NEWS & VIEWS

MARS

The flow and ebb of water

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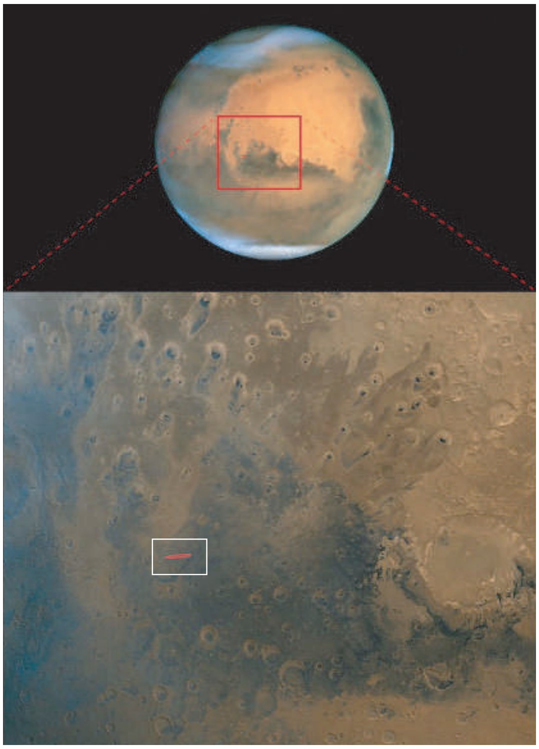
Information is pouring in about Mars. These are thrilling times for those who are proposing — and challenging — ideas about the chemical evolution of the planet and its potential for having harboured life.

Was Mars ever wet and warm for long enough to have been a crucible for life? Taking the existence of liquid water as a necessity for life, argument about that question has lately become increasingly intense and fast-moving. The newest proposals appear in two papers in this issue[1,2], in which volcanic activity and meteorite impact are respectively put forward to explain martian chemistry previously invoked as evidence for the action of water.

That water once flowed on the surface of Mars seems clear from decades of awe-inspiring spacecraft images of valley networks and giant fluid-carved channels. Most of the valley networks are in the most ancient terrains, however, and were possibly formed only by the melting of ice by impacting debris left over from the formation of the Solar System. The magnificent channels that debouched into the northern plains apparently released as much water as is found in the Mediterranean Sea, but they too were probably ephemeral. And yet, for decades, extensive spectroscopic searches for water-altered minerals, such as clays, carbonates and sulphates, yielded nothing definitive. From the geological evidence, and from climate models that consistently implied enduring and intensely cold conditions, it was difficult to escape the conclusion that Mars had almost always been in a deep freeze.

Then, in the late 1990s, the Thermal Emission Spectrometer on board the orbiting Mars Global Surveyor detected small patches of grey haematite in isolated locations on the surface[3]. This kind of haematite almost always requires liquid water for its formation. Its signature was the siren song that lured the Opportunity rover to Mars' Meridiani Planum (Fig. 1), a flat, volcanic and sedimentary plain on Mars just east of the giant canyon system Valles Marineris. Opportunity is one of two Mars Exploration Rovers whose mission has been to look for geological and geochemical signs that Mars may once have had an environment conducive to life. What was missing until the rovers' expedition was definitive evidence that water had at one time had a significant chemical role in the evolution of the martian surface, as it has had on Earth.



NASA/HUBBLE HERITAGE TEAM/US GEOL. SURV.

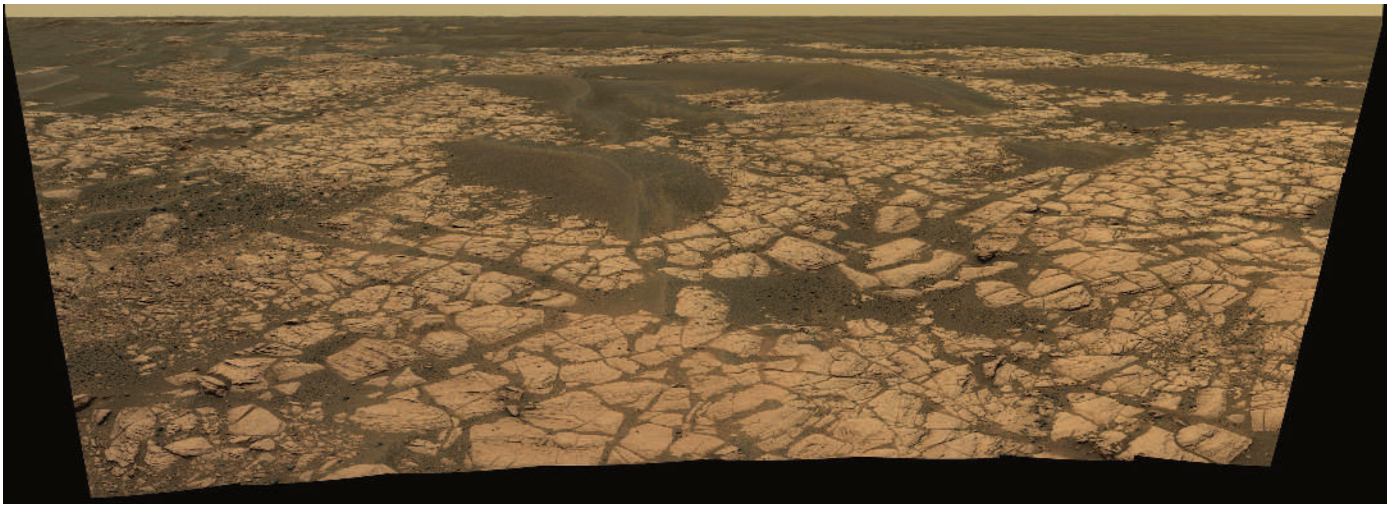
Figure 1 | Opportunity's site of operation. Top, an image of Mars taken by the Hubble Space Telescope during Mars' closest approach to Earth in June 2001. Bottom, the Meridiani Planum region compiled from Viking Orbiter images taken in 1980 during mid-northern summer on Mars. The red ellipse on the left is about 87 km long and marks the landing zone of the Opportunity lander. The large circular feature on the right is the Schiaparelli impact crater.

What Opportunity has achieved, from the moment it swung into action on 25 January 2004, has been stunning. It landed on Mars within metres of a rock outcrop, and detailed analyses of this and other outcrops at many locations over its 2-kilometre (and counting) traverse across the plains of Meridiani show that they are composed of layered sandstones. Those sandstones are primarily made of mixtures of magnesium sulphates, iron sulphates and silicon-rich, sand-sized particles of rock. Dispersed across the plains and within the sandstone matrix are enigmatic nodules of almost pure haematite[4].

The rovers' team has been consumed with trying to understand how the sulphate-rich layers were formed. The most comprehensive data so far have come from a 7-metre-high exposure within Endurance crater, some 800 metres from Opportunity's landing site. Here, the team has documented a complex history of events from a careful analysis of the stratigraphy, textures and composition of the entire exposure. Remarkably, these investigations at Endurance were completed after about 320 sols, or martian days, four times longer than the design lifetime of the rovers. The team concludes that the sandstones were formed by the erosion and redeposition of fine-grained silicate particles and evaporites that were derived from the chemical weathering of volcanic rocks by acidic waters. These volcanic rocks, called olivine basalts, are iron- and magnesium-rich silicates that are known to crystallize first from a molten magma source. They are commonly found at terrestrial hot-spot volcanic sites on Earth, such as Hawaii.

The uppermost sections of the Endurance exposure exhibit cross-bedding, which indicates deposition in shallow waters that once existed in a playa-like setting between sand dunes. Jarosite, an iron sulphate that forms only at extremely low pH, probably precipitated from these waters, and the variety of intergranular cements, haematite concretions and crystal 'moulds' attests to multiple episodes of inundation resulting from changes in groundwater levels[5].

This is the conclusion challenged by the papers in this issue[1,2]. McCollom and Hynek[1] (page 1129) hypothesize that the deposits seen at Meridiani were instead produced by the deposition of volcanic ash, followed by alteration of that ash by small amounts of acidic water and sulphur dioxide. Their primary observation, from an analysis of the data from Eagle crater during the first 45 sols of the



NASA/JPL/CALTECH/CORNELL UNIV.

Figure 2 | Sulphate, sulphate everywhere. **Opportunity's view of a vast field of sulphate-rich sedimentary rocks encountered on the way from Endurance crater to Victoria crater. This is an outcrop dubbed Olympia, near the Erebus crater. The view is to the south, in the direction of Opportunity's traverse. Outcrops such as these are common along the traverse, attesting to the large extent of these deposits.**

mission, is that the composition of the outcrops seen at Meridiani seems very like that of typical martian basalts (measured both *in situ* and in the Shergotty meteorites found on Earth) with sulphur added. They point out that any model of the chemistry of the Meridiani rocks must explain why the rocks are enriched in sulphate but not in any major cations — if the sulphate were attributable to precipitation of salts from an evaporating brine, the rocks would be enriched in a balancing cation such as calcium, magnesium or iron. This is not observed. However, this reasoning is valid only if the silicate particles in the outcrop are themselves unaltered. Cations could have been removed from the silicate portion by acid weathering before incorporation in the outcrop, and this would not have been detectable by the rover instruments. McCollom and Hynek's explanation for the exposed bedrock is that it was originally a basaltic ash deposit resulting from an explosive volcanic process, and was subsequently altered through reaction with an aqueous sulphuric acid solution derived from condensation of vapours rich in sulphur dioxide and water.

The patterns in the features seen at the Meridiani outcrops are also observed in volcanic ash deposited by surges of explosive volcanism on Earth. If McCollom and Hynek's scenario for the formation of the Meridiani deposits is correct, the origin and modification of these sediments would have occurred at high temperature with little groundwater (and no surface water), greatly reducing the possibility that these rocks indicate that a habitable environment ever existed at Meridiani.

In the second paper in this issue, Knauth *et al.*[2] (page 1123) propose a scenario for the origin of the Meridiani sulphate deposits that is similarly pessimistic about the evidence for past water. Their explanation is that the deposits were produced by a ground-hugging, turbulent surge of rock fragments, salts, sulphides, brines and ice produced by the impact of a meteorite. Subsequent weathering by intergranular water films could then account for all of the features observed, without invoking the existence of shallow seas, lakes or near-surface aquifers. It is possible that the layers traversed by Opportunity resulted from one impact event, possibly the one that produced the 450-km-wide Schiaparelli crater lying about two crater diameters to the east (Fig. 1).

Knauth *et al.* note that the patterns of sedimentary structures created by surges closely resemble those produced by wind and deposition in a shallow body of water. Because of the complexity of the flow of ejecta generated by an impact, a remarkably wide range of depositional conditions can develop that look very much like those found in other sedimentary environments. Once in place, the heterogeneous jumble of phases would undergo alteration by small amounts of interstitial waters.

All interpretations of scientific results from other worlds have the same difficulty: extrapolations from terrestrial experience must be made from limited spacecraft data. Earth's geological history is rich and complex, and that of Mars must surely have been as well. The two papers in this issue have much in common, especially given the ultimate goal of the Mars rovers — to search for evidence of past habitable conditions on Mars. McCollom and Hynek[1] suggest volcanic-ash deposits as the source of the sulphate-rich outcrops, and Knauth *et al.*[2] propose a similarly dry phenomenon — that turbulent ejecta from meteorite impacts could have been the culprit. Both groups propose scenarios that preclude the existence of significant bodies of water at the surface (at least at Meridiani), and therefore that Mars may never have had conditions conducive to life. This conclusion stands in sharp contrast to the provocative interpretation that there must have been long-lived surface water to form the Meridiani outcrops[5]. Given how enticing this latter interpretation is, it is vital to explore alternative possibilities whatever the ultimate verdict proves to be.

It is clear that the sulphate-rich rocks seen along Opportunity's path are not simply a fortuitous, local discovery. Such rocks, in the form of massive light-toned stacks about a kilometre thick, seem to underlie most of the hundreds of thousands of square kilometres of the Meridiani region[6]. Sulphates have also been seen in extensive dune fields in the north polar regions, and within the vast canyon system of Valles Marineris, by the OMEGA instrument on board the Mars Express spacecraft. Any reconstruction of the history of water on Mars must explain the existence of these massive sedimentary deposits, and the observations by OMEGA that clays are also abundant on Mars[7].

Perhaps the most wondrous aspect of this bold new era of Mars exploration is the robustness and versatility of our robotic explorers. With perseverance and luck, we can hope for the same detailed stratigraphic analysis performed at Endurance crater[8] to be carried out at more distant locales. In particular, Opportunity is making steady progress to the southern reaches of Meridiani (Fig. 2), and will hopefully reach the much larger Victoria crater. Whatever new vistas are in prospect, they are sure to provide fresh data and ideas on the history of water on Mars, and new fodder for scientific debate on the planet's habitability. ■

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