PERSPECTIVES: PLANETARY SCIENCE

Tip of the Martian Iceberg?

Jim Bell

The current climate of Mars is characterized by annual cycles of carbon dioxide (CO_2) and water condensation and sublimation, dust deposition, and erosion (*1–4*). These cycles are driven by large seasonal variations in solar heating caused by the planet's high orbital eccentricity and by longer term variations in its obliquity (or polar "tilt") and other orbital parameters (*5*).

All stacked up. High-resolution images of the surface of Mars have revealed evidence of layering all over the planet, hinting at complex, perhaps episodic or periodic variations in geologic activity and/or climatic conditions. In this Mars Odyssey image, acquired on 17 March 2002, spectacular layering can be seen in the floor of Ganges Chasma, a part of the Valles Marineris canyon system. Different layers appear to have different levels of susceptibility to erosion, suggesting physical and/or compositional differences. The origin of this layering may be related to deposition of either windblown or water-borne sediments in the canyon floor. The absence of impact craters indicates a relatively young surface. [Mars Odyssey THEMIS image V01126002 (Release 20020329 at http://themis.la.asu.edu)]

Perhaps more intriguing, however, is the evidence for longer term variations in climate preserved within layered sedimentary deposits on Mars. In the 1970s, the Mariner 9 and Viking orbiters discovered layered deposits of putatively ice-rich sediments alternating with dusty, ice-poor sediments in the martian polar regions (*6*). More recently, the Mars Global Surveyor (MGS) mission has revealed that such layered deposits are ubiquitous on Mars, although their origins are highly controversial (*7*).

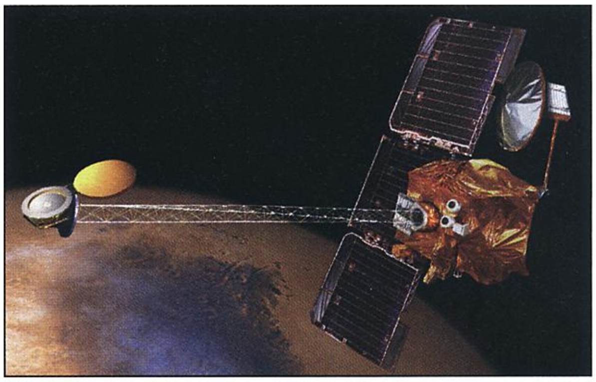
Most exciting of all, Viking and MGS data have shown evidence for channels, valley networks, and gullies on a variety of spatial and temporal scales, indicating the action of liquid water (*8*, *9*). Liquid water may remain stable for long enough in the current low-pressure, low-temperature martian environment to form some of the observed features, especially the smaller scale ones. However, many of the other features must have formed in a very different, more water-rich environment than exists on Mars today. Where has all that water gone?

Isotopic evidence indicates that Mars has lost a significant amount of water through atmospheric escape (*10*). Nevertheless, thermodynamic models and geomorphic and compositional evidence suggest that substantial amounts of water—as surface or subsurface ice and/or hydrated surface minerals—may still exist on Mars today (*11*, *12*). Three reports on pages 81, 75, and 78 in this issue present exciting measurements from the newest orbital mission, Mars Odyssey (see the figures), that appear to confirm the existence of perhaps large quantities of shallow subsurface ice in certain parts of the planet (*13–15*). The authors use measurements of the neutron flux emitted from Mars in several different energy regimes and spectra of gamma-ray emissions induced by neutron capture reactions to map the global distribution of near-surface hydrogen on the planet for the first time.

The results, even after only a month of mapping observations, are stunning. The abundance of hydrogen varies widely. The highest concentrations occur poleward of about 60°N and 60°S and are interpreted to indicate the presence of subsurface water (not CO_2) ice, on the basis of the specific patterns of neutrons detected and the spatial correlation to regions where ground ice has been predicted to be stable (*11*, *12*).

Modeling of the observed neutron and gamma-ray fluxes is complex and still preliminary, and some instrumental and atmospheric effects may still be present in the data. Nevertheless, initial results indicate that the best fits for the enhanced hydrogen regions are consistent with a model surface with a "thin and dry" [few tens of centimeters; 1 to 2 weight percent (wt %) H_2O] upper layer overlying a "thick and ice-rich" (several hundred centimeters; 20 to 35 wt % H_2O) lower layer. Details on the thickness of the ice-rich lower layer are limited by the ~1-m sensing depth of the neutron instruments, and it is not possible to determine the total quantity of subsurface ice present. However, if the modeling is correct, then the inferred ice concentration implies an extremely porous, nearly ice-filled regolith (the layer of rocky debris and dust resulting from repeated meteoritic impacts) at high latitudes. Separate lines of evidence suggest a loose and/or porous regolith that could exceed a kilometer or more in thickness (*16*, *17*), implying that the subsurface ice detected by Odyssey may represent only the tip of an iceberg frozen under ground.

The much lower measured hydrogen abundances at equatorial and mid-latitudes are consistent with telescopic and spacecraft infrared (IR) spectroscopy results (*18–20*), indicating the presence of 1 to 2 wt % of hydrated minerals on the surface. The specific mineralogy of this hydrated material has, however, not yet been identified. The Odyssey instruments only measure hydrogen, and thus cannot distinguish between H_2O-bearing hydrates and OH-bearing hydroxides. However, Odyssey data are sensitive to hydrated minerals at depths of tens of centimeters, whereas IR remote-sensing measurements penetrate only a few tens of micrometers. The combination of continuing IR observations at higher spatial and spectral resolution, ongoing collection of Odyssey neutron and gamma-ray data to improve signal and reduce noise, and better modeling on the basis of these observations may help to finally identify the specific minerals responsible for sequestering important volatiles



Flying high. The Mars Odyssey spacecraft joined the MGS in orbit around the Red Planet in February. This artist's conception shows the spacecraft in its mapping configuration, after the GRS boom has been deployed this month. Odyssey will obtain maps of the planet's elemental chemistry, thermophysical properties, and visible and IR color properties until 2004. It will also serve as a communications relay satellite for other U.S. and international Mars missions in 2003 and 2004.

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such as water and OH at low latitudes on Mars.

It is particularly impressive that the three reports in this issue were generated after the Odyssey spacecraft had completed only ~30 days of its planned multiyear mission, and during a phase of the mission before the Gamma-Ray Spectrometer (GRS) had been deployed to its nominal mapping configuration. The GRS was originally flown to Mars on the Mars Observer spacecraft, which stopped working just 3 days before entering Mars orbit in 1993. Many Odyssey investigators have been waiting more than 15 years to finally collect these data. One can hardly blame them for their enthusiasm and excitement over their early findings.

Within the next few weeks, the GRS is to be extended out on a ~6-m boom (see the second figure) to isolate it from neutron and gamma-ray signals originating in the Odyssey spacecraft itself and thus boost the instrument's sensitivity to the surface of Mars. The results from that configuration are sure to provide additional insights into subsurface ice and surface hydrated minerals, and yield unique new information on the planet's geochemistry from global maps of rock-forming elements such as Fe, Si, and Mg. The results will also be used to guide the selection of landing sites for future rovers and landers, to sample returns, and for eventual human exploration. In that sense, the most important implications of the detection of subsurface water ice deposits on Mars may not be realized for decades. It is likely to be worth the wait, however.

References

1. P. B. James, B. A. Cantor, *Icarus* **154**, 131 (2001).
2. B. M. Jakosky, A. P. Zent, R. W. Zurek, *Icarus* **130**, 87 (1997).
3. R. T. Clancy *et al.*, *Icarus* **122**, 36 (1996).
4. R. W. Zurek, L. J. Martin, *J. Geophys. Res.* **98**, 3247 (1993).
5. J. Touma, J. Wisdom, *Science* **259**, 1294 (1993).
6. K. R. Blasius, J. A. Cutts, A. D. Howard, *Icarus* **50**, 140 (1982).
7. M. C. Malin, K. S. Edgett, *Science* **290**, 1927 (2000).
8. S. W. Squyres, *Icarus* **79**, 229 (1989).
9. M. C. Malin, K. S. Edgett, *Science* **288**, 2330 (2000).
10. B. M. Jakosky *et al.*, *Icarus* **111**, 271 (1994).
11. F. P. Fanale *et al.*, *Icarus* **67**, 1 (1986).
12. S. M. Clifford, *J. Geophys. Res.* **98**, 10973 (1993).
13. W. V. Boynton *et al.*, *Science* **297**, 81 (2002); published online 30 May 2002 (10.1126/science.1073722).
14. W. C. Feldman *et al.*, *Science* **297**, 75 (2002); published online 30 May 2002 (10.1126/science.1073541).
15. I. Mitrofanov *et al.*, *Science* **297**, 78 (2002); published online 30 May 2002 (10.1126/science.1073616).
16. L. A. Soderblom, D. B. Wenner, *Icarus* **34**, 622 (1978).
17. J. F. Mustard, C. D. Cooper, M. K. Rifkin, *Nature* **412**, 411 (2001).
18. J. R. Houck *et al.*, *Icarus* **18**, 470 (1973).
19. J. F. Bell III, D. Crisp, *Icarus* **104**, 2 (1993).
20. S. M. Murchie *et al.*, *Icarus* **105**, 454 (1993).

PERSPECTIVES: BIOCHEMISTRY

DNA Building Block Reinvented

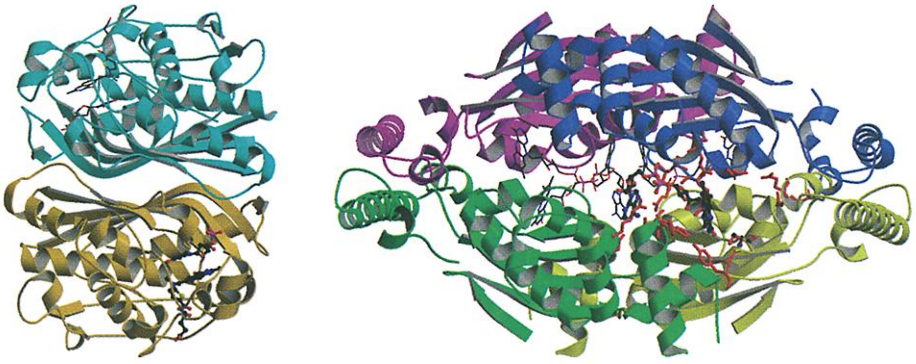
Alexey G. Murzin

The large number of complete genome sequences are fueling large-scale bioinformatics, structural genomics, and proteomics efforts that promise to accelerate the design of new drugs. But how often will independent projects converge to give functional and structural characterization of interesting drug targets? There is at least one example. On page 105 of this issue, Myllykallio *et al.* (*1*) identify a family of enzymes, ThyX (Thy1 in the slime mold *Dictyostelium discoideum*), that synthesize the essential DNA precursor thymidylate (dTMP) by an alternative pathway. ThyX enzymes are unrelated to the classic thymidylate synthase family ThyA, and ThyX is found almost exclusively in organisms that lack ThyA, including several microbial pathogens of humans. In an exciting coincidence of events, the structure of ThyX was independently determined by the Joint Center for Structural Genomics (*2*). Together these two discoveries pave the way for rational drug design (see the figure).

Given the universal role of DNA as the cell's genetic material, mechanisms for de novo synthesis of essential DNA precursors, like thymidylate, were thought to have evolved just once and thus to be conserved in all cellular organisms from bacteria to human. Surprisingly, about 25% of the 150 or so complete or nearly complete genome sequences lack detectable homologs of the classic thymidylate synthase gene *thyA*. Two observations suggest that ThyX might be an alternative thymidylate synthase. First, a *thyX* homolog from *D. discoideum* complements a thymidine-requiring mutant (*3*), and second, the phylogenetic patterns of ThyX and ThyA are complementary (*4*). Myllykallio and co-workers (*1*) found that *thyX* is distributed among many microbial genomes and is almost exclusively limited to genomes lacking *thyA*.

Myllykallio *et al.* (*1*) went on to show that ThyX from the human pathogen *Helicobacter pylori* (HP1533), the cause of gastric ulcers, has a thymidylate synthase activity both in vivo and in vitro that is mechanistically distinct from ThyA activity. In the classic mechanism, deoxyuridylate (dUMP) is reductively methylated by methylenetetrahydrofolate (CH_2H_4folate) to give thymidylate and dihydrofolate. Dihydrofolate must be recycled; first, it is reduced to tetrahydrofolate by dihydrofolate reductase (DHFR). Functionally coupled, both ThyA and DHFR are important chemotherapeutic targets. The alternative mechanism also uses dUMP and CH_2H_4folate but, in addition, it involves the oxidation of a reduced flavin cofactor to give thymidylate and tetrahydrofolate and, therefore, requires no DHFR activity. Consistent with this, DHFR homologs are absent from many of the ThyX-containing genomes. The catalytic centers in the enzyme remain to be definitively elucidated, but an invariant serine residue in a conserved "ThyX" motif is essential for ThyX activity (*1*).

A structure of a ThyX homolog from



The road less traveled. (Left) Structure of classical thymidylate synthase (ThyA). **(Right)** Structure of the alternative thymidylate synthase (ThyX). The bound ligands (the substrate and a drug in ThyA, and FAD cofactor in ThyX) show the active-site locations. Conserved ThyX residues (red) are shown in one site composed of three different subunits (yellow, green, and blue). The essential serine residue (ball-and-stick) occupies a catalytically relevant position near the flavin ring of the cofactor.

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