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J.E.Brandenburg

Morningstar Applied Physics LLC

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***Corresponding author's Name & Add.**

J.E.Brandenburg
Morningstar Applied Physics LLC

A hypothesis of perchlorate-enabled photosynthesis on Mars

Abstract

It is hypothesized that photosynthetic bacteria on Mars protect themselves from direct contact with the atmosphere by binding oxygen to chloride ions to oxidize them to perchlorate and then excrete the bound oxygen as sodium perchlorate, which binds water so tightly it prevents loss of cell water to the Mars atmosphere even at the low pressures experienced there. Other bacteria then digest the perchlorate and release oxygen to the atmosphere. This photosynthetic pathway is similar to the arsenate based photosynthesis seen in red bacteria found Mono Lake on Earth and is hypothesized to use an organic dye of similar color to preferentially utilize high energy green and blue photons for this photosynthetic process. This hypothesis is proposed to explain the ubiquitous nature of sodium perchlorate on Mars surface, a rare chemical in nature on Earth.

Keywords

Photosynthesis; Sodium perchlorate; Hygroscopic; Deliquescence; Oxygen excretion; Freezing point depression.

INTRODUCTION

One of the most serious problems for plants in desert regions is transpiration: the loss of cellular water during the respiration required for photosynthesis. On Earth, photosynthetic organisms in desert environments have adopted a variety of mechanisms to reduce water loss during the intake of CO_2 and exhalation of O_2 required for photosynthesis. Mars is now a desert planet, and we would expect any surface dwelling microbes there to display adaptations to prevent cellular water loss. Sodium perchlorate, $NaClO_4$, while rare in the natural environment on Earth, has been found to be widely distributed on Mars[1,2] (see Figure 1). In fact, the only place $NaClO_4$is found in any quantity is the most Martian place on Earth, in terms of dryness: the Atacama Desert in Chile[3]. Sodium perchlorate has the interesting properties of being a very chemically stable carrier of oxygen, hence its use as solid rocket fuel oxidizer, and also of being extremely hygroscopic, pulling moisture from the air,under Martian conditions and even displaying deliquescence: not only pulling moisture out of the air, but doing so to the extent that it forms solutions,with strongfreezing point depression of the resulting water solutions so they can remain liquid under Martian surface conditions[4]. Therefore, being able to capture water vapor from the Martian atmosphere into a liquid state, and preserving such captured water in a liquid state, sodium perchlorate in solution is the perfect medium for excreting oxygen from photosynthetic cells into the Martian environment. In this brief note, a biological oxygen cycle is proposed for Mars and the possible properties of the microbes involved, including the likelihood that photosynthetic microbes on Mars are red colored rather than green. Such microbes would be difficult to spot in the red landscape of Mars (Figure 2).

The problem of cellular respiration on Mars

The fourth most abundant gas in the Martian atmosphere is molecular oxygen, exceeding the concentration of carbon monoxide by a factor of two. This has always suggested photosynthesis was occurring on Mars, since UV photolysis of CO_2 would create far more CO than O_2. However, performing photosyn-

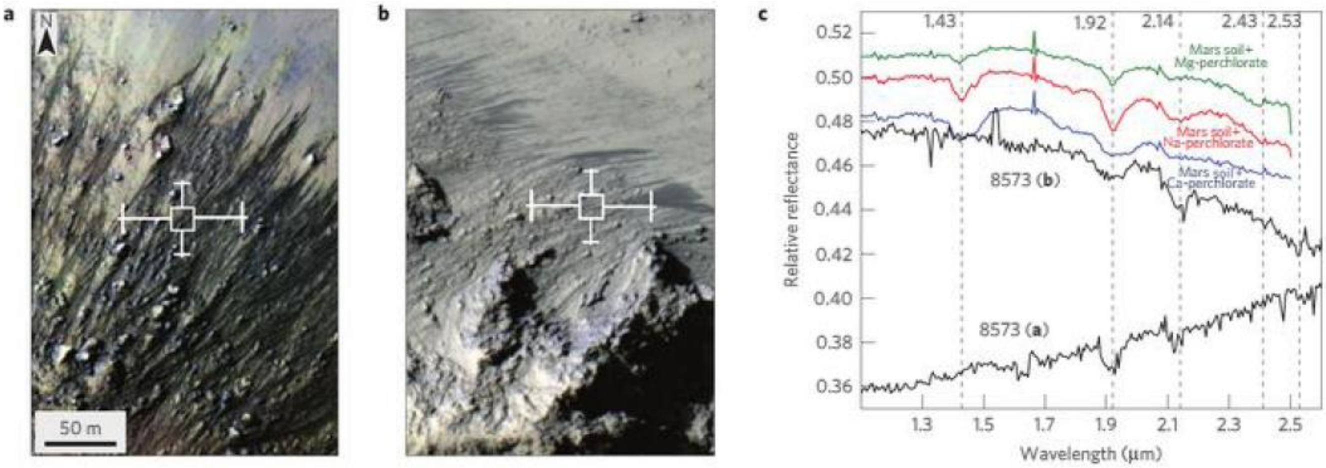

Figure 1 (a,b) : Observations of transitory linear features on Mars and (c) the infrared absorption spectraof the features including reference absorption spectra for various salts. Sodium perchlorate shows similar absorption features to Martian soil at 1.9 microns. Figure taken from reference 1

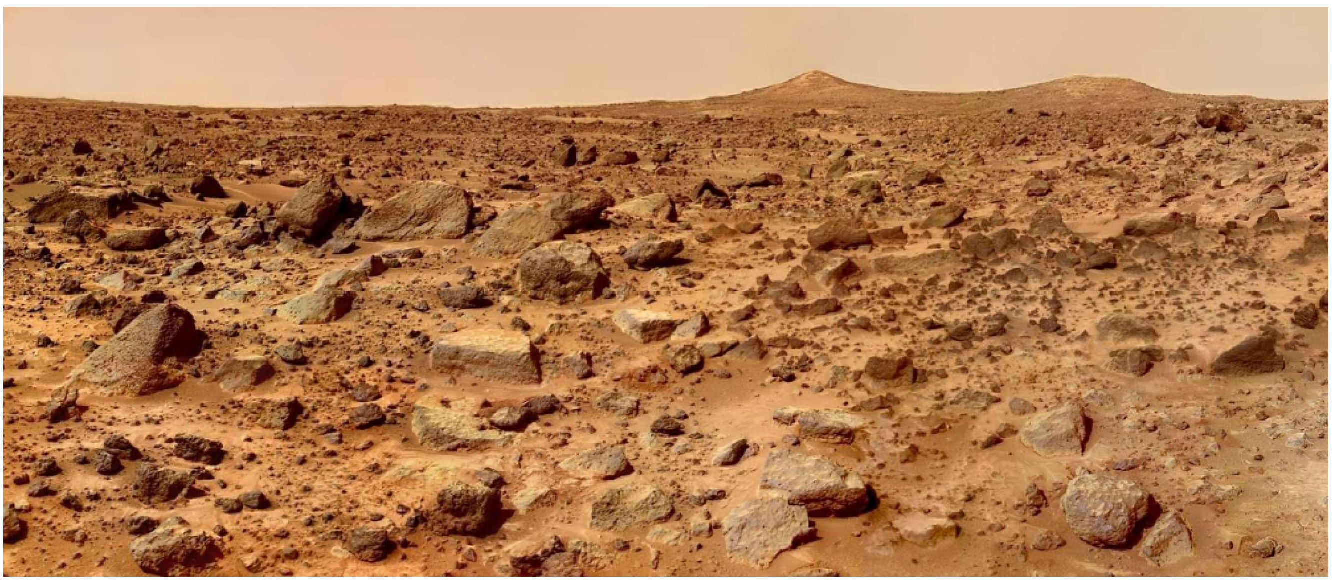

Figure 2 : The landscape of Mars showing that red colored microbes would be difficult to notice

thesis, as it is familiar on Earth, presents enormous difficulties for any biology on Mars. This is because photosynthesis requires gas exchange with the environment and the environment on Mars is very hostile to life as we know it, being extremely dry and being rich in UV light. Biological membranes for gas exchange, known on Earth, cannot function on Mars.

All microbes on Earth consist of a protoplasmic medium contained within a cell wall or membrane. Since the membranes themselves are moist, the final interface between the atmosphere and the cells is often a nonliving membrane or cuticle excreted by the cells to protect them against the outside atmosphere or water environment. On Mars any microbe living on the surface would be expected to preserve a protective shield around itself against the low atmospheric pressure and extreme ultraviolet environment of Mars surface environment. The problem with such a shield, even if transparent but UV resistant, to allow photosynthesis, is that it must impede respiration. Even if carbon dioxide could be transported inward by simple diffusion through the shield from the atmosphere, there remains the problem of transporting the more ultraviolet sensitive oxygen molecules outward. Oxygen molecules can be easily split by UV and become very reactive, forming ozone and atomic oxygen, thus eroding the organic shield around the cell. A solution would be then to bind the oxygen resulting from photosynthesis in some relatively inert molecule for excretion, a molecule stable in the presence of UV. If such a molecule existed and also had the property of being extremely hygroscopic and capable of lowering the freezing point of water, then the cell might excrete the molecule in a solution as a droplet, forming a “lung” or gas exchange organelle for getting rid of oxygen, and aiding the diffusion of carbon dioxide, and using the hygroscopic properties of sodium perchlorate to capture water out of the air so the

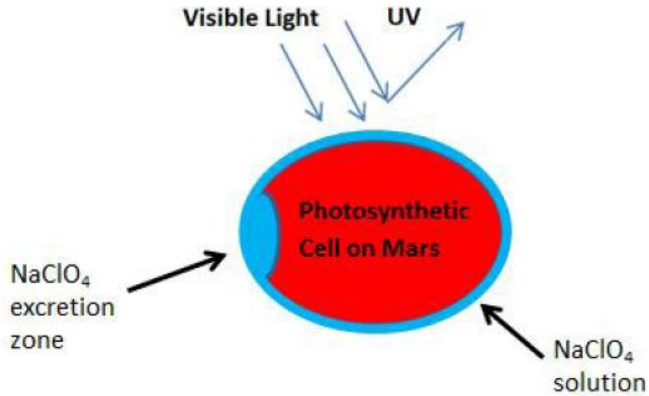

Figure 3 : A functioning photosynthetic microbe on Mars. Such a microbe would excrete sodium perchlorate through a cell cuticle and this would gather moisture out of the Martian atmosphere to form a sodium perchlorate solution enclosing the microbe and creating the possibility of a shared aqueous environment with other cells

in favor of less abundant red and blue light. On Mars we would expect a similar effect to that of the arsenate microbes, with the dominant color of photosynthetic microbes being red to more efficiently utilize lower light levels on Mars and the higher energies required for a perchlorate chemical pathway. Such red colored photosynthetic microbes on the Martian surface would also take advantage of scattered green and blue light from the surrounding landscape, which is predominately red. The proposed perchlorate-pathway photosynthesis mass-balance is compared with standard photosynthesis on Earth(see Figure 5).

On Earth, the bacteria *Moorellaper chloratireducens* and *Sporomusa* sp.are known to metabolize, perchlorates[6] to chlorides with the release of oxygen.On Earth the oxygen cycle closes though

Figure 4 : A pool with arsenic-enabled photosynthetic bacteria found at Mono Lake in California. Image is taken from reference 5. Note red color of bacteria

expanding droplet could function as suitable environment for reproduction and the forming of a colony.(see Figure 3) This would be similar to the arsenate-enabled photosynthetic pathway found in microbes at Mono Lake in California USA [5], where oxygen resulting from photosynthesis is captured on arsenate (III) ions before being excreted.

The red color of the arsenate-utilizing microbes (see Figure 4) indicates that they are capturing green to blue light, rather than red and blue seen in ordinary photosynthesis, in order to utilize the higher energy of green light photons over red light. This use of higher energy photons is consistent with the necessity for higher energies to drive the unusual chemical reactions involved. This is contrast to ordinary plant photosynthesis on Earth, which actually rejects the most abundant light wavelength in the Solar spectrum: green, the atmosphere. (see Figure 6.)We can easily imagine that any colony of photosynthetic bacteria that enshrouds itself in films of sodium perchlorate solution as an aid to respiration will also hostsymbiotic colonies of perchlorate-consuming microbes, with the release of any oxygen not used for metabolism. (see Figure 7.)Such released oxygen could be utilized by other biology, pass into the atmosphere, or be further modified into peroxides. This means that sodium perchlorate can play a central role in a biological oxygen cycle that bypasses the atmosphere almost entirely and uses instead a commonly used rocket-fuel oxidizer.

SUMMARY AND DISCUSSION

Therefore, based on experience with extremophile microbes on Earth, experience with the properties of

Earth Standard Photosynthesis:

$$6CO_2 + 6H_2O + Photons \rightarrow C_6H_{12}O_6 + 6O_2$$

Mars Standard Perchlorate-Path Photosynthesis:

$$12CO_2 + 12H_2O + 6NaCl + Photons \rightarrow 2C_6H_{12}O_6 + 6NaClO_4$$

Figure 5 : Photosynthetic mass-balance on Earth and Mars

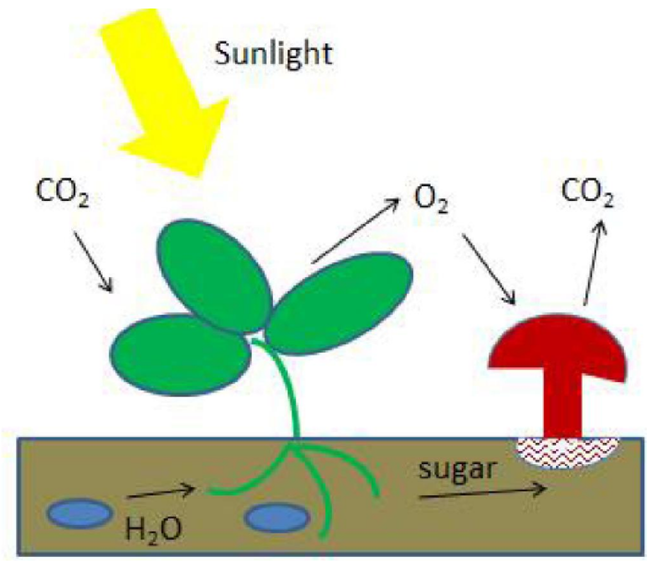

Figure 6 : The standard oxygen cycle on Earth, photosynthetic plants pass oxygen through the atmosphere to fungi and animals on Earth

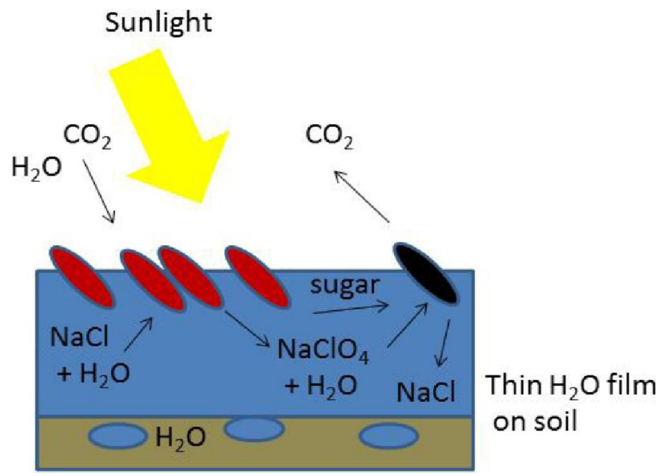

Figure 7 : The proposed standard oxygen cycle on Mars: photosynthetic plants microbe (red) pass oxygen through a thin film of $NaCl0_4$ brine to microbes (black) which consume it, bypassing the atmosphere

perchlorates from their use in rocketry, and observations of Martian conditions, it appears easy to hypothesize the ubiquitous perchlorates, particularly sodium perchlorate, found on Mars, are the waste product of Martian photosynthetic microbes. Sodium perchlorate is found on Earth, in nature, only in the driest possible conditions, and it takes little imagination to suppose that it functions there in same role there as it does on Mars, as a powerful concentrator of atmospheric moisture for biology. This suggests that Mars life communities exist where microbes excrete rocket fuel oxidizer and other microbes consume it, allowing a local aqueous environment and with it oxygen respiration that bypasses the atmosphere of Mars.

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