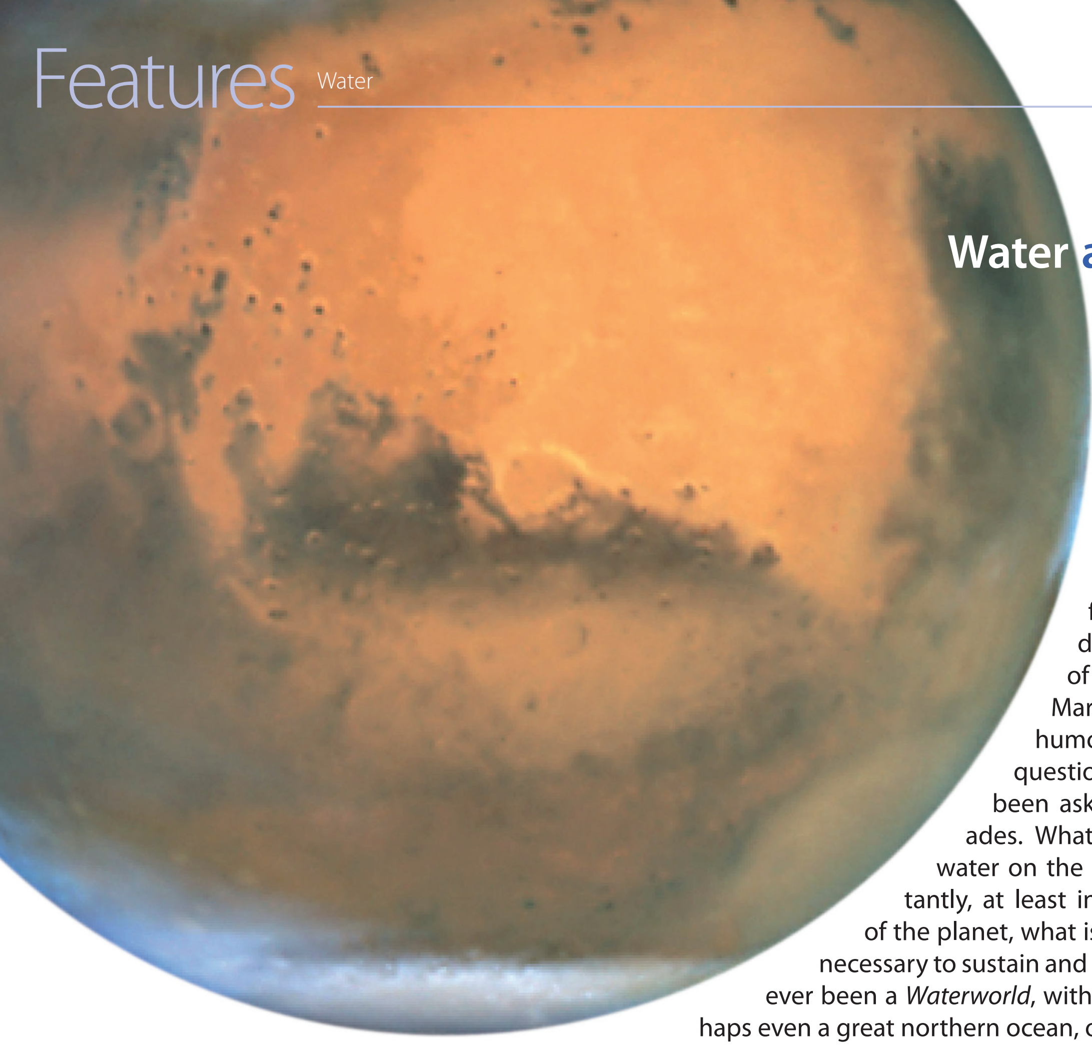

Water and life elsewhere

Mars:

There's an old email that's been doing the rounds for a while now, proclaiming that water has been found on Mars. The attached image double-clicks open to show a glass of water smartly balanced atop a Mars chocolate bar. Very droll, but this humour does hint at a fundamental question that planetary scientists have been asking about the red planet for decades. What is the prevalence and history of water on the surface of Mars? And more importantly, at least in terms of the biological potential of the planet, what is the story of *liquid* water: the state necessary to sustain and support life as we know it. Has Mars ever been a *Waterworld*, with long-standing lakes, seas and perhaps even a great northern ocean, or has the red planet forever been a desert, like Frank Herbert's science-fiction creation, Arrakis, the *Dune* planet?

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Historically, the most famous proponent of a wet Mars was Percival Lowell, the wealthy businessman who, in 1894, built himself a world-class telescope to observe the red planet with unprecedented clarity. Lowell's story is well known, as, over the years, he convinced himself that he could see an extensive network of apparently artificial canals criss-crossing the Martian globe, supposedly carrying precious melt-water from the polar ice caps to the great equatorial cities of a dying civilization.

The optical illusions and observational psychology central to this curious phenomenon are fascinating in their own right, but sadly the support for alien cities or even for such linear features on the surface evaporated with improved telescope observations. The legacy of Lowell's hopes was utterly dashed with the arrival of the first robotic explorers at Mars. The *Mariner* probes beamed back photographs of a truly bleak landscape: a string of colossal volcanoes, dusty dry plains and ancient impact craters, but no vegetation, no seas of water, and certainly no abandoned cities or mega-engineering projects. The only real feature on the Martian surface that has any correlation to Lowell's described canals is a great crevice slashing over 4000 km across the face of Mars, named Valles Marineris after the probe that discovered it. It was clear that the current Martian environment is no pleasant place for life: a gaspingly thin atmosphere provides neither the air pressure nor the greenhouse warming necessary to provide conditions for liquid water across the surface. Today, Mars is a freeze-dried desert more arid than any on Earth.

Optimism began to return about Mars, however, with a later generation of probes. The *Viking* orbiters carried far superior cameras, and could make out some very exciting features on the red planet. Many of these *Viking* images have become iconic and, pieced together, tell the story of a warmer, wetter Mars. Great channels, some tens of kilometres wide and running for thousands of kilometres, can be seen carving their way from the ancient ice-laden highlands of the southern hemisphere and spilling out into impact craters and the huge low-lying basin encircling the northern pole. Other smaller features are even more obviously fluvial: networks of valleys merging together in a system of tributaries and meandering downstream. The floors of some craters show clear concentric rings of sedimentation, deposited as a lake seeped away over time or perhaps even repeatedly topped up by a series of flash floods spilling in.

Waterworld or Dune?

Claiming these landforms as signs proving ancient flowing water is tempting, but interpreting orbital remote images is notoriously difficult, even on our own well-understood world, and confirmation of the prior action of liquid water requires ground-truth. This unmistakable evidence was discovered in just the last few years by a pair of probes, the NASA twin rovers *Spirit* and *Opportunity*, still exploring the rusty surface today.

Opportunity bounced onto the Martian surface in 2004, safely cocooned within its shell of airbags, and fortuitously came to rest right inside a shallow impact crater. The probe had been targeted to Meridiani Planum, a region thought to have once hosted an aqueous environment on Mars. As the probe first raised its robotic eyes, the mission controllers knew they had hit scientific gold: the exposed bedrock on the sides of the crater showed layers of sedimentation, perfect hunting grounds for signs of the action of water. During the early stages of the probe's mission, the geologists were able to determine, using several independent lines of evidence, that Meridiani Planum did indeed once contain a long-lasting sea.

Meanwhile, on the other side of the planet, *Spirit* has also made some ground-breaking discoveries of its own. In December of last year, it was announced that, while looking back at its own wheel ruts, *Spirit* had uncovered a patch of bright soil, rich in silica. The soil is composed of more than 90% silica, and there aren't many ways geologists know that such concentrated deposits can be created. The two possibilities that are being debated are that *Spirit* may have stumbled across an ancient hot-spring environment or alternatively a fumarole, a site where acidic steam rises through cracks in the ground. Both of these scenarios involve the action of hot water, and, on Earth, such environments absolutely teem with microbial life.

There is even mounting evidence that the large depression encircling the northern hemisphere of Mars once held a great ocean. The ground of the northern basin is much younger than that of the ancient southern highlands, and is curiously flat and smooth. Many of the giant outflow channels described above spill out into this basin, and it is clear that very large volumes of liquid water were dumped into the region. Some planetary scientists also point to a string of features that apparently form a contour running continuously around the basin: the shoreline of an ancient ocean? This interpretation has been fiercely debated, not least because the proposed shoreline doesn't actually run at a constant height: how can there be a shoreline that doesn't follow sea level? The plot thickened last June, however, when research was published showing that the potential shoreline is in fact level if the rotational axis of Mars has shifted in the long aeons since the disappearance of the ocean, the entire planet tipping upwards to its present orientation.

Figure 1. *Waterworld*: an unnamed impact crater located on Vastitas Borealis, a broad plain that covers much of Mars's far northern latitudes, at approximately 70.5° North and 103° East. The crater is 35 km wide and has a maximum depth of approximately 2 km beneath the crater rim. The circular patch of bright material located at the centre of the crater is residual water ice. Image taken on 2 February 2005 with the High Resolution Stereo Camera on The European Space Agency's Mars Express. [© ESA/DLR/FU Berlin (G. Neukum)]

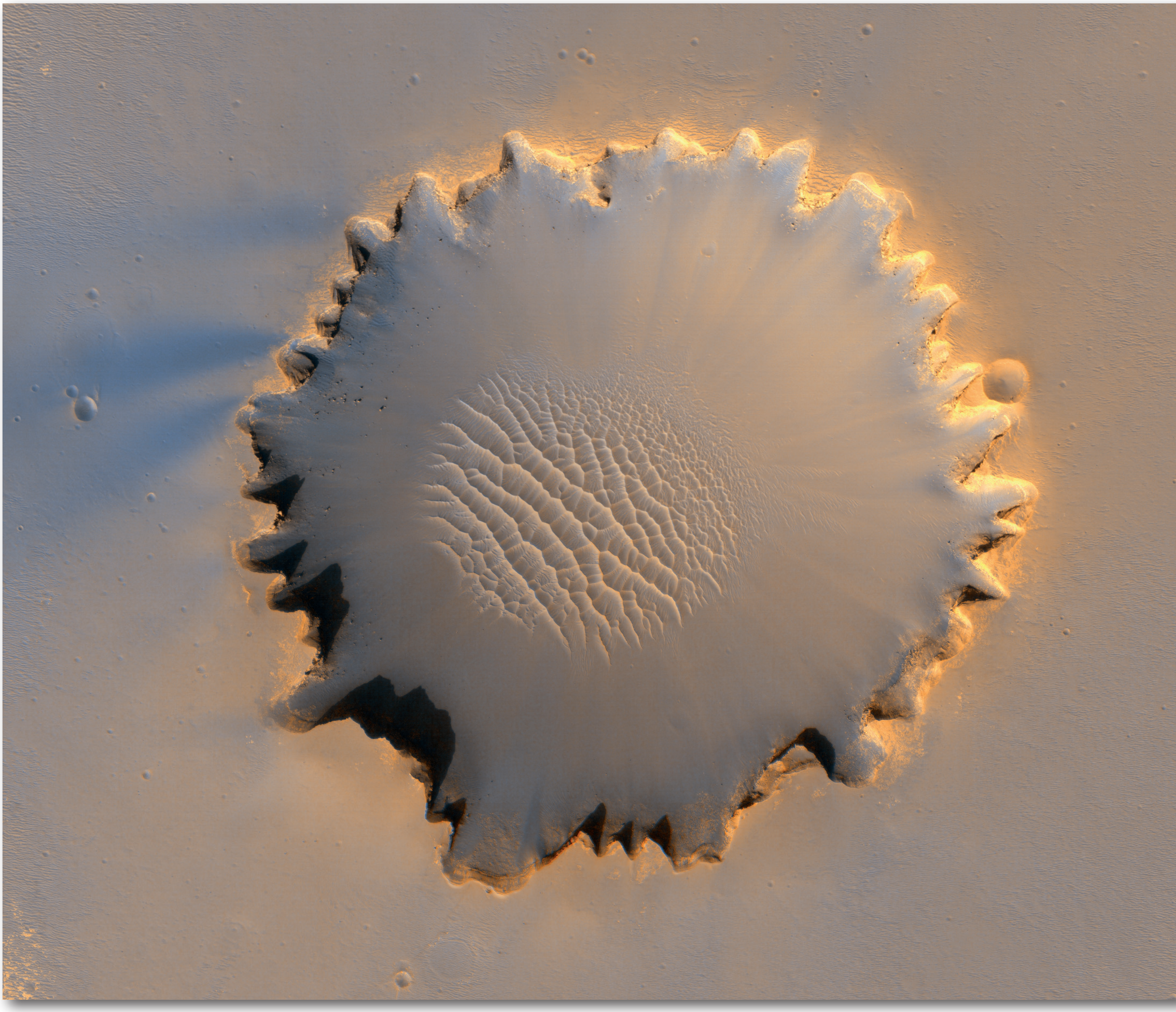

Figure 2. *Dune*: an image of the Victoria crater, an impact crater at Meridiani Planum near the equator of Mars from the High Resolution Imaging Science Experiment on NASA's Mars Reconnaissance Orbiter. The crater is approximately 800 m in diameter. It has a distinctive scalloped shape to its rim, caused by erosion and downhill movement of crater wall material. Layered sedimentary rocks are exposed along the inner wall of the crater, and boulders that have fallen from the crater wall are visible on the crater floor. The floor of the crater is occupied by a striking field of sand dunes. (© NASA)

So from many converging lines of evidence then, it does seem that Mars has been a *Waterworld*, at least at some point in its early history. But since these wetter ages, some form of environmental collapse appears to have befallen the planet, leaving its surface a desiccated wasteland. This is believed to be closely linked to the loss of the planet's once-thick atmosphere: the death of large-scale volcanism stopped topping-up the atmosphere with warming greenhouse gases and the loss of a global magnetic field like the Earth's allowed the air to steadily bleed away into space, blown away by the solar wind.

Martian life?

The big question, however, is whether the aqueous environments on primordial Mars could ever have been conducive to the development and survival of microbial life, and whether certain niches may even remain inhabited to this day. The geochemistry of the deposited minerals examined by *Opportunity* indicate that the Meridiani sea was very acidic, probably from sulfurous volcanic gases dissolved in the water. There are examples of ultra-hardy organisms on Earth, known as extremophiles, which can survive in similar harsh environments. The Rio Tinto river in Spain is also strongly acidic and laced with toxic metal ions, and is thought to be a close analogue of such Martian waters. Even here, there is a rich diversity of microbial life. The molecular mechanisms for acidity survival are not yet well understood, but many acidophiles are able to maintain their cytoplasm at near-neutrality by using membrane pumps to constantly bail out the excess protons.

"Whether life could ever have got started in such an acidic environment is another issue, however. Many of the acid-tolerant lifeforms on Earth have adapted to these extreme conditions from less hazardous habitats (indeed, their survival mechanism involves maintaining their interior environment at near-neutrality").

Meridiani also seems to have periodically dried out, before being flooded with water again, and these periods of desiccation would probably have been extremely challenging for any organisms. Certain terrestrial organisms have adapted to endure periods of desiccation, and bacterial spores have even been extracted from salt crystals millions of years old and found to be still viable. If Martian life did find a foothold within the Meridiani Sea, then, the plains left behind as it dried up may provide ideal preservation conditions. Microfossils of bacterial life can be spectacularly preserved in terrestrial sulfate precipitates or iron oxide minerals, as found at Rio Tinto, for example.

Whether life could ever have got started in such an acidic environment is another issue, however. Many of the acid-tolerant lifeforms on Earth have adapted to these extreme conditions from less hazardous habitats (indeed, their survival mechanism involves maintaining their interior environment at near-neutrality). Furthermore, the systems of prebiotic chemical reactions that produce organic molecules necessary for the emergence of life are also very sensitive to acidity. Many of the chemical processes thought to be important in generating the building blocks of life, such as amino acids, nucleobases and sugars, are inhibited by low pH. On the other hand, the concentration of reagents and promotion of polymerization reactions by evaporation or freezing of water in environments such as Meridiani Planum would have enhanced some aspects of chemical evolution. Of course, it is not necessarily true that all liquid water throughout Martian history was as acidic, and possible crucibles for the development of life on the surface, or perhaps even underground, may yet be discovered.

Waterworld to *Dune*

If life did emerge early in the history of the red planet, a genesis independent of that on Earth, it certainly would have found things getting steadily more uncomfortable as the Martian environment deteriorated. With the atmosphere leaking away, surface temperatures would have plummeted and liquid water become ever more vanishing. Remaining water became increasingly salty and toxic as the lakes and seas dried up, tightening the noose on persevering life. From about 3.5 billion years ago, Mars slipped from a *Waterworld* to a *Dune*.

Beyond the current aridity on Mars, any extant microbes must also survive a number of other environmental hazards. The Martian surface is bathed in the lethal UV radiation from the Sun, and exposed cells would be killed in minutes. Over long aeons of time, this unrelenting flux of solar UV is also thought to have built up high levels of chemical oxidants in the Martian soil. Any cells or organic molecules within this wind-blown top layer would be destroyed rapidly, and probe designers now recognize the need to be able to drill or dig beneath this oxidizing layer for any hope of finding Martian organics or persisting life. The lack of a global magnetic field or substantial atmospheric shield also means that the surface of Mars is unprotected from cosmic rays: highly energetic particle radiation flung out from solar flares or exploding stars throughout our galaxy. My research has been looking into this particular hazard: characterizing this radiation environment and working out how deep life might need to be to remain protected for long periods of time.

For various reasons, then, any surviving Martian life is likely to be sheltered away from the very surface. One potential habitat is inside miniscule crevices and pore spaces within rocks, so called endolithic niches. Such communities are found in the Dry Valleys of Antarctica, where the endolithic niches provide a warmer, wetter microenvironment than the punishing conditions outside. Lying just beneath the surface also allows photosynthetic organisms to remain productive, as the thin layer of translucent rock effectively filters out the harmful UV glare.

The best bet for life surviving on Mars, however, will be deeper underground, safely protected from the oxidizing conditions and cosmic radiation. One hope is that several kilometres deep in the Martian crust, the shell of permafrost ice has melted in the warmth of the planet's interior to provide habitable aquifers of water. Within such a deep biosphere, microbial ecosystems may be powered by inorganic redox reactions, just like terrestrial chemoautotroph life. For example, geologically produced hydrogen could fuel microbes that release methane as a by-product. Intriguingly, plumes of methane gas have recently been discovered rising up from the Martian ground. Could this be the first evidence for niches of extraterrestrial life, hiding deep beneath the surface of the *Dune*-like world that Mars has become? ■

Lewis Dartnell researches the possibility of Martian life at University College London. His new book on the science of astrobiology and the search for life beyond Earth, 'Life in the Universe: A Beginner's Guide', is reviewed on page 36 of this issue.