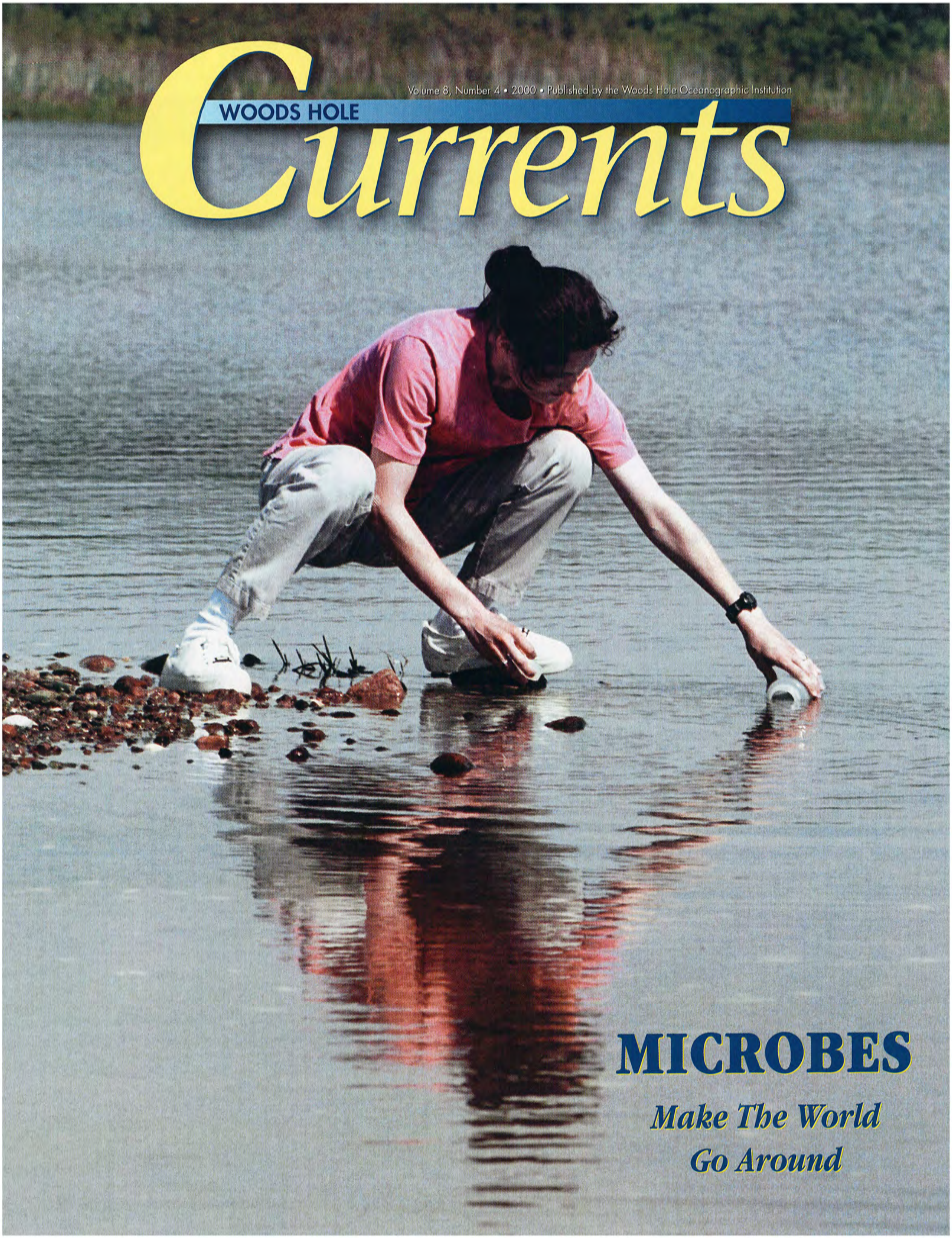
Volume 8, Number 4 • 2000 • Published by the Woods Hole Oceanographic Institution

WOODS HOLE Currents



MICROBES

Make The World Go Around

CONTENTS

Ubiquitous microbes have a huge impact on our planet.

WHOI Waypoints

COVER: WHOI Assistant Scientist Katrina Edwards collects water samples from Salt Pond in Falmouth, MA, in search of bacteria that make their own compasses. Photo by Tom Kleindinst

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Published by the Woods Hole Oceanographic Institution, Woods Hole, MA 02543, 508-457-2000, © 2000

www.whoi.edu

Editor: Laurence Lippsett; **Designer:** Jim Canavan, WHOI Graphic Services
***Currents* Editorial Advisors:** Robert B. Gagosian, WHOI Director; Robert D. Harrington, Jr., President, Woods Hole Oceanographic Associates; Jacqueline M. Hollister, Associate Director for Communications, Development, and Media Relations; Vicky Cullen, Communications Director; Shelley Lauzon, Media Relations Director

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THE WOODS HOLE OCEANOGRAPHIC INSTITUTION is a private, independent, not-for-profit corporation dedicated to research and higher education at the frontiers of ocean science. WHOI's primary mission is to develop and communicate a basic understanding of how the oceans function and interact with the earth as a whole. The Institution strives to be a world leader in advancing knowledge about the oceans and explaining their critical role in the global environment.

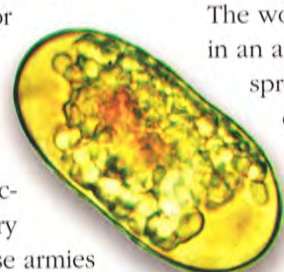
MICROBES

Undersized, overlooked organisms that hold the key to understanding life on Earth

Money doesn't make the world go around. Microbes do.

Be it ever so humbling to our human-centric view, "microbes shaped the biosphere in a way that gave humans a chance to evolve and make a living," said WHOI microbiologist Andreas Teske.

Billions of years ago, ocean-dwelling bacteria capitalized on a chemical reaction now called photosynthesis and filled Earth's atmosphere with oxygen, setting the stage for the evolution of terrestrial, multicellular life. Today, unseen, ubiquitous microorganisms still attend to the crucial biochemical reactions that keep the planetary ecosystem in balance. These armies of single-celled catalysts are at the front line, continually making, moving, breaking down, and recycling the essential chemicals of life.



"Just by existing, microbes produce and release chemicals as metabolic byproducts, which change their environment—*our* environment," said Katrina Edwards, a WHOI geomicrobiologist, who studies the fundamental but often overlooked roles microorganisms play in shaping the earth.

Some use water to produce the oxygen we breathe and carbon dioxide to produce the food on which the ocean's animal life depends. Some convert sulfur beneath the seafloor into organic materials, launching the food chain on which deep-sea life depends. Others decompose organic materials on land and sea to be reused in an ongoing cycle. Some microbes even dissolve rock into liquid that returns via rivers to the ocean.

"These are the most important organisms on our planet," said Michael Atkins, who earned his Ph.D. in biological oceanography at WHOI in June.

The world's microorganisms come in an amazing variety of forms spread among three distinct domains of life: bacteria, nuclei-containing eukaryotes (which include all fungi, plants, and animals—a large number of which are single-celled), and archaea, recognized as a distinct domain only over the course of the last two decades. Though archaea, like bacteria, are single-celled prokaryotes (microbes without cell nuclei and other organelles), they are "as different from bacteria as bacteria are from trees," said WHOI marine biologist Carl Wirsen.

Many of these microorganisms can thrive in every conceivable (and a few almost inconceivable) environments—in boiling hot springs, in the sunless, high-pressure depths of the ocean, in Antarctic ice, in desert soil, in acidic waters that would dissolve your skin, or in the stomachs of cows or deep-sea tubeworms.

"No matter how extreme an ecological niche or a particular chemical environment is, you can find some microbes that are adapted to it and taking advantage of it," said Teske, who last year helped identify the world's biggest bacterium, which prospers in sulfide- and nitrate-rich, but oxygen-poor sediments off the Namibian coast. "Almost any energy-yielding chemical reaction that exists has been exploited by microorganisms."

For all these reasons, microorganisms hold the key to understanding the evolution of Earth and life on it.

En masse, they effected the chemical transformations that spawned the planet's air, soil, and oceans.

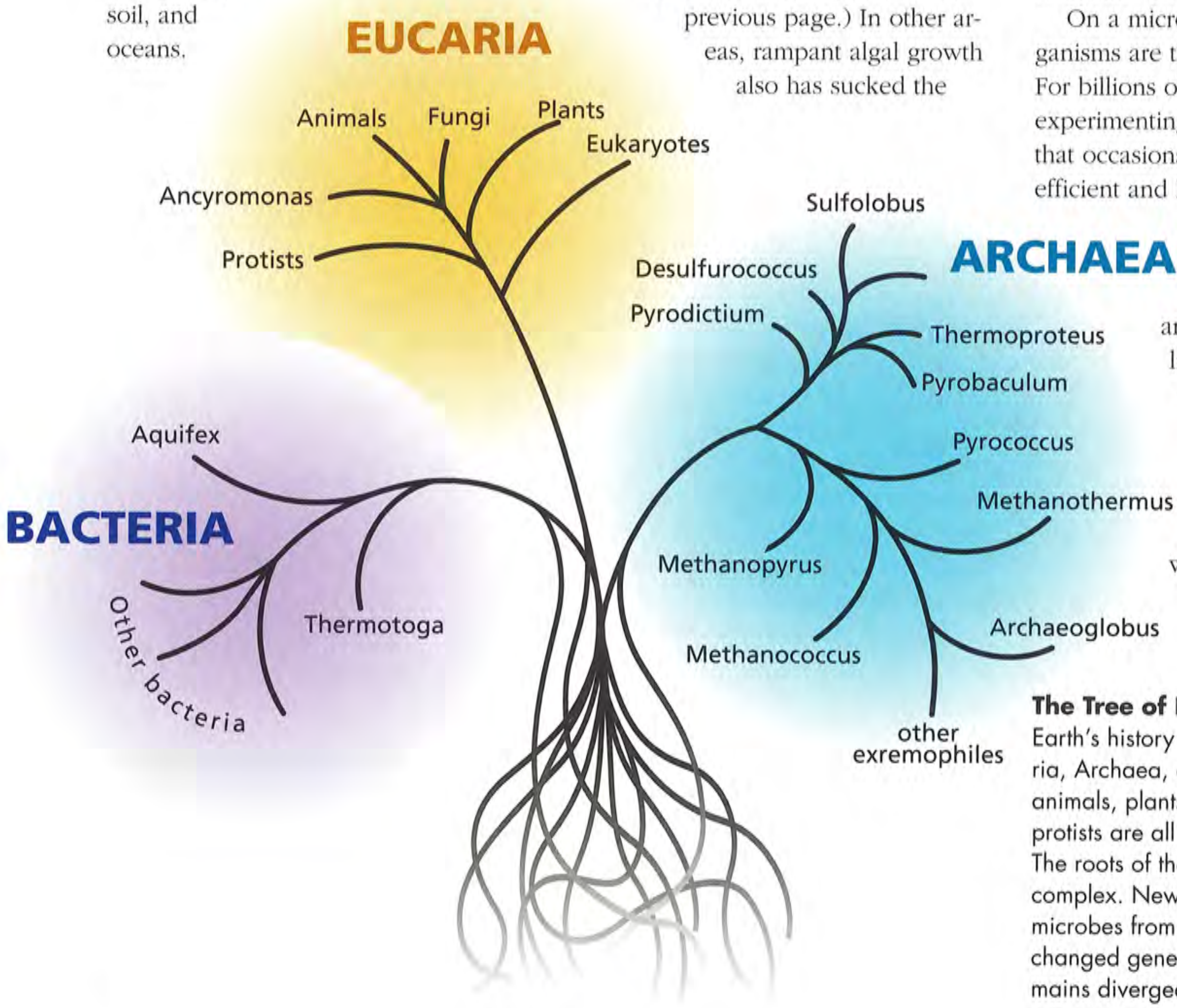
Today, they are still the worker bees of the planetary hive, on whom the health of the entire ecosystem depends. Will global warming spark wholesale changes in the ocean's microbial population, or will microorganisms help us by absorbing the excess carbon dioxide humans are putting into the atmosphere? Is excess fertilizer runoff into the ocean disrupting natural food webs? There are telltale signs: Harmful algal blooms—the proliferations of single-celled toxic marine plants that overwhelm coastal areas—have been occurring with increasing frequency and severity around the world, causing health problems and millions of dollars of damage to fisheries, aquaculture, and tourism industries. (Cysts of the toxic dinoflagellate *Alexandrium tamarense* are shown on the previous page.) In other areas, rampant algal growth also has sucked the oxygen out of ocean waters, creating and expanding "dead zones" where other marine life cannot live. On land, Edwards discovered a new species of archaea that dissolves rock into powerful acid. When long-buried rocks are exposed by human mining activities, their acidic runoff can cause devastating and expensive contamination in groundwater, rivers, and the sea.

Until we can comprehend all the diverse life forms out there and how they interact, we can only grope blindly as we try to figure out how to protect ecosystems from the excesses of human activities. On the other hand, oil-eating or toxic waste-degrading bacteria, recently discovered archaea that consume the greenhouse gas methane, or other microbes we have yet to discover could help us remediate environmental problems.

On a microscopic level, microorganisms are the laboratories of life. For billions of years, they have been experimenting with chemical reactions that occasionally prove marvelously efficient and launch life into entirely new directions.

"They invented all the biological structures and metabolic processes of life—many of which were retained by multicellular forms," Teske said.

Scientists believe, for example, that chloroplasts (the organelles within plant cells that are



The Tree of Life diverged early in Earth's history into three domains: Bacteria, Archaea, and Eucaria. (Humans, animals, plants, fungi, and single-celled protists are all kingdoms within Eucaria.) The roots of the tree remain murky and complex. New evidence suggests that microbes from all three domains exchanged genes before the three domains diverged from one another.

Wherever you go, there they are

Neither snow, rain, heat, gloom of night, thousands of kilometers of dense ocean ice pack, nor any other harsh conditions seem to prevent the proliferation of healthy populations of microbial life. Nor do they deter scientists seeking to study the diversity of life in extreme environments. Above, WHOI Assistant Scientist Rebecca Gast and Robert Sanders of Temple University collect samples of slush from the Ross Sea off Antarctica to study how microorganisms have adapted to the extreme cold and how they interact in the robust Antarctic aquatic food chain. Among the microorganisms they found were amoebae (top) and clusters of diatoms (bottom).

responsible for photosynthesis) and mitochondria (the organelles in animal cells that convert sugars into energy) were both free-standing microorganisms that were literally incorporated into eukaryotic host cells somewhere along the evolutionary line. Undoubtedly, the architectures and processes that occur within our own human cells were pioneered by microorganisms, so we can also learn a lot about ourselves by studying them.

WHOI scientists increasingly are using emerging techniques spawned by the biotechnology revolution to look for genetic differences in microbes, which are often impossible to distinguish by examining their physiology, and to identify genes that have been retained as life evolved. Atkins this year found a single-celled microorganism living near deep-sea hydrothermal vents that may be the closest to the common ancestor from which all multicellular fungi and animals emerged.

Newly discovered microorganisms also offer the potential to find compounds or enzymes with pharmaceutical or industrial uses. Only a few years ago, in a previously unknown microbe thriving in a hot spring in Yellowstone National Park, scientists found a heat-resistant enzyme. It became instrumental in the polymerase chain reaction (PCR), a widely used technique to replicate DNA rapidly that sparked the modern revolution in biotechnology. Mining industries are economically extracting metals from ores using huge vats of microorganisms with abilities similar to Edwards's archaea.

"People would be surprised to see how far bacteria have penetrated into everyday life," Teske said. "Bacterial slimes are widely used in the food-processing industry, for example, because these polysaccharides create the perfect consistency for ice cream. Certainly there are living things out there doing potentially useful things that haven't been found or invented yet."

"Out there" also includes places beyond Earth—on other planetary bodies. The search for extraterrestrial life today does not focus "on little green men," Teske said, "but on microbes." For they are the ones that have found ways to adapt, survive, and even thrive in a wide range of seemingly harsh conditions.

Out there is "a living minestrone, with the majority of bits small or microscopic," Sylvia Earle, the world-famous oceanographer and a WHOI Trustee, wrote in *The Living Ocean*. She was referring to the ocean, but microscopic life also thrives in the rocks on land, beneath the seafloor, and perhaps elsewhere in the universe. We're just beginning to open our eyes to their realm.

This issue of *Currents* introduces some interesting microbes, from each domain of life, that were unknown until last year—and the WHOI scientists who discovered them. ■

The Mystery of the Contaminated Mine

In streams of slime in an abandoned, contaminated mine, a WHOI scientist found a previously undiscovered microbe that helps convert rocks into acid.


Jillian Banfield

Depending on your perspective, this was either Hell or the Garden of Eden.

The place has been known as Iron Mountain since the 1880s, when prospectors first began tunneling into its bowels to extract gold, iron, copper, zinc, and other valuable metals. By the time the mine in northern California was finally abandoned in 1959, not much was left behind—besides a colossal environmental mess.

Highly acidic waters chock-full of dissolved metals had leached into groundwaters, killing off plant and animal life for miles around. Rains sent these contaminated waters cascading into the Sacramento River, causing massive fish kills. The waters drained all the way into San Francisco Bay, whose fish contained metals that could be traced back to Iron Mountain. The Environmental Protection Agency declared Iron Mountain a Superfund cleanup site and supervised construction of an expensive facility to control the damage.

To this not-so-idyllic spot, Katrina Edwards came to do her research. Encapsulated in protective clothing, she ventured into the hot, poorly ventilated, abandoned mine tunnels to collect samples. Dissolving rock crashed and echoed ominously in the mine's nether regions. Waters inside the mine reached 115°F and were the most acidic found on Earth. On the pH scale, which ranges from 0 (most acidic) to 7 (neutral) to 14 (most alkaline), the Iron Mountain waters measured –3.5. That's not a typo.

Edwards already suspected that these seemingly unnatural conditions had a perfectly natural cause. The mine was dark, dank, and desolate—but hardly devoid of life.

"Life finds a way, as long as you have water," said Edwards, who joined WHOI as an Assistant Scientist last year. "Microorganisms can exploit the chemistry and physics of any conditions that exist. Any situation that's out there, you can bet there'll be a microorganism wedged right in there, taking advantage of it."

Simply by living, microorganisms take in, rearrange, make, and release chemicals—catalyzing and regulating reactions that determine the environment we live in, she said. They may be out of sight, but Edwards, a geomicrobiologist, is ever mindful of their dramatic, cumulative effects. Beyond creating our essential atmosphere, they play a critical, overlooked role in dissolving and making rocks, thereby shaping Earth's surface features, such as the pathways of rivers. They regulate the chemistry of groundwaters, lakes, rivers, estuaries, and ultimately the oceans themselves. Tiny as they are, microorganisms for billions of years were the only living things capable of fundamentally changing our environment. Only recently have human beings achieved this—by producing excess industrial greenhouse gases, for example, or creating mines like Iron Mountain.

The abandoned mine may have seemed God-forsaken, but Edwards knew it was not microbe-forsaken. Iron Mountain had all the creature comforts of home-sweet-home to some microorganisms, which use sulfide minerals in metal ores to generate energy and two nasty byproducts—sulfuric acid and dissolved metal ions.

The idea that microbes can accelerate the dissolution of rocks is not new, and classic textbooks cite two iron-oxidizing bacteria as primary suspects: *Thiobacillus ferroxidans* and *Leptospirillum ferroxidans*. Edwards found these two in samples of water taken from drainage streams outside the mine, but surprisingly, they were not present in water from inside the mine. These bacteria were red herrings—Johnny-come-latelies that didn't acifidy the waters but arrived on the scene only after the waters already had become acidic.

So who were the real culprits?

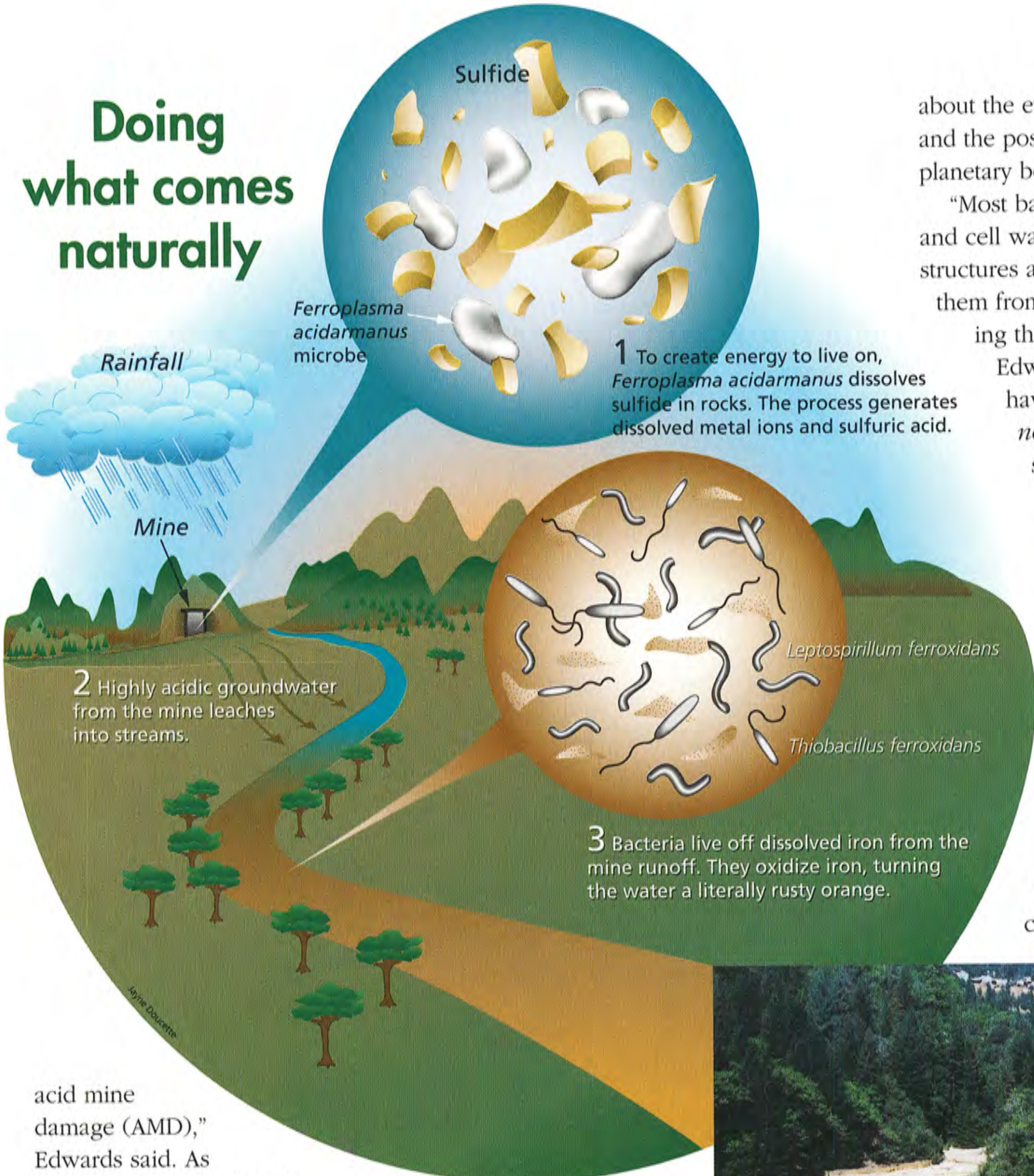
Edwards expanded her search. She used different culture media that better mimicked environmental conditions inside the mine, and she used new molecular probes that allowed her to isolate and identify different microorganisms. It soon became clear that scientists had been barking up the wrong evolutionary tree. Bacteria weren't primarily responsible. Instead the mine was rife with a previously unknown organism that came from another of the three domains of life: archaea. Edwards and her colleagues at the University of Wisconsin, where she conducted this research in pursuit of her Ph.D., called the new species *Ferroplasma acidarmanus*.

"We think this new microbe might be one of the more important players in catalyzing the reactions that cause

Philip Bond

Contaminated waters from the abandoned Iron Mountain Mine flowed into the Sacramento River, causing massive fish kills, and drained all the way to San Francisco Bay, where fish contained metals that could be traced back to the mine. Above, WHOI Assistant Scientist Katrina Edwards (left) and Jillian Banfield, of the University of Wisconsin-Madison, don protective gear to collect samples in the mine.

Doing what comes naturally



acid mine damage (AMD)," Edwards said. As soon as long-buried sulfide-rich ore bodies are exposed to air and water by mining, *Ferroplasma acidarmanus* moves in quickly. Where they come from is an open question. The sulfuric acid they create contaminates not only the immediate area, but also eventually flows to the ocean.

"It is estimated that half of the sulfates that end up in the world's oceans result from human activities such as mining," Edwards said. "Once you unearth sulfide minerals at the surface, you've opened up a big tap of sulfuric acid and broken off the handle. You can't stop it."

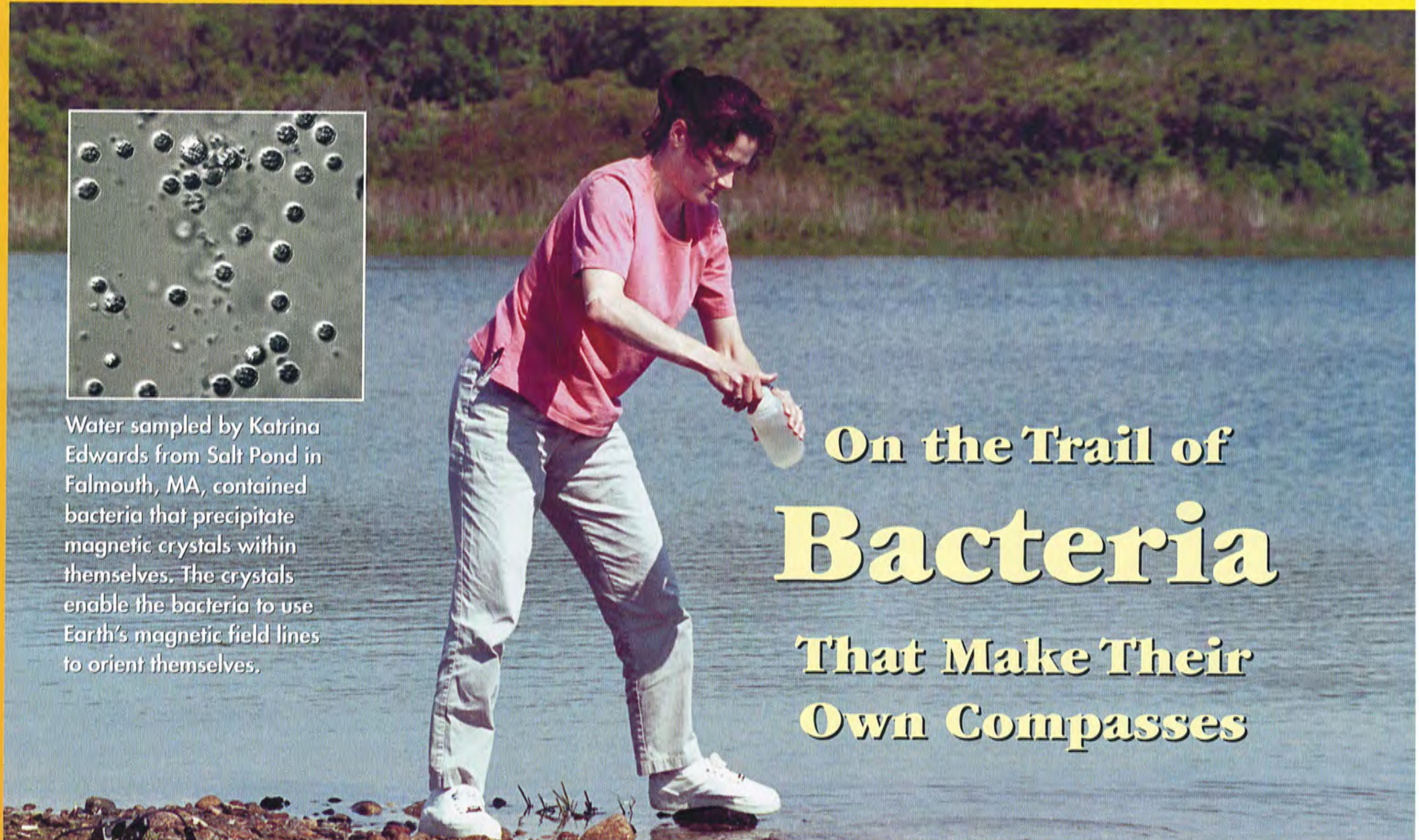
Still, discovering *Ferroplasma acidarmanus* may be a first step to understand, prevent, and mitigate AMD—or to "mine" in more economical and less environmentally damaging ways. For example, industrialists are already trying so-called bio-leaching reactors—harnessing microbial activity to dissolve low-grade ores and extract metals from them.

Further, *Ferroplasma acidarmanus*'s ability to thrive in such toxic, acidic conditions once again forces scientists to re-examine preconceived notions about the evolution of life on Earth and the possibility of life on other planetary bodies.

"Most bacteria have membranes and cell walls to hold their interior structures and fluids, while protecting them from the environment and giving the cell rigidity and shape," Edwards said. "These archaea have only one membrane and *no* cell wall. We at first assumed that *F. acidarmanus* must be really hardy, with some sort of armor around them to sustain such conditions, but we found that they are separated from their highly acidic environment by a single flimsy membrane."

How does this peculiar cellular architecture work? What possibly unknown enzymes or biochemical processes does this microorganism use to oxidize metal sulfides? This discovery of *F. acidarmanus* opens up new avenues of potential discovery and proves, once again, that life—wherever you find it and however you define it—is full of surprises. ■

Iron Mountain streams eventually flow into the Sacramento River.



Water sampled by Katrina Edwards from Salt Pond in Falmouth, MA, contained bacteria that precipitate magnetic crystals within themselves. The crystals enable the bacteria to use Earth's magnetic field lines to orient themselves.

Tom Kleindinst

On the Trail of Bacteria That Make Their Own Compasses

Katrina Edwards is no longer surprised by the extraordinary capabilities of microorganisms—but the rest of us can still be amazed. Take, for example, bacteria that make their own magnetic compasses.

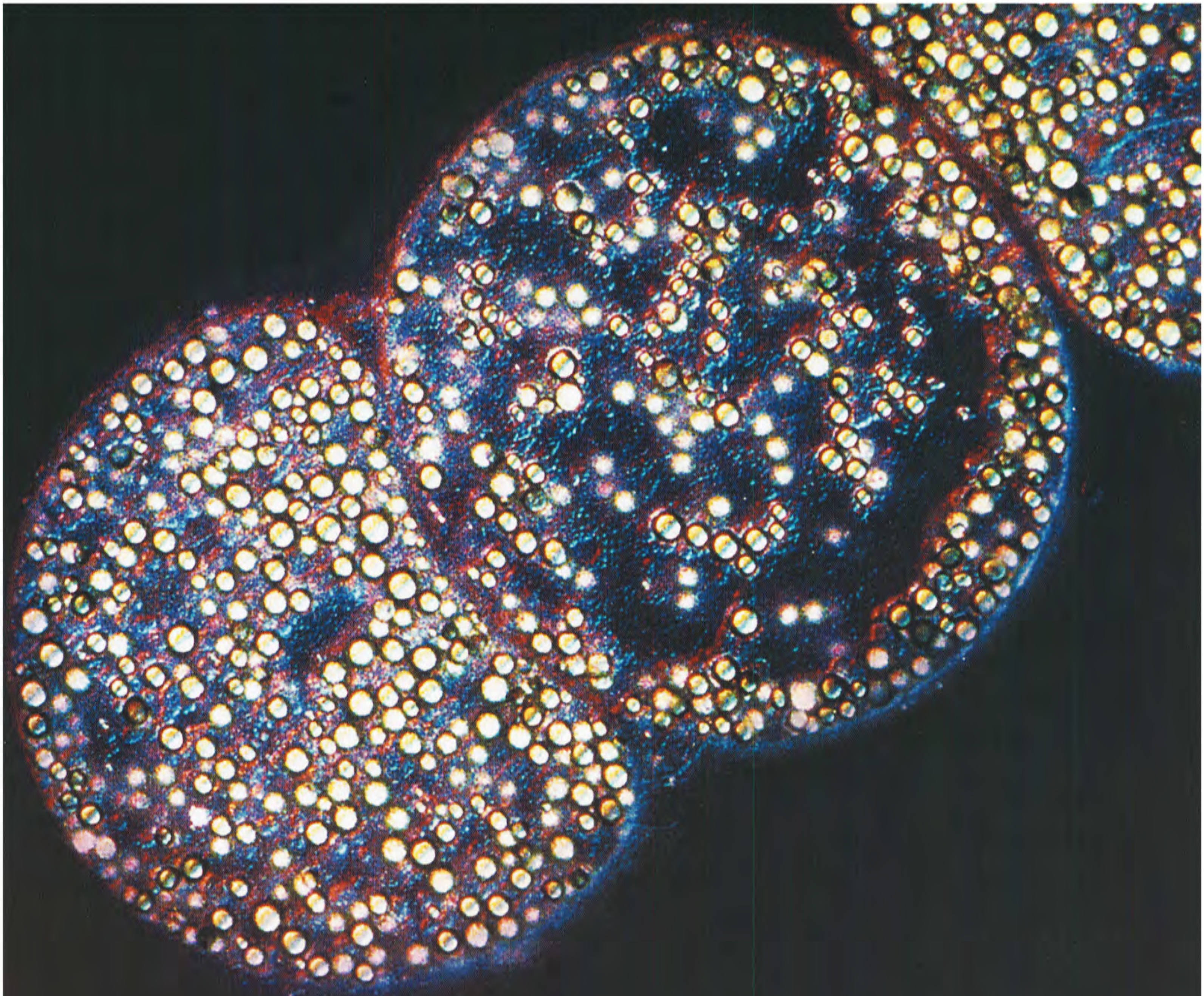
Fresh from her research on a previously unknown species of archaea that dissolves metal ores into sulfuric acid, Edwards is now investigating bacteria in Cape Cod salt ponds, in collaboration with Dennis Bayzlinski of Iowa State University. Using iron and sulfate from their environment, these bacteria precipitate crystals of a magnetic mineral, greigite (Fe_3S_4), within their cells.

The evidence to date suggests that the bacteria use these magnets to align themselves with Earth's geomagnetic field, Edwards said. They combine this ability with a mechanism that gives them the capacity to sense oxygen levels in surrounding waters. By these means, the bacteria can orient themselves in the water column in places where they find optimal living conditions.

Edwards, an Assistant Scientist at WHOI, is a geomicrobiologist who studies the crucial role that microorganisms play in dissolving or precipitating rocks and minerals at the earth's surface. Her perspective is simultaneously macro- and microscopic. If the earth were a body, microorganisms would act as the cells and enzymes that catalyze myriad reactions to regulate the planet's chemistry on land and sea.

Curiously, the greigite crystals the bacteria create are not stable in the oxygen-poor, sulfide-rich coastal waters these organisms inhabit. The bacteria have to work to keep them intact. If bacterial cells did not carefully maintain the composition and structure of greigite, these unstable magnetic minerals might react to form other, more stable sulfide minerals, such as pyrite (FeS_2). Edwards is investigating precisely how these microbes maintain these magnets within their cells, and what happens to the crystals when the bacteria die.

Not only is this significant for understanding how chemicals cycle through Earth's atmosphere, land, and ocean, it could be used as a tool to see into Earth's past. Earth's magnetic field has flip-flopped many times during its long history—with the north and south poles switching places. Magnetic minerals align with the magnetic field that exists at the time they form. Bacteria-spawned magnetic minerals preserved in coastal sediments should record the geomagnetic field that existed when they were formed. Thus, they can act like stopped pocket watches to help pinpoint the timing of geological events. ■



The World's Largest Bacteria

Without even looking at it under a microscope, Andreas Teske could tell immediately that this bacterium was unusual.

That's because he didn't need a microscope.

Unlike other bacteria, this one could be seen with the naked eye. The newly discovered bacterium is about as large as the period at the end of this sentence, making it gargantuan by bacterial standards. It was found buried in smelly, sulfur-rich, sedimentary, seafloor muck off the coast of Namibia. Growing in long lines of single cells, each stuffed with reflective white globules of sulfur, the bacterium resembled a string of pearls to its discoverers, who named it *Thiomargarita namibiensis*—"Sulfur pearl of Namibia."

With a volume about 3 million times greater than average bacteria, *Thiomargarita namibienus* is by far the world's largest bacterium ever found. It shattered the conventional wisdom that bacteria's inherent

Tom Kleindinst

WHOI microbiologist Andreas Teske helped identify a previously unknown giant bacterium discovered in seafloor sediments off the coast of Namibia. Growing in long lines of single cells, each stuffed with reflective white globules of sulfur, the bacteria (opposite) resembled a string of pearls to its discoverers, who named it *Thiomargarita namibiensis*, "Sulfur pearl of Namibia."

physiology prevented them from ever getting so big.

But Teske, who has studied bacteria for many years, is well aware of their capabilities. They don't have nuclei, let alone brains, yet bacteria have an impressive capacity for innovation and enterprise. For billions of years, they have tenaciously survived, no matter what life throws at them. They find their niche in the world, often by devising ways to thrive in conditions that would kill other living things (even other bacteria). Whatever environmental situation exists out there, chances are good that bacteria have been there and done that. They have found ways to exploit any chemical reaction that exists to create energy. In their genes, they still have the original blueprints for a wide range of possible biological structures and processes—some retained and others discarded by life forms on Earth and elsewhere in the universe perhaps.

"When you follow the evolution of bacteria, you can see the history of

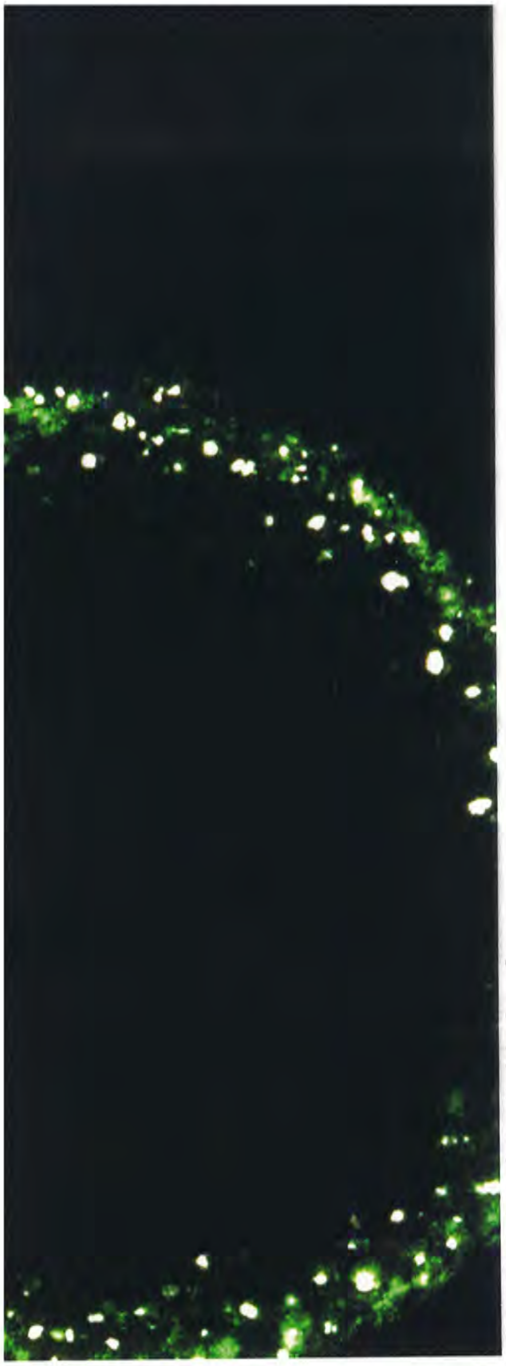
Bulking Up a Bacterium

Bacteria can't become large because they move chemicals by diffusion, which only works over tiny distances. To exchange chemicals, bacteria's cytoplasms (their liquid, metabolically active cell interiors) must be near the outside world. *Thiomargarita* overcomes this limitation by stretching its cytoplasm (stained fluorescent green) in a thin layer near its periphery and around a large nitrate-storing vacuole (black). The vacuoles fill the cell interiors like inflated balloons and give these bacteria their record-breaking bulk. The shiny white dots are globules of sulfur, which the bacteria use to make energy. The enlarged area (inset) shows the vacuole, the thin cytoplasm layer, and the cell sheath.

biochemical invention," Teske said.

Thus, the bacterial world, whose breadth humans have barely begun to explore, can show us life's full range of capabilities. Bacteria can provide clues to the origins and evolution of life on Earth, and the search for extraterrestrial life. They offer insights into biochemical reactions that affect cells within our bodies and the ecological balance of our world.

Take *Thiomargarita namibiensis*, for example, which was found serendipitously during a hunt for other recently discovered large sulfide-eating marine bacteria called *Thioploca* and *Beggiatoa*. These two were found in sediments off the coast of Chile and Peru. In these areas, upwelling currents bring to the surface deep, nutrient-rich waters that promote blooms of microscopic marine plants and explosions of microscopic animals that eat the plants. All this life eventually dies, sinks to the seafloor, and decays in the bottom sediments. This process produces sediments that are depleted of oxygen but rich in chemicals such as nitrate and the foul-smelling gas hydrogen sulfide. These chemicals provide a banquet for *Thioploca, Beggiatoa,* and *Thiomargarita*. Consuming sulfide the way we eat food and taking in nitrate the way we breathe in oxygen, they produce the energy and organic compounds they need to live and grow. These sulfide-oxidizing bacteria play an important ecological role. They act as detoxifying agents, removing poisonous sulfide that would otherwise seep into and easily



Heide Schulz/Max Planck Institute for Marine Microbiology, Bremen, Germany

accumulate in ocean waters, especially if oxygen levels are already low.

"Without these bacteria," Teske said, "the waters would stink and the fish would die."

Since bacteria readily settle in every niche that offers them the "right" chemical menu, microbiologists theorized that sulfide-oxidizing bacteria should be found in many marine habitats where the chemical properties suited them. To test this theory, an international team of scientists from the Max Planck Institute for Marine Microbiology and the University of Oldenburg in Germany, the University of Barcelona in Spain, and from Woods Hole began to search for *Thioploca* and *Beggiatoa* in other places where oceanic conditions resembled those off South America. One such place is the western coast of southern Africa, and the team examined sediments off Namibia collected aboard the Russian research vessel *Petr Kottsov*. The samples contained smatterings of *Thioploca*, but they were teeming with something completely new: the bacteria that they soon named *Thiomargarita*.

Teske examined key genes of the new bacterium that define its position in the evolutionary tree of life and determined that *Thiomargarita* was closely related to its sulfide-eating, nitrate-respiring cousins *Thioploca* and *Beggiatoa*. But they looked very different. *Thioploca* and *Beggiatoa* cells are smaller and grow tightly stacked on each other in long, motile filaments, which make them look "like overcooked angel hair pasta," Teske said. Their filamentous shape allows them to move as necessary. *Thioploca* shuttle down into the sediments to find more sulfide, for example, or up near the seafloor to bathe in seawater filled with dissolved nitrate.

Thiomargarita, on the other hand, grow in rows of individual balloon-shaped cells that do not form motile filaments; therefore *Thiomargarita* have no means of locomotion. Stuck in the mud, they have perfected "the strategy to stay put," Teske said, by evolving very large nitrate-storing bubbles, or vacuoles, that allow them to survive long periods of nitrate starvation.

"It is like a scuba tank," he said. "Without nitrate, *Thiomargarita* would suffocate, the way we would without oxygen. In times when nitrate is plentiful in surrounding seawater, they accumulate nitrate in their vacuoles, which they can subsequently draw on when nitrate supplies diminish. These vacuoles are unique in the microbial world. Only *Thiomargarita* and their close relatives, *Thioploca* and some marine *Beggiatoa*, have them."

The mammoth vacuoles give *Thiomargarita* the ability to sit tight until ocean currents sweep nitrate-containing waters past them again. If humans had scuba tanks with equivalent capacity, they could breathe under water for weeks.

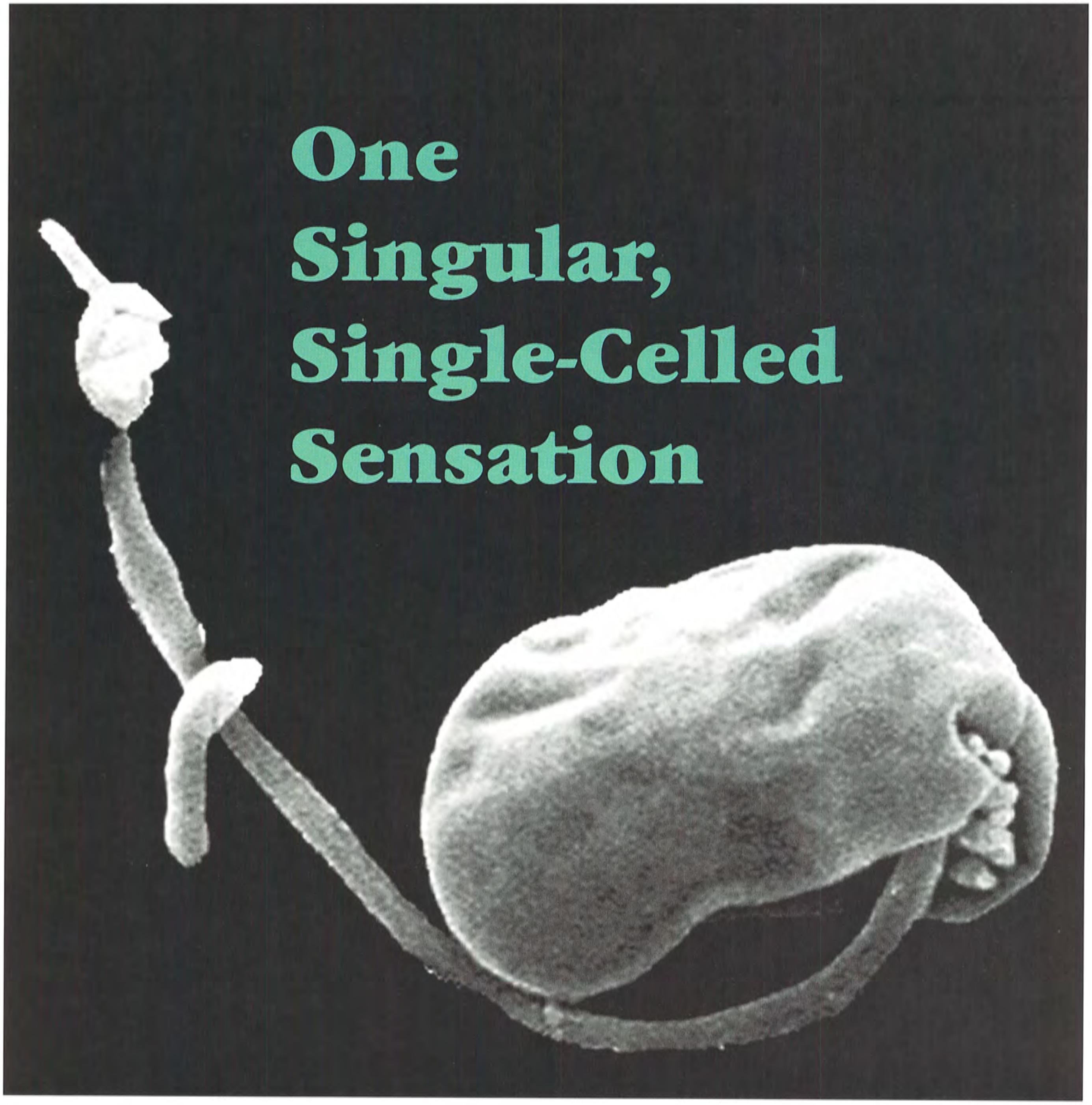
The vacuoles also give *Thiomargarita* a size that scientists thought bacteria could not achieve. One of the fundamental differences between bacteria and eukaryotes, the domain of life to which fungi, plants, animals, and protists belong, is that the latter have cells with internal structures for transporting food and wastes within the cells. Bacteria rely on diffusion to move chemicals around, a process that works only over tiny distances. So to transact business with the outside world, their cytoplasms—the liquid, metabolically active cell interiors—have to be close to their cell walls. That intrinsically limits how big they can get.

But *Thiomargarita* got around that size constraint in a novel way. Their cytoplasm forms a thin layer along the peripheral cell membrane, while the nitrate-storing vacuole occupies almost the complete interior of the cell. The large vacuoles fill *Thiomargarita* cells like a balloon and give these bacteria their record-breaking bulk.

"The discovery of *Thiomargarita* shows the oceans' barely tapped potential for new and exciting findings in the microbial world," Teske said.

The genes of microbes, he said, are often like "palimpsests—old medieval parchments that have been erased and written over many times." To him, discovering *Thiomargarita* is like finding a long-lost and unique page in our evolutionary history, one that carries crucial information about the microbial chemistry of today's oceans. ■

One Singular, Single-Celled Sensation



Meet one of your long-lost relatives—a distant patriarch from whom we all descend. And not just we humans. Michael Atkins suspects that lions, lobsters, mosquitoes, all fish, fowl, and fungi—every living thing besides plants that are composed of more than one cell—may all descend from the single-celled organism that he recently discovered living around hydrothermal vents on the seafloor.

Our common ancestor (the tiny guy magnified above) is called *Ancyromonas*, and Atkins has strong evidence that it is positioned on the evolutionary tree precisely at the momentous juncture where animals and fungi first branched out from unicellular life.

"If this organism turns out to be as important as we think it is, it holds the key to showing us what happened at a crucial evolutionary transition from unicellular to multicellular life," he said.

Atkins found *Ancyromonas* in the course of research for his Ph.D., awarded in June from the MIT/WHOI Joint Program. In a way, Atkins was bound to discover something new and interesting because he undertook the first-ever survey of single-celled protists living near deep-sea hydrothermal vents.

Ever since the vents were first discovered in 1977, WHOI has led efforts to learn about the lush microbial life that thrives on sulfur-rich fluids emitted from magma-heated rocks beneath the seafloor. But those studies have focused on two of the three basic domains of life, bacteria and archaea. No one had ever explored single-celled members of the third domain: eukaryotes, which are distinguished by their nucleus-containing cells. Such deep-sea samples are notoriously difficult to collect and to culture in the laboratory.

"I had no idea what I would find," Atkins said.

The organisms Atkins looked for are protists, single-celled eukaryotes equipped with flagella, or whip-like tails that they use to swim and to feed.

"These protists have huge ecological significance," Atkins said. "They are integral to the marine food web. Bacteria and archaea are the most important organisms on the planet because they perform the essential biochemical reactions that convert sulfur to organic compounds, for example, or carbon dioxide to oxygen. But the organisms I work on exert important controls on the populations of bacteria and archaea by eating them.

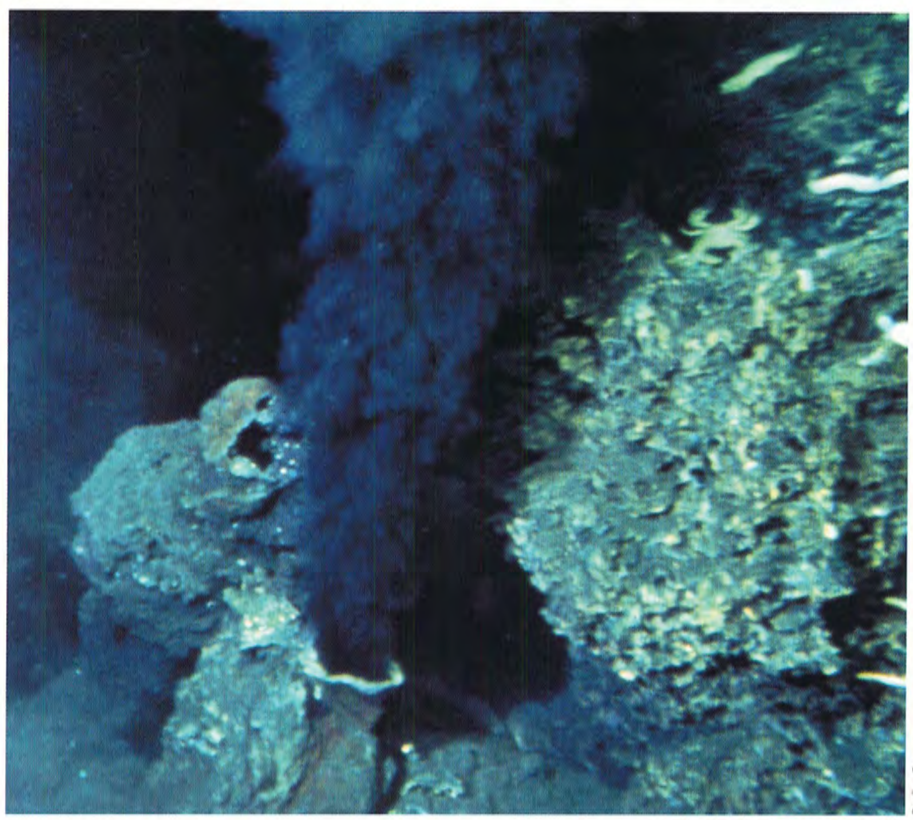
"Protozoa consume bacteria and, in turn, are consumed by larger organisms, so they transfer energy and nutrients up the food chain," he said. "They are also sloppy eaters, and they leave or excrete into the water dissolved, partially digested bits of bacteria—organic or inorganic materials that are used by other microbes."

Atkins looked for protozoa in vent fluid samples collected by WHOI's submersible *Alvin*. He expected to find new species that were adapted only to the unusual hot, high-pressure, high-sulfur conditions at the vents and would be found nowhere else on Earth. But to his great surprise, he mostly found the same species of protozoa that live in surface waters, throughout the ocean depths, along the coasts, and even in freshwater lakes.

"That realization led to a new hy-

Tom Kleindinst

WHOI graduate student Michael Atkins undertook the first-ever survey to explore what kinds of single-celled protists live near deep-sea hydrothermal vents (below). Among his discoveries was *Ancyromonas* (opposite), which may turn out to be a common ancestor from which animals and fungi first branched out from unicellular life.



Dudley Foster

What happened at the crucial evolutionary juncture when unicellular life branched into multicellular life?

Ancyromonas

pothesis: that these organisms are ubiquitous because they have the ability to adapt to any conditions they encounter," Atkins said.

He tested the theory in a series of laboratory experiments that exposed many types of deep-sea and shallow-water protozoa to the high-pressure and metal-rich conditions found at vents.

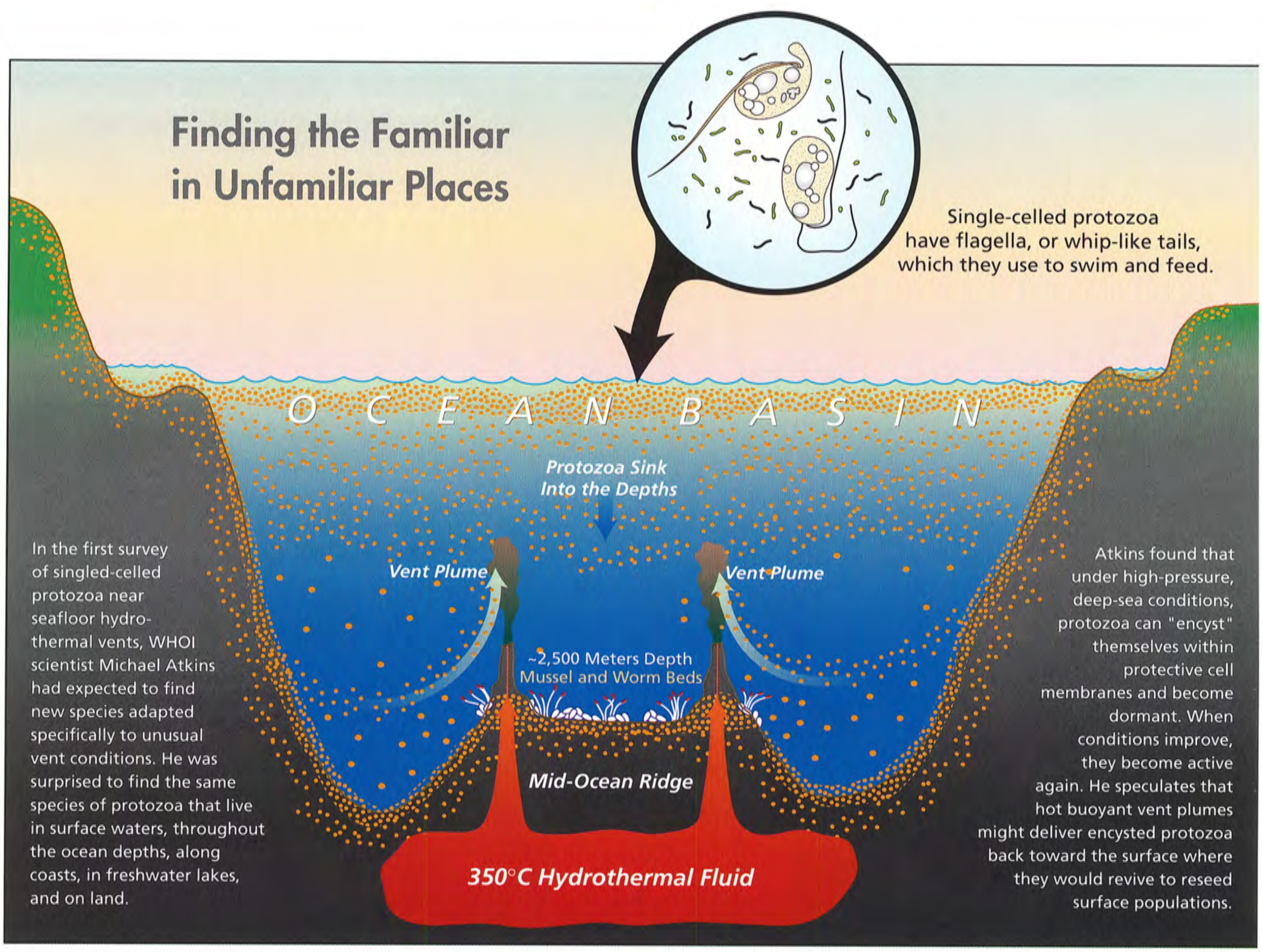
He was once again surprised to find no significant differences between deep-sea protozoa and those that live in shallow waters. All tolerated metal-rich fluids that would kill other life. He discovered that under high pressure, the protists "encyst"—that is, they draw in their flagella, enclose themselves within protective cell membranes, and become dormant. When Atkins reduced the pressure, the protists revived to become swimming, active participants in the food chain again.

"The findings offer an interesting theory to ponder," he said. "Perhaps vent plumes can transfer encysted stocks of protozoa to higher levels in the water column, where the pressure is reduced and the cysts break down and the protists revive. This reversible encystment could be a mechanism to deliver protozoa back up to reseed populations that might have been decimated by adverse conditions at the surface. It would be hard and complex to prove, but if it's true, it would have a large and important ecological significance."

In the course of his research, Atkins used emerging molecular techniques to look for genetic differences among protozoa that are often impossible to distinguish by examining their physiology. That's when he found *Ancyromonas*. Excited by the discovery, the National Science Foundation awarded Atkins a two-year postdoctoral fellowship to explore more fully its ancestral position in the tree of life. He will work with scientists at WHOI and the Marine Biological Laboratory in Woods Hole.

"It's intriguing that this little guy could be the early ancestor of multicellular life in animals and fungi," he said. "If we can pin that down, *Ancyromonas* will be very widely studied and will give us insights into where we came from and how we evolved to where we are now." ■

Three generations of WHOI's marine microbiology laboratory, spearheaded by the late Holger Jannasch, convene on the stern of R/V *Oceanus* near Cape Cod in 1996. Jannasch's last postdoctoral student, Andreas Teske (kneeling at right), was advisor to graduate student Michael Atkins (standing far left). In between them in the front row from left to right are: Italian student Constantino Vetriani, Jannasch, WHOI Senior Research Associate Stephen Molyneaux, and German student Christian Knoblauch. In the second row, from left to right, are: WHOI Oceanographer Emeritus George Hampson, WHOI Senior Research Specialist Carl Wirsen, and Steve Aubrey of Aubrey Consulting, Inc.



Jack Cook

Scientists Have Evolutionary Lines, Too.

Hydrothermal vents were discovered only in 1977, and ever since, WHOI scientists Holger Jannasch, Carl Wirsen, and others have pioneered explorations of the previously unknown microbial life that thrives in the deep sea.

"As an undergraduate, I had read about them," said Michael Atkins. "They were my heroes."

Atkins spent a summer as an undergraduate fellow at WHOI, and was hooked. He signed on as a graduate student and joined the lab that Jannasch led until his death in 1998.

"WHOI had the reputation for doing superb work on microbes in extreme environments and had all the tools," he said. "It's nice, for example, to have *Alvin* in your stable.

"I used to talk for hours with Holger, and Carl is a master of designing experimental methods," said Atkins, who earned his Ph.D. in biological oceanography in June for research that included the first-ever survey of single-celled protists around vents. "The ability to be at this institution and to interact with these people, and with my advisors, Craig Taylor and Andreas Teske, has been invaluable. Craig was Holger's first postdoctoral student and Andreas his last."

This laboratory, like the microbes it studies, has evolutionary lines—Atkins represents the third generation. ■

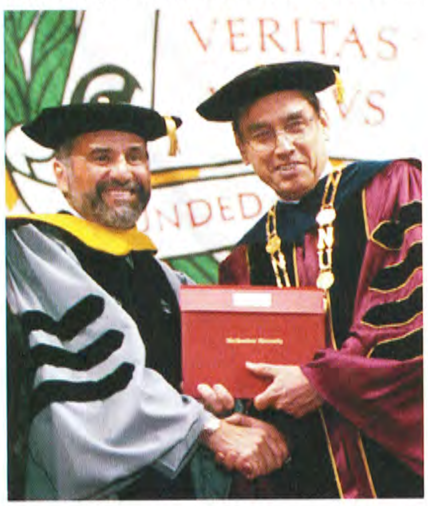
Tom Kleindinst

Russ Davis Receives Stommel Medal

Russ E. Davis of the Scripps Institution of Oceanography (left) received the prestigious Henry Stommel Medal in Oceanography, from Jim Moltz, Chairman of WHOI's Board of Trustees, in June. WHOI bestows the award to honor Stommel, the renowned WHOI oceanographer who established modern concepts of ocean circulation. Davis was cited for "his pioneering development of autonomous floats and their use to determine the ocean circulation." Davis, a long-time colleague of Stommel's, received a gold medal and $10,000—which he promptly and generously donated to help endow the recently established Henry Stommel Visiting Scholars Program at WHOI.

Gagosian Awarded Two Honorary Degrees

WHOI Director Bob Gagosian received two honorary doctor of science degrees this June from Northeastern University in Boston and from Southampton College of Long Island University. "As a scientist, you have raised our awareness of the endlessly fascinating interfaces between the oceans, the atmosphere, and the earth," his Southampton degree citation reads. "At the helm of Woods Hole, you are directing the study of ocean surfaces with *Atlantis*, and you are probing the seas' hidden depths with *Alvin*. We thank you for teaching us that our precious oceans cannot be treated as isolated components of this fragile planet." Above, Gagosian receives his degree from Northeastern President Richard Freeland.



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Tom Kleindinst

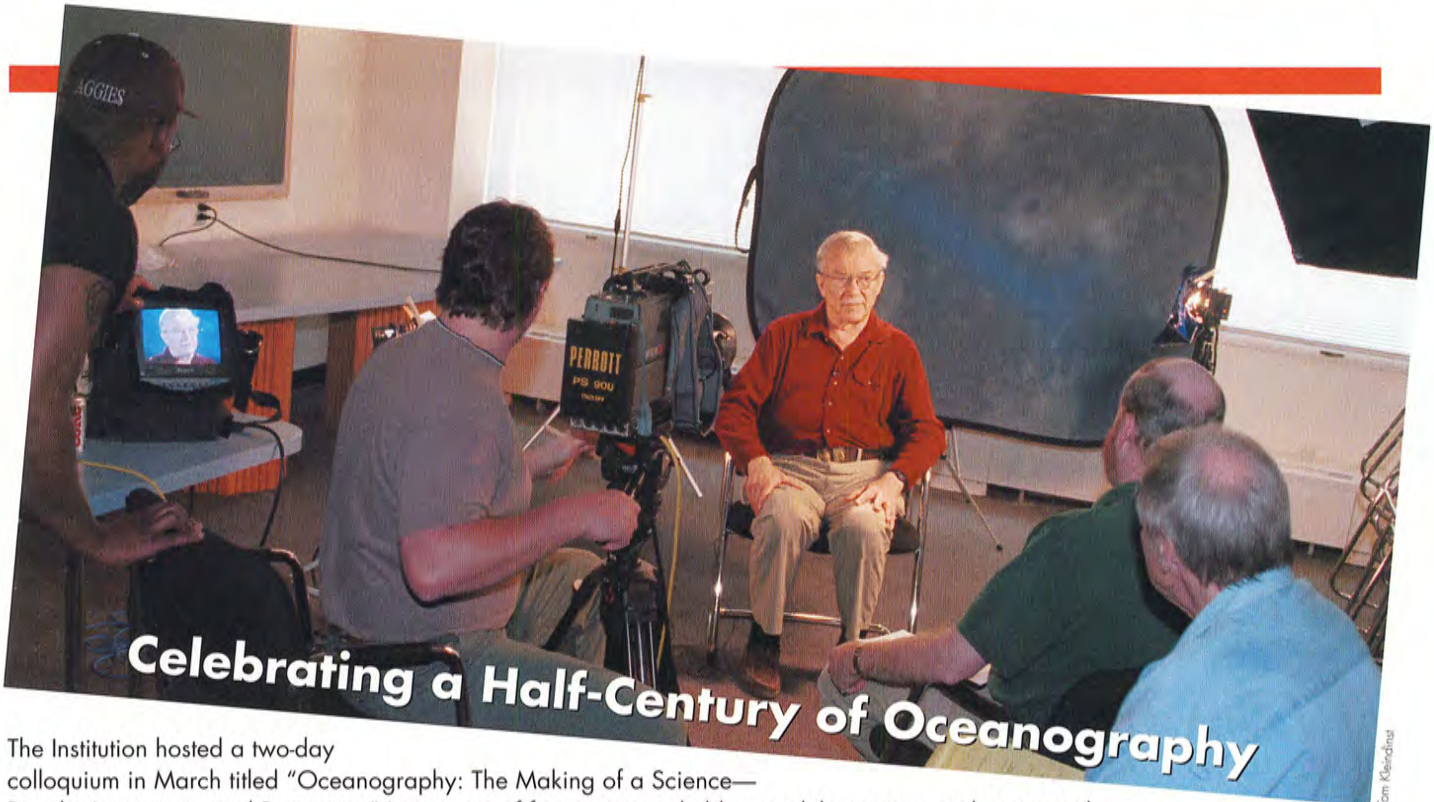
Newly Minted Oceanographers

Nineteen MIT/WHOI Joint Program graduate students assembled for graduation ceremonies at Woods Hole in June—led by Sheri White, who holds the traditional ship's belaying pin (the Joint Program's nautical equivalent of the academic mace used in commencement processions). Rear Admiral Jay Cohen, newly named Chief of Naval Research, who earned an Ocean Engineering master's degree from the Joint Program in 1972, gave the commencement address.

Tom Kleindinst

WHOI Briefs Senators

Three US senators came to WHOI in March to get special briefings from several WHOI scientists on the current scientific knowledge on climate change and fisheries. "Public policy has to be based on sound science; that's why all three of us are here," said Sen. Larry Craig (R-Idaho) who discusses issues with WHOI Director Bob Gagosian (left). Craig is chair of the Senate Republican Policy Committee, which helps develop policy positions for Senate Republicans, and a member of Energy and Natural Resources and Appropriations committees. Joining him were Robert Smith (R-New Hampshire) chairman of the Environmental and Public Works Committee, and Lincoln Chafee (R-Rhode Island) a member of that committee.



Celebrating a Half-Century of Oceanography

Tom Kleindinst

The Institution hosted a two-day colloquium in March titled "Oceanography: The Making of a Science—People, Institutions, and Discovery." It was one of five meetings, held around the country and sponsored by the Office of Naval Research and the H. John Heinz III Center for Science, Economics and the Environment, to celebrate accomplishments in understanding the oceans in the last half of the 20th century. The program featured several WHOI staff along with colleagues from other institutions. It also collected videotaped oral histories, including the session pictured above with Physical Oceanographer Emeritus Nick Fofonoff, who was instrumental in the ONR-sponsored development of mooring technology.

$5M Gift Enables WHOI to Build a "Dream" Ship

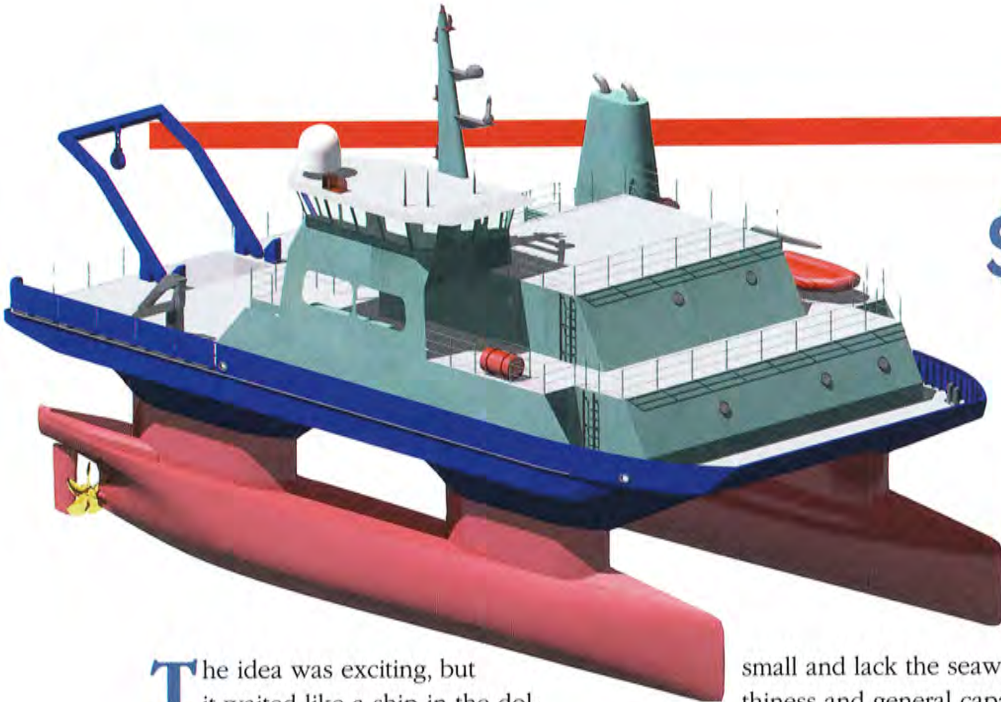
Continued from page 20

have a large working deck, 500 square feet of laboratory space, and built-in quietness for conducting high-quality acoustic measurements. Operating in bays and estuaries from the Gulf of Maine to Long Island Sound and offshore on Georges Bank, the Gulf Stream, or continental shelf, the SWATH vessel will be perfectly suited for research on red tides, beach erosion, coastal pollution, and declining fisheries.

"Going to sea is critical to making the observations necessary to advance our understanding of the coastal environment," said Mrs. Montgomery, who lives on the southeastern Massachusetts coast. "Fewer ships today provide essential access to the sea for scientists and students, our future scientists. More and more people are moving to the coast, and, as a society increasingly dependent on the sea, we must use the coastal zone wisely. I want future generations to be able to enjoy our coast as much as I have."

"We are extremely grateful for Topsy Montgomery's support of this project and for her long-term commitment to students and to coastal research in general," WHOI Director Bob Gagosian said. "She is a visionary whose love of the New England coast will be shared with countless students and scientists for decades to come. Her contributions to this Institution are allowing us to advance coastal oceanography in a major way. Several years ago her commitment to coastal research was reflected in a $5 million grant to the Gratia Houghton Rinehart Coastal Research Center. Her new gift will add immensely to our capabilities to work safely and productively at sea, especially in coastal waters." ■

A $5 million gift from Gratia "Topsy" Rinehart Montgomery (above, with her dog Sashay) will allow WHOI to fulfill a dream of building an all-season coastal research vessel.



$5M Gift Enables WHOI to Build A "Dream" Ship

The idea was exciting, but it waited like a ship in the doldrums—until Gratia "Topsy" Rinehart Montgomery arrived to put wind in the sails.

Her $5 million gift enables WHOI to move full speed ahead with a long-sought dream: building an economical vessel that can accommodate a wide range of research operations, in the open oceans and in coastal waters as shallow as 18 feet, and in all seasons—even nasty New England winters.

"This wonderful gift helps us solve one of the greatest challenges facing researchers in the coastal zone—keeping alive the dream of suitable research vessels from which to work," said WHOI Associate Director for Marine Operations Richard Pittenger. "Most are small and lack the seaworthiness and general capabilities to accomplish essential scientific tasks, particularly in the long winter season when routine operations can be very difficult and often dangerous. Larger ships are too expensive to operate and are usually assigned by federal agencies to work in more distant waters, making them unavailable for rapid response to study environmental events like major fish kills, hurricanes, and ship or barge groundings."

Previous donations enabled WHOI to design an ideal coastal research ship—with the hope of actually building it one day. It is a SWATH (Small-Waterplane-Area Twin Hull) vessel with two semi-submerged hulls that do not follow surface wave motion like regular mono- or single-hull ships. Thin struts supporting an above-water platform have small cross sections, or waterplanes, that significantly reduce the pitch and roll that make many types of research difficult or impossible on standard research vessels. The 105-foot SWATH will accommodate an economical crew of six, as well as 10 scientists. It will

Continued on page 19

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