PLANETARY SCIENCE

# Cold-Trapping Mars' Atmosphere

The Mars Reconnaissance Orbiter has observed large deposits of frozen $CO_2$ at Mars' southern polar region.

**Peter C. Thomas**

Earth's climate is buffered by massive oceans of liquid water and by gases, such as carbon dioxide ($CO_2$), which cycle through the atmosphere and through biologic and geologic reservoirs. Mars has no oceans to buffer its temperatures, and the thin atmosphere (95% $CO_2$) provides little thermal buffering. The surface pressure is close to that in equilibrium with solid $CO_2$ at Mars' polar temperatures, and early space probes explored whether large $CO_2$-ice deposits might buffer the atmospheric pressure of Mars (*1*). Subsequent investigations found reservoirs of frozen water in thick polar layered deposits, but revealed only thin perennial deposits of $CO_2$ at the south pole (termed "residual cap") in addition to the ~30% of atmospheric $CO_2$ that is cycled through the seasonal caps. On page 838 of this issue, Phillips *et al*. (*2*) report the discovery of thick deposits in the south polar region that are most likely composed of solid $CO_2$ and comparable in mass to the present Mars atmosphere.

Interest in the mechanisms of Mars' climate comes from its position as the only other terrestrial planet with a surface and atmosphere comparable to Earth's and from evidence that its climate has changed over time scales of billions of years, as well as over much shorter cycles (*3*). Changes in Mars' orbital and spin characteristics likely force many climate cycles (*4*). Obliquity, the angle between the spin axis and the normal to the orbital plane, is one such climate forcing factor. Its predicted variations are particularly great for Mars (Earth's obliquity range is restricted by the presence of the Moon). On Mars, $CO_2$ buffering is analogous to a laboratory cold finger—excess atmospheric gas accumulates at the coldest spot on the planet. For high values of obliquity solar heating at the poles can exceed that on the equator, with a possible shift of any buffering deposits, including both water and $CO_2$. At the current obliquity (25.2°), the poles should act as cold fingers and promote deposition of more volatile components.

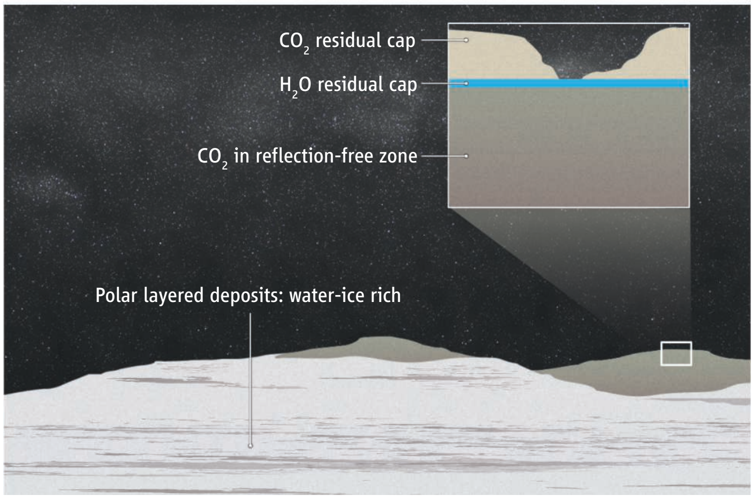
Over time scales of billions of years, Mars shows evidence of periods when liquid water was available at the surface: morphology such as channels and probable standing-water deposits, as well as chemical species found in sedimentary rocks by the Mars Exploration Rovers (*5*). For time scales of only a few million years or less, distinctive stacks of layered materials at both poles (*6*) have been the focus of inquiry into cold-trapped volatiles.

A picture of the materials above this stack has emerged, with thin water-ice caps at both poles (*7*, *8*), covered in the south only by a thin residual cap (<15 m) of $CO_2$ ice. Some of the $CO_2$ residual cap is being eroded year to year (*9*). The ongoing erosion of the $CO_2$ residual materials raises the question of whether the residual cap is likely to last for more than a few years, and if it is part of a hierarchy of climate cycles. The amount of material on this residual cap is only a few percent of the mass of atmospheric $CO_2$ (*10*); thus, it is unlikely to be a record of changes in the mass of Mars' atmosphere.

Prior results from SHARAD (Shallow Radar, on the Mars Reconnaissance Orbiter) and the deeper-penetrating MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding, from Mars Express) (*11*, *12*) had revealed the subsurface complexity of the polar layered deposits. However, these studies gave no indication that the thick polar layered deposits were other than water-ice rich. In the south polar region, SHARAD (*2*) has revealed regions that scatter back extremely small signals. Termed reflection-free zones, and unlike any other areas on Mars, these regions have been interpreted as $CO_2$ ice based on modeling the variation of the calculated depths of underlying layers; the results are more consistent with radar velocities in $CO_2$ ice than in water ice. The geographically varying calculated thicknesses reach as much as ~700 m, but generally are less than 250 m. The 700-m value is close to a predicted maximum of ~1 km based on the expected depth of liquefaction (*13*, *14*). The geographical extent of one such reflection-free zone closely matches that of an outcropping layer mapped from orbital images that has distinctive collapse forms just below the thin water-ice–rich material below the $CO_2$ residual cap (see the figure).

If released into the atmosphere, the mass of material in the main reflection-free zone would nearly double the present surface pressure; this tabulation does not include all the reflection-free zones near the south pole (*2*). This reservoir implies a previous state of Mars' climate that had a higher atmospheric pressure and which then changed to conditions in which a substantial part of that atmosphere collapsed onto the pole. This possibly happened after the last maximal obliquity-driven south polar summer heating, about 600,000 years ago (*4*), although there are predicted younger obliquity excursions nearly as great.

Mars' atmosphere at present appears to be largely vapor-pressure controlled. Although the newly found




**A complicated cold finger.** A schematic of the south polar deposits of Mars. The oldest and most voluminous materials are the "polar layered deposits" (PLD), probably water-ice rich with some admixed dust, up to 3 km in thickness. The $CO_2$ deposits in the newly found reflection-free zones (*2*) occupy several regions within the area of the PLD. Above the $CO_2$ deposits is the residual cap, with an upper part of $CO_2$ with varying thicknesses of up to ~15 m, and an underlying water–ice rich layer of unknown thickness. The $CO_2$ in the reflection-free zones is apparently dust covered where it is exposed without the residual $CO_2$ and water ice residual cap cover.

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$CO_2$ reservoir could nearly double Mars' atmospheric mass, the resulting climate alterations would be modest, and as pointed out by Phillips *et al.*, would involve effects of dust raising and extent and longevity of seasonal frosts, as well as the enhanced $CO_2$ pressure. These ice reservoirs are not the path to a "warm, wet" Mars. Indeed, the limitations of the depth of $CO_2$-ice reservoirs (*13*, *14*) probably require that high former $CO_2$ pressures needed for much warmer conditions must involve carbonate or other rock reservoirs, in addition to ice deposits. The new findings of large, and possibly multiple, buried $CO_2$ reservoirs show how complex a seemingly simple cold finger system can be. Mars' cold trapping is clearly affected by seasonal kinetics, changing dust loading of the atmosphere, obliquity and other orbital cycles, and longer-term evolution of Mars geology. There is much yet to learn about this simple system. The north-south polar asymmetry is but one example of continuing puzzles.

### References and Notes

1. R. B. Leighton, B. C. Murray, *Science* **153**, 136 (1966).
2. R. J. Phillips *et al.*, *Science* **332**, 838 (2011); 10.1126/science.1203091
3. F. P. Fanale, S. E. Postawko, J. B. Pollack, M. H. Carr, R. O. Pepin, in *Mars*, H. H. Kieffer, B. M. Jakosky, C. Snyder, M. S. Mathews, Eds. (Univ. of Arizona Press, Tucson, 1992), pp. 1135–1179.
4. J. Laskar *et al.*, *Icarus* **170**, 343 (2004).
5. S. W. Squyres *et al.*, *Science* **306**, 1698 (2004).
6. B. C. Murray *et al.*, *Icarus* **17**, 328 (1972).
7. T. N. Titus, H. H. Kieffer, P. R. Christensen, *Science* **299**, 1048 (2003).
8. J.-P. Bibring *et al.*, *Nature* **428**, 627 (2004).
9. M. C. Malin et al., *Science* **294**, 2146 (2001).
10. P. C. Thomas, P. B. James, W. M. Calvin, R. Haberle, M. C. Malin, *Icarus* **203**, 352 (2009).
11. J. J. Plaut *et al.*, *AGU Fall Meet. Abstr.* P13D-06 (2006).
12. D. C. Nunes *et al.*, *Lunar Planet. Sci. Conf.* **37**, 1450 (2006).
13. C. Sagan, *J. Geophys. Res.* **78**, 4250 (1973).
14. M. T. Mellon, *Icarus* **124**, 268 (1996).
15. I thank P. Gierasch for discussions.

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EVOLUTION

# The Cost of Being Male

Mitochondrial mutations influence nuclear gene expression more in male *Drosophila* than in females.

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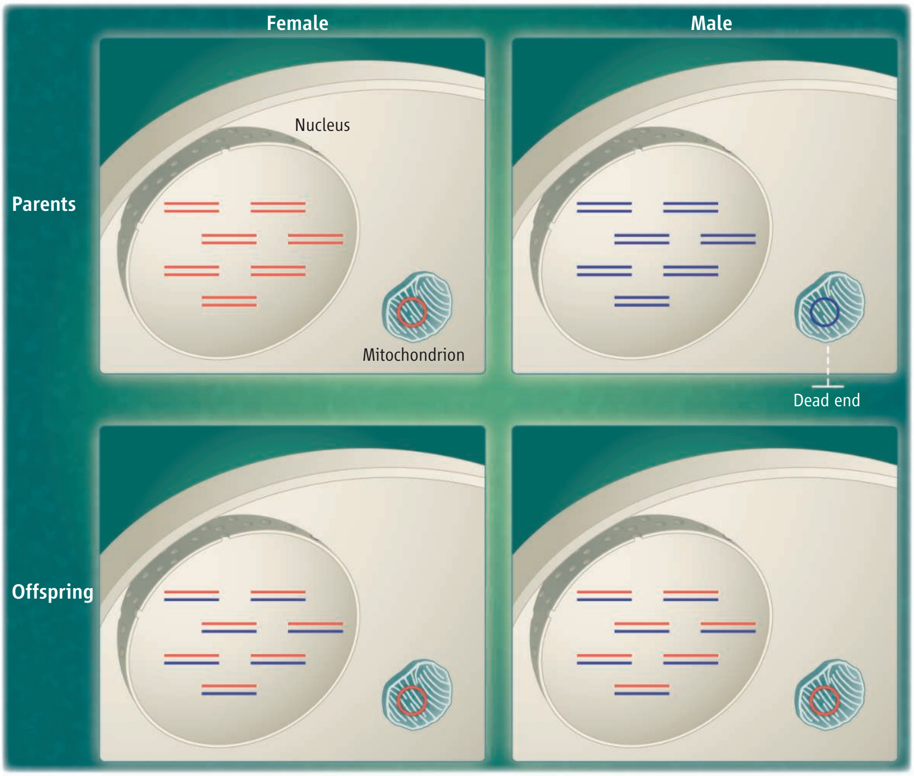
Although we often hear of "the human genome," human cells, like all other eukaryotic cells, actually contain two genomes. The nuclear genome, which garners most of the attention, is composed of the chromosomal DNA within the nucleus and encodes tens of thousands of proteins. The mitochondrial genome, which is present in the organelles that serve as the major site of energy production in the cell's cytoplasm, consists of a circular piece of DNA that encodes fewer than 20 proteins. The two genomes must function together for the cell to survive. However, because the two genomes differ in their mode of inheritance, their interaction may not be completely harmonious. On page 845 of this issue, Innocenti *et al.* (*1*) report experimental findings from the fruit fly demonstrating a sex-specific breakdown of the cooperation between the nuclear and mitochondrial genomes. In this case, it is the males who get the short end of the stick.

Upon reproduction, both mother and father pass half of their nuclear genomes to their offspring. An exception is the Y chromosome, which is passed only from father to son. In contrast, the mitochondrial genome is inherited maternally. That is, it is passed only from the mother to the offspring of both sexes (see the figure). Viewed from the mitochondrial genome's perspective, males are an evolutionary dead end: Regardless of the mitochondria's effect on a male's survival or reproductive success, they have no chance to contribute their genetic information to the next generation. This implies that natural selection will be inefficient at removing mitochondrial mutations that have a negative impact on male, but not female, fitness (*2*). Thus, mitochondrial genomes are expected to harbor more mutations that are deleterious to males than to females. This phenomenon is referred to as the "male mutational load" or, more colorfully, "mother's curse" (*3*).




**Dead-end males.** Males are an evolutionary "dead end" for the mitochondrial genome. Although offspring (**bottom**) inherit the nuclear genome from both parents (**top**), they inherit the mitochondrial genome only from the mother. This can lead to the accumulation of mitochondrial mutations that have a deleterious effect in males, but not in females.

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