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Martian Water:
Are There Extant Halobacteria on Mars?

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Abstract

On Earth, life exists in all niches where water exists in liquid form for at least a portion of the year. On Mars, any liquid water would have to be a highly concentrated brine solution. It is likely, therefore, that any present-day Martian microorganisms would be similar to terrestrial halophiles. Even if present-day life is not present on Mars, it is an interesting speculation that ancient bacteria preserved in salt deposits could be retrieved from an era when the climate of Mars was more conducive to life.

Introduction

Of all the planets explored by spacecraft in the last four decades, Mars is the only one with surface conditions even remotely similar to those of the Earth. Although the planet Mars is extremely cold and dry compared to Earth, nevertheless a major objective for NASA exploration of Mars is to determine whether life has existed on Mars in the past, and whether such life on Mars may persist to the present day.

On Earth, life has adapted to extreme environments, ranging from frozen valleys of Antarctica to the interior of rocks and the high-pressure, high-temperature environment of deep-sea thermal vents. The only criteria that is required without exception is that every ecological niche which supports life has, at least briefly, the presence of water in liquid form for some portion of the year. The strategy for Mars, then, is to search for environmental conditions that feature liquid water.

Liquid Water on Mars

The surface environment of Mars contains water in the form of polar ices, permafrost, and small amounts of atmospheric water vapor. However, it is often asserted [*e.g.,* Malin and Edgett, 2000] that liquid water cannot be present on the surface of [present-day] Mars because the atmospheric pressure is at or below the triple-point vapor pressure of water.

There are several exceptions to this generalization that are worth noting.

First, at many locations on Mars the atmospheric pressure is, in fact, above the 6.1 mbar triple point pressure of water. In fact, both of the Vikings and the Pathfinder lander (deliberately targeted to low regions of Mars) landed at locations where the surface pressures never fell as low as 6.1 mbar. Viking Lander 2 measured a peak pressure over 10 mbar [Zurek *et al.* 1992], and at the lowest elevations of Mars the pressure can be even higher. At these locations, then, water has a liquid phase between ice and vapor (about 7 C at the Viking lander 2 site).

Second, while temperatures on Mars may average below 273 K, at many locations daytime surface temperatures rise significantly above freezing. In particular, surface materials warmed by sunlight can quickly rise to temperatures above freezing. While liquid water would most certainly freeze during the nighttime at any location on Mars, it is quite possible for transient liquid water to exist during the day.

Finally, Mars is a salt-rich environment [Treiman 1999; Sawyer, McGehee,Canepa and Moore, 1999]. Any present-day water would likely be a saturated salt solution, with a lower vapor pressure and a lower melt temperature than pure water. A saturated solution of K_2CO_3, for example, will depress the freezing point of water to below 236 K. Multicomponent aqueous salt solutions can have freezing temperatures as low as 210 K [Brass, 1980]. Water in micron-scale pores between grains of regolith would have even lower freezing point due to capillary-pore effects.

These effects all add qualifications to the common wisdom that liquid water cannot be present on the surface of Mars. While it is unlikely that standing pools of liquid water exist on the surface of Mars for extended periods of time, it is quite reasonable to expect the transient presence of liquid water at selected surface locations on Mars [Landis, 2001; 2001A].

Halobacteria

If life can adapt to the transient presence of liquid water in the form of highly-concentrated brine, and if such a form of life can find ways to adapt to the other adverse conditions on Mars (e.g., surface oxidant, ultraviolet radiation), then present-day Mars could yet harbor life.

A candidate form of life which could exist in Martian brine is the family of "salt-loving," or halophile, bacteria, such as *Halobacterium halobium* [Stoeckenius, 1976; Armstrong, 1981]. Halobacteria, a form of extremophile archaeobacteria, are adapted to surviving in saturated salt solutions. These halobacteria are amazingly robust organisms, able to survive being desiccated into a crust of solid salt, returning to active life when water returns. They are capable of traveling distances of hundreds or even thousands of miles in the form of dry, windblown dust and salt, and by this means colonize transient small pools ("playas") of saturated brine [Armstrong, 1981]. Sealed in salt crystals, halophiles have an extremely high, and perhaps indefinite, longevity [Grant, Gemmell and McGenity, 1998]. Halophilic archaea have been proposed as a possible candidate for life on early Mars by Litchfield [1998], and as a possible life form on present Mars by Landis [2001].

Halobacteria are faculative anaerobes, and photosynthesize using pigments of the rhodopsin family, chemically related to vitamin A, that directly produces ATP from ADP without production of oxygen. The photosynthetic pigment used by *H. halobium* is bacteriorhodopsin, which gives *H. halobium* its striking pink-red color [Armstrong, 1981]. A pigment more widely distributed in the halophilic archaea is halorhodopsin, a chloride pump found in most halobacteria [Mukohata, Matsuno-Yagi and Kaji, 1980].

The presence of a thin crust of salt will moderate damaging aspects of the environment. Chloride salts are opaque to short-wave ultraviolet. The most common salt, sodium chloride, has a short wavelength cut-off at 200 nm [Eldridge and Palik, 1985], which will reduce the most damaging of the vacuum-ultraviolet on Mars. *H. halobium* contains a pigment opaque to the longer wavelength ultraviolet, which is used to prevent its destruction by desert sunlight [Larsen, 1967; Litchfield, 1998]. The combination of a salt crust and the UV-blocking pigment will serve as barriers to mitigate the destructive effect of the ultraviolet environment of Mars.

The growth of terrestrial halophiles is extremely slow at low temperatures. As noted by Litchfield, one of the functions of the pigmentation in halobacteria is to increase the temperature by absorbing more solar heat; this can increase the temperature by 5-8 C [Litchfield, 1998]. Nevertheless, if halophilic bacteria survive on present-day Mars, it would be likely that they must have evolved to be able to grow at low temperature during the (presumably short) time span when the pool is likely to be liquid.

An alternate microbial community, the "desert varnish" [Dorn and Oberlander, 1981] could also be a possible analogue for Martian life. Desert-varnish bacterial communities are adapted to utilize transient occurrences of water in a normally-dry environment, and as noted by Krumbein and Jens [1981]: "the 'rock-eating' microbial communities protect [themselves] from dessication and UV irradiation… [by creating] a 'niche' in several mm depth within the rock." Since these organisms use rock to shield themselves from ultraviolet, they are an alternative candidate likely to survive on present-day Mars.

Possible Survival of Ancient Organisms

The transient liquidity of surface water makes the near-surface environment of Mars a marginal environment even for extreme-cryophile, extreme-halophile life. However, in an earlier era Mars had a climate which was far more benign to life. This era is usually dated as having ended approximately 3.5 billion years ago [Fanale, 1992].

According to a recent report in *Nature* [Vreeland, Rosenzweig, and Powers, 2000], living microbes have been successfully cultured from inclusions in salt deposits that are 250 million years old. The crystal structure and sedimentary features of the salt indicate that the salt deposit has not been recrystallized since its formation in the late Permean. These microbes are a halobacterium genetically related to *B. marismortui*, a species of halobacteria that has been cultured from water taken from the Dead Sea. The organism is a moderate halophililic eubacterium that can grow in salt concentrations up to 25%. Similar results have been reported from other salt deposits. Bacteria reported from ancient samples include *Halococcus salifodinae* and several other halophilic Archaea. Bacteria have been reported to be cultured from ancient salt deposits of up to 650 million years in age, although this result is viewed with a considerable amount of skepticism as a likely artifact of contamination [Parkes, 2000]. An upper limit for the possible survival duration of bacteria preserved in salt deposits has not been established.

In many ways, the environment of Mars is far more condusive to preserving salt deposits than the surface of Earth, and the lower average temperatures of Mars make it more likely that inclusions within the salt would be preserved, as long as the salt is buried at a low enough stratum to be shielded from cosmic ray damage.

Even if conditions for life do not exist on present-day Mars, it may be possible that halobacteria may still be retrieved in salt deposits on Mars and cultivated in a suitable medium for growth. If, in fact, it is verified that bacteria on Earth can indeed survive in salt deposits that are over 650 million years old, it is reasonable to extrapolate that possibly bacteria could survive in salt deposits for over a billion years. If this were to be true, then it is not out of the question that bacteria might be retrieved and cultured from an era dating to the time that Mars had a warm climate with liquid water, approximately 3.5 billion years ago. Even if no life exists on Mars in the present day, it is still possible that encapsulated life may be retrieved from salt deposits and brought back to life on Earth. Such retrieval of ancient life from Mars would answer many questions about the origin of life, and the relationship or independence of Mars and Earth biology.

Implications for Science Missions

An initial objective for a science mission would be to verify whether transient occurrence of liquid water does, in fact, occur on Mars, and if so, at what locations. The recent results of Malin and Edgett [Malin and Edgett, 2000] supports the transient presence of liquid water at high-latitude locations; it would be useful to find whether lowland areas also have liquid water. A useful tool for such an investigation would be an orbital radar [Chappel 1999, Olhoeft 1998]; the high conductivity of brine solutions could make it possible to not only detect water, but also to make an approximate measurement of the saline concentration. Since the liquid phase is liable to be transient, an orbital mission seeking liquid water will require a long duration, and an orbit which visits the same sites repeatedly at different time of day, to elucidate the details of the water cycle.

It would also be of interest to search for life directly. Halobacteria can have a distinctive spectral signature due to the photosynthetic pigments bacteriorhodopsin [Stoeckenius, 1976] and halorhodopsin [[Mukohata, Matsuno-Yagi and Kaji, 1980]. It is an unsupported speculation to expect that Mars bacteria would utilize the identical pigments, but nevertheless, it would be an interesting experiment to use hyperspectral imaging to search for the signature of halobacteria, focusing particularly on the likely locations of low, flat areas that are likely salt beds. An observation which is more likely to produce useful results would be to search for the spectral signature of salts, in order to identify "playas" locations where salt deposits would be located.

The speculation of possible extant life in the form of halobacteria on Mars lends some suggestions toward possible landing sites. If a landing mission is designed to search for halobacteria, the desired areas to search would be low salt flats and dry lake sites. Such sites are also desirable locations for other biological investigations, and several potential sites have been identified on Mars.

Conclusions

Because of the low temperatures and atmospheric pressure ambient, any near-surface liquid water on Mars must be a highly concentrated brine solution. Therefore, if (hypothetical) microorganisms existing on Mars are similar to terrestrial microorganisms, they are likely to be similar to terrestrial halophiles. Such halobacteria could live in transient playas of concentrated brine, using the period when the brine is liquid to metabolize and reproduce, and surviving in dormant form in the dried salt deposit during periods between the liquid state when the pool is dry.

Studies of ancient halobacteria preserved in salt deposits suggest that it may be possible that halobacteria may be retrieved from ancient salt deposits of age approaching a billion years and cultivated in a suitable medium for growth. It is a fascinating speculation that ancient bacteria preserved in salt deposits could be retrieved from an era dating to the time that Mars had a climate benign to life.

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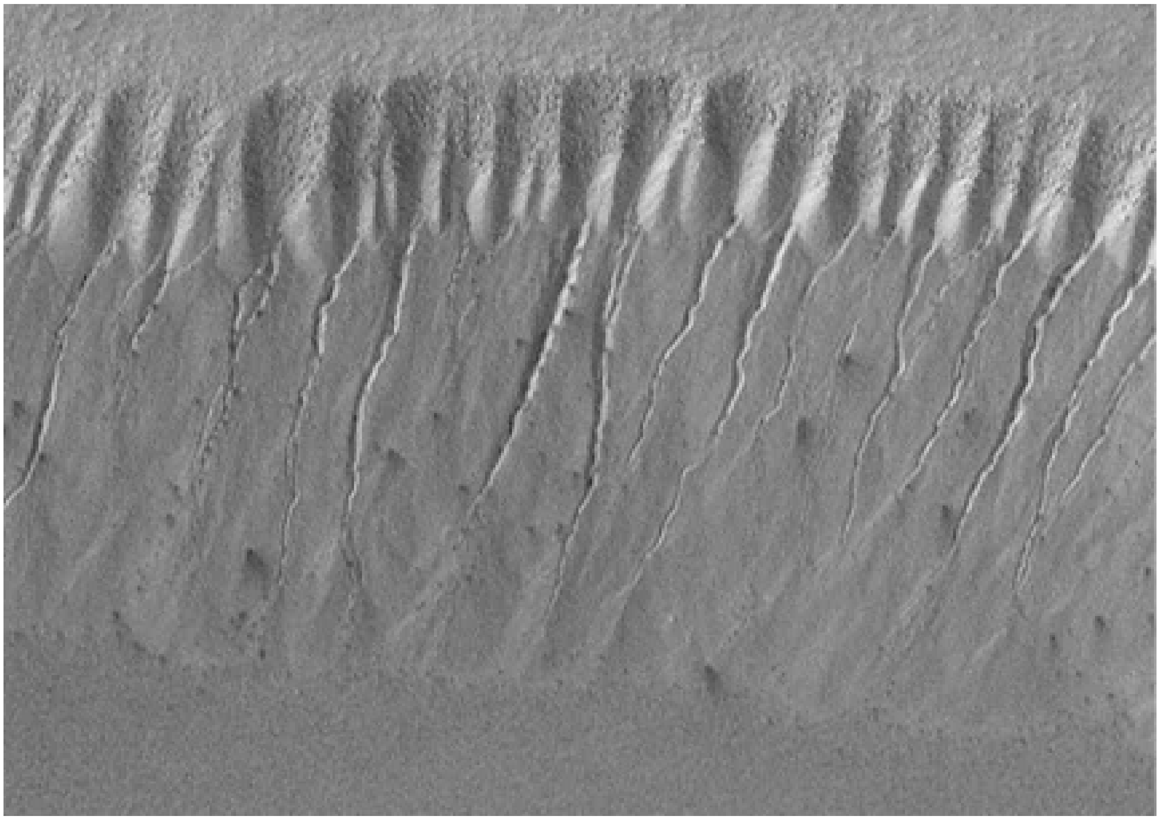
photo by Geoffrey A. Landis

Numerous dry basins east of California's Sierra Nevada contain salt-covered dry lake beds or playas, similar to features seen on Mars. In this picture, taken in Owens Valley, in California, the red color of this hypersaline pond is due to halophilic archaea. Visible in the distance is the Inyo Range.



View from Mars Global Surveyor of geologically-recent run-off channels in a crater wall on Mars. (Image from JPL/Malin Space Sciences, Inc.)