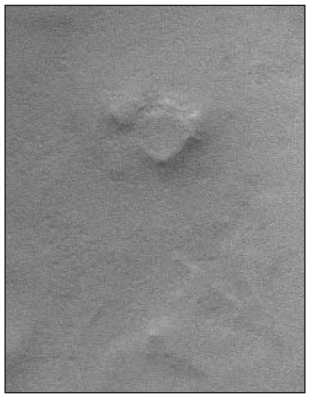
Incessant wobbling of Mars seems to trigger intermittent ice ages that could explain everything from watery gullies that have been seen as seeps to geologic layering taken to be signs of lakes

Iceball Mars?

HOUSTON, TEXAS—Planetary scientists poring over the latest data returned by Mars-orbiting spacecraft have reached a startling conclusion: Half the Red Planet appears to have been encrusted with ice in the relatively recent past. A layer of dirty ice still covers Mars poleward of latitudes that, on Earth, would encompass Anchorage, Moscow, and South America's tip. But several lines of evidence suggest that, within the past million years or so, a now-vanished ice layer cloaked Mars down to the latitudes of Buenos Aires, New Orleans, and Baghdad.

This icy coating would not have been the first to cover large areas of Mars, according to new climate modeling reported last month at a workshop here.* Mars has a tendency to wobble back and forth on its axis, and the new modeling suggests that this instability would have triggered a succession of ice ages throughout the planet's history. The tilting would have shifted polar climes to lower latitudes, vaporizing the polar ice caps and layering dirty ice toward the equator. That would help explain much geology that has puzzled researchers for as long as 30 years: swaths of "softened" martian terrain that look like they're made of ice cream scooped on a hot day, slopes that ooze like wet paint dripping down a wall, and even the enigmatic gullies where water seems to have flowed on a frozen planet.

More speculatively—and farther back in Mars history—extreme tilting of the planet may have repeatedly driven ice sheets right down to the equator. If so, that ice is gone now, but the dust left behind could have formed the mysterious layered sediments of the equatorial region.



An unraveling sheath

The notion that half of today's dry, dusty planet was recently covered by ice may seem a bit far-fetched at first glance. But it begins to look more plausible in the light of new data on the extent of current polar ice.

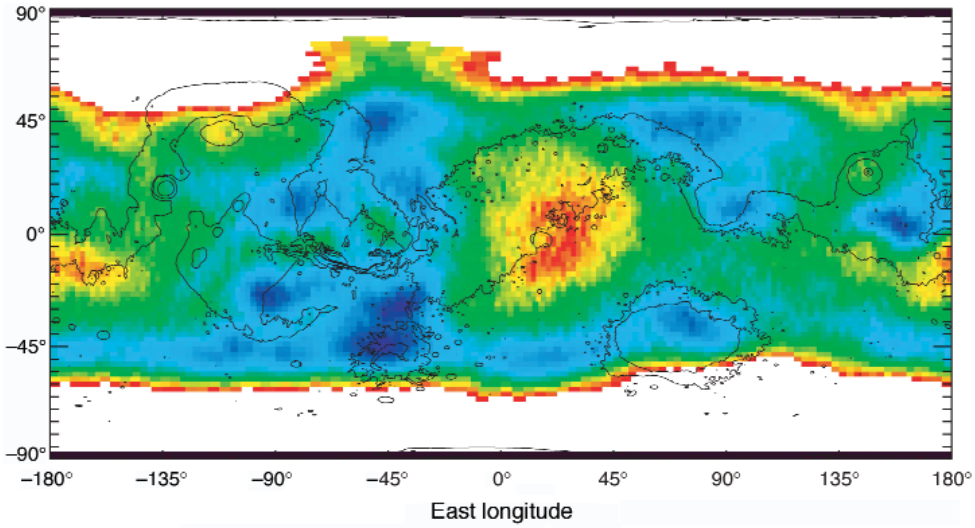
Ice was finally confirmed in the polar regions last year, after the Mars Odyssey spacecraft turned its gamma ray– and neutron-detecting instruments toward the martian surface. By measuring the gamma rays and neutrons given off when cosmic rays strike the surface, these instruments can gauge the amount and depth of water to a meter beneath the surface. At the Houston workshop, Odyssey team members William Feldman and Robert Tokar of Los Alamos National Laboratory (LANL) in New Mexico reported that the latest measurements show that ice is buried beneath several centimeters of dry martian soil in both hemispheres from the poles to a latitude of 60°. And there's a lot of it: In the high southern hemisphere, ice is 40% to 73% of the soil by volume, averaged over hundreds of kilometers, according to Odyssey data.

These data mesh neatly with the view from the Mars Global Surveyor, laid out at the workshop by researchers from Brown University in Providence, Rhode Island—including James Head, John Mustard, Mikhail Kreslavsky, and Ralph Milliken. The spacecraft's Mars Orbiter Camera (MOC) provides images of isolated, narrow strips of the planet's surface at the highest resolution ever, resolving features that measure as small as a couple of meters. Kreslavsky reported that poleward of about 60° latitude, wherever the camera looks, the surface seems smooth when viewed at low resolution; it looks as if meters of heavy snow lie upon the land.

But when viewed at the highest resolution, this smooth mantling has a texture to it. The most typical texture is a pattern of closely spaced, meter-scale knobs that give a stippled or "basketball" look to the surface. The equatorward edge of the ice mapped by Odyssey is "amazingly" coincident with the equatorward edge of the smooth-looking mantling, according to Tokar. The texturing of this high-latitude mantling could well be the result of partial loss of the very shallowest ice to the atmosphere, says Mustard. Permafrost on Earth can likewise get lumpy with warming.

Equatorward, between 30° and 60° in both

* Microsymposium 37, "Mars: Formation and Evolution of the Late Amazonian Latitude-Dependent Ice-Rich Mantling Layer," 15 to 16 March, Houston, Texas; Brown University and the V. I. Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow.



Icy, dirty Mars. Mars Odyssey found ice buried a few centimeters deep above 60° latitude (*above*, white). It looks as if it fell as dirty snow, softening and smoothing the terrain (*top*).

CREDITS: (TOP TO BOTTOM) JPL/NASA; LOS ALAMOS NATIONAL LABORATORY

hemispheres, Mustard has found what appear to be scraps of this thin mantling scattered across the landscape (*Science*, 19 January 2001, p. 422). In the latest analysis by Mustard and Milliken, they find a progressive disruption of the complete mantling seen at higher latitudes as they approach the martian tropics. In places, the mantling has been partially stripped away, revealing multiple layers that total a few to 10 meters in thickness. This dissected mantling is most abundant at about 40° latitude. It looks as if the ice has been stripped from a mantling layer or layers, says Mustard, leaving scraps of crusty layering where winds haven't just blown it all away.

Head and Kreslavsky's analysis of topography returned by the Global Surveyor's Mars Orbiter Laser Altimeter (MOLA) reinforces this picture. It shows high-latitude terrain, smooth at the scale of tens to hundreds of meters, extending to 60°, where it roughens just as the dissected, scrappy mid-latitude terrain appears in the high-resolution images. The topography and imagery therefore both give the impression of a thin layer or layers of dirty ice that were once continuous above 30° latitude but now look different because warming has driven out the ice up to a latitude of 60°.

Cosmetic alterations

A dirty ice sheet that once extended over Mars's mid-latitudes would explain several enigmatic features there. Some of these have puzzled planetary scientists ever since the two Viking orbiters returned images in the late 1970s that looked for all the world like ice-related surface features on Earth. Most suggestive of ice, perhaps, were places where the surface seemed to be sloughing off the land and oozing downhill. Generically termed "viscous flow features," they looked like the work of Earth's rock glaciers, streams of flowing rock-laden ice. Many more have since turned up in close association with the dissected mantling spotted by Mars Global Surveyor. In the 13,000 MOC images they have inspected, Milliken and his Brown colleagues reported at the workshop, viscous flow features are restricted to the same 30° to 60° mid-latitude bands as the dissected mantling. The flows peak in abundance at the same 40° latitude as the dissected mantling.

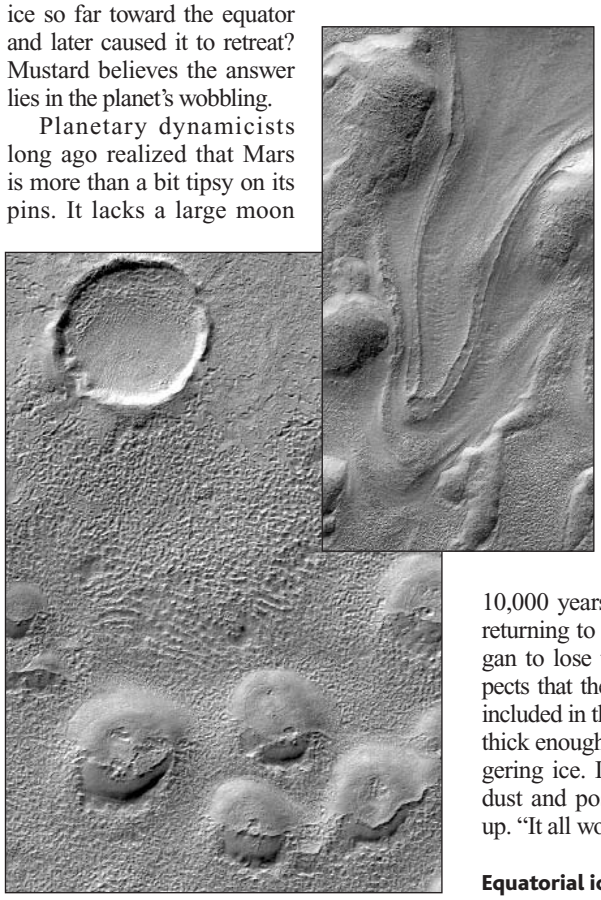
Furthermore, the mysterious gullies—where liquid water seems to have flowed down steep slopes in the recent past—follow the same latitudinal distribution as viscous flow features and dissected terrain; they even tend to cluster in the same three or four places as the viscous flow features do. The currently favored explanation for gullies is that lingering patches of dirty snow melted there (*Science*, 28 February, p. 1294).

Taken together, the Brown researchers say, these features could be explained by the warming of an ice-rich mantling. That could have produced meltwater that formed gullies, ice softening that gave rise to viscous flow, and ice loss through sublimation that weakened the mantling and allowed dissection. "That's consistent with what I've seen" in images, says planetary geologist James Zimbleman of the Smithsonian Institution's National Air and Space Museum in Washington, D.C. "I'd call it a working hypothesis."

Wobbly ice ages

Those pieces all fit together neatly, but one big part of the puzzle remains: What drove the ice so far toward the equator and later caused it to retreat? Mustard believes the answer lies in the planet's wobbling.

Planetary dynamicists long ago realized that Mars is more than a bit tipsy on its pins. It lacks a large moon like Earth's to steady it against the gravitational tug of nearby Jupiter, so it wobbles over and back every 100,000 years or so. For the past few hundred thousand years, according to various calculations, it has been gently nodding a few degrees about its present tilt of 25.2°. But half a million years ago and more, Mars was swinging between a modest 15° tilt up to an inclination of 35°.



Falling apart. Warm, dirty ice may flow like a glacier (*top right*) or vaporize and let some of the dirt blow away (*bottom*).

Wobbling doesn't change how much solar energy Mars as a whole receives from the sun, but it does drive huge swings in the temperatures of the seasons. When Mars was tilted 35° on its side, martian summers at the poles would have been much warmer, driving water frozen in the ice caps into the atmosphere. While the summer poles warmed, the equatorial region would have cooled. Researchers have pointed out that during those relatively warm polar summers, water in the caps would have sublimated into the atmosphere, been carried toward the equator, and gotten trapped at lower latitudes as snow and frost by the intensified cold there. Along with the new ice would have come dust from the intensified dust storms expected with heightened seasonal extremes on an already dusty planet. Once the tilt had eased, in this scenario, the water would have begun to go back where it came from. Water would have sublimed from the warming dirty ice and returned to the ice caps, leaving behind a crusty dust layer in the mid-latitudes subject to dissection by martian winds.

In a test of this wobbling climate scenario, Michael Mischna and Mark Richardson of the California Institute of Technology in Pasadena and their colleagues ran a Mars climate model under varying degrees of planetary tilt. At a higher-than-present tilt, water did migrate from ice caps to mid-latitudes in the model, fast enough to accumulate a few tens of meters of ice in the 10,000 years of a cycle's maximum tilt. On returning to a lower tilt, the mid-latitudes began to lose their ice. However, Mischna expects that the dust left behind, which was not included in the model, would have built a layer thick enough to insulate and protect some lingering ice. If the process repeated, layers of dust and possibly dirty ice could have built up. "It all works out," says Mischna.

Equatorial ice?

Having half the planet covered with ice may seem surprising, but Richardson and his colleagues are raising an even more dramatic possibility: that the whole of Mars, right down to the equator, has been mantled at one time or another. When they crank up the tilt in their model into the 45° to 60° range—the upper limit for Mars—ice sheets grow down to the equator. And they note that ancient, sometimes rhythmically layered deposits have been found throughout the equatorial region, although their origins are much debated (*Science*, 8 December 2000, p. 1879).

As a hint that ice has in fact been laid down in the martian tropics, Head and David Shean of Brown and glacial geologist David Marchant of Boston University make a case

CREDITS: JPL/NASA

that the odd flowlike deposits on each of the three giant volcanoes of Tharsis Montes may be the remains of glaciers. Straddling the equator, the three volcanoes each have fan-shaped deposits off their northwest flanks. Taking a close look at Arsia Mons, the southernmost of the three, Head, Shean, and Marchant see a strong resemblance between its deposits and those left by the withdrawal of the so-called cold-based glaciers of the Dry Valleys of Antarctica, which are too cold to lubricate their flow across the land with melted water. It's as if prevailing northwesterly winds dropped so much snow on the volcanoes' upwind flanks, they say, that thick ice deposits formed and began to flow.

That a wobbling Mars periodically coats itself with dirty ice "is a very interesting scenario," says planetary scientists Bruce Jakosky of the University of Colorado, Boulder, "but I have questions." The polar and mid-latitude layers may well be related, he says, but "there are a lot of ways to emplace ice at low and mid-latitudes." Planetary scientist Stephen Clifford of the Lunar and Planetary Institute in Houston allows that the ice and dust may well have been deposited together as dirty snow or frost. But the dirt could just as easily have formed first and the water diffused in from the atmosphere and frozen in the soil, he cautions. Then temperature variations might have concentrated the ice to the high abundances seen by Odyssey.

Confirmation of a pivotal geologic role for large amounts of ice may come with some of the next missions to Mars. In December, the Mars Express orbiter arrives at the Red Planet. The European spacecraft carries a deep-penetrating radar capable of detecting ice lingering below the reach of Odyssey. NASA's Mars Reconnaissance Orbiter, slated for launch in August 2005, will carry a similar instrument.

–RICHARD A. KERR

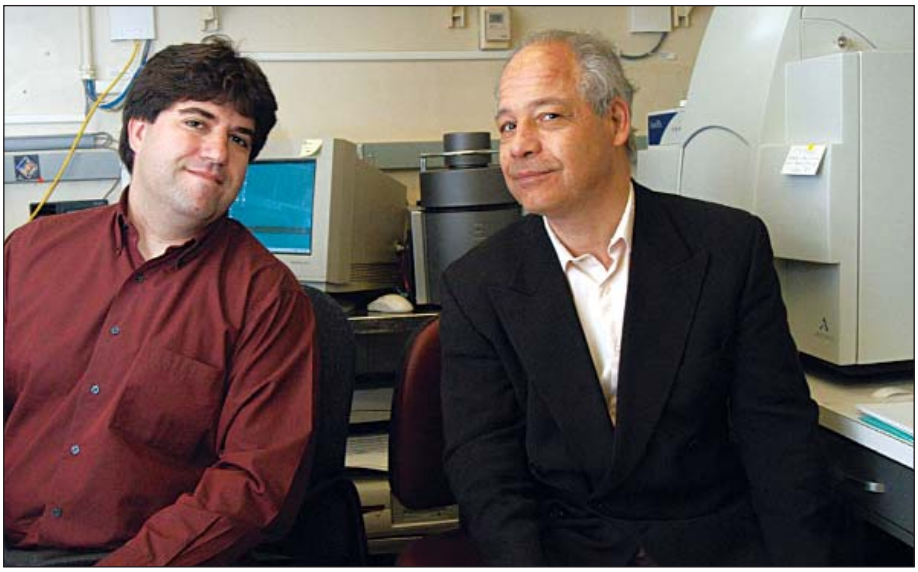
Genetics and Medicine

Recruiting Genes, Proteins For a Revolution in Diagnostics

As companies create medicines for special conditions that require molecular testing, they are helping change the way common diseases are diagnosed

If you want a glimpse of medicine's future, take a look at Herceptin. This new drug from Genentech homes in on a specific cell receptor to block an aggressive form of breast cancer. Approved by the U.S. Food and Drug Administration (FDA) in September 1998, it racked up sales last year of $385 million, making it one of the most successful new anticancer compounds ever released.

But what makes Herceptin (also known as trastuzumab) noteworthy is not just its precise targeting and impressive sales. It is a highly specialized medicine, intended only for 25% to 30% of women with breast cancer —those whose cancer cells overexpress a growth-related protein receptor called *her-2/neu.* Designed for patients who can be identified by this molecular marker, the therapy has been hailed as one of the first examples of personalized medicine. Lost in the fanfare, however, is one of the keys to Herceptin's success: Like a cruise missile, its effectiveness depends on sound intelligence. Patients who can benefit from the drug must be identified with a diagnostic test that flags the presence of the cell receptor.



CREDIT: MARTY KATZ

Early warning. FDA's Emanuel Petricoin (*left*) and NCI's Lance Liotta have teamed up on methods of testing blood to identify complex protein patterns associated with cancer.

Several companies already offer *her-2* tests to pinpoint women likely to benefit from the drug. In an industry in which a product with $100 million in sales qualifies as a blockbuster, this test is off to a fast start, generating more than $22 million. "Soon there will be many more examples like this," predicts Jonathan Peck, vice president of the Institute for Alternative Futures, a think tank in Alexandria, Virginia. Herceptin, in other words, could be a model for a new wave of diagnostics.

Drug companies are creating a host of new drugs linked to molecular indicators of disease, while medical diagnostic companies and academic teams are pursuing a bevy of new testing strategies. Long viewed as the drug industry's stepchild, medical diagnostics are starting to benefit from the molecular technology boom. Researchers aim to use gene- and protein-sensing devices to flag patients with genetic susceptibilities, identify those who might suffer side effects of drugs, and spot diseases even before they produce symptoms.

"This is going to have a really dramatic impact on cancer," predicts Lee Hartwell, who heads the Fred Hutchinson Cancer Research Center in Seattle, Washington. Even mainstream cancer therapies—surgery, radiation, and chemotherapy—that have changed little in recent decades are expected to benefit from better diagnostics. Their success rates have already improved dramatically because cancers are being spotted earlier, Hartwell notes. According to one recent diagnostics market survey, the technology boom could generate $9 billion in new revenues for diagnostic companies over the next decade, a growth of almost 50%.

But the transition isn't likely to be straightforward. Many factors—including the insurance industry's reluctance to reimburse for anything new and physicians'