (except in the case of obligate xerophiles). Upon humidification and nutrification, the Martian soil samples gave off O_2, N_2, CO_2, and Ar. The evolution of oxygen was thought to be due to the reaction of water with superoxides within the soil. Nitrogen and argon evolution was probably due to the release of adsorbed gases. Part of the carbon dioxide evolution may have been due to release from adsorption, but some may also have been due to oxidation of the injected organics by γ Fe_2O_3 in the soil samples (Oyama and Berdahl 1977).

Analyses of the photographs taken by Viking Lander 1 revealed greenish patches on some of the smaller rocks (reviewed by Levin and Straat 1986). In addition, the shape of the patches changed over long periods of time, and these changes could not be attributed to the actions of the Viking lander. Levin and Straat (1986) have suggested that the greenish color may be due to the presence of lichens within or on the rocks. When they photographed terrestrial lichen-bearing rocks in one of the Jet Propulsion Laboratory's Mars simulators, the resulting images were very similar to the photographs of the rocks in question on Mars. Color saturation analyses of the terrestrial and Martian rocks were also similar.

At the end of the Viking biology experiments, only the labeled release experiment and color saturation analysis showed any possibility of Martian microbial life (Klein *et al.* 1976, Klein 1977, Levin and Straat 1986). However, in 1982, Huguenin presented experimental evidence that a single chemical agent, probably a peroxide formed by long-term frost weathering, may have been responsible for the results of all Viking biology experiments (except color saturation). Seemingly, using the evidence of the Viking missions, there is no life on Mars. The results are, however, equivocal. Given that the conditions for life on Mars are marginal at best, a sample size of two is much too small to determine the habitation of the entire planet. The two Viking lander sites are probably not representative of the majority of the Martian surface (Jakosky and Christensen 1986). Also, the green patches observed on some Martian rocks have not been explained abiotically. And finally, the Viking landers may have been looking in the wrong places.

OLD MODELS AND NEW DISCOVERIES

The major problem in trying to construct models of the Martian environment on Earth is that there are no ecosystems on Earth equivalent to Mars. Considering the incredibly harsh Martian environment, the closest analog on Earth is probably the dry valleys of Antarctica. Starting in 1966, experiments pertaining to the microbiology and ecology of Antarctica were used in preparation for the search for life on Mars (Cameron *et al.* 1976). Like Mars, the Antarctic dry valleys are characterized by low temperatures, low precipitation, diurnal freeze–thaw cycles, high-velocity winds, high radiation, and high sublimation/evaporation rates. The soils of the Antarctic dry valleys support only a few microorganisms when compared to temperate areas (Cameron *et al.* 1976, Horowitz *et al.* 1972). Thus, at the time of the Mars missions, the Antarctic soils seemed to be the best model of Mars.

At the same time that the Antarctic research was starting, Vishniac *et al.* (1966) published a simple model of a speculated martian ecosystem. At the time of publication, oxygen had not been detected on Mars (the minimum detectable amount at the time was 2.5 Pa) so Vishniac's group speculated that life on Mars would be fermentative or use electron acceptors other than oxygen. However, they also stated that if oxygen existed at a partial pressure of 2.5 Pa, some organisms would be able to respire aerobically. This model also suggested that some of the primary production could occur by abiotic photochemical processes in addition to biological photosynthesis. Although not included in this model, other nutrient cycles on Mars could have photochemical pathways, too.

The Viking project revealed that photochemical carbon fixation does indeed occur. However, the organic analysis experiment did not detect any organic substances in the top few centimeters of the Martian soil. Therefore, any carbon fixed by abiogenic means must be quickly mineralized by oxidants in the soil. Since the Viking landers did not detect any life on Mars, the rest of this model seems meaningless. However, since the Viking landers could sample only the top few centimeters of soil, organic matter below the oxidizing soil layer could have been missed (Kanavarioti and Mancinelli 1990). Also as we stated before, the Vikings may have been searching in the wrong places.

At approximately the same time as the Viking probes were approaching Mars, a new, and very relevant discovery was made on Earth. Friedmann and Ocampo (1976) discovered the first known primary producers in the Antarctic dry valleys. They found cyanobacteria, not in the soil, but within the rocks. Since then, other endolithic microorganisms have been described: bacteria, fungi, algae, and lichens (Friedmann 1977, 1982, Friedmann *et al.* 1980, Siebert and Hirsch 1988). Based on the ecology of endolithic microorganisms and the previously described model, we will present two—not necessarily independent—models of possible Martian ecology.

THE ENDOLITHIC MARTIAN MODEL

In order to survive on Mars, organisms would have to have evolved adaptations which allow them to cope with extreme cold, diurnal freeze–thaw cycles, low atmospheric pressure, low pO_2, low water potential, high winds, and high levels of ultraviolet radiation. In the terrestrial Antarctic dry valleys, the endolithic organisms must cope with similar conditions, though to differing degrees (Friedmann 1982).

The aforementioned Antarctic endolithic communities reside within sandstone. Direct evidence of sandstone on Mars is lacking. However, much evidence exists for the possibility of lake bed sediments (reviewed by McKay 1986). While lakes still existed on Mars, some of these sediments may have been compressed to form sandstone and brought to the surface before Mars lost its tectonic activity. Also, there is abundant evidence of volcanic activity on Mars. Endolithic communities might form within porous volcanic rock, especially pumice. If this is the case, light penetration and other factors may be different than they are presented here. For the purposes of this paper, we are assuming that sandstone exists on Mars.

By living within porous rocks, endolithic biota are protected from desiccating winds. Also, the temperature within the life zone of the rock can be as much as 11°C warmer than the ambient temperature (Friedmann *et al.* 1987, McKay and Friedmann 1985, Nienow *et al.* 1988a). Some endolithic and epilithic lichens are capable of metabolism at temperatures as low as −8°C. The fungal components of the lichens also produce dark pigments

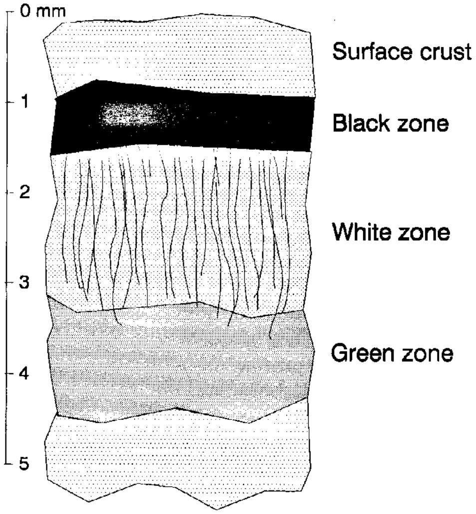

FIG. 1. Cross section of a typical endolithic community. The black zone contains lichenized algae and fungi. The white zone consists of free fungal filaments. The green zone is composed of free algae. Adapted from Friedmann (1982).

which aid in the conversion of sunlight to heat. Consequently, since the primary producers live within or below the pigmented layer (Fig. 1), the amount of light available for photosynthesis is greatly reduced. Light fluxes in the photosynthetic region range from 150 μM photons m^{-2} sec^{-1} at the top to 0.1 μM photons m^{-2} sec^{-1} (Nienow *et al.* 1988b). Because of the low light levels (often below the compensation point) within the rock, net carbon fixation should not occur. However, dark respiration does not occur since the temperature drops below $-8°C$ at night, halting all metabolism (Vestal 1988). Also, herbivory by animals is nonexistent (Friedmann 1982). Consequently, net fixation, though slight (2×10^{-11} to 1×10^{-10} mol C/cell/year) does occur (Nienow *et al.* 1988b).

On Mars, organisms in endolithic habitats would be at a distinct advantage. Wind speeds on Mars can exceed 15 m sec^{-1} (Hess *et al.* 1977). Microorganisms exposed to the wind would be quickly desiccated and/or blown away from nutrient sources (or possibly blown to new ones). Endolithic organisms would be protected from the wind, and windblown dust trapped in the rock pores could become a source of new nutrients (Ca, K, P, S, etc.). Pigments similar to those in Antarctic lichens could aid in keeping the temperature of the rock above freezing for a longer period of time. Also, pigments and rock could reduce the amount of UV radiation reaching the Martian organisms. Vishniac *et al.* (1966) speculated that some Martian microorganisms might have pigments which fluoresce in UV, giving off light which could be used for photosynthesis. While this is an intriguing thought, we are unable to provide a terrestrial analog. Hypothetically, a chlorophyll-containing organism could produce pigments which absorb UV and fluoresce at the wavelengths utilized by chlorophyll (red and blue).

Although CO_2 would probably not be limited in Martian endolithic communities, oxygen could very well be in short supply. The fungal components of lichens would have an advantage in that they have an immediate oxygen source: the lichenized algae. Procaryotic consortia similar to lichens could also exist. Besides oxygen, other molecules could be used as final electron acceptors. In terrestrial systems, some microbes use nitrates or sulfates as oxidizers (Atlas and Bartha 1987, pp. 333–346). The regolith of Mars is highly oxidizing, presumably due to adsorbed H_2O_2 (Huguenin 1982). On Earth, peroxides are poisonous to cells. However, terrestrial aerobic organisms have evolved enzymes which detoxify H_2O_2 by producing O_2 and H_2O (catalases) or by oxidizing organic compounds (peroxidases) (Boyd 1988, pg. 336). On Mars, organisms could use the O_2 produced by the action of catalase-like enzymes, or they could evolve a metabolism which uses a peroxidase-like enzyme to use H_2O_2 directly as an electron acceptor.

Both Mars and the Antarctic dry valleys lack liquid water. In the dry valleys, some precipitation occurs in the form of snow, but the snow offers minimal moisture. Most of the time, the dry valleys are precipitation free. Precipitation is even scarcer on Mars—mostly in the form of ice fogs or haze. However, some Antarctic endolithic lichens are capable of utilizing moisture from the air at 80–100% relative humidity (Hale 1983, pp. 50, 52); Martian microorganisms might be capable of similar feats. In addition, the endolithic environments of Antarctica have average relative humidities higher than the surrounding atmosphere (Friedmann *et al.* 1987). A similar phenomenon on Mars could further reduce moisture stress on hypothetical Martian microorganisms.

In addition to the problems of low precipitation and low water potentials, other problems arise when precipitation occurs and water potential increases suddenly. Many microorganisms accumulate amino acids or polyols within their cytoplasm in order to compensate for low environmental water potentials. When the environmental water potential suddenly increases (due to precipitation), an osmotic imbalance occurs between the cell and the environment, and water moves into the cell. If the cell cannot compensate for the sudden increase in volume, it lyses (Kieft *et al.* 1987). In terrestrial systems, microbes compensate for increases in water potential in several ways (reviewed by Harris 1981). Some microbes (mostly gram-negative bacteria) excrete internal solutes, usually salts or amino acids. Some eucaryotes use a similar strategy, but excrete polyols instead of amino acids in response to rapid increases in water potential. Other microorganisms (gram-positive bacteria, some eucaryotes) have thick cell walls which allow them to withstand higher internal pressures. Still others use a combination of these mechanisms. In the Martian environment, where nutrients are probably scarce, excretion of internal solutes would be extremely wasteful and might lead to a slow death instead of a quick one. Although the excreted solutes may be trapped close to the excreting organism—within the rock pores or the organism's cell wall—other organisms might use the solutes as food. The original organism would then be deprived of needed nutrients. Instead, a thick cell wall would probably be more beneficial to the organism in question. Although the thick cell wall might impede gas exchange, other Martian conditions would favor a slow metabolism, and slow gas exchange would not be a problem. Also, just as terrestrial gram-positive bacteria have pores in the cell wall which allow gas diffusion, a similar cell wall structure could exist in Martian microbes. For maximum survivability, Martian microorganisms could use both types of osmotic equalization mechanisms, excreting internal solutes only when the intracellular pressure becomes too great for the cell wall to withstand.

The Martian environment might also result in different nutrient cycles than are found on Earth (see Atlas and Bartha 1987, pp. 307–363). Terrestrial nutrient cycles generally have aerobic and anaerobic components. Although Mars' has an oxidizing environment, its oxidizing capacity may be limited. Mars also has a very low pO_2; thus it is anaerobic. The exact pathways within the following proposed Martian nutrient cycles would depend immensely on whether the oxidizing component or the anaerobic component of Mars' environment prevails. For the purposes of this model, we are assuming that the oxidizing component is prevalent.

On Earth, sulfur cycles from sulfate to sulfide and back to sulfate. Some microbes are capable of either producing or utilizing elemental sulfur. Although sulfur was found on Mars (most probably sulfate), no sulfide or elemental sulfur was found (Toulmin *et al.* 1976, 1977). This is thought to be due to the highly oxidizing Martian environment. Since most microorganisms acquire sulfur in the form of sulfate, and release it in the form of sulfate or organics, dissimilatory sulfur-oxidizing bacteria would not be needed on Mars since any sulfide that might be produced would be quickly abiotically oxidized, or taken up by other microorganisms. This does not imply that sulfur-oxidizing bacteria could not exist on Mars. But because liquid water does not exist in great quantities on Mars, the source of sulfur for the endolithic organisms would probably be recycling of wind-borne, sulfate-containing dust, and sulfur might be a limiting nutrient (Fig. 2). If sulfate is in limited supply in the Martian endolithic community, then reduced forms of sulfur would be much rarer. The lack of liquid water and tectonic activity on Mars also prevents geochemical cycling of sulfur as it occurs on Earth. Thus, wind becomes the only mechanism to transport sulfur to and from individual endolithic communities.

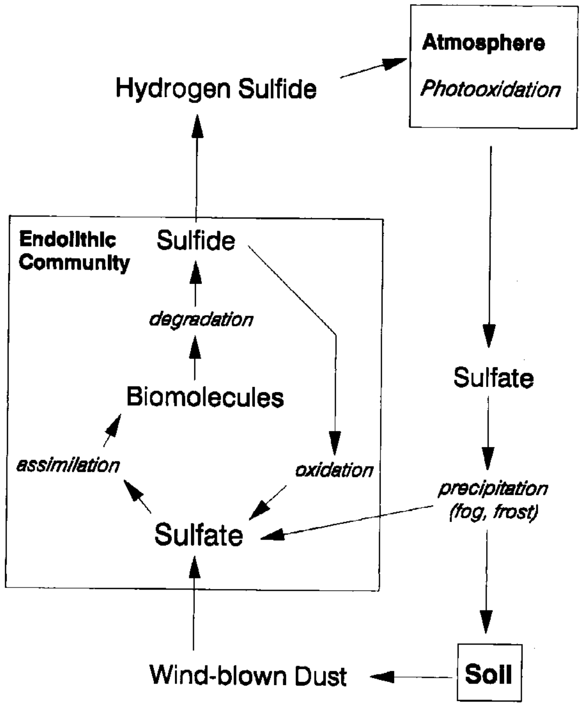

FIG. 2. A proposed Martian sulfur cycle including an endolithic community. Note that there is no dissolved (aqueous) sulfur phase as in terrestrial ecosystems. Sulfur transport between endolithic communities could occur only by gas diffusion or by sulfur-containing dust carried by the wind.

Similarly, phosphorus cannot be cycled geochemically on Mars as it is on Earth. It too must be carried by the wind in the form of dust. Since phosphate is not respired into any volatile form, it would be readily scavenged from dead organisms and cycled within the community (Fig. 3). Some new phosphorus could be introduced into the communities as dust formed by eolian processes.

Nitrogen cycling on Mars could be as complex as nitrogen cycling on Earth, but it could also be much simpler (Fig. 4). Nitrogen-fixing organisms would be required to convert N_2 to NH_4^+ for use in biomolecules. Also, some NO_2^- and NO_3^- could be formed by UV irradiation of atmospheric N_2 and O_2 so some organisms would probably have to be capable of assimilatory reduction of nitrite and nitrate. In the simplest Martian ecosystems, a single microorganism could perform several functions using several pathways. For example, in some terrestrial ecosystems, the bacterium, *Thiosphaera pantotropha* is capable of both nitrification and denitrification (and also sulfur oxidation) (Robertson *et al.* 1988). An analogous microbe on Mars might perform nitrogen fixation and as-

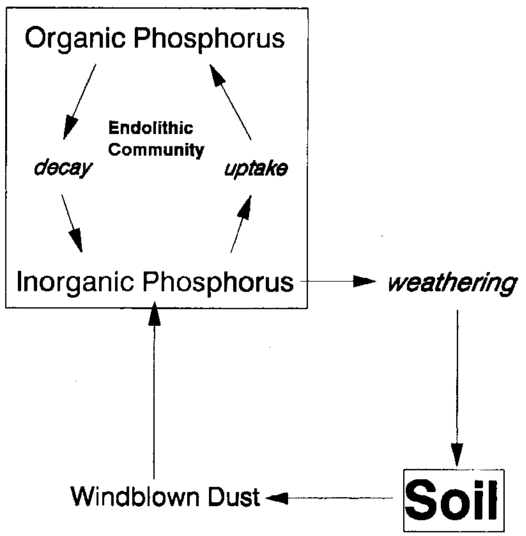

FIG. 3. A proposed Martian phosphorus cycle. Note that in its present state, Mars could not have geochemical cycling of phosphorus as it occurs on Earth.

increase, causing a release of CO_2 into the atmosphere. In turn, the atmospheric pressure would increase beyond the triple point of water, and Mars would be more hospitable to life. When the axial tilt returned toward vertical, organisms would be frozen into stasis only to return in another 25,000 years.

At the time when Sagan proposed his theory, the Martian polar caps were thought to be composed mainly of carbon dioxide. Later, after the Viking program, it was discovered that the polar caps were mostly water ice with a surface layer of frozen CO_2 (Fanale 1988, Moore 1977, Murray *et al.* 1981). Without the large reservoir of CO_2, heating of the polar caps would probably not increase the atmospheric pressure to the extent where large bodies of open water would exist. Nevertheless, water is also a radiatively active gas which could further increase the temperature of Mars. As the polar caps and the water locked in permafrost continued to melt, the atmospheric pressure might increase enough to allow smaller bodies

similatory nitrate reduction. Since O_2 is scarce on Mars, some microbes may utilize NO_3^- as a final electron receptor. On Earth, anaerobes and facultative aerobes utilize NO_3 in this manner (reviewed by Focht and Verstraete 1977). Some nitrate-reducing bacteria reduce NO_3^- to NO_2^-. Others reduce NO_3^- all the way to N_2, thus denitrifying in addition to reducing nitrate. On Mars, the latter case would probably be the predominant form of denitrification as opposed to having two separate groups (one reducing NO_3^- to NO_2^-, the other reducing NO_2^- to N_2).

The model we have just presented is based on the current conditions on Mars as we know them. One issue we have not yet addressed is the low atmospheric pressure of Mars and its effect on microorganisms. Published research on the subject is scarce. However, O'Brien (1976) reported that growth of *Bacillus cereus* increased 22% under a pressure of only 1.28×10^{-6} atmospheres (0.13 Pa). But O'Brien's study involved liquid media with no gas phase, and its applicability to the Martian model is limited. The next model takes into account, at least in part, some of the problems of low pressure atmospheres.

THE MARTIAN "ICE AGE" MODEL

Before the Vikings were launched, Sagan (1971) theorized that Mars goes through an "ice age" every 50,000 years (reviewed by Moore 1977). These ice ages are presumably due to precession of the planet. During the 50,000-year precessional cycle of Mars, its axial tilt changes from 14 to 35°. Presently, Mars' axial tilt of 24° is almost the same as Earth's. According to Sagan, as the axial tilt increased, the temperature at the poles would

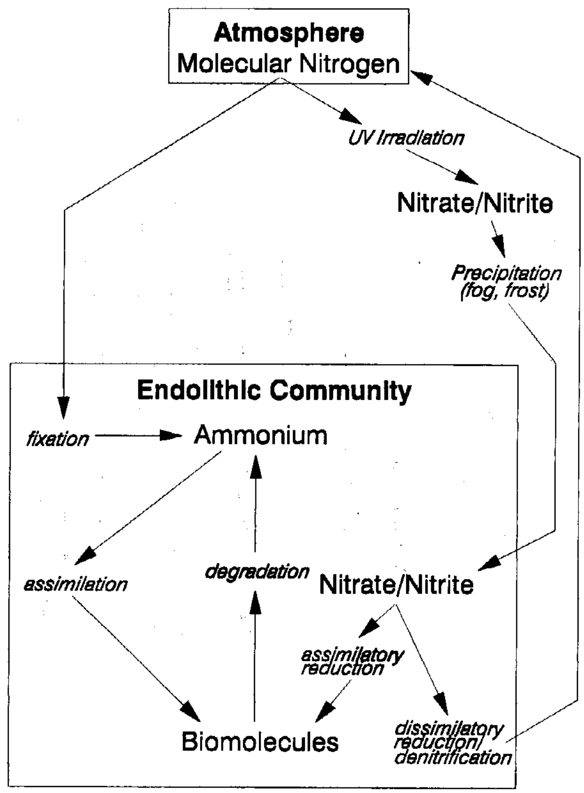

FIG. 4. A proposed Martian nitrogen cycle. Although Mars could have a nitrogen cycle as complex as Earth's, the only necessary steps are fixation of molecular nitrogen, assimilation of nitrates and nitrites, and assimilation of ammonium and/or organic nitrogen by the Martian biota. Since O_2 is scarce in Mars' atmosphere, some microbes might utilize NO_3^- as an electron acceptor. If oxidized forms of nitrogen are formed by UV irradiation, they could be precipitated only by fogs, frost, and ice haze.

of water to persist. In addition, a small increase in atmospheric temperature and pressure could allow the formation of dew—an ample water source for endolithic microorganisms.

Long-dormant (10^7–10^8 years) microorganisms are not unheard of on Earth. Lipman (1931) reported viable bacterial [endo]spores in anthracite coal. Viable osmophilic bacteria have been found in Permian salt crystals (Reiser and Tasch 1960). On Mars, microbes would have to be preserved for only 25,000 years or so. However, preservation on Mars would be very difficult due to the high UV flux and the highly oxidizing environment. Also, once preserved, the microorganisms would have to be able to take advantage of the periods of favorable climate. This means the perimeters of the polar caps would probably be the only areas capable of supporting cyclic communities. During the cold period, the ice would advance, covering the organisms, and protecting them from the atmosphere and UV radiation. During the warm period, the caps would recede, exposing the organisms to the ambient environment. If this model is combined with the endolithic model, the active period for the microorganisms could be prolonged, even to the extent of the full Martian precessional cycle.

If conditions were hospitable for only several thousand years out of every 50,000 years, life probably could never evolve on Mars. However, the current body of knowledge suggests that the early environments of Earth and Mars were quite similar, and life could have evolved during this early period (McKay and Stoker 1989). Any remaining life would probably be in evolutionary stasis due to the proposed short hospitable periods on Mars.

CONCLUSIONS

While the Viking landers did not detect any convincing evidence of life, the possibility of extant life on Mars cannot be completely ruled out. Although both of the models presented in this paper make many assumptions about the types of possible organisms on Mars, they explain how life could exist on the red planet. McKay (1986) uses a scenario similar to our endolithic model to explain how life could have once existed on Mars. We have taken this one step further to say that even though the chances are remote, life could still exist on Mars in very specialized niches.

An apparent drawback of these models is that they assume that Martian life has the same biochemical basis as terrestrial life. It is possible that extraterrestrial life forms use completely different biomolecules and metabolic pathways (Pimentel *et al.* 1966). For example, instead of chlorophyll, Martian primary producers might use a compound which is capable of utilizing the high UV flux found on Mars, either directly or by fluorescing in at a wavelength which can be utilized for photosynthesis. Martian life forms might use genetic materials other than DNA and RNA. The potential for unusual biochemistries is almost limitless. However, whether the mechanisms are terrestrial-like or completely alien, the resulting adaptations to Mars' environment could be similar to those presented in this paper.

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