coast—could explain the location and diversity of the coral communities he saw. The researchers also discussed whether the seamount organisms were actually reproducing on the summits or drifting in from other areas. If the populations were sustaining themselves, they wondered whether circular seamount currents known as Taylor cones were preventing eggs and larvae from drifting into the nearby abyss.

To help answer such questions, UCSD's Stocks has been urging researchers to share data through electronic databases such as Seamounts Online. To draw robust conclusions, she says, "you need to bring together data from a lot of seamounts, not just one or two." That goal got a boost recently when Russia agreed, with U.S. help, to contribute 2 decades of cruise results to the site. Another site, meanwhile, is collecting seamount maps, starting in the Pacific (see NetWatch, p. 1025).

Other scientists hope the Oregon meeting will spur coordinated research. For instance, marine biologist John Dower of the University of Victoria, Canada, would like to see researchers conduct studies that compare seamounts with similar physical characteristics but different biological productivity. Such comparisons could help reveal why some seamounts have higher rates of endemism or richer fish communities than others.

Dower's own studies in the Pacific off Canada may have already answered one puzzle: How do isolated seamounts support fish populations that appear to be genetically identical to distant inshore stocks? Studies suggest that in the northeast Pacific, the answer is that giant eddies periodically swirl off the coast, carrying larval fish out to the peaks. Such findings have implications for conservation, he adds, because "you couldn't just protect the seamount; you'd need to protect the source [of the fish] too."



Armed. A seamount shrimp sports a hefty claw.

Similarly, "policymakers will want to know if bottom trawling is going to be a problem on every seamount or just some," says conservationist Matthew Gianni, an Amsterdam-based adviser to the International Union for the Conservation of Nature, who has been urging nations to impose a moratorium on seamount trawling. His goal is a global agreement, and he hopes that a U.N. ban on high-seas drift netting a decade ago will serve as a precedent. Several major conservation groups, including Conservation International and the World Wide Fund for Nature, have taken up the cause.

Researchers also hope to raise the profile of seamounts with Web sites that let the public experience scientific cruises vicariously through pictures and daily updates. "Seamounts are big, photogenic features," says Gianni. "We just need to bring them out of hiding." Such exposure, researchers hope, will help turn the current molehill of seamount data into a mountain of useful knowledge. **–DAVID MALAKOFF**

Planetary Science

Eons of a Cold, Dry, Dusty Mars

Evidence is mounting that, although water has at times flowed across the martian surface, it has not lingered as a liquid long enough to alter the planet much chemically

PASADENA, CALIFORNIA—The trio of missions that will touch down on Mars this December and January are "following the water" as they search for signs of life on another planet. Each targets an ancient site where water may once have stood, perhaps during an oft-hypothesized warm and wet era on Mars. But the spectral data pouring back the last few years from instruments orbiting Mars are starting to build a case for a volcanic planet only gently touched by the chemical alteration that water has wreaked on Earth for billions of years. In the emerging view, a perpetually frigid climate has kept Mars's modest store of water locked up as ice most of the time. The surface may never have been particularly hospitable to life, at least not for long. If so, the search for signs of life will have to focus on the martian interior and its rare surface exposures.

Planetary scientists presented new evidence for a long-cold, long-dry Mars here last month,* and a report in this issue of *Science* (p. 1084) provides additional support for that notion. Researchers are finding minerals long exposed on the surface that would have been quickly destroyed by liquid water. And the products of extensive weathering expected under a warm, wet climate, such as clays, are showing up in unexpectedly tiny quantities, if at all. "That argues it's a dominantly dry planet," says planetary geologist and spectroscopist Philip Christensen of Arizona State University (ASU) in Tempe, and it has almost always been that way. Water does seem to have flowed on the surface briefly, early in martian history (*Science*, 6 June, p. 1496). And it has gushed to the surface in the planet's midlife and seemingly trickled down gullies in the geologically recent past (*Science*, 28 February, p. 1294)—perhaps as a tiny bit of present-day "ice-ball Mars" melted at higher latitudes (*Science*, 11 April, p. 234). But "it hasn't been warm and humid and tropical," says Christensen, at least not long enough to leave its mark on the rocks.

Christensen has been pushing the strongest version of the cold, dry Mars hypothesis. He has argued that, so far, remote sensing has shown the surface to be unaltered basalt, the volcanic rock of Earth's ocean crust, and unaltered andesite, a more silica-rich volcanic rock. There are, he concedes, a few small areas that look like once-buried aquifers. In support of a Mars unaltered by water, he points to olivine, the greenish mineral found in basalt and recently recognized on the surface. With a modicum of moisture at even low temperatures, olivine should crumble away in just a few thousand years, according to laboratory work reported at the meeting by Julie Stopar of the University of Hawaii (UH), Manoa, and her colleagues.

Yet this year, using data from the Thermal Emission Imaging System (THEMIS) orbiting on the Mars Odyssey spacecraft since 2001, Christensen, Roger Clark of the U.S. Geological Survey in Denver, Colorado, Victoria Hamilton of UH, and others have reported the detection of olivine-rich basalt at several places on Mars. For example, thanks to the high spatial resolution of THEMIS, Christensen can point to a 100-meter-thick layer of olivine-rich basalt exposed near the bottom of the gorge of Ganges Chasma. The olivine is "really old," says Christensen. It has been at or near the

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* Sixth International Conference on Mars, 20 to 25 July, California Institute of Technology.

surface for hundreds of millions of years, he guesses, to judge by the age of the gorge that has exposed it. Its survival argues "for a pretty dry Mars," he says.

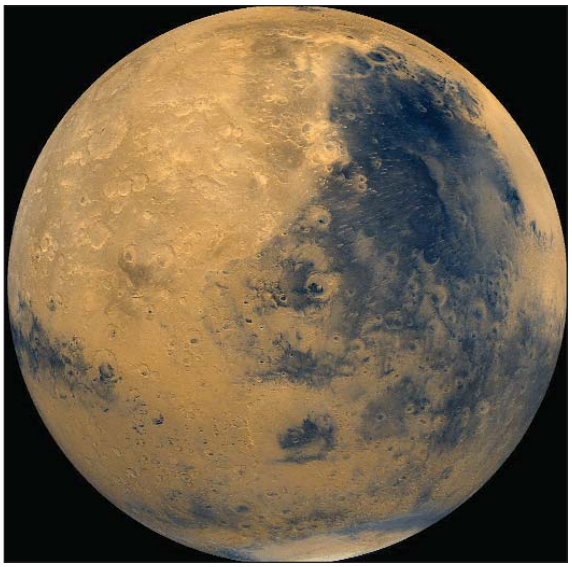
At the same time, spectroscopists are failing to find the clays that result when basalt weathers in damp warmth. At the meeting, Steven Ruff of ASU reported that spectral data returned by the Thermal Emission Spectrometer (TES) operating onboard the orbiting Mars Global Surveyor since 1997 cannot rule out the presence of clays on the surface. But his latest analysis pushes the potential abundance down to a few percent at most. "We have extremely good spectra of the dust," says Clark. "We haven't detected the weathering products, particularly the clays."

Researchers are reporting subtle signs of other weathering products, but their presence is consistent with the limited weathering expected on a cold, mostly dry Mars. In the latest development, Joshua Bandfield and Timothy Glotch of ASU and Christensen identified the mineral carbonate in TES spectra, as they reported at the meeting and describe in this issue. "The quantity of TES observations has allowed us to develop techniques to correct for all the [interfering effects of] dust, water vapor, and carbon dioxide in the atmosphere to give us a high-quality spectrum of the dusty surface," says Bandfield. The wiggles and squiggles of that spectrum are "consistent with a small amount of carbonate," he says, about 2% to 3%.

On Earth, water and atmospheric carbon dioxide combine to form carbonic acid that eats away at rocks and flushes their remains into lakes and oceans. There, dissolved carbonates will eventually precipitate to form solid carbonate deposits like the White Cliffs of Dover, with or without the help of animals that form carbonate skeletons. But geochemists imagined that wet weathering would produce something like 20% carbonate in martian dust, not 2%. That's no more than might form over the eons by the dust's reaction with today's vanishingly low martian humidity, notes Christensen, or the higher humidities possible during the ebb and flow of martian ice ages. And he adds that the TES detection of scarce carbonate in dust only reinforces the instrument's failure to detect any exposed carbonate rock deposits on Mars larger than an area of a few tens of square kilometers. TES isn't somehow failing to see sizable carbonate deposits, he says, they just aren't there.

At the meeting, planetary spectroscopist Richard Morris of NASA's Johnson Space Center in Houston reported another sign that Mars has weathered only moderately. Because TES operates at long, thermal-infrared wavelengths, it samples beneath the rock's surface, up to 10 micrometers in. At less penetrative visible and near-infrared wavelengths, where the Hubble Space Telescope (HST) operates, spectra reflect the composition of just the outer micrometer or two.

In visible and near-infrared images taken by HST, Morris noted, dark areas of Mars have clear signs of a weathered rind. Because TES doesn't see it, he says, it must be only a micrometer or two thick. Spectrally, it resembles the clay-free material called palagonite that forms on moderately—but not severely—weathered basalt on Earth. On Mars, the yellow-brown palagonite could form under cold, humid conditions over the eons and flake off to add to the planet's soil and ubiquitous dust, says Morris, giving the planet its tint. The visually bright areas on Mars, including the northern lowlands, do spectrally resemble such palagonitic debris, he says, although he can't rule out Christensen's unaltered andesite there.



Just a bit rusty. Eons of cold, icy weathering may have been enough to give Mars its yellow-brown dusting.

Other signs of weathering under relatively dry conditions were reported at the meeting. Spectroscopist Scott Murchie of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, reanalyzed spectra returned by the Mars Pathfinder lander in 1997 and found that some rocks at the landing site have a thin coating of "desert varnish" of the sort that forms in the desolate Dry Valleys of Antarctica. Even monomolecular layers of dew over a few millennia could have cemented a thin, iron-rich dust layer onto the rock to give a similar spectral signature, says Murchie. But only the rocks that have been exposed the longest, as suggested by their positions beneath rocks that arrived later as impact ejecta, have the varnish. That would put the more humid era required for varnish formation back a billion years or more, says Murchie.

This emerging spectral evidence presents a problem. "We have a real contradiction between the mineralogy and the geomorphology," says planetary scientist Bruce Jakosky of the University of Colorado, Boulder. Geologists are seeing more and more evidence that water cut networks of valleys during earliest Mars history, and water seems to have cut small gullies throughout martian mid-latitudes in recent geologic times. "If water is that abundant," asks Jakosky, "where are the weathering products?"

A nearly perpetually cold Mars is one possible answer. Cold could lock up water as ice almost all the time except when a particularly extreme swing of the planet's axis brings extra solar heating to polar regions. Then the water could move to lower latitudes as water vapor and snow. Subsequent melting of that snow at the height of rare summer days could then shape the landscape as seen today, before an easing of the tilt returned Mars to a complete deep freeze.

At the meeting, spectroscopist Michael Wyatt of ASU reported an intriguing spectral pattern that could reflect such an ice-ball Mars. He showed how, in both the northern and southern hemispheres of Mars, the intensity of weathering as gauged by the strength of the palagonite-like spectral signature varies by latitude. Apparent weathering is greatest near the polar ice cap, where subsurface ice was recently found. It declines across mid-latitudes, where intermittent near-surface ice has recently been suggested, and is lowest in the martian tropics, where ice is least likely ever to have formed. That pattern fits an ice-ball Mars.

Even spectroscopists do not yet trust their squiggly lines to tell them all about Mars, however. Upcoming missions will take a closer look. Earlier this month NASA announced plans to land a soil and ice analyzer on the ice-laden northern plains of Mars in 2008 (*Science*, 8 August, p. 743). And three Mars landers—two NASA and one European—are now on their way to the planet. A U.S. rover is headed for what appears to have been a wet, buried hot spot. The other will investigate an ancient lakebed. Both carry a bevy of analytical instruments, including a "mini-TES" for a close-up look. The European Beagle 2 lander will come down on what may be an ancient sea floor. With luck, they'll have a firsthand chance to spy water's work on Mars. **–RICHARD A. KERR**

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