PERSPECTIVES: MARS

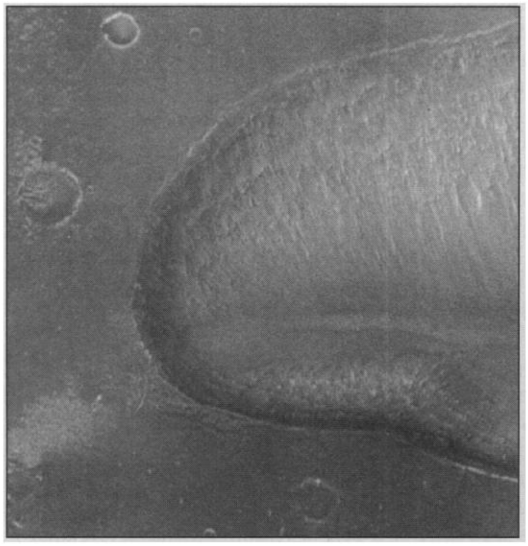
Water, Climate, and Life

Bruce M. Jakosky

The search for life on Mars cannot be carried out only by looking for evidence of life. Rather, one must understand the planet as a whole, to interpret observations that may tell us about possible life and to understand the implications of its presence or absence. The Mars Global Surveyor spacecraft, currently in orbit around Mars but not yet in its "mapping" orbit (*1*), is now providing fundamental insights into the history of water and climate. Four new results, presented at the recent meeting of the American Geophysical Union (*2*), provide key constraints on the nature of water and volatile compounds on Mars.

The Mars Orbiter Camera (*3*) has obtained high-resolution images of some of the planet's valley networks. These are systems of branching valleys, typically a few hundred meters deep and a kilometer across, that occur almost exclusively on surfaces that are 3.5 billion years old. To some, their appearance is similar to valleys formed on Earth from the runoff of precipitation, and they have been used as evidence to argue that liquid water must have been either more abundant or more stable on Mars some 3.5 to 4.0 billion years ago (*4*). One valley shows a channel at the bottom that was probably at one time filled with water. The most recent images, presented by Michael Carr (U.S. Geological Survey, Menlo Park), show valleys that end upstream in theater-shaped heads, with no visible channels leading into them. Another valley is discontinuous, with narrow, uneroded surfaces between continuations of the same valley. Both of these configurations are most consistent with the source of the valleys' water being within the subsurface rather than at the surface. That is, the valleys were carved by flowing water, but the water sprang forth from beneath the surface and eroded the channels by a process of "sapping," rather than by runoff of surface water. Although this probably requires an ancient climate warmer than today's, it does not necessarily require an atmosphere warm enough to allow substantial atmospheric precipitation and runoff.

Observations from the Surveyor's magnetometer have provided a fundamental change in our view of martian geophysical history and its connections to volatile compounds. During the aerobraking phase of the mission, in which the spacecraft descends on each orbit to between 170- and 120-km altitude, the spacecraft passes beneath the ionosphere and can detect the remnant magnetic field of the surface materials. As presented by John Connerney (NASA, Goddard Space Flight Center), a large number of anomalies with high remnant magnetism have been discovered (*5*). These probably formed when crustal materials cooled below the Curie temperature in the presence of a global-scale intrinsic magnetic field. As no such field exists today, it suggests that a magnetic field must have been present at some times during martian history. Remarkably, almost all of the magnetic anomalies discovered so far concentrate in the older parts of Mars. This suggests that Mars had a substantial ancient intrinsic magnetic field, comparable in strength to Earth's, and that, subsequent to the period ending about 3.5 billion years ago, it has not had one. One important effect of an intrinsic magnetic field is that it would keep the impinging solar wind from getting too close to the atmosphere. When the intrinsic field ceased, it allowed the solar wind to begin to "strip" the atmosphere away. The atmospheric scavenging may have been so effective as to have removed enough gas to lower the atmospheric pressure by 1 bar from the early atmosphere, with the resulting decrease in the strength of the greenhouse effect possibly explaining the transition from an early warmer climate to the present cold one (*6*).



Reading the lines. A typical valley network system in central Terra Meridiani (6.2°S latitude and 357.4°W longitude). The surface into which the valley has formed is dark and exhibits many circular impact craters and pits. The valley appears brighter than its surroundings, owing to sand and dust deposits; bright sand can also be seen on the floors of craters. The outline of the valley wall shows various protrusions and alcoves that suggest the margin of a lava flow. Craterlike rings within the valley adjacent to the wall are the resistant portions of impact craters that survived the retreat of the wall as the valley widened. This is evidence that processes of valley widening were relatively gentle, probably related to groundwater seeping from beneath a resistant cap of volcanic rock. [Image, taken on 14 April 1998, covers an area 11.5 km by 27.4 km]

The Thermal Emission Spectrometer on Surveyor measures the emission spectrum of the surface and atmosphere and was designed to identify and map surface minerals (*7*). The most remarkable identification to date is a large concentration of coarsely crystalline hematite. Hematite is an iron-bearing mineral that forms only in high-temperature aqueous systems. This is compelling evidence for hydrothermal systems on Mars, although their existence had been suspected previously on the basis of images showing volcanoes (which may have had groundwater associated with them) and catastrophic flood channels (with crustal water as their source) and of measurements made of meteorites that came from Mars. Martian hydrothermal systems would provide a suitable environment either for a martian origin of life or for its continued existence; geochemical energy is abundant there, and the oxidation state (at least in terrestrial systems) is such that formation of organic molecules should proceed easily and there should be abundant energy available for construction of cells (*8*). In addition, Philip Christensen (Arizona State University) presented convincing evidence that it is possible to remove atmospheric features from their spectra and identify minerals on the surface. The observed presence of basalt is important for possible biota, as the chemical reaction between basalt and water also yields energy that can support life.

Finally, the Mars Orbiter Laser Altimeter has measured the topography of the martian north polar region (*9*). The polar cap, thought to consist predominantly of

The author is at the Laboratory for Atmospheric and Space Physics and Department of Geological Sciences, University of Colorado at Boulder, Boulder, CO 80309, USA. E-mail: jakosky@argyre.colorado.edu

water ice, is now known to be about half the volume previously thought. Although the Northern Hemisphere topography is such that water released during the catastrophic floods would have flowed toward the north cap, other processes must have acted as well—the cap is not located at the region of lowest elevation, and it has a "bubble" shape rather than the flat-topped shape that a frozen lake would yield. Together, these require that the last major process acting on the ice was its transport as vapor through the atmosphere and freezing out at the pole; clearly, the polar ice is an indicator of climate-related activities. The "reduction" in the size of the cap exacerbates a water-inventory problem that had been previously recognized. On the basis of the amounts of water thought to have been released to the surface by geological processes and the amounts that currently reside in the polar cap, a substantial amount of water must be somewhere else. Although some may have percolated back into the crust, the majority may have escaped to space along with the early atmosphere.

There is a strong connection between the expectation of finding life on Mars and the presence of liquid water, either at the surface or within the crust. In turn, there is a connection between the presence of liquid water, the geological, geochemical, and geophysical history of Mars, and the history of the atmosphere's interactions with the solar wind. The recent Surveyor results underscore this complicated interweaving of the various processes. At the same time, they point to a history of water and geochemical processes on Mars that would allow the planet to support life (*4, 8, 10*). The question that needs to be addressed, and that will be addressed by sample return missions over the next decade, is whether there ever was life on Mars. Whatever the answer, it will have a large impact on our understanding of the nature and occurrence of life in the universe.

References

1. A. L. Albee, F. D. Palluconi, R. E. Arvidson, *Science* **279**, 1671 (1998).
2. Fall Meeting of the American Geophysical Union, 6 to 10 December 1998, San Francisco, CA.
3. M. C. Malin *et al.*, *Science* **279**, 1681 (1998).
4. M. H. Carr, *Water on Mars* (Oxford Univ. Press, Oxford, UK, 1996).
5. M. H. Acuña *et al.*, *Science* **279**, 1676 (1998).
6. D. A. Brain and B. M. Jakosky, *J. Geophys. Res.* **103**, 22689 (1998).
7. P. R. Christensen *et al.*, *ibid.* **97**, 7719 (1992).
8. B. M. Jakosky and E. L. Shock, *ibid.* **103**, 19359 (1998).
9. M. T. Zuber *et al.*, *Science* **282**, 2053 (1998).
10. B. Jakosky, *The Search for Life on Other Planets* (Cambridge Univ. Press, Cambridge, 1998).

PERSPECTIVES: IMMUNOLOGY

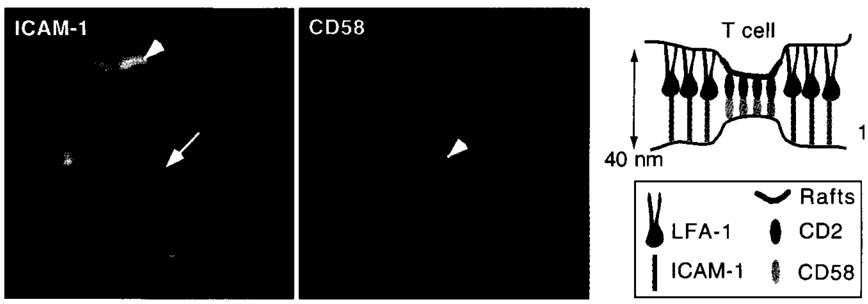
Costimulation: Building an Immunological Synapse

Michael L. Dustin and Andrey S. Shaw

A central event in the development of immunity is the activation of the T cell. At the center of this process is the T cell receptor (TCR), which triggers activation by a specific interaction with antigen [usually a foreign peptide bound to, or "presented by," the organism's own major histocompatibility complex (MHC) molecule on the surface of an antigen-presenting cell]. Because of the small size of the TCR, its low affinity toward antigen, and the limited numbers of antigens on the antigen-presenting cell, an elaborate adhesion complex must be formed to allow the TCR to contact, sample, and then be activated by the rare antigenic ligands (*1*). This specialized contact area has been termed the immunological synapse (*2, 3*). Reports by Wülfing and Davis in a recent issue (*4*) and Viola *et al.* (*5*) on page 680 of this issue focus attention on how the immune synapse is built and unify what had been thought of as two distinct signals needed for efficient T cell activation.

Efficient T cell activation requires engagement of at least two types of T cell surface receptors. This phenomenon has been interpreted in terms of a "two-signal model," which proposes that T cell activation requires one signal from the TCR and a second signal from a "costimulator" molecule. Although many molecules have been implicated as costimulators, CD28 has become the archetype for costimulatory molecules. Engagement of CD28 either by its ligand on the antigen-presenting cell [B7 (CD80)] or by antibody can strongly enhance TCR signaling responses. Although current models suggest that CD28 functions as a specific activator of the Jun kinase JNK or the nuclear transcription factor NF-κB, CD28 engagement by itself is not sufficient. Activation of either JNK or NF-κB always requires coengagement of the TCR. This has led to a counterproposal that costimulation might function to amplify the signals transduced by the TCR (*1*).

In a recent issue of *Science*, Wülfing and Davis (*4*) demonstrated a novel mechanism for costimulation in formation of the immune synapse. They demonstrate that costimulation initiates active directional transport of protein and lipid domains to the area of cell-cell contact. This transport process requires myosin and correlates with enhanced, as well as sustained, signaling—a hallmark of costimulation. In these experiments, directed transport could be stimulated by either CD28 or LFA-1 engagement, but occurred most efficiently when both were engaged together. Wülfing and Davis propose that costimulation works by activating an actin-myosin–driven transport process that delivers receptors and signaling complexes to the contact area. In this study, however, the transport process appears to be



Topological anatomy of the immune synapse. (Left) The pattern of LFA-1 and CD2 engagement in an activated T cell contact with an artificial membrane containing CD58 (blue) and ICAM-1 (red) (*3*). Arrowhead indicates the area of engagement of respective ligands. Arrow indicates exclusion of 20-nm-diameter ICAM-1 from the 15-nm contact formed by interaction of CD2 and CD58. **(Right)** The position of sequential molecular filters (40 and 15 nm) that are encountered by complexes such as rafts as they are transported toward the center of the immune synapse. The TCR clusters in the central 15-nm region (*13*).

The authors are in the Department of Pathology and Center for Immunology, Washington University School of Medicine, St. Louis, MO 63110, USA. E-mail: dustin@pathbox.wustl.edu