MARS

Ancient fingerprints in the clay

David C. Catling

The thermodynamics of ancient clays on Mars seems inconsistent with the idea that a thick atmosphere of carbon dioxide caused a warm, wet era in the planet's early history. What did cause it remains an enigma.

Volcanic rocks dominate the surface of Mars. In the cold, dry conditions that prevail there today, these rocks can persist with little chemical alteration. But the recent discovery by Mars orbiters and landers of sulphate and clay deposits on the planet indicates that Mars' ancient environment was different, and involved liquid water[1]. On page 60 of this issue[2], Chevrier *et al.* add a new twist to this idea, with calculations showing how ancient martian clays formed in aqueous environments, but with little carbon dioxide present. That runs contrary to a popular view of an early Mars where liquid water was sustained by the greenhouse effect of a thick, CO_2-rich atmosphere.

Evidence that Mars was wetter before about 3.7 billion years ago comes from various geomorphic features[1]. In particular, valleys with characteristic branching forms seem to have been eroded by water, and some evidence also argues for the influence of rainfall. The heavily degraded rims of ancient craters and crater infilling are similarly interpreted as fluvial features in some models.

But whether a warmer, wetter earlier climate on Mars was persistent, intermittent or even existed at all remains controversial. If it did exist, what caused it? The idea that Mars' early atmosphere contained much more CO_2 than it does now is an appealing suggestion. More CO_2 provides greater warmth through its own greenhouse effect, together with that of increased water vapour. Because the early Sun was about 25% fainter around 3.5 billion years ago than it is today, several bars of CO_2 pressure would be required to achieve the necessary warming (1 bar is Earth's approximate atmospheric pressure).

At around 1.5 bar, however, CO_2 ice clouds start to form under the faint Sun. It has been suggested that these clouds might themselves produce warming, but up-to-date models show that CO_2 particles precipitate out or dissipate and cannot sustain a sufficient greenhouse effect[3]. Moreover, a substantial amount of atmospheric CO_2 should have left behind carbonate deposits. But on Mars' surface, not a single carbonate outcrop has been identified down to a horizontal scale of 100 metres. One possibility is that carbonates did not form because waters were rich in sulphuric acid, which displaces CO_2 (ref. 4). Although this is true in equilibrium, it still leaves the temporal evolution of CO_2 in the martian atmosphere unresolved.

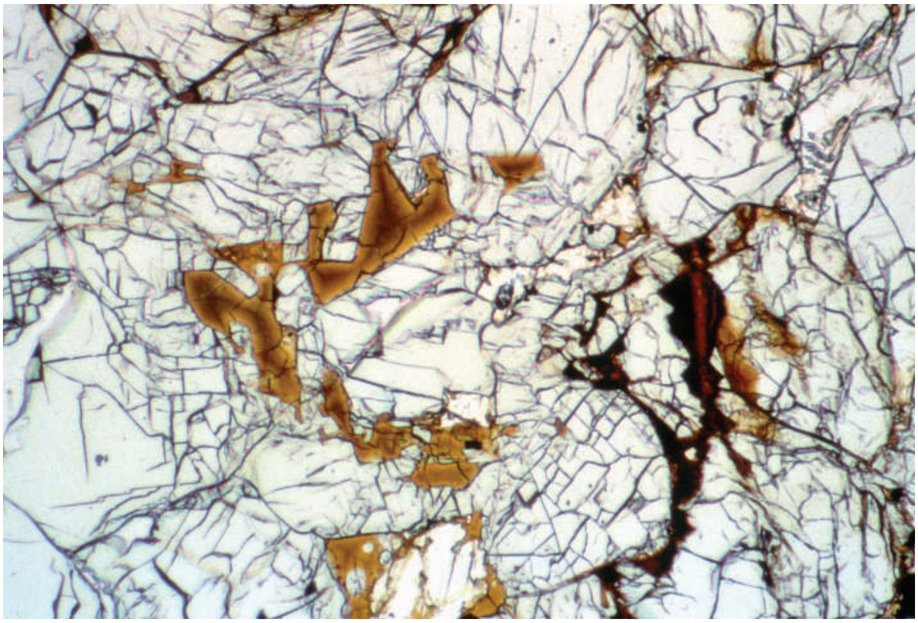

Figure 1 | Subsurface smectites. The yellow, reddish-brown and black veinlets in this view (about 1 mm across) of the 'Lafayette' martian meteorite are mixtures of clay and iron oxides that formed when small amounts of saline water infiltrated bedrock beneath Mars' surface and reacted with basaltic mineral grains. The presence of such clays beneath the martian surface is one caveat to interpreting Chevrier and colleagues' findings[2] as clinching evidence against a carbon-dioxide-rich early martian atmosphere. (Picture courtesy of A. Treiman, Lunar and Planetary Institute.)

Chevrier *et al.*[2] contribute to this debate by considering the thermodynamic equilibrium of clay minerals known as smectites. These clays, which have a characteristic layered-sheet structure, are found on Mars in both iron-rich and aluminium-rich forms. During the process of aqueous weathering, soluble ions are leached from 'primary' igneous rocks. 'Secondary' salts and clays, such as carbonates, sulphates and smectites, subsequently precipitate from the leaching fluid. What secondary minerals are deposited depends sensitively on the composition, pH and temperature of the leaching fluid. These minerals are consequently 'Rosetta stones' for deciphering past environments.

Chevrier *et al.* show that the equilibrium between carbonates and smectites implies the presence of less than 0.001 to 0.01 bar CO_2 in Mars' early atmosphere for smectites to predominate as observed. Moreover, the neutral to alkaline conditions required to form the clays are inconsistent with the presence of sulphuric acid postulated to explain the absence of large carbonate deposits. According to this model, Mars' extensive sulphate deposits date from a later, more acidic geochemical era.

The lack of CO_2 in the early martian atmosphere could be explained by its early atmospheric loss. Mars' gravity is two-fifths that of Earth, making two processes, hydrodynamic escape and impact erosion, effective. Hydrodynamic escape would have occurred during Mars' first few hundred million years, when atmospheric hydrogen flowed out in a 'planetary wind' — analogous to the solar wind — that dragged along and removed heavier gases. Impact erosion results from the cumulative effect of large impacting bodies releasing enough energy to blast parts of the atmosphere away. There is evidence for both processes in noble-gas isotopic ratios on Mars.

In the absence of CO_2, Chevrier *et al.* suggest[2] that other greenhouse gases promoted warmth. One candidate is methane; but methane is decomposed by ultraviolet sunlight, so a methane source comparable to Earth's biosphere would be needed to warm Mars above freezing. Another possibility is sulphur dioxide (SO_2), which, judging by the bulk chemistry of martian meteorites, could have been released from martian volcanoes in amounts similar to or exceeding their water emission. But SO_2 is soluble, and could have acted only as a 'lever' to raise temperatures to near freezing, making it easier for perturbations, such as asteroid or comet impacts, to cause temporary wet climates. Such impacts would have flash-heated the surface and released water, producing rain and erosion. Irrespective of any long-term greenhouse effect, the conclusion seems unavoidable that Mars was warmed transiently by many impacts early in its history[5].

A pivotal assumption made by Chevrier *et al.* is that the clays were formed in equilibrium with the atmosphere. But if the clays were formed in isolation from the atmosphere, beneath the surface, their thermodynamics might be of little relevance. Smectites are found in martian meteorites (Fig. 1) that formed in the subsurface when small amounts of saline waters infiltrated basalt[6]. Generally, suitable subsurface environments include long-lived hydrothermal systems that result from impacts on ice-rich ground; indeed, on Earth, smectites are characteristic of some hydrothermal systems in impact craters[7].

A further unresolved problem is that sulphates are found on Mars in places that range from young deposits around the planet's northern cap[8] to the ancient Meridiani outcrops[9], which are thought to be more than 3.7 billion years old. The stratigraphy of sulphate-rich deposits in an enormous chasm, Juventae Chasma, suggests that some of those deposits are similarly ancient[10]. The interpretation of Chevrier and colleagues' findings could therefore be more complicated than a geochemical history of an early age of clays succeeded by a sulphate era.

The history of recent Mars exploration shows that observations on the ground can completely overturn ideas inferred from orbit. Gusev Crater was chosen as a landing site for NASA's Spirit rover because it was interpreted from above as a lakebed. But what the rover found was a largely basaltic surface, rather than fluvial sediments. Meridiani Planum was selected for NASA's Opportunity rover because orbital data showed abundant haematite. But surface minerals there proved to be even richer in sedimentary sulphates.

Only a complete picture on the ground can provide confidence about the early environment of Mars, and whether it was ever conducive to life. Two rovers, NASA's Mars Science Laboratory rover and the European Space Agency's ExoMars, planned for launch in 2009 and 2013, respectively, might supply the answers — if targeted to the clays and sulphates of the planet. ■

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1. Carr, M. H. *The Surface of Mars* (Cambridge Univ. Press, 2006).
2. Chevrier, V., Poulet, F. & Bibring, J.-P. *Nature* **448,** 60–63 (2007).
3. Colaprete, A. & Toon, O. B. *J. Geophys. Res. Planets* **108,** doi:10.1029/2002JE001967 (2003).
4. Fairen, A. G., Fernandez-Remolar, D., Dohm, J. M., Baker, V. R. & Amils, R. *Nature* **431,** 423–426 (2004).
5. Segura, T. L., Toon, O. B., Colaprete, A. & Zahnle, K. *Science* **298,** 1977–1980 (2002).
6. Treiman, A. H. & Lindstrom, D. J. *J. Geophys. Res. Planets* **102,** 9153–9163 (1997).
7. Naumov, M. V. *Geofluids* **5,** 165–184 (2005).
8. Langevin, Y., Poulet, F., Bibring, J.-P. & Gondet, B. *Science* **307,** 1584–1586 (2005).
9. Squyres, S. W. *et al. Science* **313,** 1403–1407 (2006).
10. Catling, D. C. *et al. Icarus* **181,** 26–51 (2006).

SYNTHETIC BIOLOGY

Designs for life

Philip Ball

The genome of one bacterium has been successfully replaced with that of a different bacterium, transforming one species into another. This development is a harbinger of whole-genome engineering for practical ends.

If your computer doesn't do the things you want, give it a new operating system. As they describe in *Science*[1], Carole Lartigue and colleagues at the J. Craig Venter Institute in Rockville, Maryland, have now demonstrated that the same idea will work for living cells*.

In an innovation that presages the dawn of organisms redesigned from scratch, the authors report the transplantation of an entire genome between species. They have moved the genome from one bacterium, *Mycoplasma mycoides*, to another, *Mycoplasma capricolum*, and have shown that the recipient cells can be 'booted up' with the new genome — in effect, a transplant that converts one species into another.

This is likely to be a curtain-raiser for the replacement of an organism's genome with a wholly synthetic one, made by DNA-synthesis technology. The team at the Venter Institute hopes to identify the 'minimal' *Mycoplasma* genome: the smallest subset of genes that will sustain a viable organism[2]. The group currently has a patent application for a minimal bacterial genome of 381 genes identified in *Mycoplasma genitalium*, the remainder of the organism's 485 protein-coding genes having been culled as non-essential.

This stripped-down genome would provide a 'chassis' on which organisms with new functions might be designed by combining it with genes from other organisms — for example, those encoding cellulase and hydrogenase enzymes, for making cells that respectively break down plant matter and generate hydrogen.

Mycoplasma genitalium is a candidate platform for this kind of designer-genome synthetic biology because of its exceptionally small genome[2]. But it has drawbacks, particularly a relatively slow growth rate and a requirement for complex growth media: it is a parasite of the primate genital tract, and is not naturally 'competent' on its own. Moreover, its genetic proof-reading mechanisms are sloppy, giving it a rapid rate of mutation and evolution. The goat pathogens *M. mycoides* and *M. capricolum* are somewhat faster-growing, dividing in less than two hours.

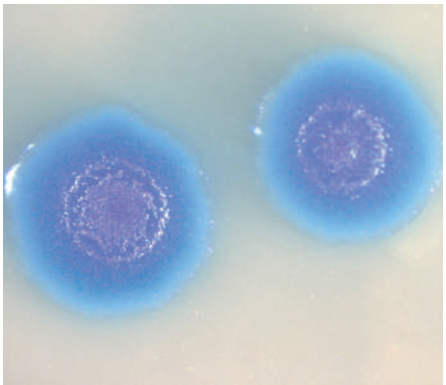
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Figure 1 | **Genome swap.** Colonies of the transformed bacteria (about 1 mm across).

Incorporation of foreign DNA into cells happens naturally, for example when viruses transfer DNA between bacteria. And in biotechnology, artificial plasmids (circular strands of DNA) a few kilobases big are routinely transferred into microorganisms using techniques such as electroporation to get them across cell walls. In these cases, the plasmids and host-cell chromosomes coexist and replicate independently. It has remained unclear to what extent transfected DNA can cause a genuine phenotypic change in the host cells — that is, a full transformation in a species' characteristics. Two years ago, Itaya *et al.*[3] transferred almost an entire genome of the photosynthetic bacterium *Synechocystis* PCC6803 into the bacterium *Bacillus subtilis*.
