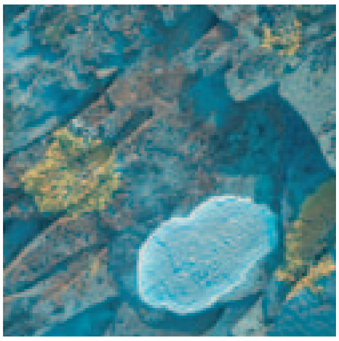
Could Lichens grow on Mars?



Richard Armstrong boldly goes where few microbiologists have gone before and concludes the truth is out there

Artist's impression of the exploraration of the Martian surface. Artwork courtesy of Pollard Creativity

MARS IS AN inhospitable, barren, and rocky planet unprotected from ultraviolet light and subjected to freezing temperatures and frequent sandstorms. In the past, however, it was a warmer planet, probably with large oceans, and with an atmosphere closer in composition to that of Earth.

Over long periods of time, the surface water on Mars has been lost resulting in the arid planet that we see today. There has been considerable debate over the last few years as to the possibility of life on Mars. This debate has arisen as a result of studies of Martian meteorites, of Earth environments considered to be analogues of those on Mars, *e.g.*, the dry valleys of Antarctica, and the discovery of exposed water ice near the edge of the southern pole of Mars (Titus *et al.*, 2003).

The idea that lichens could grow on Mars is not new having been proposed as early as 1949 to explain the colour changes that had been observed on the surface. Lichens could fulfil some of the requirements for growing in such an extreme environment. First, they can be dried to water contents between 1-15% of their dry weight and survive for a considerable time in a dehydrated state. Second, some Antarctic lichens can be plunged into liquid nitrogen and survive and third, lichens are unusually resistant to levels of radiation that would kill most other types of plant. It was the discovery of endolithic lichens living within the rocks of the dry valleys of Antarctica which has provided a new impetus to the debate. Hence, this article considers first, aspects of the biology of lichens, second, considers the Martian environment and the prospects for present and past life on the planet, and third, discusses the arguments in favour and against the possibility that lichens could have developed on Mars.

What are lichens?

Anatomy and physiology

Lichens are very common organisms on Earth and are found in a range of environments including the surfaces of rocks, trees, and man-made structures (Fig 1). Lichens occupy some of the most inhospitable terrestrial environments from hot arid and semi-arid regions to the cold Polar Regions. The ability of lichens to tolerate extremes is partly physiological, *e.g.*, their tolerance of extreme conditions, but also behavioural in that lichens can adapt to relatively protected niches within extreme environments.

Lichen is an intimate association between two quite different organisms, *viz.*, an alga and a fungus. The two organisms are so intimately associated that the term

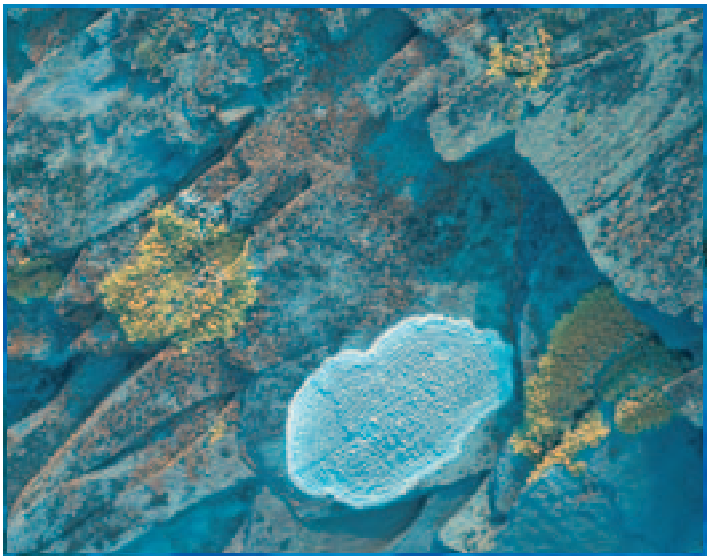


Figure 1. A community of foliose and crustose lichens on a slate rock surface in Wales, UK. A rich lichen flora is present on the surface of the rocks and orange lichens of the genus *Caloplaca*, yellow species of *Xanthoria*, and light grey species of *Pertusaria* are visible.

mutualism or symbiosis has been applied to it. In cross-section (Fig 2), a typical lichen is composed mainly of fungal tissue but embedded in the upper cortical layers are eukaryotic algal cells. Some lichens are also associated with cyanobacteria (blue-green algae) found in special structures called cephalodia. The algal partner carries out photosynthesis and supplies the fungus with carbohydrate but there is little experimental evidence that the fungus supplies nutrients to the alga (Smith and Douglas 1987). There are three major types of lichen, viz., the fruticose type in which the lichen thallus is attached to the substratum at a single point and forms a complex branched structure, the foliose type that comprises a series of radially arranged leaf-like lobes, and the crustose type that is tightly attached to the substratum. Most lichen communities have a mixture of the three growth forms (Fig 1).

The foliose and crustose types of lichen grow radially over the substratum rather like a fungus on an agar plate but growth rates are very slow. Many foliose species have rates of radial extension between 2 and 5 mm per year but many crustose lichens grow much more slowly with rates of less than 0.5 mm year (Armstrong 1973, 1983). Some species grow so slowly that larger thalli growing in the Arctic may live to be over 5000 years old, thus making them some of the oldest organisms on Earth. The slow growth of lichens is not attributable to slower than normal physiological processes but to the fact that lichens lose much of their carbohydrate due to respiration. A lichen can spend a considerable amount of its time in a dehydrated state (Fig 3), but when the lichen is wetted there is a loss of carbon due to resaturation respiration. After wetting, photosynthesis begins to replace the carbon lost but the lichen has to remain wet for a sufficient period in the light to make good the carbon losses and then to make new carbon for growth (Armstrong 1976). Frequent rain showers combined with rapid rates of drying in the sun may continually deplete carbon with little left over for growth processes. As a result of slow growth, however, the lichen may make little demand on the environment for nutrients thus enabling the organism to grow in potentially nutrient-poor habitats.

Endolithic lichens

The Viking Lander photographs taken on the surface of Mars in the 1970s show a cold desert landscape with scattered boulders (Fig 4). Examination of these boulders shows no evidence of lichens growing on their surfaces. Nevertheless, as in the cold, dry valleys of Antarctica, there is the possibility that endolithic lichens were present in the rock in the past or may even survive today.

Three types of endolithic organisms have been described: (1) ‘chasmoendoliths’ — which occupy fissures and cracks in rocks but the organism may be partially exposed on the surface, (2) ‘cryptoendoliths’ — which occupy pores and pre-existing structural cavities, and (3), ‘euendoliths’ — that bore into relatively soluble rock substrates such as those rich in carbonate (Lawrey 1984). In 1974, numerous microorganisms were discovered in Beacon sandstone rocks of the dry valleys of Antarctica. Cyanobacteria were present but the dominant flora was chasmoendolithic and cryptoendolithic lichens. The lichens occupied a narrow zone of the subsurface of the rock 10 mm thick and formed colonies from a few centimetres to a metre in diameter (Friedmann 1982). The lichens had a similar structural organisation to those that live on the surface but a true fungal zone was absent, with instead, the fungal hyphae filling the available pore space. In cross section, a typical rock consists of a black zone just below the surface containing the alga *Trebouxia*, below that a white zone of fungal tissue, then a green layer of non-lichenised green algae, and finally, in some samples, a layer of cyanobacteria. The subsurface layers are often solubilised by fungal hyphae resulting in the upper surface peeling away to expose the lichen tissue.

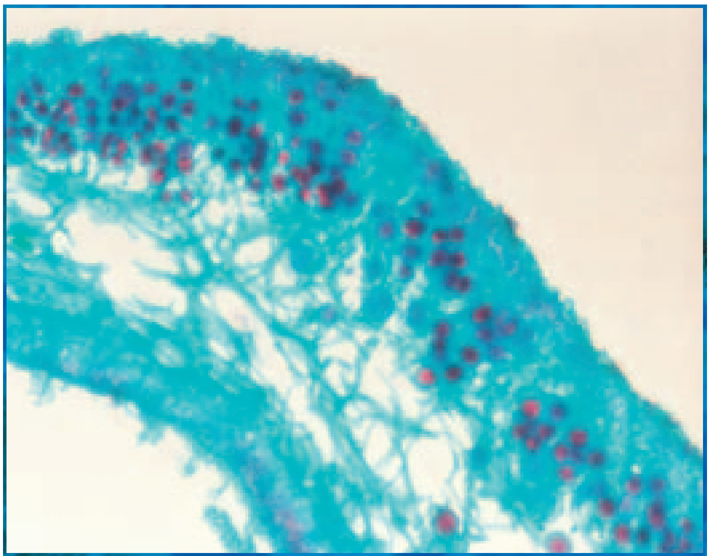


Figure 2. Vertical section through the thallus of the foliose lichen *Xanthoria parietina*. The algal cells (dark red spheres) are confined to the cortical layer just below the surface of the lichen. Below, the medulla composed of fungal hyphae can be seen.

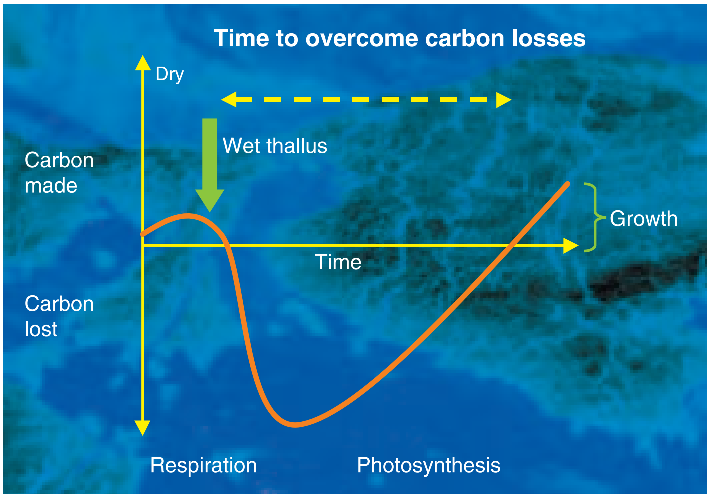


Figure 3. The consequences of wetting a dry lichen. Little carbon is made when the lichen is dry. When the thallus is wetted, there is a burst of respiration and carbon is lost from the thallus. Photosynthesis then begins to replace the carbon lost but the lichen has to be wet long enough in the light to overcome the carbon losses and to make new carbon for growth.

Further penetration of the rock results in more rock layers being lost and the consequence of this 'biogenic weathering' is a characteristic pockmarked surface on the sandstone surfaces of the dry valleys. Close-up photographs of Martian boulders may therefore be useful in detecting the possible presence of endolithic lichens (Fig 4).

The Martian environment

In "Cosmotheoris", published in 1698, and one of the earliest expositions on the possibility of extraterrestrial life, Huygens deduced that Mars was much colder than Earth. Recent measurements of temperature on Mars have confirmed these early impressions in showing that the daytime surface temperature may vary from 26.6°C during rare sunny days to –93°C at the poles in winter. The air temperature, however, rarely rises above zero and decreases markedly with altitude above the surface.

In 1784, Herschel commented that Mars and Earth have a similar diurnal motion and length of year but also mentioned the more tenuous atmosphere on Mars. The first attempts to detect oxygen and water on Mars spectroscopically were made in 1867 but were inconclusive. However, in 1909, Campbell failed to detect water vapour in the Martian atmosphere using a spectroscopic method and concluded that the environment was extremely arid, a result confirmed by Adams in 1926. In 1947, Kuiper, using infrared spectrograms, detected carbon dioxide in the Martian atmosphere at twice the levels of Earth but no oxygen. Viking 1 showed that the atmosphere of Mars was composed mainly of carbon dioxide with trace quantities of nitrogen, argon, oxygen, and carbon monoxide (Nier *et al*., 2003).

Spinrad in 1963 was one of the first scientists to study the possibility that water was present in the Martian atmosphere and reported, using spectroscopic observations, that the level of water was one thousandth of that in the atmosphere above the Sahara desert on Earth. Subsequent studies using theoretical climate models and experiments on Earth simulating Martian environments (Kuznetz & Gan, 2002) demonstrated that liquid water may be stable for extended periods of time on the Martian surface under present-day conditions. These studies have culminated in the discovery of water ice near the edge of the southern polar cap by Mars Odyssey using the Thermal Emission Imaging System (THEMIS) (Titus *et al*., 2003). Hence, surface water ice may be widespread around and under the carbon dioxide polar cap.

Could lichens live on Mars?

Microorganisms

Lichens are composite organisms consisting of an alga and a fungus living in mutualistic association. Hence, the presence of lichens on Mars presupposes the evolution or transport to Mars of both the fungal and algal components of the symbiosis. The presence of microorganisms on Mars, either living today or as fossils of past life, however, is highly controversial. On August 1996, NASA announced that there was evidence of life in a Martian meteorite (ALH84001) that had entered Earth's atmosphere 13,000 years ago and landed in Antarctica. The existence of life in the meteorite was based on four lines of evidence. First, that the carbonate patterns had a unique life signature consistent with those expected of terrestrial bacteria. Second, that polycyclic aromatic hydrocarbons, usually created by bacteria, were present in the meteorite. Third, that magnetite globules are created by bacteria on Earth as well as by some chemical processes. However, only bacteria are likely to have caused the distinctive tear-shaped globules present in the Martian rock. Fourth, worm-like structures were observed in the meteorite. These structures are much smaller than most bacteria but recently similar sized terrestrial fossils have been discovered. In addition, biogenic features have been found in three Martian meteorites, including eight of the amino acids that are constituents of terrestrial proteins, but there is still no conclusive proof that these are evidence of ancient life (Gibson *et al*., 2001).

On the surface of Mars itself, experiments have also produced ambiguous results. The Viking Landers sent to Mars in the 1970s carried out experiments to detect the presence of organic materials in Martian soil. One such experiment detected no organic compounds while another showed positive results. The positive result could have been attributable to superoxides or peroxides present in the Martian soil and which reacted with the test solution when it was mixed with these oxides. There have also been attempts to detect atmospheric biomarkers of subsurface life on Mars. Bacterial life below the surface may depend on hydrogen and carbon monoxide as energy sources (Summers *et al*., 2002) and it may be possible to observe the metabolic by products of these organisms as trace gases in the atmosphere. Organic trace gases in the atmosphere tend to have very short chemical lifetimes but CH_4 has a much longer lifetime and tends to be more uniformly distributed. However, the flux of CH_4 into the Martian atmosphere is 10^5 times less than on Earth suggesting that there can only be a minute biological component on Mars. Hence, there is no convincing evidence, at present, for the existence of past or present microorganisms on Mars, a necessity for the evolution of lichens.

Endolithic lichens on Mars

In the dry valleys of Antarctica, the absence of water and low temperatures are the most important factors limiting endolithic lichens. The lichens that live in these environments on Earth are not better adapted to colder or drier conditions than their surface counterparts but occupy a new niche by changing their pattern of organisation. In addition, the relative humidity below the surface is consistently higher than at the surface where evaporative water loss is high. Studies suggest that the lichens require snow meltwater as a source of water as no endolithic lichens occur on the steep or vertical faces where snow cannot accumulate (Kappen *et al.*, 1981). Endolithic lichens on Mars would be able to tolerate the low temperatures of the Martian surface but as in the dry valleys of Antarctica, the rock subsurface is likely to be warmer and subjected to smaller fluctuations than the surface of the rocks. Nevertheless, the lack of a ready supply of surface water would be a significant problem for the lichens. It is a possibility, however, that in certain areas, water ice on the surface melts and penetrates the boulders, the lichens remaining in a dehydrated condition during the long intervening periods.

In Antarctica, carbon dioxide exchange takes place very slowly through a relatively thick surface crust (Kappen & Friedmann 1983) and this could presumably also take place in Martian rocks. In addition, in regions of high light intensity, approximately 1% of the light reaches the lichen zone inside Antarctic rocks, the harmful UV being screened out by the dark-pigmented fungal layer and this process would be even more important in Martian rocks. The main source of nitrogen for endolithic lichens is abiotically fixed nitrogen by atmospheric electric discharge, the fixed nitrogen then being conveyed to the rock by atmospheric precipitation. However, there are only trace amounts of nitrogen gas in the Martian atmosphere (Nier *et al.*, 2003) and hence, it is unclear how a Martian endolithic lichen would obtain its nitrogen supply. One possibility is that cyanobacteria in the rocks can fix sufficient nitrogen from the trace levels available to supply the lichens.

Conclusions

Lichens meet some but not all of the criteria that must be fulfilled by inhabitants of Mars (Salisbury, 1962). They could withstand many aspects of the hostile environment especially if they live within the rocks as they do in the dry valleys of Antarctica. Lichens, however, are dual organisms and we have to presuppose the successful establishment of a variety of microorganisms on Mars and especially algae and fungi. To date, the evidence for the existence of microorganisms in Martian meteorites is controversial and there is no conclusive evidence of present life on the surface. In addition, if endolithic lichens have evolved on Mars and are alive today they would be subjected to a considerably more hostile environment than the extreme environments on Earth, which are regarded as at the limit of tolerance of present day lichens. The lack of liquid water over most of the surface and the problem of obtaining sufficient nitrogen resources are particular problems for Martian lichens. Further landings on Mars, scheduled for 2005 and future missions are likely to substantially increase our knowledge of the Martian surface and the possibilities for life by attempting to bring back samples of rock and minerals. In addition, the use of techniques such as Laser Raman technology and the development of gas chromatographic methods for use in space increase the probability that an answer to the question of whether lichens have existed on Mars will be obtained in the near future.

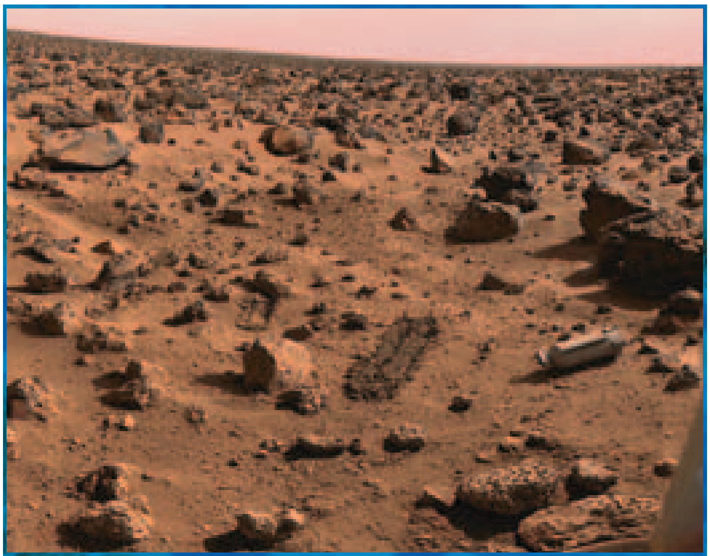


Figure 4. Viking 1 panorama of the Martian surface. Could the pitted and scarred boulders in the foreground have resulted from the activity of endolithic lichens? Photograph courtesy of Dr Edwin V Bell II (NSSDC) and Mary A. Dale-Bannister, Washington University, St Louis, USA.

Richard A Armstrong
Aston University

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