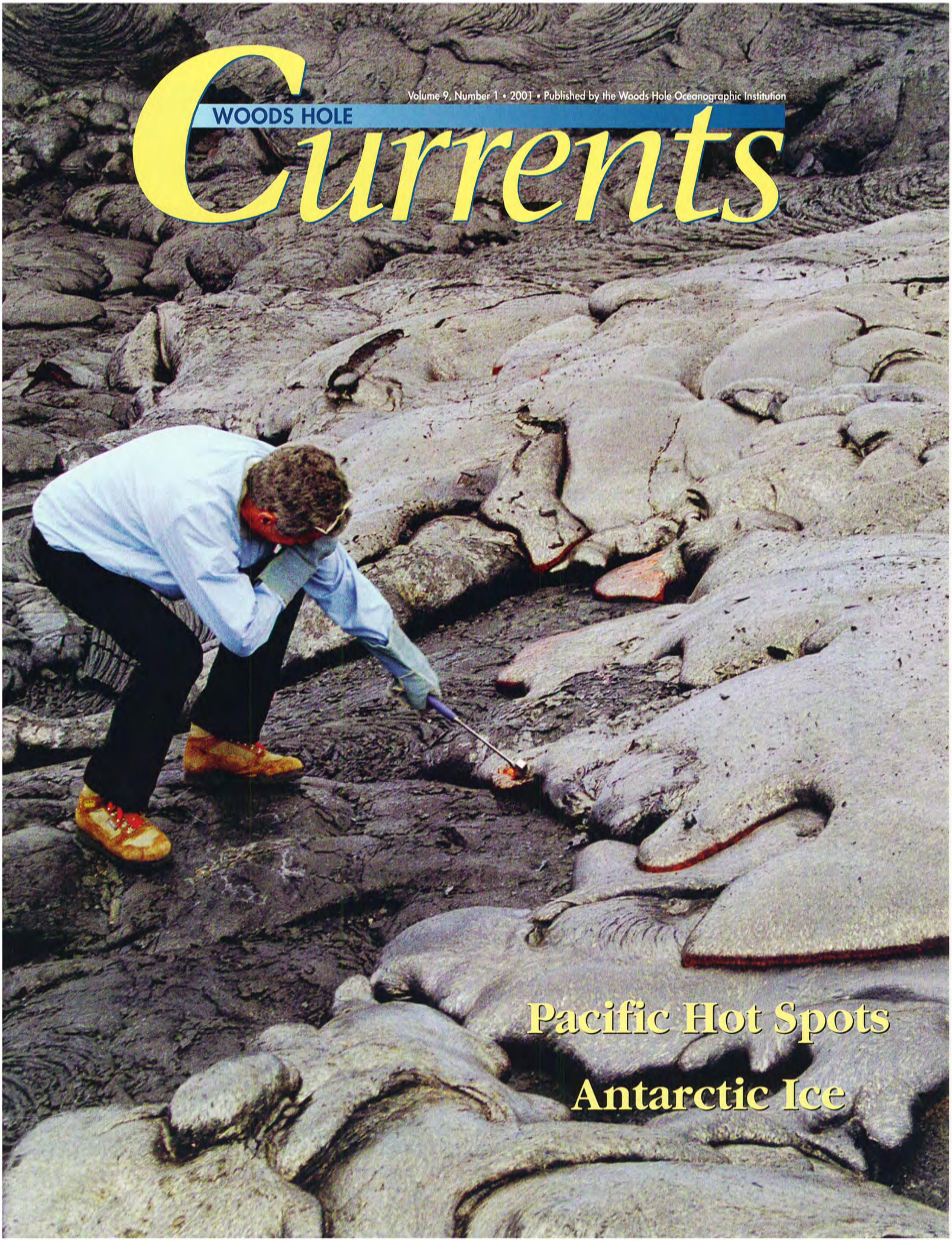

WOODS HOLE Currents

Volume 9, Number 1 • 2001 • Published by the Woods Hole Oceanographic Institution

Pacific Hot Spots

Antarctic Ice

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WOODS HOLE Currents

COVER: Shielding his face with an asbestos glove, WHOI Senior Scientist Stan Hart uses a rock hammer to collect freshly erupted lava samples from Kilauea volcano in Hawaii. The lava reaches more than 1,850°F. Photo by Albrecht W. Hofmann.

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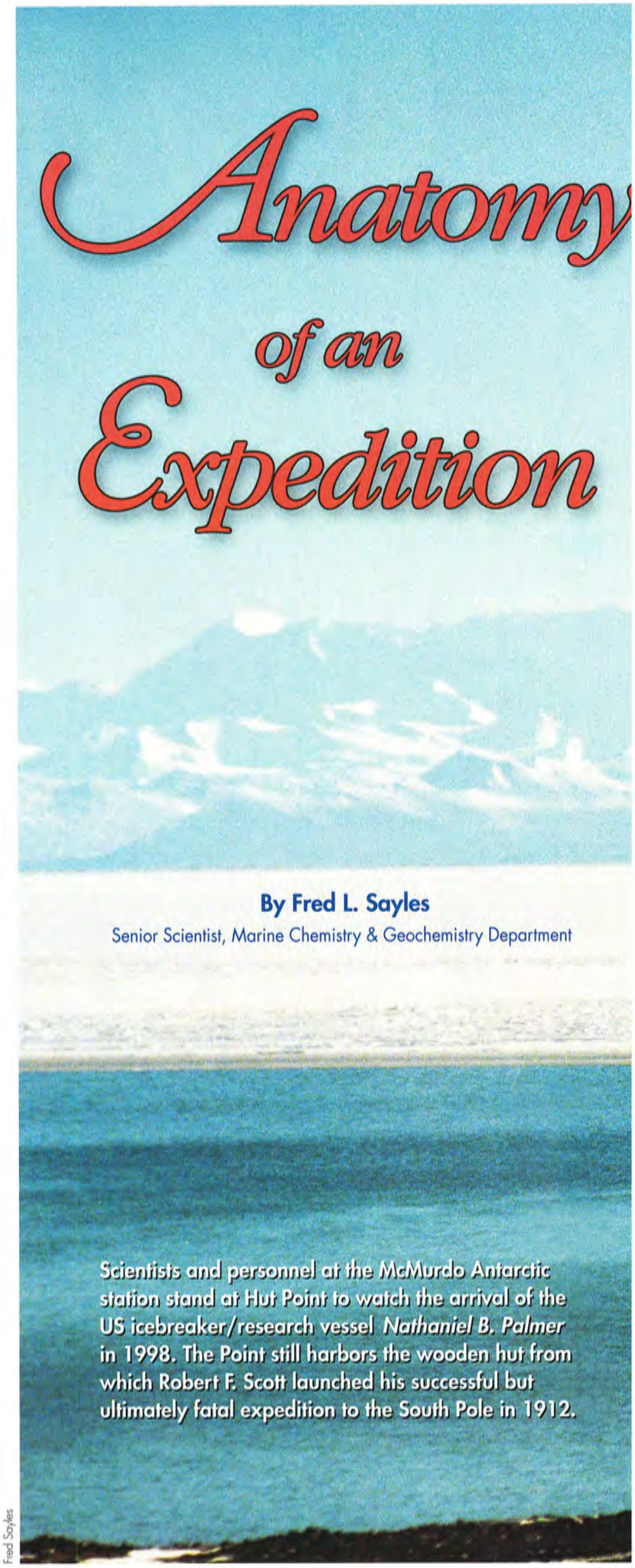
THE WOODS HOLE OCEANOGRAPHIC INSTITUTION is a private, independent, not-for-profit corporation dedicated to research and higher education at the frontiers of ocean science. WHOI's primary mission is to develop and communicate a basic understanding of how the oceans function and interact with the earth 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.



Fred Sayles

Anatomy of an Expedition

By Fred L. Sayles
Senior Scientist, Marine Chemistry & Geochemistry Department

Scientists and personnel at the McMurdo Antarctic station stand at Hut Point to watch the arrival of the US icebreaker/research vessel *Nathaniel B. Palmer* in 1998. The Point still harbors the wooden hut from which Robert F. Scott launched his successful but ultimately fatal expedition to the South Pole in 1912.

On a journey to the most remote continent on Earth and across its roughest ocean, I anticipated the experience of a lifetime—one that has included more than 30 years of research at sea. I was not disappointed.

In the late winter of 1998, we carried out an expedition through one of our planet's most inhospitable regions—working our way from Antarctica some 2,500 miles across the southern ocean to New Zealand, aboard the icebreaker *Nathaniel B. Palmer*. This is an account of our adventures.

The big picture and the tiny target

Our expedition's broad focus was the inner workings of the great ocean that surrounds Antarctica. More particularly, we sought to learn how the ocean absorbs carbon from the atmosphere, transfers it to the depths, and buries it in the seafloor.

The central protagonists of this so-called "biogeochemical pump" are microorganisms at the sea surface, which take carbon dioxide from the atmosphere and convert it via photosynthesis into the organic carbon of their cells. When the microorganisms subsequently die, or are consumed and excreted, some portion of that carbon sinks to the seafloor, where it is buried.

As we confront the threat of global warming, understanding the pump is important because it could extract huge amounts of excess heat-trapping carbon dioxide from our atmosphere. A key clue lies in the tiny interface where seawater meets seafloor—where critical chemical reactions determine how much carbon dissolves back into the water and how much remains in the sediments. I focus on that piece of the puzzle.

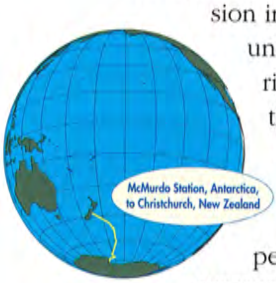
Joanne Goudreau

With their plane to Antarctica delayed, expedition members wait on an airport runway, stripping off Extreme Cold Weather gear in the 80° heat of the New Zealand summer.

A one-ton WHIMP

All seagoing expeditions require extensive planning and preparations that often begin years in advance. In a way, we started preparing for this trip in the 1980s when we first began to develop an instrument that could precisely extract water samples from upper layers of seafloor sediments—at intervals as fine as one millimeter.

Frankly, it's hard to design a precision instrument that works under the unusual and rigorous conditions in the ocean and at the seafloor. Materials behave differently under 7,000 pounds per square inch of pressure. Often, the smaller the samples you want, the bigger and more complex the instrument you need to get them.



The tool we ultimately built is a one-ton, 11-foot-tall tripod device that lands on seafloor muds and inserts probes into the sediments. Much like a syringe, it extracts water samples at various depths, ranging from less than an inch to two feet. We called it the Woods Hole Interstitial Marine Probe, or WHIMP.

Nantucket road test

SUMMER 1997—We anticipated little opportunity to troubleshoot and modify the WHIMP in an environment where snow, ice, and 20-foot seas would be constant companions on deck. Since no local test vessel existed that was big enough to put the WHIMP through some paces, we organized a five-day cruise aboard R/V *Oceanus* off Nantucket.

Testing equipment is critical. Things may work like a charm on deck, and then you can get the dickens beat out of you on the seafloor. As it turned out, we found two design flaws that would have been terminal in the Antarctic.

Turning a whale into a tricycle

FALL 1997—We spent the months following the *Oceanus* cruise making essential modifications to the WHIMP and assembling and packing five tons of equipment. This is a major undertaking under normal circumstances, but shipping to Antarctica hardly rates as normal.

Our equipment had to be trucked in containers to California, where cargo was consolidated and loaded by the Navy onto *Greenwave*, a supply ship that makes annual voyages to Antarctica. Because interior storage is extremely limited in Antarctica, we were instructed to put equipment that could not be frozen in boxes painted black.

The WHIMP created some challenges. In many respects, it is akin to a whale—robust and extremely functional in water, but a fish out of water on land. The WHIMP was too tall to fit into a standard container. WHOI machinist Charlie Peters, who (before his death in September 1997) was instrumental in building the WHIMP, found the solution by tipping it onto its side and supporting it on three wheels. This, in essence, created a one-ton, 7.5-foot-tall tricycle that we could maneuver in and out of shipping containers without using forklifts, whose rough movements jeopardized the WHIMP's precision components.

In November we were ecstatic to see our 18-wheeler pull away from the WHOI loading dock with our equipment. Seeing it halfway around the world in February seemed quite soon enough.

Fred Sayles

Joanne Goudreau, Senior Research Assistant (right), and Cal Eck, Research Engineer, reach McMurdo Playhouse, where the WHIMP was stored before it was loaded aboard *Palmer*.

Past the point of no return

February 11 to 16, 1998—A 24-hour trip took us from the northern winter to late summer in New Zealand. The flowering plants of Christchurch provided pleasant contrast to the Cape Cod winter we left behind—as well as what awaited us in the Antarctic "summer" (a misnomer if ever there was one). Over three days, we received the required Antarctic indoctrination and safety lectures and were issued Extreme Cold Weather (ECW) gear.

Our flight was one of the last scheduled into Antarctica before the nine-month "winter over" started. Since we would have no chance to dress on the cargo plane, we were required to wear our full ECW gear—in case of an unintentional landing in Antarctica and to provide some warmth in the unheated aircraft. Human and regular cargo are treated similarly, and we would be packed in with the boxes.

We were bused to our waiting C-130 plane, but it was being worked on by mechanics. So we spread out on the tarmac, fully dressed for sub-zero Antarctica in bright orange survival suits and white snowpack boots. It was 80°, and the airfield provided little shade. Two hours later, we had shed our ECW gear and the mechanics had given up on our plane. But the Kiwis stepped into the breach, issued us earplugs, and put us aboard a New Zealand Air Force C-130.

We were packed onto strap benches with our fellow travelers for an eight-hour flight that seemed much longer. The planes cannot carry enough fuel for a roundtrip and often turn back this late in the season in the face of storms. But fortune smiled. A snowstorm had indeed developed during our flight to McMurdo Station, the US Antarctic research base—but not until after we reached "the point of no return." We had no choice but to fly on, which spared us a repeat of the whole muster process.


Joanne Goudreau

Senior Scientist Fred Sayles (right) and Engineering Assistant Larry Costello prepare to load the WHIMP aboard *Palmer* in Antarctica.

Welcome to the Hotel California

February 16 to 24—Landing on McMurdo's ice runway in a heavy snow squall was a fitting introduction to summer in Antarctica. It snowed frequently during our stay. McMurdo reminded me of pictures of early 20th-century mining camps in Alaska: rows of quonset huts and cargo containers not very neatly placed, and heavy equipment everywhere—some operable, some derelict. Snowdrifts piled against or over anything standing out for more than a few days, driven by nearly incessant strong winds. All road surfaces were made of snowpack.

We were assigned to the "Hotel California," a standard McMurdo dormitory. I bunked with three pleasant youngsters some 40 years my junior. They excitedly awaited their flight out before the imminent onset of winter and were completely averse to sleep. It had been almost four decades since my last dorm stint. The strong smell of stale beer in the dorm lounge stirred

Sayles (foreground) and *Palmer* crew members deploy the WHIMP, which lands on the seafloor to collect sediment samples.

ancient memories of fraternity houses.

At this time of year, the sun worked its way around the horizon, providing light throughout the day. On bright days the Antarctic is an awesome landscape of stark yet beautiful contrasts. Brilliant white dominates, but is broken by the black of the volcanic rock that surrounds much of McMurdo. What little color there is comes from the light blue sky and reflections of sky in a few slivers of open water in the ice. All horizons, near and far, are mountainous. The air is so dry and clear that distances are very deceptive. The Antarctic explorer Robert Scott once set off with dog sleds to cross the Ross Ice Shelf to the Royal Society Range, which he believed was less than 30 miles away. It is about twice that far.

This difficult environment appeals to only the most dedicated and resourceful. The last plane out of Antarctica before winter left during our stay, and we mingled with the "winter-overs" who would remain at McMurdo for nine months, including four in darkness. Most were young, with an unmistakable air of pioneers living on the edge. McMurdo is definitely the edge of civilization, far from help, in time and distance. Everyone we dealt with was determined to meet our needs. Rarely did things go as planned, but with a large measure of ingenuity they always got done.

The best-laid plans

The WHIMP awaited us at a quonset building called McMurdo Playhouse—the only place with heat and a door high enough for the WHIMP to fit through. But finding the rest of our equipment proved challenging.

In California, the Navy had repacked all gear bound for Antarctica. Our boxes ended up liberally distributed throughout five 40-foot cargo containers, which were spread over a square mile of snowdrifts and mostly buried.

We used a frontloader to dig a road through five feet of snow and cleared a space to offload boxes. This offloading space tended to refill with snow at surprising speed. Boxes typically weighed 250 to 350 pounds, but we had to haul them by hand because forklifts could not make it through the snow.

We also discovered that our carefully prepared black boxes ("Do Not Freeze") were interspersed throughout the unheated vans. We grabbed as many black boxes as possible to store in the warm Playhouse and moved the remaining equipment directly to the dock to await our icebreaker. There we found about 20 boxes offloaded from *Greenwave* two weeks earlier and left to be covered by drifts.

The McMurdo staff was as helpful and cooperative as one could wish—even though some of them nervously kept an eye on nearby cargo planes. They didn't want to miss the last flight out of Antarctica and have to winter over.

Nathaniel B. Palmer arrived a day early and we put our gear aboard, often in a blinding snow.

In the ice

February 25 to March 6—In a heavy snow, fittingly, we departed McMurdo and broke through rapidly forming ice toward the center of the Ross Sea. *Palmer*'s mess deck at the bow is not far above the waterline, and the sound of breaking through ice was absolutely deafening and precluded any mealtime conversation.

Through new ice, two to three feet thick, we picked our way at six to eight knots, but slowed when it reached five feet thick. The entire ship rumbled as three-foot blocks of ice tumbled along the sides of the ship and often stacked up at the bow wedge.

The early sea ice cover seemed to bode ill for our primary task in the Ross Sea: retrieving three moorings set the year before. But Captain Joe Borowski deftly opened the ice over the mooring locations, then moved updrift to fend off the ice as the moorings surfaced and were recovered. He only became edgy when we scientists futzed around with the release signals. Once he had the ice open, he wanted the moorings up. Had they come up under the ice they would almost certainly be lost, but our recovery record was perfect.

Along with the early ice came unusually cold temperatures. During our 10 days in the ice it remained at 5°F. Despite our best-laid plans, this was too cold for WHIMP. We had used antifreeze to prepare the WHIMP's hydraulics to work in cold temperatures, but our seafloor water samples would freeze as soon as they hit the air and corrupt any chemistry we wanted to examine. Further, as water turned to ice, it would expand and damage our apparatus. The WHIMP remained in a well-heated helicopter hangar during our entire stay in the ice.

We took the opportunity to observe our spectacular surroundings. Sea ice stretched from horizon to horizon, broken by huge tabular icebergs released from Antarctica's ice shelves. At times we counted as many as 80 bergs surrounding us. Emperor penguins, the most anthropomorphic wildlife I have ever seen, appeared regularly. They seemed little concerned with what to them must have been a gigantic and strangely colored (orange in a sea of white) object. They watched our approach, at first waddling and then tobogganing away on their bellies, always in single file.

Across the southern ocean

March 6 to April 2—Once out of the ice, the air temperature rose to a balmy 32°F, well-suited to WHIMP's tolerance range. The seas rose along with the temperature, and we experienced the southern ocean's just reputation as a very rough body of water. Over 26 days we took samples and measurements at eight locations. We recovered moorings at five of them and did seafloor coring, water sampling, and WHIMP deployments at all eight.

Anti-cyclonic low pressure cells, many hundreds of miles in diameter, barreled across our path nearly every 36 hours. Winds from these storms typically topped 50 knots. On several occasions winds exceeded hurricane force. Back home, everyone runs from storms like these. In the southern ocean, there was no place to hide from them.

A good day was one during which the winds did not reach 40 knots. For the most part, we could work in winds up to about 45 knots, but only with a good deal of angst. I found it particularly unappealing to look up at wave tops. Sustained winds above 45 knots led us to secure the decks and ride out the blow.

The ship's performance under these trying conditions was nothing short of remarkable. We held station to within 50 meters using the Global Positioning Satellite system in winds of 40 knots. We launched a variety of large equipment, and the mooring crew recovered five moorings averaging 4,000 meters in length and containing five sediment traps and other instrumentation, without mishap. The variety and complexity of operations successfully carried out under extreme conditions is a testament to the skill and care of both the ship's personnel and the scientific parties. Indeed, had someone told me that we would need to work routinely with winds of 35 to 40 knots, I almost certainly would not have undertaken this trip.

As it turned out, the weather did not prevent us from achieving any scientific objectives. Given the difficulty of getting to and operating in this part of the world, we were grateful to come away with as much information as we did. It was a very good cruise.

As for the open ocean, its raw power was impressive. The sky was gray and so was the water, unless it was whipped to a white froth by the latest storm. It was a long and trying experience. With the recovery of the last mooring at 53°S, it was most definitely a relief to head for balmy autumn in Christchurch. ■

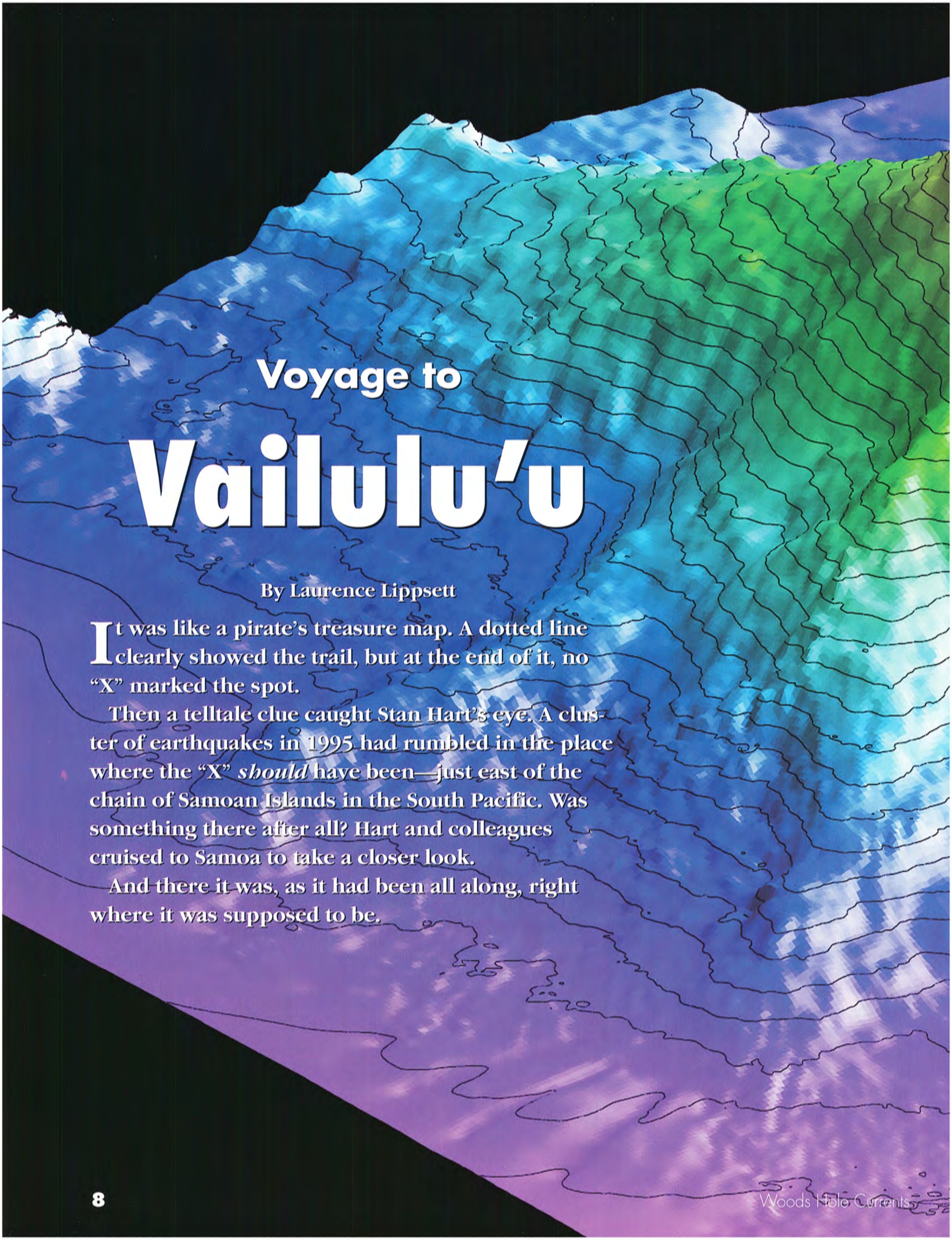
SeaLab: ANTARCTICA

Eight WHOI scientists and staff will participate in a 44-day Antarctic voyage aboard the icebreaker *Nathaniel B. Palmer* that will be documented on the National Geographic Society Web site:

www.nationalgeographic.com/sealab/antarctica.

Beginning April 23, a nationalgeographic.com correspondent will send written and audio dispatches, as well as still and video images, from the field. The NSF-sponsored expedition is the first to study the southern ocean's ecosystem during the nearly sunless austral winter. It will investigate the distribution and abundance of marine life in the region—ranging from krill (the microscopic marine animals that are the base of the food chain) to krill-eating fish, penguins, seals, and whales.

NATIONAL GEOGRAPHIC .COM



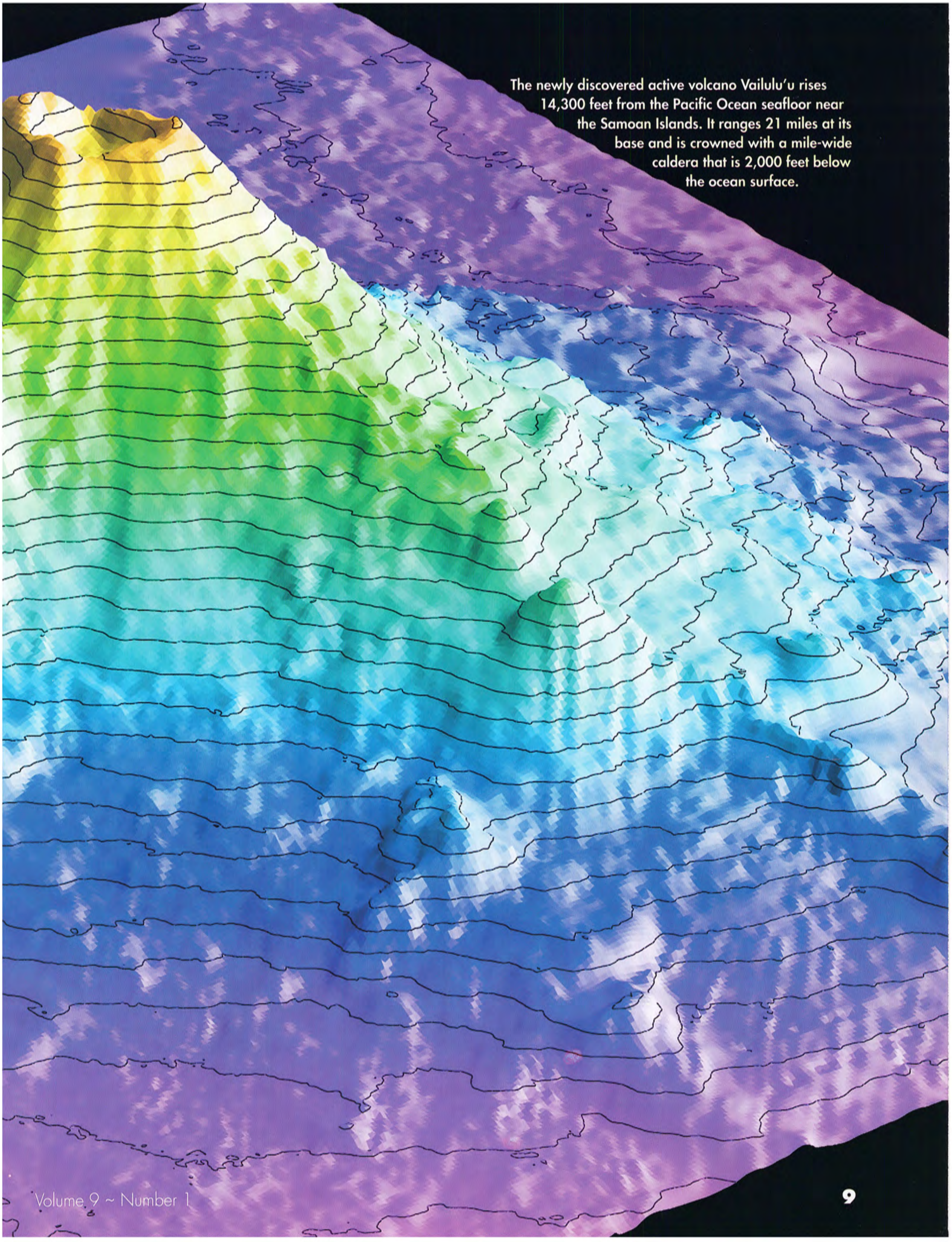
Voyage to Vailulu'u

By Laurence Lippsett

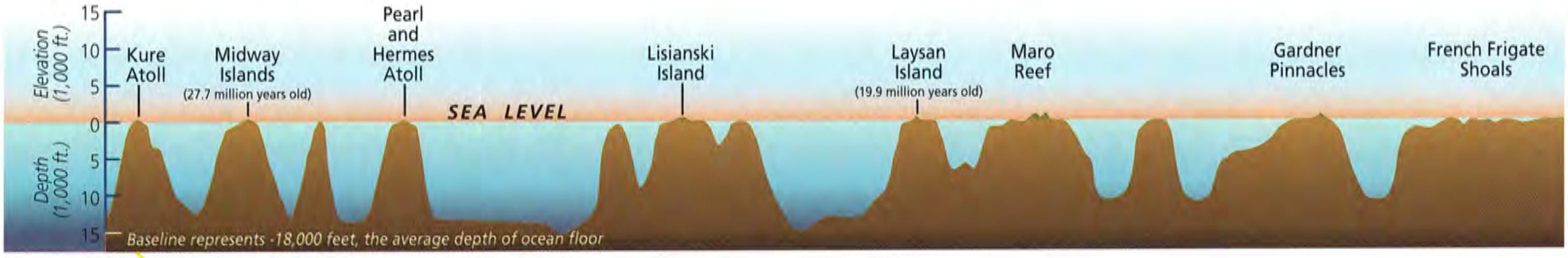
It was like a pirate's treasure map. A dotted line clearly showed the trail, but at the end of it, no "X" marked the spot.

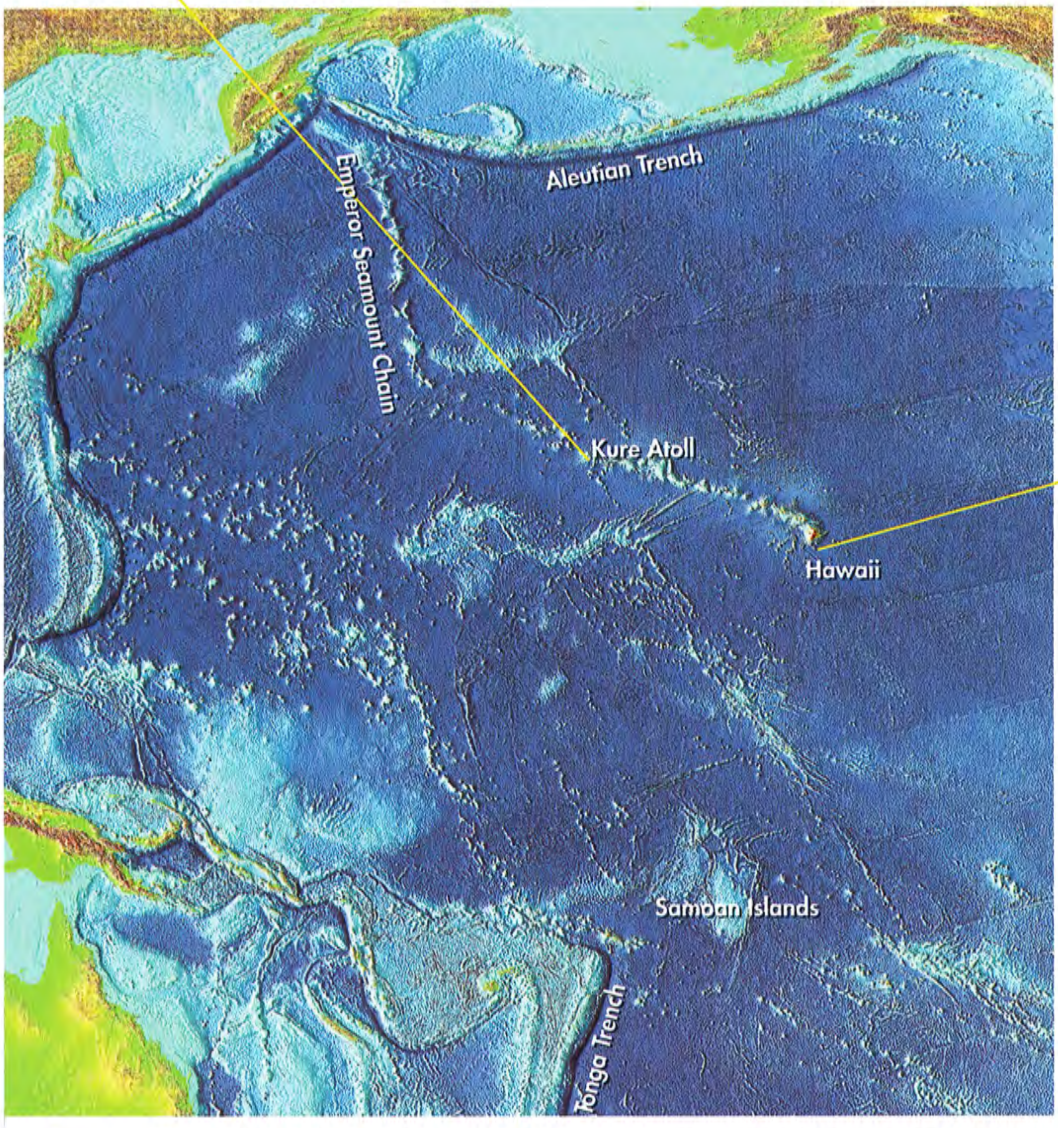
Then a telltale clue caught Stan Hart's eye. A cluster of earthquakes in 1995 had rumbled in the place where the "X" *should* have been—just east of the chain of Samoan Islands in the South Pacific. Was something there after all? Hart and colleagues cruised to Samoa to take a closer look.

And there it was, as it had been all along, right where it was supposed to be.



The newly discovered active volcano Vailulu'u rises 14,300 feet from the Pacific Ocean seafloor near the Samoan Islands. It ranges 21 miles at its base and is crowned with a mile-wide caldera that is 2,000 feet below the ocean surface.





Over millions of years, the Pacific Plate moved northward and later westward over the top of the Hawaiian hot spot, carrying away islands formed at the hot spot. The result is a trail of progressively older islands and re-submerged, now-extinct seamounts, extending from the young Hawaiian islands to the older Emperor Seamount Chain.

About 27 miles east of Ta'u, the easternmost Samoan island, Hart and company found a 14,300-foot active, submerged volcano. In size and appearance, it resembled Mount Fuji in Japan or Mount Rainier in Washington State (without the snow, of course). But it had remained hidden—buried beneath 2,000 feet of ocean. Sometime in the next millennium, however, the newly named volcano of Vailulu'u will rise above the waves and become the next island in the Samoan chain.

"It just blew us away," said Hart, a Senior Scientist at Woods Hole Oceanographic Institution. He and co-chief scientist Hubert Staudigel of the Scripps Institution of Oceanography had entertained the possibility of finding a modest volcano. Instead, they found a spectacular volcano—one that ranged 21 miles across the seafloor at its base, rose $2\frac{1}{2}$ miles high, and peaked with an elegant cone-shaped caldera more than a mile wide.

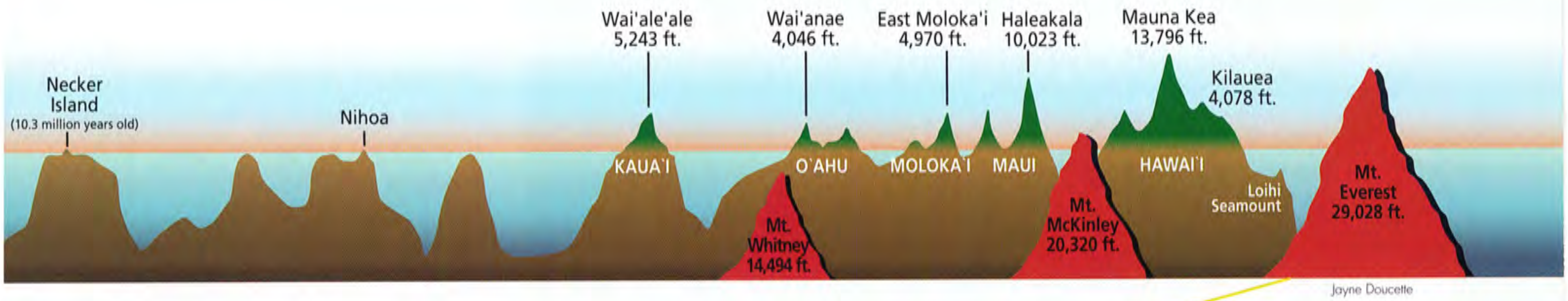
But what really makes Vailulu'u such a potential scientific gold mine is that it is no cold relic. On the contrary, it's truly a hot spot.

Hawaii, the classic hot spot

In geologic terms, a "hot spot" is a dot on Earth's face where a narrow plume of hot mantle rock rises from deep within the earth, melts, and bursts through the crust. Hot spots beneath oceans create undersea volcanoes that sometimes rise above the ocean surface to form islands.

Hot spots remain stationary, but above them, Earth's outer crustal plates move slowly but inexorably. Imagine moving a sheet of paper horizontally a few inches above a burning candle. Similar to the candle's flame, a hot spot leaves a scorched trail of volcanic islands on its overlying plate.

These island-volcanoes ride atop the migrating plate, at a speed of only about 3 inches per year—about the rate one's fingernails grow. But over millions of years, even 3 inches per year carries the islands hundreds of miles. As they retreat from the hot spot where they were born, the is-



lands progressively become less volcanically active. As they cool, they erode and may subside back beneath the waves to become extinct seamounts.

The Hawaiian Islands are the classic example. The big island of Hawaii emerged most recently. The Kilauea volcano on Hawaii is still very active, but the crust below the island has already begun to drift west of the hot spot. Just east of Hawaii, more squarely atop the hot spot, is the undersea volcano Loihi, whose erupting lava will eventually pile up above the ocean surface and extend the eastern end of the Big Island.

West of Hawaii, the islands are progressively farther from the hot spot and older. Beyond the oldest island, Kauai, the northwestern Hawaiian islands barely poke out of the surf. (Former President Bill Clinton recently declared them a coral reef sanctuary.) Still farther out are the Emperor Seamounts—former islands now in their submerged dotage. They create a dotted undersea trail that leads almost to Russia.

The enigmatic islands of Samoa

At first glance, Samoa also seemed like a classic hot spot chain that included (west to east) the islands of Savai'i, Upolu, Tutuila, Ofu, Olosega, and Ta'u. But both Savai'i and Ta'u had erupted this century. That violated the rule of diminishing volcanism as islands move away from a hot spot. The major conflict to the hot spot theory, however, was the apparent absence of an active volcano next in line, just east of Ta'u.

Lacking this "smoking gun," geologists sought another mechanism to explain the existence of the Samoan Islands. They noted that the islands aligned with the northern plate boundary of Tonga Trench, a vast slab of the Pacific Plate that is colliding with the neighboring Indo-Australian Plate and plunging beneath it. The downward pulling of the Pacific Plate, they said, stretched and bulged the plate. That created cracks and channels for underlying mantle rock to rise, melt, erupt, and form islands at the surface.

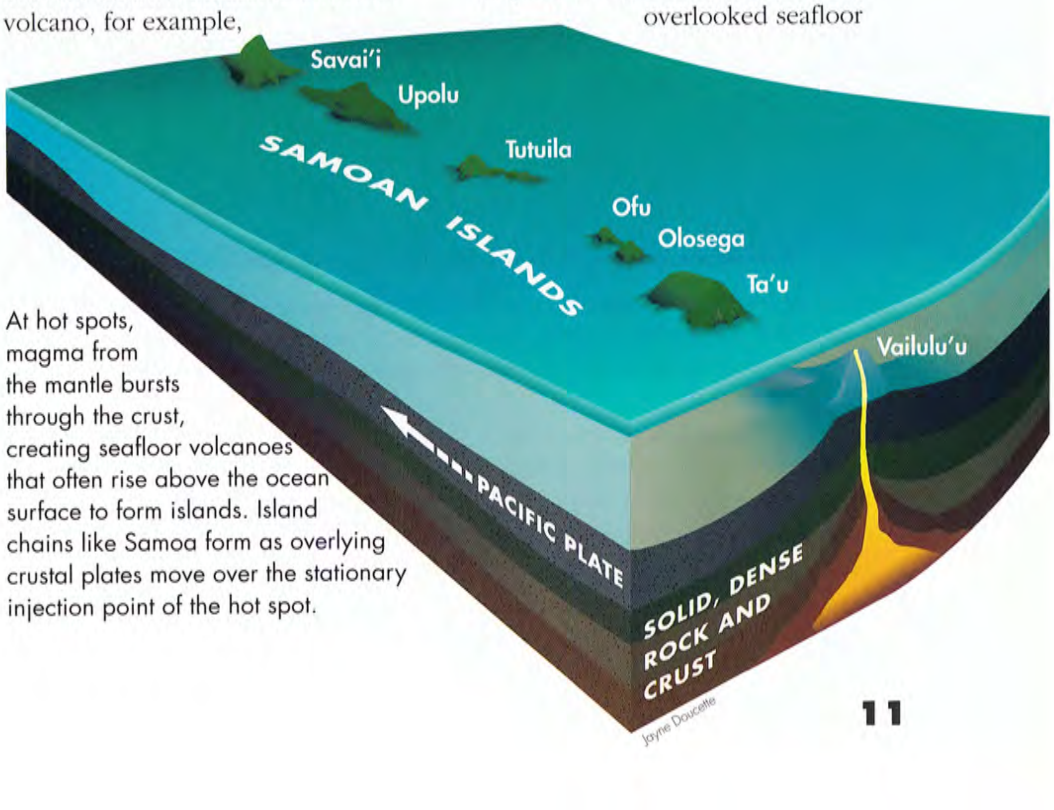
The dilemma remained unresolved. In lieu of an ambitious undersea search, Hart and MIT/WHOI Joint Program student Alberto Saal looked closely at seafloor maps created with data gathered by satellites. With extraordinary precision, the satellites can measure centimeter-scale differences in the height of the ocean's surface. These heights, in turn, reflect the gravitational pull of structures on the seafloor below. A massive undersea volcano, for example, exerts a gravitational pull that attracts water and creates a small but often measurable bulge in the sea surface above it.

Though satellites offer invaluable global coverage of oceans too vast to investigate ship by ship, their indirect view of the seafloor can't hope to provide the details of a direct look. In the case of Samoa, satellite data did not reveal anything noteworthy east of Ta'u.

Seismic screams

But a bit of scientific serendipity ensued. The satellite maps of the area that Saal retrieved also included data on any earth-shaking seismic events recorded in the region. These events are caused by earthquakes, undersea landslides, or volcanic eruptions.

The maps showed that a swarm of seismic events occurred in 1995 around what appeared in the satellite maps to be an unremarkable, easily overlooked seafloor



At hot spots, magma from the mantle bursts through the crust, creating seafloor volcanoes that often rise above the ocean surface to form islands. Island chains like Samoa form as overlying crustal plates move over the stationary injection point of the hot spot.

Stan Hart

A helicopter from the US Coast Guard's *Polar Star* deploys one of five ocean-bottom hydrophones to record sound waves generated by any earthquakes or eruptions near Vailulu'u. After a year on the job, the hydrophones were retrieved in March 2001.

bump off Ta'u. Digging deeper, Hart uncovered records of another similar swarm in the same area in 1973. It was almost as if the volcano, unseen in the dark depths, was screaming to be heard.

Heeding the seismic clarion, Hart assembled a team of scientists that included Staudigel of Scripps, Saal and Senior Scientist Mark Kurz from WHOI, and Hart's former graduate student Erik Hauri, now at Carnegie Institution of Washington. They persuaded the National Science Foundation to fund a cruise to Samoa in the spring of 1999. Aboard the Scripps research vessel *Melville*, detailed sonar mapping of the area revealed the true size and height of the volcano east of Ta'u and the stunning perfection of its summit caldera. The team also dredged lava rock samples, whose pristine glassy veneer and sulphurous odor offered clear evidence that the volcano may have erupted very recently.

Name that volcano

Hart and company raised a toast to their discovery and informally christened the new volcano Fa'afafine, a Samoan word that very loosely translated means "wolf in sheep's clothing."

"It seemed an appropriate name since the size of the volcano was a surprise and wasn't at all what it appeared to be on the available ocean floor maps of the area," Hart said.

No doubt, the exhilaration of discovery brought out the oceanographers' irreverent, swashbuckling sides. Less loosely translated, "fa'afafine" in Samoan means "transvestite." Clearly, the new volcano required a more fitting name.

Hart surveyed scientific literature for previous mentions of the new volcano. As it turned out, a man named Rockne Hart Johnson reported finding the volcano using a fathometer aboard a sailboat in 1975. But the discovery remained virtually unknown because he did not have the means to determine that the volcano was active. He called it Rockne Volcano.

That didn't seem like an ideal appellation, either. So Hart helped organize a naming contest among students in American Samoa. Taulealo Vaofusi from Samoa High School submitted the winning entry, which was announced during the islands' centennial Flag Day celebration on April 21,

2000. The name of the new volcano and future Samoan island is Vailulu'u. The word describes the sacred sprinkling of rain that reportedly always fell as a blessing before a gathering of King Tuimanu'a, the last king of the Samoan nation.

Hitchhiking a cruise to Samoa

Back in their labs, the team compared lava dredged from Vailulu'u to samples from the other Samoan islands. Much the way biochemists track genes to determine people's heredity, geochemists can analyze chemical isotopes in rocks to identify their family lineage. The rocks from all the islands and the new undersea volcano were, chemically speaking, the progeny of the same mantle source. What's more, the shape of the volcanoes, from the westernmost island of Savai'i to the new volcano, were progressively more youthful in appearance. Add in the fact that the new volcano's location veered too far away from the Tonga Trench to be influenced by it, and the evidence all pointed to the existence of a Samoan hot spot.

Hart and company still could not explain why some of the older islands in the Samoan chain, unlike their Hawaiian counterparts, remain volcanically active. Hawaii may be the classic hot spot, but perhaps each individual hot spot has its own slightly quirky mantle plumbing system and modus operandi.

The scientists had found what was really down there. The next step was to find what was really *going on* down there. More specifically, they were eager to prove that Vailulu'u was still active.

Unfortunately, finding a research ship in the vicinity for a follow-up cruise isn't as easy as flagging a taxi. So Hart sort of stuck out his thumb.

He found out that the US Coast Guard's 430-foot icebreaker *Polar Star* would pass right by Samoa the following March—returning to Seattle from its annual southern hemispheric summer voyage to resupply the US scientific station in Antarctica. The Coast Guard graciously agreed to let Hart and colleagues rendezvous in Samoa and come aboard to conduct several days of research.

Smog, haloes, and tow-yos

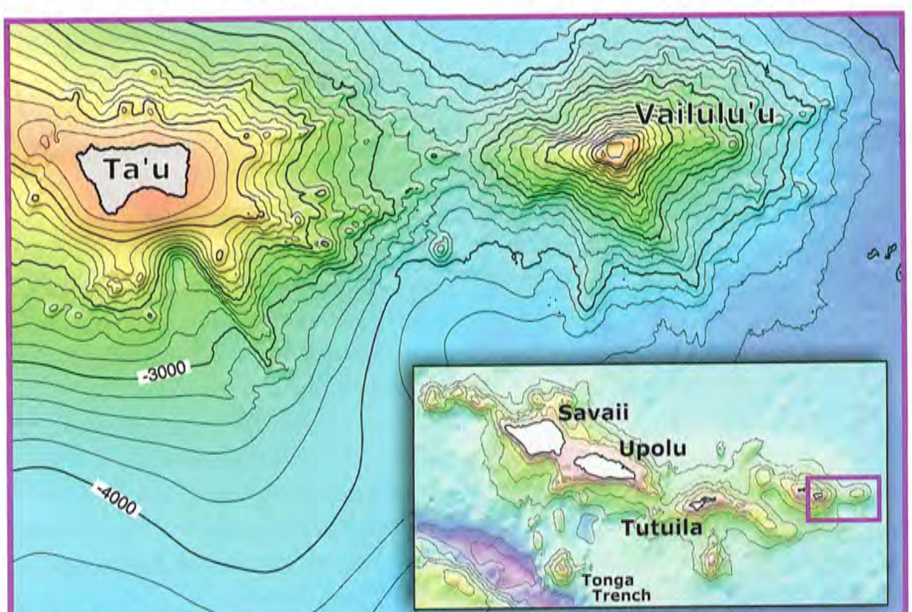
Helicopters from *Polar Star* picked up Hart, Staudigel, and David Willoughby, also of Scripps, on Fiji in March 2000. The next day, the ship arrived atop Vailulu'u, where the scientists lowered into the crater a CTD (conductivity/temperature/depth) instrument, which measures water temperature and salinity, and a nephelometer, which measures particulate matter in the water.

As soon as the instruments entered the volcano's crater, they recorded abnormally warm temperatures and high turbidity levels in the water. Samples from water within the crater also had much-higher-than-normal levels of the element manganese.

It was clear evidence of volcanic activity. Hot, buoyant fluids were escaping from the seafloor within the crater. The hot fluids dissolve minerals from volcanic rocks. When the hydrothermal fluids hit cold seawater, the minerals precipitate instantly, filling the water with particles like a smokestack belching smog into the air. The hot, chemical-rich fluids presumably also create a haven for microorganisms, which produce a different, but no less abundant, stream of particulate matter. As the instruments descended into the crater, the water became increasingly hotter and smoggier.

Polar Star also circumnavigated the crater using the "tow-yo" technique. As the ship towed a CTD and nephelometer, the instruments' cable was alternately reeled upward and downward, like a yo-yo.

By sampling outside the crater, the scientists also discovered that hot, smoggy water from the crater was spilling over the top or through breaches in the crater rim and billowing outward. It formed a halo around the rim that was hundreds of feet thick and extended more than 4 miles.



The discovery of the active volcano Vailulu'u, just east of the Samoan island of Ta'u, was "smoking gun" evidence that the Samoan Island chain was created by a hot spot—not by other geological forces related to the nearby Tonga Trench.

The Samoan island of Tutuila once had a classic cone shape and caldera like Vailulu'u, but these were eroded after the volcanic island rose above the ocean surface.

"Wiretapping" Vailulu'u

Before departing, Hart and company left a few calling cards. They deployed five ocean-bottom hydrophones—four around the crater and one in it—to detect sound waves generated by eruptions or earthquakes. The hydrophones lingered and listened, recording seismic events far more sensitively than faraway land-based seismometers ever could.

In March 2001, when *Polar Sea*, another Coast Guard icebreaker, returned from an annual Antarctic pilgrimage, it retrieved the hydrophones—with a full year's worth of previously undetectable rumblings from Vailulu'u.

Now, Hart's team hopes to persuade funding agencies to take the next step—mounting an expedition to lower exploratory robotic vehicles into the billowing cauldron of the volcano's 1,300-foot-deep crater. The idea is to use WHOI's DSL-120 sonar to map the crater floor in great detail and to search for what would be the first hydrothermal vents ever found within an undersea mid-plate volcano.

Do such vents exist in this unique environment? Would they look and operate differently from vents found elsewhere on the seafloor? Would they generate a different sort of ecosystem where previously undiscovered species and communities might thrive? To answer these questions, WHOI's tethered robot *Jason II* would be deployed to take a closer look, using its camera "eyes" to see and its "arms" to collect samples.

Hart and company have good reason to believe that they will find something completely new—because no volcano exactly like Vailulu'u has ever been discovered on Earth. It's a geological gem whose ideal shape offers scientists unprecedented opportunities to witness the ubiquitous, but hard-to-capture phenomenon of undersea volcanism, as well as to take a rare peek deep into Earth's interior.

Geological genealogists

Human beings have almost no access to the great heat engine that drives and shapes the face of their planet—the mantle. Its boundary begins several miles below even the thinnest part of Earth's crust, and it extends thousands of miles deep, all the way to Earth's core. It is a vast vat of hot, highly pressurized plastic rock that continually boils up and churns around like a stew in a pressure cooker.

We get only tantalizing glimpses of the processes going on down there in places where material from the mantle melts and bursts through the crust—at volcanoes, for example, or at the globe-encircling mid-ocean ridges, where buoyant magma upwells in the seams between tectonic plates. The magma is quenched to create new ocean floor. As new seafloor crust spreads outward on both sides of the ridges, it expands ocean basins, rends continents and drives them apart, and shoves plates into collisions that generate mountain ranges, islands, volcanoes, and earthquakes.

Hart and other mantle geochemists have analyzed long-lived radioactive isotopes in lava from mid-ocean ridges and volcanic islands throughout the world. They have determined that all ridge lava is similar and probably emanates from the top of the mantle. But they have also identified three other "families" of mantle rocks from oceanic islands—each chemically distinct from ridge rocks and from one another. Much like the various races of humankind, these rocks remained distinct because they resided and evolved separately from one another over long time periods. Thus, the three pedigrees of rocks probably originate from segregated, deep realms within the mantle, perhaps even as deep as the core-mantle boundary.

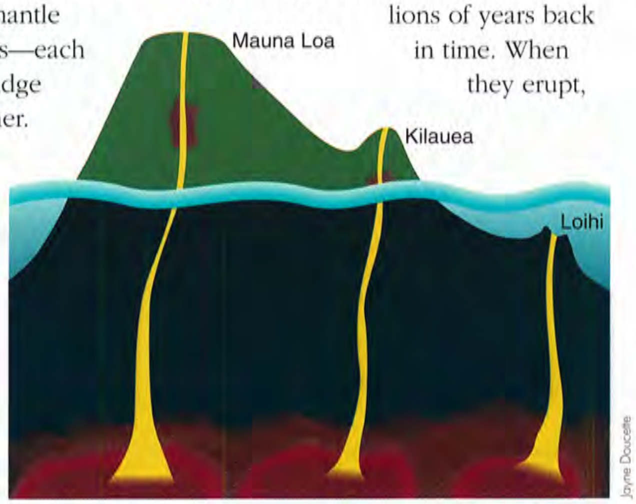
"These volcanic rocks are the first direct information on the composition of the lower mantle," Hart said. "They provide rare windows into the interior of the earth."

By tracing the rocks' lineage backward in time and downward into the mantle, scientists/detectives such as Hart hope to unveil how the mantle works and how it has evolved.

A telescope into Earth's mantle

Not a day goes by without a few volcanoes erupting somewhere on the always active mid-ocean ridges, but they don't offer ideal conditions for studying the underlying mantle. Magma flows beneath the ridges in all directions over thousands of seafloor miles. Hydrothermal vent fluids on ridges are instantly swept away by currents. In short, ridges are just too widespread and wide open for scientists ever to be able to measure and constrain all the variables and grasp the big picture.

On the other hand, a volcano erupting *within* a plate offers almost a surgical incision. Hot spot volcanoes, in particular, often sit atop long, narrow plumes that can reach into deeper regions of the mantle and billions of years back in time. When they erupt, they can bring up rare gases that were created when the solar system was just born and that have been sealed in the mantle ever since.



The active undersea volcano, Loihi, is really one of a trio of active volcanoes, including Mauna Loa and Kilauea, which together comprise the island of Hawaii.

Hot spot volcanoes above water are convenient to study, but their scientifically precious gases are quickly dispersed into the air. Beneath the sea, however, thousands of feet of water pressure keep those rare gases in solution. That's why an active, undersea, hot spot volcano is such a rare find for scientists. Conveniently located off Hawaii, Loihi has been the only such volcano to be studied in any detail.

Lady and the tramp

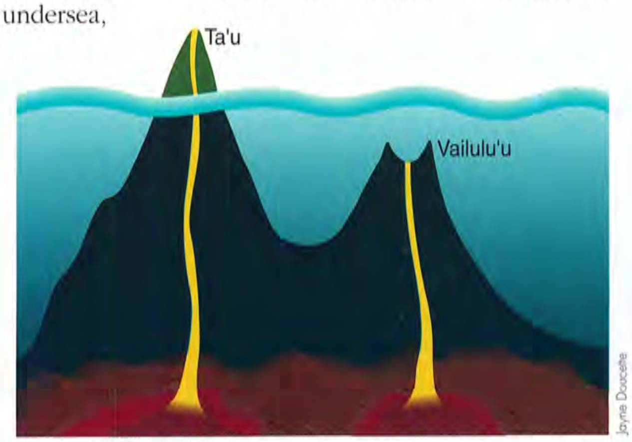
Now this may sound politically incorrect, but it is certainly geologically correct: Loihi is an inelegant mongrel of a submarine volcano. It is attached to the Big Island of Hawaii and has bumps and pits that together comprise no distinct shape. Its lava is a mixed breed, coming from a variety of sources in the mantle.

In contrast, Vailulu'u lava is one of the three scientifically interesting pedigrees from deep mantle regions. And unlike Loihi, Vailulu'u is isolated and gloriously crowned with an enclosed crater.

"Vailulu'u has beautiful ramparts that contain everything coming out of the seafloor," Hart said. "The magma is coming straight up. The water is circulating straight up. It's like having the whole system you want to study in a neat box."

Near to port and not very deep, Vailulu'u is also relatively convenient. In his wildest scientific fantasies, Hart envisions wiring Vailulu'u with instruments to continuously monitor all the interacting physical, chemical, and biological phenomena that occur where volcanism and oceans combine. Hart sees Vailulu'u as a natural laboratory to observe Earth's unique fundamental processes. Once established, the laboratory would be poised to capture something that humankind has never witnessed before—the eruption of a great undersea volcano.

"Presumably there's an incantation to make a volcano blow," Hart joked. ■



Unlike Loihi, Vailulu'u is separated from the neighboring island of Ta'u and will eventually create a distinct island. That characteristic makes Vailulu'u much more scientifically valuable as a potential natural laboratory, says WHOI Senior Scientist Stan Hart.

Grateful WHOI Pays Tribute to Topsy Montgomery

Gratia R. "Topsy" Montgomery was presented the sixth Cecil H. Green Award at the January Board of Trustees meeting. Director Bob Gagosian said Topsy's support for coastal research activities "has inspired the Institution to think more broadly and daringly about its future. She has been a catalyst for innovation and change."

Affiliated with the Institution for more than three decades, Honorary Trustee Montgomery has supported a number of education programs, helping dozens of summer student fellows, graduate students, and postdoctoral fellows launch their oceanographic careers. Her commitment to coastal research, both shore-based and seagoing, has made it possible for the Institution to move forward with plans for a new coastal research vessel and to expand its coastal research activities.

The Rinehart Coastal Research Center was endowed in 1996 by a $5-million gift from Topsy, and a second $5-million gift last year allowed the Institution to proceed toward construction of R/V *Montgomery*, an innovative coastal SWATH (Small Water-Plane Area Twin Hull) research vessel that will serve a variety of oceanographic research needs.

Tim Silva

Director Bob Gagosian presents Topsy Montgomery with the Cecil H. Green Award for outstanding contributions to WHOI oceanography.

"Topsy represents the essence of the Institution," the Director said. "She has an energetic spirit, fierce dedication, and deep commitment to making this planet a better place."

The Green Award was established in 1991 in honor of its first recipient, Sir Cecil H. Green, to honor individuals who make outstanding contributions to oceanographic research at WHOI. It has also been awarded to Scientist Emeritus Stanley Watson, former Chairmen of the Board Charles Adams and Guy Nichols, and Honorary Trustee Walter Smith.

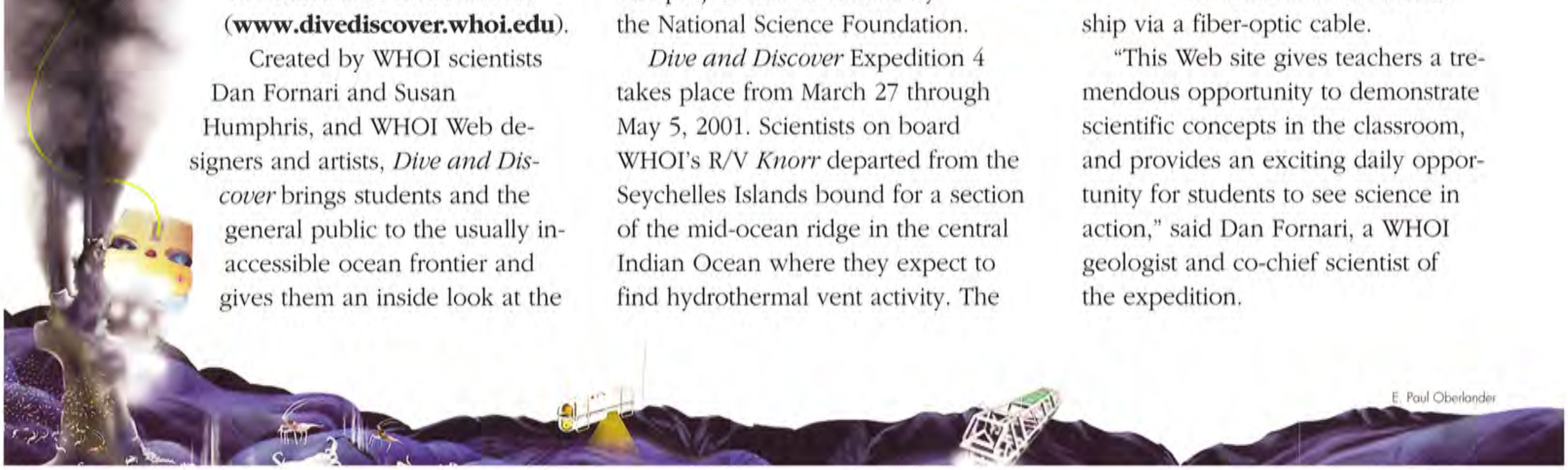
Web Site Takes Students to the Ocean Frontier

Students and teachers in 22 states and Guam will be among the first to know about never-before-seen creatures discovered by a pioneering expedition to explore seafloor hydrothermal vents in the Indian Ocean this spring. They are following the daily activities and progress of the expedition's scientific teams using a new Web site called *Dive and Discover* (**www.divediscover.whoi.edu**).

Created by WHOI scientists Dan Fornari and Susan Humphris, and WHOI Web designers and artists, *Dive and Discover* brings students and the general public to the usually inaccessible ocean frontier and gives them an inside look at the sights, sounds, and action of scientific research—almost as it is happening. The site gives teachers and their students unprecedented access to the ship, scientists, and seafloor through daily updates, slide shows, and videos, and through e-mail correspondence with shipboard scientists. The project was co-funded by the National Science Foundation.

Dive and Discover Expedition 4 takes place from March 27 through May 5, 2001. Scientists on board WHOI's R/V *Knorr* departed from the Seychelles Islands bound for a section of the mid-ocean ridge in the central Indian Ocean where they expect to find hydrothermal vent activity. The team, which includes biologists, microbiologists, geneticists, chemists, and geologists from eight US universities and institutions, will use the remotely operated vehicle *Jason* and other deep-diving mapping and imaging vehicles that transmit video and still images in real time from the seafloor to the surface ship via a fiber-optic cable.

"This Web site gives teachers a tremendous opportunity to demonstrate scientific concepts in the classroom, and provides an exciting daily opportunity for students to see science in action," said Dan Fornari, a WHOI geologist and co-chief scientist of the expedition.



E. Paul Oberlander

Photos by Tom Kleindinst

Alvin Gets an Overhaul

WHOI's famed submersible *Alvin* is hoisted off its support ship R/V *Atlantis* in December (above) for its periodic top-to-bottom, inside-and-out maintenance. At right, *Alvin* Chief Pilot BLee Williams works in the space where *Alvin*'s titanium sphere (in background) usually sits, as Engineering Assistants Dave Olds and David Hamblin work at the bench. *Alvin* will be reassembled and ready to resume duty this summer.

WHOI Scientist's Photos Grace US Stamps

A set of first-class US postage stamps featuring deep-sea photographs taken by Senior Scientist Larry Madin was issued in October 2000. The five-stamp "Deep Sea Creatures" set included Larry's images of a sea cucumber, an amphipod, and a medusa.

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Associates Events and Expeditions

- June 15 – **Summer Science Supper**
- July 1–10 – **Galápagos Islands** (Sorry, this trip is full. Another Galápagos Family Voyage is scheduled for Feb. 3–12, 2002.)
- August 2 – **"Just for WHOI Retirees" Lecture/Reception**
- September 14 – **Afternoon of Science**

Please contact Lesley Reilly for further information: lreilly@whoi.edu or 508-289-3313

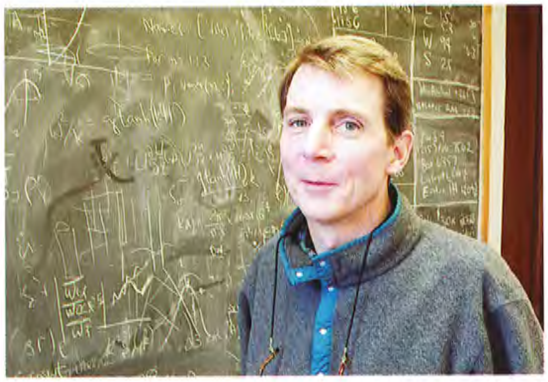
Awards Recognize Senior Technical Staff

The Institution announced two $60,000 Senior Technical Staff Awards in 2000—to recognize extraordinary accomplishments in engineering, instrument development, information systems, or oceanography, and mentoring of younger staff.

Gene Terray, a Research Specialist in the Applied Ocean Physics & Engineering Department (AOP&E), received the first Allyn Vine Award, named after the legendary WHOI scientist. The award was sponsored by Palisades Geophysical Institute, whose principal, J. Lamar Worzel, collaborated closely with Vine at WHOI in the 1930s and 1940s, and a matching grant from the George F. Baker Trust.

Jean Whelan, a Senior Research Specialist in the Marine Chemistry & Geochemistry Department, received an R.K. Mellon Award—initiated by a 1996 gift from the R.K. Mellon Foundation to enhance transfer of knowledge within the WHOI technical staff.

Gene Terray has been the lead investigator on a number of experiments to study the small-scale mechanics of air-sea interaction, in particular the role of surface waves in transferring energy, heat, momentum, and mass between atmosphere and ocean. He has developed several new instruments, including Doppler sonars and, with Research Engineer Don Peters, the 40-foot Air-Sea Interaction Spar (ASIS) buoy, designed to provide a stable platform for obtaining near-surface observations on both sides of the air-sea surface.



Tom Kleindinst

Research Specialist Gene Terray

Jayne Doucette

Senior Research Specialist Jean Whelan

More recently, working with AOPE Department members John Trowbridge and George Voulgaris (now at the University of South Carolina), Gene employed the Southampton Oceanography Centre's *Autosub*, an autonomous underwater vehicle, to map near-bed flow over sand ridges in the North Sea.

Whelan's research interests include the mechanisms of petroleum formation and migration, and the effects of natural oil and gas seeps on ocean chemistry. She and colleagues advocate a theory that some of the world's oil and gas fields may be continuously refilling, refreshed by pools of hydrocarbons that lie deep within the earth.

A current focus of her work concerns gas hydrates, solids composed of cages of water molecules that trap methane under certain temperature and pressure conditions. Gas hydrates occur at the seafloor/water column interface and are buried within seafloor sediments.

"There is growing recognition," Jean said, "that there is huge movement of gas beneath the sediments and that it happens not only on geological time scales but also on very short time scales. Gas hydrates are one expression of this movement, which I suspect has an enormous effect on the biogeochemistry of the ocean."

Senior Scientists Earn Prestigious Chairs

Three Senior Scientists were awarded five-year chair appointments for excellence in oceanography at the October joint meeting of the Board of Trustees and Members of the Corporation. The presentations were made by Institution Director Bob Gagosian. Geologist Peter Kelemen received the Charles F. Adams Chair. The Stanley W. Watson Chair went to geochemist Dan Repeta, and marine mammal expert Peter Tyack was awarded the Walter A. and Hope Noyes Smith Chair.

Peter Tyack

Peter Kelemen

Dan Repeta

Gagosian Participates in World Economic Forum

Director Bob Gagosian traveled to Davos, Switzerland, in late January as one of some 200 Fellows invited to the World Economic Forum.

The annual forum attracts more than 2,000 distinguished world political, business, and academic leaders and is designed to give them new connections and information to address key global economic, political, environmental, and societal issues.

At a talk and video presentation about the frontiers of oceanography, Bob told his audience that understanding the oceans has become essential for sustaining life and the quality of life on Earth—at a time, fortuitously, when technological breakthroughs are giving oceanographers unprecedented abilities to comprehend the oceans.

Bob also participated in two expert panel discussions—on the economic and social consequences of global environmental change and on the search for extraterrestrial life. Bob said that astonishing, "extraterrestrial" life discovered in extreme ocean environments has expanded our understanding of the conditions and locales in which life can exist.

WHOI's Mary Sears Goes to Sea at Last

Continued from page 20

as well as the Institution's annual report and summary of investigations. She was a founding editor of *Deep-Sea Research* and *Progress in Oceanography*. Roger Revelle, longtime director of the Scripps Institution of Oceanography, called her "the conscience of oceanography who initiated and maintained an uncompromising standard of excellence in scientific publications about the oceans… She played a major role in creating the present world community of oceanographers from numerous countries and almost as many specialties."

Portrait by Richard Whitman

WHOI commissioned a portrait of Mary Sears and donated it to the Navy.

Mary chaired the First International Congress on Oceanography, held at the United Nations in 1959, and co-edited, with Daniel Merriman, *Oceanography, The Past*, as part of the Third International Congress on the History of Oceanography, held at Woods Hole in September 1980 in celebration of the Institution's 50th anniversary.

In addition to her scientific and editorial contributions to WHOI, Mary was a longtime Member of the Corporation, serving as Clerk for more than 25 years. A bequest from Mary upon her death in 1997 has helped the Institution pursue its oceanographic research.

Because women were not permitted to go to sea until very late in her career, Mary's only research voyage was aboard a Peruvian fishing vessel (and it was she, not the men aboard, who dove into the sea to retrieve a plankton net that had parted from the line!). Director Bob Gagosian concluded his remarks at the launch of USNS *Mary Sears* by observing, "I think it's wonderful and altogether fitting that—at last— Mary Sears gets to go to sea in a manner befitting her."

New Science Writers' Program Launched

Seven science writers converged at WHOI for a challenging week last September as the first recipients of the Institution's new annual Ocean Science Writing Fellowships. Organized by Media Relations Director Shelley Lauzon, the program introduced the fellows to the interdisciplinary nature of ocean sciences and engineering, along with many current and planned research programs in oceanography.

Through lectures, demonstrations, interviews with scientists, and a short research cruise aboard *Asterias*, the fellows learned about subjects ranging from the ocean's role in Earth's climate to marine mammals, coastal erosion, and the tools and technologies of deep-sea research.

The 2000 Science Writing Fellows were children's science writer and illustrator Lynne Cherry, Matt Crenson of the Associated Press, Josh Fischman of *US News & World Report*, Tim Friend of *USA Today*, Richard Hill of *The Oregonian*, Eric Sorenson of the *Seattle Times*, and Anastasia Toufexis of *Discover* magazine.




US Navy Photos

USNS Mary Sears Honors WHOI Scientist

Planktonologist Mary Sears, a student of first Director Henry Bryant Bigelow, was one of the first 10 researchers appointed at the Woods Hole Oceanographic Institution. Many years later, on the occasion of her 80th birthday, the editors of the journal *Deep-Sea Research* dedicated an issue to her and said she "has probably played a greater role in the advancement of oceanographic studies than any other woman."

The US Navy honored Mary's long service to marine science by naming its sixth Pathfinder class multi-mission oceanographic survey ship for her. Launched October 19, 2000, it is only the 12th Navy ship—and the first oceanographic vessel—to be named for a woman. The 329-foot (100-meter) Pathfinder class vessels are equipped for mapping the ocean floor to update nautical charts

US Navy

Officials assist Leila Sears, Mary's sister, as she christens the Navy's newest research vessel: *USNS Mary Sears.*

and for a variety of research tasks including sampling, measuring, and data processing.

Mary Sears was commissioned a Lieutenant Junior Grade in the Waves (Women Accepted for Volunteer Emergency Service) in 1943. She was called to Washington, where she organized and headed the new Oceanographic Unit of the Navy Hydrographic Office. Her reports, titled *Submarine Supplements to the Sailing Directions,* predicted the presence of thermoclines (areas of abrupt water temperature change), where submarines could hide to escape enemy sonar detection. This information gave US forces an advantage. Mary returned to Woods Hole in 1947, transferring to the Navy Reserves and retiring as a commander in 1963.

Mary Sears made her most enduring contribution to oceanography as editor of several journals and books,

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