"road-map" proposal for a blue-ribbon panel headed by Nobel Prize–winning physicist Charles Townes. The panel will evaluate the final road map for NASA—and, NASA hopes, generate public interest in the planet search with the help of members who might include prominent writers and movie directors. The study groups aren't likely to recommend that NASA rely exclusively on any one technology. Instead, Beichman told the gathering, "what we need is a series of steps, on different paths, but with definite payoffs every few years."

Learning how common Jupiters are near other stars, for instance, would provide a test for current theories of planet formation. It would also yield clues to the existence and habitability of smaller, Earthlike worlds. In fact, argues George Wetherill of the Carnegie Institution of Washington, a planetary system may need a planet the size of Jupiter or Saturn to deflect comets that would otherwise bombard its smaller planets, forestalling the development of life.

Ultimately, however, astronomers would like to follow Goldin's dream to what Caltech's Anneila Sargent calls "the Emerald City"—actual images of Earthlike planets around other stars. Participants at the Boulder meeting agreed that doing so lies beyond the limit of any practical road map, as it would almost certainly require an interferometer orbiting Earth or the sun. That's a daunting prospect not only because of its cost, but also because of the difficulty of maintaining the spacing of the orbiting telescopes down to billionths of a meter and coping with the glare from myriad interplanetary dust particles. "And even if all those technical challenges can be overcome," says Beichman, "we might find Earths, but we won't get much of a picture."

For the foreseeable future, Goldin's Landsat image of an alien Earth may be only a remote hope. But a mere point of light from such a planet might be enough for astronomers to look for signs of life. The presence of oxygen or ozone in the light's spectrum would be a strong hint of life, and the presence of methane along with oxygen would be powerful evidence for methane-generating organisms, as the gas oxidizes quickly and vanishes unless it is somehow replenished.

"The realm of [extrasolar] Earthlike planets is difficult to explore," admits Beichman. "But we shouldn't think this is impossible—and we shouldn't forget the lesson of the pulsar planets: Expect the unexpected."

–Donald Goldsmith

Donald Goldsmith is an astronomy writer in Berkeley, California. His most recent book, Einstein's Greatest Blunder? The Cosmological Constant and Other Fudge Factors in the Physics of the Universe, *will be published in August by Harvard University Press.*

ACOUSTICS

Listen Up! The World's Oceans May Be Starting to Warm

For a strategy so quick and elegant, long-range acoustic thermometry—taking the temperature of entire oceans with pulses of sound—has been a long time coming. Expected to provide solid data on one environmental threat, global warming, the technique has run afoul of concerns that it could pose another: harm to marine mammals from the powerful sound (*Science*, 17 May 1991, p. 912 and 15 April 1994, p. 339). But while a major experiment is on hold, smaller tests in the Arctic and Pacific oceans have been allowed to go ahead and are heating up the field with evidence that measurable ocean warming is under way.

These early results, discussed last week at a meeting of the Acoustical Society of America in Washington, D.C., say nothing about the warming's cause, researchers emphasize. To determine whether the warming is the steady heating predicted by computer simulations of global warming or just a temporary change in slow-moving ocean "weather" will take repeated measurements in many ocean basins over decades. But these data do boost researchers' confidence in the technique's ability to deliver fast and frequent snapshots of ocean temperatures—a boon to a field long fettered, says William Kuperman, an oceanographer at Scripps Institution of Oceanography, by "the need to go to sea to get data."

Traditionally, taking the temperature of the deep ocean has meant steaming across the seas, stopping repeatedly to drop temperature probes. Using sound, goes a saying ascribed to the field's father, Walter Munk of Scripps, "is like having a 3000-knot ship." Pulses of low-frequency sound can travel thousands of kilometers through the ocean and still be detected. Because the speed of sound underwater depends on the water temperature, the time it takes a pulse to traverse an ocean basin reveals the average temperature at a wide range of depths. By making repeated measurements and comparing the pattern and rate of warming with the changes predicted by climate models, researchers hope to look for the signature of greenhouse warming.

That promise is on hold for the major experiment in the field, the Acoustic Thermometry of Ocean Climate (ATOC) experiment, conceived by Munk and his colleagues at Scripps. ATOC has been delayed a year and a half while the National Marine Fisheries Service decides whether plans to send sound from California and Hawaii to arrays of receivers as far as 6000 kilometers away in the Pacific pose a threat to marine mammals. Final word may come this month. Meanwhile, the Transarctic Acoustic Propagation Experiment (TAP), a U.S.-Russian-Canadian project in the Arctic Ocean, faced no such hurdles because of its smaller scale and the scarcity of mammals under the polar ice.

SOURCE: MIKHALEVSKY *ET AL.*

Cross talk. A transmitter at one ice camp broadcast sound across the Arctic Ocean to receivers at two others.

At the meeting, oceanographer Peter Mikhalevsky of Science Applications International Corp. in McLean, Virginia, reported that in April 1994, TAP transmitted sound signals from an ice camp near Spitzbergen to receiver arrays at two other camps, one 900 kilometers away in the Lincoln Sea and the other 2600 kilometers away in the Beaufort Sea. Decade-old temperature data gathered by ship and submarine enabled Mikhalevsky and his collaborators to predict sound travel times, assuming no change in Arctic temperatures. But the researchers found that travel times along both legs were slightly shorter than predicted, implying that the ocean had warmed by half a degree at middle depths.

That arctic waters could have changed so much in a decade "was, frankly, quite hard to believe," says Mikhalevsky. He notes, however, that a U.S.–Canadian research expedition aboard icebreakers last summer reported a similar warming using traditional in situ measurements (*Science*, 23 December 1994, p. 1947). Both the shipboard measurements and the acoustic data imply that the source of the temperature increase is warm water seeping from the Atlantic into the Arctic. But it's too soon to say whether the intrusion of warm water is the handiwork of global warming or just part of a natural cycle of variation in the ocean, say researchers. As Scripps oceanographer and ATOC project manager Andrew Forbes puts it, "A single measurement is very tantalizing, but inconclusive."

Forbes and his colleagues have some tantalizing results of their own. Even though the full-scale ATOC experiment is on hold, the Scripps group managed to get permission for a short "engineering test" of a single sound source last November. Intended mainly as a dry run for their instruments, the test clocked acoustic travel times from California to New Zealand that were noticeably shorter than models based on scattered historical measurements had predicted. The results, say the Scripps researchers, point to up to 0.05 degrees of warming along the sound path.

Physical oceanographer Peter Worcester, also of Scripps, emphasizes that the apparent warming is a "quick-look result," not to be heavily interpreted. The sparse past measurements don't provide a solid baseline for the warming estimate, he says, and even if the warming is real, sporadic ocean events like El Niño, rather than a global greenhouse warming, could be to blame. But the engineering test has left Worcester "very encouraged" with the quality of the sound signal. He says he's optimistic that acoustics will eventually become the "weather service" of the ocean, providing oceanographers with the continuous data flow they crave.

–Antonio Regalado

MYCOLOGY

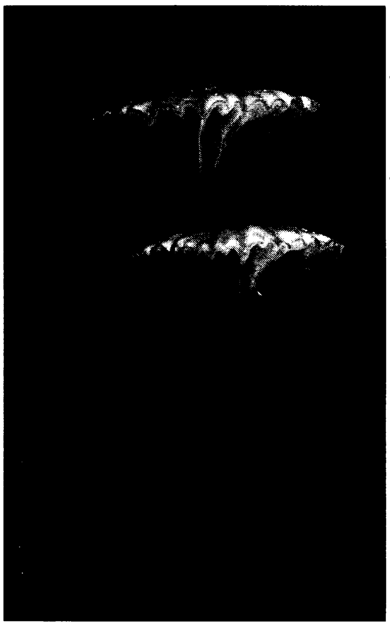
Origins of Lichen Fungi Explored

A hiker encountering a scaly gray growth on a rock is likely to recognize it as a lichen. She may also remember from a long-ago biology class that every lichen consists of a fungus and an alga living in a symbiotic union. But despite being the poster child of symbiosis, lichens have a low profile among the biologists who study fungi. "A lot of the known fungi are lichens, maybe 20%," says mycologist John Taylor of the University of California, Berkeley. "But mycologists often don't think of lichens when they think of fungi. People who teach classes about fungi, myself included, certainly don't give 20% of the time to lichens; we give much less."

Now lichens may be moving into the mycology mainstream. On page 1492, Andrea Gargas and Paula DePriest of the Smithsonian Institution in Washington, D.C., and their colleagues report the results of a DNA analysis that dispels the widely held notion that lichen-forming fungi are a closely knit fringe group in the fungus world. Instead, the Smithsonian team shows that lichens are scattered throughout the fungus family tree, a finding that indicates the lichen lifestyle has apparently arisen multiple times during fungus evolution. "What is really exciting and interesting about this paper," says Duke University lichenologist William Culberson, "is that this is the first molecular information about the evolutionary origin of major lifestyle differences" in the fungi.

Researchers who work on lichens have recognized that the union—in which algae provide organic nutrients to fungi, while the fungi may provide algae with less tangible benefits such as protection from harsh conditions—must have arisen multiple times during the course of evolution. But until now they have had little direct proof. Pinpointing species' origins requires a good family tree, and such a tree has been hard to come by for the fungi. The problem is that the organisms don't have many physical characteristics that can be compared among all the species and used to determine their relationships.

The Smithsonian team got around that obstacle by using something every fungus does have: DNA. They compared DNA sequences from 75 different fungus species, including 10 that form lichens, and used a computer program to generate the most likely family tree for those 75 species. The lichen-forming fungi fell into five separate groups, each of which was more closely related to groups of non–lichen-forming fungi than to each other. This suggests that each group of lichen-forming fungi evolved from a different initial liaison with an alga, DePriest says: "The fungi are opportunists. Throughout their evolutionary history they have taken up occupations as they are available."



SYLVIA DURAN SHARNOFF

Partners. This fungus belongs to one of several lichen-forming groups that apparently evolved independently.

Mitchell Sogin, an evolutionary biologist at the Woods Hole Marine Biological Laboratory in Massachusetts who has used DNA trees to show relationships between micro-organisms, fungi, and animals, says the Smithsonian group's tree makes a solid argument for multiple origins of the lichen lifestyle. "I see four independent events at a minimum," he says. "What the upper limit is nobody can say." Berkeley's Taylor agrees. "There are a lot more lichens out there," says Taylor. "It is likely that as you look at those, you will see further evidence of multiple origins."

Not only did lichens apparently evolve multiple times, but the new tree suggests that they arose "from fungi that are doing different things for their living," says DePriest. The closest relatives to the different lichen-forming groups span the spectrum of fungal lifestyles, from free-living saprobes that live off dead organic matter, to mycorrhizae that live symbiotically in the roots of plants, to pathogens that cause diseases in plants and animals.

Because those close relatives are the best indicator of the ancestors that gave rise to the different lichen-forming fungi, that means they apparently evolved from fungi whose lifestyles range from benevolent to virulent. Moreover, the authors point out, lichen-forming fungi apparently have given rise to fungi that act as harmful parasites on lichens. Together, that evidence puts one more nail in the coffin of a notion that has been around for years—and falling out of favor recently—that symbiotic relationships evolve in an orderly progression from those that are parasitic and damaging to one partner to those, like the lichens', that are more benign. Instead, says DePriest, it appears "that lichenization can take different evolutionary pathways," and that, from the fungus's perspective, at least, a benign relationship is not necessarily the evolutionary stopping point.

But the details of the Smithsonian team's work are certainly not carved in lichen-covered stone. Phylogenetic trees are based on probabilities, and some of the relationships are certain to change as more data are added. Indeed, a competing group led by Joseph Spatafora at Oregon State University and including Culberson and others at Duke has unpublished results that suggest there may be fewer independent origins for one lichen group than the Smithsonian team has proposed. Nevertheless, the new work has boosted some researchers toward what may be a long-overdue recognition that lichens are mainstream fungi. "I think instead of teaching lichenized fungi as a separate unit," says Berkeley's Taylor, "I should teach them when they come up. That way the students would know they are diverse and that [lichen formation] is a common thing" among fungi.

–Marcia Barinaga