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Extremophiles

How to find life on Mars

The surface of Mars – a picture taken by Mars Pathfinder in 1997.

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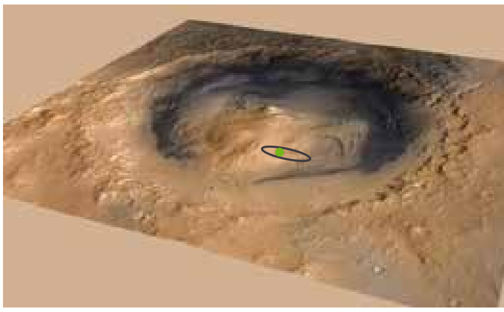
Where should we look for signs of life on Mars? Perhaps some of the strangest forms of life on Earth can give us ideas, suggest ***Louisa Preston*** *and* ***Lewis Dartnell****.*

When the Viking landers arrived at Mars in 1976 they sent back images to Earth of a rocky, dusty, red-brown landscape with no obvious signs of life. The world was watching, eagerly awaiting the results that would finally demonstrate that we are not alone in the Universe.

Since this time we have not given up hope that we might one day find life on Mars. Missions since Viking have shown us pictures of ancient rivers that used to flow on the surface and seas that may have covered large areas of the planet, and have provided evidence that water ice currently exists beneath the surface. Water has therefore been present on Mars in many forms throughout its history, providing a crucial ingredient for life.

In August 2012 our latest mission to the red planet, NASA's Mars Curiosity, finally reached and landed on the planet, searching for signs that Gale Crater – a 154 km wide impact crater just south of the equator - may have once been, or still is, a habitable environment i.e. a place with the right conditions for life to be able to survive.



NASA/JPL-Caltech/ESA/
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NASA's Curiosity rover landed in the Martian crater known as Gale Crater, which is approximately the size of Yorkshire and Lancashire combined. A green dot shows where the rover landed, well within its targeted landing ellipse, outlined in blue. The picture of the rover is an artist's impression.

What are we looking for?

The search for life on Mars focuses on two main questions – what are we looking for and where should we be looking? The answers, however, lie right here on Earth. One of the developments in recent years that really opened up scientists' eyes to the possibility of life on Mars has been the realization of just how adaptable and versatile life here on Earth is. The **extremophiles** are a broad class of organisms found surviving in the most hostile and extreme environments on the planet. These range

Two extreme sites: an acidic boiling lake and a geyser, both in New Zealand

from volcanic lakes of boiling hot, acidic water, to freezing-cold, bone dry deserts, and high up in the atmosphere bombarded by harmful radiation from the Sun. The fact that earthly organisms can tolerate such extremes bolsters our optimism that life could thrive in similar habitats on other planets and moons, but it is the survival mechanisms that these endurance superheroes use that are truly fascinating. How are these extremophiles built differently to our own cells to ensure their persistence?

There are various ways in which an environment can be deemed extreme (from our point of view). Different organisms tolerate extremes of pH (acidophiles and alkaliphiles), temperature (thermophiles and psychrophiles), salinity (halophiles), or high concentrations of toxic substances like hydrogen peroxides or heavy metals. Acidophiles, for example, thrive at very low pH by protecting the vital molecules inside their cells, like DNA and proteins, from the high concentration of protons in their environment. They're toiling constantly to pump protons back across their membrane to the outside, like a shipwrecked sailor desperately trying to bail out his leaking lifeboat. Alkaliphiles face the opposite challenge, and struggle to generate energy with too few protons in their environment.

Microorganisms can't regulate their own temperature (they can't cool themselves in the same way that we mammals can, for example, by sweating) and so instead must adapt all of their cellular machinery to different operating conditions. Thermophiles – heat-lovers – have evolved reinforced proteins to hold themselves together against the violent shaking of thermal motion at high temperatures (and so some have been co-opted for human technology). Psychrophiles, instead, must have enzymes and membranes that are loosened to remain dynamic and active even at very low temperatures. Some of the most extreme psychrophiles reside in tiny channels of salty water inside solid icebergs, growing at temperatures right down to −20°C, and are killed at human body temperature.

The halophiles grow in high salt solutions – it turns out that the Dead Sea isn't actually all that dead at all. The danger posed by very briny water outside of cells – more concentrated than their interior – is that it draws water out of the cells by osmosis and effectively desiccates them (that's the very reason we use salt to preserve meat and butter). There are two ways to deal with this. Some halophiles have modified their inner workings to cope with higher salt, keeping their inside balanced with the outside, and so safe from osmosis. Others have taken a different approach and stuff their cells with different solutes to produce an equally concentrated solution to guard against osmosis, but avoiding the issues of a briny interior. These cells protect their innards from getting too dry or salty by keeping them nice and sugary.

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The photograph on pages 10-11 shows the Mars Curiosity rover. This is a composite of 66 images taken by the rover's Hand Lens Imager and shows Curiosity on the flat outcrop of rock chosen for its first drilling operations.

For more about Curiosity's instruments, see CATALYST Vol 23 issue 1.

A self-portrait of the Mars Curiosity rover, at its first drilling site on the surface of Mars in February 2013.

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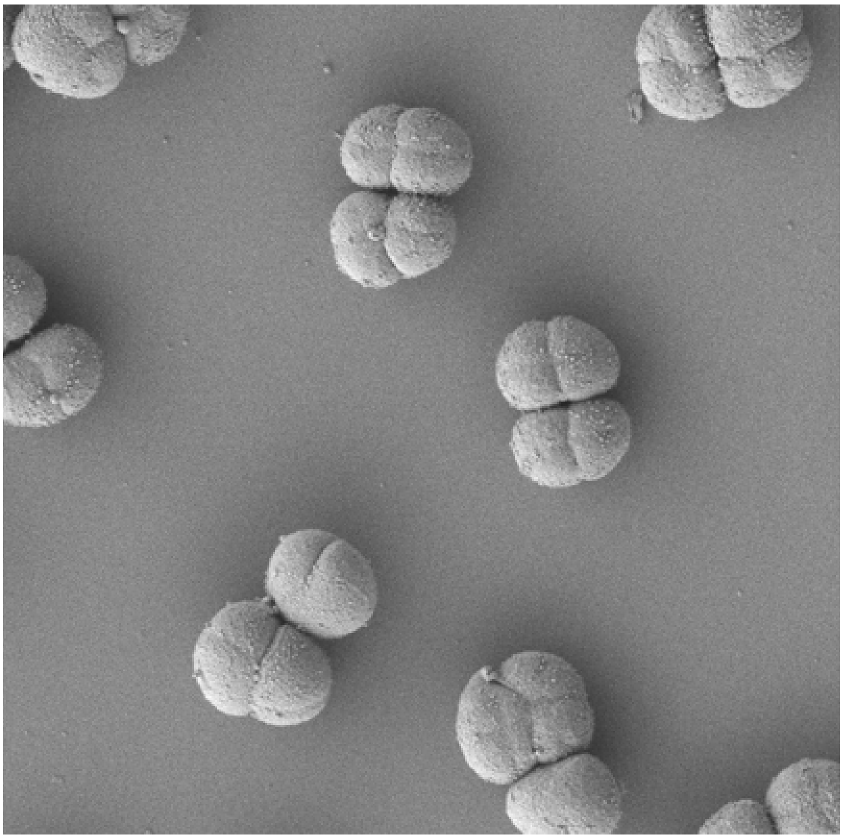
Surviving radiation

The sorts of extremophiles we focus on in our research are those able to endure very high levels of ionizing radiation. This is important because, unlike the Earth, Mars receives no shielding against cosmic radiation from its thin atmosphere and failed magnetic field. So if there is any life near the Martian surface it's going to need to tolerate this hazard alongside the cold temperatures and lack of liquid water. The most radiation-resistant organism known on Earth is a bacterium called *Deinococcus radiodurans* that can endure doses thousands of times higher than would kill human beings. In fact, this hardy little bug can prevail in such a range of hostile conditions that it's sometimes nicknamed *Conan the Bacterium*.

At first, it was a mystery as to why *Deinococcus* had ever developed such enormous tolerance of radiation - it can survive exposures far higher than those encountered in any natural environment on Earth. It is now thought that since being irradiated results in similar internal damage to the cell as being dried out, that *Deinococcus* actually evolved for desiccation tolerance, and the radioresistance is an adaptive spin-off. The organism is a master repairman, and can reassemble its radiation-damaged DNA after it is shattered into thousands of fragments, piecing it back together again like a life-or-death jigsaw. Exactly how *Deinococcus* protects itself is the subject of intense research at the moment; the hope being that we could learn how to better shield our own bodies against the harmful effects of radiation.



Radiation resistant Deinococcus*; the name means 'fearsome balls'. Each group of cells is about 3 μm across.*

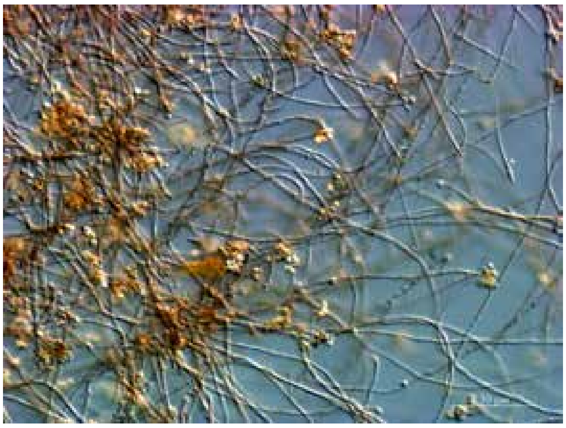
Analogue environments

All the above extremophiles can be found within hundreds of places on the Earth that mimic a physical, chemical and/or biological feature on Mars. We call these places 'analogue environments'. No analogue environment is ever a perfect replica of a site on Mars but it will have a number of specific features that can be compared and studied. We combine analogue research with laboratory simulations and data collected from Mars itself to create theories about where to look for life and what life to look for. In addition, analogue environments help us to practise methods for life detection; landing and driving rovers; and even test astronaut spacesuits and vehicles. Three places that are particularly like Mars and have been used to practise tools and techniques for searching for extra-terrestrial life are Rio Tinto in Spain, The Antarctic Dry Valleys and Iceland.

Rio Tinto, a highly acidic blood red river system in SW Spain, resembles ancient river channels on Mars. Here, the pH is so low (2.3) that only acid-loving extremophiles can survive in the waters, such as the bacteria *Leptospirillum ferrooxidans* and *Acidithiobacillus ferrooxidans.* Banks of iron-rich rocks line the sides of the river building up for the last 2 million years.

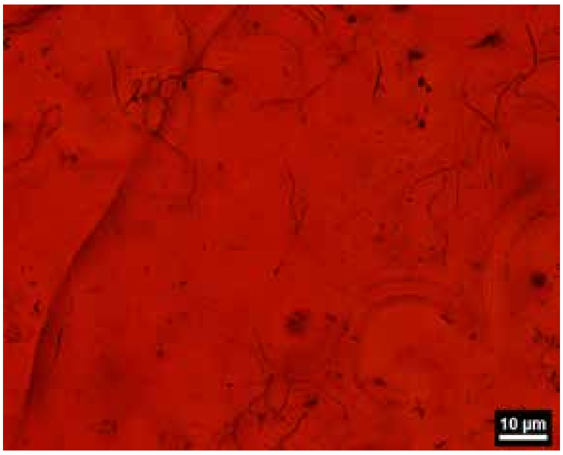
Lewis Dartnell by the Rio Tinto in Spain

The Rio Tinto in Spain resembles the rivers that might have flowed once on Mars.



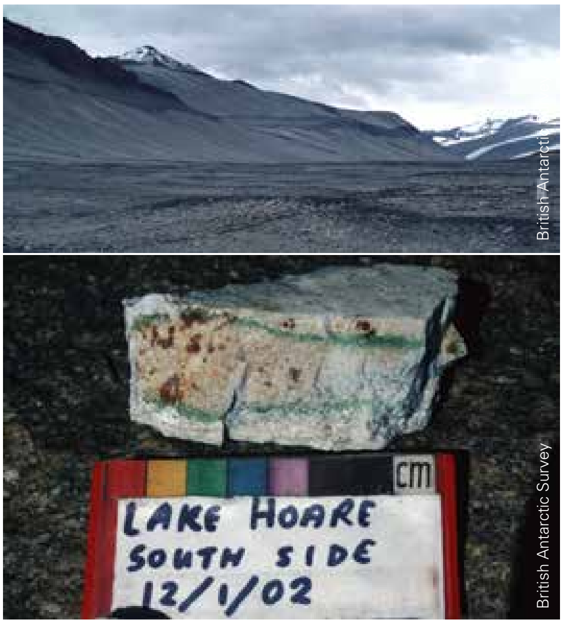
The acid-loving extremophile Acidithiobacillus ferrooxidans

Over this time, the bacteria and other microbes living in the river have been trapped inside the rocks forming black filament-like fossils, which we can study today. This site is therefore a perfect natural laboratory to study life living in the river and to compare it to that which lived millions of years ago. We can test instruments designed to identify the biomolecules that make up the bacteria, such as proteins, fatty acids and even DNA, experiment with cameras that can image the micro-organisms and rocks, and develop drills that penetrate the surface to access life buried deep within the rocks.



Fossils of bacteria from the rocks of the Rio Tinto

The Antarctic Dry Valleys are one of the most Mars-like environments found on Earth and the largest ice-free region in Antarctica. Conditions here are extremely dry and cold with temperatures recorded down to − 40 °C. The Sun's UV radiation is also very strong here which combined with the cold and lack of liquid water creates an environment that mimics the conditions on Mars today i.e. a world that is incredibly difficult for life to survive in. Life does exist here, however, as extremophilic communities of microorganisms, lichen and even tiny animals, living within the pores of sandstone rock to avoid drying out on the harsh Antarctic surface. Cryptoendolithic communities, typically a combination of cyanobacteria and lichen, are found living within the pores of sandstone rock to avoid drying out on the harsh Antarctic surface.



British Antarcti

British Antarctic Survey

A dry valley in the Antarctic; a sample showing signs of the community of organisms living within the local rock

Finally Iceland has been used for decades as an analogue environment for Mars and also the Moon. Here, NASA have tested rovers and instruments, and trained their astronauts in planetary exploration techniques and geological protocols. Iceland has numerous volcanoes and lava flows, glaciers, ice sheets and hundreds of hot springs which have all been used as analogues to similar features that are currently observed, or would once have been found, on Mars, together with many forms of extremophilic life.

Louisa Preston at a hot spring in Iceland

The search for life outside of the Earth is the backbone of the fast growing and highly exciting field of astrobiology. This subject is an oddity within science as it has yet to prove its subject matter i.e. extra-terrestrial life, actually exists. But this doesn't matter. For us it is all about the hunt for life, and at the heart of this search is the study of Earth's most exceptional organisms and the Mars-like environments they live in.

Dr Louisa Preston *is a TED Fellow and astrobiology Postdoctoral Research Associate at The Open University. Dr Lewis Dartnell is a UK Space Agency astrobiology research fellow at University of Leicester and author of 'Life in the Universe: A Beginner's Guide'*