

Figure 1 The experimental set-up of Hau *et al.*<sup>1</sup>. The circularly polarized probe pulse takes about 7 μs to traverse the 0.2-mm cloud of cold atoms — this is 1/10 millionth of the speed of light in a vacuum.

ty of the probe pulse — which is by a factor of about 20 million compared with the speed of light in a vacuum — is a stunning proof of the dramatic changes that can occur to the optical properties of laser-dressed atoms. In contrast to a normal atomic medium, the atoms here are in the presence of the coupling laser field so the probe pulse should be thought of as interacting with a system composed of the atoms plus the coupling field. The atoms alone could not have stored the energy of the probe pulse for the required time because of the normal dissipative process of spontaneous emission (see box). However, when the probe pulse enters the medium, its energy goes into the combined atom and field system where it is immune from rapid spontaneous decay. At the end of transmission the energy is returned to the probe field from the system. The energy of the probe pulse is, in a sense, kept safe within the non-decaying 'dark state' of the atom created by quantum interference.

Hau *et al.* have not yet found out if the atom cloud remains in the Bose–Einstein condensed state during the interaction with the probe. It may be that the main role the condensate plays in the slow velocity propagation is in providing a high density of cold atoms. The authors propose that with some technical improvements (higher frequency stability, lower coupling powers) still lower velocities can be achieved, perhaps down to a few centimetres per second.

Another important aspect of the work was the observation of large optical nonlinearities, in the form of an intensity-dependent refractive index. This was inferred from measuring the intensity-dependent frequency shift in the position of the transparency peak. Hau *et al.* conclude that, at 0.18 cm<sup>2</sup> W<sup>-1</sup>, the nonlinear refractive index is unprecedentedly large.

Earlier work also considered potential applications of the optical properties of laser-dressed atoms. For instance, there have been detailed proposals to use these systems in highly sensitive magnetometers<sup>8</sup> or as an

intracavity element to narrow a laser cavity linewidth. The slow pulse velocities reported by Hau *et al.* have yet to find a specific application, but laser-dressing clearly results in profound modifications of the optical properties of the medium. In the laser-dressed cold atoms, the pulse takes 7 μs to traverse the 0.2-mm sample. Propagating in a vacuum for the same period, by contrast, the pulse would have travelled 2 km! Perhaps this phenomenon could be used in optical delay lines for generating very long delays, or in allowing a shorter reference arm for an interferometer in which the other arm is many kilometres in length. Other applications might use the long

time the pulse can be stored in the medium without significant dissipation, for instance in optical data storage.

Finally, the massive nonlinearities observed in this system are of a type that lead to a strong coupling between pairs of photons. Photons are particles that normally cannot interact strongly, so this is an unusual regime. Potentially these interactions may be large enough that it would become possible for a single photon to switch an optical cavity<sup>9</sup>. Nonlinearities of this kind have also been shown to be the key ingredient in experiments in quantum optics such as optical squeezing, quantum non-demolition measurements and studies of non-locality. The increased magnitude in the nonlinearities observed by Hau *et al.* may lead to improvements in these experiments. □

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Planetary science

## Snapshots of an ancient cover-up

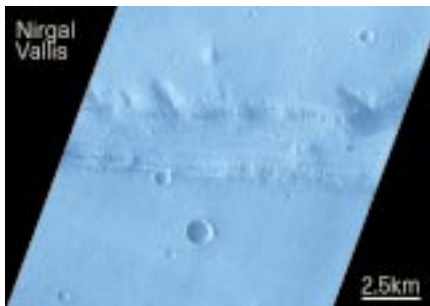
Maria T. Zuber

Mars is a superb and arguably unique natural laboratory for the study of climate in the early stage of evolution of the terrestrial planets. As described in four papers in this issue<sup>1–4</sup>, beginning on page 584, spectacular images from the Mars Orbiter Camera, an instrument on the Mars Global Surveyor spacecraft currently orbiting Mars, are providing a new view of the processes that shaped the Martian surface.

Shortly after the planets formed 4.5 billion years ago, planetesimal impacts on their surfaces, and the differentiation of metal and rock to form planetary cores and mantles, heated the interiors of the terrestrial planets. As these planets rapidly cooled they liberated volatile gases to form atmospheres and, at least on Earth, the oceans. Both Earth and Mars underwent these processes, but the geological record on Earth predominantly preserves surfaces younger than 500 million years old; earlier records have been eradicated by processes such as subduction, continental collision and erosion. On Mars, however, most surfaces have ages greater than three billion years and they retain tantalizing

hints that the early heat-loss phase on this planet produced climatic conditions that were much more hospitable than the cold, desert-like environment that exists now<sup>5,6</sup>.

Today, Mars is too cold and the atmosphere is too thin for liquid water to be stable at the surface. Most water is currently stored as ice in the polar caps and in 'frozen aquifers' beneath the surface. However near-global images, of moderate resolution (around 200 metres per pixel) that were taken by the Mariner 9 and Viking Orbiter space probes in the 1970s, revealed a planet on which liquid water had flowed on the surface. From the early images, a diversity of early Martian climates were proposed, ranging from warm conditions with hemispheric-scale oceans to near-freezing conditions where water flowed on the surface for only the briefest of periods. Previous data have not been able to distinguish between specific evolutionary schemes, but spectacular new high-resolution images from the Mars Orbiter Camera (MOC) are allowing the range of possibilities to be narrowed considerably. In the four reports<sup>1–4</sup> now published, MOC principal



**Figure 1** Mars Orbiter Camera image 605 illustrates, in a single view, many of the insights about Mars gained from recent high-resolution pictures<sup>1-4</sup>. It shows Nirgal Vallis, one of the Martian valley systems, and the surrounding surface. The absence of tributaries from the surface of the plains, and the presence of side-wall alcoves, point to its origin through groundwater processes rather than from precipitation-fed run-off. The floor of the canyon is filled with sediments that form dunes, obscuring features that might have formed by sustained flow within the canyon. On the upland, surface craters in a range of states of preservation attest to a dynamic history of cratering and atmospheric dust deposition that are likely to obscure age relationships.

investigator Michael Malin and colleagues analyse images with a resolution of four to eight metres per pixel — 20 to 40 times better than obtained before.

Malin and Carr<sup>3</sup> (page 589) address the origin of valley networks, which are kilometre-wide channels that occur on some of the oldest (typically 3.5-billion-year-old) surfaces on the planet. Whereas previous orbiters imaged these features, which represent evidence for flowing water<sup>5</sup>, it has been debated whether their source was predominantly precipitation or ground water<sup>7,8</sup>. Malin and Carr show images of channels that clearly indicate a groundwater source (Fig. 1). In addition, an image of a meandering valley in Nanedi Vallis indicates that water, at least in this area, flowed on the surface for an extended period rather than being due to a transient catastrophic outflow. Other images show that wind-distributed material has filled certain channels, in some cases completely, probably obscuring additional evidence for early surface water.

The report by Thomas *et al.*<sup>4</sup> (page 592) specifically describes the modification of the Martian surface by windblown dust. These authors describe surprising evidence that Martian dunes are composed of two distinctive materials, demonstrating that dust on Mars has not completely homogenized over geological history, despite mixing by global dust storms. Of particular significance is the identification of widespread deposits of sediment up to thicknesses of tens of metres. As Hartmann *et al.*<sup>2</sup> discuss (page 586), sediments are often deep enough to fill small craters completely, which is problematic

because records of craters of various sizes are used to determine the relative ages of planetary surfaces. The new data exacerbate a previously recognized problem<sup>9</sup> — that the ages of some Martian surfaces may have been underestimated — making it difficult for scientists wishing to construct a consistent timeline of geological and environmental events. In addition, the accumulation of thick sediments presents a challenge to future NASA lander missions that want to sample ancient bedrock.

Finally, on page 584, McEwen *et al.*<sup>1</sup> provide evidence for ubiquitous, fine-scale layering within the vast Valles Marineris canyon. Such detailed wall structures had not been previously observed in any of the Martian canyons. From the few images obtained so far it is not possible to unambiguously distinguish between a volcanic or sedimentary origin for the layering, but this may be resolved with upcoming observations. In either case, the existence of the layering is significant.

Previous studies have suggested that the dominant process for shaping the earliest surfaces was pervasive fracturing and mixing of crustal material by impacts. But it is now apparent that volcanic and/or sedimentary processes operated extensively during this early period. If the origin of the layering is sedimentary it should be possible to address the questions of the volume and persistence of surface water needed to deposit the observed 8-km-thick column. A volcanic origin would imply the release to the surface of significant amounts of subsurface water, and would allow for better estimates of the amount of water released in outflow channels and valleys. In addition, volcanic outgassing represents a source of atmospheric gases, and is a dominant factor in determining whether Mars ever developed a runaway greenhouse effect<sup>10</sup>, which has been invoked in climate

theories favouring a 'warm, wet' early Mars.

The picture that emerges from these high-resolution views is unmistakable evidence of the dynamical processes that shaped primordial Mars. Unfortunately, the processes that appear to have dominated early Martian history have also conspired to cover up surfaces of all ages and may be obscuring evidence of Mars' early climate. But the images obtained so far by Malin and colleagues cover only a minuscule fraction of the Martian surface and provide only enticing teasers of observations to come. Orders of magnitude increases in spatial sampling to several metres resolution are expected from the MOC during the two-year-long continuous mapping phase of Mars Global Surveyor, which commences in March. These images, combined with observations from other orbital sensors and with local views from surface landers, offer the hope of piecing together a self-consistent view of Mars' early climate — with implications for the development, or not, of early life on the planet. □

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## Neurobiology

# A place for space and smells

J. N. P. Rawlins

The hippocampus lies deep within the temporal lobes of the human brain, and clinical studies suggest that it is essential for normal, everyday memories of many different events. In contrast, animal studies indicate that the hippocampus is a highly specialized memory store, dealing with a strictly limited information set. This issue has been hotly debated over the past two decades or so and, on page 613 of this issue, Wood *et al.*<sup>1</sup> report data from a new animal study, which adds weight to the view that the hippocampus has a general role in memory.

The hippocampus has a simple, cortical structure in which the neurons are arranged

in three layers (rather than the six layers of the neocortex, which makes up the convoluted surface of the brain). The name hippocampus derives from its elegantly curved structure, somewhat fancifully supposed to resemble the shape of a seahorse. (An alternative name, Ammon's horn, reflects a more plausible similarity to the horns of a ram-headed Egyptian god.)

Experimental analysis of hippocampal function was kick-started by clinical observations in the early 1950s. A patient known as H. M., who suffered from uncontrollable epilepsy, was treated with a "frankly experimental" surgery — the structures on the inner faces of his left and right temporal