dying or restoring their ability to function.

Choi's team is now examining the various possibilities so that they can determine how to get better results. "We've got to figure this out," Choi says. "Otherwise it's a random walk." They would also like to extend the delay before treatment from 9 days to a month or two, which would be a better test of prospects for fixing human spinal cord injuries that are years to decades old. Nevertheless, Choi is thrilled to have taken this first step. "We're breaking new ground," he says.

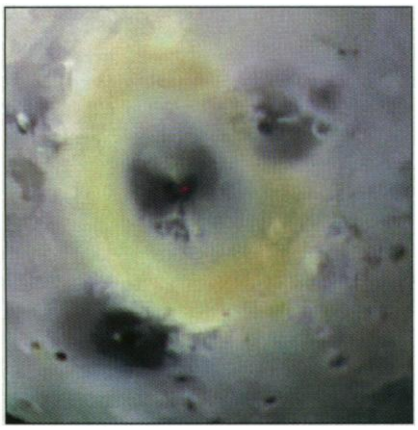
–INGRID WICKELGREN

PLANETARY SCIENCE

## Another 'Ocean' for a Jovian Satellite?

Oceans seem to be popping up everywhere among the satellites of Jupiter. First it was Europa's 100-kilometer-deep, ice-encrusted ocean, which might even harbor some life; then Ganymede and Callisto's deep waters turned up, buried deeper than Europa's. Observations from the ground and the Galileo spacecraft now suggest that it may be fiery Io's turn. But there are no tantalizing prospects for life in Io's proposed ocean. At something like 2000 Kelvin, the ocean seething beneath Io's volcanoes and lava lakes would vaporize the hardiest creature, for this ocean would consist of molten rock.

If Io's magma ocean is really there, it may be fueling geologic "processes we don't see on Earth and that haven't been seen in billions of years," notes geophysicist Susan Kieffer of Kieffer & Woo Inc., in Palgrave, Canada. The magma ocean that roiled Earth in the earliest days of the solar system left no geologic record, but Io could be a living example of how an infant planetary body shapes itself.



**A hot spot.** Io's volcano Pele glows at 1300 Kelvin (central red dot) in the infrared.

When the Voyager spacecraft returned the first closeup images of Io in 1979, planetary scientists learned that it is outrageously active. More recent observations from Earth and now from the Galileo spacecraft have shown just how extreme its volcanism is. Io's huge calderas dribble lava onto the surface at temperatures exceeding 1500 K, when the hottest terrestrial lavas today are hundreds of degrees cooler (*Science*, 17 April 1998, p. 381). Such high temperatures implied compositions with high proportions of magnesium and iron, called ultramafic, which would raise the melting point of the rock. Hot ultramafic lavas were common billions of years ago when Earth itself was hotter but have been scarce since.

In the October issue of *Icarus*, planetary geologists Laszlo Keszthelyi and Alfred McEwen of the University of Arizona, Tucson, and Jeffrey Taylor of the University of Hawaii, Honolulu, consider what Io's surface might be saying about the satellite's interior. Jupiter's gravity kneads Io, driving heat through the interior. Keszthelyi, McEwen, and Taylor calculated that if Io is solid down to its liquid iron core, as Earth is today, Io should have thoroughly extracted silica-rich magmas from its rock to form a thick, silica-rich crust. In this scheme, the crust would now melt from place to place to produce lavas with a low melting point, just the opposite of what is seen.

So Keszthelyi and his colleagues assume that Io never managed to extract much silica-enriched magma from its interior. In their preferred model, beneath a 100-kilometer-thick crust built of silica-poor lavas churns an 800-kilometer-thick magma chamber that melts away the bottom of the crust as fast as surface lavas build it. Their calculations suggest that the magma would be heavy with mineral crystals—more so toward the bottom as increasing pressure encourages their growth.

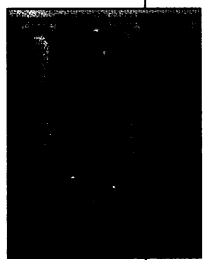
This mushy magma ocean must be global, the researchers conclude, to feed the volcanic hot spots that seem to be uniformly distributed over Io's surface—Galileo observations have yielded 100 of these so far and counting. Io's mountains, which range up to 10 kilometers high, are also evenly distributed, so they may be blocks of crust tilting as they founder into the magma ocean below. The early Earth or moon may have looked this way, says McEwen, before it cooled enough to solidify.

"The evidence for globally distributed magma plumbing is very good," says Galileo project scientist Torrence Johnson of the Jet Propulsion Laboratory in Pasadena, California. "That implies a global source." But short of dropping seismic stations onto the surface, he says, proof may be hard to come by. Still, McEwen suggests at least two ways Galileo might help. During its last scheduled flyby of Io, made on Thanksgiving Day, the spacecraft recorded magnetic observations that may show whether Io generates a magnetic

CREDITS: (TOP TO BOTTOM) SAM OGDEN PHOTOGRAPHY; JPL/NASA

## ScienceScope

**Northbound** MIT's dean of the school of science, Robert Birgeneau (below), will leave the Cambridge, Massachusetts, campus next summer to become head of his alma mater, the University of Toronto. That's causing jitters among the women faculty at MIT, who praise the physicist as their most important advocate in a long battle to address gender inequality (*Science*, 12 November, p. 1272). But Lotte Bailyn, an MIT management professor and former faculty chair, is optimistic that the issue won't die with the dean's departure. And Birgeneau himself says that the effort to address inequality issues "is in transition—but there's enough momentum" to ensure that the issue remains on the front burner. Both academics note that the other four MIT schools have already organized committees to examine the status of faculty women similar to the one Birgeneau helped create.



**Who's No. 1?** Japan's investment in research has reached record levels. According to new figures from the country's Management and Coordination Agency, total R&D spending was $122 billion for the year ending on 31 March, a 2.5% increase over the previous year despite an economy that shrank by 2.1%. Japan devoted 3.26% of its $3.7 trillion gross domestic product to research, well ahead of the 2.79% figure posted by the second-place United States for its $8.8 trillion economy (*Science*, 29 October, p. 881), although the countries use different accounting methods.

The 1998 numbers for Japan show that public spending grew by a robust 9%, to $27 billion, while spending by the recession-battered private sector edged up 0.7%, to $95 billion. "Given the severe [economic] conditions, the spending trend is very positive," says an official at the Science and Technology Agency.

The government's share of the spending pie rose to 21.7% in a deliberate effort to bring it in line with rates for other industrialized countries. Meanwhile, the U.S. government's contribution to R&D spending continues to drop, reaching a record low of 26.7% of a projected $247 billion in 1999. Ironically, many U.S. officials are wringing their hands at the declining federal contribution, caused largely by a surge of industrial R&D in conjunction with a booming economy.

**Contributors: Robert Koenig, Dan Clery, Andrew Lawler, Dennis Normile**

field. The heat of a magma ocean would frustrate the generation of a magnetic field in Io's molten iron core by erasing the temperature gradient that drives a dynamo. And Io's gravitational signature, which Galileo returned during its close passage, could reveal the unusually low density of a magma ocean. But everyone agrees that the clearest answer would come from an Io orbiter, which could probe for a soft, molten interior by measuring the rhythmic kneading of the satellite by Jupiter. Then a unique, albeit lifeless, ocean might join the club.

–RICHARD A. KERR

CLIMATE CHANGE

## Will the Arctic Ocean Lose All Its Ice?

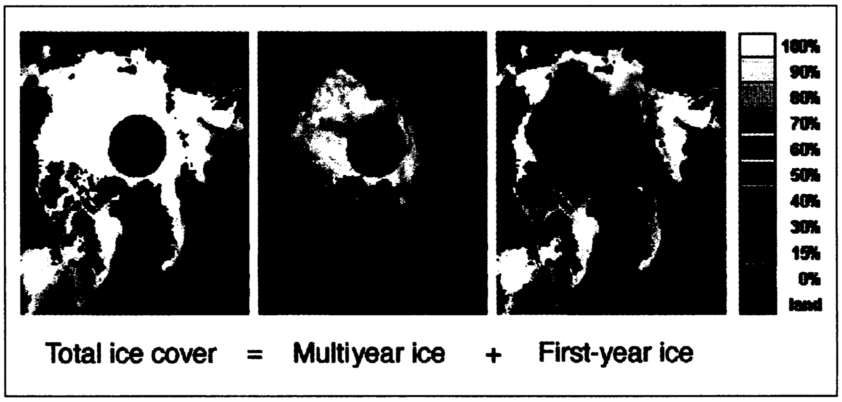
Miners have their canaries to warn of looming dangers, and climate change researchers have their arctic ice. The sea ice floating at the top of the world—enough to cover the United States—is highly sensitive to changes in the air above and the ocean below, and for several years Arctic watchers have been detecting what looked like slow shrinkage—a change they've read as a suggestive sign of global warming. But now they see warnings that their "canary" is in deep trouble and could expire in a matter of decades.

"Suddenly, all these different, relatively weak indicators [of arctic change] are making a coherent story that looks really intriguing," says polar climate researcher Douglas Martinson of the Lamont-Doherty Earth Observatory in Palisades, New York. The story, as updated in reports in this issue of *Science* and the 15 December issue of *Geophysical Research Letters*, tells of an arctic ice pack that is not only shrinking in area but rapidly thinning as well. The big question now is what's causing the shrinkage: natural polar climate fluctuations or global warming due to increasing levels of greenhouse gases. If it's all natural, the loss of arctic ice should eventually reverse, but if global warming is at fault, the entire ice pack will eventually disappear, with drastic climate implications for the Northern Hemisphere.

The decline of arctic ice had seemed real enough, though not yet alarming. By combining satellite observations and historical records of ice extent, various groups had found that the area covered by the ice in the summer has been decreasing by about 3% per decade during recent decades. At that rate, notes Martinson, it would take another 350 years for the Arctic Ocean to be ice-free in summer. The shrinking caught everyone's attention but remained tantalizing.

But polar researcher Ola Johannessen of the Nansen Environmental and Remote Sensing Center in Bergen, Norway, and his colleagues report on page 1937 that the arctic ice is undergoing a much more rapid change. As do all materials above absolute zero, ice emits microwave radiation, the exact spectrum of which depends on whether the ice is newly frozen or has thickened over a number of years. By compiling and analyzing satellite observations of these microwave emissions made from 1978 to 1998, Johannessen and his colleagues found that the area of multiyear ice had declined by 7% per decade during the 20-year period—twice the rate at which the total ice area has been shrinking.

Another change in arctic ice appears to be progressing at an even faster rate, according to the *Geophysical Research Letters* report. In that paper, polar oceanographers Andrew Rothrock, Yanling Yu, and Gary Maykut of the University of Washington, Seattle, compared two sets of measurements of polar ice thickness taken by U.S. Navy nuclear submarines. The first were made from 1958 to 1976 while on military patrol. The second were made in 1993, 1996, and 1997 during the Scientific Ice Expeditions program. Upward-looking acoustic sounders mapped the ice depth the way depth sounders map the sea floor.




**A weakening heart.** While the extent of arctic ice (left) is shrinking, the thicker ice frozen over several years (center) that forms the ice pack's core is wasting away even faster.

Overall, the Seattle team found, the ice over the deep-water Arctic thinned from an average thickness of about 3.1 meters to about 1.8 meters, or about 15% per decade. That's five times faster than the ice area has been shrinking. What's more, the ice thinned at every one of the 26 sites for which the researchers compared data. Overall, says Rothrock, the arctic ice has lost 40% of its volume in less than 3 decades.

"The current evidence is pointing to something going on" with arctic ice, says polar researcher John Walsh of the University of Illinois, Urbana-Champaign. If thinning continues at this rate, he notes, "there really are only a few decades before ice thickness reaches zero." That would convert the Arctic Ocean from a brilliantly white reflector sending 80% of solar energy back into space into a heat collector absorbing 80% of incident sunlight, with effects on ocean and atmospheric circulation extending into mid-latitudes. These could include shifts in storm tracks, says Walsh, with changes in precipitation.

However, adds Walsh, "there's quite a bit of debate about why" the ice is thinning and therefore whether it will continue to do so. Most fingers are pointing at the Arctic Oscillation (AO), an erratic atmospheric seesaw that alternately raises and lowers atmospheric pressure over the North Pole while lowering and raising it in a ring around the edge of the polar region.

Through its changes of pressure, the AO can change wind patterns and thus affect ice thickness, notes Rothrock. In its positive phase, to which it shifted abruptly around 1989, the AO pumps more warm air into the Arctic, tends to warm the water entering the Arctic from the North Atlantic, and blows more thick, multiyear ice out of the Arctic—all changes that should thin the ice. Although the AO, like El Niño, is a natural oscillation, some climate modeling has recently suggested that building greenhouse gases may have driven the AO to its current extreme (*Science*, 9 April, p. 241). "I'm going to wait and see," says Rothrock. "I would lean toward the view that this is a fairly extreme state [of the AO], and it will likely come back toward more normal conditions."

However, on page 1934, climate researcher Konstantin Vinnikov of the University of Maryland, College Park, and his colleagues suggest that increasing levels of greenhouse gases may be the prime mover behind the shrinking arctic sea ice. The Maryland team compared the observed ice loss and the ice loss in two climate models simulating the strengthening greenhouse. The chances that the losses seen since 1953 are just an extreme of a natural cycle and will swing back toward normal are less than 0.1%, they say. Whatever your faith in such model studies, says Walsh, "we've got a region to watch now."

–RICHARD A. KERR

CREDIT: JOHANNESSEN, SHALINA, AND MILES