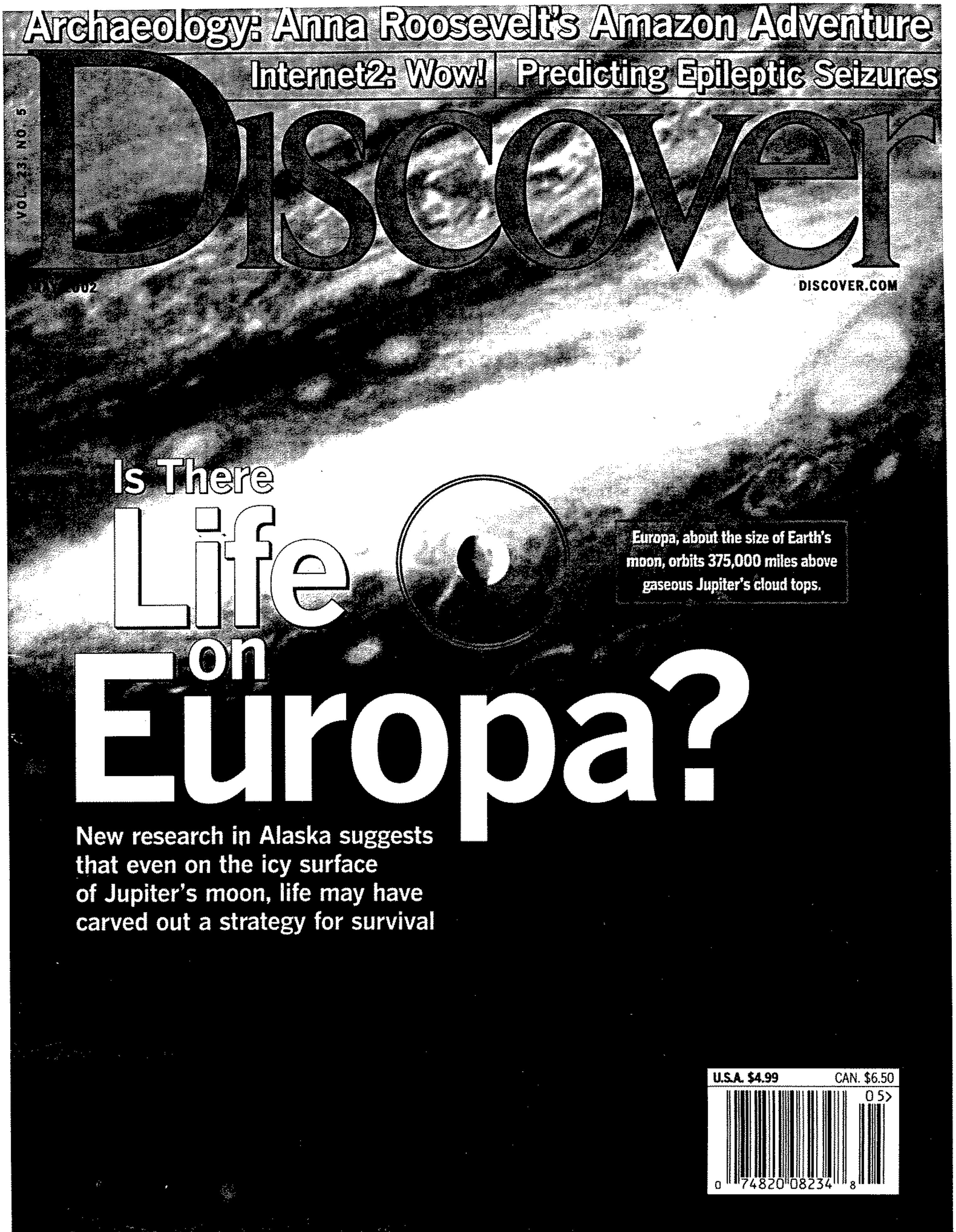

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Discover

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Is There Life on Europa?

Europa, about the size of Earth's moon, orbits 375,000 miles above gaseous Jupiter's cloud tops.

New research in Alaska suggests that even on the icy surface of Jupiter's moon, life may have carved out a strategy for survival

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Does Life Exist Elsewhere in Our Solar System?

SOMEONE AT NASA MUST THINK SO. A GREAT DEAL OF THE MONEY the U.S. space agency has spent on sending probes to Mars—starting with two Viking landers in 1976—has gone toward trying to figure out if life ever took hold there. So far, scientists have found no proof there ever was, is now, or ever will be life on the Red Planet.

In 1997 NASA launched *Cassini*, one of the largest and most complex probes ever built, to study Saturn and its moons. It will arrive in 26 months. Aboard is a secondary probe, called *Huygens*, which will parachute through the dense atmosphere of Saturn's moon Titan. Although astronomers agree there's virtually no gaseous oxygen on Titan (the atmosphere is mostly nitrogen and methane) and it probably has lakes of ethane, serious scientists theorize that precursors of life could have arisen there.

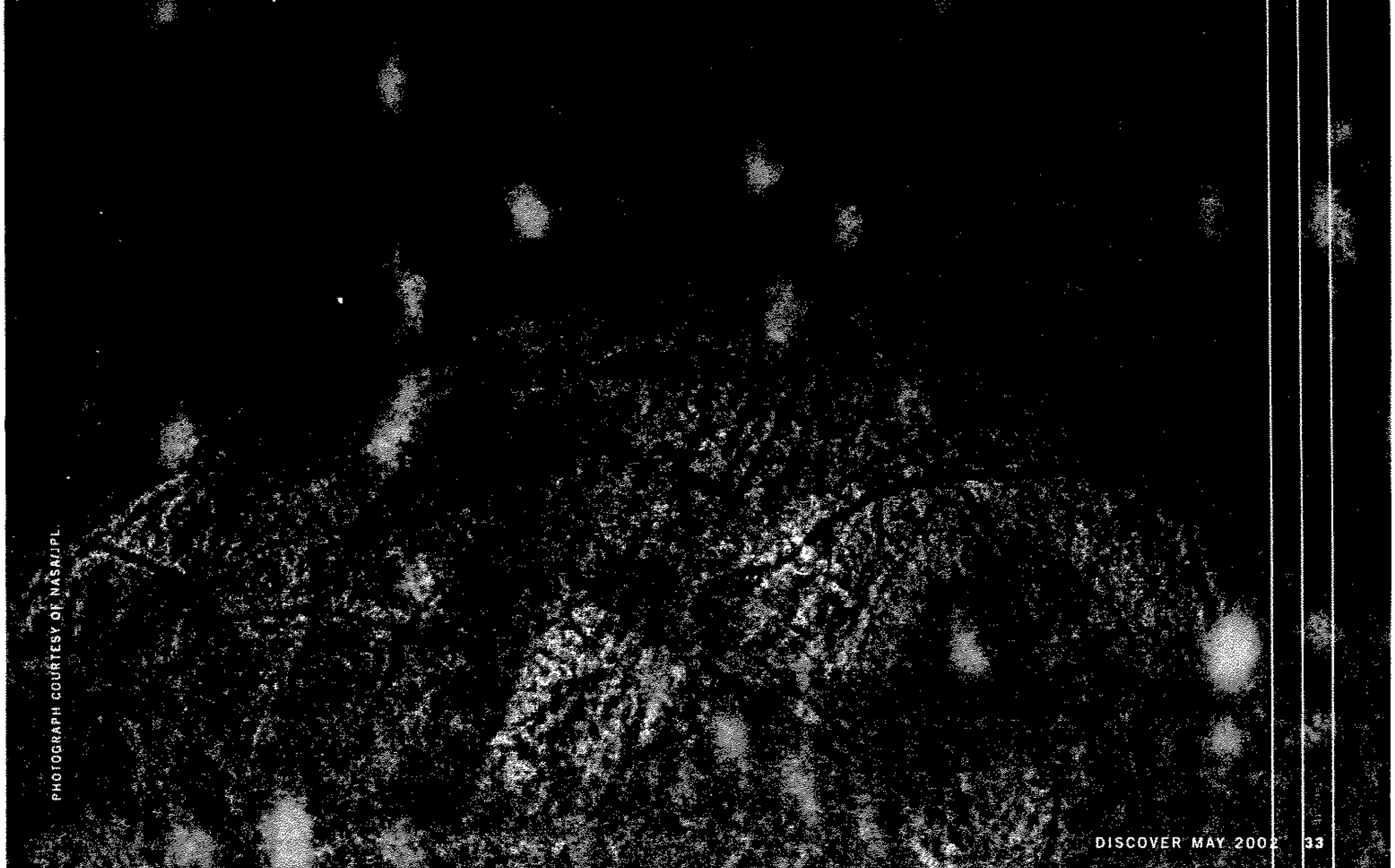
Titan isn't the only moon that life seekers are panting over. Based on studies in Antarctica and the Arctic, scientists have begun to speculate that life may exist on Europa, a moon of Jupiter. At -260 degrees Fahrenheit, Europa's surface is colder than some people's version of hell. But at least it seems to have plenty of ice, which astrobiologists believe may be covering up a vast ocean of much warmer water. Water, of course, really gets the astrobiology crowd worked up.

Does any of this speculation make sense? Perhaps. Before you guess, read the article by Robert Irion, which begins on the following page. In it you will discover that life on Earth does not always have all the fussy requirements we think it needs. *Discover* has previously reported on creatures that thrive in the depths of the ocean in the presence of temperatures in excess of 700 degrees Fahrenheit. And geologists are constantly finding new life in bizarre places, such as deep under the surface of Earth's crust. The resiliency of microbes seems to be far greater than we ever guessed.

So if there's a chance that life may exist elsewhere in our own solar system, the obvious next question: What does that suggest about the likelihood of life on other planets in other solar systems?

Consider this: A dozen years ago there was no conclusive evidence that any planets existed anywhere outside our solar system. Now we know of more than 70 of them. And in a few years, NASA will begin an extensive search for Earth-like planets around nearby stars. There may be millions and millions of planets in our galaxy alone, and there are billions of galaxies. Imagine how unlikely it is that life does not exist elsewhere. Perhaps the more important question is whether any life exists elsewhere that could be characterized as intelligent.

In its second orbit of Jupiter and its moons in 1996, the spacecraft *Galileo* captured an icy image of Europa from a distance of 418,000 miles.



PHOTOGRAPH COURTESY OF NASA/JPL

snow across the ice, a white desert stretching in all directions.

During the past three years, Eicken and his research team have braved biting winds and occasional carnivores here, at the northernmost spot in the United States, to probe the finest details of the ice. What they've found sheds a wholly unfamiliar light on the Arctic. For starters, it's crawling with life. Even in the hardest parts of the ice, at temperatures as low as –4 degrees Fahrenheit (as cold as any environment known to host active organisms), bacteria and diatoms live contentedly in minuscule pockets of brine. Their cells seem to survive by clinging to bits of sediment or by emitting a sort of gunk that keeps ice crystals from piercing their delicate membranes. Some brine pockets are isolated bubbles, but many are connected by a spidery network of liquid-filled channels that persist no matter how cold the ice gets. Those channels supply the microbes with water and nutrients during the long winter.

To Eicken and the others, such survival strategies aren't just fascinating in their own right; they offer hope for life in even more forbidding environments. Point Barrow's frozen lagoons conjure dreams of the Jovian moon Europa, which appears to encase an alien sea beneath its cracked shell of ice. Planetary scientists dearly hope to explore those waters with a robot, but the first spacecraft that lands on Europa will probably prod only the surface. "If you're a realist," Eicken says, "we won't be going to the bottom of Europa's ocean in the next 30 years. Whatever we learn about life there will come from within the ice." And Barrow may be the best place in this world to learn how to find it.

EICKEN NEVER USED TO CARE ABOUT FARAWAY MOONS. A GLACIOLOGIST by training, he first worked in the ice of Siberia's Laptev Sea and in tanks of frozen seawater at the Alfred Wegener Institute in his native Germany. He became known for his careful studies on the microphysics of sea ice—specifically, how varying temperatures, salt levels, and impurities affect the ice's structure. Then in 1998 he went to the University of Alaska at Fairbanks, whose glaciologists use Barrow as a field site.

"In Barrow we can get to our sites easily, and we can run experiments all year long," the tall, sandy-haired Eicken says in a quiet and pleasantly accented voice. He's inserting Frey's ice pucks into a centrifuge to drain the brine, leaving behind a dry matrix of pores and channels that his team will analyze in Fairbanks. The small oceanfront lab, formerly operated by the Navy, is made up of spartan metallic buildings that shelter the team and house its equipment. The location also offers a less tangible advantage: the deep environmental knowledge of native Inupiat Eskimos, who now own the lab. Every spring the Inupiat venture to the ice's ragged edge to hunt bowhead whales. Senior hunters recognize the types of ice that form each season and when and where ice will break up. If the ocean current starts flowing toward the shore underneath the ice, for instance, they know to abandon their whaling camps because the shelf will soon crack. Thanks to such foresight, Eicken says, "We can freeze expensive sensors into the ice for months and not worry about losing them."

It was at Barrow that Eicken teamed up with Jody Deming, a microbiologist at the University of Washington in Seattle. Deming had begun by focusing on organisms that thrive on the deep ocean floor, then joined Arctic icebreaker expeditions to study cells locked within the ice pack. Harsh conditions in both places, she felt, forced microbes to adapt or perish. "The ice cover melts and re-forms," she says. "That forces an evolutionary selection. The most successful organisms not only tolerate extremely cold conditions but favor them."

To test her hypothesis, Deming needed to collect many samples of ice at different times of year under known conditions. The lab at Barrow was the ideal alternative to the occasional icebreaker expedition, so she and Eicken joined forces. The combination of her microbial expertise and Eicken's insights on the structure of sea ice proved irresistible to the National Science Foundation, which funded the duo under its now-defunct Life in Extreme Environments initiative.

The team did its first fieldwork at Barrow in the winter of 1998–99. When Eicken described the results later that year at a geophysics meeting, planetary scientists took note. Among those especially interested were members of the science team for *Galileo*, the durable NASA orbiter that has studied Jupiter and its moons since 1995. "That's just the kind of environment we thought we'd have to find," Robert Pappalardo of the University of Colorado remembers thinking. "They're finding active communities and fluid-filled pore spaces at the temperatures that should exist within masses of warmer ice on Europa."

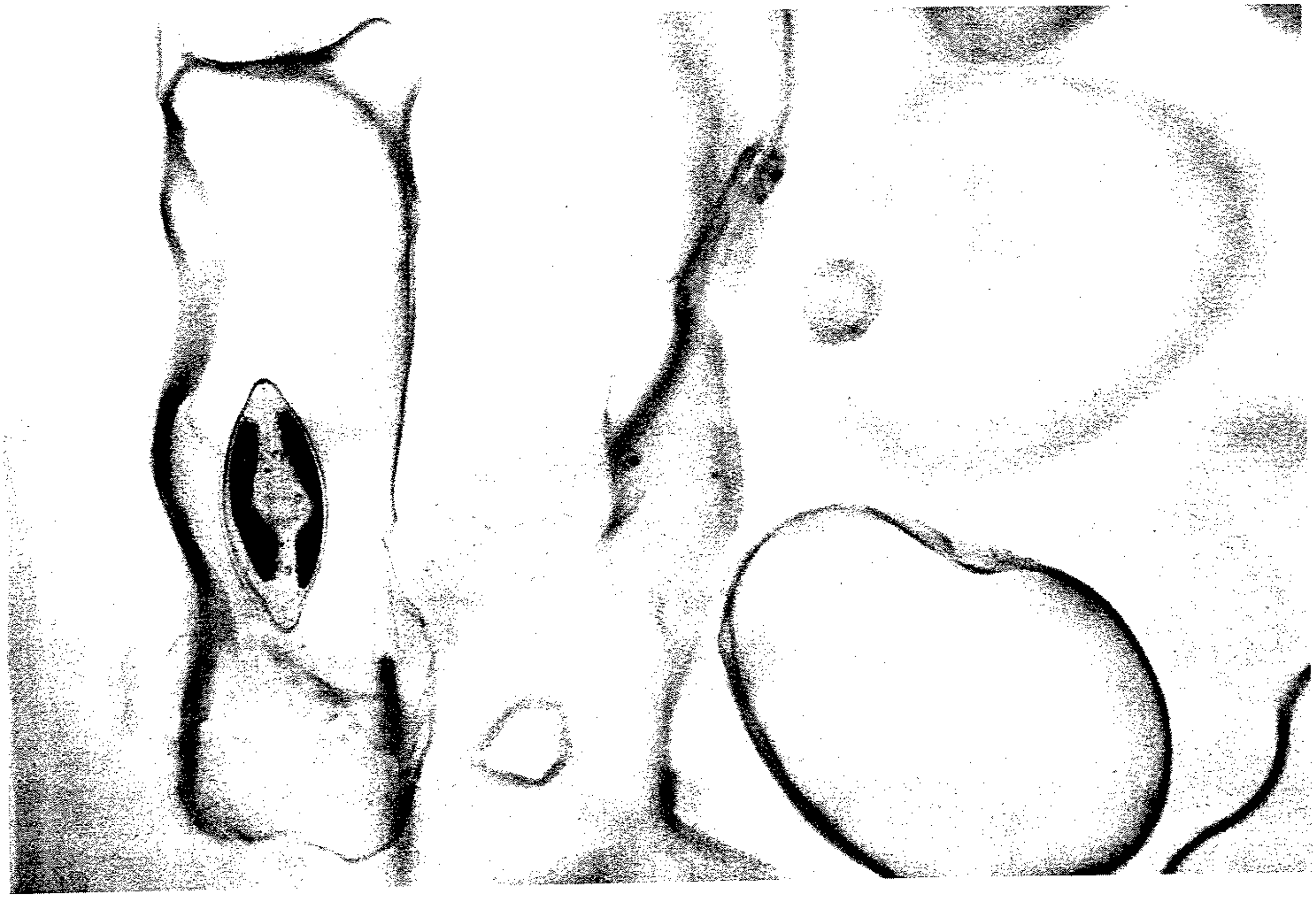
THE LANDSCAPE AT BARROW IS OTHERWORLDLY. ON CLEAR DAYS THE AIR is so pristine that visibility seems endless. Ridges of ice fracture the horizon, a chaos of sharp angles and startling hues of gray and milky blue. Bright halos and sun dogs frame the low sun throughout the long days of spring, when the ice begins to thaw. When the researchers are on the frozen ocean, under the grand sweep of the polar sky, they don't want to be anywhere else. "I'm totally hooked on it," Deming says. "The scientific questions are stimulating, and I find the cold very energizing. I think clearly, and I feel better about being alive."

Still, air temperatures in winter and early spring at Barrow range from 0°F to –40°F, and the wind is unforgiving. Heavy boots and layers of thick protective gear are essential, but hard

EUROPA AT THE SOUTH POLE

"There is no [single] terrestrial analogue for Europa," Hajo Eicken says. "We need to look at many environments, not just Arctic ice." Some planetary scientists are particularly excited about Lake Vostok, near the heart of Antarctica. Vostok is about the size of Lake Ontario and lies under a sheet of ice more than two miles thick. Shielded from the atmosphere for as long as 30 million years, the lake may contain the most pristine waters on Earth. Still, biologists suspect that bacteria thrive within its depths. Heat and mineral-rich fluids may even seep into the lake through rifts in its rugged floor.

Lake Vostok's waters are more accessible than Europa's, but scientists have yet to sample them. When they do, Vostok may serve as a test bed for devising a robotic explorer for Europa. Such a probe would have to burrow through miles of ice to reach the sea beneath it and then search for microbes without first fouling the waters with Earthly hitchhikers. Whether on Earth or any other heavenly body, that's a challenge so stiff it may take decades to engineer. —*R.I.*



physical labor saps body heat and leaves inner clothing soaked with sweat. Despite the best gloves, the researchers' hands can get painfully cold from handling ice, taking notes, and grappling with wet corers. One gusty morning, Andy Mahoney spent so much time downloading data from several research stations with a laptop that his fingertips were nearly frostbitten.

Reaching most of the field sites requires a snowmobile, and the 10-mile trek to the most distant site is a frigid rite of passage. Passengers hurtle into piercing headwinds, their arms clutching numbly for support as they surf over the choppy ice. (The most exposed spot—on a wooden equipment sled towed in back—is reserved for newcomers.) A rifle strapped to the back, with a casual warning to keep an eye out for bears, completes the experience.

The roughness of the ride attests to the Arctic's constant unrest. "Arctic sea ice is a large thin veneer, like rice paper," says Barrow veteran Tom Grenfell, a sea-ice physicist at the University of Washington. "It's the size of the United States, about 2,500 miles across, but it's only 10 feet thick. What looks like good solid ice is a fragile continuum that gets pushed around by wind and currents. It's a big engine, a tremendously dynamic system."

"It's like real-time plate tectonics," adds Grenfell's colleague, geophysicist Don Perovich of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) in New Hampshire. "Why wait a million years to watch continents move when it's happening all around you on the pack ice?"

To study their part of that system, Eicken and his graduate students set up stations on different types of ice: "fast ice" both close to shore and a few miles out, coastal lagoon, and tundra lake. Sensors measure the ice thickness, the amount of snow on top, and the strain that waxes and wanes inside the moving ice. Data

Above: Suspended in a brine pocket, buffeted by micro-currents and nourished by sediment, an algal cell only 20 micrometers long can weather temperatures as low as –4°F. Below: Glaciologist Hajo Eicken (right) and student Andy Mahoney find such cells in ice cores extracted with a drill.

PHOTOGRAPH: BOTTOM, DEBORAH LORKHE.

Think of sea ice as rock very close to its melting point. But that rock is laced with brine channels of ever finer dimensions, down to the very limits of our perception

loggers, hidden inside ice chests under mounds of snow, record those numbers during the weeks between visits. Metal tubes shield the cables that run from the sensors to the chests, thwarting the gnawing jaws of Arctic foxes.

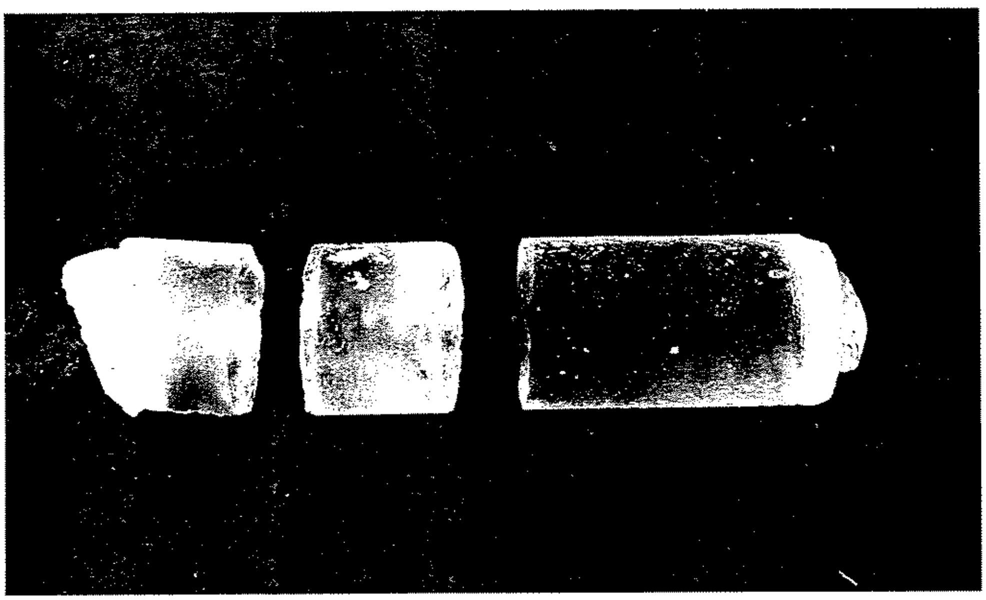
The most precious hauls from the four or five annual field trips are the ice cores. Gone are the days when scientists had to turn hand cranks to plunge coring tubes into the hard ice. Now generators and electric drills do the trick, extracting cylindrical cores in minutes. Most of Eicken's cores from Barrow are as wide as the hole in a putting green and about five feet long, although they come out in pieces. The coldest ice is near the surface; the warmest is near the water below.

The cores meet different fates. Some are sliced with a delicate saw to reconstruct the three-dimensional pattern of brine channels inside. "We have the advantage that ice is pretty soft, so we can take an ordinary metal blade and cut it," Eicken says. "You can think of sea ice as a rock very close to its melting point." A computer-controlled microscope digitally records the spaces in the slices, each of which is about 10 times thinner than a human hair. The program then stacks the digital images atop each other to render a three-dimensional volume.

The results are consistent, Eicken says. "We always find liquid inclusions in the ice, all the way to the optical limit of our resolution. We see hundreds or thousands of them per cubic millimeter. There is the potential for always having liquid, no matter how small you go." The pockets are often interconnected, even at the most extreme conditions, Eicken adds, creating a filigreed network of channels and pores that resembles the neurons in a brain.

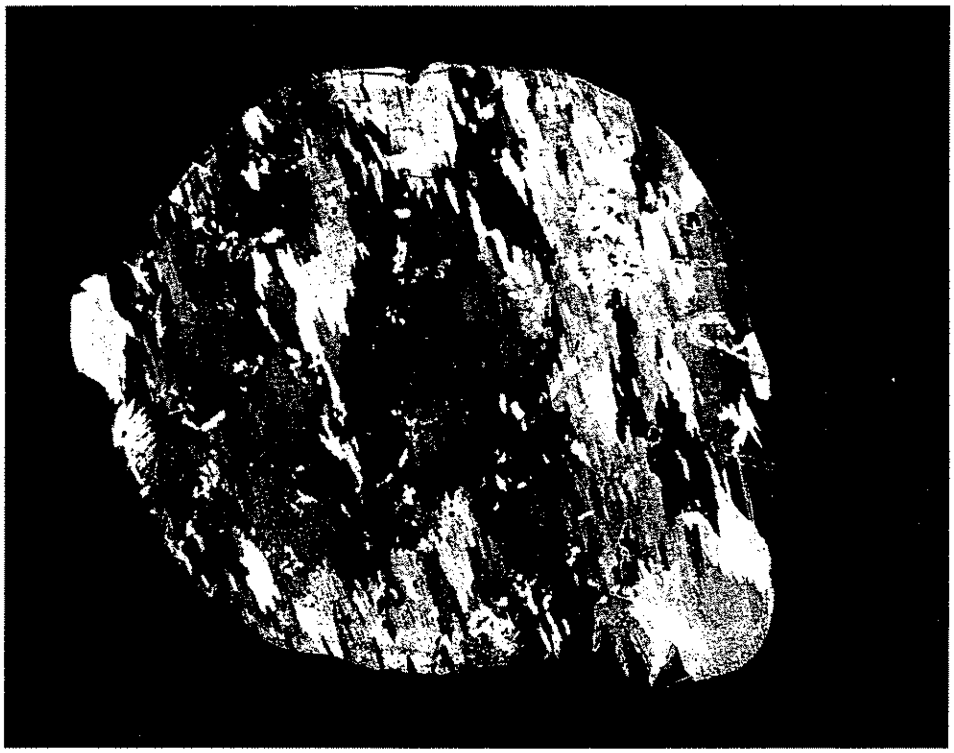
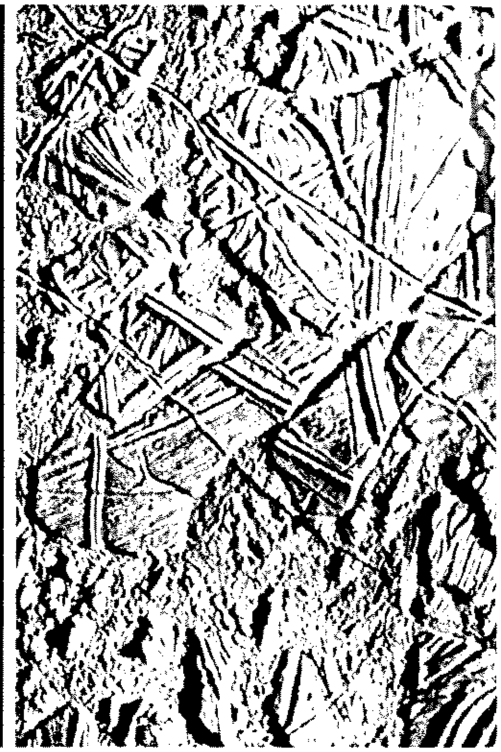
The channels run along the edges of intricately arrayed crystals in the ice, says David Cole, a materials scientist at CRREL whose lab in Barrow sometimes doubles as a walk-in freezer for whale meat and blubber. To demonstrate how the microscopic crystal patterns determine the macroscopic properties of the ice, Cole dons heavy gear and walks 100 yards out onto the sea. Working with a glaciologist, he extracts two gravestone-shaped slabs of ice sliced out of the ocean with a six-foot chain saw. When Cole sets the slabs against a black cloth, their brine channels pop out like tall, spectacular ferns. Brine drains out through thick central arteries near the bottom, where the ice is warmest and the crystals are largest. The channels branch into smaller offshoots as the ice gets colder and harder toward the surface. The near-surface crystals are tiny, since they were exposed to wind and rough waters as they formed. Cole thinks their haphazard alignments force channels to splinter in every direction. "The way that sunlight noodles down through the sheet along these channels," Cole says, "has a lot to do with where a bloom of algae appears."

ALGAE COAT THE RELATIVELY WARM UNDERSIDES OF ICE EVERY SPRING, when there's enough light to spur their growth. But Jody Deming and her student, Karen Junge, are interested in hardier inhabitants: the microbes that survive the dark winter within microscopic channels in the frigid upper ice. Junge takes intact ice cores back to Fairbanks and cuts out chunks the size of Scrabble pieces. There, she and Deming mark the organisms with a DNA-sensitive stain that percolates through the brine without melting the ice. It's the first time scientists have studied ice-bound microbes without destroying their habitats. "No one has ever looked into a frozen matrix at this scale," Junge says. "It's the best way to tell how they are able to survive."



Ice cores taken from a tundra lake near Barrow, Alaska, are beautifully translucent—and relatively barren—because they are made of nearly solid ice. Those taken from sea ice, opposite, are riddled with gas bubbles and networks of brine that harbor life. These bubbles are about 0.1 millimeter wide.

The microbes tend to reside within tiny indentations in the channels or at the junctions of two or three channels—like microscopic fish tanks linked by narrow feeder tubes, with one or sometimes many organisms in each tank. Primarily bacteria and diatoms, they can be half the size of their temporary homes. "I was surprised to find so many microbes in the upper reaches of the ice at the severest point of the winter," Deming says, "but we find plenty. Even very cold, hard ice contains small wet areas that can and do support life." →

From the microbes' perspective, the brine has the consistency of honey and flows with micro-currents. To keep from getting swept away, the microbes glom on to clumps of sediment that are too large to squeeze through the channels. "There are lots of clay minerals in the ice, and they give you tremendous surface areas," Aaron Stierle says. "It's not one single grain but thousands packed together with very rough surfaces."

Stierle finds 10 to 100 times more dirt than living material in the ice cores he analyzes. He believes most of the sediments come from muds stirred up from the seafloor or the bottom of the lagoon by strong winds. The cold air causes ice crystals to form in the seawater. As the crystals drift toward the surface, they collect sediments. The floating ice crystals then freeze together, trapping the captured sediment particles in the ice cover. To the microbes, the sediments are the equivalent of fast food—chock-full of dissolved carbon and other nutrients. Attached to such manna, they can ride out the winter until the spring thaw sets them free.

Much of Europa's ice may hold the same muddy promise. Collisions with asteroids or comets scatter debris across the surface, and Jupiter and the volcanic moon Io shed particles into space, some of which Europa sweeps up. No one yet knows whether Europa's deep ocean is active enough to stir sediments into the ice from below. Even so, Stierle and Junge's results suggest a possible approach for future missions. "If we do go look for life on other moons and planets, we should look in places where there are plenty of particles," Junge says. "Those are the environments that favor active and diverse communities."

If sediments are scarce, Europan organisms could rely on another common survival strategy in the Arctic ice: They may churn out what Deming calls "mucus goop," the bacterial equivalent of a head cold. The technical term for this stuff is "extracellular polymeric substances," or EPS—long chains of sugars that exit the cell when triggered by extreme cold or a lack of nutrients, swaddling it in a protective sheath. "Some bacterial cultures produce so much EPS that you can flip over the test tube and it doesn't run out," says Christopher Krembs, an oceanographer who recently finished his postdoctoral research under Deming. EPS is a good adhesive, Krembs adds. It may even allow microbes to stick to the walls of brine channels like anemones to the seafloor, sweeping the currents for nutrients as they waft past.

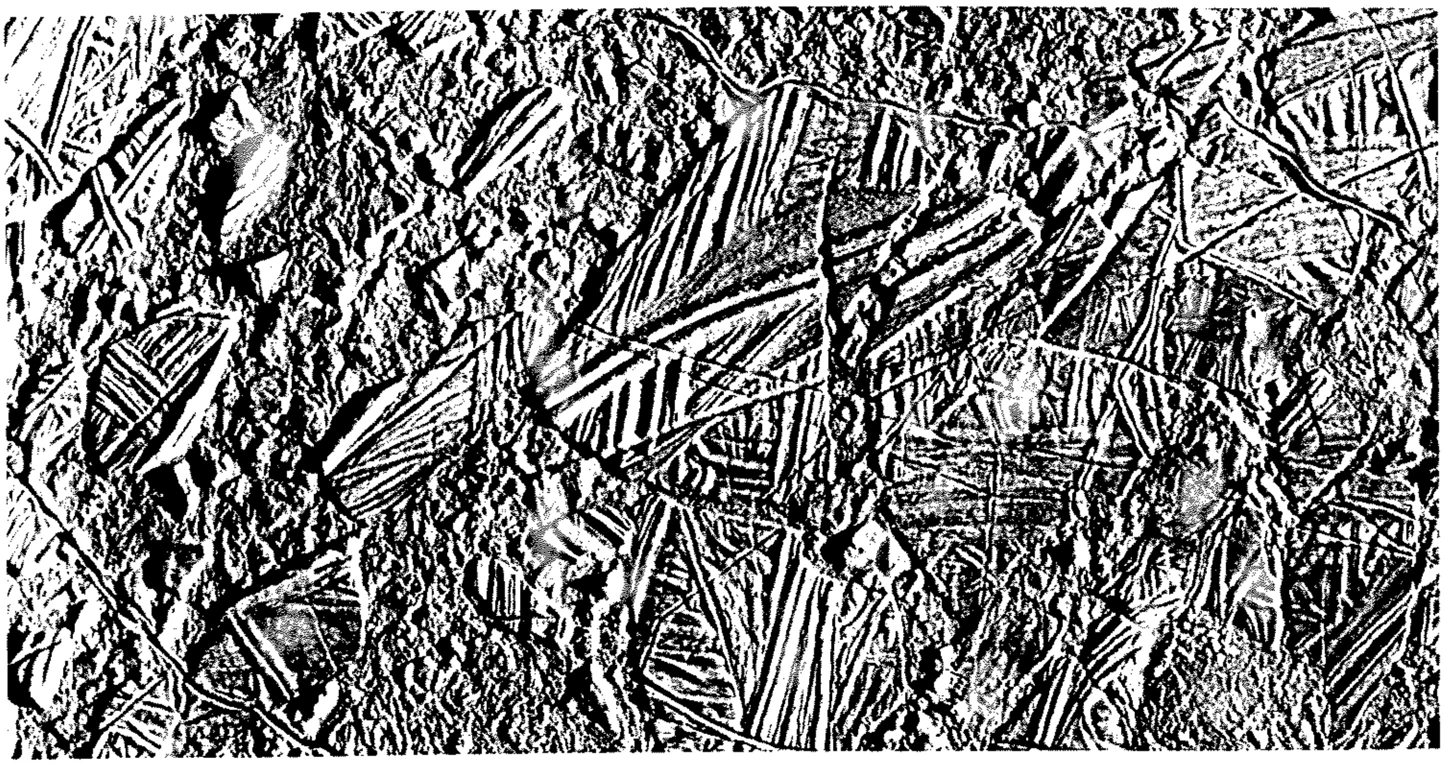
Deming and Krembs believe that once a microbe finds a space within the ice, it secretes EPS to pad out its pore for the coming

BRINY LIFE ON MARS?

Like the researchers at Barrow, NASA astrobiologist Christopher McKay has found active cells at temperatures as low as -4°F. But he has found them in Siberia, not in Alaska. And he imagines them as stand-ins not for life on Europa but for the polar regions of Mars.

The Siberian permafrost contains dust particles that are coated by extremely thin films of water. These films provide a home for microbes, McKay and his Russian colleagues have found, and allow them to grow in a nutrient-deprived state. "They're not frozen; they're starved," McKay says. The same scenario could occur close to the surface near the Martian poles, where ice and dirt also are mixed together.

At the same time, images from the *Mars Global Surveyor* satellite strongly suggest that water may flow farther underground. "If there's any liquid water on Mars, it's got to be briny," McKay says, and some of that water could exist in ice pockets like those in the Arctic. Testing the hypothesis should prove a lot easier than sending a probe to Europa: Mars, after all, is just one planet away. —*R.I.*



winter. "Temperatures go down, salinity goes up, nutrients get used up, and the ice closes in from all sides," Krembs says. "Producing EPS is their desperate attempt to survive. The biggest threat is not from temperature but from ice crystals that rupture cell membranes." The mucus is an antifreeze, Krembs says, keeping the salty brines liquid at surprisingly cold temperatures.

The polysaccharide chains in EPS are distinctly biological—no inorganic process is known to make them—yet they diffuse through the brine channels and stay preserved for long periods. That could make them an ideal indicator of life on Europa. "You're much more likely to find these compounds than the organisms themselves," Krembs says. "It's like the alcohol in beer. It's a fingerprint of the former life that produced the alcohol, but the life itself is gone." Deming hopes such possibilities will help shape future missions to Europa. Before launching a probe into space, she says, mission planners had better make sure that their instruments can detect life in the Arctic ice or places like it. "This is as close to walking on the surface of Europa as we're going to get."

IF ARCTIC ICE IS A GOOD MODEL FOR THE SURFACE OF EUROPA, THEN Europa will be an active place. Indeed, when *Galileo* snapped its first detailed images of Europa in 1996, the fractures, ridges, and giant chunks looked eerily like aerial views of sea ice on Earth. Still, researchers don't yet know whether Europa's icy rind is many miles thick or just one or two—and the difference may determine how easy it will be to find life there, if it exists at all.

Robert Pappalardo thinks the ice is relatively thick but not static. *Galileo*'s images of the moon's surface show domes, pits, and mottled areas that look as though they were pushed up from below. The features suggest a solid shell of ice at least 10 miles thick. Blobs of warmer ice—as toasty as 14°F—may ooze upward

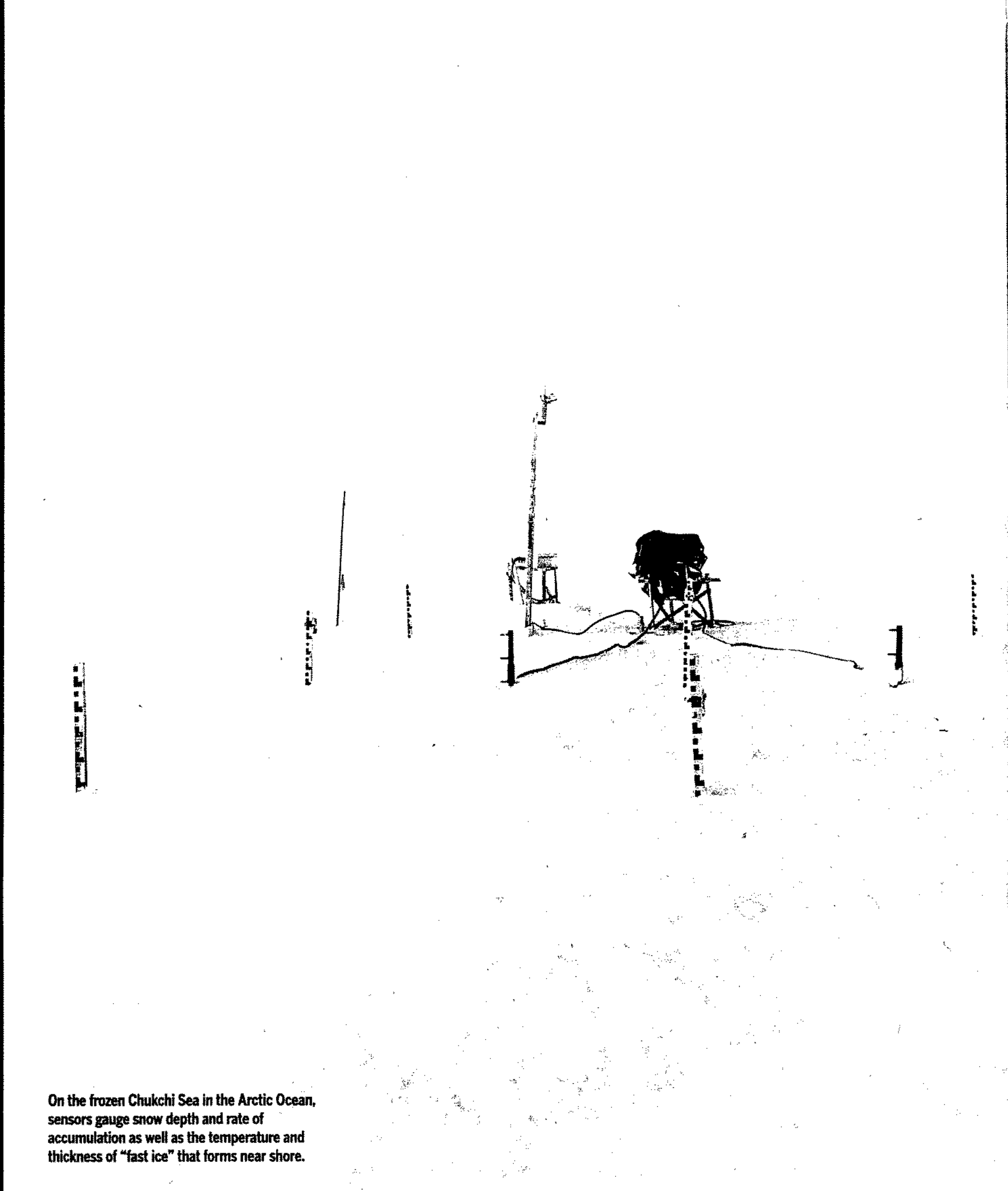
PHOTOGRAPH COURTESY OF NASA/JPL.

Left: When a thin section of sea ice is photographed between cross-polarizing filters, its crystals appear in different shades, oriented in the direction that the ice was growing. Above: Similar patterns fracture the frozen surface of Europa, on a much greater scale. The icy crust has been crushed into huge slabs—the largest here is about eight miles across—probably as a result of the tectonic flexing of powerful and relentless tides. This gravitational pushing and pulling from Jupiter may also heat a vast sea miles below.

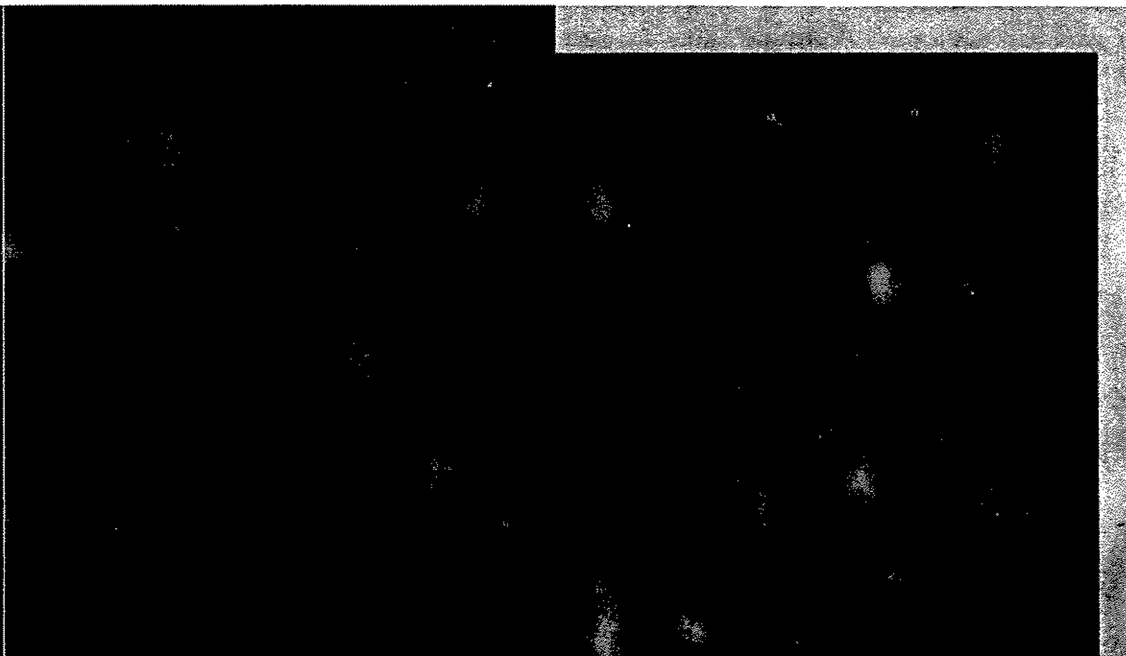
and partially melt the overlying ice. "It's like a planetary lava lamp," Pappalardo says. *Galileo*'s measurements also suggest that minerals similar to Epsom salts may be mixed into the ice. Where there's salt there's brine, Pappalardo says, and where there are pockets of brine there could be organisms, just as in the Arctic.

As Europa whirls around Jupiter every 85 hours, its surface and interior are distorted by tremendous tides from the gravitational pull of the planet and its other two closest moons, Io and Ganymede. The tides heave the ice up and down by about 100 feet. According to Richard Greenberg, a *Galileo* scientist based at the University of Arizona in Tucson, such flexings account for the scallop-shaped cracks that craze Europa's surface. But Greenberg thinks the cracks could form only in a layer of ice at most a few miles thick. "We think the cracks reach the liquid, and the tidal openings and closings squeeze ice and slush up to the surface," he says. If so, brine with nutrients from Europa's sea could suffuse the ice regularly, forming niches for life "that last for thousands of years."

Hajo Eicken is content to leave that debate to planetary scientists: He is delighted with the mere fact of Europa's existence. "There's a moon out there that is completely covered by ice," he says. "If you're a glaciologist, that's your morning star." When it finally rises, that star may herald a new dawn in our awareness of life elsewhere. ☒



On the frozen Chukchi Sea in the Arctic Ocean, sensors gauge snow depth and rate of accumulation as well as the temperature and thickness of "fast ice" that forms near shore.



ALASKA'S ARCTIC ICE IS RIDDLED WITH SOME OF THE WORLD'S HARDIEST AND MOST ADAPTABLE BACTERIA. DOES THAT MEAN FROZEN EUROPA SUPPORTS SOME EXTRATERRESTRIAL COUSINS?

LIKE ALASKA LIKE EUROPA

BY ROBERT IRION PHOTOGRAPHY BY CATHERINE WAGNER

HAJO EICKEN KNEELS ON THE FROZEN ARCTIC Ocean near Point Barrow, Alaska, poking a temperature gauge into a long tube of ice. He dictates to a chilled Karoline Frey, who stops stomping up and down long enough to record the numbers with a pencil. Nearby, Aaron Stierle drills a hole with a huge auger, Karen Junge curses a frozen generator switch, and Andy Mahoney drives a snowmobile in circles, patrolling for polar bears. ¶ "Karoline, why don't you cut this core, it will warm you up," Eicken says, giving Frey a small saw. She slices the ice into pieces the shape of hockey pucks and puts them into plastic containers. Eicken, his red goggles visible within the fur-lined tunnel of his parka hood, walks over to help Stierle lower a $12,000 device into the new hole to measure water currents nearly five feet below. The wind muffles their words and whips ribbons of