NEWS & VIEWS MARS

Twin studies on Mars

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The twin Mars Exploration Rovers don't themselves range widely, but the observations they make do. Information on partial solar eclipses, salty rocks and magnetic dust are among the latest highlights of the rovers' findings.

Sending probes to Mars is a risky business. Roughly half the spacecraft ever sent have crashed, burnt up or simply missed the planet altogether. In contrast, Spirit and Opportunity, NASA's Mars Exploration Rovers, landed successfully on opposite sides of Mars in January 2004, and continue operations today. Six papers[1–6] in this issue announce new analyses of the scientific data being beamed back to Earth.

Before the rovers landed, an array of remote-sensing data was already available, mostly from NASA's recent orbiters sent to Mars. Golombek *et al.*[1] assess the accuracy of that information, and conclude that physical characteristics of the martian surface — such as rock abundance, dustiness and topography — were accurately forecast beforehand. The prediction for average atmospheric density was 8% too high, so parachutes opened late. Fortunately, both spacecraft still descended safely, which for Spirit was critically aided by small rockets that compensated for winds. Nonetheless, when you look at Mars as a small red speck in the night sky, it seems an incredible feat to land spacecraft on specific parts of it.

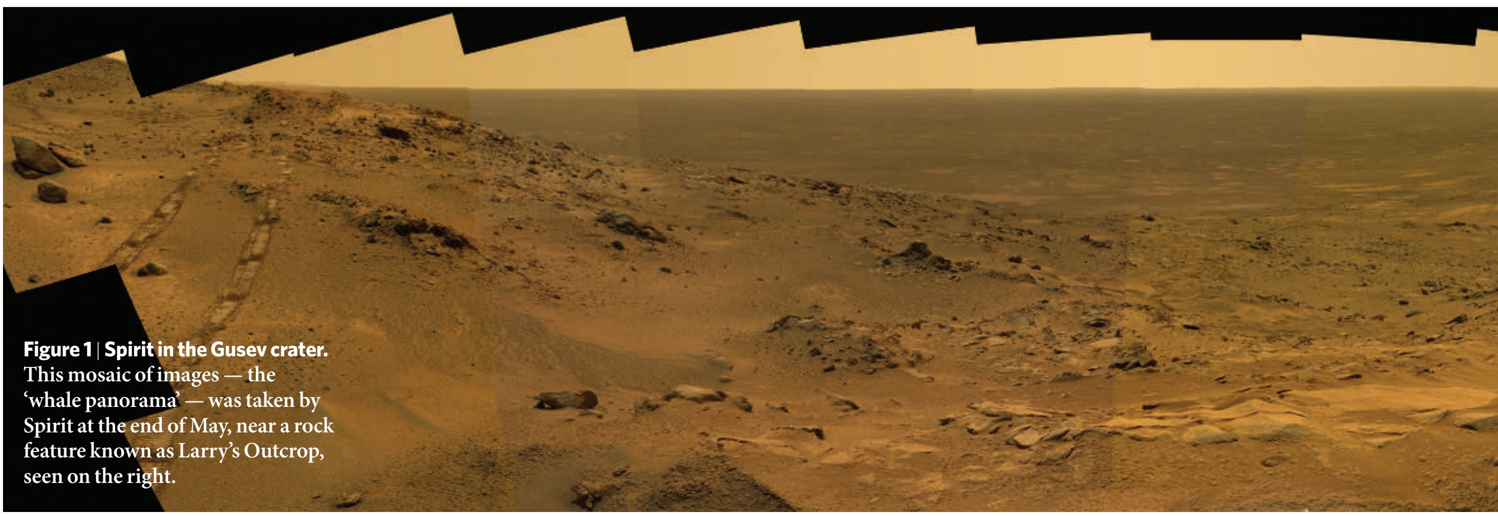
The rovers have been making their own celestial observations, picturing silhouettes of Mars' moons as they move across the disk of the Sun[2]. Viewed from the martian tropics, Phobos, the larger moon, rises in the west and scoots across the sky in several hours in a low orbit. In a transit, Phobos covers about a quarter of the solar disk. Deimos, which is smaller and with a much higher orbit, appears only as a dot. Analysis of six transits implies that the moons' positions are within the 10–20-km uncertainty range of astronomical predictions, but further transit observations could improve orbital models. Because of the solid-body tides that it raises on Mars, Phobos is losing height and will strike Mars within 40 million years, assuming it remains intact[7]. Meanwhile, Deimos is drifting away. Greater accuracy in the acceleration rates of both moons would provide better information on the moons' futures and histories, as well as on Mars' interior (from tidal physics).

In contrast with the predictions for moon transits and landing safety, geological predictions have proved less dependable. Spirit landed inside a feature known as Gusev crater (Fig. 1), the aim being to find a dried-up crater lake. But Gusev's interior has turned out to be largely volcanic, strewn with wind-blown dust and basaltic rocks, created by volcanic activity, that have been ejected by impacts. Opportunity's site, Meridiani Planum, was correctly predicted to contain abundant haematite (Fe_2O_3; ref. 8). But no one imagined that the haematite would exist as blueberry-sized concretions (nodules precipitated from groundwater), or that the concretions would originate within sulphate-rich sedimentary rocks[9].

Early in the mission, one scientist on the Spirit team complained that he felt stuck in a "basalt prison" when he saw the riches available to Opportunity. Haskin *et al.*[3] now report that rocks at the Spirit site are coated in material enriched in sulphur, oxidized iron, chlorine and bromine (Fig. 2a). The oxidized iron in the rocks has apparently been extracted from the basaltic mineral olivine [$(Mg, Fe)_2SiO_4$]; similarly, oxidized iron in soils has been derived from soil olivine[4]. Salts in the subsurface soil seem to have been separated according to solubility, and the filled cavities and veins of rock interiors are enriched in bromine, an element known to form highly soluble salts.

All these observations could be explained by interaction with acidic water and subsequent evaporation. But only small quantities of transient water are required, not the pools of water thought to have produced sulphate-rich sediments at Meridiani[9]. Mars undergoes ice ages that are more extreme than those on Earth: ice migrates from the poles to the tropics as the martian spin axis periodically tips over[10]. Ice deposited in the tropics could form films of low-temperature brines that chemically alter basaltic rocks. Indeed, Yen *et al.*[4] argue this case for the soils generally. At the same time, pristine olivine indicates that neither soils nor dust have ever been soaked in water for long periods[4,5].

Where did the soil come from? Some components of the soil (Fig. 2b), such as the haematite at Meridiani, are remnants of sedimentary deposits. And about 1% of soil



NASA/JPL/CORNELL (J. BELL)

Figure 1 | Spirit in the Gusev crater. This mosaic of images — the 'whale panorama' — was taken by Spirit at the end of May, near a rock feature known as Larry's Outcrop, seen on the right.

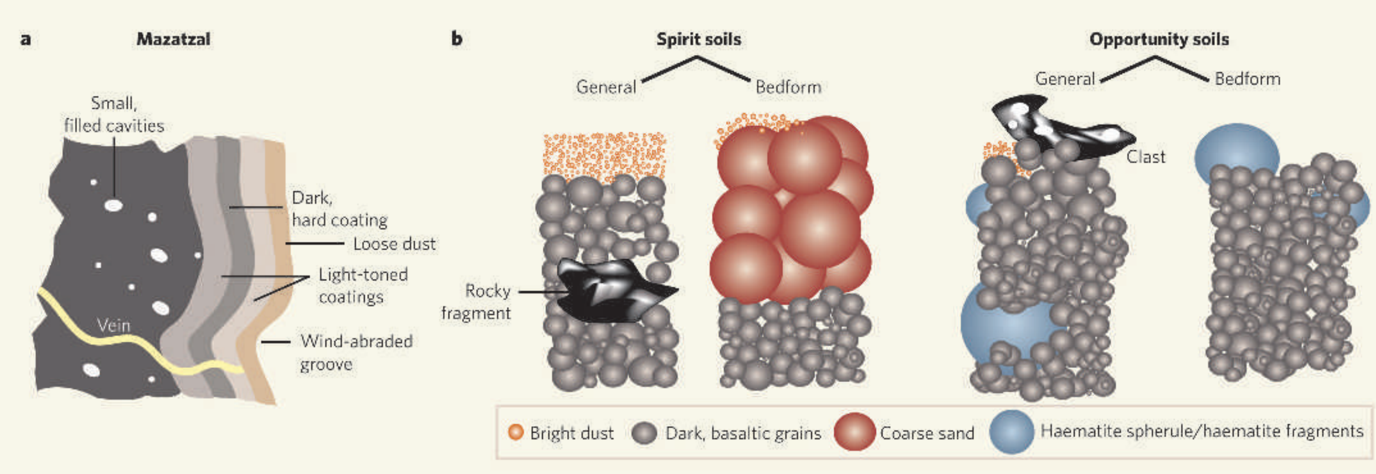


Figure 2 | Rocks and sands of Mars. a, One basaltic rock, Mazatzal, at the site of the Spirit rover, contains features that indicate interaction with water. Light-toned and dark coatings are enriched in sulphur, chlorine and oxidized iron, which can be explained by interaction with acidic water and subsequent evaporation. (Coating thicknesses are exaggerated, colours in both **a** and **b** are arbitrary.) **b**, Soils at each rover site have four components[4]. At Spirit's site, generally bright dust at the surface is underlain by dark basaltic soil (with grain sizes up to about 100 μm), and interspersed rocky fragments. Bedforms, such as ripples, have coarse millimetre-sized sand at their surface which contains magnetite. At Opportunity's site, bright dust is found in patches, but otherwise the soil is made up of haematite spherules or their fragments, and dark basaltic grains. Clasts (bits broken from larger rocks) are also occasionally found near the surface, often with vesicles, which are holes that formed when gas was released from the parent lava.

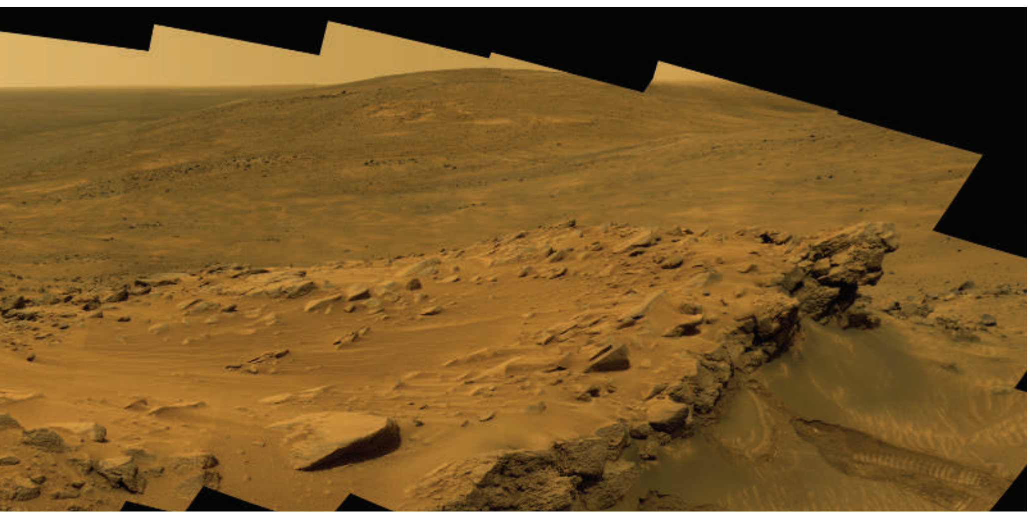
arguably came from meteorites, resulting in a high abundance of nickel[4]. Wind has supplied both rover sites with the major components of bright dust and dark basaltic sand[4].

How the wind interacts with the surface is a topic examined by Sullivan *et al.*[6]. It is difficult to measure martian atmospheric circulation, but dark and bright streaks downwind from craters indicate wind direction. Seen from orbit, the crater where Opportunity landed had a bright streak to its southeast. Surface observations confirm that the streak derives from bright dust-sized particles, probably deposited from the air during a dust storm. Dunes and ripples on Mars have been predicted to consist of much coarser particles, 200 μm or more in size, that are driven along the surface — with smaller particles being lofted into suspension by wind turbulence[11]. However, some ripples at Meridiani, inside craters and pits, contain surface sand well below the predicted threshold size. Theory therefore needs revising: near-surface wind turbulence is less effective at suspending particles than predicted[6].

A nearly uniform elemental composition shows that the bright dust is distributed globally by winds. But the source of the dust's magnetism has remained elusive. On the basis of compositional analysis of dust captured on magnets, magnetite (Fe_3O_4) is now identified as responsible[5]. Evidently, the dust is a mixture of basalt and oxidized minerals, but the origin of the latter is unclear. Examining the dust morphology would help, but the rovers' microscope lacks the magnification to see micrometre-sized dust or its mineral components. Fortunately, NASA's Phoenix lander, due for launch in 2007, carries both a colour optical microscope and an atomic force microscope that will open up these unseen vistas.

The overall picture is that much of the martian surface consists of volcanic soils and that Mars is sulphur-rich, with a geochemistry — like Mars' location — lying between that of Earth and of Io, one of Jupiter's moons. Sulphur and oxidizing waters have reacted with the basaltic surface, producing sulphates, iron oxides, and presumably a clay or silica component that remains to be characterized.

Indeed, the largest gap in our understanding of the martian surface is caused by the absence of comprehensive data on mineral chemistry. So far, instruments have only measured elemental abundance or partial mineralogy from spectra. NASA's Mars Science Laboratory, slated for a 2009 or 2011 launch, will have X-ray diffraction capability[12]. With definitive mineralogy, we should get answers to such tantalizing questions as how much of the salts come from evaporated seas, from meltwater at the end of ice ages, or — like ancient acid burns — from past reactions of volcanic gases with martian rocks and soils. ■



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