An 'Outrageous Hypothesis' For Mars: Episodic Oceans

The Mars Observer spacecraft is due to arrive at Mars in August, and U.S. planetary scientists are already choosing sides on the question of what kind of planet the craft's instruments will see. The two sides can be described, in the playful words of one researcher, as the "conservatives" of the planetary community versus the "macho" types. The conservative majority opts for the conventional view of Mars: that during the past 3 billion years the atmosphere has been so thin and cold that the planet's water has remained locked up underground as ice. A risk-taking macho minority prefers the radical alternative: a Mars periodically shrouded in an Earth-like atmosphere, with a temporary ocean and massive ice sheets.

It's not just bravado that led long-time planetary geologists Victor Baker, Robert Strom, and their colleagues at the University of Arizona to develop this episodic climate change hypothesis for Mars. For one thing, says Baker, "planetary science changes so rapidly that it's more open to 'outrageous hypotheses' " than other fields. And some sort of far-reaching hypothesis is needed, he feels, to explain the odd assortment of surface features—huge channels, apparent ocean shorelines, and possible glacial features—that he and his colleagues see in images sent back by the Viking spacecraft of the late 1970s.

The planetary community as a whole, though, is sticking with the conservative line. "I am very skeptical of the whole hypothesis," says Michael Carr of the U.S. Geological Survey in Menlo Park, who is the interdisciplinary geoscientist on the Mars Observer team. "There are an incredible number of unknowns in it; Vic admits that." Perhaps the fundamental unknown is the true nature of the surface features glimpsed by the Vikings. Are they really shorelines and glacial terrains, or have the less than ideal Viking images misled researchers? However skeptical they may be, planetary scientists are eager to find out. And that's adding to the excitement of August's rendezvous, because Mars Observer's high-resolution camera, with a resolution 10 times better than that of the Vikings' cameras, should tell just how outrageous an explanation Mars requires.

If the verdict on the Arizona hypothesis turns out to be favorable, it wouldn't be the first time Mars specialists have had to accept an outlandish scenario for the planet's past. The Viking images alone were enough to convince the community that, in the middle years of its history, Mars was scoured by catastrophic floods 10,000 times larger than the flow of the Mississippi. The evidence was incontrovertible: huge channels up to 1000 kilometers long gouged out of the Martian landscape between about 1 billion and 3.5 billion years ago. Carving them, researchers calculated, would take water gushing at 10 million to 1 billion cubic meters per second.

As most researchers envisioned these floods, though, they were isolated outbursts, and the water didn't survive for long on the chilly, dry surface. In what might be taken as the conventional scenario, the water probably first accumulated in underground aquifers beneath a layer of frozen permafrost, where Mars' internal heat was enough to keep the water liquid. Eventually, the subterranean pressures burst the permafrost cap and drained an aquifer over days or weeks. The resulting flood generally surged down an outflow channel into Mars' northern lowlands, formed a lake with three times the area of the Caspian Sea, and quickly froze solid. Ultimately, the ice evaporated or was covered with dust.

NASA/JPL

An ancient Martian seacoast? According to one interpretation of these Viking images, catastrophic floods filled a lowland basin *(top of image at left)* and water crept up the canyons to the south. In the detail *(above)*, a putative shoreline runs north-south.

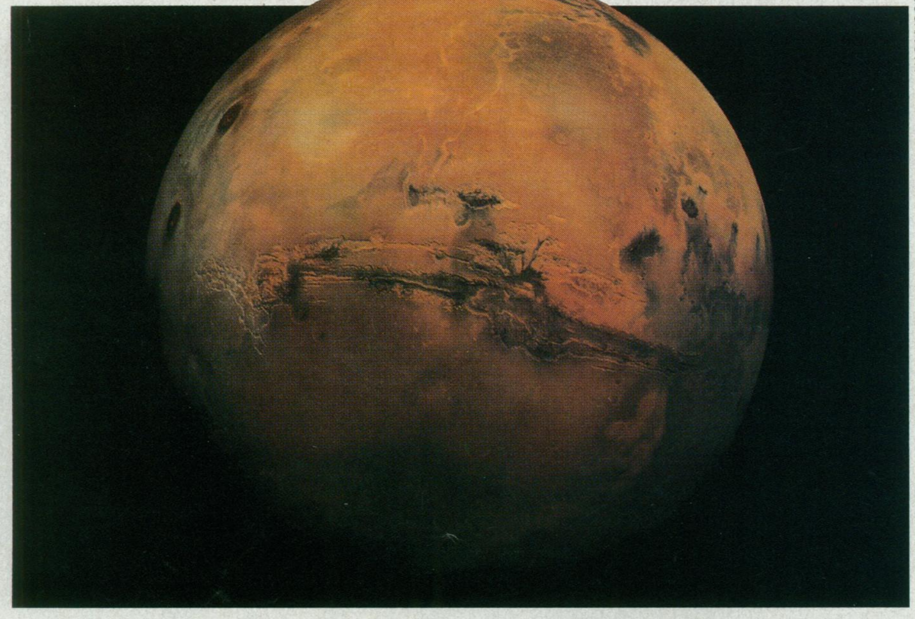
A sea change. At first this conventional view of things was fine with Victor Baker, who has been working on Mars images for decades. He stuck with convention even when Timothy Parker and his colleagues at the Jet Propulsion Laboratory suggested in the mid-1980s (*Science*, 29 August 1986, p. 939) that Viking images showed signs of ancient shorelines—evidence that liquid water had persisted on the surface for much longer than had been thought. Around the northern lowland plains, Parker and his colleagues saw what they took to be wave-generated barriers of sediment linking onetime islands and possible strand lines marking high-water levels. He also saw impact craters that looked as if they had been eroded by the sea, which Parker estimated at up to 100 meters in depth, covering 10% to 15% of the planet's surface.

But Baker, and most others, remained unconvinced. The "shorelines," they argued, could actually have been formed by lava flows.

"What changed my opinion, with some reluctance, were the glacial landforms," Baker recalls. Researchers had long recognized possible signs of sculpting by flowing ice on Mars, but the ice was generally thought to be scattered and scarce. But in the past few years, as Strom and Jeffrey Kargel, then at Arizona, studied Viking images of the planet's southern high latitudes, they began to think they could discern abundant and widespread glacial features.

Strom and Kargel's putative glacial landforms, which seem to be 1 billion to 2 billion years old, run the gamut of shapes familiar from glaciated regions on Earth: scour marks, ridges called moraines where ice dumped its load of sediment and boulders, pits called kettles where great blocks of ice were left half-buried and then melted, meandering ridges built by debris carried in rivers beneath the ice, and Matterhorn-like mountain peaks gouged on all sides by the upper reaches of glaciers. And, according to Kargel and Strom, these features are laid out across the landscape in a sequence much like the one created by advancing and retreating ice sheets on Earth. That was enough to convince Baker. "Either nature played a bizarre trick to make it look like glaciation or it is glaciation," he says. "As a scientist, I went with the glaciation."

And once you go with extensive glaciation in the south, Baker points out, Parker's case for a northern ocean looks a lot stronger. For every ice sheet, there has to be a source of liquid water that can evaporate, leading to snowfall that nourishes the ice sheet. And as Baker and his colleagues began thinking through these implications, the scenario took on larger dimensions. "Initially, I was looking at it as others did, using multiple working hypotheses" to explain the diverse landforms, Baker says. "But planets tend to operate so that things are connected to each other. Earth operates as a system. Do we want to study Martian landforms as a bunch of oddities or as part of an overall operating system?" The Arizona group has opted for the latter—and an eye-popping system it is, too.


NASA/USGS

A once-wet planet. Channels cut by huge floods lead north *(up)* from the center of this color-enhanced Viking mosaic toward a putative ocean basin.

To weld an ice sheet and an ocean into a single system, the group needed a climate warm enough to keep the ocean from freezing. That would be a dramatic change from what everyone agrees must have been the Martian atmosphere's normal state over most of the past 3 billion years: bone dry, with a surface pressure of about 10 millibars—the pressure of Earth's mid-stratosphere—and temperatures below freezing.

Timely floods. Warming and moistening that unpromising climate would take an extraordinary event. To do the job, the Arizona researchers invoked a spate of catastrophic floods, all cutting their channels at the same geological moment. And to pull that off they appealed to Mars' abundant volcanism, which has left the surface dotted with massive volcanoes and lava flows. If some of that activity came in great outbursts, it could have melted enough subsurface ice to drive surges of water out of the crust. At the same time, the volcanoes would have belched out carbon dioxide, and additional gas would have been released as the water interacted with the crust. All told, enough carbon dioxide would have been pumped into the air to produce a strong greenhouse warming, according to the Arizona scenario.

But the resulting Earth-like balminess couldn't have lasted too long, or Mars' ancient landforms, dating from the earliest era of the planet's 4.5-billion-year history, would have been eroded away. Presumably, the water and carbon dioxide seeped back into the crust until the cold returned in a million years or so and the surface of the planet was dry again. One episode wouldn't be enough to explain apparent multiple glaciations, say the Arizona researchers, so they propose that the volcanic outbursts recurred, each one temporarily turning Mars into an Earth-like place—though most likely a lifeless one.

It's a provocative story, say other planetary scientists, but it rests on a dubious foundation. "[The Arizona group] is looking for a single mechanism, an overriding process. That's the Occam's razor approach to science, but nature is too perverse for that," says planetary geologist Michael Malin of Malin Space Science Systems Inc. in San Diego, principal investigator for the Mars Observer camera. For Malin, the key problem is the supposed shoreline and glacial features. "I think their interpretations are speculative," he observes. "With about half of the landforms they describe, the feature I see is somewhat different from what they see." Even when there's no disagreement about a feature, he says, "there are many times, especially at Viking [camera] resolution, when there are other processes that could form it."

Leaving aside the interpretation of the photos, some planetary scientists see problems with many of the steps in the scenario, such as the mechanism of climate change. "Quantitatively, it won't work," says James Kasting of Pennsylvania State University, who specializes in modeling planetary climate change. "They need huge belches of greenhouse gases [to warm the climate]. That is pretty ad hoc. The total planetary inventory of carbon dioxide may be several bars [of atmospheric pressure], but that may be tied up in carbonate rocks. It's hard to see how you could release it. And even if they get it, I don't think it will give them the warming they want."

Even Parker, who was the first to claim evidence of shorelines, doesn't invoke a warming in Mars' recent history. An ocean would have been easier to maintain, Parker notes, far earlier in Martian history. There are signs that the atmosphere of the newborn planet may have been warm and dense enough to allow flowing water on the surface without extra help from volcanic outbursts. And an old ocean is just what he thinks he sees. Based on the number of meteorite craters that have scarred the supposed shorelines, Parker estimates that any sea existed roughly 2.5 billion to 3.5 billion years ago. The Arizona group's ice sheet—and therefore its ocean—was around as recently as 1 billion to 2 billion years ago. "I'm willing to allow a good bit of error in the dating," says Parker, "but I'm not sure it's big enough to allow their younger ocean."

But the Arizona researchers point out that this battle is being waged over dozen-year-old photographs. The high-resolution camera aboard Mars Observer, says Malin, would reveal "a large number of landforms that ought to be there if the Arizona group is right." With its tenfold improvement in resolution over the best that the Vikings could do, the camera should allow the identification of features as small as car-sized boulders. From the size and distribution of the boulders, says Malin, investigators should be able to infer how the boulders were transported—by glaciers, by floods, or by the waves of a long-lasting ocean.

Baker is ready for any test. "I would be absolutely delighted if the new data proved our hypothesis wrong," he says, because whatever alternative hypothesis explains the varied surface features of Mars "would be at least as interesting as this one."

–Richard A. Kerr

Additional Reading

V. R. Baker *et al.*, "Ancient Oceans, Ice Sheets and the Hydrologic Cycle on Mars," *Nature* **352**, 589 (1991).

J. S. Kargel and R. G. Strom, "Ancient Glaciation on Mars," *Geology* **20**, 3 (1992).