Where to look for life on the red planet

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By determining the minimum criteria for life, researchers have narrowed down the locations where life may lurk on Mars.

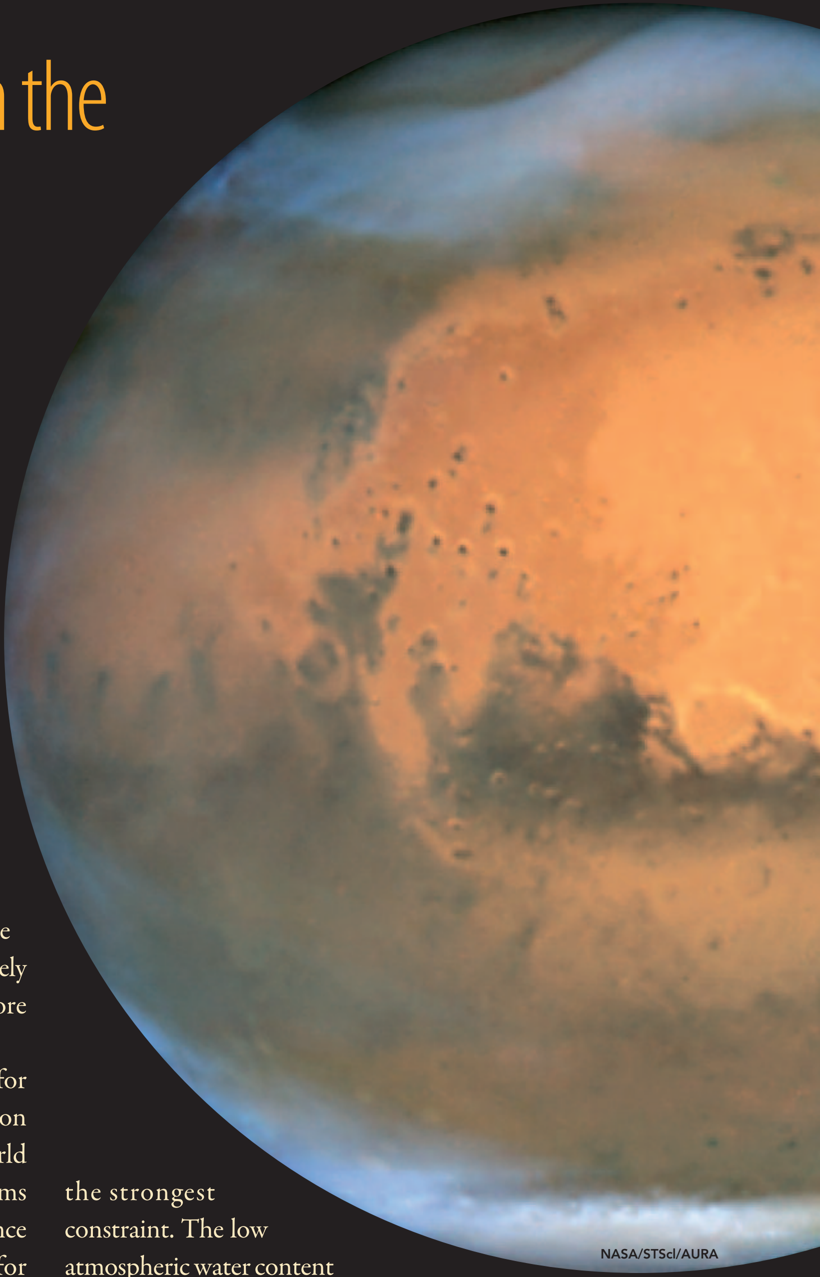
Is there life on Mars? It's a difficult question to answer when we have only closely investigated the Martian surface in six locations where missions such as the Phoenix Lander and the Spirit and Opportunity rovers have sampled it directly.

Making the question even more challenging is that it is entirely plausible that the kinds of organisms that could have evolved to inhabit Mars' unique environments have a completely different biochemistry to those on Earth, and would therefore be difficult to detect.

Despite these challenges, we have examined the chances for Earth-like life to thrive on present-day Mars. Studies of life on Earth have shown that there is strong potential for any world that harbours liquid-water to also harbour life, as all organisms require liquid-water during some phase of their life cycle. Hence searching for liquid-water is a logical approach to search for life on other planets, and "follow the water" is the mantra adopted by NASA and other space agencies.

Mars is a fascinating candidate for life as its surface is the most akin to Earth's within our local neighbourhood, and it also records the occurrence of extensive liquid-water erosion throughout the past but also the present. Throughout the past ~4.5 billion years of Martian history, liquid-water has left its mark on the surface of the planet, scarring canyons, a temporary ocean, gullies and flooding craters, and leaving extensive deposits of minerals such as clays formed through the interaction of water with Martian rock.

However, the conditions that have dominated the surface of Mars for the past ~500 million years to the present mean that any liquid-water environments are transient. Rather than the low subsurface temperatures that restrict the possible liquid-water chemistries to brines and extremely thin liquid films, it is the low abundance of water vapour within the atmosphere that provides the strongest constraint. The low atmospheric water content results in an evaporation rate at the surface that is about ten times that of Earth.



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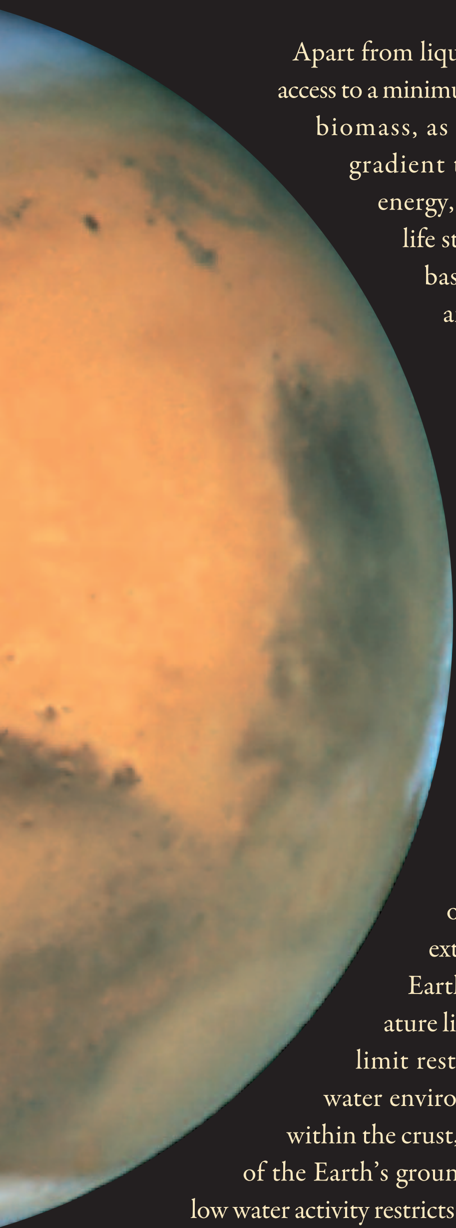
Hence, any liquid-water exposed to the Martian atmosphere will be unstable and difficult to observe. Despite this, evidence is growing that liquid-water in very small volumes runs seasonally across the surface in some locations, making Mars an exciting place to look for life.

The train of logic that we applied was that in order to assess the habitability of other planets, the minimum criteria for life must first be established. In other words, what qualities does a Martian environment need to have a chance of supporting life?

We investigated this by examining the physical attributes and chemical resources that life on Earth requires from its environment. This helped us to identify the necessary conditions for life given our understanding of the thresholds of organisms on the Earth. The approach is inevitably Earth-centred, but that is unavoidable.



Apart from liquid-water, life must also have access to a minimum quota of nutrients to build biomass, as well as a chemical energy gradient to fuel metabolism. Given energy, nutrients and liquid-water, life still has additional limitations based around the temperature and the activity of the water. Water activity refers to the availability of the water molecules for biological reactions, with high solute content (e.g. dissolved salts or sugars) and low temperature retarding the water molecules and lowering water activity.

We examined the diversity of organisms on Earth and found that, based on the currently known extent of life, the Earth's biosphere inhabits only a small subset of the full extent of liquid-water within the Earth. The current high temperature limit for life is 122°C, and this limit restricts life from many liquid-water environments below ~4 km depth within the crust, and potentially from ~53 % of the Earth's groundwater. We also found that low water activity restricts life in many cold near-surface regions in ice and permafrost. The cold liquid brines in permafrost and ice represent 3.5–15% (volume) of the soil at high latitudes, and may be inhospitable to life. These limits to life within liquid-water environments on Earth have important implications for the habitability of other planets.

The strategy of "follow the liquid-water" can be refined by including other fundamental requirements of life, such as temperature and water activity. We were interested in using pressure and temperature to model the extent of environments on Mars that are potentially hospitable for life. These two parameters of pressure and temperature are useful, as both of them increase with depth within a planet: temperature becomes warmer and the overburden pressure of rock becomes larger. As pressure and temperature determine whether water will exist in the liquid state necessary for life, these parameters can be used as a first step to search for potentially habitable environments.

So, where are there likely to be liquid-water environments in the subsurface of Mars, and are they likely to be habitable for life with similar requirements to that on Earth? Representing every Martian environment on a pressure–temperature diagram was very difficult. Although the variation in the atmosphere and surface is fairly well constrained, we have very limited information on the Martian interior.

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Instead, we had to look at geophysical models and take the best estimates of the conditions deep within the crust of the red planet. We were amazed to find that there are many pressure–temperature environments in the Martian subsurface that could be hospitable to terrestrial life.

Liquid-water on Mars can extend to a maximum subsurface depth of ~260 km, but geological constraints could restrict the maximum depth of subsurface liquid-water to anywhere between 30 km and 230 km. Using the hottest known temperature environment of life on Earth (122°C) as a guide, the potential biosphere of Mars most likely extends from the surface to an average depth of ~37 km.

The upper boundary of the potential biosphere occurs where temperatures exceed –20°C and liquid-water exists as either brines or thin films. This low temperature is an estimate of the coldest liquid-water that may have an activity high enough for active biology.

Although the conditions on the Martian surface only allow for transient liquid brine due to the low atmospheric pressure of water, our pressure–temperature model showed that there are environments at the surface and in the shallow subsurface that are potentially hospitable to life. These occur in equatorial locations with high rock abundance and dark (warm) surfaces where high humidity, exposed salts and sheltered environments promote the deposition of frost and seasonal melting.

We have concluded that the potential biosphere of Mars can extend from the surface in some locations to a typical depth of 37 km, with many subsurface environments potentially hospitable for life as long as liquid-water and a source of chemical nutrients and energy are available. These results show that Mars has a strong potential to support active biology, and should remain a prime focus in the search for life outside Earth.

We look forward to new results on Martian surface materials and their interaction with liquid-water that will be announced by the Mars Science Laboratory this August.

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