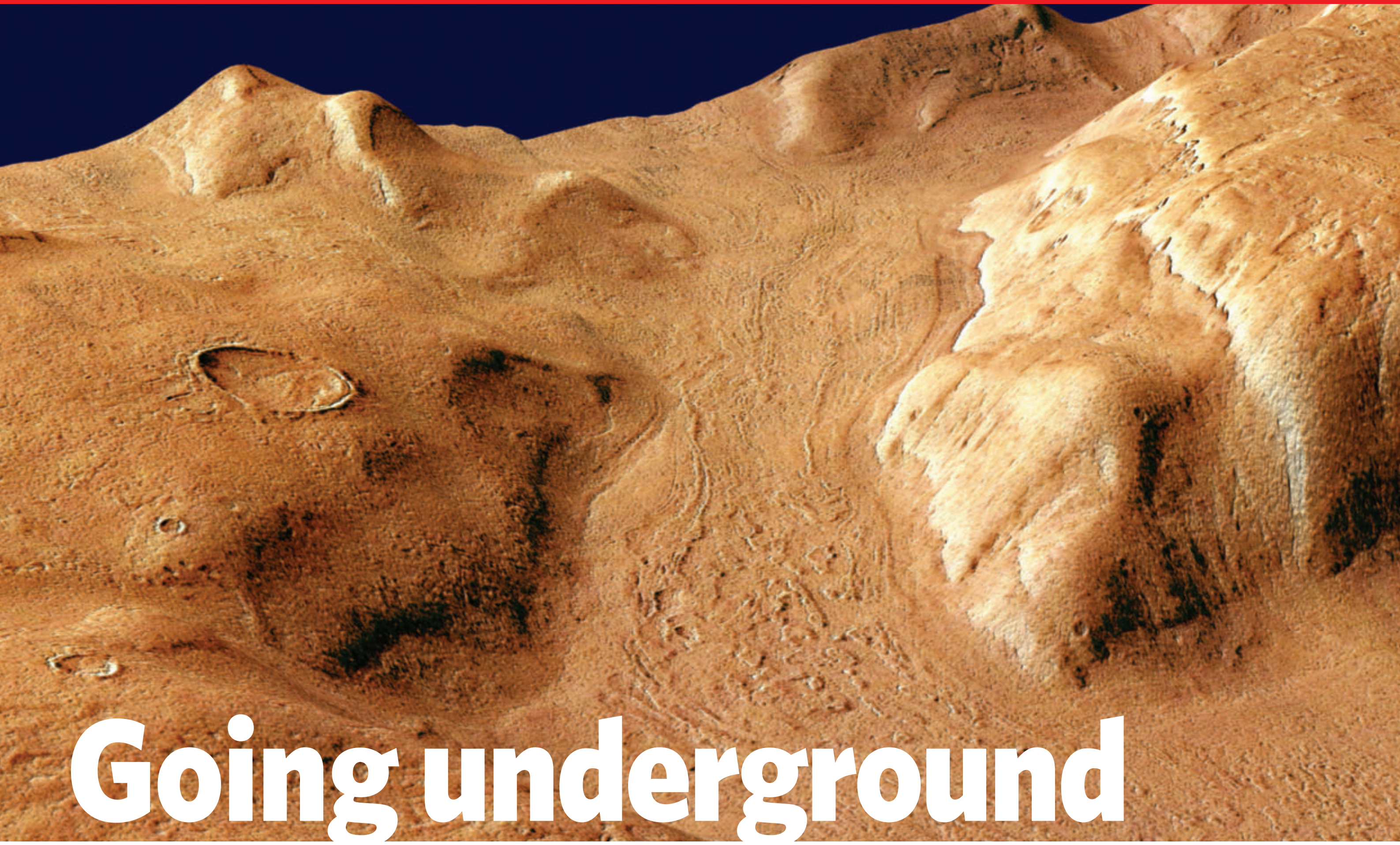


Going underground

ESA/DLR/FU BERLIN/G. NEUKUM

A new generation of planetary radar aims to look deeper than ever into some of the Solar System's most enduring mysteries. **Tony Reichhardt** gets ready for a trip to the interior.

Photographs of the martian surface are undeniably beautiful, but uncovering the truth behind the sinuous river beds and suggestive gullies is not easy. Spacecraft and rover missions have turned up plenty of evidence that water once flowed on Mars, but today the planet's surface is bone dry. There is water ice at the poles and hints of a frozen sea near the equator — but any large reservoirs of water are likely to be kilometres down where conditions are warmer. So the hunt for liquid water, which might provide a habitat for martian life, has gone underground.

In the coming months, an instrument called MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) on Europe's orbiting Mars Express spacecraft could supply some long-awaited answers. If it works as planned, it will be a kind of divining rod for Mars, and could pave the way for future radar projects.

As with divining rods on Earth, the answers are likely to be ambiguous, and MARSIS may draw a blank. But for the moment, project scientists will be happy if it works at all.

In April 2004, the MARSIS team had to delay starting up their radar, the last of seven instruments on Mars Express, after concerns that the antenna's two 20-metre-long fibreglass booms might whip around and damage the European Space Agency's (ESA) craft after their release. A team including experts from the Italian Space Agency and NASA's Jet Propulsion Laboratory, who created the radar, ran computer simulations and ground tests to assess the risk. ESA went ahead with the deployment in early May, but a glitch as the first boom unfolded has resulted in more analysis and delay. Meanwhile, precious radar viewing time is being lost. As Roberto Seu, a MARSIS investigator at the University of Rome 'La Sapienza', admits: "It's been very, very frustrating."

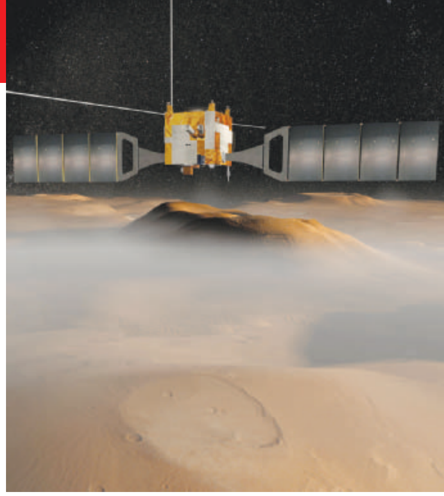
Prime time

As the spacecraft's orbit shifts, the lighting and ionospheric conditions on Mars change, and the long wait has resulted in MARSIS missing much of its prime viewing window for this year. "We're very eager to get started," says Jeff Plaut, one of MARSIS's two principal investigators, who is based at the Jet Propulsion Lab in Pasadena, California. The radar scientists hope that Mars Express will be extended beyond its scheduled two-year mission, which would let the experiment continue early next year.

Meanwhile, a project called SHARAD (Shallow Subsurface Radar) is being readied for launch on NASA's Mars Reconnaissance Orbiter in August. If these experiments prove successful, radars could be attached to rovers destined for the martian surface, and sent to study Jupiter's ice-covered moon Europa or the interior of an asteroid.

Sounding radars such as MARSIS and SHARAD work by transmitting a radar pulse from orbit down to a planet, then analysing the signal that bounces back. Depending on the pulse frequency and the properties of the materials it strikes, the signal will penetrate a certain depth below the surface. In general, the lower its frequency, the deeper it will penetrate. Water ice is very transparent to radar. Dry soil can be too, depending on factors such as its electrical conductivity and porosity. Liquid water is a strong radar reflector. Tracking how much radar energy bounces back, how it's scattered, and how fast it moves through different patches of underground material can, with some coaxing, yield a rough map of subsurface geology.

If all goes well, MARSIS will begin scanning the planet's northern hemisphere this year. The radar's low frequency (1.3–5.5 MHz) allows it to penetrate, in principle, down to 5 kilometres. But such low frequencies result in low resolution — between 5 and 10 kilometre horizontally, and about 100 metres vertically. Any reservoir of groundwater smaller than that will not show up.



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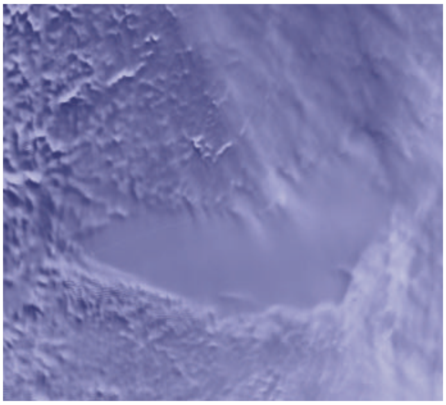

CANADIAN SPACE AGENCY RADARSAT-1 (1997)/NASA-GFSC

On the radar: Mars Express (top) has radar antennae that will search beneath the martian surface (left), hoping to discover subterranean reservoirs like Lake Vostok in Antarctica (above).

SHARAD's higher bandwidth and operating frequencies (15–25 MHz) mean that it won't penetrate as deep as MARSIS (about 1 kilometre), but it will have higher resolution — as little as 300 metres horizontally and 15 metres vertically. Data from the Mars Odyssey project suggest there is ice in the planet's shallow subsurface, which may be detected by SHARAD.

Broad spectrum

On Earth, geologists, engineers and archaeologists use portable ground-penetrating radar (GPR) units to hunt for everything from mineral deposits to buried artefacts. Mounted on aeroplanes, radars are also handy for exploring vast icy regions. They were used in 1996 to confirm the existence of Lake Vostok, a 10,000-square-kilometre reservoir hidden under 4 kilometres of ice in Antarctica.

Elsewhere, high-frequency orbiting radars have been used to map the surfaces of cloud-covered worlds such as Venus and Saturn's moon Titan, which are hidden from ordinary telescopes. But these radars barely scratch the surface. The only body apart from Earth to be probed by a deep sounding radar is the Moon — the Apollo 17 spacecraft carried an antenna that penetrated more than a kilometre below the dry lunar dust in 1972.

Roger Phillips, a geophysicist at Washington University in St Louis, Missouri, who worked on the Apollo experiment, recalls that interpreting the results was a nightmare. "We went into the Apollo thing pretty naively," he says. The radar data were full of echoes from surface features as well as underground rock layers, and real subsurface features got lost in the noise. It wasn't until they used stereo pictures of the surface taken from orbit that Phillips' team could factor out the radar echoes. And it was years before they were confident enough to publish their findings, which tentatively identified structures a kilometre down.

Eliminating confusing radar echoes will still be a problem on Mars, says Phillips, now co-leader of the team that is building SHARAD. But the Mars investigators know much more about the topography of the planet than the Apollo investigators did about the Moon in 1972. Using elevation data from NASA's Mars Orbiter Laser Altimeter and stereo pictures from the high-resolution camera on Mars Express — not to mention 33 years of improvements in computing power — they will be able to model the radar noise from surface features ahead of time.

But we still do not know how well MARSIS and SHARAD will work in practice. On Earth, a geologist would survey the subsurface rocks before using a sounding radar by mapping the local outcrops and mineralogy. But the Mars radars will be peering into terra that is mostly incognita. That makes their chances of penetrating the martian crust unpredictable. Some minerals with high metal content are good radar reflectors, and could prevent the radars from probing deep enough to find water.

Current models suggest that liquid water could exist 2–6 kilometres below the martian surface, but the radar signature for water is not unique, and other conductive materials, including certain clays and metallic minerals, could be mistaken for groundwater.

Phillips believes that the search for water will be difficult. But that is not MARSIS's sole purpose. Mapping the base of the planet's thick northern ice cap would be valuable for planetary geologists, for example — as would any clear picture of the subsurface.

Interior designs

John Grant, a planetary geologist at the Smithsonian Center for Earth and Planetary Studies in Washington DC, thinks that MARSIS will work over some areas but not others. He hopes to land a small, mobile GPR on the planet in the future and proposed one for NASA's next rover mission, the Mars Science Laboratory. It wasn't picked, but a successful MARSIS experiment could boost his chances when the next opportunity arises.

Grant's proposed GPR system would take very high-resolution (tens of centimetres) radar soundings to depths of 10–20 metres. When mounted on a rover, the device would take quick radar pulses of the subsurface at every place it stopped. Eventually it would build up a map of the geology underfoot. If tapping into water ice near the martian surface requires drilling, as most people think it will, radars could help future explorers pick the best site.

Europa is also in the sights of the radar gang. It is an intriguing target for planetary scientists because of the ocean thought to underlie its icy crust. However, any radar built to penetrate the thick ice would have to operate in Jupiter's strong radiation environment.

Even more exotic is a proposal from a team led by Erik Asphaug of the University of California, Santa Cruz, designed to probe the insides of an asteroid. The concept lost out in NASA's last competition for mid-sized planetary missions, but is likely to be submitted again. Earth-based radars have already been used to scan the outside of asteroids. Deep Interior, as it is called, would use a sounding radar in close orbit around an asteroid to take a three-dimensional image similar to a medical ultrasound. Combined with active experiments such as NASA's Deep Impact mission, which will blast an artificial crater in a comet this summer, it could provide the most complete picture of an asteroid yet.

But for all its promise, sounding radar still suffers from a lack of respect, or perhaps awareness, among planetary scientists. It's a complicated technology, and interpreting the data is tricky. "Most planetary scientists don't believe in radar," admits Seu. But MARSIS investigators are hoping that their experiment will soon change that. And all they really need is one Lake Vostok. ■

Tony Reichhardt writes for *Nature* from Washington DC.