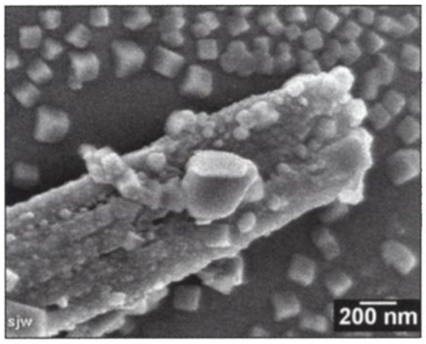
It's not just springlike seeps but young lava flows, salty meteorites, and unblemished water channels that are making the Red Planet look alive again

A Wetter, Younger Mars Emerging

Early in the 20th century, Mars seemed a living planet. Some astronomers thought they saw plants flush green over huge areas each spring as water coursed through planet-girdling canals. But images from the Mariner spacecraft killed off Mars in the 1960s when they revealed barren, lunarlike landscapes and no canals. Although huge water-carved channels eventually turned up, they dated from way back in the middle years of martian history, 1 or 2 billion years ago. Mars seemed geologically lifeless, its meager portion of water locked beneath a deeply frozen surface and its inner fires damped. But now planetary scientists are reviving Mars, restoring it if not to youthful vigor at least to modest geologic activity.

Breathing new life into the Red Planet are continuing analyses of martian meteorites and stunning images from the Mars Global Surveyor (MGS), which has been in orbit since 1997. Last month's announcement that the camera aboard MGS had spied signs of geologically recent—possibly even ongoing—water seeps (*Science*, 30 June, pp. 2295, 2325, and 2330) has caught everyone's attention. Other, perhaps more persuasive, signs also suggest that water may even now flow on or beneath the frigid surface.

"We keep seeing more and more evidence there's at least a little bit of water still running around," says geochemist Timothy Swindle of the University of Arizona in Tucson, who has analyzed martian meteorites. And the heat needed to unlock that water from the planet's frozen stores also seems to still be available, at least at times. "There is considerable evidence Mars is still quite active" volcanically, says planetary scientist Stephen Clifford of the Lunar and Planetary Institute in Houston. "There is a [volcanic] heat engine that continues to the geologic present." It all adds up to what planetary geologist William Hartmann of the Planetary Science Institute (PSI) in Tucson calls "Youthful Mars": the emerging view that volcanic heat can still mobilize abundant, near-surface water. Whether truly youthful, or just experiencing the odd flicker of the fires of youth, a wetter Mars is good news for researchers looking for martian life and engineers looking to sustain off-planet visitors.



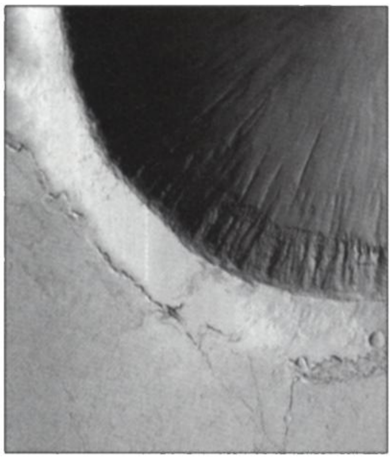
Harbingers of martian (geologic) life. The Los Angeles meteorite (*left*, beside a centimeter cube) is the latest find among the shergottites, geologically young martian meteorites. The namesake of the group, Shergotty, contains salt (*right*) deposited from a brine.

CREDITS: (LEFT TO RIGHT) NASA/JPL S. J. WENTWORTH/LOCKHEED MARTIN SPACE OPERATIONS

Well into the '90s, most researchers believed that the planet, although perhaps geologically and hydrologically active in its early years, had long since fallen into a geologic coma. Gone were the days of water splashing on the surface, or even near it. Rains may have cut valley networks 4 billion years ago under a thicker, warmer atmosphere; an ocean may have filled the northern lowlands a few billion years ago; and water may have burst from the southern highlands to cut great channels debouching northward. But that was long ago. Water flows from a planet's high spots to low ones, where it stays unless it's recycled into the atmosphere and deposited as rain or snow in the highlands. Mars seemed to have had no such weather for eons. Even the occasional rising fingers of magma that had fueled volcanic eruptions and melted ground ice to cut the great outflow channels apparently ceased within the past billion years. So the planet's water, many planetary scientists thought, would have drained from beneath the southern highlands into or beneath the northern lowlands and frozen there.

A dead Mars started to look suspiciously active, however, as geochronologists began dating the 14 meteorites known to have been blown off Mars by large impacts. ALH84001 (of putative microfossil fame) came in truly ancient at 4.5 billion years, having solidified from magma to form a bit of Mars's earliest crust. But the others—which came from at least two other randomly located impacts—solidified from molten lavas relatively recently. One group, including the so-called nakhlites, named for the Nakhla meteorite, is 1.3 billion years old. The other young group, including the shergottites, is as young as 165 million years, or less than 4% of the age of the planet. Geochemist Laurence Nyquist of NASA's Johnson Space Center in Houston and his colleagues will report at next month's meeting of the Meteoritical Society that the newest shergottite, called Los Angeles—it was found years ago by a rock hound in the desert near L.A. but only recently recognized—has the identical 165-million-year age as the meteorite Shergotty, which gave the group its name.

If impacts were flinging young rocks off Mars, researchers wondered, where were the young-looking terrains? Early estimates suggested that the last volcanic resurfacing of the planet with lava occurred up to a billion years ago. But dating the surface of Mars from orbit is a tricky business. The usual approach is to count the number of craters punched in the surface by the steady stream of asteroidal and cometary debris that rains onto every planet like the grains of an hourglass. Uncertainties abound, but planetary scientist William Hartmann and his colleagues have been working to decrease them using crater counts from MGS imaging. Comparing the rain of impactors calculated for Mars with that on the moon, planetary scientists can now calibrate martian dating against Apollo isotopic dating of lunar surfaces. MGS images allow Hartmann and his colleagues to see and count much smaller martian craters, down to 11 meters in diameter. And Hartmann has focused on the youngest terrains, where the lingering error of a factor of 2 or 3 produces the smallest errors in absolute ages.



Crater counting in MGS high-resolution images has produced some eye-popping ages for the surface of Mars. "We've got a robust case," says Hartmann, "for surfaces that are below 100 million years" in lava flows within the Arsia Mons volcanic caldera. Last year, Hartmann and his colleagues reported the region to be no older than 40 million to 100 million years. Planetary scientist Alfred McEwen of the University of Arizona pointed out young-looking lava flows in the Elysium Plains that Hartmann and Daniel Berman of PSI date at 10 million years or less, and earlier this month Hartmann found a similarly young age for parts of Amazonis Plains. McEwen estimates that perhaps 10% to 20% of the planet's surface is younger than a few hundred million years old—roughly the same proportion as that of the youngest martian meteorites. And there's no reason to suppose that Mars was volcanically active for 99% of its existence and then happened to shut down just before humans could take a look; in all likelihood, Hartmann says, Mars is still volcanically active, at least episodically.

Because the martian internal fires seem to still be licking the surface, it may not be so surprising that geochemists working on the martian meteorites are finding signs that liquid water has been moving near the surface in geologically recent times. In the January issue of *Meteoritics and Planetary Science*, Swindle and his colleagues reported that a rustlike product of weathering deposited within veins in a 1.3-billion-year-old nakhlite is only about 650 million years old, according to the potassium-argon method of isotopic dating. Geochronologist C.-Y. Shih of Lockheed Martin Space Operations in Houston, Nyquist, and their colleagues have confirmed that date using the rubidium-strontium method. That's too old to be contamination picked up after falling to Earth, suggesting that water flowed through the crust within the last 15% of martian history.

The latest results from the martian meteorites argue for even younger water flows quite near the surface of Mars. Meteoriticists John Bridges and Monica Grady of the Natural History Museum in London reported in the 30 March issue of *Earth and Planetary Letters* that a variety of minerals in three nakhlite meteorites, including a fragment of the Nakhla meteorite collected within days of its fall, seem to have precipitated from a brine. Waters had leached minerals from the crust, then evaporated, concentrating the liquid. Water evaporates most readily near the surface, which is where the dynamics of impacts would place the salt formation, too. Only rocks within a few meters of the surface can make it off a planet, according to the prevailing mechanism for impact launching. And meteoriticist Susan Wentworth of Lockheed Martin and her colleagues told the Lunar and Planetary Conference in March that the 165-million-year-old Shergotty meteorite contains a group of evaporitic minerals "remarkably similar" to those of the older Nakhla, implying an evaporitic origin on Mars for the deposits.

Although young lavas and weathering imply the requisite combination of near-surface heat and water, imaging hadn't caught a clear example of geologically recent, volcanically triggered water flows until MGS. McEwen and his colleagues are finding that floodwaters cut Marte Vallis, a smallish to medium-size outflow channel, within the past few hundred million years, making it the youngest known outflow channel. And it happens to lie just southwest of the Elysium Plains, whose lavas flow into it. "That's probably not a coincidence," says McEwen. "The magmatism melted the ground ice to create the flooding," and lavas flowed in later.

The increasing evidence of a wetter, more active Mars "reminds me of what happened at the beginning of the Magellan mission" to Venus in 1990, says planetary geologist Raymond Arvidson of Washington University in St. Louis. "All our preexisting paradigms went out the window. With MGS, we're giving birth to one or more new paradigms, but we're still trying to figure out what Mars actually did."

Not dead yet. A young lava flow, as evidenced by its relative paucity of impact craters, laps onto the rim of a 4-kilometer impact crater on the Elysium Plains of Mars *(left)*. That such volcanic heat still reaches the surface gives hope of finding geothermal springs, depicted in the above painting by planetary scientist William Hartmann.

CREDITS: (LEFT TO RIGHT) MALIN SPACE SCIENCE SYSTEMS, JPL AND PLANETARY SCIENCE INSTITUTE; W. K. HARTMANN/PSI

At one extreme of the possibilities is the MEGAOUTFLO hypothesis (Mars Episodic Glacial Atmospheric Oceanic Upwelling by Thermotectonic Flood Outbursts) espoused by hydrogeologist Victor Baker of the University of Arizona and his colleagues (*Science*, 12 February 1993, p. 910). In MEGAOUTFLO, the great outflow channels are cut by water released by deep heating, as has been generally assumed. In this scenario, however, the pulse of heating is planet-wide thanks to some internal convulsion of the planet. It drives massive, simultaneous outbursts of water down the channels into the northern lowlands from the southern highlands and releases into the atmosphere carbon dioxide that had been locked up with the water in icelike clathrates. The water fills the northern lowlands to form a temporary ocean, and the carbon dioxide beefs up the atmosphere and its greenhouse to provide 100,000 years or so of relatively mild, wet climate before the ocean and atmosphere return to the subsur-

Only dormant? Olympus Mons, the largest volcano in the solar system, may erupt once more.

face. At least a few such cycles are evident in Viking images, say Baker and his colleagues, cycles that could presumably repeat again. Other scientists, however, find the available imagery unconvincing or doubt that all that water could get back into the southern highlands fast enough for the next episodic outburst.

In an upcoming *Icarus* paper, Clifford and planetary geologist Timothy Parker of the Jet Propulsion Laboratory in Pasadena, California, reject such episodic rejuvenation. Instead, they propose, Mars has more or less steadily wound down geologically but not to a dead stop. They start with an "inevitable" ocean on early Mars, albeit an ice-covered one; the young planet's inner heat would have been too great to allow the water to be locked up beneath the planet's surface, they say. Water cycling slowly from lowlands to highlands by sublimation from the ice would feed into the subsurface highlands, from which it might occasionally burst to cut the outflow channels. But eventually, as internal heat waned, such a thick barrier of frozen ground would form that only the isolated and increasingly infrequent intrusion of magma could allow water to break out.

Sorting out what Mars actually did "is an incredible challenge," says McEwen. "It's probably a complicated story, and we've barely begun to figure it out." Doing geology from orbit is never easy, he notes, but on Mars today it's proving particularly difficult. The Mars Orbital Camera onboard MGS is providing unprecedented detail of the surface. Still, its high-resolution images come in strips just 3 kilometers wide that will cover perhaps only 1% of the planet. Given the fuzzy Viking views of terrain surrounding the strips and the alien nature of the landscape, at times "you don't know what you're looking at," says McEwen. Diametrically opposed interpretations are common. Add in the uncertain dating, and "we're asking questions we can't answer without sending people and collecting the samples," says planetary geologist Kenneth Edgett of Malin Space Science Systems in San Diego. A wetter Mars would certainly help sustain any such visitors.

–RICHARD A. KERR

ECOLOGY

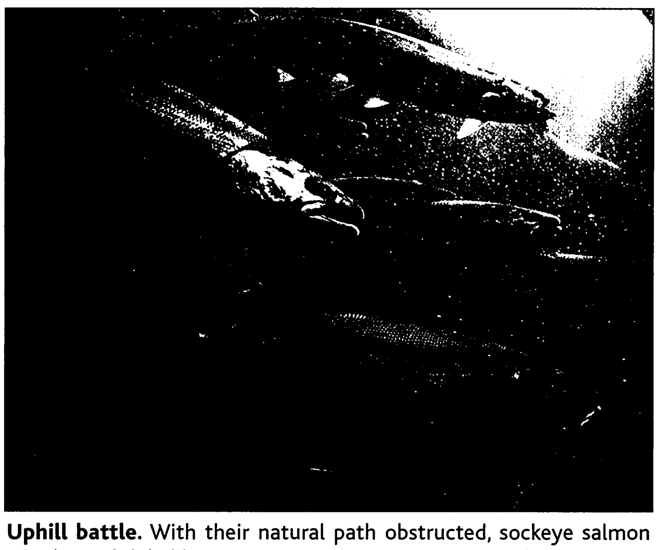
Can Science Rescue Salmon?

As scientists wrangle over whether breaching dams will save endangered Snake River salmon, the Clinton Administration has decided to bypass the controversial decision

PORTLAND, OREGON—For now, at least, the dams will stay, as the controversy swirling around them escalates. At a press conference on 27 July, the National Marine Fisheries Service (NMFS) released a long-awaited plan to save the Columbia River's endangered salmon by restoring fish habitat, overhauling hatcheries, limiting harvest, and improving river flow. What the plan did not do, however, was call for immediate breaching of four dams on the Snake River, the Columbia's major tributary—an option that has been the subject of a nationwide environmental crusade. The NMFS will hold that option in abeyance while it sees whether the less drastic measures will do the trick. Responses from both sides were immediate and outraged. "This plan keeps the fuse burning on the extinction time bomb," charged Tim Stearns of the National Wildlife Federation, while presidential candidate George W. Bush and Senator Slade Gorton (R–WA) had already slammed NMFS for not ruling out breaching absolutely.

Without question, the stakes are huge: Wild salmon are cultural symbols of the Pacific Northwest. Yet breaching the Snake River dams—bypassing them with newly constructed channels—would cost almost $1 billion and affect thousands of jobs. No one disputes that these dams, and the 14 other major and hundreds of minor dams in the Columbia Basin, have drastically reduced Northwest salmon populations, some of which are headed for extinction. The disagreement concerns whether breaching the dams is indeed the silver bullet or whether the salmon can be rescued by other means.

In theory, at least, the warring parties all agree that salmon conservation should be driven by science. Indeed, Vice President Al Gore has promised to convene a post-election "salmon summit" to save the fish with an "objective, science-based process." But science is unlikely to provide the answer to an intrinsically political debate—especially because the scientists themselves disagree, often vocally, providing ample ammunition for both camps. At the heart of the dispute is the maddeningly incomplete body of data on Columbia Basin salmon—and especially the role the multiple threats play in driving the fish to extinction.



Uphill battle. With their natural path obstructed, sockeye salmon travel up a fish ladder to return to their spawning grounds.

In the past 18 months, two scientific teams have issued their conclusions about the relative contribution of the chief threats to Snake River salmon: hydropower, habitat degradation, hatchery misuse, and overharvesting—collectively called the "four H's" (see sidebar, p. 718). One team, composed of state, academic, and tribal scientists, fingered dams as the major culprit and called for bypassing them. The other team, scientists from NMFS, countered that other factors were equally to blame and that fixing them would have more certain benefits. The new NMFS plan signaled a clear winner in the debate: The fisheries agency listened to its own scientists. But because the plan is expected to be challenged

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