# Oceanus®

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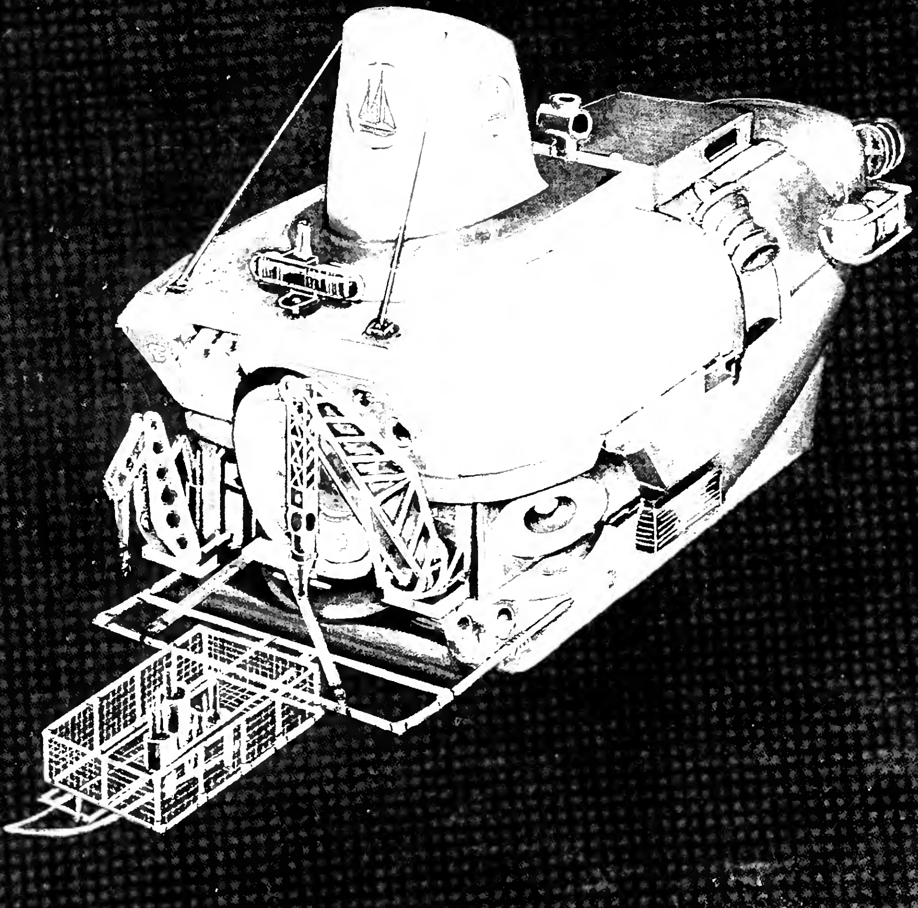

## *DSV Alvin*

## 25 Years of Discovery

# Oceanus®

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**The International Magazine of Marine Science and Policy**
Volume 31, Number 4, Winter 1988/89

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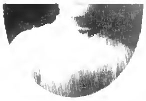

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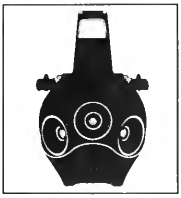
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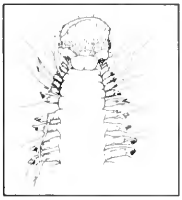
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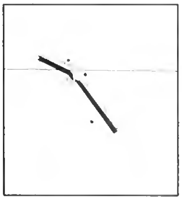
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Illustration by E. Paul Oberlander

exploration of the deep sea, to say nothing of the affections of countless admirers around the world.

In its odysseys under the sea, the plucky little submersible has created an astonishing record of firsts, journeying to places that never before experienced a human presence. It took part in some of the earliest visits to the mid-ocean ridges, where new continental material is birthed from deep within the Earth. It found entirely unknown and unexpected life forms at the hydrothermal vents, a world where the sun never shines and living things depend on the Earth's internal heat. It reached beyond pure science into the realm of adventure, bringing the first human visitors to the rusted, mollusk-eaten remains of the star-crossed liner *Titanic* two miles below the surface.

Now, as *Alvin* approaches its 2,200th dive—its 2,000th took place on the East Pacific Rise, off Mexico, on March 22 1988—it is about to mark another milestone in its illustrious career. It will soon celebrate its 25th birthday. On 5 June 1964, in the waterfront parking lot of the Woods Hole Oceanographic Institution (WHOI), Adelaide Vine, wife of veteran oceanographer Allyn Vine (profile, pp. 61–68), christened *Alvin* by cracking a bottle of champagne across its mechanical arm, its sturdiest external part. With that midwife-like whack, life officially began for what has become the world's best-known, and undoubtedly most successful, explorer of the deep.

To commemorate this occasion, we can think of no more fitting tribute to *Alvin*, as well as to those who conceived, built, and continue to operate it for WHOI, than to recall its dramatic history. And what better way to tell this exciting deep-sea yarn than to turn to some of those who've played an intimate part in *Alvin*'s story?

In the pages that follow, you'll find an imposing lineup. Al Vine, who more than anyone else was *Alvin*'s symbolic father, and also official namesake, recalls how the idea was born. Veteran pilots Marvin McCamis and Dudley Foster provide us with first-hand accounts of what it's like to be at the controls of the submersible, even in so harrowing an assignment as looking for a lost hydrogen bomb. Biologist Holger Jannasch describes an unexpected scientific finding from the worst 11 months in *Alvin*'s history, when it lay at the bottom of the sea after an accidental sinking. Science writer Victoria Kaharl, who is at work on an authoritative history of *Alvin*, takes us back to Project FAMOUS, *Alvin*'s first major scientific expedition, the journey to the Mid-Atlantic Ridge.

Most of *Alvin*'s early work involved the geology of the deep sea—in part because it was assumed that the rocks there were more interesting than the life, if any. Biologist Fred Grassle makes plain just how wrongheaded this assumption was in his analysis of the profound significance of the colonies of strange creatures discovered by *Alvin* around deep-sea vents. More than one scientist has described these thriving communities as one of the great scientific finds of the twentieth century. Graduate student Cindy Lee Van Dover provides a Holmesian footnote to the bizarre vent life. She explains the fascinating deductive process that led her to hypothesize an unusual "seeing" ability in deep-dwelling shrimp who live around these hot spots, as well as an extremely low-level glow from the superheated vent waters. Since the confirmation of the mysterious light on an *Alvin* dive on the Juan de Fuca Ridge in July, it has become known as the "Van Dover glow."

A trio of authors offers perhaps the most definitive description yet published of the wreckage of the *Titanic*, which was visited by *Alvin* a year after its discovery in 1985 by remotely operated cameras. The authors are WHOI's Elazar Uchupi, Bob Ballard, and William Lange. In addition to the poignancy their report evokes about a calamity at sea that still has the power to move us today, it settles old arguments about what happened to the great liner in her last agonized moments afloat.

Finally, because we thought you'd enjoy learning more about the prolific career of the extremely modest, self-effacing man after whom *Alvin* was named—and who did so much to foster the use of deep-diving submersibles—we present a profile of Al Vine, written by our colleague Sara Ellis.

### *Alvin*'s Changing Face

There's one thing that needs to be acknowledged right off. *Alvin*, at its silver anniversary, is a far different boat than the one christened 25 years ago. As anyone who has looked closely at pictures of the submarine knows, it has undergone continual evolution. Not in its basic configuration, to be sure. In this respect *Alvin* remains very much the same lovable ugly duckling of its baptismal day. But it has been altered in less conspicuous aspects, as in the shape of its propellers, the color of its sail (don't say conning tower—that will mark you as antedeluvian!), the curve of its plastic skin, the form of its mandibular mechanical arm. Even the spherical pressure hull—the very heart of the ship because that's where the sub's three occupants stay—is no longer the same as the original.

So, if today's *Alvin* is so very different from the boat first dunked into Woods Hole Harbor more than two decades ago, why all the fuss? The answer is that we're celebrating more than the birthday of a vessel. We're honoring an idea—indeed, a conviction—that hasn't changed at all over the years. It's the determined belief that no part of the planet's surface—even the bottom of the deepest ocean—should be beyond the reach of humans to explore, to ponder, and to understand.

In looking back, what seems so incredible

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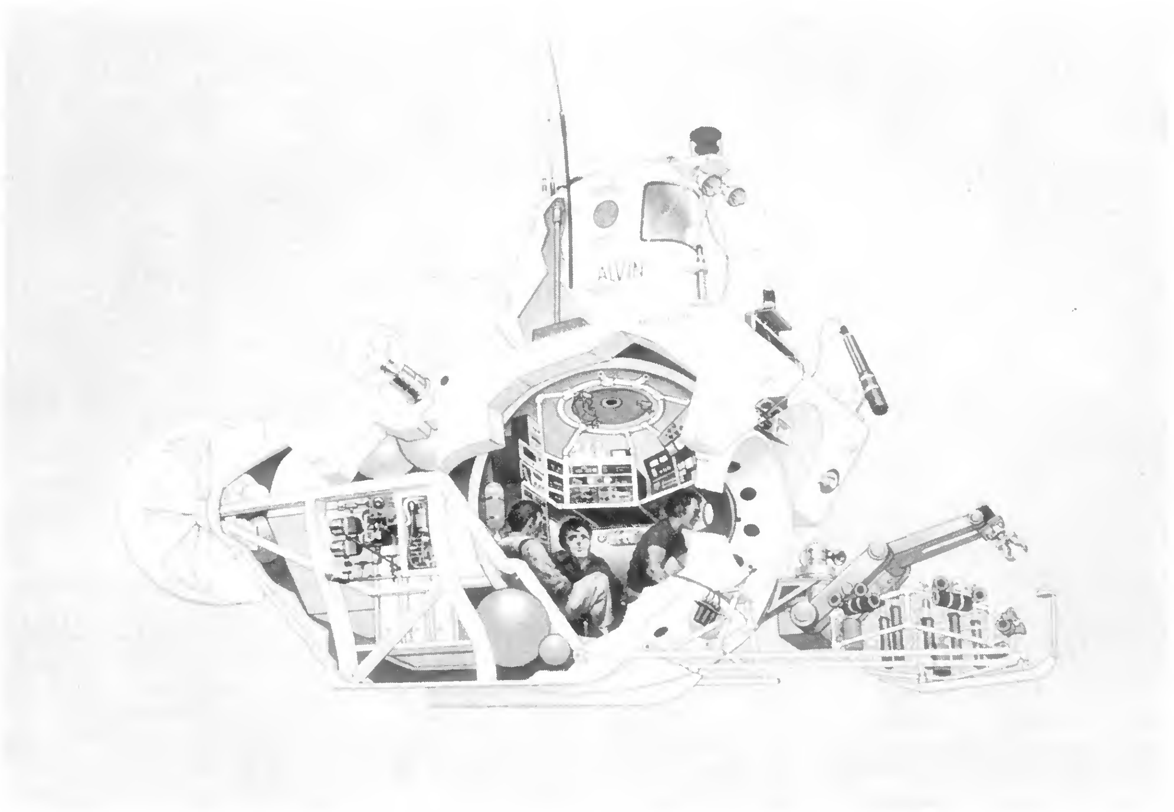
*Frederic Golden is the Acting Editor of* Oceanus.



*How* Alvin *was configured during the submersible's explorations of the Mid-Atlantic Ridge in the summer of 1974. (Drawing by Davis Meltzer, courtesy of National Geographic Society© 1975)*

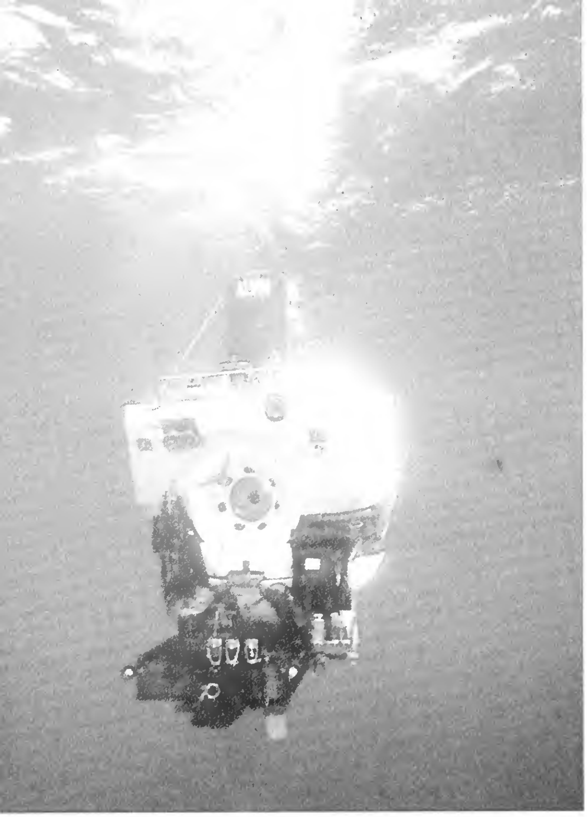
now is that only a handful of oceanographers were really believers in research submersibles on that auspiciously sunny day 25 years ago. Most, in fact, were outright skeptics. Deep-sea diving, they felt, was the stuff of adventurers and daredevils, like the Beebes and Piccards, not of sensible scientists. In the 1930s, William Beebe, a zoologist and writer, had created a splash (both in the water and in the press) when he let himself be lowered by cable more than 3,000 feet off Bermuda—deeper than anyone had ever gone before into the sea—inside a steel ball with viewing ports that he called a "bathysphere" (from the Greek *bathys* for depth). Not a few old salts thought he was crazy to take such risks. The Piccards, *père* and *fils*, advanced this daring art form with what the father, Auguste, a Swiss physicist, dubbed the bathyscaphe (*scaphe* being Greek for small boat). Bathyscaphes were also spheres with viewports, but unlike Beebe's ball on a string, they were free-floating with their own ballast and maneuvering systems.

Still, even as late as 1972 when leaders of the oceanographic community were considering Project FAMOUS, one very senior scientist wanted to know what worthwhile science had ever come from a deep-diving submersible. ("How could they have produced anything," retorted a colleague, almost under his breath, "when they'd never been tried.")

## If Darwin Hadn't Been Aboard the *Beagle*

No one single person can claim credit for *Alvin*, although certainly Allyn Vine is as close as anyone to deserve the honor, even if he is himself too modest to claim it. In the post-World War II era, the subject of submersibles as research vehicles was very much on the minds of many people. Some, like Vine, had wartime experience with submarines. Others were simply intrigued by the growing evidence that the ocean floor was not merely a dull, scientifically uninteresting carpet of sediment, as had once been commonly thought. Echo sounding and seismic studies were showing that it was comprised of a far more complex terrain. It had ridges and valleys, deep canyons and trenches, even ancient, sheered off volcanoes called guyots. In their view, such a place ought to be visited first-hand.

Vine made an eloquent pitch for deep-diving submersibles at a conference of leading oceanographers in Washington, D.C. on February 29 and March 1, 1956. In his own recollections on the following pages, Vine, characteristically, makes only a passing reference to his role in that conference. But it was his talk, strongly seconded by another oceanographic visionary, Willard Bascom, who helped to persuade the assembled scientists to urge upon the Navy and the National



*Off the coast of Bermuda in 1986, with new thrusters installed,* Alvin *begins a post overhaul engineering test dive. (Photo by Rodney Catanach)*

Academy of Sciences the creation of a national program that would produce deep-diving submersibles for research. What particularly moved him, Bascom said, was Vine's insightful comment that the best possible instrument that could have been put aboard *HMS Beagle* was Charles Darwin. Perhaps more than anything else, it was the resolve of that conference that set in motion the events that led to *Alvin*.

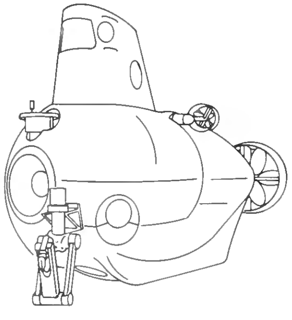
Of course, the thought of going into the deep was not exactly new. As long ago as the fourth century B.C., Aristotle studied the sea in a small diving bell that took him down 75 or 100 feet. So apparently did Alexander the Great. In 1620 a Dutchman by the name of Cornelius van Drebel built a leather-and-wood submersible for England's James I, that could navigate at 12 to 15 feet below the surface of the Thames River. In 1701 the polymath Sir Edmund Halley (of comet fame) built a diving bell with glass ports that he took down off the English coast. Later submarine-builders had martial motives.

In the New World, a Connecticut Yankee by the name of David Bushnell tried to sink British warships in New York harbor during the Revolutionary War by attaching explosives to their hulls with his hand-powered, propeller-driven sub *Turtle*. Only his explosives-attaching device didn't work. Robert Fulton sought unsuccessfully to peddle two iron-framed, copper-skinned submarines—first to Napoleon, then to the Frenchman's enemies, the British—before settling on building steamboats in the young United States.

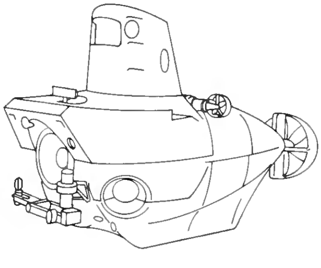
Perhaps the first true modern submersible was the American inventor Simon Lake's *Argonaut*. Launched circa 1894, it had a gasoline engine that breathed through a snorkeling tube and was the first submarine to have blowable ballast tanks. Once the sub was pressurized, a hatch could be opened on the bottom that allowed Lake to gather such samples as oysters. Subsequently, he even managed to build a submersible barge that scooped up a sunken cargo of anthracite coal from the bottom of Long Island Sound.

But more than half a century elapsed before other submersible builders followed in the path of Lake's pioneering work. (The Piccard bathyscaphe, or tethered vehicles like Beebe's steel ball aren't true submersibles because they have little or no freedom of lateral movement.) One notable American builder in the post World War II years was John Perry in Florida. His *Cubmarine*, capable of going down several hundred feet, was used in the search for the lost American hydrogen bomb in 1969, along with

### *The Evolution of a Submersible*



1964



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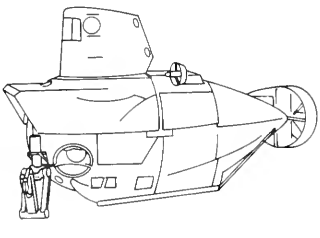


1970

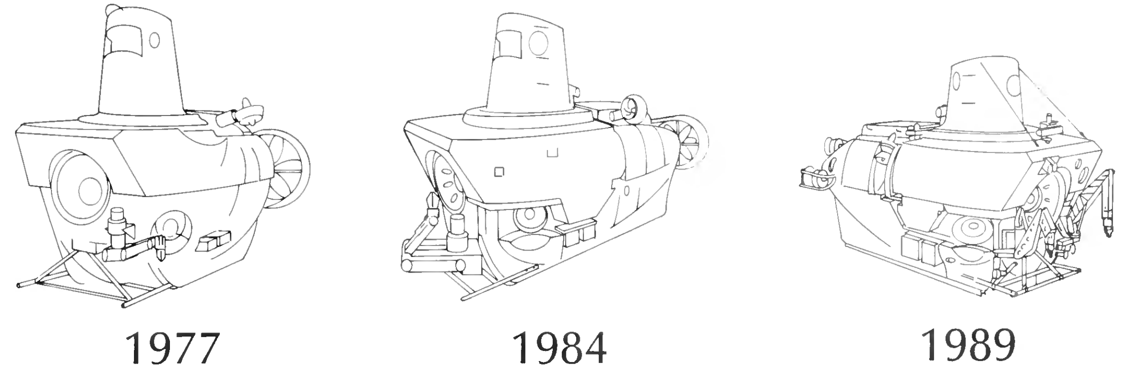
*Divers prepare* Alvin *for recovery by the submersible's mother ship* R/V Atlantis II *after a dive. (Photo courtesy of WHOI)*

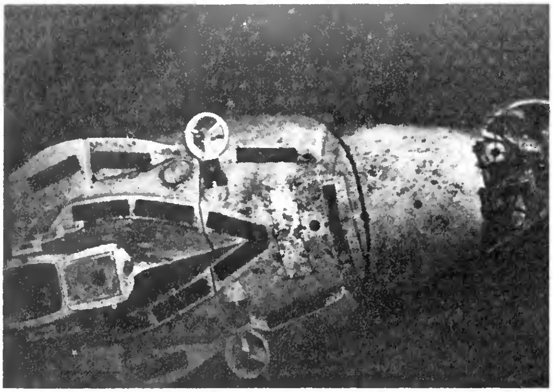
*Alvin* and *Aluminaut*. Another important figure was Jacques Cousteau, the inventor of scuba diving, and a major champion of oceanic research. His submersible *Diving Saucer* (*La Soucoupe Plongeante*) went through many changes before it was acquired by the French government and became *Cyana*, *Alvin*'s companion along with *Archimède* in Project FAMOUS.

### The Differences from Ordinary Subs

Submersibles differ from conventional submarines in significant ways. Generally, they're much smaller, with room for only two or three people. They're usually used for nonmilitary purposes, concentrating on basic science (*Alvin*, in its early days, inspected the bottom for the Navy, which had paid for its construction). Their operation is also different. Whereas traditional submarines usually try to avoid groundings at all cost, submersibles are expected to touch bottom. Nor do they have to have sleek lines, since they travel at only a knot or two. The time spent underwater is typically no more than a half a day, whereas the Navy's nuclear submarines are likely to remain on station for months. Finally, submersibles are invariably dry-sailed, hoisted out of the water after each immersion by a mother ship, which in *Alvin*'s case was originally a catamaran named *Lulu*, made from two castoff Navy pontoons.

There are also important differences in construction. In conventional submarines, the machinery—motor, fuel, ballast tanks, and so on—is kept within the hull, along with the crew, whereas in deep-diving submersibles, the two are separated. The crew rides in a small steel or titanium sphere, capable of withstanding enormous pressures, while most of the mechanical components are hitched onto a so-called exostructure, a framework external to the hull. Lacking the protection of an enclosing compartment, each component on the exostructure must be able to withstand the pressure on its own. In *Alvin*, as with other submersibles, a smooth plastic skin, or fairing,





*The low point in* Alvin*'s career was from October 1968 to September 1969, when it sank to 5,040 feet near Hydrographer Canyon, south of Nantucket. At left,* Alvin *on the bottom, as photographed by the U.S. Navy's* Mizar. *At right, when* Alvin *was hoisted to within 50 feet of the surface, divers wrapped these harnesses around it for the tow to Martha's Vineyard. (WHOI archives)*

surrounds the exostructure. This skin isn't watertight, however. On the contrary, it lets in water, equalizing pressure on the two sides. If it didn't, the skin would be crushed as pressure built up. At *Alvin*'s maximum diving depth of 13,100 feet, this may be as much as 5,900 pounds per square inch.

### A Tight Squeeze

Needless to say, since submersibles are so small, they aren't very comfortable. *Alvin*'s seven-foot-diameter sphere barely enables all three passengers to sit down simultaneously without contorting themselves. Smoking is taboo because air is at a premium. During a dive, the inside temperature may go down to a chilly 55 degrees Fahrenheit. Food and liquid plainly can't be carried in any great quantity. Toilet facilities consist only of a primitive tubelike device, euphemistically called a HERE (for Human Element Range Extender) bottle.

After *Alvin*'s commissioning, it took about a year and a half before the submersible could be considered operational. The engineers tinkered, the pilots learned how to guide the sub, and the support crews on the surface mastered the delicate skill of getting the 23-foot-long, 33,000-pound boat in and out of the water.* If winds were over 20 knots, launches were scrubbed as too risky. There were many practice dives, including two to *Alvin*'s then depth limit of 6,000 feet.

In the spring of 1966, *Alvin* was about to begin its scientific sleuthing in the seas, when the Navy recruited the little sub for a very special—in fact, extraordinary—mission. An H-bomb was missing off the Andalusian coast of Spain. In a collision of two U.S. Air Force bombers, one of their thermonuclear weapons had dropped into the Mediterranean. *Alvin*, hastily assembled, was flown to Spain. In the ensuing weeks, as all the world watched the American recovery effort, *Alvin* made 35 dives. On one of these it hit paydirt. It found the missing bomb, still wrapped in its parachute. Members of the *Alvin* Group were especially pleased that they had discovered the bomb, not their rivals aboard the submersible *Aluminaut*, owned by Reynolds Metals company, which had also been recruited by the Navy in the search.

*Alvin*'s achievement was hailed around the world, even in cartoons. One newspaper dubbed it "The Little Sub That Could." But the triumph was short-lived. At the end of the 1968 diving season, calamity struck. On 16 October, as *Alvin* was being launched on what was to have been its last dive before an overhaul, a hoisting cable snapped while the hatch was still open, and it slid off its elevator platform into the water. As water spilled into the open pressure sphere, the sub's occupants scampered to safety in the nick of time. *Alvin* sank ignominiously to the bottom, about 5,000 feet down, about 135 miles from Woods Hole.

Some people thought that *Alvin* was gone forever. But the never-say-die spirit that got the submersible built in the first place ultimately prevailed. Despite some official resistance at first, WHOI decided to attempt a salvage. Eleven months later, *Alvin* was tugged off the bottom, thanks to a toggle-bolt-like snare that was placed inside the open hatch. That delicate mission was performed by none other than rival *Aluminaut*. As *Alvin* was hoisted, divers wrapped it into so much netting the little sub looked like a captured whale when it finally surfaced. Yet in spite of the hapless appearance, most of *Alvin*'s major components were in good shape. The aluminum frame was badly corroded, and the sail had been bashed away during the recovery, but the key item—the pressure hull—needed no more than a good scrubbing. By June 1971, after undergoing a complete overhaul, *Alvin* resumed its scientific career.

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**Presently, Alvin is 25 feet LOA, and weighs 36,000 pounds.*

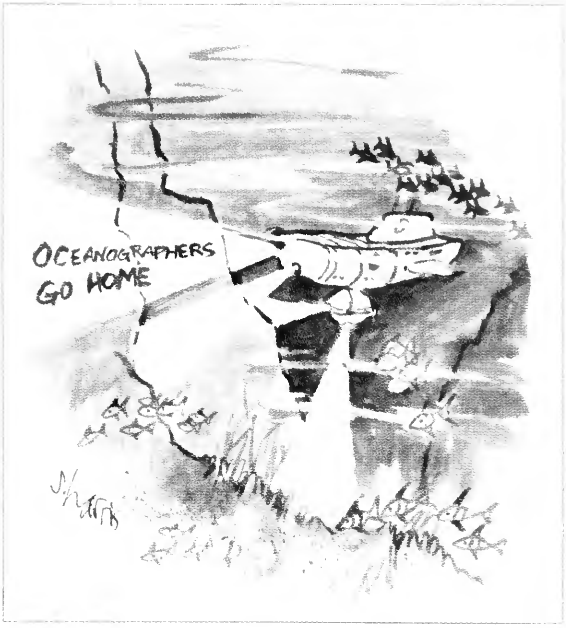
The sinking wasn't the only trouble in *Alvin*'s early days, however. On 25 September 1967, it had lost its mechanical arm when it hit against the mother ship on recovery in rough seas, in 4,400 feet of water some 100 miles from Woods Hole. Six weeks later, it managed to snare the arm with a long, scimitar-like steel hook, and bring it back to the surface none the worse for the experience. Off Florida, *Alvin* was once attacked by a swordfish (which lost the battle when it got caught in the sub's skin, and was subsequently eaten aboard ship). A few years later, off Grand Bahama Island, it was struck by a blue marlin. On other occasions, there have been smoky electrical fires and scary rock slides triggered by the sub's movements on the bottom.

Nor was life very comfortable for scientists or crew aboard the pokey 105-foot *Lulu*. Crammed into her pontoons, they found their nerves often rubbed raw by the close quarters. (*Alvin* is now carried aboard the much more spacious and reliable *R/V Atlantis II*.) But none of these difficulties resulted in serious injury or loss of life. Indeed, they were vastly outweighed by *Alvin*'s list of achievements.

These went beyond purely scientific discoveries. They also included such an important "social" breakthrough as carrying the first women scientists into the deep ocean. Harvard biologist Ruth Turner went down in *Alvin* as early as 1971. Perhaps most important of all, *Alvin* proved what its proponents had said from the very first: that a submersible could become a reliable research tool for the entire oceanographic community, not just the scientists from Woods Hole.

For this reason, unlike some of the less successful submersibles of similar vintage, *Alvin* managed to weather periodic economic crises created by reductions in government funding for oceanography. *Alvin*'s major patrons have been the Office of Naval Research, the National Science Foundation, and the National Oceanic and Atmospheric Administration. The typical cost for taking the sub to sea is about $20,000 a day. Recently, *Alvin* has averaged 175 dives a year.

The lessons of *Alvin*'s success haven't escaped the attention of oceanographers overseas. In France, the Soviet Union, and Japan, submersibles—some of them *Alvin* lookalikes—that can dive deeper than *Alvin* are now either available or under construction. This suggests that the original may soon have to undergo another metamorphosis so it can match or exceed those depths. In any case, the spurt of submersible-building is in itself something of a birthday tribute to *Alvin*. It's one more sign that the little submersible out of Woods Hole has opened up not only the murky depths but the scientific mind as well.



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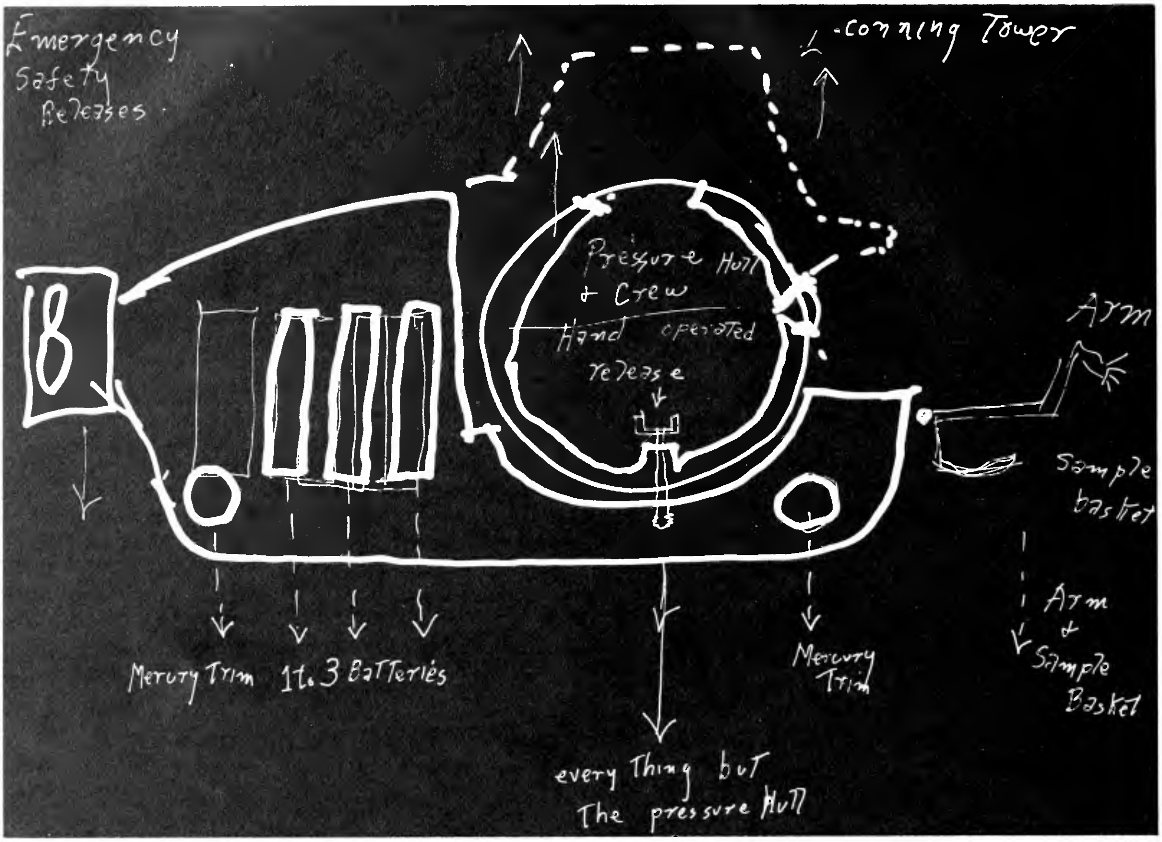
**Acknowledgment**

This special issue on *Alvin* could not have been undertaken without the advice and counsel of Barrie Walden and his *Alvin* Group, who helped steer us through potentially stormy technical waters; Bill Dunkle, WHOI's archivist who guided us to many vintage photographs; WHOI science writer Victoria Kaharl, who graciously let us read a draft of her forthcoming *Alvin* history, or any of the other authors in the pages that follow who very kindly contributed their words and ideas to this commemorative enterprise.



*The author's sketch illustrating the emergency safety features of* Alvin. *Should the sub become unable to surface normally, the batteries, the mercury trim, and finally everything but the pressure hull could be dropped to allow the surfacing of the pressure hull.*

# The Birth of *Alvin*

### by Allyn C. Vine

For land scientists life is relatively easy. They can sample and inspect rocks, plants, and animals almost at will. But oceanographers have a much more difficult time examining the seafloor. Although they did remarkably well with nets, corers, grapples, and other ingenious sampling devices for many years, the essential nature of the ocean depths long eluded them. Not until the perfection of the echo sounder, undersea cameras, and seismic profiling (a technique that uses sonic echoes to map the seafloor, *Oceanus* Vol. 22, No. 3, cover) in the years after World War II was the complexity and variability of the ocean floor fully appreciated.

Inspired by these new findings, a few of us began to argue that oceanographers should be able to enjoy the same easy access to our subject matter as our colleagues who worked exclusively on land. One obvious approach would be to develop closed-circuit television systems, carried to the seafloor by largely self-sufficient robots, which could act as the electronic eyes—and perhaps even the mechanical arms—for shipboard scientists. Another approach was to develop small deep-diving submersibles that would enable scientists to explore the seafloor directly.

Today, of course, both options are available. But at the time, a small group of oceanographers at the Woods Hole Oceanographic Institution (WHOI) and elsewhere felt that it was preferable to look at this exciting "last frontier" directly from small deep-diving manned submersibles rather than with remote viewing systems.

By the 1950s, these ideas had gathered support at higher levels. Several reports strongly recommended incorporating manned submersibles into the oceanographic research fleet. And scientists and engineers at the Office of Naval Research (ONR), especially those who had worked with submarines during the war, gave them a sympathetic hearing. By contrast, those whose experience was largely limited to surface ships were at best lukewarm to submersibles.

### An Invitation to the Piccards

Then, on 1 March 1956, under the auspices of the Navy and the National Academy of Sciences leading oceanographers strongly endorsed the potential of submersibles as a research tool. This encouraged the Navy to get more deeply involved with them. One of the outcomes was an invitation to Jacques Piccard, son of submersible pioneer Auguste Piccard, to bring the deep-diving bathyscaphe *Trieste* to San Diego to work with Navy and civilian scientists on the biological and acoustical character of the deep scattering layers. These are the broad areas of sound reflection detected by echo sounders at depths of several hundred meters, that seem to move down in daylight or bright moonlight. This rise and fall suggested that the layers were of biological origin, probably corresponding to the movements of schools of fish and plankton.

Eventually the Navy bought *Trieste*, and on 23 January 1960, Piccard and Navy Lieutenant Don Walsh set a deep-diving record that still stands, by taking the bathyscaphe to the bottom of the 37,795-foot Marianas Trench in Pacific. This demonstrated that scientific submersibles could operate in the deepest areas of the sea.

An important byproduct of the Navy's *Trieste* program was that it provided deep submersible training for a forward-looking cadre of young Navy officers and enlisted men who would later became influential in many aspects of deep-sea research. One of these officers was Larry Shumaker, who became chief pilot of *Alvin* and manager of the *Alvin* program after his retirement from the Navy. Another was Rear Admiral John B. Mooney Jr., who became Oceanographer of the Navy and later Chief of Naval Research.

Another boost for submersibles came from influential reports issued by ONR and the National Academy of Sciences, outlining proposed directions for oceanographic research in the coming decade of the 1960s. These emphasized the need for new and better research vessels, including ones that could go into the ocean depths. Then on 4 October 1957, the Soviet Union provided an indirect incentive with the successful launch of Sputnik I, the first earth satellite. Though the little unmanned spacecraft explored the heavens rather than the "inner space" of the deep ocean, this display of Soviet technological and scientific prowess sharply increased American interest in, and the funding for, all sorts of scientific research, including oceanography.

*Litton Systems engineers commemorate the completion of their new creation of 1964,* Alvin. *(WHOI archives)*

Established oceanographic centers wouldn't take on the job of designing, funding, constructing, and operating a deep submersible by themselves. It needed the Navy's strong support, which was not only financial but moral, in the form of backing from such enthusiastic and knowledgeable Navy officers as Commanders Charles Bishop and Charles (Swede) Momson of the Office of Naval Research and Captain Richard (Skee) Dzikowski of the submarine desk at the Bureau of Ships.

Individual scientists and engineers began to look into particular aspects of such a large and difficult undertaking. At the Southwest Research Institute in San Antonio, Texas, Edwin Wenk led a team working on deep submersible design.

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*Allyn C. Vine, Scientist Emeritus at the Woods Hole Oceanographic Institution, is one of the earliest and most persistent exponents of the use of deep-diving submersibles such as* Alvin *in oceanography.*

While investigating aluminum as a hull material, he found an enthusiastic supporter in J. Louis Reynolds, vice president of the Reynolds Metals Company.

Under a proposed pact with the Navy, his company agreed to sponsor the construction of a 42-foot submersible, called *Aluminaut.* WHOI would operate it for scientific work, and ONR would pay the bills. At Woods Hole, we drew up contracts and operating plans. Pilots and maintenance people were hired. The project seemed off and running. But then there were snags. Disagreements developed over the cost and extent of modifications for safety reasons, as well as the issue of ultimate ownership—Reynolds wanted permanent title after WHOI and the Navy were through with renting the sub. Finally, the idea of a collaborative effort with Reynolds was dropped, and the company eventually completed and operated *Aluminaut* on its own. A good thing, too, because it was *Aluminaut* that helped retrieve *Alvin* from the depths after it accidentally sank off Cape Cod in 1969.

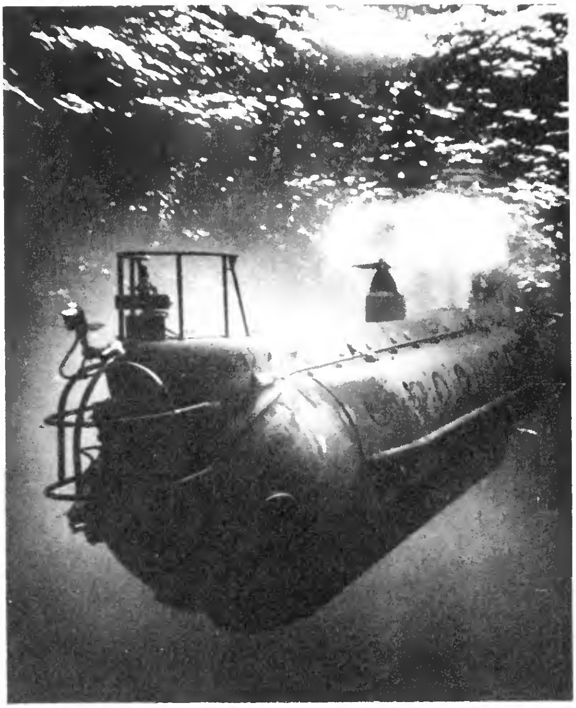
### Turning to General Mills' *Sea Pup*

Once WHOI bowed out of the *Aluminaut* project, our attention switched to a design by Harold Froehlich, an engineer at the electronics division of the General Mills Company in Minneapolis. Froehlich had proposed a very simple 15-foot submersible called *Sea Pup*. The General Mills division built mechanical arms for industry, and Froehlich hoped that submersibles might provide a future market for such devices.

Smaller, simpler, and less expensive than *Aluminaut, Sea Pup* looked to us like a possible way to continue our quest for a submersible within available budgets. With Navy cooperation, our group at WHOI, under the leadership of Earl Hays, drew up specifications for a somewhat changed and enlarged version of *Sea Pup* that was deemed more suitable for the anticipated scientific work. WHOI put this proposal out to public bid, and after discussions with several potential builders, General Mills was awarded the contract. The cereal maker initially offered to build the sub for less than a half million dollars. After WHOI's additions and changes, it would cost nearly twice that amount. Meanwhile, General Mills sold off its electronics division to Litton Systems, Incorporated. Litton, however, let Froehlich complete the job.

On 5 June 1964, as a spring sun shone brightly overhead, the little sub was christened at Woods Hole. It was no longer *Sea Pup*. It had become *Alvin*, a name that was already being used informally by WHOI's Deep Submergence Group, which was in charge of preparing the submersible for sea duty. I'm told the name was picked in my honor for campaigning so long and hard for the little sub, but I also know that it was the name of a popular song and cartoon character at the time—Alvin the chipmunk!

I wasn't able to attend the festivities because I was 18,000 feet down in the Puerto Rico Trench in the new French bathyscaphe *Archimède*. But Adelaide, my wife, smashed a bottle of champagne across the sub's sturdy mechanical arm. With that, the little boat had joined the oceanographic fleet. Though we still faced such problems as training pilots and crew, debugging, getting certification from the Bureau of Ships, and installing scientific apparatus, we finally had a real submersible—not just drawings of one. Now the *Alvin* gang could get to work.



*Alvin's sometime rival, sometime partner, and one time rescuer,* Aluminaut. *(WHOI archives)*

Early usage was to be close to home because of the relatively easy logistics. In summer, *Alvin* would be in waters off New England, concentrating on the biology and geology of the many submarine canyons. In winter it would move down the coast, and work near the mile-deep Tongue of the Ocean Basin, near Nassau in the Bahamas, which was protected from big ocean swells. The U.S. Navy also had an acoustical test range there, where *Alvin* could help with underwater inspections and repairs. But as our experience and confidence grew, *Alvin* operated much farther from home, in more distant seas.

### Making the Tradeoffs in Design

In laying out our original specs, we had considered a number of issues. One key question before us was how deep should our submersible be able to go? The answer invariably demanded tradeoffs: if the hull were strengthened by being made thicker, then the payload, for example, would have to be reduced.

Operating depth can theoretically be increased by using a light hull material such as aluminum, or a stronger material such as high-strength steel, or an in-between material such as titanium that combines light weight and strength. All these possibilities were considered. The titanium hull appeared the most promising to a few of us, but it wasn't chosen initially because of the cost and the added time that would be involved. Instead, the choice was a good high-strength steel that gave us an operating depth of 6,000 feet. (Ten years later we would double the working depth with a new hull of titanium.)

From the beginning, we hoped that the submersible would carry two scientists and one pilot. Even so, *Alvin*'s initial design called for a two-seater to keep it from getting too big, and to ensure that there wouldn't be two pilots and only one scientist.

Most important was the issue of safety. No one—not WHOI Director Paul Fye, or our naval architect, James Mavor, not our ONR sponsors, and certainly not the pilots or scientists who would go down in the sub—were willing to compromise on safety. Also, in enforcing safety rules, the Bureau of Ships had every intention of being as tough on little submarines as it was on big ones. But safety also posed a quandary. Everyone wanted to be as strict as possible, yet safety standards for research submersibles were an unknown. None had yet been carefully described or officially accepted. Still, there were some things we could obviously ignore: as a nonmilitary research vessel dedicated to peaceful work, *Alvin* didn't have to be built to withstand depth charges. Also in our favor was the intended mode of operation: being small, *Alvin* would be recovered from the water after each dive—in effect, "dry sailed," as yachtsmen say—and could be looked over thoroughly like a small boat. (In fact, the U.S. Coast Guard considers it a small boat and inspects it accordingly.)

Size was also a help in safety. *Alvin* had far fewer parts—valves, motors, cables, and the like—than a large submarine. So there were fewer components that could fail. Also, apart from the ports, there was only one hull opening (a hatch for getting in and out); unlike conventional subs, *Alvin* had no additional apertures for torpedoes, garbage, or cooling water. And with batteries, motors and all major wiring outside the pressure hull, no hydrogen could build up inside, thereby greatly reducing the chance of a fire onboard.

*WHOI ocean engineering technician, George Broderson, putting the finishing touches on* Alvin's *first pressure hull. (Photo courtesy of WHOI)*

Another factor in our favor was people. William O. Rainnie Jr., the chief pilot, and Marvin J. McCamis, Valentine Wilson and Ed Bland, the three original relief pilots, were all ex-submariners with plenty of saltwater experience. They knew submarines, and had the respect of the Navy sub people, which helped to get *Alvin* certified by the Bureau of Ships. One meeting in Washington still stands out in my mind: the Bureau's Dzikowski, who believed this was the kind of R & D the Navy should support, told his somewhat hesitant inspectors: "Certify it, or fix it up and then certify it."

We had tried to think of almost every conceivable situation that might imperil human life, and devised ways to avoid such crises. *Alvin*'s major safety feature was the crew's ability to return to the surface by releasing the pressure hull—the sphere that formed their compartment— from the sub's propulsive underbody and chassis. In that way, the crew could escape if, say, the sub's arm or other projection became entangled in debris on the bottom.

At first, some people were uneasy about the four plastic portholes—one in front for the pilot, two on the sides for the science observers, and a fourth on the bottom. However, extensive testing, as well as the existence of somewhat similar ports on *Trieste*, reassured them. The pilot's porthole let him look straight ahead. In clear water he might be able to see fifty feet. But in water thick with mud or plankton, his vision wasn't more than a foot in front of the sub. So it became important to incorporate sonar, letting the sub maneuver in the deep by reflecting pulses of sound off objects, as whales and dolphins do. The system eventually installed was somewhat like a mine-hunting sonar; it could usually "see" large objects hundreds of yards away and smaller ones tens of yards away. The system also was designed to keep *Alvin* from becoming ensnared in old cables on the bottom.

*Alvin* was designed to be highly maneuverable. Its props—a large one aft, two smaller ones on the sides— enabled it to make very sharp turns, even at zero forward speed. Its backup power, achieved by reversing the props, was designed so that if an object were sighted only ten feet ahead, the submarine could still stop and reverse in that distance. (Bathyscaphes such as *Trieste* and *Archimède* are much less maneuverable.)

The breathing equipment, relying on tanks of oxygen, and canisters of lithium hydroxide that absorbed carbon dioxide, was designed to support three adults for about two days (now lengthened to three), even though dives wouldn't normally take longer than 8 to 12 hours. In an emergency, the crew and support personnel on the surface would have a day to figure out how to get the ship to the surface before "abandoning" ship—that is, releasing the pressure hull with its passengers and letting it float up like a balloon. Except for tests in Woods Hole, we never had to resort to such a drastic procedure.

### Two Classes of Instruments

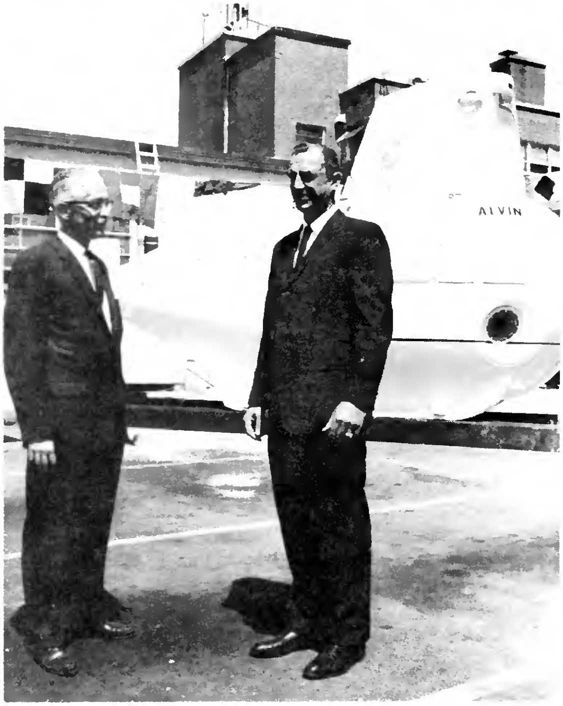
Instruments fell into two classes. The first group was for the operation and safety of the submarine. It included depth gauges, a gyrocompass, an underwater telephone (using acoustic signals rather than a wire) to communicate with the mother ship, controls for propulsion and maneuvering, life-support apparatus, and so on.

The second group of instruments consisted of scientific apparatus. These could be loaded on or off at will, or even altered, depending on the scientific requirements of a particular dive. Very strict weight considerations (no more than 400 pounds of payload) limited the number of instruments aboard at any one time.

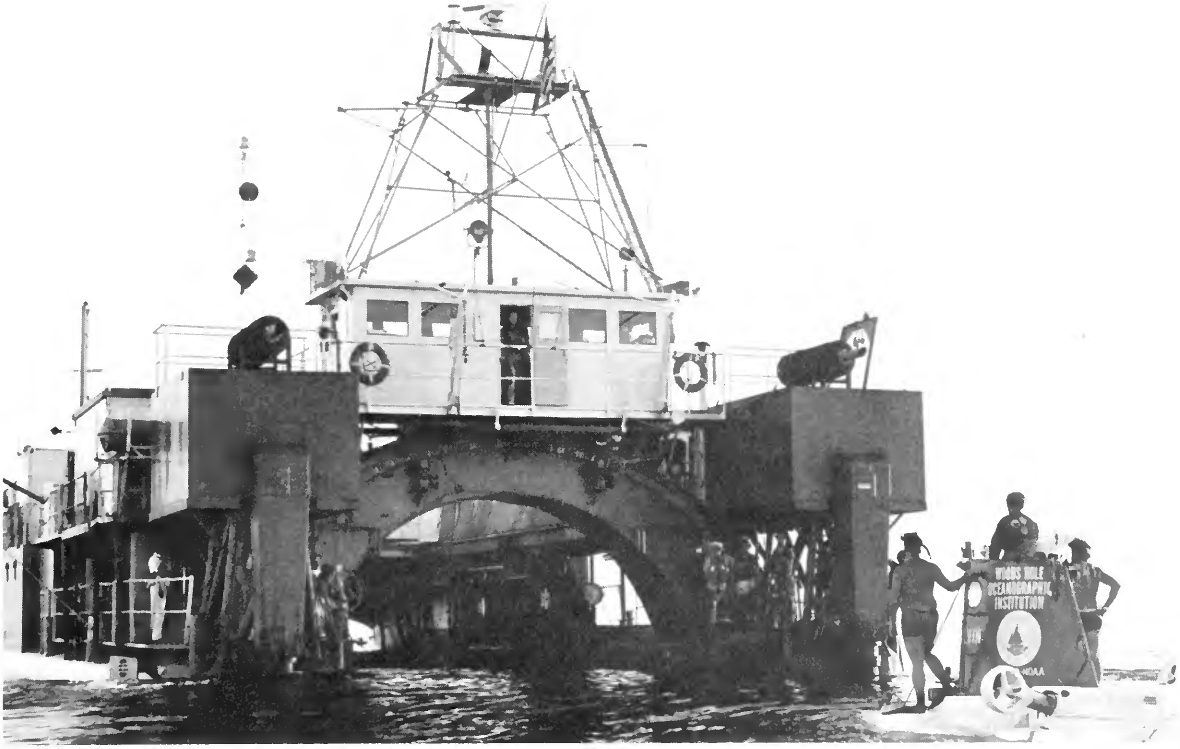
William N. (Skip) Marquet and his instrument group at WHOI used considerable ingenuity, to say nothing of their long hours of work, to cram as many instruments as possible aboard in the shortest possible time, but they sometimes encountered an insurmountable obstacle: oceanographers who went down in submersibles tended to be above average in size.

Another important—indeed,vital—feature was the mechanical arm. To see something interesting through the porthole is wonderful; to get a picture is even better. But to return to the surface with a carefully selected and preserved sample is best of all. From the beginning, *Alvin*'s mechanical arm accounted for a sizeable portion of its payload, as well as its budget. Considering the number of things it has picked up from the bottom—from rock samples of the Mid-Atlantic Ridge to the strange fauna that dwell around the hydrothermal vents—this has turned out to be a very logical decision.

A major technical achievement was the



*Paul Fye (left), WHOI's fourth director, and William Rainnie (right),* Alvin's *first chief pilot. At top, dignitaries, WHOI employees, and townspeople turn out for* Alvin's *commissioning on June 5, 1964. At middle, with an "I christen thee* Alvin,*" and a splash of champagne, Adelaide Vine does the honors at the baptismal ceremony. (WHOI archives)*

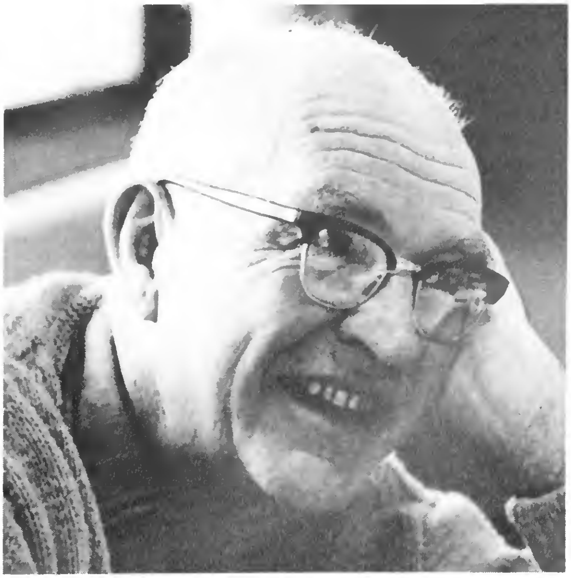


Lulu *awaits the return of* Alvin *at the end of a dive.* Lulu *served as the mother ship until* R/V Atlantis II *was modified to perform this function in 1983. (Photo courtesy of WHOI)*

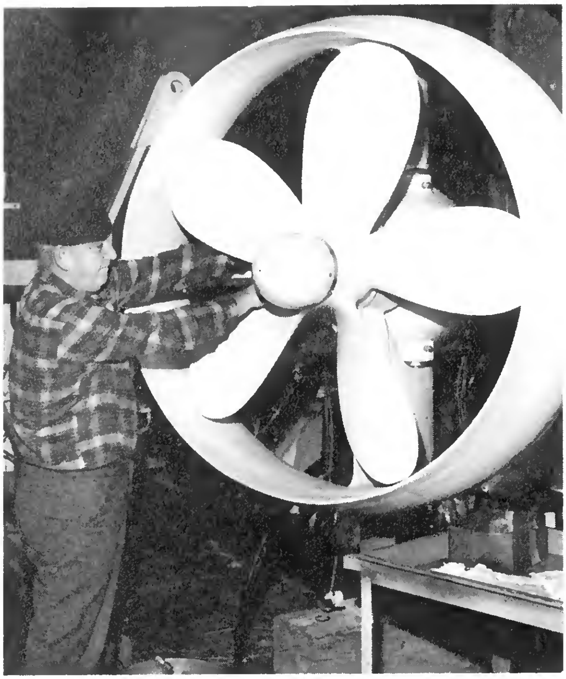
development of a bottom-beacon acoustic navigational scheme. Three acoustical beacons were placed on the ocean floor, which could listen to pings from the submarine and relay them to the surface. By comparing the different arrival times of these sounds with those picked up directly from the sub, surface controllers could triangulate *Alvin*'s position and advise it where it was. Since then, this navigational method has been widely adapted in bottom research even when no submarines are used, as in the deep-sea drilling voyages of the *Glomar Challenger*, or some of the recent work on the *Titanic*.

### The Debut of a Mother Ship Named *Lulu*

Unlike larger submarines, a small submersible clearly needs a capable mother ship, which determines how far it can go, the sort of bad weather it can operate in, and how big a scientific and maintenance group can join the expedition. At first, *Alvin* was launched by a crane from the dock, then from a barge. Soon, a 100-foot catamaran was improvised from two large surplus Navy pontoons—one hull for machinery, the other for living quarters. Laboratories were installed in portable vans on the deck. Propulsion came from large diesel outboards at the stern of each pontoon. The speed was slow (no more than 8 knots) and the living primitive—crew and scientists slept in the pontoons—but the cost was low, and the *Alvin* group finally became reasonably self-sufficient. Earl Hays, who ran the *Alvin* program, named the mother ship *Lulu*, after my mother, a lady who didn't particularly like ships or the sea, but was happy one of her children did. (The repeating



*Earl Hays, the* Alvin *group's first project leader. (WHOI archives)*



Alvin's *original stern propeller gets a final inspection before installation. (WHOI archives)*

syllables made an especially fitting name for a twin-hulled ship.) Such gestures, in any case, were typical of the esprit de corps of the *Alvin* group.

*Alvin* was carried on deck on a midship cradle that could be lowered into the water by steel cables. When afloat, *Alvin* would back out between the hulls, guided by helpers alongside who handled her mooring lines. Once *Alvin* was clear of *Lulu*'s props, the lines would be taken off by swimmers, the pilot would go below, close the hatch, and test the underwater telephone and report, "Ready for dive!" Swimmers would then doublecheck if all was well outside the sub. When the pilot, or surface controller, on *Lulu*'s bridge gave permission to dive, *Alvin*'s pilot would start down.

Surfacing procedures were essentially the reverse of the launching, except when the weather turned bad. On those days, the handling crew, headed by its colorful crew chief, George (Brody) Broderson, performed heroic feats in getting *Alvin* back on board unharmed, and earned the gratitude of all involved.

As experience with *Alvin* grew, new operations brought on additional needs, and better ways for accomplishing them. Both pilots and researchers were greedy: they always wanted more depth, more range, better instruments, and increased capability to operate in rougher weather. To meet these needs, unlike most submarines, *Alvin* and its supporting systems were continually altered and improved.

By 1970, funding for a major overhaul finally enabled us to order the titanium hull that we had considered from the start. It doubled *Alvin*'s depth capability to 12,000 feet, and finally let us explore at the average depth of the ocean (about two miles), including the mid-ocean ridges, where new seafloor is being created through upwellings of lava from within the Earth (pp. 34–40).

In retrospect, the level and breadth of cooperation that this little project received—from the government and industry, from scientists in the U.S. and abroad—was little short of amazing, and certainly heart warming. This was evident even at the christening, which was attended by hundreds of people—scientists, politicians, high-ranking Navy officers—who crammed into the WHOI parking lot on that pleasant spring day 25 years ago. There may have been some differences of opinion then as to how well the experiment would work out, but there was no doubt about *Alvin*'s potential for scientific research—a faith that has turned out to be well repaid by *Alvin*'s crew and the submersible's scientific programs.

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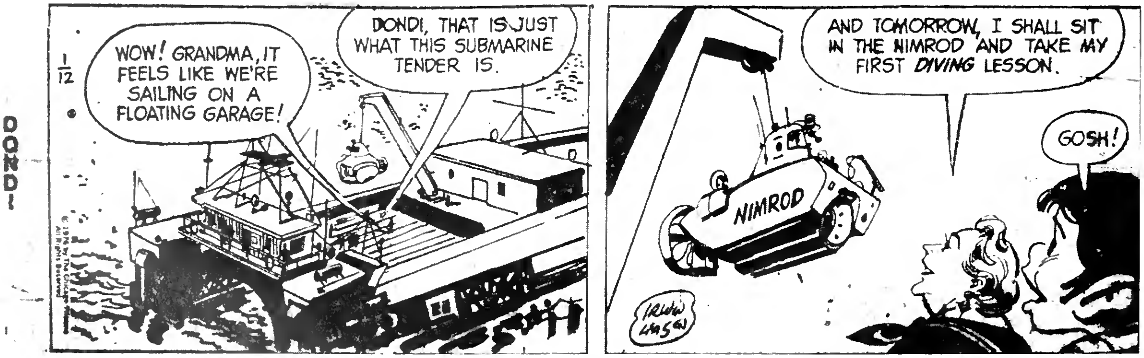


Alvin's *exploits have captured the imagination of syndicated cartoonists as well as scientists.*

## A Pilot's View

# Some Dangers and Many Delights

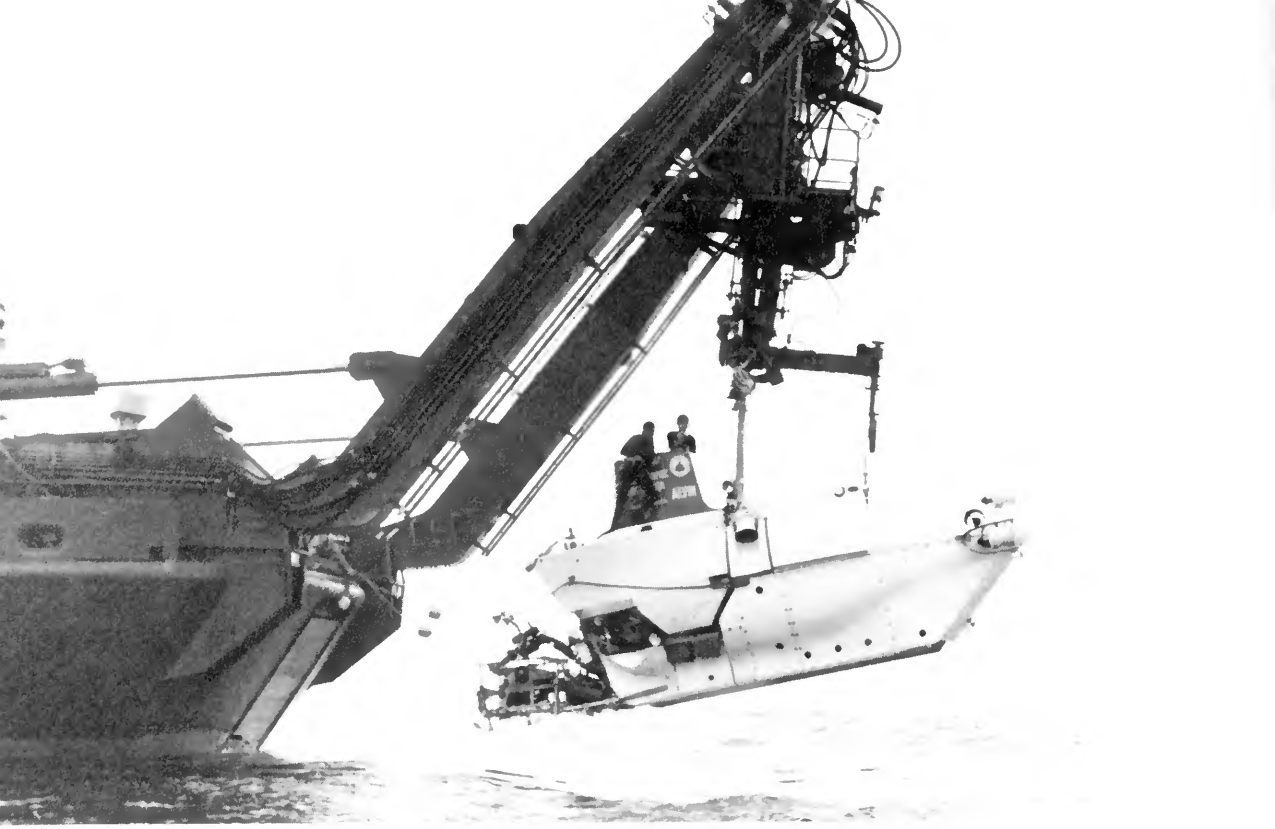
*Peering into the depths of the Cayman Trough in 1976. (Photo courtesy of WHOI)*

### By Dudley Foster

We pass 8,000 feet. I scan my instruments, checking attitude, heading, vertical speed, and the electrical system. They are my only reference to the outside world, which is blacker than any night and near freezing cold. Inside, things are calm and quiet. Only the whine of the gyro and soft discussions of our mission by the two science observers break the absolute silence. We'll be leveling off soon, and I know the scene will change to one of rushed activity.

I think how similar this is to the nights I flew jets for the Navy in the late 1960s. But now I am piloting *DSV* (for Deep Submergence Vehicle) *Alvin*, the three-man submersible owned by the U.S. Navy and operated by Woods Hole Oceanographic Institution.

My day had started at 5:30 A.M. aboard the *R/V Atlantis II*, the 210-foot research vessel that



*Divers aboard,* Alvin *is lowered by the A-frame crane on* Atlantis II*'s stern. (Photo courtesy of WHOI)*

carries *Alvin* and acts as its mother ship. I sought out the two scientific observers for the day and discussed our mission. We would look for geyser-like eruptions on the seafloor, sample sulfide deposits around these hydrothermal vents, and collect biological samples in the vicinity of the hot, sulfide-rich waters. I arranged water sampling bottles, scoops, nets, and retrieval chambers in *Alvin*'s external basket. By 7 A.M., our well-trained crew had completed the 14 pages of predive checks to ensure that the sub was ready for diving. I entered *Alvin*'s two-foot-wide hatch and began powering up the systems to check their operation. Battery voltages, ground detector circuits, communications equipment, sonar gear, life support, propulsion and hydraulic systems, manipulators, dataloggers, video and still camera systems, variable ballast system, weight dropper circuits—the list goes on: all had to be checked and operating properly.

### Down to the Depths

By 7:30 A.M., the surface controller for diving operations, working with shipboard navigation equipment, had *Atlantis II* positioned over the dive site. *Alvin* was pulled from its hangar and positioned under the giant A-frame crane on the fantail. I climbed atop *Alvin*, and as the crowd gathered to watch the launch, I jokingly asked if anyone would like to go ashore. We three would be the only ones on *Atlantis II* to be "touching ground" today.

The designated observers quickly joined me for boarding. I turned on vital equipment and carefully sealed the hatch. We were now encapsulated in a seven-foot titanium sphere capable of sustaining us for three days in an environment that would, in event of a failure,

*Pilot Foster in the midst of predive safety checks. (Photo by Cindy Van Dover)*

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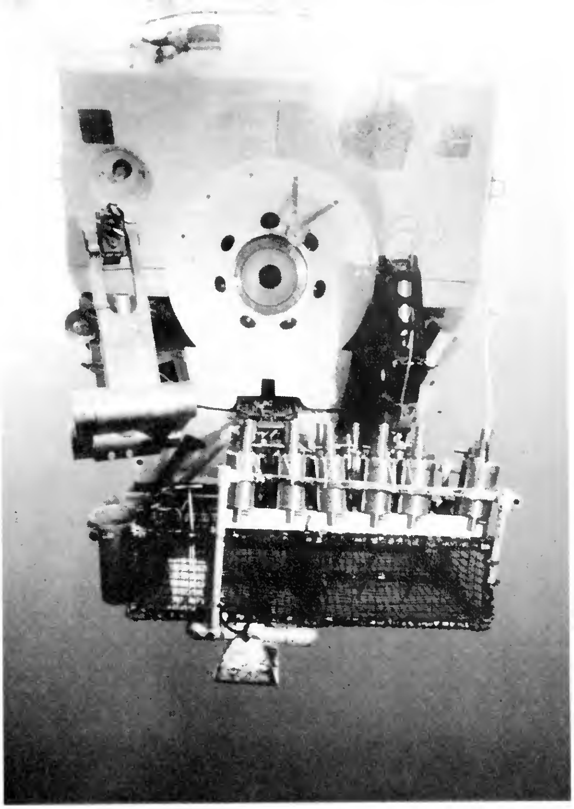
*Dudley Foster is* Alvin*'s senior pilot, and has made some 325 dives in the little submersible since joining the Woods Hole Oceanographic Institution's Deep Submergence Group in 1972.*

crush us with nearly 4,000 pounds of pressure per square inch. Although we'd be diving to only 8,000 feet today, *Alvin* could easily dive to more than 13,000 feet, where the pressure would rise to nearly 6,000 pounds per square inch.

The A-frame had effortlessly lifted 34,000-pound *Alvin* over the fantail of the ship and into the water in less than three minutes. I had done my final dive checks, flooded the main ballast tanks, and begun the 100-foot-per-minute descent.


*About to descend for another scientific mission. (Photo by Rod Catanach, WHOI)*

Now we're about 600 feet from the bottom. We've been drifting downward for nearly two hours. I prepare for our "landing" by turning on the sonar system and outside light. The sonar shows a scarp, or vertical wall, about 600 feet away. I turn toward it, anticipating that we'll get closer as we approach the bottom. At 200 feet altitude, I drop the 500 pounds of ballast (in the form of bolted steel plates) that has allowed us to free fall this far without using *Alvin*'s propulsion batteries. We're still drifting slowly down; apparently our science payload is a little heavier than we had thought it would be. I turn on the variable ballast pump, and water in our tanks—two-foot diameter spheres—is pumped out, increasing the sub's buoyancy. At 50 feet above the bottom, *Alvin* comes to a halt.

Neutrally bouyant, we drift slowly in a weak current of perhaps a quarter of a knot. We are a large suspended mass amid thousands of small particles, slowly moving fish, and gelatinous creatures. For a moment, I gaze at the wondrous variety of microorganisms, visible only if you let your eyes focus on a point in the water only two or three feet in front of you. Then back to business: I use the vertical thrusters to propel us gently to the sediment bottom.

### A Tight Squeeze

The seafloor has been pitted with burrows made by unseen creatures, though some of its life is visible. We see brittle stars moving across the bottom, using one of their five legs as if it is a pointer while the others follow behind. We also notice sea cucumbers, trailed by a continuous bead of digested sediment. But *Alvin*'s bow wave rolls the virtually weightless critters away.

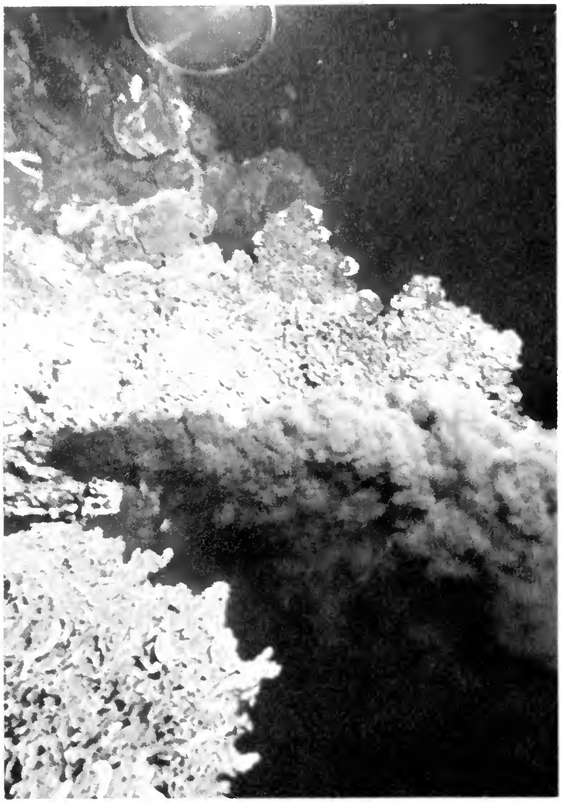
We're moving at barely a knot toward the scarp. The sonar shows a canyon-like feature developing in it, so we decide on a closer inspection.

As we start into the canyon, we notice that our path along the bottom has become scoured with ripple marks. It reminds me of a desert gulley, carved by wind and flash floods. Now the sonar reveals both sides of the canyon, and I move over to the right wall, a nearly vertical limestone cliff. There's no debris at the base to sample, so I move the manipulator arm over to scrape the wall, checking its hardness. The steel fingers gouge the clay-like cliff, but the clumps of carbonate ooze through the jaws of my mechanical limb. I'll have to maneuver along the wall, hoping to find a loose sample elsewhere.

As we move deeper into the canyon, it narrows, and soon I can see both sides through the viewports. Because *Alvin*'s lights can illuminate only about 40 feet of the watery darkness in front of us, I judge that the canyon here is about 50 feet wide. Barely visible at its base is a possible sample. Moving forward slowly, I find the canyon narrowing still more. By now, the canyon walls are only about 12 feet apart, and just ahead the seafloor veers sharply upward. I see only sheer cliffs on either side, that look as if they're curving in over the sub. But I decide that it's only a distortion created by the viewports. Or is it? I wonder. My apprehension grows as I think of how many pilots I knew in the Navy who crashed because they'd flown into canyons from which they couldn't fly out.

My situation is similar: In this narrow space, I can't turn the 25-foot sub around. And I can't back up because there are no rear viewports. But even if we had them, the props would churn up so much sediment that I'd be blinded. Nor do I want to go up and risk disturbing the soft sediment cliffs. They could easily collapse and bury the sub. One of the science observers, unaware of our predicament, sees the sample I was heading for and implores me to pick it up. I tell him not to get excited: he may have the rest of his life to get the chunk of clay.

The only way out, I finally decide, is up. So I slowly move up and forward, doing my best to stay between the walls. Slowly, slowly, only



*A black smoker spewing sulfide-rich, 350-degree-Celsius water. If* Alvin *would approach such springs too closely, its windows would melt. (Photo by John Edmond)*

inches at a time. After about 30 feet, the top edge of the wall comes into view, and for the moment, I can relax. As *Alvin* goes over the top and onto a sediment plain, I wonder whether the sample is really worth the grey hairs.

From *Atlantis II*, the surface controller sends word that the target is 1,500 meters, or about a mile, ahead. He bases his calculation on signals received from the long baseline acoustic navigation system we'd placed on the ocean floor at the start of the cruise. We continue across the sediment plain and start to see isolated outcrops of old basalts, the dark volcanic rocks typical of oceanic rifts. Farther along, the basalts become fresher with less sediment cover. We've been going uphill slowly, and now see large bulbous formations called pillow basalts, many of them covered with grotesque buds. These have a shiny coating of "glass," or obsidian, formed when the molten lava that created the pillows was quickly quenched as it emerged from the rift by the cold water. This is a good indication that the rocks are relatively fresh, geologically speaking, since the glass on older basalts would have long since weathered.

### A Deep-Sea Stonehenge and China Shop

As we go over the crest of the hill, the pillow basalts flatten and the bottom drops away. The altimeter says we're 20 feet off the seafloor. I can see from the sonar that we're suspended above a large oval pit. We start descending and see large isolated columns, looking like megaliths of an undersea Stonehenge. We've come into a lava lake; the columns were left behind when the molten lava around them receded back into the Earth.

The bottom of the pit sparkles with the reflections of our lights, as if thousands of diamonds are scattered about. I hear the crinkle of broken glass. We're breaking up the glass surface of this very fresh lava as we slide over it.

We continue across the pit and up the other side. Until now, the marine life here has been pretty sparse compared to the sediment's, but suddenly the number of galatheid crabs increases. Such a "crab gradient" usually means we're near an active vent. Another hint: the appearance of a few dead, partially dissolved foot-long clam shells.

As we follow the steepening slope, the black basalts change to a reddish brown deposit. The small crabs are now everywhere, and we sight several large spider crabs as well. Large live clams, *Calyptogena magnifica*, up to a foot across, are nestled in depressions between outcroppings of basalt. I maneuver *Alvin* into position and carefully pick up some of them with our mechanical arm and place them in our external sample box. Cautiously, we approach a large, vertical, sulfide structure, identifiable by its reddish-brown color. The rich concentration of life around it indicates that it's probably venting hot water. Colonies of six-foot tube worms, *Riftia pachyptila*, are clinging to the sides of this sulfide "chimney," anchored in its crevices and bathing in its warm water. Crawling among the worms are brachyuran crabs, *Bythograea thermydron*. They're trying to nip a bit of the brilliant red plumes that the worms wear like feathers at their exposed ends. The plumes quickly retreat into their Teflon-like sheaths whenever the worms are disturbed, but missing chunks of plume show they're often not quick enough. In this thriving

*Foster guiding Robert Ballard through the Galápagos Rift, in 1979. (Photo courtesy of WHOI)* community there also lives a large collection of limpets, shrimp, fish, and mussels. I grab a clump of tube worms near their tops, hoping they'll retract enough to minimize damage, and rip them out of the crevice to stuff into the sample basket.

At the top of the chimney, a great blast of black "smoke" is shooting up from a small stack about six inches across and two feet high. It looks like an Old West locomotive at full throttle, the smoke rising and diffusing in the currents. I carefully position the smokestack between the side of the basket and the manipulator. With a quick side stroke of the manipulator, I knock the top of the stack into the sample basket. The flow is even greater now, with the water blasting out of a 3-inch diameter hole. I pick up our temperature probe and insert it into the searing gusher. We watch the datalogger excitedly as the temperature soars through 250, 300, 325, 358 degrees Celsius. That's more than 675 degrees Fahrenheit! At that temperature the water would be steam if it weren't for the extreme pressure here. We're only a few feet away. But we dare not go any closer because our acrylic plastic viewports would start to soften at about 200 degrees Fahrenheit. With the manipulator, I pick up a hot water sampler—actually, a high-tech syringe made of titanium—and insert it into the flow to draw a sample. I try to keep the sampler's nozzle well down in the vent to keep the sample from being contaminated with ordinary sea water. To stop the sub from moving during this delicate procedure, I remind the observers to remain still.

### A Relaxing Ascent, A Jolting Pick-up

We've been on the bottom now for about four hours, and I call the surface controller for clearance to return. Advised that no ships will be in our way when *Alvin* surfaces, I move away from our work area, drop another 500 pounds of steel, and begin rising. It's been a productive dive and, as *Alvin* floats up, I finally have a chance to chat with my two diving companions and get to know them a little better.

When we arrive at the surface, *Atlantis II*'s small launch is waiting. I blow air into the main ballast tanks for additional buoyancy and more freeboard, as the swimmers attach safety lines to the sample basket and prepare the outside of the sub for recovery. We're towed to the stern of *Atlantis II* for pickup. The sea is unsettled, and the changing waterline on the hull show that the ship is pitching almost six feet. This could be a wild ride. I hear the launch coordinator tell the A-frame operator that the lift lines are on. Suddenly, there's a jolt, and I feel us start up out of the sea. As water spills down the sides of the sub, the view out of our ports looks like the window of a washing machine. As we swing perilously close to the A-frame, I hold my breath and hope that the basket or manipulators aren't clobbered. But the deck crew does its job expertly. The lines get snubbed, the sub straightens out, and the main hook is engaged, solidly securing *Alvin* to the A-frame. We're safely back on deck.

Still, several more hours of work remain. The scientists must begin analyzing, logging, collating, and storing samples. *Alvin*'s crew must complete five more pages of postdive inspections, make repairs, duplicate data, copy video tapes, and prepare the basket for the next dive. They must also help set up for night science work, complete paperwork for this dive, and prepare the paperwork for the next.

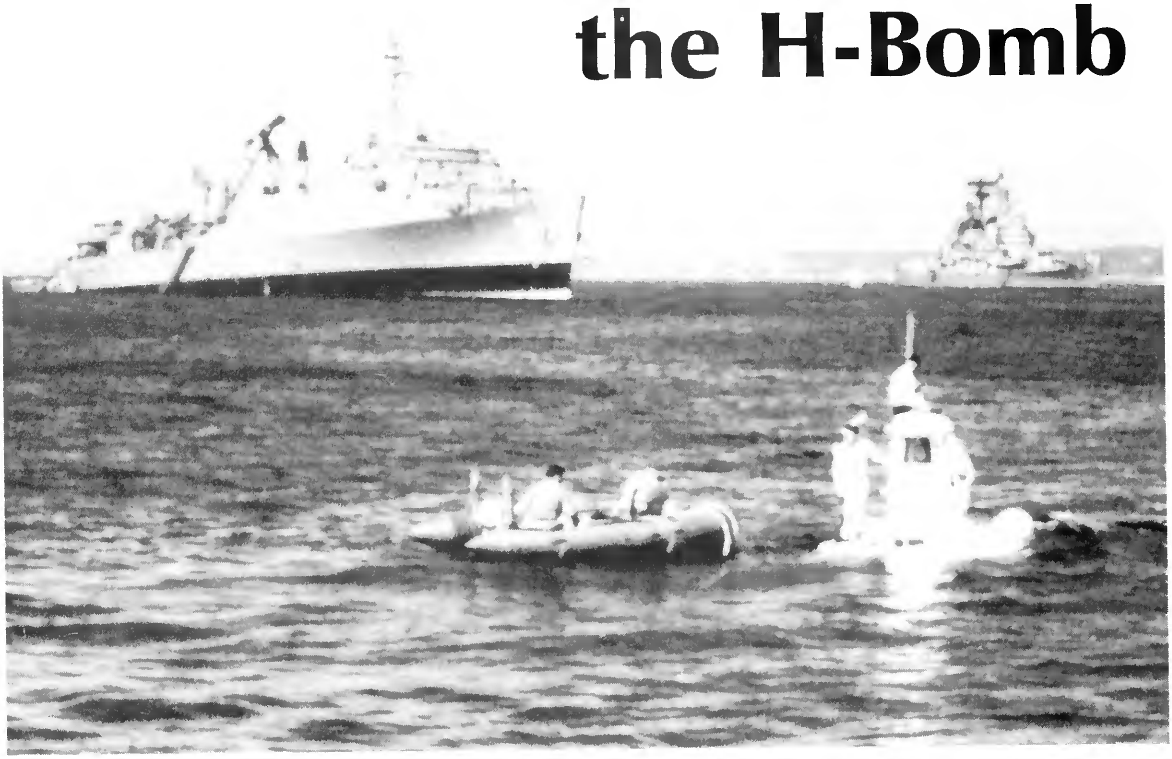
As we head for our next port, usually a voyage of two or three weeks, we'll continue our daily routine. In our three days in port, it would be nice to take in the sights, but there's too much to do. Besides periodic maintenance and jobs too time-consuming for hectic diving days, we must remove science equipment from the cruise we've just completed and install gear for the next one.

The months of seven-day work weeks are physically wearing, but the excitement of seeing a small portion of the Earth never seen before, or possibly ever again, keeps me looking forward to my next day at the bottom of the sea.

Spoke Too Soon?

*Courtesy of the* News-Times, *Portland, Oregon.*

# 'Captain Hook's' Hunt for the H-Bomb



*Alvin on the surface with some of the U.S. Navy ships assisting in the H-bomb recovery. (WHOI archives)*

## By Marvin J. McCamis

When the call came from the U.S. Navy, my hair stood instantly at attention. The Navy wanted the help of our little deep-diving submersible *Alvin* in the search for a lost 20-megaton hydrogen bomb. On January 17, 1966, an Air Force B-52 carrying 4 bombs had collided with a KC-135 refueling tanker in the skies over Palomares, Spain. Three multi-megaton bombs fell on Spanish soil, and a fourth bomb was missing in the Mediterranean Sea. We knew the U.S. government was in trouble and that the world would be watching. Everyone in our group was eager to help.

My life until then had been fruitful and exciting—20 years in the U.S. Navy submarine service, then to the Deep Submergence, or *Alvin*, Group at the Woods Hole Oceanographic Institution (WHOI). But never in all my experience had I encountered anything like this: an invitation to ride a submersible into the depths in search of a stray thermonuclear weapon.

As *Alvin*'s chief engineer and senior pilot, I knew we had our work cut out for us. At the time, the sub was completely disassembled for servicing and inspection. Yet by February 1, *Alvin* was ready and loaded onto an Air Force C-133 transport for the trip to Rota, Spain, near Gibraltar. After a very cold and rough ride over

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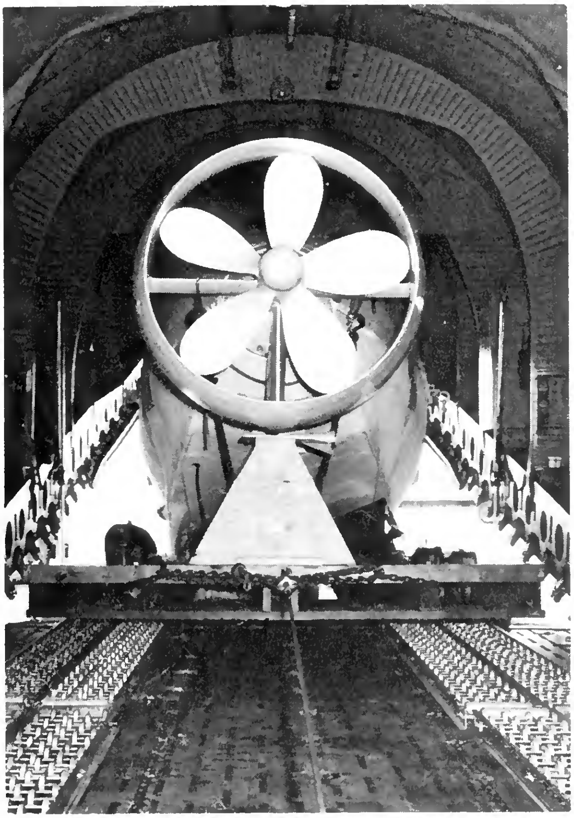
*Marvin J. McCamis served as* Alvin's *chief engineer and senior pilot until he left to set his own marine repair business in 1975. He is now the proud skipper of* Gemini, *out of West Palm Beach, Florida, a privately owned, classic wooden yacht once in the service of the* Duke and Duchess of Windsor.

the North Atlantic, including a stopover in Greenland to change a propeller that wouldn't stay in sync, *Alvin* was tested in the harbor. But the dive had to be aborted almost as soon as it began because of a saltwater leak into the batteries. Repairs took 3 days. We found that because of the faulty prop, a screw holding the battery covers had vibrated loose.

Apart from simply wanting to get the country out of a jam, we had a personal stake in the operation. This was *Alvin*'s first big job. Our group had proven that the sub could operate to depths of 6,000 feet—this was before she was rebuilt for deeper diving—but many critics still considered the entire deep submersible program a waste of money. An added incentive for us was the presence of a rival, Reynold's deep-diving *Aluminaut*.

We made a second test dive on February 9. This time everything worked. On the same day we loaded *Alvin* and her crew aboard the *LSD* (Landing Ship Dock) *Plymouth Rock* and joined Task Force 65 off Garrucha, south of Cartagena. There we transferred to the *LSD Fort Snelling*, which become our mother ship.



Alvin *entering the U.S. Air Force C-133 transport that carried the sub from Massachusetts to Spain. (WHOI archives)*

On February 14, the hunt began. It was our 110th dive with *Alvin*. Until then most of the work had involved testing and training. William O. Rainnie, Jr. and I were the pilots, and Valentine Wilson, a third pilot, was in charge of surface control. The surface controller, by clocking the acoustical signals from the sub—in those days, our voices, rather than a pinger—was able to keep track of *Alvin*'s movements and provide us with directions over the hydrophone link. (Conventional radio communications isn't practical at *Alvin*'s operating depths.) Whenever possible on subsequent dives, we rotated position of controller and pilot.

We began our search about 5 miles from shore. In this area, the floor of the Mediterranean follows a long, gradual slope. But as you move further from the coast, the bottom suddenly drops at a 45 percent incline. At 2,400 feet, there is a ridge, and the incline steepens to 70 percent. At about 3,000 feet, the bottom levels somewhat. Then a short distance away, it drops again. Finally, at 3,600 feet, it levels off.

The Navy had the search area mapped off in half-mile squares. Our task was to move back and forth across an assigned sector, covering every inch of the bottom in it.

*Alvin* is very maneuverable, much like a helicopter. The main prop at the rear, which swung from side to side, was for thrust and steering; the two lift props on each side were for moving up, down, or around. All were controlled by a single joystick.

At 1,800 feet, we had our first look at the bottom. *Alvin*'s powerful mercury-vapor lights gave us 20 to 25 feet of visibility. The bottom was muddy and featureless. Without vegetation, it resembled wrinkled old skin. If *Alvin*'s propellers happened to stir up the loose top layer, visibility dropped to zero.

Tracking across this blank terrain was discouraging. And as you listen to the tapes of our conversations inside *Alvin*'s personnel sphere, you find it hard to believe that Rainnie, Wilson, and I were working in complete harmony.

"Wait a minute. I see something."

"What?"

"I'm not sure."

"A little to the left. That's it. No, damn it! You went right over it!"

"What?"

"To the right, damn it! That's it. Right on target."

"What is it?"

"Tin can."

"You better get a closer look."

"I know a damned can when I see it."

"Well, let's get a picture of it."

"Back off a little and bring the nose down. You hear me? Bring the nose down! How the hell can I get a picture with the damned camera up in the air."

"How's that?"

"O.K.—good, I got it."

This is only a mild example of the dialogue. At times the language got much saltier.

Typically, we would dive 4 days, then take a day off for rest and repairs.

After two uneventful weeks, we decided to try something different. We'd been told that a Spanish fisherman had seen a large gray parachute drop into the sea, with an object attached to it, after the planes collided. On three occasions, when asked by the Navy to pick out the place where it had plunged into the sea, he took them out to the same site. He never used any navigational aid—just his good fisherman's sense of the sea. I wanted to search this area but couldn't get the Navy's approval. Also, no one had given us any idea what the bomb looked like. I made such a fuss about this that an Air Force sergeant finally took Wilson and me aside and showed us a picture of a bomb. He told us its length, diameter, and that the can at one end contained a 64-foot diameter cargo-type 'chute. Now we really knew what we were looking for, and the days passed quickly as we stepped up our search.

**March 1.** I was aboard the minesweeper *Ability*, taking my turn as the surface controller, assisted by WHOI's Earl Hays, our very able expedition leader. (We used *Ability* and *Mizar* for surface control rather than *Snelling* because it had none of the electronic gear that was needed.) We rigged up the crude tracking gear and started tracking *Alvin* not far from where the fisherman said he saw the object go into the water. This is my chance, I thought. I asked the captain if we might play stupid and search a little out of our area. He replied, "You're the controller—why not?" *Alvin* prowled the bottom, but Rainnie and Wilson found nothing promising—just more steep slopes and seafloor gullies.

Still, at the post-dive debriefing with task force leaders, during which we showed our pictures from the bottom, a shot of a mark on the seafloor caught my eye. It was a track in the mud that looked as if it could have been made by a skidding object—say, a bomb. I hadn't seen the likes of it before and asked Hays to get permission for another look. Hays bluntly told Rear Admiral William S. Guest, leader of the task force, that if the Navy didn't cooperate we'd take *Alvin* home. The Navy cooperated.

**March 2.** For 7 hours and 16 minutes, *Alvin* groped among steep, muddy slopes. "This is not the right area," I told Hays and Wilson, who were both aboard with me. "It's too deep."

**March 3.** Another dive, and again no luck.

**March 4.** My day at surface control. On *Mizar* you control facing the stern, which wasn't my way of navigating. Yet I managed to steer *Alvin* to the 2,800 foot area—though we didn't have much time to search there; the dive was cut short after only 3 hours and 26 minutes because of bad weather. We didn't want to bring *Alvin* back aboard ship in a storm.

**March 7.** We went to shallower depths, but apparently we were still too deep to find the mark again.

**March 8.** They had us diving at only 750 feet in an area where there was thought to be aircraft wreckage from the collision. But we found nothing. I told Rainnie, who was navigating, we ought to go back to the fisherman's spot. "That bomb isn't going to float uphill," I said.

**March 9.** My turn at surface control, and we're still messing around in 800 feet of water. However, Hays and Wilson, joined on this dive by Chuck Porembski, an electronics technician, managed to find aircraft wreckage. I figured that might persuade the Navy to let us look in the right spot.

**March 12.** We're in the fisherman's area. Wilson was at the starboard window, I was in the front, and Mark Fox, our mechanic, was at the port window. After about 4 hours we found the drag mark we'd photographed, and, sure enough, it led downhill at a steep 70 percent. As I tried to drive down the incline, the stern propeller kicked up a cloud of mud, and we lost the track. By now it was already late in the day. So we decided to resurface before sunset and let our crew chief George Broderson get *Alvin* ready for another dive early next morning.

**March 13.** When Rainnie and I got back, the area looked unrecognizable. *Aluminaut* had been there, and the larger and less maneuverable sub tore up the bottom. Though visibility was poor, we slalomed down a steep slope, first going in one direction, then in the other. I was Rainnie's lookout, calling out directions from either side of

*"No fooling, men—let's try to avoid losing any more of them."* © *1966 by Herblock in the Washington Post*

the sub. This worked well, until we came to what looked like a snowdrift hanging over a cliff. Somehow we made a wrong turn and—thud!—went right into the cliff, unloosing a cloud of mud that thoroughly blocked our visibility. All I could think of was being buried alive. Rainnie gave me the control box and I slowly backed down. We saw we hadn't triggered an avalanche. When we were finally in the clear, we continued the search, barely saying a word to each other. It turned out to be another fruitless day.

**March 15.** Though the Navy wanted us to shift to a new area, we decided to make one last attempt to find the track. As we headed down, I told Rainnie, who was surface controller, that he had to put us on the track because it was my son Jay's birthday.

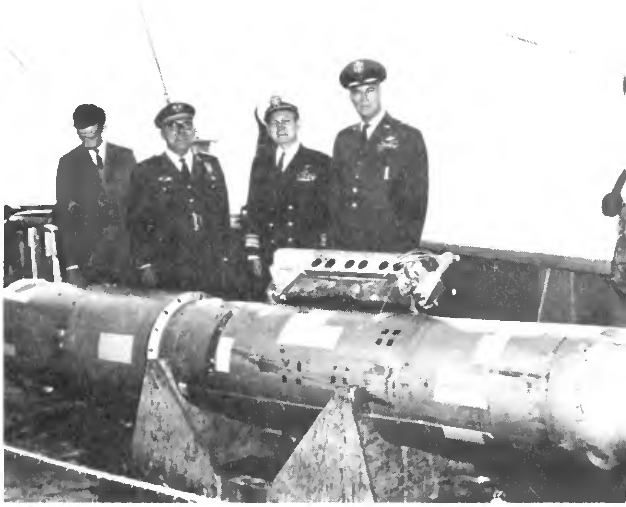
I started backing over the slope very slowly to keep from stirring up mud and silt. And soon I had the track in sight from the front window. Wilson kept a lookout from the side windows, telling me to come right or left, or go higher or lower. This continued until both Wilson and Arthur Bartlett, an electrical technician on board as an observer, began shouting, "I see it! I see it! There it is!" I told Wilson, "Keep me the hell off of it." Trying to contain our excitement, we backed over what we thought was the bomb. I set *Alvin* down in a crevice just below the bomb's huge parachute. Disregarding our prearranged code for signaling a discovery, Wilson started shouting over the phone, "We've found it." I ordered Wilson to calm down because we still couldn't really be sure we had the bomb. We were told to sit tight until *Aluminaut* could join us and confirm the discovery.

We waited for 8 hours with our lights off (to save electricity), until we spotted a faint glow in the distance. *Aluminaut* came in over the underwater phone. We turned on our lights so the bigger sub wouldn't run over us. The rendezvous was successful, and *Aluminaut* took position just below, thereby marking the site so we could return to our mother ship to recharge *Alvin*'s batteries and mount its mechanical arm. *Aluminaut* and her crew remained on station for 22 hours until we could return.

**March 16.** As soon as we had voice contact with *Aluminaut*, we homed in on her with our sonar. At a distance of a hundred yards, *Aluminaut* turned on her lights and we turned ours off. That instantly bathed the entire area in bright light. Ordinarily, *Alvin*'s lights reflect off particles and small marine life, creating such severe backscattering that you feel you're diving through fog or a snowstorm. We couldn't see much further than 20 feet or so. But with the backlighting from *Aluminaut*'s lights, we had good visibility all around, able to see as far as 150 feet.

We landed just behind and below *Aluminaut*, but suddenly had a scare. *Aluminaut*'s stern was coming down toward us. "What the hell are you guys doing?" I shouted over the phone. There was no reply. I took off with *Alvin*, scooting to a little hill off to the right. Later I found out that one of *Aluminaut*'s larger crewmen had walked to the after part of the sub, changing her trim and causing her stern to sink. A second scare occurred when *Aluminaut* took off, showering us with her discarded ballast—steel shot—and mud from her underside.

When things finally cleared up, we moved toward the parachute and anchored a pinger, an acoustic signaling device, into it with fish hooks. I could see that the bomb was still attached to its rack, which had been ripped out of the plane; the toggle pins were still in place. But I couldn't get a good picture of the rack or the bomb because the 'chute was partially obscuring them. I did manage to photograph the serial numbers on the parachute; as it turned out, no one had recorded them. By now the weather was changing and we were ordered up. Even though we still didn't have proof of our find, we had no doubt what it was, thanks to what we had learned from the sergeant.



*U.S. and NATO brass inspect the dubious prize of* Alvin's *most ticklish operation. (WHOI archives)*

But there was a different reaction on the surface. When we showed our pictures and told our story to the leaders of the task force, I'm sure some of them believed us, but Admiral Guest asked sharply, "How do you know that it isn't a bag of mud?" In all my life, I'd never had my intelligence so insulted. We returned to our mother ship tired, discouraged, and disgusted. But we were determined to finish the job—to prove we had located the bomb.

**March 18.** After a day's delay because of stormy weather, Wilson and I started another dive. We carried a harpoon in the mechanical arm with 3/8-inch line attached. As we descended, the line was led out from the mother ship. Near the site of the bomb, I trimmed *Alvin* to an angle of 20 percent, straightened the mechanical arm, and

THE WASHINGTON POST
Friday, March 18, 1966

# Sub Finds H-Bomb Off Spain

### Weapon Reported Intact in Water 2500 Feet Deep

PALOMARES BEACH Spain, March 17 (AP)—The U.S. midget submarine Alvin has found the hydrogen bomb that was lost two months ago in an American bomber-tanker plane crash over Spain, official sources said tonight.

They reported that it was sighted with its parachute still attached 2500 feet under the Mediterranean Sea, five miles offshore. The weapon was apparently intact — indicating no lethal leakage in the waters of this resort.

The New York Times March 18, 1966

SEARCH IS SUCCESSFUL: H-bomb has been found in sea off Palomares (cross).

*The H-Bomb operation was* Alvin's *first media splash.*

plunged the harpoon into the bottom with all the power I could get out of *Alvin*. When the cloud of debris that this stirred up cleared, I saw that the harpoon was firmly anchored up to its hilt. On the surface, the line was bouyed off with a small marker. It could now be used to pass down a heavier line to lift the bomb. We took more pictures in order to find a good place to attach the line to the bomb. It was still hooked to the rack, safety pins in place. I thought the best strategy was to hook a toggle pin or snaphook into one of the rack's limber holes. But I couldn't get a good picture of the rack to make my case, so the idea wasn't bought. Also, our batteries were getting low and we had to resurface.

For the next 4 days, the recovery was put on hold because of bad weather. Meanwhile, just about everyone seemed to be building capture devices.

**March 23.** Wilson and I took a large clamp down with us in *Alvin*'s mechanical arm. It was to be pushed around the bomb's midsection, whereupon it would automatically lock shut. But as hard as we tried, we couldn't get the clamp around the bomb. There was too much mud, and too much parachute in the way.

Things were going just as badly on the surface. Trying to pass a heavier line down to the harpoon, the seagoing tug *Petrel* managed to pull the harpoon out of the bottom. In the face of these problems, we called it quits for the day, frustrated as ever.

While we set about getting *Alvin* ready for her next dive, another contraption was rigged up. Nicknamed "Poodle" for reasons I could never find out, it was a six-foot-by-six-foot steel frame designed to carry down lines attached to grappling hooks and electronic pingers. It was dropped to the bottom with a 1,400-pound Danforth anchor, about 70 feet from the bomb. For our part, we made a special hook for the mechanical arm—about the size of a butcher's hook—that we hoped could be used to pull away the parachute's shroud lines and untangle the mess in which the bomb was wrapped.

**March 24.** With our meat hook in *Alvin*'s "hand," we started pulling the shrouds and flaking the 'chute down slope. Things went well; it looked like we might finally unravel our ball of string. After hooking a shroud, we would back down the slope, making sure the damned 'chute was lying flat so we wouldn't get entangled in it. Then I found that the 'chute wasn't completely out of its compartment on the bomb. So I pointed the hook into the compartment and tugged on a bunch of shrouds. Nothing happened—except *Alvin* was pulled right onto a 20-megaton hydrogen bomb. I tried again, this time fishing out one shroud. I was able to pull it some distance. Slowly, we were getting the job done. All the while, surface was asking us how we were doing. How can you answer when you aren't really sure yourself? We told surface that everything was going well, but that we had to come up because we didn't have enough power left in our batteries. We would finish the job on our next dive.

**March 25.** Broderson told us Captain Hook—meaning *Alvin*—was ready for another tussle with the bomb. When we got down, everything was as we had left it. Just about parked atop the bomb, I thought to myself, "How lucky can you get?" After only a few hours, we had the 'chute completely removed from the container and safely stowed down slope from the bomb. Now we turned to Poodle; everything was a mess. But we managed to untangle a fine-looking grapple that someone had spent hours making. It was attached to the anchor with a 1-inch nylon line. We managed to attach the grapple right to the top of the parachute shrouds and started pulling shroud by shroud. Then in real Navy fashion, we pulled the line tight back down slope to the anchor. We reported to the surface what we had done, and it was agreed that the bomb was ready to be lifted. As a precaution, we moved to a small hill about 200 yards away and waited.

Then we got word from topside that they'd changed their minds. They were going to drag the entire mess up slope to shallower water before picking up the bomb. I begged them to pick it straight up, but didn't win this argument either. We returned to our mother ship after a dive of more than 8 hours. While trying to get some food, we heard the bomb had been dropped.

Next day, on March 26, Wilson and I returned to where the bomb had been. The slope looked if it had been torn up by bulldozers. We found huge chunks of sand stone, clay, and mud—but no bomb. On 6 more dives, we searched up slope because that was where the track indicated it had dropped. On our thirtieth dive, I found an imprint that seemed to have been caused by the bomb's nose; it even had a bump matching a dent I'd noticed on the nose. My suspicion was that the bomb had slid back down the slope, and that's where Rainnie and I began to look on the next dive. Just 300 feet below our previous location, we found our prize, resting in a crevice at the foot of a 70 percent slope.

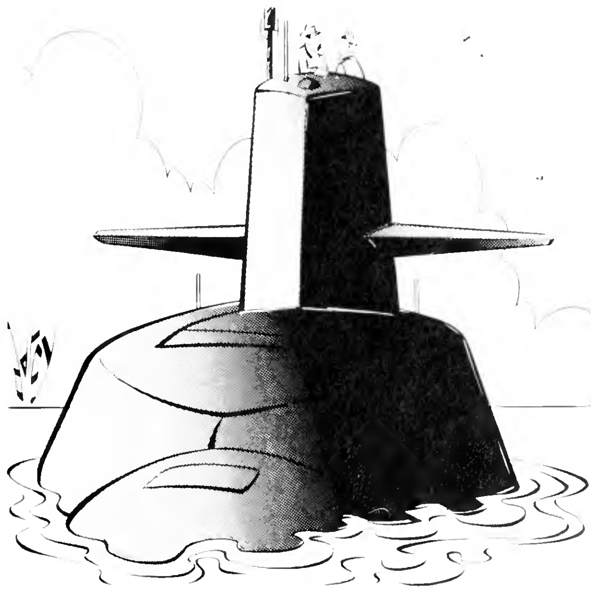
Next day Wilson and I went back down. We pulled the parachute down slope again and placed another pinger in the parachute's spill hole. The pinger would guide a new device, called CURV (Controlled Underwater Recovery Vehicle), developed by the U.S. Naval Ordnance Test Station in Pasadena, California, to recover torpedoes. Held in a rectangular steel frame only a little smaller than a compact car, it had four ballast tanks, two small motors to drive it forward and a third to move it up and down, sonar, two mercury vapor lamps, a television camera, and a large claw for grasping objects. It was controlled electronically through a long cable by a five-man crew aboard *Petrel*.

We noticed that our grapple was still attached to the shrouds with about 50 or 75 feet of line. We stretched out the 'chute as well as we could and put another pinger in the spill hole. After we surfaced, CURV was sent down to attach a line to the 'chute.

Again bad weather delayed the operation for a day. On April 5, Wilson and I rode *Alvin* down to the bomb; we were moving very cautiously through the silt when just ahead I saw the 'chute billowing in the current like a huge circus tent. We took a closer look. For a moment, Wilson thought we had moved under the 'chute, and scared the wits out of Rainnie on the surface when he heard that report. He told us to surface.

On April 6, *Alvin* stood by as an observer as CURV paid another visit to the target. It managed to attach one line, but the machine became hopelessly entangled in the billowing 'chute. So it was decided to bring CURV back to the surface and just hope that the bomb would follow along. The maneuver was slow and tedious but it proceeded without mishap. Wilson and I watched on sonar until the retrieval was halted at 200 feet so Navy divers could attach additional lines. Finally, the lost H-bomb broke the surface.

The job done, *Alvin* was returned to the *Snelling*. All told it had made 34 dives, operating down to 3,200 feet for nearly 222 and a half hours. *Alvin* proved that a deep submersible could do the most difficult job, retrieving not only an extremely dangerous weapon but also the nation's honor.

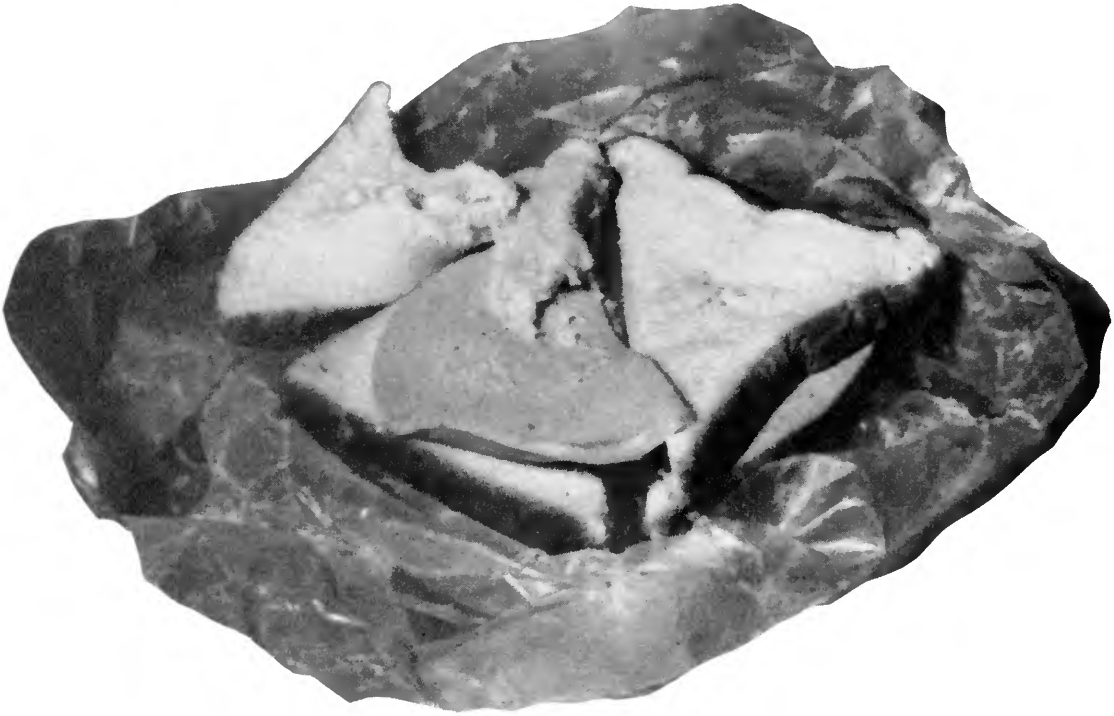


'I WOULDN'T BE SO EMBARRASSED IF THE ANDREW JACKSON OR THE GEORGE WASHINGTON OR THE NATHAN HALE OR THE SAM HOUSTON OR THE WOODROW WILSON FOUND IT ... BUT ALVIN!'

© 1966 by Tom Darcy.

## *Serendipity in Deep-Sea Microbiology*

# Lessons from the *Alvin* Lunch



### by Holger W. Jannasch

Accidents often provide lessons, but rarely has this been as true as for the sinking of *DSV Alvin* in the fall of 1969, and the recovery of its lunch box 11 months later. The apparently well-preserved state of the box's contents initiated a series of experimental studies that broke a roadblock in deep-sea microbiology.

Where was that roadblock? It was well known that microbes are common and important inhabitants of the permanently dark and cold (2- to 4-degree-Celsius) deep ocean. In addition, it was known that some of them experienced enhanced growth at low temperatures, and so were designated "psychrophilic" (or "cold-loving") bacteria. There were also many hints that an adaptation such as that to cold also existed for growth at considerable hydrostatic pressure, which increases by about 1 atmosphere per 10 meters depth in the water column. But since the term "barophilic" (or "pressure-adapted") was coined by microbiologists F. H. Johnson and C. E. ZoBell in the 1940s, little

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work had been done in this area, and no barophilic bacterium was available for physiological studies on this particular metabolic trait.

Considering the fact that more than 90 percent of our planet's biosphere is represented by the open ocean, and that the deep sea (arbitrarily set as deeper than 1,000 meters) comprises about 75 percent of the biosphere, the role of microbial decomposition and remineralization of organic matter in the deep sea becomes an important topic of study. Of particular interest is the effect of physical factors, such as low temperature and high pressure, on microbial metabolism. The well-studied psychrophilic bacteria grow best at temperatures between 8 and 15 degrees Celsius, and are inactivated or killed when raised above 20 degrees. In other words, to retrieve them from the deep sea—especially for quantitative assessments—care has to be taken to ensure that water or sediment samples are never exposed to temperatures higher than 20 degrees. If there are organisms even more sensitive, ones not able to survive 15 degrees, they will escape detection.

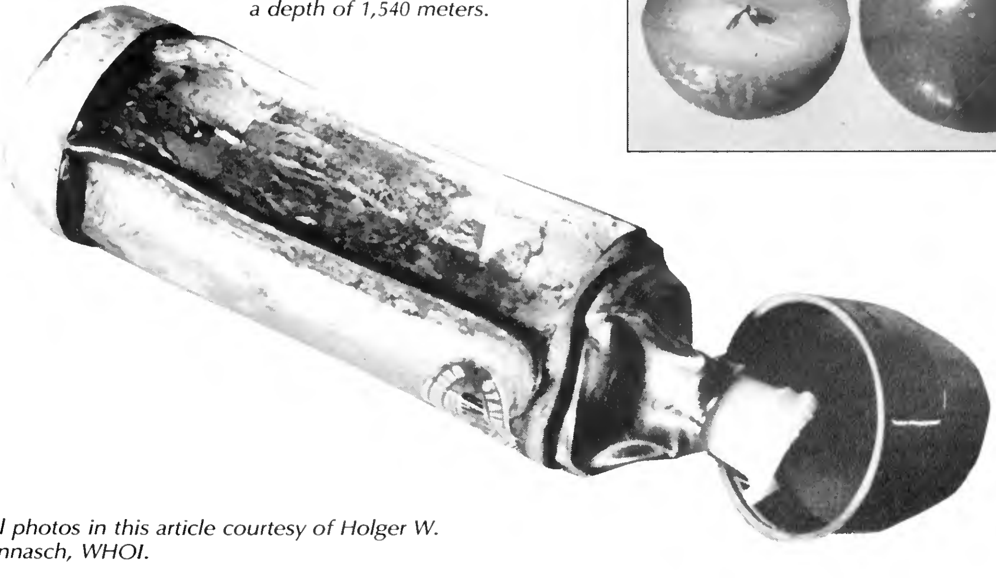
For some time it has been possible to retrieve deep water or sediment in cold latitudes without a warming-up of the samples, and so preserve the psychrophilic bacteria. But until the development of tools and techniques inspired by the recovery of the *Alvin* lunch box, preventing the loss of hydrostatic pressure during recovery of samples was technically out of reach. As the cooling of warmed-up samples in a ship's laboratory does not revive psychrophilic microbes, the recompression of the decompressed bacteria might fail similarly. It must be assumed that the unavoidable loss of pressure preselects for those organisms that are more or less tolerant to such pressure changes. Indeed, the absence of a comparable technique might have led to the general impression that the microbial tolerance for decompression is higher than for the corresponding deleterious effects of increasing temperature. Still, unless decompression is avoided, only a partial job can be done in experimental studies on the question of barophilic microbial activity in the deep sea.

### Sandwich Recovery Breaks Roadblock

How did the recovery of the *Alvin* sandwich break the roadblock? It was not the well-preserved quality of the foodstuffs that startled us, but the utterly simple means of overcoming the decompression problem used in this involuntary experiment. Instead of running experiments on microbial growth with deep-sea samples brought to the surface, the substrates to be used by the microorganisms can be put down to any depth in the ocean. There they can be automatically inoculated with ambient sea water or sediment, and "incubated" at the site for a given time period. The results of this in situ microbial activity can be measured in the retrieved sample containers.

Using this approach, we measured the decomposition rates for chitin, starch, and cellulose, at depths to 5,300 meters, over time periods of two to six months. At first, the cooperation of physical oceanographers was necessary. They allowed us to put packages of sample bottles inoculated with surface-borne

*Opposite, the* Alvin *sandwich, and below and right, the thermos bottle and apples, as they appeared after spending 11 months at a depth of 1,540 meters.*



*All photos in this article courtesy of Holger W. Jannasch, WHOI.*

bacteria (Figure 1) on deep-sea mooring anchors, just above the acoustic retrieval link. Control samples were incubated at normal atmospheric pressure, and temperatures equal to those at 5,000 meters depth—2.0 to 3.5 degrees Celsius. When compared to controls, the rates measured on the ocean floor were as much as 100 times slower.

Later, we used the recommissioned *Alvin* for inoculating sample bottles containing radiolabeled substrates on the deep-sea floor, and incubating them for a larger variety of time periods. To this end, we constructed simple aluminum housings for transporting racks of bottles, containing various sterile substrates, to two permanent stations, at 1,830 and 3,640 meters (Figure 2). On station, a valve was opened by *Alvin*'s mechanical arm, allowing water or sediment slurry to fill the housings. The bottles filled through a slit in the rubber stoppers. When the pressure inside and outside of the housing had equalized, the lid was lifted off and the bottle rack was removed and placed on the ocean floor for incubation of 2 to 15 months.

The results of this second series of experiments were surprising. Almost the same reduction in microbial activity was found with both deep-sea and surface-borne populations when incubated in the deep sea. No barophilic response was found; and there did not seem to be more barotolerant organisms in deep-sea populations than in those collected near the surface.

## An Advancing Technology

At this point, the development of decompression-free sample vessels became a necessity, and Woods Hole Oceanographic Institution engineers, Clifford L. Winget and Kenneth W. Doherty helped us to do it. The negative results of the sea-floor incubation and inoculation experiments may have been due to the considerable pressure shock and high shear forces that occurred during the filling of the pressure housings and bottles. Also, mere end-point measurements do not reflect whether rates of activity are constant or continuous over the extended incubation periods. For instance, the deep-sea bacteria may have been very active for a very short time.

This work ended with a complete technical system, enabling us to retrieve and concentrate samples, without decompression and change of temperature, from the deep sea into the laboratory, transfer subsamples to a chamber for the isolation of individual strains of bacteria, and return a cell suspension of the pure culture into a prepressurized culture chamber for measurements of its growth capacity under various environmental conditions (*Oceanus*, Vol. 21, No. 1, pp. 50–57). During all of these operations, the deep-sea bacteria remain at their normal in situ pressure and temperature.

The sampling/culturing devices used at this point (Figure 3) were lowered to a desired depth on a cable from a ship, and mechanically triggered to open. The sea-water sample entered a sterilized chamber at a set rate, because the pressure difference and shear forces were taken up by sterile fresh water passing through a small orifice between two free-floating pistons. When these samplers were subsequently used as culture vessels, small amounts of media, up to 13 milliliters, were added to the 1-liter sample by a

*Figure 1. The equipment used in the first controlled repeat of* Alvin's *unintentional venture into microbiology. The boxes, made from plastic household dish pans, held a variety of sample vessels. The boxes were fastened to the mooring chain of deep-sea buoys, and incubated for 5 months.*

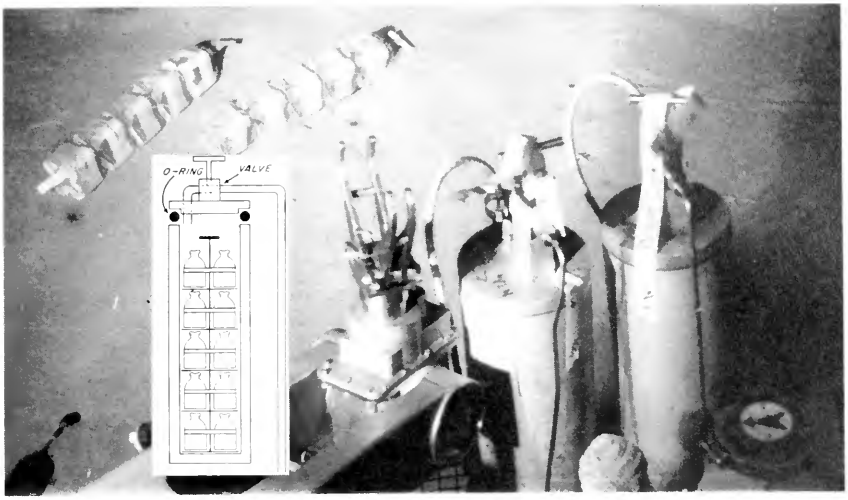


*Figure 2. Bottles containing radioactive food materials are inoculated on the deep-sea floor by opening a valve with* Alvin's *mechanical arm. The racks of bottles (upper left) are then removed from the pressure housings, and dropped on the ocean floor for up to one year of incubation. After retrieval, the contents of the bottles are fixed and studied for the degree of microbial transformation. Inset shows arrangement of bottle rack in pressure housing.*

transfer unit. This was an easy operation, in that no external source of pressure was needed. An equal subsample was removed at the same time. Further subsamples were taken at various intervals to measure the uptake and respiration of the radioactive substrates metabolized by the microorganisms in the sample.

One drawback of this method is the low sampling capacity. Since the two samplers are also used as culture vessels for several weeks of incubation, only two samples per cruise could be taken. Large numbers of samples, however, are needed. The case of a few observations receiving more attention than their actual significance merits has been a problem of deep-sea biology since its inception. Conclusions tend to be drawn more quickly if the chances for repeating an observation are small. Reproducibility and statistical significance of results depend on a sufficient number of samples.

With this in mind, a filter sampler was devised that concentrates bacteria from 3 liters of deep-sea water 200 times over a filter with a porosity of 0.2 microns (Figure 4). After retrieval of the sampler, subsamples of this concentrate were withdrawn, stored, and later transferred into the prepressurized culture vessels. These samplers were then resterilized and used again on the same cruise. At this time, then, our sampling capacity was limited only by the number of transfer vessels we had available.

Our studies using this equipment supported our findings in the in situ incubation experiments—namely that increasing pressure decreased metabolic activity. No barophilic response was yet found, only varying degrees of barotolerance. Still, these data were not sufficient to conclude that completely pressure-adapted barophilic microorganisms do not exist. To this point we had been working with mixed populations. If a constant input of barotolerant microorganisms from the surface is carried down by particles to the deep-sea floor, these organisms might well outnumber by far, and hence outcompete, the pressure-adapted forms.

In order to address this problem, we needed to grow deep-sea microorganisms in pure culture. That is, samples not only had to be retrieved from the deep sea under pressure, but also had to be streaked out on agar plates and transferred to new media several times, in a window-equipped chamber holding pressures of 600 atmospheres or more.

This isolation chamber was designed by Doherty, and built by Martin C. Woodward. Inside the chamber there is a rotating belt for the manipulation of nine agar-filled plates, a sterilizable loop for streaking samples onto the plates, vials containing sterile liquid nutrient media, and lamps for illumination, all of which are operated by outside controls. After a seawater sample has been transferred into the isolation chamber from a sampler/concentrator, it is streaked onto one or more agar plates. When colonies begin to grow on a plate, they can be sampled with the loop and transferred to other plates, where they can grow in isolation from the other types of microorganisms that had accompanied them in the original sample.

When a pure culture is attained in this system, the isolated colony is transferred into one of the vials containing sterile nutrient media. After growth, the liquid culture is removed by a transfer unit, and introduced into a prepressurized 1-liter growth chamber. Thus, original deep-sea conditions of pressure and temperature are maintained throughout the entire transfer, purification, and cultivation procedures.

### What We Have Learned

The general outcome of these studies, originally inspired by *Alvin*'s accident, shows, in short, the existence and types of psychro- and barophilic bacteria in the deep ocean, and quantified the general effect of temperature and pressure on the microbial capacity for the breakdown of

*Carl O. Wirsen lowering the sampler from the deck of the* Oceanus.

organic matter in the world's largest ecological niche, or as it is often called, the "ultimate sink." Beyond the advancement of basic research, this work is important because the fate of manmade products or pollutants dumped in the deep sea depends on the activity of the microorganisms living there. If not just the "out-of-sight out-of-mind" idea, but the true removal of pollutants is intended, then the slow rates of microbial degradation argue clearly against deep ocean disposal.

How about the well-preserved state of the *Alvin* lunchbox after its 11-month sojourn on the deep-sea floor? It was remarkable. The apples were in a condition equal to that of conventional careful storage, and the bread, mayonnaise, ham, and boullion appeared to fare considerably better than they would have under normal conditions of refrigeration. Yet, this unplanned experiment lacked the most important controls, and for scientific purposes, the observations had to be taken for what they were: intriguing, and suggesting some more experiments, but not useful for proving scientific theories. The

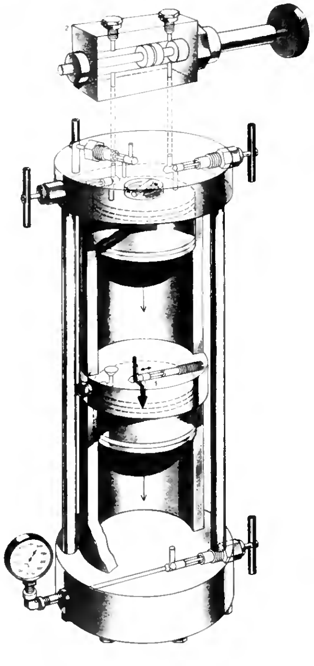


*Figure 3. A central plate divides the sampler into two cylinders; an orifice in the plate* (1) *acts as a flow snubber. Before the intake of a sample, the upper of two free-floating pistons is at the top of the upper cylinder, supported by a column of fresh water; the lower piston is also at the top of its cylinder, supported by pressurized nitrogen gas. When the intake (not shown) is opened, admitting a sample of seawater, the upper piston slowly descends as the fresh water is forced into the lower cylinder. The lower piston descends reciprocally, compressing the nitrogen gas until its pressure is equal to the outside pressure. A check valve then closes, and the sampler is hauled back to the surface. Transfer unit* (2) *allows withdrawal of portions of the sample or introduction of nutrients without loss of pressure.* ©*1977 by* Scientific American

serendipity lay in the simple fact that the lunch, the decomposable material, was enclosed in a box that allowed sea water containing the bacteria to enter, but not animals. Keeping out the voraciously scavenging amphipods turned the experiment into a microbiological one.

Even more remarkable was the use of a common bacteriological medium. For a soup, the cook had dissolved some meat extract concentrate in hot water—a material very similar to what microbiologists call "peptone." Contained in a thermos bottle, it went down with the sinking *Alvin*. While the insulating jacket of the bottle was crushed by the 200 atmospheres of pressure, the stainless steel liner was not. Instead, a small amount of sea water leaked in, equilibrating the pressure and "inoculating" the solution of meat extract with marine bacteria. When we finally designed our own experiments, this part did not look too different.

As many frequent *Alvin* users would agree, the sub has a happy disposition. Even in the most distressful 11 months of its career it did some work that started a novel line of research. *Alvin* took an active part in it later, and the end of its involvement in deep-sea microbiology is not in sight.

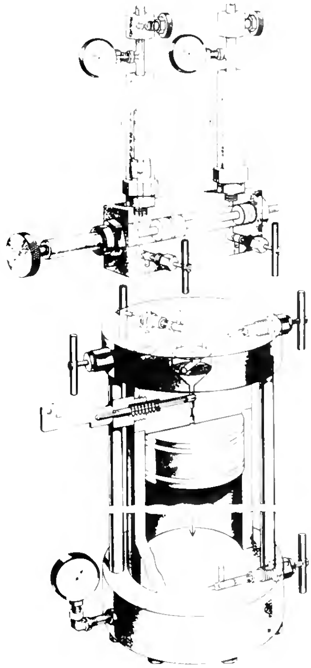
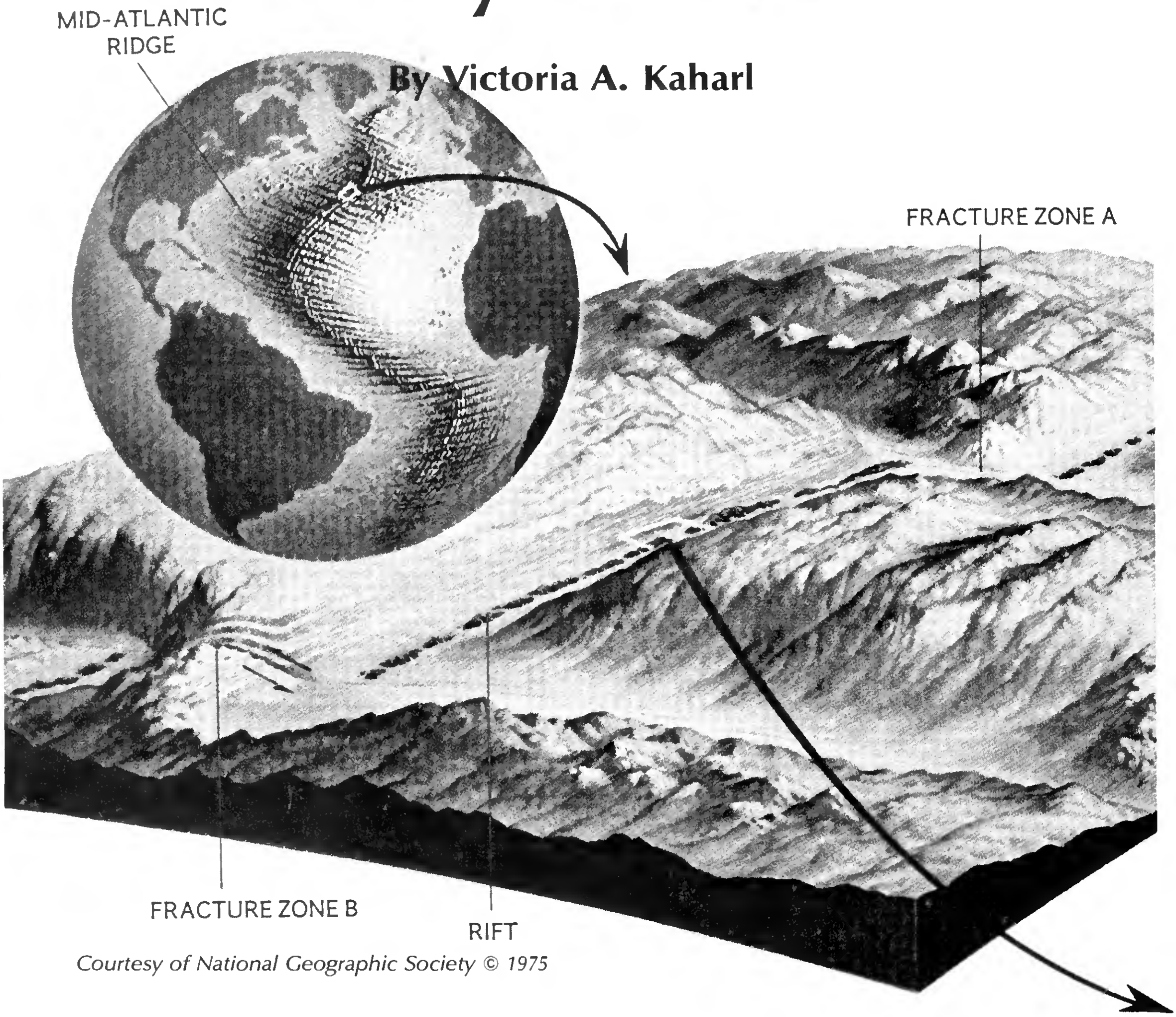


*Figure 4. The sampler/concentrator is a single-piston system where a 3-liter sample of seawater passes through a fine membrane filter* (1), *with a flow-snubbing device similar to the two-piston sampler. A storage transfer unit* (2) *is equipped with small gas cushions* (a) *and* (b) *that prevent loss of pressure during prolonged storage. ©1977 by* Scientific American

*Sausage-shaped bacteria filtered from seawater sampled at 4,400 meters depth. Magnification is 21,000 ×. (Photo by A. Cundell, Harvard University)*

# A Famously Successful Expedition to the Boundary of Creation

## By Victoria A. Kaharl



*Courtesy of National Geographic Society © 1975*

The idea came out of diplomacy, not science. In 1967, the executive secretary of President Lyndon Johnson's cabinet-level Marine Council, Ed Wenk, opened discussions with other countries in hopes of initiating joint oceanographic projects with them. Long an enthusiastic proponent of deep-diving submarines—he had designed *Aluminaut*—Wenk found a kindred spirit in Yves LaPrairie, director of CNEXO (*Centre National pour L'Exploitation des Océans*), France's chief oceanographic agency.

In the course of several meetings between them, a bold plan emerged. LaPrairie and Wenk proposed a joint French-American expedition to the Mid-Atlantic Ridge, the mountain range that bisects the Atlantic Ocean. Almost none of the

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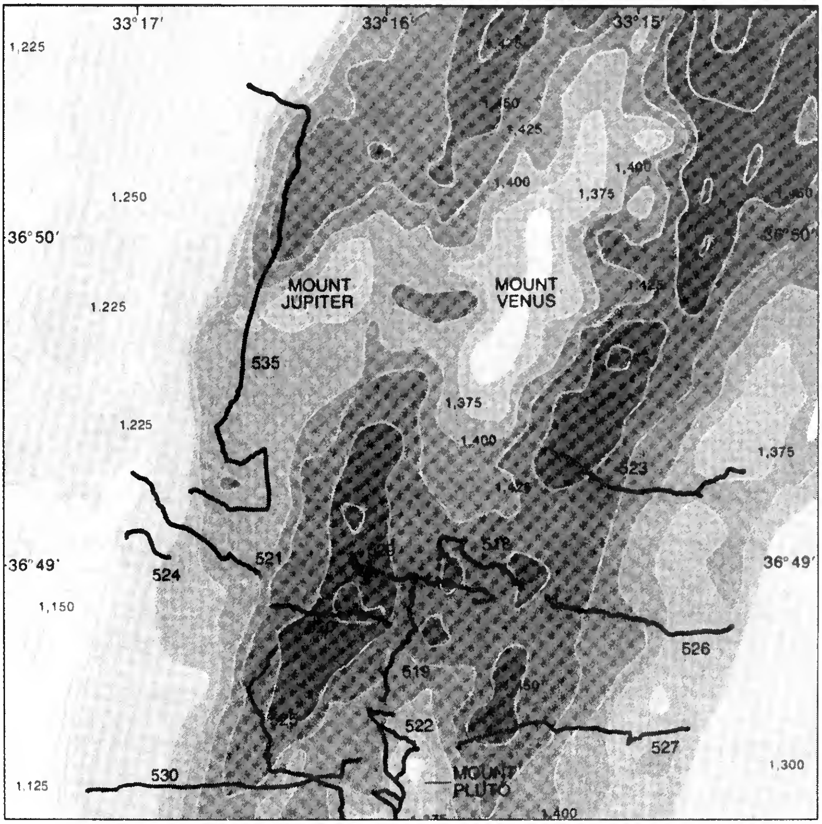
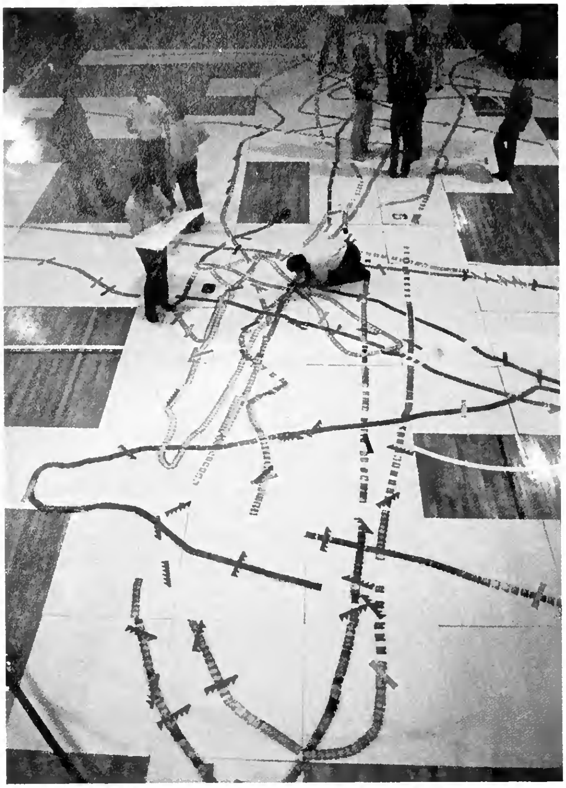
*Departing from Woods Hole on June 4, with* Alvin *aboard (near stern) and* Lulu *in tow,* R/V Knorr *begins the trip to Project FAMOUS's home port, Ponta Delgada in the Azores. (Photo courtesy of WHOI)*

deep ocean had ever been visited before. The scheme, endorsed by Presidents Charles de Gaulle and Richard Nixon, tantalized many oceanographers. Jim Heirtzler, Bob Ballard, Bill Bryan, and Joe Phillips of the Woods Hole Oceanographic Institution (WHOI) promptly moved to take WHOI's research submersible *Alvin* on that dramatic voyage. *Alvin* had only recently been fitted out with a new titanium pressure hull and its depth limit had been extended to 10,000 feet, easily within range of the ridge.

Many oceanographers still had their doubts about the scientific worth of getting inside the deep ocean. At a high-level symposium at Princeton University in January 1972, Ballard described how classic geology—mapping, observation, and sampling—could be done under water, as he had done with *Alvin* in the Gulf of Maine. But when he finished his talk, he was bluntly asked by Frank Press, then a leading geophysicist at the Massachusetts Institute of Technology and later president of the National Academy of Sciences, to name one significant piece of science that had ever come out of using a submarine. The late Maurice Ewing of



*(Opposite) The Rift Valley of the Mid-Atlantic Ridge. Major breaks (fracture zones A and B) occur across the axis of the main rift, caused by complex forces moving the plates apart. At left, detail of the bathymetry of the Project FAMOUS site. (Courtesy of* Scientific American *© 1975)*



*Scientists studying the photographic track of the project area made by the LIBEC (LIght BEhind Camera) towed-camera system. About 5,000 prints were pieced together to give scientists an idea of the Rift Valley bathymetry in the FAMOUS area. (Photo by Emory Kristof, courtesy of* National Geographic Society, *©1975)*

Columbia's Lamont (now Lamont-Doherty) Geological Observatory made especially sure the young WHOI scientist, who was still shy his Ph.D., knew his feelings. Wagging a finger in Ballard's face, he threatened to melt down *Alvin* into titanium paper clips if the expedition didn't turn out to be worthwhile.

In spite of these doubts, Project FAMOUS (French-American Mid-Ocean Undersea Study), as it came to be called, got the official blessings of its governments on 4 July 1972. The United States would use *Alvin*, and France would employ the bathyscaphe *Archimède* and the small deep-sea submersible *Cyana*, Jacques Cousteau's renamed and refitted SP-3000, which could now go down to 11,000 feet.

For the American scientists, the pressure was especially high. The success or failure of FAMOUS would determine the future of *Alvin*, which had yet to establish itself as an accepted tool of oceanographic research.

To prepare themselves, the American and French scientists underwent exhaustive training, traveling to Hawaii and Iceland to study the type of volcanic terrain they would likely encounter at the ridge, where new seafloor erupts from the Earth in fiery lava, and pushes apart the tectonic plates that form the planet's outer surface. They were also joined by two new *Alvin* pilots: Jack Donnelly, WHOI's former liaison with the Office of Naval Research, and Dudley Foster (pp. 17–21), a former Navy fighter pilot.

Based on the likelihood of favorable weather—submersibles can't be launched or retrieved in stormy seas—and the nearness of land for emergency repairs, the French and Americans decided they would explore a small, but presumably typical, section of the ridge, less than 60 miles square, some 400 miles southwest of the Azores. The area was thoroughly swept beforehand by sonars, magnetometers, and seismometers. In addition, thousands of underwater photographs were taken from a camera-carrying sled towed by the U.S. Navy's research vessel *Mizar*. The pictures were laid out in a giant mosaic on the floor of a Navy gym in Washington, D.C., where the scientists spent days walking back and forth among them to familiarize themselves with what awaited them on the bottom of the ridge.

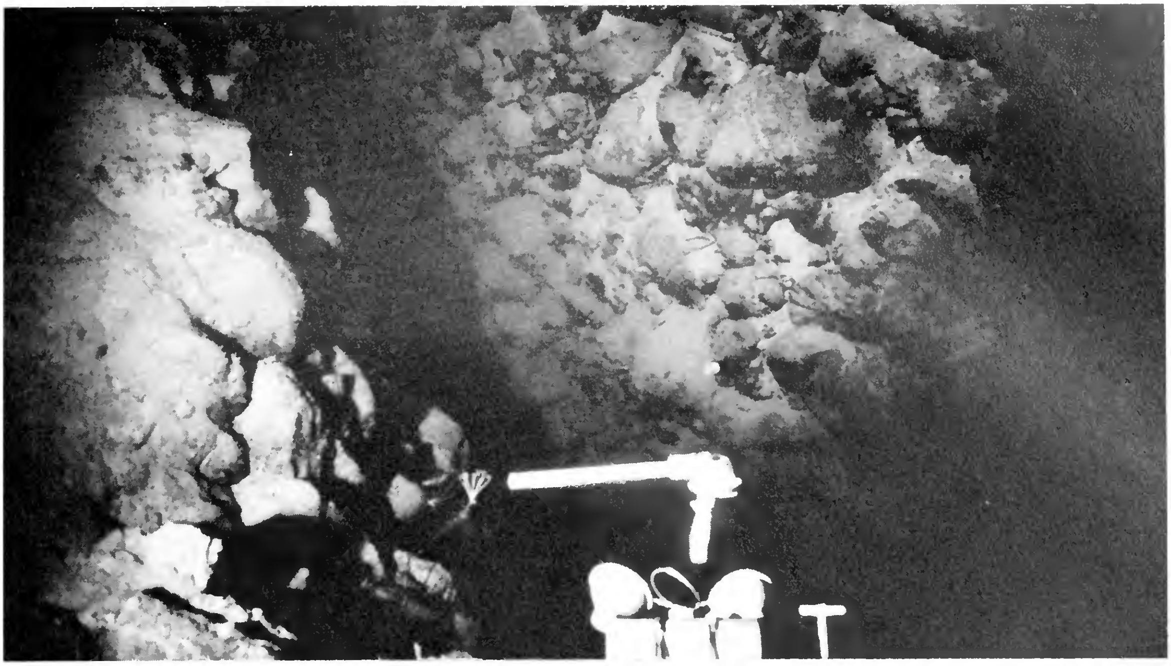
### A Frightening Dive with the French

But in the summer of 1973, *Alvin* was still troubled with problems: sensors weren't working properly,a new pumping system continued to act up. Above all, there were questions about the watertight integrity of the penetrators—the little conical plugs through which wires were threaded into the hull. Growing antsy waiting on *Alvin*, the French invited Ballard, a member of the American scientific team, to make a dive aboard *Archimède*. During the dive, a fire broke out, quickly filling the bathyscaphe's passenger sphere with thick black smoke. The three men donned their oxygen masks, but Ballard found his wasn't providing any oxygen, so he tried to take it off. The French thought he was panicking. They forced the mask back on his face until he was gasping and choking. In a desperate effort to make himself understood, he made a knife-cutting gesture across his throat—an internationally recognized signal used by divers to signify they aren't getting air. At last, the French pilot turned on Ballard's oxygen.

The following summer, the joint French-American project finally began. In June 1974, *R/V Knorr*, with *Alvin* aboard, and *Alvin*'s mother ship, *Lulu*, in tow, left Woods Hole for a rendezvous with the French in Ponta Delgada on the island of São Miguel in the Azores. Only a day before Ballard had successfully defended his thesis (on the tectonics of the Gulf of Maine), and was now Dr. Ballard.

Apart from its officers and crew, *Knorr* carried 24 people—scientists, graduate students, and technicians.

The FAMOUS site was 20 miles long, and ranged in width from half a mile to two miles. On the western side was a nearly vertical wall. Down the center ran the rift, hugged by two deep canyons. A pair of volcanoes, subsequently named Mount Pluto and Mount Venus, marked



*Tension fracture in the Rift Valley as photographed from* Alvin. *(Photo courtesy of WHOI)*

the ends of the canyons. The French dived in the Mount Venus area; the Americans explored around 700-foot-high Mount Pluto.

With only limited resources, the *Alvin* group showed its usual ingenuity and resourcefulness. Engineer Cliff Winget made a water sampler with two toilet plungers. When the device was triggered from inside the sub, the suction cups clapped together, enclosing a water-gathering tube. The device worked extremely well—though its various nicknames couldn't be repeated on prime time. *Alvin* also carried Skip Marquet's datalogger that let the scientists know with more precision than ever before where *Alvin* was.

### The Problem of Playful Porpoises

Marquet's system used transponders, basically pingers that emitted sound waves. Three were dropped on buoyed lines in the dive area, and all fixes were made from this triangular network. Each pinged in a unique pattern, recognizable by the navigational gear aboard *Lulu*. By *Alvin*'s fourth dive, the system was working so well that the sub was landing within 50 feet of the chosen spot. The upshot for geologists was that they knew precisely where a particular rock came from in relation to other samples.

Such accuracy took hard work. Marquet, who had toiled five years to perfect the system, had to plug in the coordinates with a borrowed hand calculator, because the *Alvin* group couldn't afford a computer. Playful porpoises were even more of a problem because of their wonderful miming ability. Somehow they figured out the unique pattern of pings that made each transponder respond. On one dive they "talked" so much that they managed to exhaust the batteries of one of the devices.

There were other problems. The surface teams dredged rocks and towed heat sensors, but one day the dredges were lowered seven times from *Knorr* and came back with only two rocks.

Because of the earth-birthing processes under way at the ridge—hot lava emerging from deep within the Earth—the oceanographers had expected to find higher than normal temperatures on the seafloor. But nobody got any anomalous readings. There was neither fire nor brimstone at the boundary of creation. Creeping along this seam in the Earth was like driving in first gear through a light snowfall at night. The "snow" was comprised of the millions of tiny particles—the detritus of marine plankton and animals—that are everywhere in the ocean.

But there was also grandeur along the ridge. The nearly vertical west wall rose a thousand feet or so. "Your eye doesn't believe it," said Oregon State geologist Tjeer van Andel.

Instead of a single break marking the plate boundary, the deep-sea explorers found a more complicated topography. Crevasses and faults bisected and ran parallel to the valley. The seafloor had been ripped apart by the forces of plate tectonics, rather than flowing lava. This molten rock hadn't erupted in a single outpouring. It oozed out as if squeezed from huge toothpaste tubes and hardened into the most bizarre shapes. Some resembled gnarled tree roots, huge peanuts, or sausage links. Others evoked images of swans and elephant trunks.

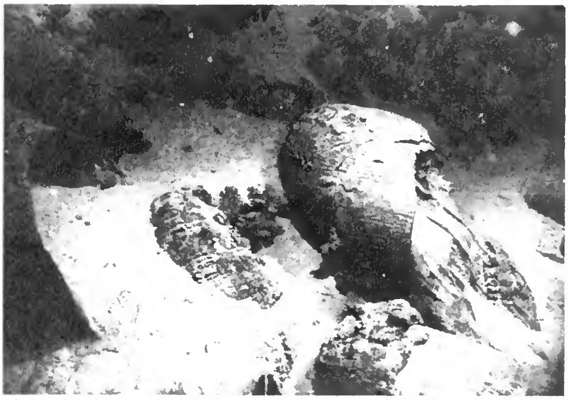
None of the experienced geologists on

# *Pillows, Tubes, and Sausage Links*

*The lava found at the Mid-Atlantic Ridge took many bizarre shapes, some of which are shown below.*

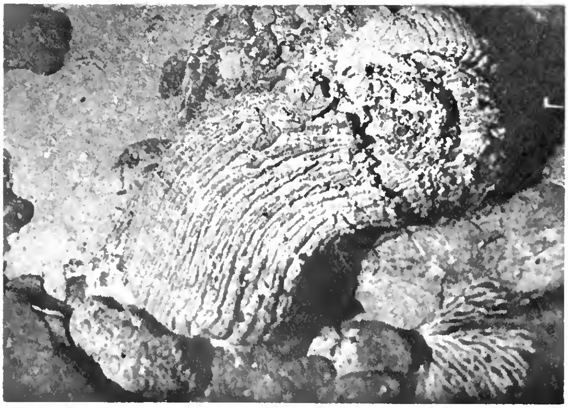
*Elongate pillow and Alvin's mechanical arm. (Photo courtesy of WHOI)*

*Toothpaste buddings. (Photo by Robert Ballard, WHOI)*



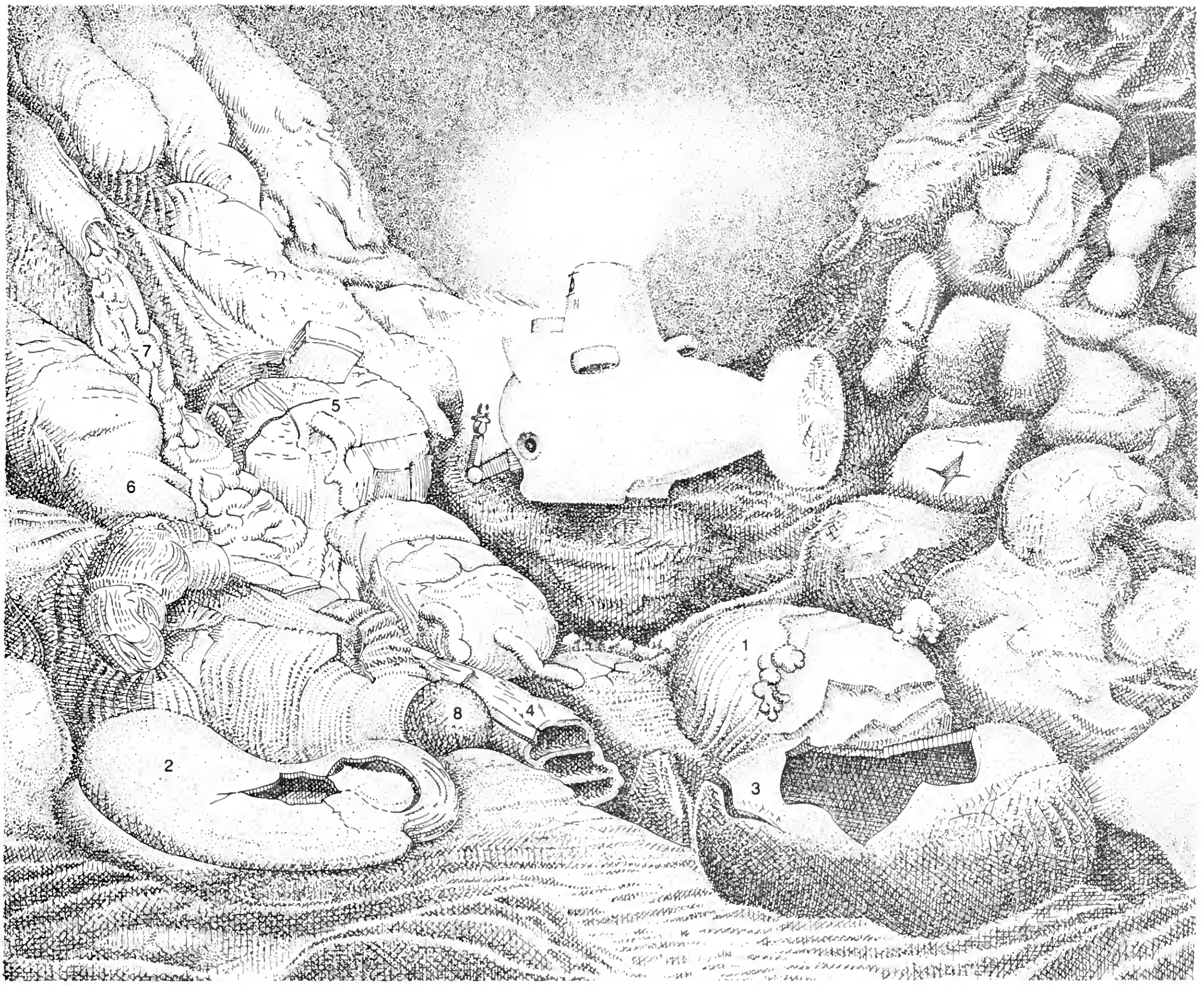
*Hollow blister pillow. (Photo courtesy of WHOI)*

*Pillow lava with probable sponge. (Photo by Robert Ballard, WHOI)*



*Broken elongate pillow. (Photo courtesy of WHOI)*

*Wrinkled pillow with two sponges and antler-like soft corals. (Photo by Robert Ballard, WHOI)*



*The diversity of lava forms seen at the intersection of two lava-flow fronts in the Mid-Atlantic Rift: (1) bulbous pillows with knobby budding, (2) a flattened pillow formed by the rapid drainage of lava while the skin was still soft, (3) a hollow blister pillow formed by the drainage of lava after the skin had solidified, (4) a hollow layered lava tube formed by temporary halts in a falling lava level, (5) a bulbous pillow with a "trapdoor" and toothpaste budding, (6) an elongate pillow, typical of a lava extrusion on a steep slope, (7) a breccia cascade, formed on very steep slopes where the lower end of an elongate pillow has ruptured, releasing a cascade of fluid lava, and (8) an elongate pilow swelling into a bulbous form along a longitudinal spreading crack. (Drawing based on a sketch by Wilfred B. Bryan, courtesy of* Scientific American *© 1975)*

Project FAMOUS had ever seen lava in such wild configurations. To Van Andel, one patch of basalt looked "exactly like a baked potato with a crack on top and sour cream coming out." The Americans dubbed some of the formations "toothpaste" and "trap door." The French used such names as "breadcrust," "broken eggs," and "phalluses."

"We were totally excited with every new thing we saw," said Jim Moore, a volcanologist with the U.S. Geological Survey. "It was an incredible experience. Every outcrop was different. It was a geologist's dream."

When the rocks were brought on deck, some of them crackled, sizzled, and jumped, like popcorn. Apparently, the tiny explosions were triggered by pressure changes at the surface that released the trapped gases within these rocks.

The geologists couldn't help being fascinated by the life they saw as well. WHOI marine geologist Bill Bryan said it was a zoo down there. During one dive, a 20-foot sea pen, a member of the jellyfish family, draped itself over *Alvin's* collecting basket, looking like a feathery boa. On another occasion, a line of pale sponges, looking like ghosts about 3 feet high, came into view and sent shivers through the passengers.

### Getting Out of a Tight Situation

But it was the geology that really mattered during Project FAMOUS.

On dive number 526 Bryan and Moore encountered a fissure, about 3 feet wide, then a still bigger one. The dive's transcript conveys their excitement:

"Look at that!"

"Oh, here's another one. This is one we can go down into it's so big."

"Look at that mother!"

"The time is 1409 and we are in the fissure." Moore said into his tape recorder. "The width of the fissure . . . ."

"Oh, my lord, the size! Look at that thing!"

"We've sunk down, oh, maybe 6 feet into this fissure . . ."

"Depth is 2,552 [meters]. We seem to be touching both walls. The width is, ah, about 12 feet . . . . The width of Alvin . . . well, that's funny."

"*Alvin*, this is *Lulu*," said Bob Ballard, impatiently from the surface. "Are you still at station four? Better get under way. Mission time is running out."

"We're trying." Pilot Jack Donnelly's voice was remarkably calm. "We don't seem to be able to rise."

Donnelly tried everything, moving the ship forward, then back but every time it would hit something. "It was as if somebody had put a big lid over us," Bryan said later.

Fortunately, before *Alvin*'s descent into the fissure, Bryan and Moore had taken detailed notes. They knew the fissure widened to the north. And from the drifting marine snow, they concluded that the current was running from north to south. That meant that as *Alvin* descended into the crevasse, it must have been carried toward the narrow end.

Using the scientists' reconstruction, Donnelly began to reproduce all of the sub's original movements in reverse, inch by painful inch. Finally, after two and a half hours, *Alvin* emerged out of the crack. The notes had saved their lives.

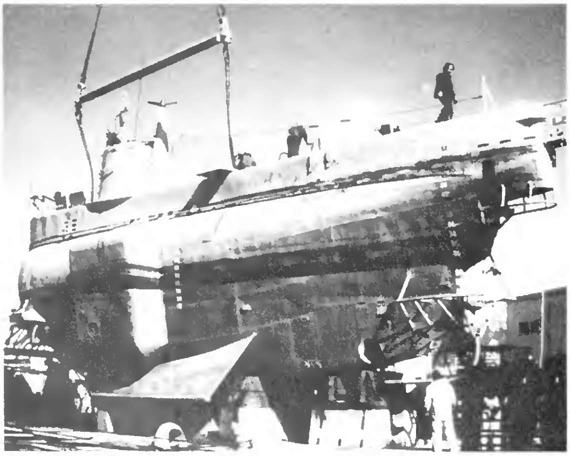
"We're clear and under way again and proceeding to our next station," Donnelly said. Those at the surface could scarcely believe that the three men would continue after their narrow escape.

There were other close calls. The less maneuverable *Archimède* was repeatedly pushed into canyon walls by the swift current, and once briefly trapped by a landslide. *Cyana* bashed against its mother ship on an early dive and had to be taken to Ponta Delgada for repairs.

The French came closest to finding the evidence everyone was looking for. They saw a small hole in the seafloor surrounded with what looked like streaks of metallic deposits. This seemed at least indirectly to support the theory that seawater seeped into the cracks in the ridge floor, where it was heated in subterranean magma chambers—the same hot furnaces producing all that lava—and finally re-emerged saturated with dissolved minerals. However, the French scientists couldn't locate the telltale hole during a second trip.

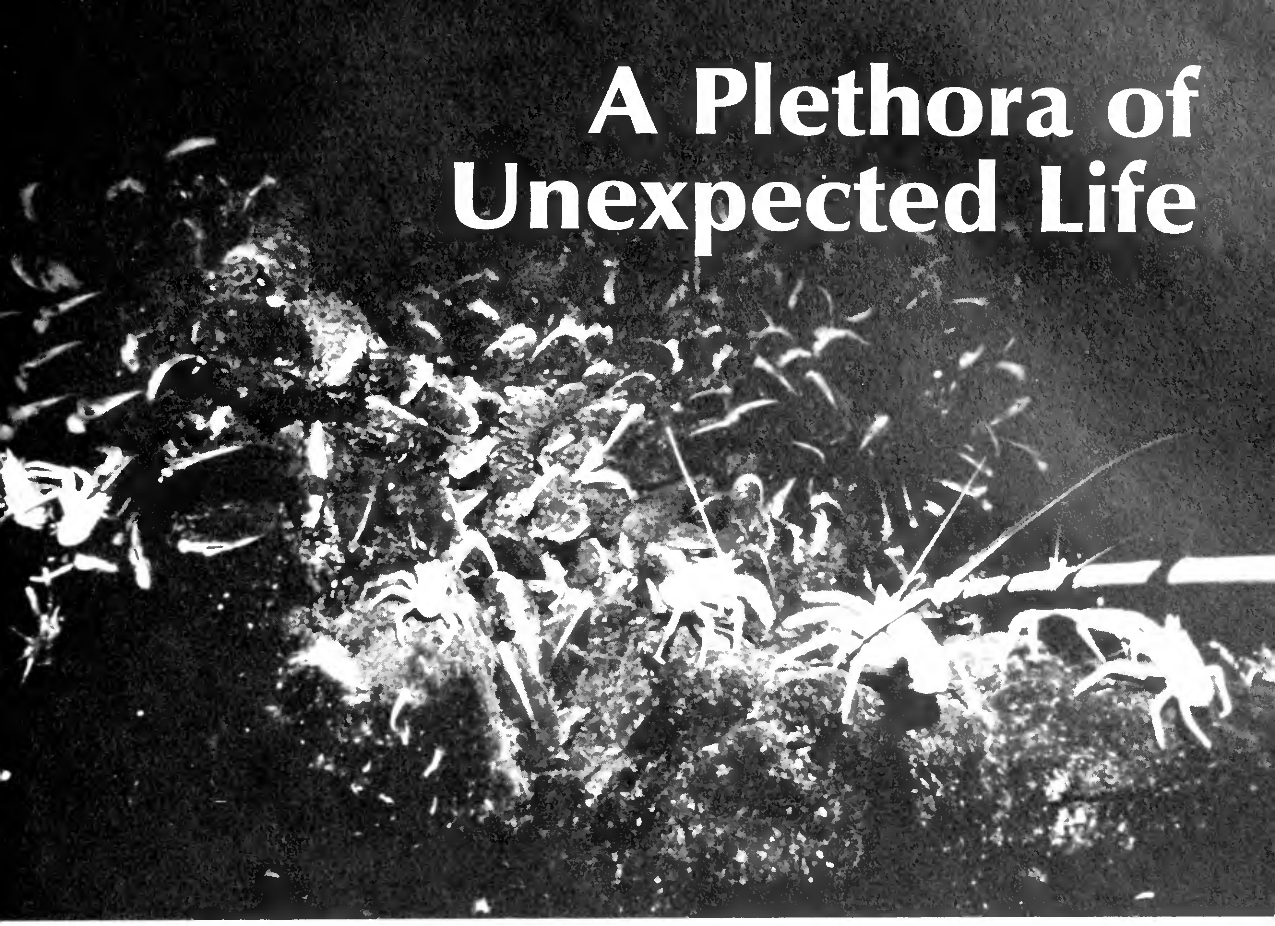
*Alvin* made 17 dives during that summer. *Archimède* and *Cyana* made a total of 27. In all, the submersibles hauled up 3,000 pounds of rocks, and cores of sediment—more than all the rocks and soil brought back by the Apollo astronauts in their missions to the moon—and returned with more than 100,000 photographs.

France's chief scientist Xavier Le Pichon initially had serious misgivings about using submersibles in such explorations of the deep. At the end of Project FAMOUS, he sent a post card to an American colleague. "I was wrong, now I believe," was all Le Pichon wrote.



Alvin*'s massive partner in Project FAMOUS, the French bathyscaphe* Archimède. *(Photo courtesy of WHOI)*

# A Plethora of Unexpected Life



*A parade of galatheid crabs marching over a bed of mussels at a vent in the Galápagos Rift. (Photo by Robert Hessler, Scripps Institution of Oceanography)*

### by J. Frederick Grassle

The first news of life at hydrothermal vents arrived in Woods Hole early in 1977 via a news report from the *San Francisco Chronicle*. The descriptions of giant tube worms and other unusual large animals clearly showed that life at the vents was something qualitatively different from anything known. A number of biologists who had worked together on the sea floor using *Alvin*, including myself, wanted to see these strange animals for ourselves, and to compare the ecosystems with those found elsewhere in the deep sea. We had used *Alvin* to conduct experiments on the deep-sea floor, and many of our ideas about deep-sea life had been radically changed as a result of these efforts. Thus, following the discovery of the vents, Howard L. Sanders and Holger W. Jannasch of the Woods Hole Oceanographic Institution, Bob Hessler and Ken Smith of the Scripps Institution of Oceanography, and Ruth Turner of Harvard University suggested that I coordinate the submission of a combined set of study proposals to the National Science Foundation (NSF).

Because deep-sea ecology, invertebrate zoology, and microbiology were well represented in our group, we sought collaborations with other investigators for studies of the physiology, biochemistry, and genetics of the unusual vent animals. Jim Childress at Santa Barbara, and George Somero at Scripps added physiology and biochemistry proposals, while Rich Lutz of Rutgers University, and Don Rhoads and Karl Turekian of Yale University agreed to study the growth of clams and mussels. Large clams, mussels, and tube worms collected at vents were to be kept alive and transferred to pressurized chambers in laboratories at sea for observation and experimental manipulation. Microorganisms

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*J. Frederick Grassle is a Senior Scientist in the Biology Department at the Woods Hole Oceanographic Institution.*

brought to ambient surface pressure were to be cultured for physiological studies in several land-based laboratories.

### Twenty-Five New Families

The proposals were accepted by NSF, and many of the major biological discoveries concerning hydrothermal vents were made on the 1979 expedition to the Galápagos spreading center (*Oceanus* Vol. 22, No. 2, pp. 2–10, and Vol. 27, No. 3). All of the animals at the vents proved to be extremely unusual — they belonged to approximately 25 new families or subfamilies, twice that many new genera, and four times as many new species. The nearest relatives of these species were among the several families of limpets known from the Paleozoic period, more than 250 million years ago. Vent animals only live where there's a supply of reduced chemical energy from hydrothermally altered seawater. Almost all the species recurred at every vent explored at the Galápagos spreading center, although they were found in different relative proportions.

We concluded that the age of vents and chance events in colonization were less important in determining community composition than relative flux of hydrothermal fluid. The more typical deep-sea fauna does not invade vent habitats, a fact that emphasizes the special adaptations acquired by vent fauna to cope with toxic levels of hydrogen sulfide and other compounds. The number of species at vents is low compared to the number of species occurring at other sites in the deep sea. In addition to communities of living animals, sites marked only by dead shells that dissolve in less than 20 years attest to the ephemeral nature of the vent environment. Vent animals rapidly grow to maturity and produce large numbers of larvae. These tactics are a response to the dynamic nature of vents, and contrast with the slow growth and small number of offspring in typical deep-sea species.

In this way, new vents are colonized before the populations perish with the cessation of hydrothermal flow. Each vent area has its own unique set of species that is found nowhere else, as well as some species that are known from other sites. Distant vent fields are genetically isolated, and colonization by mussels appears to occur episodically from distant sites.

**(continued on page 44)**

*At top, a bouquet of tube worms in the Galápagos (Photo by Jack Donnelly, WHOI). Opposite page, clockwise from top: a bed of mussels at a cold seep in the Gulf of Mexico; a giant sea anemone in the Galápagos with Alvin's temperature probe at right; acorn worms (enteropneusts) in the Galápagos; a dandelion-like siphonophore, kin to the Portuguese man-of-war; a close-up of tube worms.*

Photo by Holger Jannasch, WHOI

Photo by Robert Hessler, Scripps

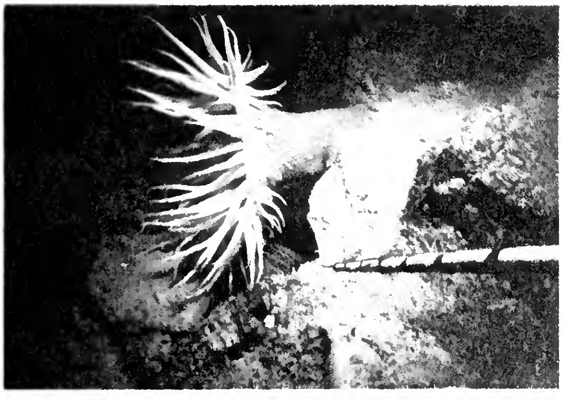
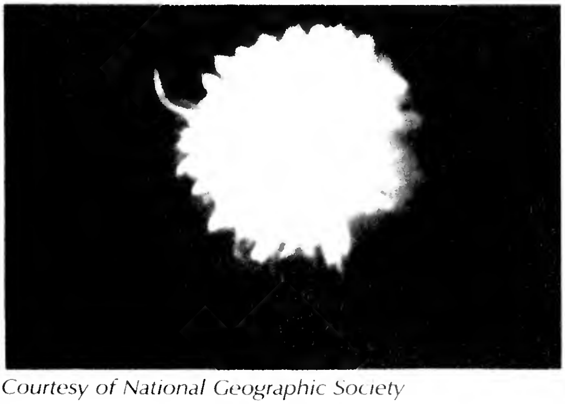
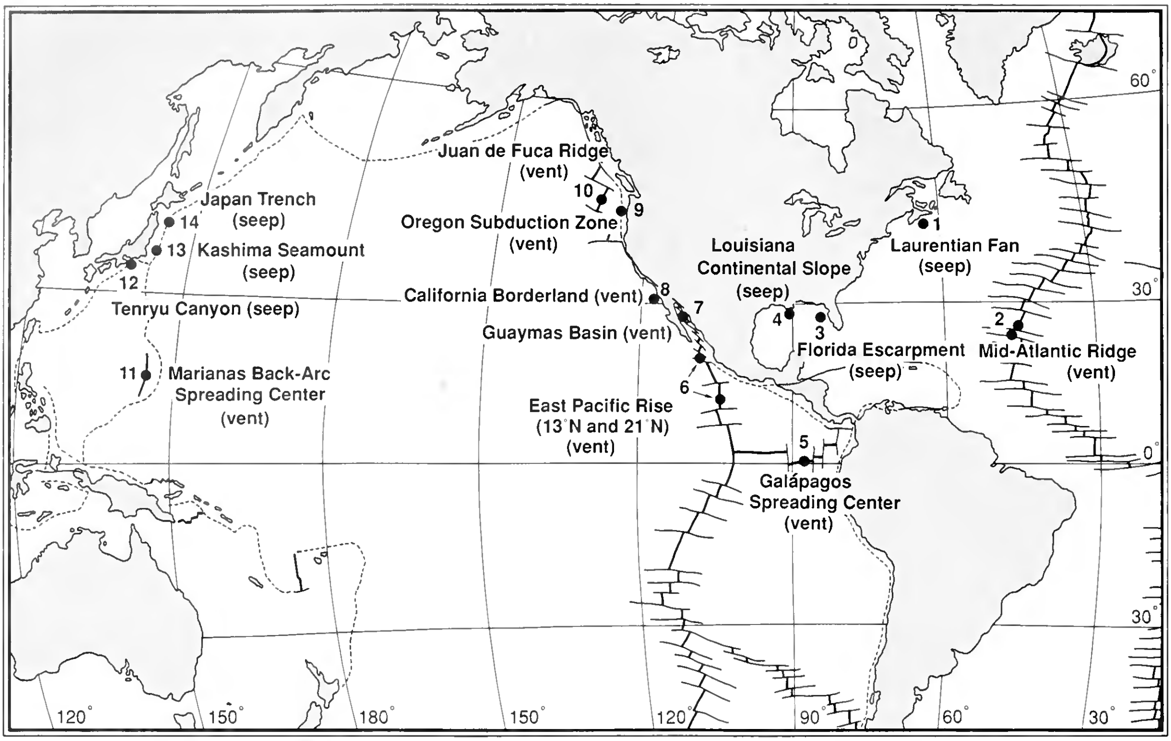


Photo by J. Frederick Grassle, WHOI



Courtesy of National Geographic Society

Photo by James Childress, UC/Santa Barbara



*A worldwide collection of hydrothermal vents and cold seeps investigated by biologists with the help of* Alvin *and other deep-diving submersibles.*

Chemosynthetic microorganisms dependent on reduced sulfur compounds were identified as the main primary producers within the vent ecosystem. A major surprise was the discovery of bacteria living on hydrogen sulfide within the tissues of the large animals; the bacteria supply their hosts with food. Physiological, biochemical, and morphological observations in the laboratory were crucial to this discovery. The variety of free-living microorganisms living in hydrothermal plumes and colonizing surfaces was also a major surprise. Other reduced compounds in the vent fluids, such as hydrogen, ammonia, methane, and reduced forms of manganese and iron, supply energy for microbial growth.

### Unanswered Questions

There's still a great deal to be learned about every aspect of these studies. Especially exciting are the somewhat unpredictable discoveries that occur as each new vent field is explored. Inevitably, these cause vent workers to modify the recent hypotheses that until then had seemed to explain most of the previously observed phenomena. Giant "megaplumes," for example, are now known to spew forth occasionally from sites on the Juan de Fuca Ridge off the American Northwest Pacific Coast. Do these vent extrusions of hydrothermal fluid provide the chief means for vent species to be transported great distances?

In comparison to other vent fields, the Mid-Atlantic Ridge has yielded a very different fauna, dominated by shrimp (article, pp. 47–52), despite similarities in the chemical composition of vent fluids and the temperature regime. Is this a consequence of the comparative geographic isolation of this region of the Mid-Ocean Ridge system? Or does it reflect the possibility that the Atlantic vent fields may last thousands of years instead of just tens of years? Biologists still haven't had the opportunity to visit the Atlantic vents, and other surprising phenomena are certain to be discovered.

The time scales of major volcanic, tectonic, and hydrothermal events are unknown. Future biological studies must be closely integrated with the study of these processes at long-term "observatories" on the sea floor. In addition, exploration of new sites by biologists, geologists, and chemists will form a basis for global comparisons of hydrothermal ecosystems. Reduced compounds, such as methane and sulfides, seep from the continental margin at depths to 3,900 meters, and support communities similar to those in vent areas, yet the chemical composition, temperatures, and hydrodynamic regimes are quite different. What are the essential features of the environment that allow these cold seeps to support communities similar to those of hydrothermal vents? Is it simply the source of chemical energy, or is the temporal pattern of flow important?

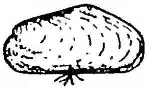
# *The World of Vents and Seeps*

*These varied creatures represent the rich inverterbrate life at the vents and seeps on the ocean floor. The sites are indicated by the numbers below and on map, opposite page. Ruth Turner drew the clams and mussels, Austin Williams the shrimp and crabs, Cindy Van Dover the tube worms, and Daniel Desbruyères, Marian Pettibone, Bob Zottolli, and James Blake the polychaetes. Rosemarie Petrecca provided research assistance.*

### CLAMS

*Calyptogena*
1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14

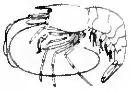
### MUSSELS



*Bathymodiolus*
5, 6

Mytilid, new genus
2, 3, 4, 11

### SHRIMP



*Alvinocaris*
2, 3, 4, 5

*Rimicaris*
2, 11

### CRABS

*Bythograea*
2, 5, 6, 11

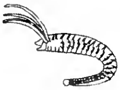
*Munidopsis*
1, 3, 5, 6, 7, 10, 12

### POGONOPHORAN WORMS

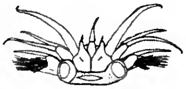
Pogonophorans
1, 4

### POLYCHAETE WORMS

*Alvinella*
6



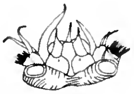
*Amphisamytha*
3, 5, 6, 7, 10



*Branchinotogluma*
5, 6, 7, 10

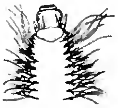
*Euphrosine*
5, 7

*Hesiospina*
5, 6



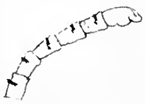
*Lepidontopodium*
5, 6, 7, 10

*Levensteiniella*
5, 6, 10

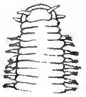


*Nereimyra*
5, 7

*Nereis*
5, 6, 7



*Nicomache*
2, 3, 5, 6, 7



*Ophryotrocha*
5, 6, 7

*Paralvinella*
5, 6, 7, 10, 11

*Prionspio*
5, 6

### TUBE WORMS

*Escarpia*
3, 4, 8

*Lamellibrachia*
4, 8, 9

*Oasisia*
6

*Ridgeia*
10

*Riftia*
5, 6, 7

*Tevnia*
6

*The animals are not drawn to scale*

Ever since Darwin, evolutionary biologists have been intrigued by oceanic islands, and events occurring on the geologic time scales important to the origin of species. For example, the spacing and temporal sequence of new islands of the Hawaiian chain formed by volcanic eruptions have played a major role in the speciation of the highly diverse terrestrial insect fauna. Deep-sea vents are linearly arranged along the Mid-Ocean Ridge and the pattern of cessation and initiation of flow can be thought of as a template for the evolution of species.

Critical data on the spacing of vents, on the length of time they are habitable, and the age of whole vent fields, as assessed by geological and chemical investigations, are needed to understand the life histories and evolution of vent populations. Water circulation associated with vents provides the means by which the dispersal stages of vent organisms are transported from one vent site to another. This circulation has not been well studied, but is expected to occur on several spatial scales, including local heat-driven convection, mesoscale eddies*, and deep-sea currents. In addition to providing the connecting link between vent populations, this circulation disperses vent productivity to organisms in surrounding deep-sea communities.

Our study of vent communities has greatly extended the range of physical and chemical environments known to support life. There is renewed interest in the animal diversity represented by marine invertebrates. Ecologists have begun to think more broadly about potential sources of energy for both natural and aquacultural systems. Archaebacteria, living anaerobically at high temperatures, are related to the most ancient forms of life. These bacteria are genetically distinct from other organisms, and have been classified as a separate kingdom distinct from plants, animals, and other microorganisms. The existence of these organisms in the high-energy vent environments has led to increased speculation that similar environments may have led to the origin of life. The chemistry of organic compounds, and their interaction with organisms, need to be much better known in a variety of hydrothermal environments to evaluate this possibility.

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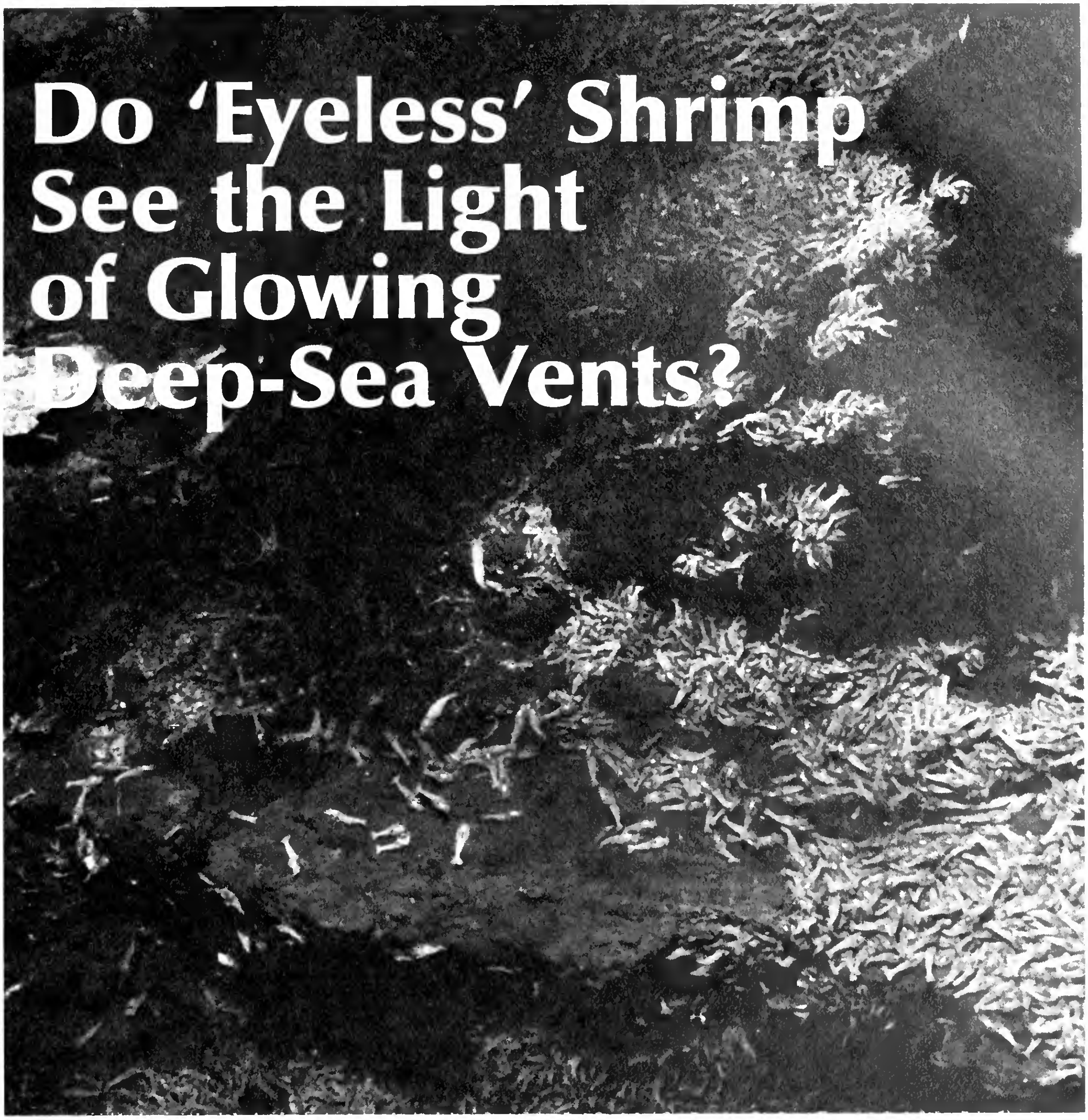
*Very energetic eddies, hundreds of kilometers in diameter, spiraling off major current systems.

*The author, center, looking over* Alvin *before a dive. (Photo courtesy of WHOI)*

# Do 'Eyeless' Shrimp See the Light of Glowing Deep-Sea Vents?



*Swarms of shrimp cover the surface of a black smoker chimney in a Mid-Atlantic Ridge hydrothermal vent field. (Photo courtesy of the author)*

### by Cindy Lee Van Dover

My visitors quickly focus on the heart of the matter. "But do they turn pink when they're cooked?" I'm asked, as I try to describe the gray shrimp living at hot springs deep in the Atlantic Ocean. It is a reasonable enough question, since the shrimp crowd around plumes of black, 350-degree-Celsius water pouring out of sulfide chimneys on the seafloor. The shrimp are protected from the cauldron, though, by seawater drawn up beside the rising plume. Further, the heat escaping from the earth's interior is quickly absorbed by the surrounding seawater. Within a few centimeters above the chimney orifice, the temperature of the plume is a comfortable 20 degrees, and within a meter it is an icy 2 degrees. Still, wouldn't the occasional shrimp find itself caught up in water hot enough to turn it instantly to deep-sea bouillabaise?

It was a geologist, Peter A. Rona with the National Oceanic and Atmospheric Administration laboratory in Miami, who first discovered hot springs in the Atlantic in 1985 (Location 2, map, p. 44), and collected shrimp for biologists to examine. Using a dredge to sample the

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*Cindy Lee Van Dover is a Ph.D. candidate in the Biology Department of Woods Hole Oceanographic Institution.*

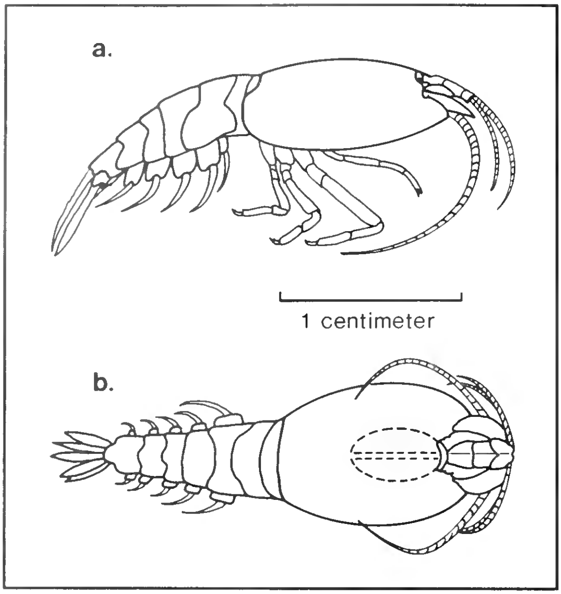


*Figure 1. (a) Side, and (b) dorsal views of* Rimicaris exoculata. *Shaded area indicates the location of the unique "eyes," visible as bright spots in the photo on page 47.*

seafloor from a surface ship, Rona picked up hundreds of shrimp and pieces of black sulfide chimneys. Most of the shrimp (Figure 1) quickly found their way to the Smithsonian Institution in Washington, D.C., where Austin B. Williams, one of the world's experts on animals such as shrimp, lobsters, and crabs—collectively known as decapod crustaceans—studied them. Williams and Rona published descriptions of two new species of shrimp, assigning them the names *Rimicaris exoculata* and *Rimicaris chacei*. The generic designation, *Rimicaris*, is from the Latin *rima*, meaning rift or fissure, and refers to the Mid-Atlantic Rift; and *caris* means shrimp. The specific name *exoculata* refers to the fact that this species is deprived of any vestige of the usual shrimp eyestalk or cornea; *chacei* is named in honor of Fenner A. Chace, a renowned taxonomist of decapod crustaceans. Both species are members of same taxonomic family as the shrimp that are known from Pacific hydrothermal vents.

### Swarms at hot vents

The Pacific shrimp live inconspicuously as ordinary scavengers among groups of other animals at deep, warm (2- to 20-degree-Celsius) water springs. But the Atlantic branch of the family is far and away the more remarkable in terms of its ecology. For one thing, *Rimicaris exoculata* has been found only on active, high-temperature sulfide chimneys; investigations of chimneys venting "cooler" (200-degree) water have yet to show any presence of *R. exoculata*. In this environment they encounter extreme water temperature gradients—only a few millimeters may separate 350-degree water from 2-degree water. Spectacular crowds of these shrimp, with as many as 1,500 individuals per square meter, have been observed completely obscuring the surface beneath them. And they don't just sit quietly, but constantly move about in such a way as to prompt John M. Edmond, a geochemist at the Massachusetts Institute of Technology who has visited the Atlantic hot springs in *DSV Alvin*, to describe them as "disgustingly like swarming maggots on a hunk of rotten meat." While I might have opted for a more engaging analogy—say, "bees dancing on a hive"—Edmond's imagery does justice to the sight.

Another extraordinary feature of the Atlantic shrimp is that they dominate the fauna at Atlantic hot springs. This contrasts sharply with springs of the eastern Pacific, where lush, exotic communities of tubeworms and bivalves crowd around cracks in the seafloor through which warm water issues (article, pp. 41–46). It is the tubeworms and bivalves that have become famous for their symbiotic associations with sulfur-oxidizing bacteria, housed within special tissues, and producing most, if not all, of the animals' nutrition. The Atlantic shrimp, however, do not host symbiotic bacteria. Instead, the shrimp appear to gather their food by mining the sulfide surface of the black smoker chimneys on which they live. The tips of the legs of these shrimp have strong, file-like spines that may be used for rasping. Their first pair of legs, located very near the mouth, have scoop-shaped claws that look well-designed for picking up small bits of loosened sulfide; a brush-like appendage then sweeps the sulfides out of the scoop and into the mouth (Figures 2 and 3).

On post-mortem examinations of collected specimens, I found every stomach packed solidly full of sulfide minerals. Of course, there isn't much nutrition to be gained from the sulfide minerals themselves. But we think that associated with the sulfides are tremendous numbers of free-living bacteria. Like the symbiotic bacteria of the eastern Pacific, these bacteria would have to grow by using the chemical energy in reduced sulfur compounds (plentiful in the hot vent water) to convert carbon dioxide and water into bacterial tissue, in much the same way as green plants use the energy of sunlight to convert carbon dioxide and water into plant tissue. Bacteria-laden sulfide minerals are ingested by the shrimp, the bacteria are digested, and the undigested minerals are eliminated. This mode of feeding would account for the determined way the shrimp seem to attack the sulfide chimneys, as if desperate to glean yet more bacteria from an otherwise unpalatable substrate.

Palatability raises another issue: are the shrimp good to eat? The opportunity to address this question arose during the visit of a very distinguished and discriminating colleague from the University of Newcastle, Great Britain, J. R. Cann. In the true spirit of scientific experimentation, we gathered around the laboratory Bunsen burner one afternoon, took one of the shrimp from the freezer, and boiled it. It did not turn an appetizing pink. If anything, it turned a still more unappealing shade of gray. As we might have expected, given the sulfide environment of the shrimp, the flesh tasted of rotten egg, and if that were not enough, the texture of the beast was as I imagine a rubber band might be. Perhaps it was overcooked. We concluded from our experiment that there will be no market for these shrimp among the gourmandizing public.

### To see, or not to see?

In studying photographs and videotapes of the shrimp to learn about their behavior, I could not help but notice a bright reflective spot on the dorsal surface, or back, of the shrimp. Knowing that sooner or later someone would ask me about those spots, I carefully looked at some preserved specimens and discovered that the spots correspond to the paired lobes of a very large and unusual organ just beneath the thin, transparent carapace. Each lobe was connected to the brain of the shrimp by a large nerve cord. Despite the absence of lenses or another image-forming device, I guessed that the lobes corresponded to eyes of a sort never encountered before. My guess was hardly proof, as my colleagues were quick to point out, so I set out to find what was needed to prove that they were indeed some sort of weird eye in this otherwise eyeless shrimp.

The proof required turned out to be the unequivocal demonstration of the presence of a light-sensitive visual pigment. There are two straightforward ways of doing this: one relies on immunological techniques, which identify molecules on the basis of structure; and the other is a biochemical assay, which identifies molecules on the basis of function. Ete Z. Szuts, a sensory physiologist at the Marine Biological Laboratory in Woods Hole, was willing to perform the biochemical assay. Together we dissected the organs from frozen shrimp under the surreal conditions of a red-lit laboratory. Then Szuts purified the membranous material that should contain the visual pigment, and extracted whatever pigment there was in the membranes with a mild detergent. We used a spectrophotometer to measure the amount of light at different wavelengths absorbed by this extracted material, first in the dark and then after bleaching the extract with a light. The two measurements are necessary since visual pigments are light-sensitive, and have characteristic absorption spectra under these different light conditions.

It is an elegant procedure, producing satisfyingly concrete evidence when it works, as it did for us. In the extracted material, there was a substance that absorbed maximally in the long wavelength, blue-green part of the spectrum; on bleaching, the product absorbed maximally at shorter wavelengths. The shape of the absorption spectra of the shrimp pigment closely match those of rhodopsin, the visual pigment found in eyes of both vertebrates and invertebrates.

Building on this evidence, we turned to Steven C. Chamberlin of the Institute for Sensory Research at Syracuse University, New York, for a morphological description of this novel organ. His work, involving the laborious preparation and sectioning of material for microscopy, identified the photoreceptor, or light-sensitive, cells. These cells are grouped into six-cell clusters, with 1,300 to 1,500 clusters per lobe. Each cell has a cylin-

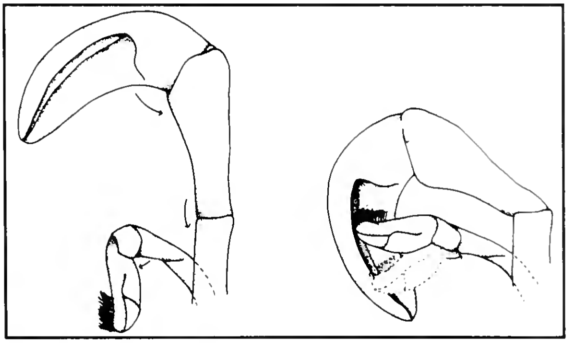


*Figure 2. The first pair of legs, or chelae, of the shrimp are scoop-shaped. Sulfide particles with encrusting bacteria are scraped from the chimney surface, and shoveled into the shrimp's mouth using them.*

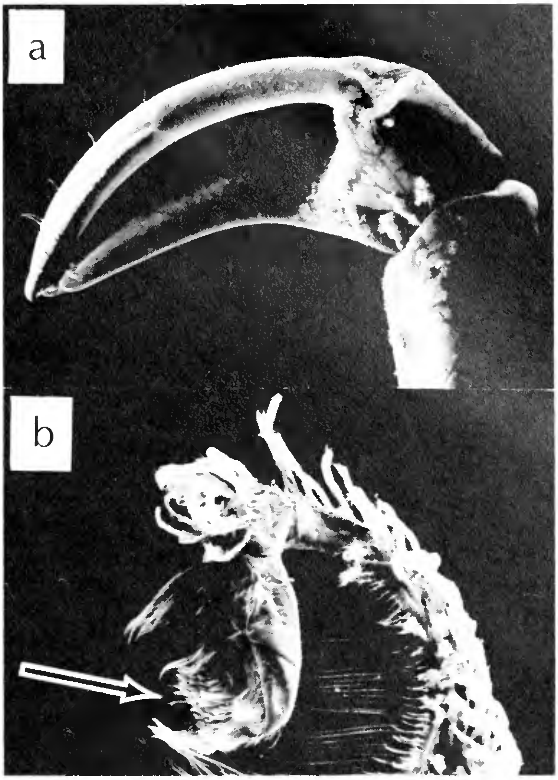


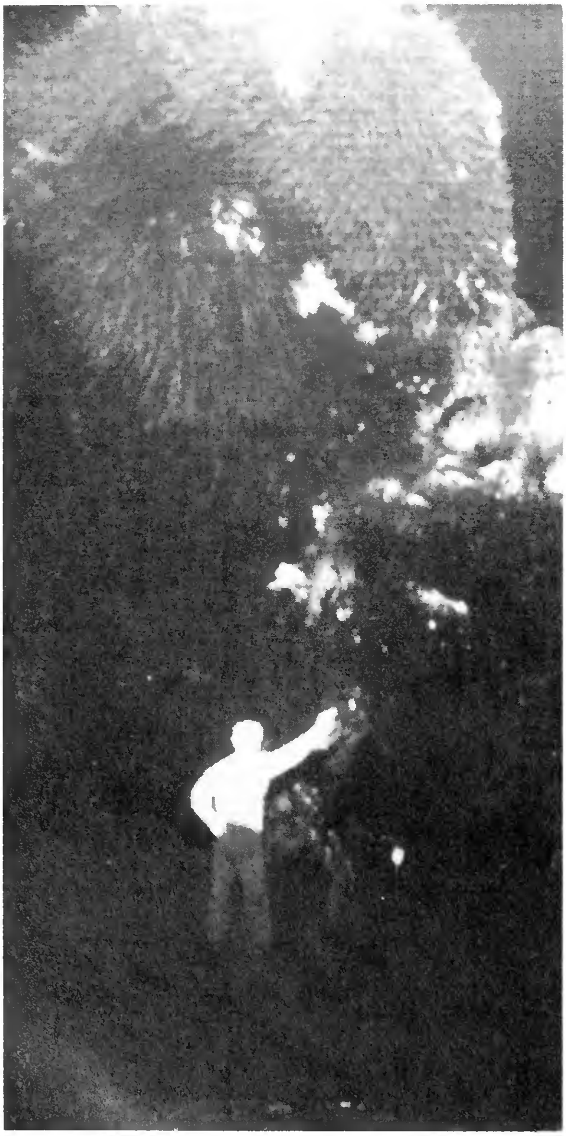
*Figure 3. (a) Scanning electron micrograph of claw of first leg. (b) Arrow points to brush that sweeps sulfide particles into shrimp's mouth. Arrow also indicates scale, length = 1 millimeter.*

drical region filled with rhabdomeral membranes, the membranes containing the visual pigment. A thin stalk leads down from the rhabdomeral region to the cell nucleus, beyond which is the junction with a nerve cell.

Chamberlain's morphological evidence suggests that the unusual organs of *Rimicaris* are modified compound eyes, specialized for high sensitivity by:

- Extreme proliferation of rhabdomeral membranes, and high concentrations of visual pigment.
- Absence of lenses or other image-forming devices, thereby minimizing the potential for absorbance of photons by non-photoreceptive tissues.
- Presence of reflective properties that might allow reflected light a chance to be absorbed by the photoreceptors.

As these lines of research progress, and as we become more confident that we are indeed dealing with a visual organ, the issue turns to what the shrimp may be looking at. Without lenses, they cannot be seeing an image. Instead, we guess that the shrimp are detecting gradients of light. Based on the structure of the organ, we hypothesize that it is particularly well-adapted for detecting low levels of light. What sources of light are there in the deep sea? These shrimp live 3,600 meters below the surface of the sea, far beyond the reach of sunlight; it is a pitch-black environment, seemingly darker than one can even imagine. From *Alvin*, the only light to be glimpsed at that depth is the occasional, eerily blue-green flash from a bioluminescent organism. Normal shrimp eyes can detect this type of light; but why should the vent shrimp have evolved such an unusual eye if this was all it was looking at? We began to wonder about other sources of light that might be peculiar to the extreme hydrothermal vent environment.



*A full-sized "Dudley Unit" (plywood mannequin of Dudley Foster) standing in front of a sulfide chimney, in 2,500 meters of water at the Juan de Fuca Ridge. Mannequin was used to show the scale of the chimney, and to test the CCD camera. (Photo by Milton Smith, University of Washington)*

### Glowing hydrothermal vents

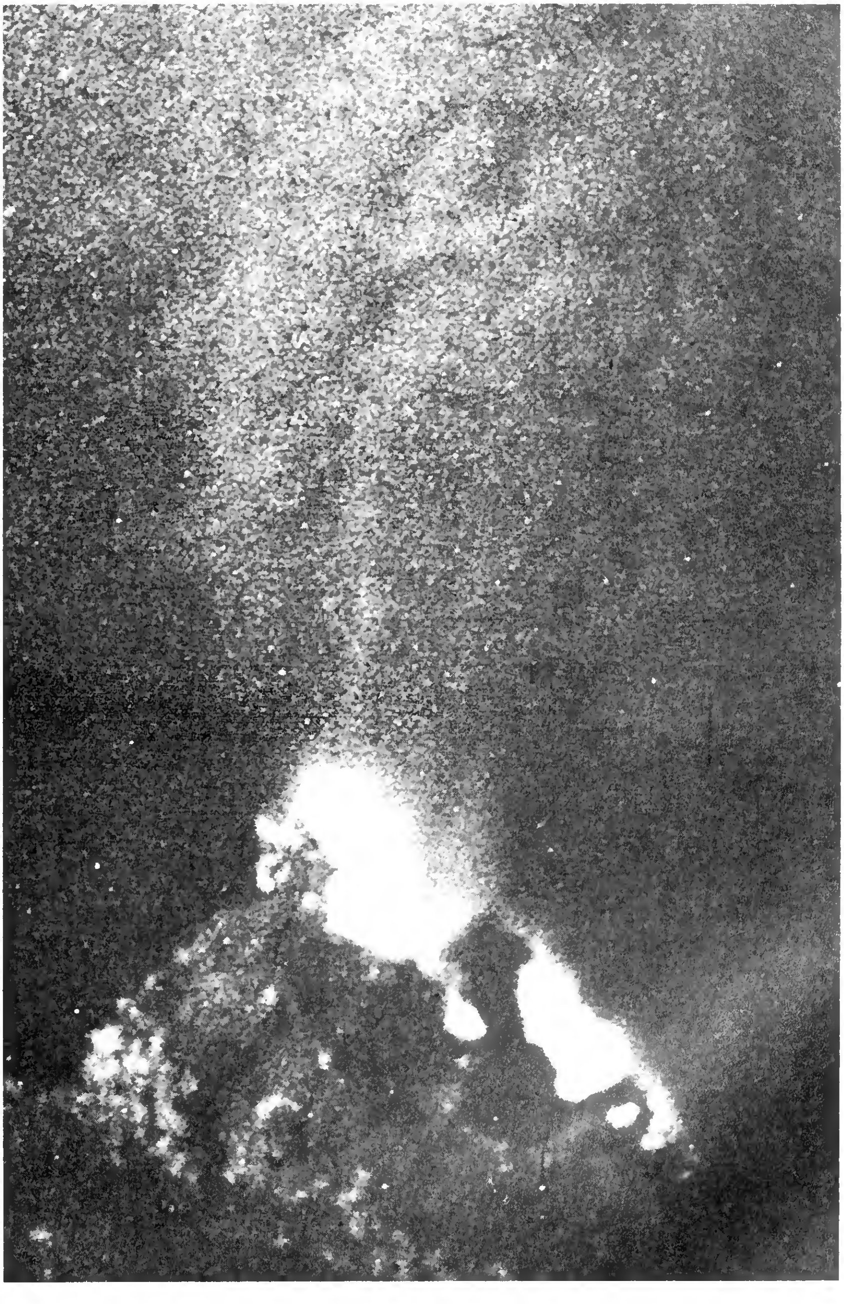
The dominant physical features of the Mid-Atlantic Ridge vents are the sulfide chimneys on which *Rimicaris* lives. Could there be light, detectable by the shrimp, associated with the springs of 350-degree-Celsius water? The advantages to the shrimp of such a situation are clear; the light could serve as a beacon to draw them to areas where they can feed, and such a light could also serve as a warning signal to deter them from too close an encounter with water hot enough to cook them instantly.

We know that hot things glow with thermal radiation, a phenomenon known as "black body" radiation. Are black smokers hot enough to be emitting light visible to the shrimp? Rough calculations, based on estimates of the threshold light intensity necessary for vision, the emission spectrum of a black body radiator, and the absorption spectrum of the visual pigment of the shrimp, indicate that the shrimp may indeed be able to see such a glow, even though it might be too dim for a human eye to detect.

Testing this hypothesis means returning to Mid-Atlantic Ridge vents with *Alvin,* carefully measuring light levels and wavelengths at the chimneys, studying the shrimp's behavior in response to experimental light stimuli, and shipboard physiological experimentation. The earliest we could hope to visit the Mid-Atlantic Ridge is next summer; after that, *Alvin* heads into the Pacific for an extended period, leaving studies in the Atlantic on hold indefinitely.

Logic led us to believe that our hypothetical light at Mid-Atlantic Ridge vents could be a universal phenomenon at similar high-temperature vents elsewhere in the deep sea. Thus, while we could not immediately find out what light *Rimicaris* may be detecting, we could ask a simpler question: What are the ambient light conditions at other black smoker chimneys?

The opportunity to begin answering this question came unexpectedly and quickly. John R. Delaney, a professor of Geology at the University of Washington, invited me to participate as the biologist on a cruise to hydrothermal vent sites on the Endeavour segment of the Juan de Fuca Ridge, 180 miles off the coast of Vancouver, Canada (Figure 4). I learned that he was to use an electronic charge-coupled device (CCD) camera to create a digital mosaic of seafloor images in the vicinity of these vents. At about the same time, I was reminded by Alan D. Chave, a scientist at AT&T Bell Laboratories, in Murray Hill, New Jersey, that such a camera ought to be sensitive enough to detect the levels of light I expected the shrimp to be seeing. Conventional photographic emulsions would have to have an ASA rating on the order of 50,000 to 100,000 to detect the same level of light. CCD cameras are



*350-degree-Celsius water, glowing eerily as it rises from a vent in the Endeavour Ridge hydrothermal vent field. The glow, predicted by the author, is yet to be fully explained. (Photo by Milton Smith, University of Washington)*

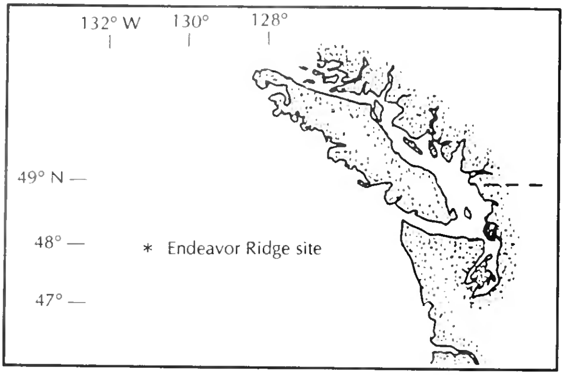


*Figure 4. Location of the Endeavour Ridge segment of the Juan de Fuca Ridge, where the glow of hydrothermal vents was first discovered.*

used extensively in astronomy to capture light from distant galaxies; there is a satisfying, if somewhat pre-Copernican, symmetry in turning to the same technology in oceanography to capture light emissions fueled by the core of our own planet.

On reaching *R/V Atlantis II* and meeting Delaney, I suggested aiming the CCD camera at a black smoker orifice, while all of *Alvin*'s outside lights were extinguished, and letting it record what was there. John enthusiastically agreed to try this simple experiment. Dudley B. Foster, *Alvin*'s chief pilot and expedition leader (article, pp. 17–21), agreed to work the submersible for brief periods of time without external lights.

What initially sounded like a simple experiment in fact required a great deal of effort and many unsung heroes, not the least of whom were the *Alvin* pilots and technicians. Together with Milton Smith, an expert in remote sensing at the University of Washington, the *Alvin* crew worked into overtime to configure the camera so that it could collect the required information. This group usually remains nameless; but this efficient, wonderfully competent team makes *Alvin* and *Alvin*-dependent research so successful. In addition to Foster, they are pilots Gary Rajcula, Pat Hickey, and Tom Tengdin; pilots-in-training Steve Etchemendy and Tim Connors; and technician Soc Carello.

Finally, on the last dive of a 19-dive series, *Alvin* was lifted off the deck, carrying the CCD camera mounted on the front basket. Inside the pressure hull were Foster, Delaney, and Smith. That day I haunted the lab where surface communication with the submersible takes place every half hour. In response to brief surface queries about their status, only a "busy" signal was returned in Morse code. At the end of the dive, as the submersible began its hour-long ascent, I gave up on learning anything about the success of the experiment, and left the room. On returning, I was handed a note by Hickey, the dive's surface controller. It was a message relayed up from the submersible, a message with only two words: VENTS GLOW.

With *Alvin* on deck, scientists and pilots gathered around the computer work station as Smith was recalling images of the glow. I expected to see some ambiguous hint of a fuzz which, if one was willing to stretch the imagination, might be called a glow; I doubt that I was alone in that expectation. Instead, what came up on the screen was a dramatic, unequivocal glow with a sharply-defined edge at the interface between the sulfide chimney and the vent water. Just a centimeter or two above this interface, the glow became very diffuse, disappearing altogether within 5 centimeters. The same phenomenon was documented at two different 350-degree chimneys within the same vent field.

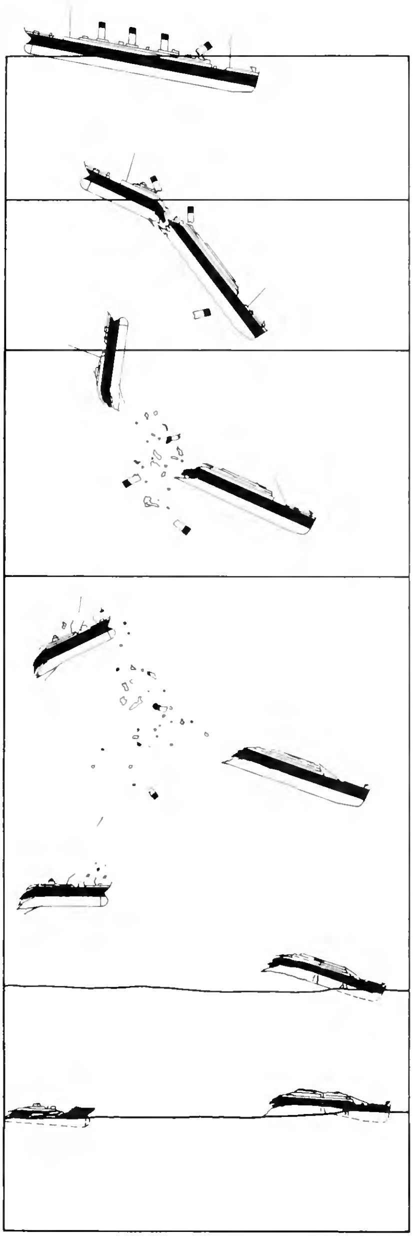
The discovery of this glow at high-temperature vents opens up a new area of research. At the moment, the glow is an intriguing and aesthetically-pleasing phenomenon; its importance will be judged by what we will learn in the future about the mechanisms of its production and its biological consequences.

*The author displays a specimen of* Rimicaris exoculata *that escaped the gastronomic experiment. (Photo by Rob Brown, WHOI)*

## *New Evidence About* Titanic's *Final Moments*

# Resting in Pieces

### By Elazar Uchupi, Robert D. Ballard, and William N. Lange



Titanic's *presumed demise: Aft section breaks off and rotates before sinking.*

Shortly before midnight, 14 April 1912, as she was making her maiden voyage across the Atlantic, *RMS Titanic* collided with an iceberg southwest of the Grand Banks off Newfoundland. The White Star liner, a proud symbol of British prowess on the seas—and in the mythology of the time, widely considered "unsinkable"—vanished from sight less than three hours later at a position approximately determined as latitude 41° 46′ North, longitude 50° 14′ West. Only 711 of her estimated 2,201 passengers and crew survived.* The tragedy stunned the world then and continues to fascinate the public today.

For more than 73 years, the *Titanic* lay unseen in the depths of the North Atlantic, a lost relic that provoked endless curiosity about her fate. In particular, there were questions about her condition after her two-mile plunge to the seafloor. Had she sunk in one piece, as most experts believed—including those who hoped, fancifully perhaps, to raise her from the bottom one day—or did she break in two just before she disappeared beneath the waves? If so, how much was left of the great luxury liner, which was a symbol both of the opulence of the Edwardian era and of its engineering prowess.

As the ship nosed into the sea, the first of the four funnels toppled forward, flattening the starboard flying bridge, and ended up in the water, where it crushed a number of swimmers. Apparently the fourth funnel (a dummy added for esthetic reasons by the ship's architects) also collapsed at the time, tumbling aft onto the stern well deck. So much was undisputed, but what else happened on that starry night varied with the witnesses.

In testimony after the disaster, Officers Charles H. Lightoller and Herbert J. Pitman, and passengers Colonel Archibald Gracie and Lawrence Beesley seemed sure that *Titanic* sank intact. Their account became the generally accepted version. But other observers, including such members of the crew as Quartermaster A. J. Bright, Greaser Thomas Range, and Able Seaman

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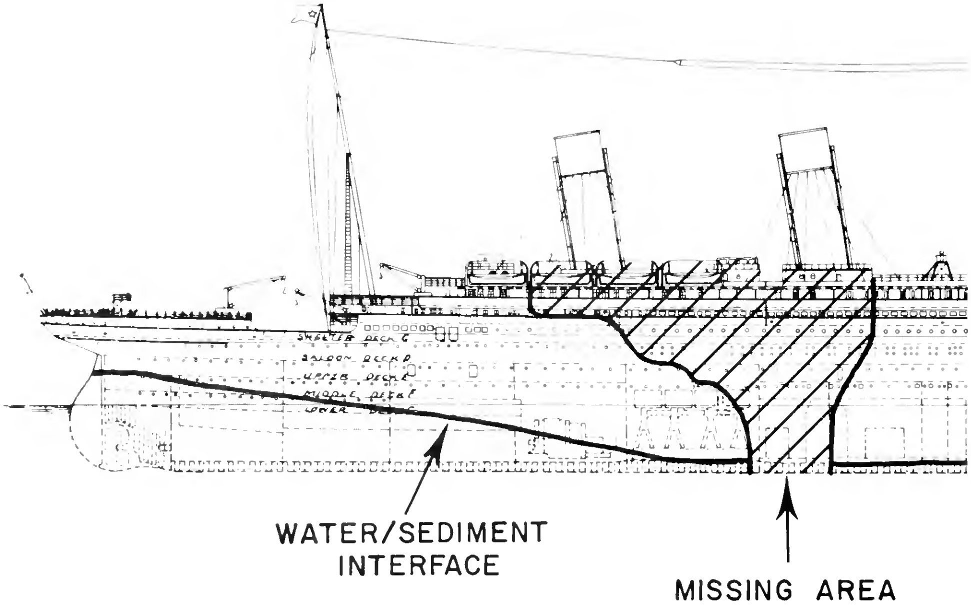
*The source of these figures is the original British inquiry, as quoted in Lord (1986). Other authors use slightly different numbers because of discrepancies in the passenger and crew lists.



F. O. Evans, as well as passengers Mrs. Arthur Ryerson, Jack Thayer, and Richard N. Williams, described a very different sequence of events in *Titanic*'s final moments afloat. According to these eyewitnesses, the hull broke in two while the ship was still on the surface. As the bow section dipped beneath the waves, the stern section tilted upward briefly, rotated 180 degrees, then also began to sink.

Which accounts of the survivors are we to believe? Until recently, there seemed to be no way of resolving these great differences in the testimony that emerged from that horrifying night on the North Atlantic. But that has now changed; shortly after midnight, 1 September 1985, the long-lost wreckage of the great ship was discovered by scientists of the Woods Hole Oceanographic Institution (WHOI), in collaboration with French scientists, using remote viewing systems developed at WHOI, and carried to the area aboard the WHOI research vessel *Knorr*. From the trove of photographs taken at the site that summer, and in the summer of 1986, we were able to reconstruct *Titanic*'s last minutes, finally settling many of the questions that had arisen over her fate.

## The Discovery of the Site

Two ships took part in the initial expedition. Besides *Knorr*, there was *Le Suroît* of the *Institut Français Recherches pour l'Exploitation des Mers* (IFREMER), based in Toulon. *Le Suroît* used a side-looking sonar, capable of mapping a 1-kilometer swath of the seafloor. But in three weeks of searching, she was unable to find any trace of *Titanic*, though she succeeded in greatly narrowing down the search area.

*Knorr*, continuing the hunt in August and September, 1985, after the French ship's departure, used the Argo and ANGUS (Acoustically Navigated Geophysical Underwater Survey) imaging system developed by WHOI's Deep Submergence Laboratory (DSL). She examined three areas: Cameron Canyon; a dune field east of the canyon; and a gently undulating region north of the field. The *Titanic* site was discovered during an east-west traverse when a single boiler, with its characteristic three hatches, suddenly appeared on a video screen in the early hours of the morning. Later, when the video tapes of that traverse were reexamined more closely, they revealed that *Knorr* had actually crossed the wreckage earlier in the sweep. In addition to the boiler, the tapes showed debris and coal, a telegraph (a mechanical apparatus for sending instructions from the bridge to the engine room), the stern section, and a crane motor.

ANGUS is a color camera system that can work to a maximum water depth of 6,000 meters. The system, which is towed on a standard half-inch trawl cable, consists of three 35-mm cameras, one of which was equipped with a 16-mm lens, another with 28-mm lens, and the third with a 50-mm lens. The cameras carried enough color film to take 3,000 frames each time the system was lowered. Photos were taken every 20 seconds as the vehicle was towed at 0.8 to 2.0 kilometers per hour, some 8 to 9 meters above the seafloor. This gave us as much as a 50

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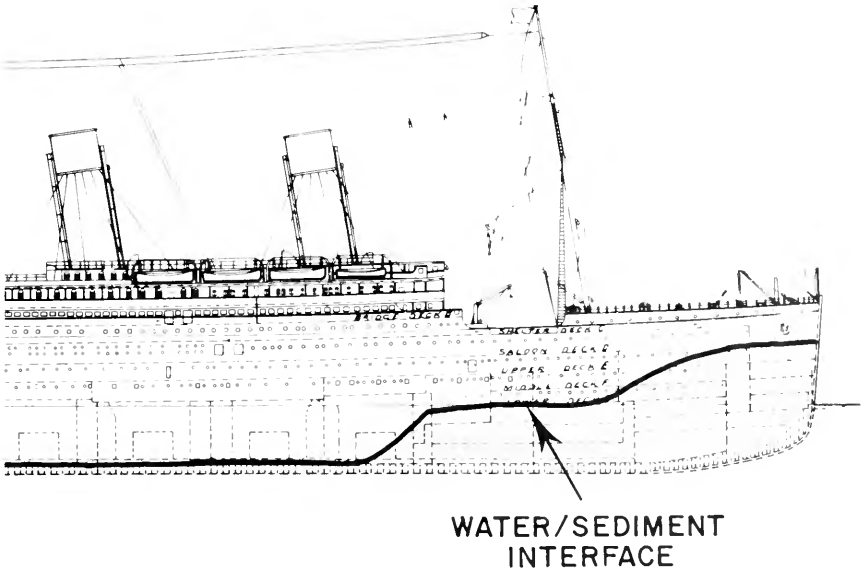
*Elazar Uchupi is a Senior Scientist and member of the Geology and Geophysics Department at the Woods Hole Oceanographic Institution. Robert D. Ballard, also a Senior Scientist at WHOI, is Chief Scientist of its Deep Submergence Lab, a member of its Ocean Engineering Department, and director of the Center for Marine Exploration. He and Jean-Louis Michel of IFREMER were co-chief scientists of the 1985* Titanic *expedition. William N. Lange is a member of WHOI's Graphic Services Department.*



*This cross-section shows where* Titanic *split up. The striped area fragmented during and after the separation. The shaded areas are now buried under sediment.*

percent overlap in the photo coverage.

Argo, named for the mythological Jason's ship in his search for the Golden Fleece, is a compact-car-sized camera-carrying sled, capable of operating to a depth of 6,000 meters. It has three "silicon intensified target" video cameras: one with a 12-mm down-looking lens, another with a 24-mm forward-looking lens, and the third with a down-looking 24-to-80-mm zoom lens. During reconnaissance runs, the sled was towed at speeds of just less than 3 kilometers per hour, at an altitude of 10 to 40 meters above the seafloor. Lighting came from strobe lamps in the aft end of the sled. Data from the cameras were sent to the surface vessel by coaxial cable, displayed as images on video monitors, and recorded on both half- and three-quarter-inch magnetic tape, as well as onto a laser disc.

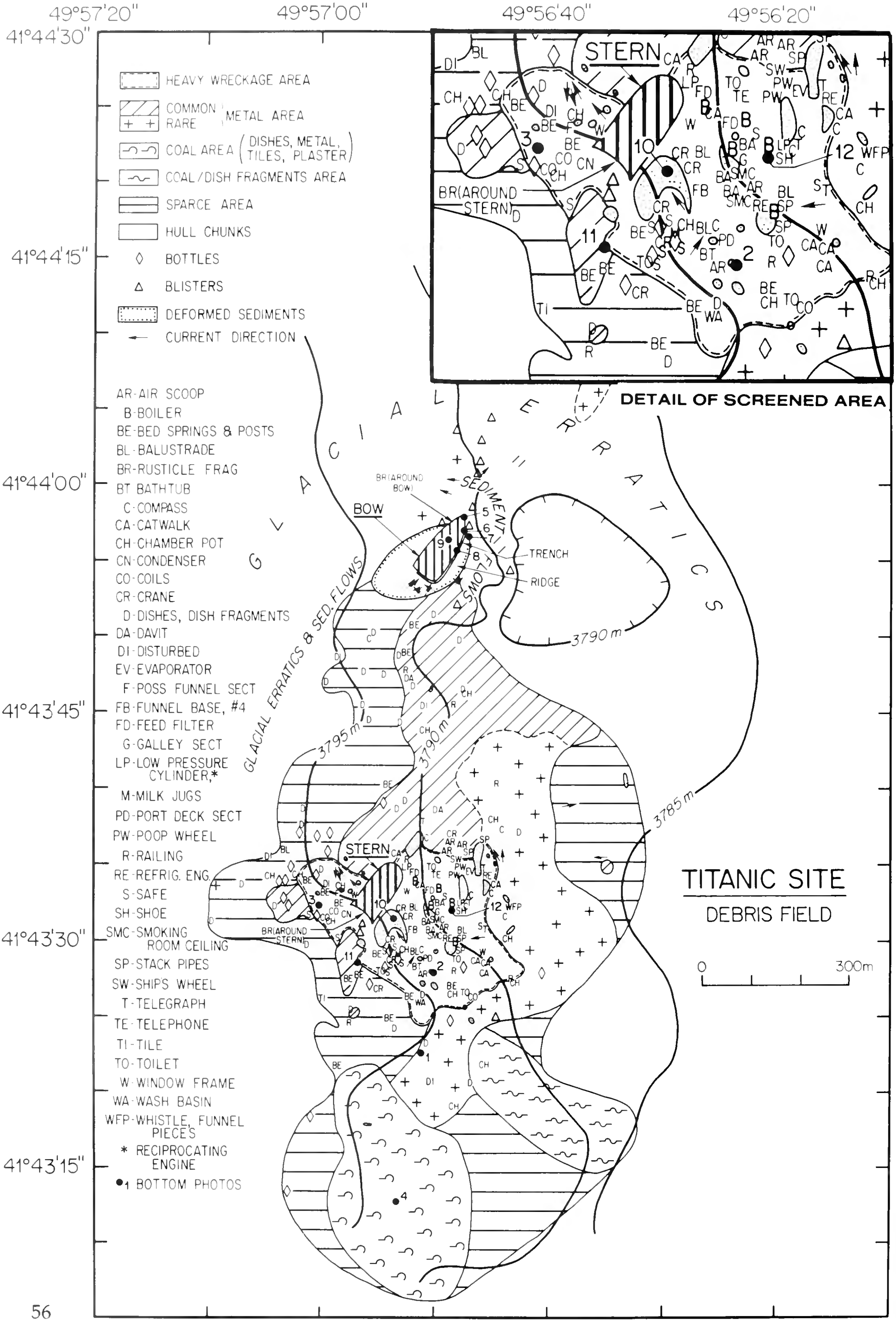
The following summer, in July 1986, an expedition from Woods Hole returned to the *Titanic* site to map the wreckage in greater detail. This time the ship was actually visited by members of our team using the deep-sea research submersible *Alvin*, which is operated by WHOI for the Navy, and can range to a depth of 4,000 meters. The expedition also had the services of a tethered remote viewing system, developed by the DSL. Playfully called Jason Junior, or "J.J.," it's a preliminary version of what will be a more complex completely free-floating Jason system that will eventually be carried to the bottom aboard Argo (*Oceanus*, Vol. 30, No. 3, pp. 11–15). For the present, the self-propelled J.J. and both its video and 35-mm still cameras are controlled from a console inside *Alvin*. A 62-meter cable links J.J. with the submersible. The third major piece of equipment was ANGUS. All three components were carried aboard our mother ship, the research vessel *Atlantis II*.

The *Titanic* wreckage was located at a depth of 3,795 meters, east of Cameron Canyon, one of the largest submarine canyons on the eastern North America continental margin. Indeed, if *Titanic* had been lying in the canyon itself, it might never have been discovered. In 1929, the region was struck by a powerful earthquake that triggered massive slumps and slides. These in turn produced a turbidity current, or undersea avalanche, that swept down the axis of the canyon and might well have broken up the wreckage even more completely, or possibly have buried the entire ship under sediment and debris. At the *Titanic* site itself, poorly defined tributaries drain into the canyon from the Southeast Newfoundland Ridge and the continental slope west of the Tail of the Bank.

*RMS Titanic* is resting on a gently undulating bottom covered by bioturbated muds (muds reworked by bottom organisms), intermingled with glacial erratics (boulders and other debris from melting icebergs), mud waves, and scattered patches of rippled sand. The center of the bow section is at latitude 49° 56′ 49″ W, longitude 41° 43′ 56″ N, and the center of the stern is at latitude 49° 56′ 55″ W, longitude 41° 43′ 33″ N, about 600 meters to the southwest. Both face slightly east of north. The site is about 24 miles east-southeast from where the original position indicated it might be found.

### The Wreckage

The hatch covers on the forecastle and forward well deck are gone, but the gate between the well deck (third class) and B deck (first class) still remains—closed, as it was even in the ship's final moments. (By far the greatest loss of life among *Titanic*'s passengers was in third class, or steerage.) Segments of the forecastle railing are missing, and cables from the forward mast are draped over the port side. The fallen foremast



TITANIC SITE
DEBRIS FIELD

resting on the port wing bridge still supports the crow's nest and running light. The arm of one of the starboard side cargo cranes on the well deck is broken, and the bulwark railings of A deck and bridge have fallen forward. The bulkheads of the wing bridges have been pulled apart and flattened, and the only section of the wheel house still in place is the bronze telemotor control.

The bulkhead from the officers' quarters aft of the bridge is partially pulled out and flattened; a davit (a small crane used for launching lifeboats) rests on the flattened section on the port side. The forward-most davits of the starboard and port sides are still in place and extend out, still in the position they were in when they lowered fortunate survivors into the sea. The aft davit from lifeboat 8 on the port side is resting on the boat deck. The boiler vents in the area of stack 1 show considerable damage; stacks 1, 2, and 3 are missing; and the grand staircase roof, aft of stack 1, has collapsed. The compass tower between stacks 2 and 3 is missing, and the expansion joint aft of the first stack displays a wide gap. The bow section ends just aft of missing stack 3, and the decks between stacks 2 and 3 have also collapsed, dipping at an angle of about 45 degrees, although the hull plating remains partially upright. The wooden deck has been consumed by wood-boring mollusks (*Xyloredo ingolfia*), but a few pieces have survived, such as the beam forward of the bronze telemotor control, for reasons that couldn't be determined because we had agreed beforehand that no samples would be taken.

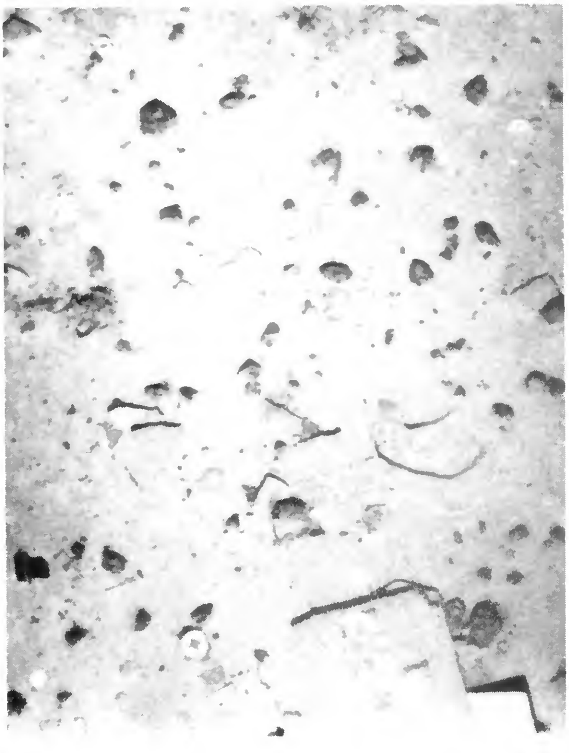
In profile, the bow section is warped upward with the shallowest portion located near the expansion joint. The hull displays vertical buckles; but there is no evidence of the 77-meter gash, supposedly made by the iceberg on the starboard side. Instead, the collision damage consists of creased plates and horizontally opened seams. On the starboard side, the prow sits in sediment up to the base of the starboard anchor, whereas much less of the bow is buried on the port side. Also, a narrow trench runs along the starboard side, bordered by a ridge of deformed sediment, including glacial erratics. The trench extends discontinuously to the end of the bow section, where it turns westward, parallel to the tear where the bow and stern sections parted. By contrast, on the port side, there is no trench whatsoever. (The only object of interest found in the deformed ridge is a miniature copy of the statue "Artemis of Versailles," after an original in the Louvre. Probably made of spelter, a pewter-like zinc alloy, and painted bronze, it had rested on the mantlepiece in the first-class lounge, and now sits by itself in a field of glacial erratics.)

The sides of the hull are marked by stalactites, nicknamed "rusticles" by Ballard. They were produced by iron-oxidizing bacteria. Because they prefer a medium more acid than seawater, the bacteria create slime layers between the seawater and the iron sulfide to form the rusticles. The structures continue to grow until they break of their own weight and fall, which accounts for the rusticle remains found scattered around the periphery of the bow and stern sections.

In the stern, the ship's big screws are buried beneath 14 meters of sediment; the rudder, however, is still exposed. Around the periphery of the stern is a wide expanse of stained sediment. The poop deck (the roof of the third-class smoking lounge) has been peeled back and partly overhangs the stern. The docking bridge on the poop deck is gone, as are the two cargo cranes, deck benches, air scoops, and parts of the railing. The well deck forward of the poop deck has been torn away, the two cargo cranes are missing, and the shell framing has been pulled outward from the hull. The aft mast is in place but down. The cargo cranes on the boat deck are still in place, so is the second-class entrance deck house. But part of the hull, and superstructure just forward of the dummy fourth stack, are missing.

### Soup Tureens and Sinks, Chamber Pots and Coal

The debris field associated with *Titanic* extends 1,700 meters in a north-south direction and 875 meters in an east-west direction. There are two



*This section of the coal area (see chart opposite page), photographed by ANGUS with a 28-mm lens, shows tiles, plaster, and metal fragments. Note the cup in the upper lefthand corner.*

*At left, a head-on view of* Titanic's *bow with rusticles falling from it. Above, a bronze telemotor control stands over degraded deck. Below, rusticled port hole on starboard side of bow. Photos taken from* Alvin.

overlapping segments originating from the bow and stern sections. These are separated partly by a region of hull chunks and other pieces of heavy wreckage. Both the bow and stern sections are oblique to the trails of debris that trace their paths to their final resting place on the bottom. These angles indicate that as the bow and stern sections sank, they slowly turned away from their wakes.

The field can be divided into heavy wreckage, metal, coal, coal/dish fragments, and patchy areas. Within the heavy wreckage area are seven large and 16 small hull pieces representing segments from a V-shaped section between stacks 3 and 4. Six other small hull pieces also were observed within the metal area, and another within the coal area. An isolated piece was found along the eastern edge of the debris field more than 500 meters from its probable place of origin. This flat piece must have behaved like a falling leaf, allowing the currents to carry it eastward to its final resting place.

Associated with the hull pieces in the heavy wreckage are the five single boilers from boiler room 1, where the ship parted; two low-pressure cylinders from two reciprocating engines, weighing more than 50 tons each; main feed filters; evaporators; a tube plate from one of the condensers; a direct-contact heater; towers and booms from the stern; a gear shaft from a watertight door; catwalks; pumps; and/or refrigeration motors and coils. This area also contained the base of stack 4, and the possible remains from two other stacks.

Among the smaller pieces in the area are a binnacle that held the compass in the docking bridge, a telephone stand from the docking bridge, a helm quadrant from the wheel house telemotor, bridge telegraphs, a steam valve wheel, davits, safes from the office of the second-class purser, metal and wood pantry cabinets, spring and chain mattresses, wrought-iron and gilt-bronze balustrades from the aft grand staircase, sections of leaded glass windows from the first-class smoking room, and a wall sconce from the first-class lounge.

There are also many more smaller objects, including toys, stoking shovels, a stack of pails, pots, pans, toilets, wash basins, light fixtures, soup tureens and serving platters, sinks, range tops and rows of serving bowls neatly stacked with the wooden shelves gone, baseboard vents, metal head/foot boards from first-class staterooms, light fixtures, water taps, chamber pots, shoes, boots, and suitcases. The leather objects probably survived because of the chemical (chrome salt) or synthetic methods used to tan the leather. Wine and champagne bottles also were found in the heavy wreckage area, some of them neatly stacked, though their cases are gone. One can only speculate on the contents of the bottles, which probably are heavily infiltrated by seawater.

Within the metal area are smaller pieces of unknown origin, metal grills, more chamber pots, dish fragments, coal, a compass, and a pile of four davits. Although coal is pervasive throughout the debris, it is more noticeable in the coal and coal/dish fragment areas. The pieces of coal were distinguished from black glacial erratics by their size (the erratics tended to be as much as 20 centimeters in diameter) and their shape (the erratics tended to be subrounded whereas the chunks of coal were generally angular to subangular). This coal originated from breached boiler rooms 1 and 2, and the bunkers on G deck.

*Titanic* left Southampton on her maiden voyage with 5,892 tons of coal, some of which had been diverted from other ships because of a coal strike in Britain. (A fire broke out in one of the bunkers on the day she sailed and continued to simmer until she sank.) *Titanic* steamed six hours to Cherbourg and 15 and a half hours to Queenstown, Ireland, to pick up additional passengers. Then she was under way for 85 hours and 40 minutes until her collision with the iceberg. This represents a total of 107 hours 10 minutes, or 4.47 days, of steaming at cruising speed, about 22 knots. If she used up 650 tons a day—her rate at that speed—her 159 furnaces would have consumed 2,906 tons of coal; and 2,936 tons would have been left in her bunkers and boiler rooms at the time of the collision. If the coal were evenly distributed among her six bunkers, there would have been at least 489 tons in the bunker where the ship parted. This amount of coal could easily account for the coal noted in the ANGUS and Argo images.

Associated with the coal are dish fragments, a few chamber pots, tiles of various designs that originated from different rooms, plaster onto which the tiles were attached (some of the tiles are still in place), and a few bottles. Dish fragments become more noticeable toward the southeast in the coal/dish fragment area. Although a few whole dishes were encountered in the area, most are so fragmented they could be identified only by color.

### The Descent of the Bow and Stern

The spacing between where the bow and stern sections came to rest demonstrates that the ship broke apart at the surface—the halves moving further from one another during their individual descents to the bottom. The survivors agreed that the ship's bow sank first; and as the stern was uplifted, it reached an angle of 45 degrees, though they differed on what happened next. Now we know that as the stern rose higher and higher off the water, it experienced increasing torsional forces until finally the keel snapped between stacks 3 and 4 along the forward part of the reciprocating engine room. It is this twisting action that accounts for the extensive damage along the plane of separation.

As the ship split, the forward low-pressure cylinder of the reciprocating engines and single-ended boilers broke way, falling straight to the bottom. The bow section slowly filled with water as it sank and drifted northward from its point of separation from the stern section. The northern segment of the debris field marks the course of this descent. The bow was tilted slightly to starboard when it struck the bottom at a speed that Ballard calculated to be 25 or 30 miles per hour. As it skidded along the bottom, it plowed through the sediments to form the narrow trench and the deformed ridge that we observed on the

*Rusticles hang from bow on starboard side. Top, piece of metal apparently from stack 4 area. Middle, boiler from boiler room 1.*

starboard side and the mounds and debris flows we saw beyond the ridge. When the prow finally came to a stop, momentum caused the rest of the bow to jack-knife. When the rear end of this section slammed into the bottom, the decks near the tear collapsed one atop another.

The stern took a different course. As it separated from the bow, it righted itself temporarily, then turned straight up and rotated 180 degrees in the direction of the bow. Possibly this rotation occurred later, as the stern sank, rather than at or near the surface. In any case, when the stern stood almost on end, all the loose debris fell away and began to sink separately. The heavier fragments came to rest near the stern; the lighter material, descending more gradually, ended up some distance from the ship. Rushing waters crushed the weaker bulkheads as the stern flooded; and escaping air caused the poop deck to peel back onto itself.

The presence in the debris field of refrigeration coils and motors, condensers, and liquor bottles from the lower decks in the stern section indicates that either an explosion or combination of rushing waters and escaping air caused the stern's skin to burst outward, at the surface or on the way down. The rupture allowed these objects to leave the ship and settle to the bottom with the rest of the debris. That the screw section is buried beneath 14 meters of sediment indicates that this section of the stern hit the bottom first. There is no evidence that the burial is due to bottom currents. As the rest of the stern impacted, the decks pancaked atop each other and the ship's skin burst outward, causing even more damage.

Beyond settling many of the arguments about the fate of the ship, our studies underscored another important point: the devastation found at the site of the wreck is so complete that any hopes of ever refloating the *Titanic* now seem like nothing more than a romantic fantasy. The extent of the destruction also is a poignant reminder of what can happen when we ignore the elemental forces of nature, which are superior to any human technology.

When we first found *Titanic*, the vessel's resting place was undisturbed. It had escaped the catastrophic 1929 earthquake that cut many underwater cables south of the Grand Banks. It also had eluded earlier attempts to locate it. Since its discovery, a number of artifacts have been removed from the site, in spite of the expressed hope of many people, including the U.S. Congress and the President, that the wreckage remain a permanent memorial to those who perished with the ship. Still more objects are likely to be removed in the future. Under the circumstances, the ship's best protection from such invasions remains its largely inaccessible location rather than any promises to leave the site intact, for these are as likely to be forgotten as quickly as words written in sand.

### Acknowledgments

We wish to thank members of the Deep Submergence Laboratory, especially Thomas K. Dettweiler and Earl M. Young, Jr., who operated the ANGUS system at sea, and Thomas Crook and Stephen R. Gegg, who processed the navigation. We are indebted to the officers and crew of the *R/V Knorr* and *R/V Atlantis II* for their cooperation during the two expeditions to the *Titanic* site.

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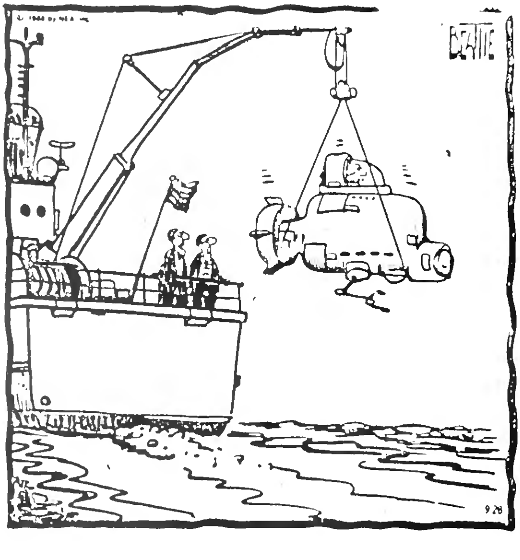
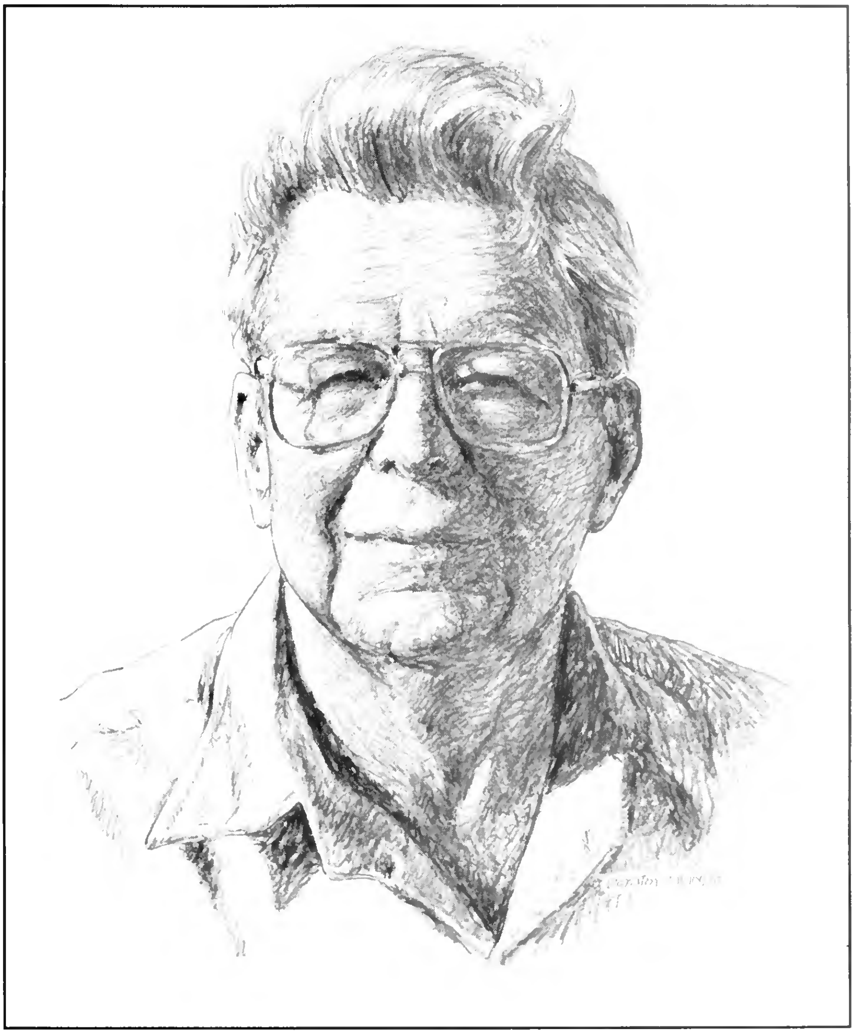


*"Our most important research is finding out if there's any money in making a TV documentary."*

*SNAFU ® by Bruce Beattie Reprinted by permission of NEA, Inc.*

profile

# Allyn Collins Vine


Portrait by Dorothy Meinert

# Man of Vision

### by Sara L. Ellis

Allyn Vine is best known for promoting and supporting the idea of *Alvin* and doggedly pushing the project to fruition. But the little submersible is only one of Vine's many ingenious contributions to oceanography.

For more than 50 years, Vine has been involved in everything from deep-sea geology and underwater sound studies to antisubmarine warfare. Always looking for new techniques, Vine has a gift for producing many types of novel oceanographic equipment, usually participating every step of the way: from conception and

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*Sara L. Ellis is the Editorial Assistant of* Oceanus.

design, to construction, testing, and finally usage. Often converting basic research into practical applications, he holds several patents on commonly used oceanographic devices. Impressed with Vine's inventiveness, a close friend and colleague says, "Al was never *on* the cutting edge of science, he *was* the cutting edge."

At the age of 74, he is spry and cheerful, with a whimsical, off-beat sense of humor. He is also modest, a team player. During my several chats with him, he was always quick to stress the collaborative nature of his projects, and very reluctant to take any personal credit.

## School Days

The second of four sons, Allyn Collins Vine was born 1 June 1914, in Garrettsville, Ohio. His father, Elmer, was a second generation butcher, his mother, Lulu, a housewife and antique dealer. He loved school, and fondly remembers several marvelous teachers, particularly one who taught history and poetry. His scientific aptitude surfaced early: as an adolescent he raided the local telephone company junkpiles for wires and electronic equipment to build contraptions such as burglar alarms. Today, Vine believes that one of the shortcomings of engineering education is that "we don't use junkpiles. Too many engineers are designing from catalogues, while not enough are doing innovative work. This just doesn't tend to inspire creativity."

Vine went to Hiram College, a small liberal arts college only 4 miles from his home, mainly because it was his least expensive option. He feels "very fortunate that it also happened to be an extremely good school." Majoring in physics, Vine helped to pay his way by being a teaching assistant in the physics laboratories. He also prepared laboratory demonstrations for his professor Donald Dooley. "You just couldn't have a nicer job than that. Dooley would tell me things he wanted done, and if time permitted I was allowed to be creative." Al especially enjoyed making loud, colorful displays. It was in the physics department that he met the high-spirited young woman, Adelaide R. Holton, whom he would later marry.

*Mixing explosives for deep-sea seismic work on the* Atlantis *in the late 1930s. (Courtesy of Adelaide Vine)*

After graduating from Hiram in 1936, Vine left Ohio for Pennsylvannia, where he entered a Master's program at Lehigh University. His advisor was the redoubtable W. Maurice (Doc) Ewing, one of the fathers of modern oceanography. During the summers of 1937, '38, and '39, Ewing brought Vine and several other graduate students to the fledgling Woods Hole Oceanographic Institution (WHOI) for cruises aboard the *R/V Atlantis*, WHOI's first ocean-going research vessel. Ewing's group was involved in deep-sea seismic work—exploding satchels of dynamite at sea to get sonic echoes off the various layers of the sea floor—and underwater photography. They tried to understand, as Vine puts it, "the geologic differences between land and the ocean bottom."

Vine was never intimidated by the ocean's two- to three-mile depth. He recalls, "That was simply how deep the ocean was, and it seemed logical to try to find ways to study it at those depths. In my naive way I considered the deep ocean as the standard, or typical, ocean, and the continental shelves as merely the damp sidewalks of the continents. The deep ocean was also where our group expected to find the most fun, and the most answers."

In those days you usually had to build your own apparatus. Except for one course in electrical engineering early in college, Vine gained all his designing know-how on the job. In addition to many other projects in college, he put a lot of energy into designing and calibrating equipment to be used for deep-sea gravity measurements. Lehigh had a strong department of civil engineering, complete with a large testing facility that Vine used frequently. He says that he has been "forever grateful that they trusted a graduate student in *another* department to use their facilities, day or night. Nowadays you'd have to have a committee behind you to be allowed to do that!"

## The War Years

Soon after World War II broke out in Europe, the Navy began to fund major research projects at WHOI. In the fall of 1940, Ewing's group moved to Woods Hole on a year-round basis to study the behavior of sound in the ocean. For Al, his Master's diploma fresh in hand, this turned out to be a permanent move. Shortly after receiving his first paycheck from WHOI, he placed a phone call to Ohio and proposed marriage to Adelaide.

Vine remembers the war years as exciting times for oceanographic research. The war brought together many top scientists. In those days before intensive specialization, when a "hot topic" arose, researchers would tend to drop what they were doing to concentrate on it. Columbus O'Donnel Iselin, then Director of WHOI, would "return from Washington with a project on Thursday, and we'd all work on it 'til it was finished on Monday," says Vine. Such collaboration ensured a high probability of success. In addition, there was a great deal of cooperation between the Navy and oceanographers.

The Ewing group's first major effort was to improve detection of enemy submarines. Their past research experience proved to be very applicable. Underwater cameras could now be used to look for mines, sunken ships, and submarines; and seismic experiments helped show how sound was transmitted horizontally through water.

Headed by Alfred C. Redfield, a smaller group, including Vine, Dean F. Bumpus, and William E. Schevill, began working directly with subs. At least one of them would try to ride on each new sub's first dive to take measurements, such as compressibility of the sub, which helped forecast exactly how much ballast would be needed to keep the sub in trim. During these times, Al began to see submarines as a very logical way to go to sea. The close contact between oceanographers and sub people would later prove to be very important in the conception of *Alvin*.

### The Bathythermograph

One of Vine's projects was redesigning the bathythermograph (BT), a now common oceanographic instrument measuring temperature with depth. Athelstan Spilhaus had been developing it in the late 1930s at the Massachusetts Institute of Technology (*Oceanus*, Vol. 30, No. 4, pp. 99–104). Until then, taking temperature profiles involved stopping the ship and lowering a string of thermometers to various discrete depths. The BT was considered a great improvement because it could record temperature continuously as it was lowered.

In 1937, Iselin realized that BTs could be useful in antisubmarine warfare. Water at different temperatures exhibits different densities, and sound waves traveling through changing densities of water will bend in characteristic ways. Knowing the temperature profile of an area of water would allow predictions of how sound would behave—particularly SONAR (SOund NAvigational Ranging). Sonar is a technique, used by bats, dolphins, ships, and submarines, for locating objects by sending out a beam of sound and detecting its reflection; the time the sound takes to return is a measure of how far away the object is. Convinced that German subs were "hiding" beneath layers of low density water that deflected searching sonar beams away from the subs, Iselin and Spilhaus recommended that British submarines be equipped with BTs to help to find potential hiding places.

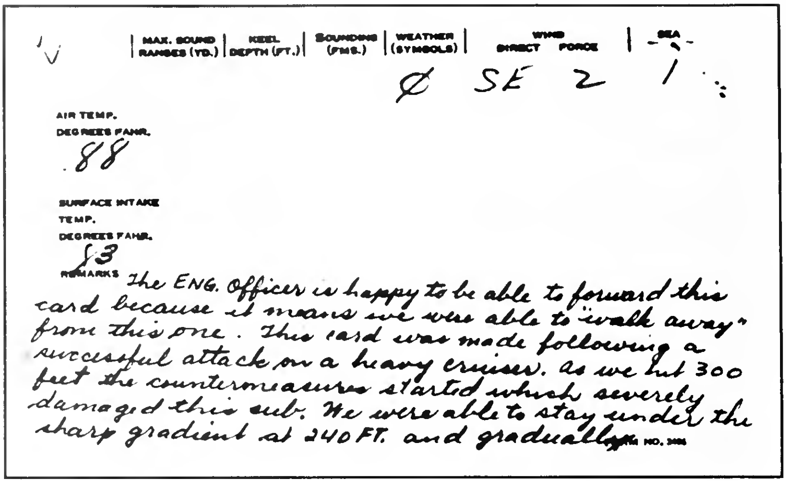
In 1940, Ewing's group was assigned the project of redesigning the BT and building 200 of them for naval use. Vine increased the accuracy and reliability of the BT by adding a bimetallic coil that compensated for temperature differences inside and outside of the instrument. The group also improved the BT's hydrodynamic characteristics by making it into the shape of a small, weighted rocket, and attaching it to a thin wire on a special winch. These improvements allowed BTs to be deployed from moving ships.

The corollary use of BTs soon became apparent: if they could detect subs, they could also help them to escape detection. Ewing and Vine designed a stationary version of the BT to be used in submarines. Al and his collaborators took turns riding the subs, and trained submarine operators to operate the new BTs and interpret their data, which came out on 3- by 5-

*Preparing to test, in 1940, the first remotely controlled camera that could photograph the deep ocean floor. (WHOI Archives)* inch index cards.

In 1972, the Navy belatedly cited Vine's contribution to the BT project, recalling "the savings of untold numbers of lives, and millions of dollars in ships and equipment." Present at the surprise ceremony was an engineering officer whose submarine, the *USS Guitarro*, had escaped Japanese pursuers 28 years earlier by moving away under a thermal gradient detected with their BT. Directly after that encounter, the officer had scrawled these words of praise for Allyn on the back of the data card from the BT:

> *"...The Eng[ineering] Officer is happy to be able to forward this card because it means we were able to 'walk away' from this one. This card was made following a successful attack on a heavy cruiser. As we hit 300 feet the countermeasures started which severely damaged this sub. We were able to stay under the sharp gradient at 240 feet and gradually pull away from the scene of the attack licking our wounds. The 7 Jap escorts continued to harass us, but their efforts became less and less fruitful as we moved away under the layer. My sincere thanks to Allyn Vine of Woods Hole Inst. [sic] for the time he spent explaining the value of the BT observations to me. When we were finally able to come to periscope depth the escorts were still getting an echo back at the scene of the attack and dropping sporadic charges. We on the SS 363 have always believed in the BT but this attack made salesmen for BT out of us."*



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| MAX. SOUND RANGES (YD.) | KEEL DEPTH (FT.) | SOUNDING (FMS.) | WEATHER (SYMBOLS) | WIND DIRECT | WIND FORCE | SEA |
|---|---|---|---|---|---|---|
| | | | 0 | SE | 2 | 1 |

AIR TEMP.
DEGREES FAHR.
88

SURFACE INTAKE
TEMP.
DEGREES FAHR.
83

REMARKS The ENG. Officer is happy to be able to forward this card because it means we were able to "walk away" from this one. This card was made following a successful attack on a heavy cruiser. As we hit 300 feet the countermeasures started which severely damaged this sub. We were able to stay under the sharp gradient at 240 FT. and gradually

NO. [illegible]

*Data card written by a submarine engineering officer during World War II applauding Vine for his work on the bathythermograph.*

### After the War

Though many oceanographers, including Ewing, left WHOI after the war, Vine remained on permanent staff. He and Adelaide soon bought a barn on scenic Juniper Point in Woods Hole. They lived upstairs in the ready-made chauffeur's quarters with their children, Vivian, Norman, and David, while they gradually finished off the downstairs, doing most of the work themselves. It is now a beautiful, spacious house with a magnificent view of Vineyard Sound and the Elizabeth Islands.

Vine retained close ties with the Navy. In 1946, he was one of the oceanographers to make wave measurements at the atomic bomb test site in Bikini—"a tremendous but sobering experience," he recalls. From 1947 to 1950, he commuted on alternate weeks to Washington to serve at the oceanographic desk of the U.S. Navy Bureau of Ships, Sonar Division. While in Woods Hole, he worked mainly on long range sound transmission, and continued to evolve and improve oceanographic equipment such as towed sonar and underwater camera gear. Because he was long one of WHOI's key links with the Navy, a friend of his once said, only half-jokingly: "There may be some Navy people who think Vine *is* WHOI!"

In fact, Vine is particularly good at keeping up ties with people, and usually does so in person. When he wants to have a discussion, he tends to drop in unannounced to bounce around an idea. It's as likely to be a machine shop in Woods Hole as a naval office in Washington. Once, WHOI pilot and machinist Bobby Weeks (profile, *Oceanus*, Vol. 30, No. 3, pp. 87–91) flew Vine to a security base in Nantucket, and they made arrangements to meet later that afternoon. When Vine didn't show up at the appointed time, Weeks learned that he had decided to take an earlier flight back, not to Woods Hole, but to Washington. On another occasion, a member of his family phoned WHOI asking whether anyone knew where Al was, and by the time they tracked him down, he had spontaneously visited colleagues in three or four cities.

Just as he travels quickly, whether by jet or by foot, Vine also thinks at high speed. Spouting ideas at a breathtaking rate, he often leaves his listeners behind. Still, people really enjoy talking with him. To make himself clear, he likes to use analogies. For instance, to illustrate his view of how shallow the ocean is, Vine used a simple comparison. He asked me to imagine dipping a grapefruit briefly into water and then shaking it gently.

"Relatively speaking," he explained, "the water on the grapefruit's surface will be deeper than on the surface of the Earth. Most of the depth of the ocean is only in people's heads."

Ever the creative tinkerer, Vine takes advantage of the materials at hand. Shortly after the war, he was faced with the prospect of an early wake-up. But alarm clocks were in short supply, so he simply hooked his vacuum cleaner into the electric outlet on his stove and set the timer. Another time, when Woods Hole's Water Street drawbridge became stuck in the raised position for several weeks, forcing pedestrians to walk a mile around Eel Pond, Vine converted a huge tire into a floating platform to ferry passengers. The contraption was powered by a pulley system. As far as anyone can remember, only one girl fell overboard.

### Pushing Relentlessly

Vine would often go to the WHOI machine shop, and sketch out an idea on the floor with chalk. Weeks remembers that the machinists soon learned not to go straight to work from the sketch; instead they would wait for Al to come back and modify it—perhaps radically—or else erase it. Vine has been criticized for sometimes not following through on ideas, but as with any "idea man," some of his ideas are more realistic than others. But if he's convinced an idea is really good, his own or someone else's, he will push for it relentlessly. *Alvin* is a perfect example of that persistence.

When a small submersible was first proposed as an oceanographic tool—no one recalls exactly who first came up with the idea ("It was in the air," says Al)—it met with little enthusiasm from the oceanographic community. Oceanographers felt it was too risky, and that the money could be better spent. However, to ex-submariners like Vine, a small submersible seemed an obvious new technique for studying the ocean. As Vine puts it: "We had about 45 oceanographic vessels around the world at the time. That was like having a huge tool bag with 45 wrenches pretty much the same size. We wanted to see what a completely different wrench might be able to show us."

The Navy was more sympathetic to the idea. There were several technical meetings with the Office of Naval Research in the late 1950s. It soon became a matter of working out the difficult problems of who would fund, design, build, and operate the submersible. Still receiving little support from oceanographers, Vine persevered, backed by a small group of scientists, including Willard Bascom of the National Research Council, John D. Isaacs of Scripps Institution of Oceanography, and later Dick H. Backus and Bill Schevill of WHOI. They continued to push ahead for years, laying their reputations on the line until they finally won the day.

When it came time to christen the little submersible, there was an almost unanimous decision to call it *Alvin*—a contraction of the name Allyn Vine—in recognition of his tenacity (however,


*When the Woods Hole drawbridge became stuck in the raised position, Vine used typical ingenuity to create a makeshift ferry. (WHOI archives)*

some members of the submersible group were also infatuated with a popular cartoon chipmunk of the time, named Alvin). Vine was unable to attend the ceremony. He had been scheduled to dive in the French submersible *Archimède* in the early spring of 1964, but the schedule had slipped behind so that on the day that *Alvin* was christened, 5 June 1964, Vine was 3 miles below the surface of the Atlantic. When I asked him if he had been disappointed, he smiled and asked impishly: "How could I be?" He felt it was a wonderful coincidence, emphasizing the bright future ahead for *Alvin*.

This is a characteristic response. Vine's main concern is not who uses new technology, but rather with getting it developed. When *Alvin* was in the planning stages, it was not clear whether it would go to Scripps Institution of Oceanography in La Jolla, or to WHOI, but that did not influence Vine's attitude. He was merely interested in the design itself, and the potential uses for such a vessel.

In spite of his love of submersibles, Al has supported all sorts of oceanographic vessels. He estimates that he spent as much time lobbying for Scripps' *Floating Instrument Platform (FLIP)*, and WHOI's *Oceanus* and *R/V Atlantis II*, as he did for *Alvin*. Although retired as scientist emeritus since 1979, he is still keenly interested in the design of new vessels. Besides dropping in on his Woods Hole colleagues, he attends many conferences, often as a speaker. One of his great enthusiasms is now the semisubmerged, twin-hulled research vessel (*Oceanus*, Vol. 25, No. 1, pp. 15–17), an innovation he has been recommending for several decades.

Twin-hulled ships offer greater stability than conventional ships, which is important for handling sensitive oceanographic equipment. They also offer expansive operating decks capable of supporting large, heavy equipment. *Lulu*, the original mother ship of *Alvin* was a primitive version of such a vessel, made with two surplus Navy pontoons as hulls. Designed with the help of Vine (and named after his mother), *Lulu* is the only large twin-hulled vessel that has been used extensively in oceanographic research. Though more modern semisubmerged catamarans have been used in other capacities, oceanographers have not taken advantage of them. "That's a bloomin' disgrace," says Vine, with characteristic directness.

*Vine's mother, Lulu, circa 1920. A duplicate of this photograph was donated by Al and Adelaide Vine to* Alvin's *first mother ship,* Lulu. *(Courtesy of Adelaide Vine)*

Although Al and Adelaide used to sail after work, they sold their boat soon after they bought their home. For relaxation they now keep up their lovely gardens, both at their home in Woods Hole and at their house in Waquoit, where Adelaide raises azaleas and rhododendrons. When I asked Adelaide what were her husband's interests, she replied "Everything—that is, everything except rock music!" Both share a passion for convertibles, having owned several since their marriage. Their current model, a dark 1967 Chrysler, has been dubbed the "Black Bat" by colleagues.

### Ice from Antarctica

One of his "fun projects," as Vine calls them, was a scheme devised by him and his good friend John Isaacs (sometimes called a second Al Vine), to tow ice from Antarctica to Saudi Arabia as a source of fresh water. "We were trying to point out that over a century ago we had wooden ships with linen sails, utilizing gradients of wind to sail to Antarctica, get a renewable oil from whales, and bring it back at a profit. With our improved oceanographic know-how and technology, why not transport ice, which already floats, by taking advantage of favorable winds and currents?" Vine suggests that inland U.S. states, in order to preserve their own fresh water, should demand that coastal states look into such possibilities.

In 1966 Isaacs, Vine, and two colleagues from Scripps speculated that it should be possible to run a tapered cable down to the surface of the Earth from an orbiting satellite—an idea independently proposed earlier, but not openly published, by a Soviet engineer. This "sky hook" could serve to launch materials into space, as if from a sling, or could be used to transport materials to and from the satellite, like an elevator. The idea, Vine told me with a twinkle in his eye, could provide a theoretical basis for Jack and the Beanstalk.

Some scientists call Vine an engineer. Some engineers call him a scientist. Actually, he is a hybrid. Trained in an era before specialization became pervasive, Al Vine is an innovator whose combination of daring, persistence, and good humor, clearly has made for some very interesting and important results.

# *A Challenge to* Alvin *from the USSR*

There are four manned research submersibles in the world today that can dive deeper than Alvin. France's Nautile, the U.S. Navy's Sea Cliff, and the Soviet Union's Mir (Peace) I and II. All are certified to 6,000 meters, compared to Alvin's 4,000 meters. The Japanese are developing a submersible that will operate at 6,500 meters (Oceanus, Vol. 30, No. 1, pp. 29–32). A depth of 6,000 meters means that these submersibles can cover 98 percent of the ocean floor.

The two Soviet submersibles were built by the Oceanics Unit of the Rauma-Repola Subsea Technology Group in Finland, for $50 million. They underwent sea trials in December 1987, and are now operational, under the Institute of Oceanology, of the USSR Academy of Sciences.

Their design is similar to Alvin. They carry a pilot and two scientists. The total working cycle is 10 hours, of which four hours is bottom time at 6,000 meters. Both are launched from the same mother ship, one being used as a backup for the other, allowing for a continuous diving schedule. The maximum forward speed is five knots, and energy capacity is 100 kilowatts, reportedly about double the operating capability of Nautile and Sea Cliff. The vehicles are 7.8 meters long, and weigh about 18.7 tons in air.

The crew sphere for Alvin is made of titanium alloys. Those of the Soviet submersibles are made of maraging steel, which allowed Rauma-Repola to cast the separate halves in such a way as to avoid the need for welded seams. According to Anatoly M. Sagalevich, head of the Laboratory of Manned Deep-sea Submersibles at the Institute of Oceanology:

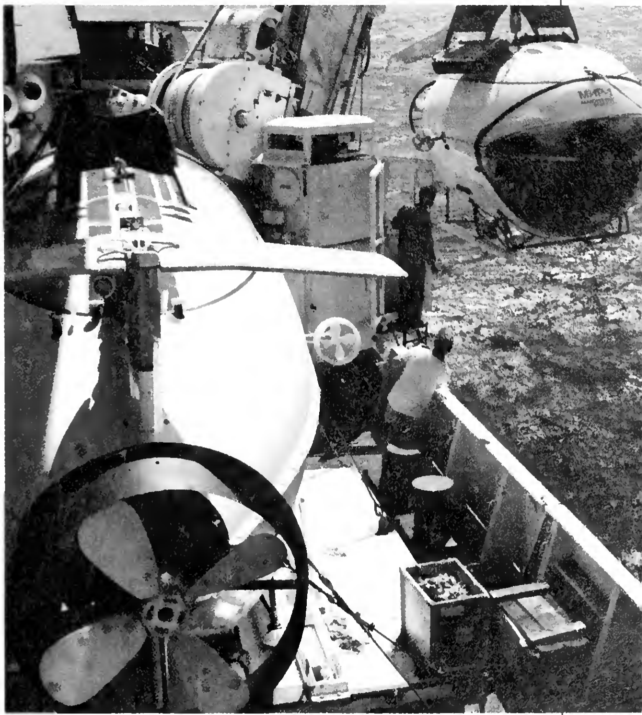
> "The most demanding project [during the construction of Mir I and II] was the crew spheres. Rauma-Repola used their steel expertise to develop a special alloy that met our specifications, and this was the first time in the world that deep-sea spheres were made of cast steel."

The strength-to-weight ratio is said to be about 10 percent greater than that of titanium. Cast maraging steel is isotropic; that is, it has the same physical properties in all directions—an advantage in an environment where pressure can be 600 times greater than that on the surface.

Again according to Sagalevich, the institute expects these subs to be involved in mineral explorations, since:

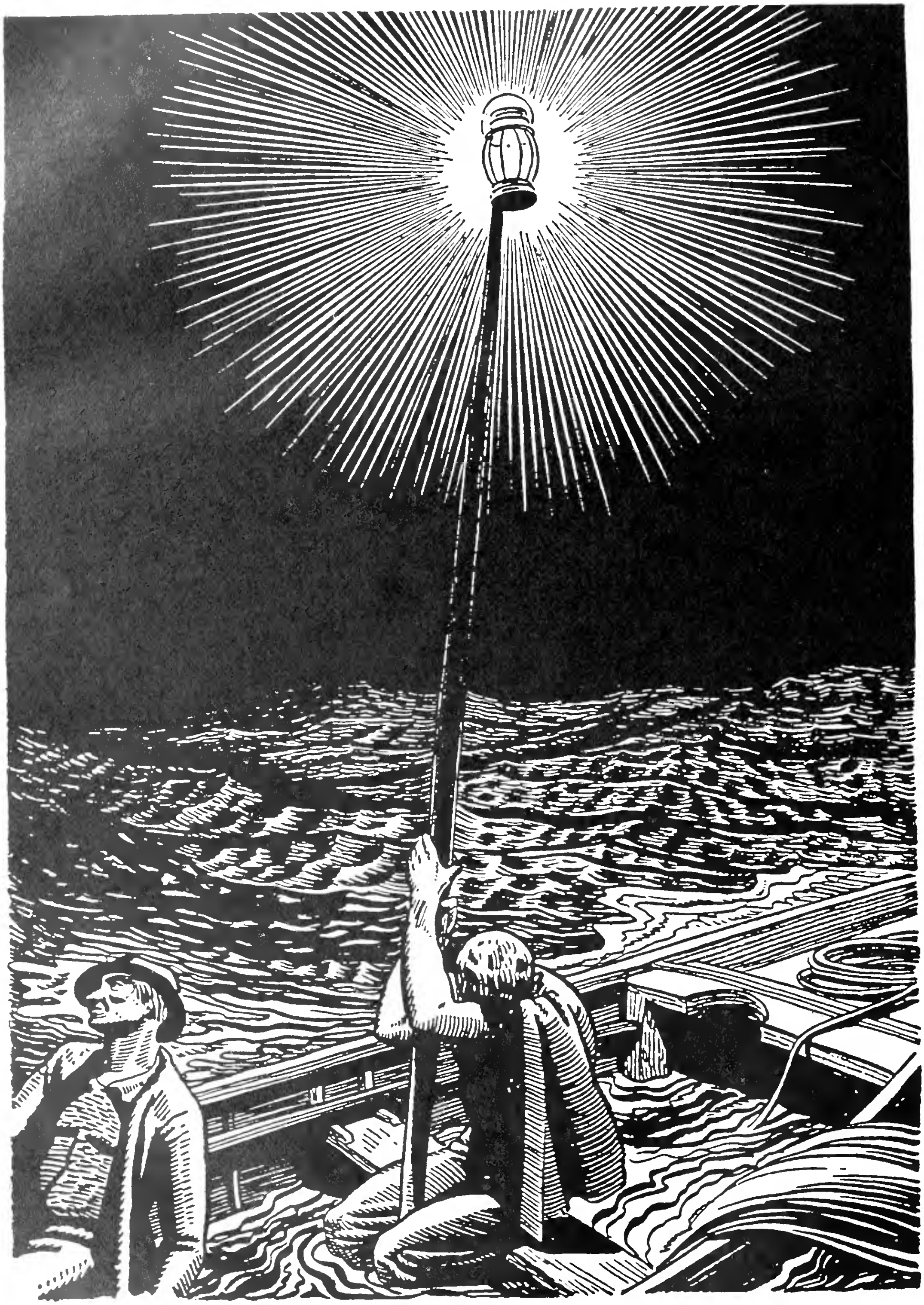
> "Now [the taking of mineral nodules from great depths] is no problem any longer. And I think that within perhaps five years, underwater mining—even in great depths—will no longer be a problem, either. Methods and equipment already exist, but they still need some development. The most important thing to solve is how to cut the crust into pieces that can be taken up to the surface."

Rauma-Repola is also looking to the tourist market. A member of the Finnish Subsea Technology Group—Malmari & Winberg—is presently developing three such submersibles, with a capacity of from 49 to 62 passengers and a three-man crew. They will be capable of operating in depths of up to 100 meters, from an hour to 15 hours.They are 19.5 meters long, 3.6 meters wide, and 3.3 meters high. They have a maximum speed of 3 knots, and are designed to meet U.S. Coast Guard regulations. The three being built are for Finnish, American, and Japanese owners.



The new Soviet submersibles *Mir I* and *II*. (Courtesy of Institute of Oceanology)

**—Paul R. Ryan**
**Editor, *Oceanus***
**On fellowship in Japan.**



**The Shipwreck**

*The drawings in this article are by the American artist Rockwell Kent and are from the Random House edition of* Moby-Dick *by Herman Melville. (Courtesy of the Rockwell Kent Legacies)* essay

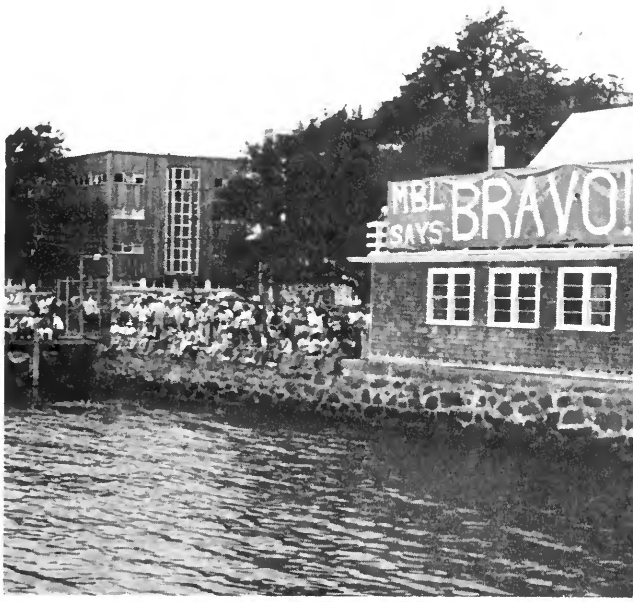
# *Titanic* and Leviathan

### by Gerald Weissmann

> Why upon your first voyage as a passenger, did you yourself feel such a mystical vibration, when first told that you and your ship were now out of sight of land? Why did the old Persians hold the sea holy? Why did the Greeks give it a separate deity, and make him the own brother of Jove? Surely all this is not without meaning.
>
> —Herman Melville, *Moby-Dick*

We had almost forgotten that *Atlantis II* was returning to Woods Hole that morning, when the rumble of helicopters overhead reminded us. Looking out the windows of the laboratory, we could see the ship less than a mile offshore. The July sky was cobalt, the sea a Prussian blue, and the sun sparkled on rare whitecaps in Vineyard Sound; it was 9:30 on the clearest day of summer. The research vessel was headed home in triumph after its second voyage to the wreck of the *Titanic*. Above, the ship was circled by a corona of helicopters and photo planes: on the water, a flotilla of powerboats and racing sloops kept pace.

In shorts and lab coats we rushed down the stairs to cross Water Street in order to be on the Woods Hole Oceanographic Institution (WHOI) dock when the *Atlantis II* pulled in. WHOI was established in 1930, and is the youngest of the three scientific installations that share the harbors of our small village. The others are the Marine Biological Laboratory (MBL, est. 1888) and the U.S. Bureau of Commercial Fisheries Biological Laboratory and Aquarium (est. 1870). The three institutions, each eminent in its own right, tend to coexist as separate little universes: engineering and physical sciences set the tone at WHOI, cell and molecular biology dominate the MBL, and applied ecology is the business of the Fisheries. But while the professional—and, alas, the social—spheres of the three enclaves do not overlap greatly, the scientists and technicians of Woods Hole are united by perhaps the most ancient of terrestrial diseases: sea fever. Physics, biology, or ecology can well be studied under the pines of Duke or the ivy of Princeton, but folks at Woods Hole seem drawn to the seaside by the kind of urges that moved the ancients to worship a "separate deity, and . . . own brother of Jove."



*A neighborly welcome for the* Titanic *discoverers. (Photo by Tom Kleindinst, WHOI)*

Neptune's kingdom has drawn scholars to many harbors: Naples, Villefranche, and Bermuda come to mind as centers where marine science has flourished. But the New England shore has a special meaning for those engaged in voyages of discovery. From the landfall of the *Mayflower* at Provincetown to the triumph of the New Bedford clippers, the path to new worlds was by way of the sea. Perhaps it is no accident

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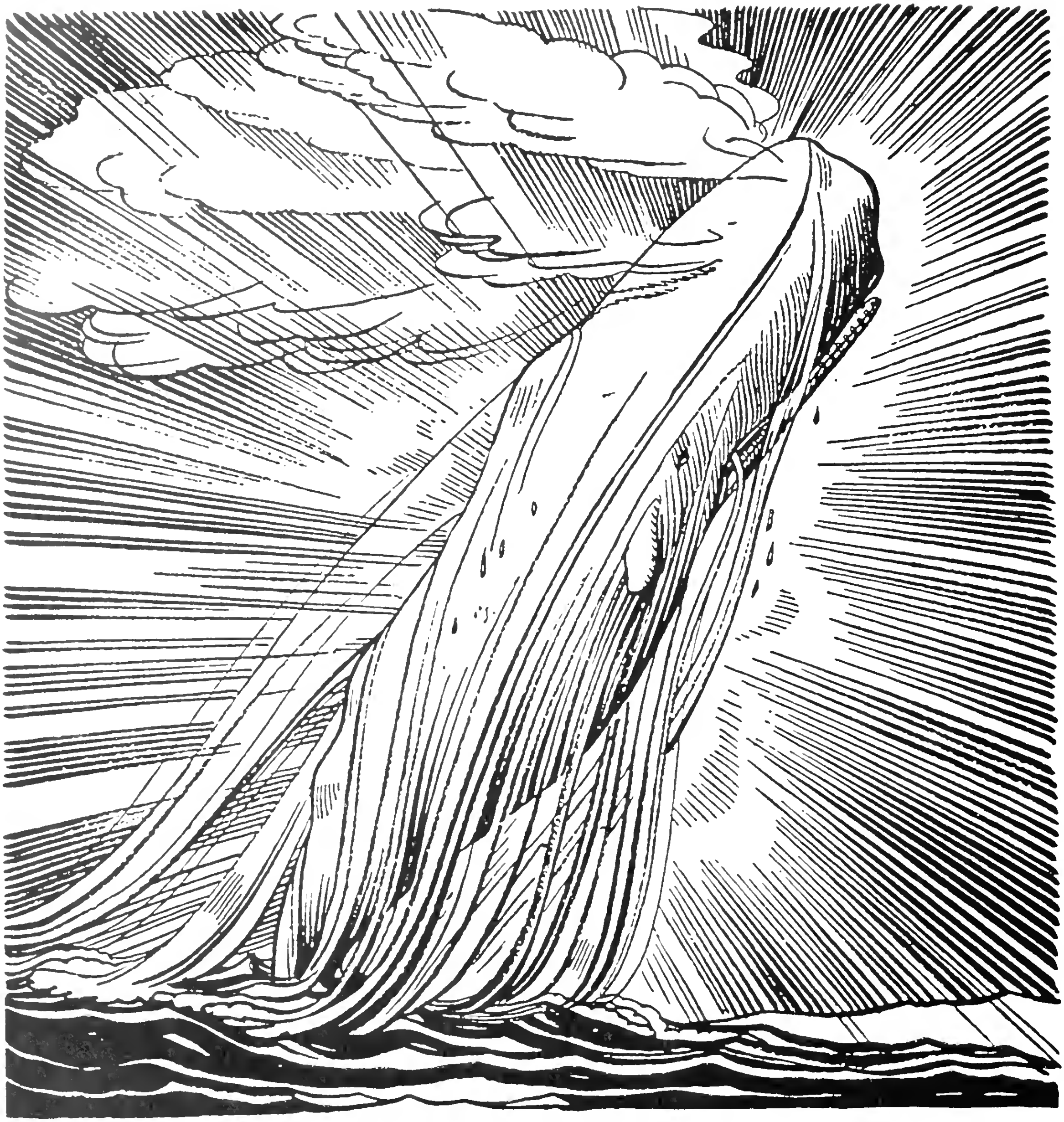
*Gerald Weissmann, Professor of Medicine and Director of the Division of Rheumatology at New York University School of Medicine, is the author of two collections of essays:* The Woods Hole Cantata *and* They All Laughed at Christopher Columbus. *During summers, he conducts his research into the immune system at the Marine Biological Laboratory in Woods Hole. This essay originally appeared in* Hospital Practice.



The Great White Whale

that the most dazzling of our epics is that of a Yankee in search of a whale.

> What wonder, then, that these Nantucketers, born on a beach, should take to the sea for a livelihood! They first caught crabs and quahogs in the sand; grown bolder, they waded out with nets for mackerel; more experienced, they pushed off in boats and captured cod; and at last, launching a navy of great ships on the sea, explored this watery world; put an incessant belt of circumnavigations round it; peeped in at Bhering's Straits; and in all seasons and all oceans declared everlasting war with the mightiest animated mass that has survived the flood; most monstrous and most mountainous!
>
> —*Moby-Dick*

> That sea beast Leviathan, which God of all his works Created hugest that swim the ocean stream.
>
> —John Milton, *Paradise Lost*

Melville may have worked in a Manhattan countinghouse, but the whalers of his mind left from colder waters; Ishmael took the packet for Nantucket through the waters off Woods Hole. So, too, for a hundred years have marine scholars plied their craft by the shores of the Cape and its islands; the search for Leviathan—as fish, ship, or secret of the cell—does not seem entirely preposterous there.

Our small lab is only a hundred yards or so from the main dock of WHOI, and we were there in no time at all. The scene on the dock was Preston Sturges in a nautical setting: the crowd had clearly assembled to welcome Jimmy Stewart back from the wars to his hometown. Reporters of all shapes and sizes jockeyed for position; television cameras were mounted on scores of tripods; Coast Guard and naval officers strutted their stripes; dockhands in cutoffs and gym shirts lugged hawsers by the pier. Assembled on a kind of grandstand were bigwigs in blazers, officials in seersucker, and the gentry of Falmouth in pink linen slacks. The Marine Biological Laboratory was represented by a packet of students and faculty from courses in physiology, embryology, and neurobiology. There were also teenagers with spiked hair and bubble gum, fresh-scrubbed wives of the ship's crew, outdoor types from WHOI and the Fisheries, grease-stained kids from the boatyard across the street, aproned staff from the four local restaurants, firemen, and town cops.

> But to omit other things (that I may be brief) after long beating at sea they fell with that land which is called Cape Cod; the which being made and certainly known to be it, they were not a little joyful.
>
> —William Bradford, *Of Plymoth Plantation*

The ship, now upon us, was the size of a minesweeper, and its silhouette in the sun displayed great winch posts at the stern. As the vessel berthed broadside, general applause and happy cheers greeted the explorers. Near the top stood Robert Ballard, the head of the expedition. He stood the height of a hero, wearing a baseball cap that bore the sailboat logo of the Oceanographic Institution. Next to him stood a naval officer in khaki as a reminder, perhaps, that the Navy had supported much of this research. A platoon of oceanographers leaned against the railings of a lower deck. They were outnumbered by grinning crew members and a few lab types wearing round spectacles. The air rang with shouts from ship to shore and back again as friends and relatives hoisted the kind of encouraging signs that one sees at footraces. Tots and schoolkids were hauled aboard as the ship made fast. Flashbulbs popped, and so did the corks from champagne bottles. Oceanographers soon looked like winning playoff pitchers at Fenway Park. Kisses were exchanged and animals petted. More cheers and applause. It took a while for the crowd to disperse, but we didn't wait. We crossed the street, reverting to the lab to watch the dissociated cells of marine sponges clump together in a test tube.

Within the week, posters appeared all over Falmouth announcing that Ballard would give two lectures at the Lawrence Junior High School auditorium on August 6. He would show pictures of the *Titanic* exploration before they were released to the general news media. The pictures would include footage obtained by means of novel television cameras mounted on the little robot, Jason Jr., that had poked down the grand stairwell of the liner. My wife and I bought tickets for the first of the talks. In preparation for the event, we scoured junk shops and bookstores for literature on the *Titanic* disaster. Although it cannot be said that we stumbled across unknown masterpieces of prose, the dozen or so accounts were reasonably accurate jobs of popular history. Written at various times between 1912 and 1985, they told pretty much the same story, owing, no doubt, to their reliance on the same primary sources, chief of which were the records of two investigative commissions, American and English.

On April 14, 1912, at 11:40 p.m., while on its maiden voyage from Southampton to New York, the largest and most luxurious ocean liner of its age struck an iceberg at latitude 41°46′ North, longitude 50°14′ West, some 360 miles off the Grand Banks of Newfoundland. At 2:20 a.m. the ship sank. Only 711 out of 2,201 souls on board survived. A U.S. Senate investigating committee, headed by William Alden Smith of Michigan, began its hearings on April 19 and shortly thereafter reported:

> No particular person is named as being responsible though attention is called to the fact that on the day of the disaster three distinct warnings of ice were sent to Captain Smith . . . .
>
> Ice positions, so definitely reported to the *Titanic* just preceding the accident, located ice on both sides of the lane in which she was traveling. No discussion took place among the officers, no conference was called to consider these warnings, no heed was given to them. The speed was not relaxed, the lookout was not increased.
>
> The supposedly water-tight compartments of the *Titanic* were not water-tight, because of the non-water-tight condition of the decks where the transverse bulkheads ended.
>
> The steamship *California*, controlled by the same concern as the *Titanic*, was nearer the sinking steamship than the nineteen miles reported by her captain, and her officers and crew saw the distress signals of the *Titanic* and failed to respond to them in accordance with the dictates of humanity, international usage, and the requirements of law . . . .
>
> The full capacity of the *Titanic*'s lifeboats was not utilized, because, while only 705 persons were saved (6 died in lifeboats) the

**Ahab**

> ship's boats could have carried 1176.
>
> No general alarm was sounded, no whistle blown and no systematic warning was given to the endangered passengers, and it was fifteen or twenty minutes before Captain Smith ordered the *Titanic*'s wireless operator to send out a distress message.
>
> The *Titanic*'s crew were only meagerly acquainted with their positions and duties in an accident and only one drill was held before the maiden trip. Many of the crew joined the ship only a few hours before she sailed . . . .

The commissioners might have noted several other factors that contributed to the disaster. Whatever number of additional persons might have crowded into lifeboats, there was room for only about half of those aboard (1,100 of 2,201). In addition, the two lookouts in the crow's nest had not been given binoculars with which to spot the iceberg, and once the berg was unavoidable, an error of navigation compounded the wreck. Although the design of the ship was such that she would probably have survived a head-on collision of almost any force, the first officer swung the liner hard astarboard, thereby exposing a broadside target for impact.

Seventy-five years of rehashing details of the *Titanic* disaster have not added much to this bare outline, although recent opinion has tended to lay a good share of the blame at the feet of the owners of the White Star Line. Social critics accuse Bruce Ismay and his financier, J. P. Morgan, of sacrificing safety for speed, and prudence for luxury. In contrast, amateur steamship enthusiasts trace the ocean wreck to many individual flaws of naval conduct, culminating in negligence by the captain of the *California*. But if one is neither a special pleader nor a buff of shipwrecks, the story of the *Titanic* can be read as that of a unique, unlikely accident that was not part of a general pattern of nautical malfeasance. Only the sentimental can derive from the sinking ship an intimation of Western mortality. But the wreck had no immediate predecessors, and no similar accident happened again. Between the wars, large ships that were faster and more luxurious than the *Titanic* made hundreds of trips in similar waters and lived out their useful lives without incident.

Nevertheless, over the years a more or less constant set of moral lessons has been drawn from the disaster; these cautionary tales split predictably in accord with the plate tectonics of class and party. The first of them is captured in the popular image of handsome men in evening clothes awash on a tilting deck. The band plays "Autumn."

> Said one survivor, speaking of the men who remained on the ship: "There they stood—Major Butt, Colonel Astor waving a farewell to his wife; Mr. Thayer, Mr. Case, Mr. Clarence Moore, Mr. Widener, all multi-millionaires, and hundreds of other men, bravely smiling at us. Never have I seen such chivalry and fortitude . . . ."
>
> But these men stood aside—one can see them!—and gave place not merely to the delicate and the refined, but to the scared Czech woman from the steerage, with her baby at her breast; the Croatian with a toddler by her side, coming through the very gate of death, and out of the mouth of Hell to the imagined Eden of America.
>
> —Logan Marshall, *The Sinking of the Titanic* (1912)

This lesson—the "noblesse oblige" theme—includes the story of Mrs. Isidor Straus, who returned from her place in lifeboat No. 8 to her husband, the owner of Macy's. Taking her husband's hand, she told him, "We have been living together many years. Where you go, so shall I." And the magnate refused to go before the other men. Harry Elkins Widener, grandson of a Philadelphia mogul, went to his death with a rare copy of Bacon's *Essaies* in his pocket; Harvard owes not only its library but also its swimming requirement to his memory. Benjamin Guggenheim, the smelting millionaire, went downstairs to change into his best evening attire. "Tell my wife," he told his steward, who survived, "I played the game out straight and to the end. No woman shall be left aboard this ship because Ben Guggenheim was a coward." Then there was Major Archibald Butt, aide and confidant of President Taft. Mrs. Henry B. Harris reported that:

> when the order came to take to the boats he became as one in supreme command. You would have thought he was at a White House reception, so cool and calm was he. In one of the earlier boats fifty women, it seemed, were about to be lowered, when a man, suddenly panic-stricken, ran to the stern of it. Major Butt shot one arm out, caught him by the neck, and jerked him backward like a pillow. . . . "Sorry," said Major Butt, "but women will be attended to first or I'll break every bone in your body."

This gallant behavior on the part of the moneyed class probably derived from the English code of the gentleman. On the *Titanic*, that code was honored to a remarkable degree. As the captain was going under with his ship, his last words were "Be brave, boys. Be British!" The gentlemanly code explains in part the hard statistics of survival. Whereas 140 of 144 (97.2 percent) of the women and all of the children in first class survived, only 57 of 175 (32.6 percent) of male first-class passengers made shore. This example of social discipline served as a moral lesson for the gentry, who went to the trenches of Flanders as if to a game of rugger.

More recent students of the *Titanic* story have drawn a quite different set of lessons from the statistics and offer an analysis that one might

The Harpooner

call the "upstairs, downstairs" version of the disaster. Pointing out that the social classes were quartered on ship as in Edwardian society at large, they find that steerage passengers fared less well than their upstairs shipmates: half as well, in fact! Of the women in third class, only 76 survived of 165 (46 percent); of men, 75 of 462 (16.2 percent); and only 27 of 79 children. These statistics—literally the bottom line—yield another irony. Only 8 percent, a mere 14, of 168 men in second class survived. One might conclude that middle-class men adhered more closely to upstairs values than did the entrepreneurial folk on top deck.

Darker streaks of division mar the canvas. Many of the accounts of the time stirred up nativist sentiment, and the worst charges were leveled against swarthy foreigners. Reporters grew indignant that "men whose names and reputations were prominent in two hemispheres were shouldered out of the way by roughly dressed Slavs and Hungarians." Rumors were commonplace—and since disproved—that violent battles took place in steerage:

> Shouting curses in foreign languages, the immigrant men continued their pushing and tugging to climb into the boats. Shots rang out. One big fellow fell over the railing into the water. . . .One husky Italian told the writer on the pier that the way in which the men were shot down was horrible. His sympathy was with the men who were shot.

Another rumor of the time is contradicted by later accounts:

> An hour later, when the second wireless man came into the boxlike room to tell his companion what the situation was, he found a negro stoker creeping up behind the operator and saw him raise a knife over his head. . . . The negro intended to kill the operator in order to take his lifebelt from him. The second operator pulled out his revolver and shot the negro dead.

Those oft-told dramas of the *Titanic* can be squeezed for the juice of class struggle, but the real fear of the time was not of social unrest. Led by the Great Populist, William Jennings Bryan, the moralists found their true target: the enemy was luxury—luxury and speed. "I venture the assertion that less attention will be paid to comforts and luxuries and. . .that the mania of speed will receive a check," said Bryan.

Speed and comfort are among the declared goals of applied technology; those who worry about the goals—like Bryan—tend to worry about technology. For 75 years, those uneasy with machines have used the sinking of the *Titanic* to illustrate the Puritan-sampler admonition that "pride goeth before a fall."

The proud *Titanic* was 882 feet long—almost three football fields. Contemporary illustrations show her as longer than the then towering Woolworth Building in height. She had a swimming pool, a putting area, squash courts, a Turkish bath, a Parisian café, palm-decorated verandas, a storage compartment for automobiles, and a full darkroom for amateur photo buffs. In the hold were hundreds of cases of luxury consignments, which ranged from 34 cases of golf clubs for A. G. Spalding to 25 cases of sardines and a bale of fur for Lazard Frères. Beverage rooms stocked 1,500 champagne glasses. This splendid, "unsinkable" hotel was powered by engines that could generate 55,000 horsepower. Rumor had it that she was not far from her maximum speed of 25 to 26 knots per hour when she hit the iceberg. Other hearsay had it that Captain Smith was going for a trans-Atlantic speed record. The pride of speed was blamed for the sinking of the *Titanic*.

Journalists complained that "subways whiz through the tunnels at top speed; automobiles dash through the street at a speed of a mile in two minutes, and ocean liners tear through the water," but it was clergymen who had a field day on the Sabbath after the disaster. Technological pride took a beating from the Reverend William Danforth of Elmhurst, N.Y., who blamed "the age of mania for speed and smashing records. The one on whom one can fasten the blame is every man to whom all else palls unless he rides in the biggest ship and the fastest possible. He will be guilty in his automobile tomorrow." The pulpits of all denominations were hard on the pride of luxury. Had William Bradford been alive, he would have been the first to see the luxury steamer as "a right emblem, it may be, of the uncertain things of the world, that when men have toiled themselves for them, they vanish into smoke." The leader of the Ethical Culture Society, Felix Adler, was alive enough to voice the sentiment: "It is pitiful to think of those golf links and swimming pools on the steamship which is now 2,000 fathoms deep." And Rabbi Joseph Silverman of Temple Emanu-El was of the same mind: "When we violate the fundamental laws of nature we must suffer."

In the decades since 1912, the *Titanic* has ranked high on the list of violators of fundamental law (applied technology division). Fans of natural law put the steamship right up there with the *Hindenburg* and Icarus, the Tower of Babel and the Maginot Line. Not long ago, the space shuttle *Challenger* joined those other violators. In our recent mythology, *Challenger* and the *Titanic* have been linked in the popular mind. Both craft were the largest and fastest vectors of their kind, both were the darlings of general publicity, both carried the banners of Anglo-Saxon pride—and both voyages went haywire for almost mundane reasons. In the hagiography of disaster, the binoculars absent from the crow's nest of the liner and the faulty O-rings of the booster rocket have both been offered as examples of how the best of our science is in bondage to chance—or retribution.

On August 6, when we heard Ballard speak on his discovery of the *Titanic*, I was sure that memories of the recent *Challenger* disaster were not far from the minds of many. That summer, with the shuttles grounded, the discovery of the *Titanic* 12,000 feet beneath the sea must have engaged sentiments, in an American audience, deeper than those of hometown curiosity. It seems unlikely that the community turned out in overflow numbers because of its concern for the traditional themes of *Titanic* literature. One doubts that the seats were packed by citizens who wished to hear replayed the moral lessons of "noblesse oblige," the social notes of "upstairs, downstairs," or the canons of technology's pride and fall. No, one might argue that the people of Falmouth went to hear the technical details of how a captain from Cape Cod tracked down the largest, most elusive object beneath the waves: *Titanic*, the Leviathan.

> For the buckling of the main beam, there was a great iron screw the passengers brought out of Holland, which would raise the beam into his place; the which being done, the carpenter and master affirmed that with a post put under it, set firm in the lower deck and otherwise bound, he would make it sufficient.
>
> —*Of Plymoth Plantation*

> The whale line is only two thirds of an inch in thickness. At first sight, you would not think it so strong as it really is. By experiment its one and fifty yarns will each suspend a weight of one hundred and twelve pounds; so that the whole rope will bear a strain nearly equal to three tons. In length, the common sperm whale-line measures something over two hundred fathoms.
>
> —*Moby-Dick*

> The echo on our sonar indicated that we were approaching bottom, at a little more than 12,000 feet. Larry released one of the heavy weights on the side of the *Alvin*, and our descent slowed. Soon in the spray of lights under the submersible, I could see the ocean floor slowly coming closer, seeming to rise toward us, rather than our sinking to it. Pumping ballast in final adjustments, Larry settled us softly down on the bottom, more than two miles below the surface
>
> —Ballard, *Oceanus*, Vol. 28, No. 4, p. 106

In the logbook style of his Yankee predecessors, Ballard here describes an early training dive of the deep submersible craft *Alvin*. And in the same informative fashion, Ballard went on, that summer afternoon at the school, to detail his two trips to the *Titanic* site. He spoke of the principles of oceanography, of the ground rules of hydrodynamics, and of how optics and sonar had been used to establish the site of the wreckage. He told of the dark, sterile sea two miles beneath the surface and of the rare creatures that inhabit those depths. He acknowledged his French collaborators, without whom the wreck could not have been found, and praised the technicians of Sony who fashioned the pressure-resistant TV apparatus of the robot, Jason Jr. And then we saw film clips of the second voyage to the wreck of the *Titanic*, taken by Jason Jr. and its larger partner, the remotely operated vehicle, Argo.

By the blue lights of Argo's cameras, we saw the decks, the winches, the bridge. The stern had become undone, and the huge boilers had been scattered across the ocean floor. We saw stalactites of rust and intact bottles of wine. We went with Jason Jr. into the cavern of the great staircase and marveled at the preservation of metal work, silverware, and leaded glass in that cold sea. We had entered the belly of the whale.

Guided by our Ahab/Ishmael, we returned to the surface as the submersibles were retrieved and stowed. Ballard suggested that these pictures tended to discount the hypothesis that the iceberg had torn a great gash in the liner's side and that, instead, the welds had popped from the impact. The ship's hull had cracked like a nut. But his peroration was not devoted to further anecdotes of how sad it was when that great ship went down. Ballard ended with the message he had brought to the shore for a decade: the ocean and its depths are a frontier as awesome as that of space itself.

The applause that followed was long and loud. The happy crowd, from starry-eyed teenagers to oldsters with aluminum walkers, emerged into the sunlit afternoon, looking as if each had been given a fine, personal present. Many of us from the Woods Hole laboratories shared that sentiment; town and gown, we folks of Falmouth had been told a tale of victory for science and technology. The reception of *Titanic Redivivus* suggests that science appeals to people not only for the gadgets it invents but also because it answers some of the most important questions we can ask: What happens when we drown? How deep is the ocean? How terrible is its bottom? How big is the whale?

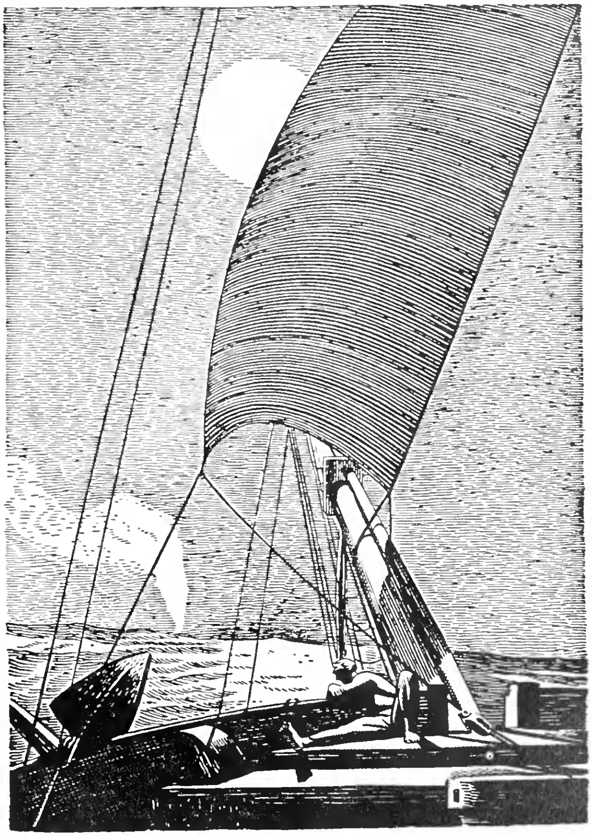
After his first voyage, Ballard had told the House Merchant Marine and Fisheries Commission that he was neither an archaeologist nor a treasure hunter. "I am" he told the congressmen, "a marine scientist and explorer. I am here to point out that the technological genius most Americans are so proud of has entered the deep sea in full force and placed before us a new reality."

Influenced, no doubt, by Ballard's publicity on television, in newspapers, and in magazines, not all of the scientists at Woods Hole shared my enthusiasm for the *Titanic* adventure. At a number of gatherings later that summer, one heard the nasty buzzing of such pejorative adjectives as "publicity seeking," "grand-standing," "applied," "not really basic," "developmental," and—perhaps most damning—"anecdotal." Since *The Double Helix,* it has been no secret to the public at large that scientists are no more charitable to each other than are other professionals. But the detractors of the *Titanic* adventure were upset not only by Ballard per se. The naysayers also complained that technology rather than science was imprinted in the collective unconscious of television. Some of those most vexed by Ballard's sudden prominence had themselves made major findings in the "new reality" of genetic engineering, neurobiology, and immune regulation. Were not their achievements also part of the "technological genius most Americans are so proud of?" They argued that their contributions to basic science will affect the world of the future in ways more fundamental than adventures on the ocean floor.

But this reasoning strikes me as very self-serving. Historians of science and technology assure us that it is difficult to decide whether public practice follows private theory or whether the opposite is true. It is, they teach us, hard to know where technology ends and science begins. Moreover, real discoveries—basic or applied—influence our social arrangements as they in turn are influenced by them. Important discoveries tend to attract attention. The Spanish scribes did not ignore the voyages of Columbus, and Galileo managed to catch the ear of the Vatican. Einstein's theory of relativity was featured in headlines by *The New York Times,* and polio was conquered in public. When one of the new dons of DNA discovers something as spectacular as the wreck of the *Titanic,* he may fill auditoriums larger than that of a junior high school on the Cape. When he finds the vaccine for AIDS or solves the riddle of schizophrenia, purists may carp at the publicity, but I want to be in the audience to hear his "grandstanding."

> And still deeper the meaning of that story of Narcissus, who because he could not grasp the tormenting, mild image he saw in the fountain, plunged into it and was drowned. But that same image, we ourselves see in all rivers and oceans. It is the image of the ungraspable phantom of life; and this is key to it all.
>
> —*Moby-Dick*

When Ishmael, or Melville, emerged from the sinking *Pequod* to tell the story of Moby-Dick, he told us as much about the science of whales as about the descent into self. Ballard's tale of the *Titanic* is not only the story of deep-ocean science but also a tale of memory, of desire, and of that search for the ungraspable phantom of life that some have called Leviathan.



**The Ship**

concerns

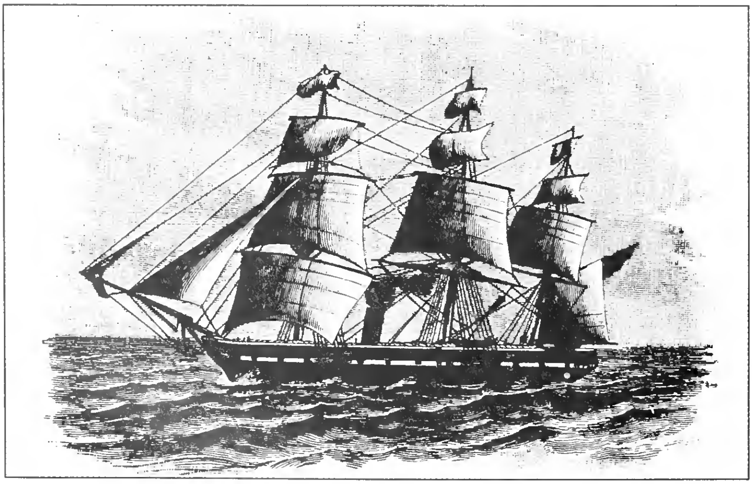
# Problems for British Oceanographers

### by Henry Charnock

There is growing concern among British oceanographers for the future of their science, which some sense to be losing its momentum. The more philosophical among them link this loss to the end of the immediate post-war generation of marine scientists, together with the fact that few of the major British institutions have had close connections with a university: more interaction with bright graduate students and postdoctoral fellows might well have helped.

Most of the marine science in the United Kingdom (UK) is done at government-funded institutes. Two university departments (at Bangor in North Wales, and at Southampton in the South of England) have recently been expanded and are making an increasing contribution, but the bulk of the work continues to be done at government laboratories, especially those of the Natural Environment Research Council (NERC).

Sir George Deacon (profile, *Oceanus,* Vol. 28, No. 1, pp. 90–94), founding director of what is now the Deacon Laboratory of the UK Institute of Oceanographic Sciences, at Wormley in Surrey, would probably have dated the decline from 1965. For it was then that his institute was one of a mixed bag thrown together to form NERC under a central, and centralist, administration. Others bemoan a government decision in 1975 to treat much scientific research as a service, to be provided by a contractor for a customer. Substantial amounts of NERC research funding were transferred to departments of government who were to act as customers for work they considered of practical importance. They in turn commissioned NERC as a contractor to do the work, but they did so in decreasing amounts, in an unpredictable way, and with a vast increase in administrative paper. Long-term research has not been favored by recent British governments, and the overall effect on the science budgets of NERC marine institutes, particularly those most concerned with physical oceanography, has been a marked decline in the funds available. They have been forced increasingly to rely on short-term commissioned projects which cannot be good for the continuing health of marine research.



HMS Challenger *gaver her name to the first oceanographic expedition to circle the globe (1876–1879). Sponsored by the British Navy and the Royal Society, it was headed by Sir Wyville Thompson and has been called the most innovative single oceanographic research voyage ever made.*

## Their Lordships' Report

A thorough analysis of UK marine science and technology was carried out by a select committee of the House of Lords in 1985. They studied a lot of written evidence, saw many witnesses, and made several visits— including one to the Woods Hole Oceanographic Institution (WHOI). Their report—*Marine Science and Technology*, Her Majesty's Stationery Office, (47-I 1985)—announced that

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the UK has a valuable pool of talent in marine science and technology, whose work needed to be protected for its scientific worth and its relevance to issues of commercial and national importance. They recognized that specific areas of future exploitation cannot be predicted, so that it is necessary to acquire the knowledge on which wise use of the oceans can be based.

The committee also recognized that a critical factor is the lack of adequate financial resources, giving as an example that the budget of WHOI (then $52 million a year) was about two-thirds of the total UK Government expenditure on civil marine science and technology. They thought this shortage of funds might be due to the UK's piecemeal approach, and called for a framework in which major projects of national and international importance can be identified, planned, and mounted without detriment to individual research.

This led to the committee's major recommendation, that there should be an executive Marine Board, in a Research Council, to be responsible for the support of marine research from the science budget. They doubted whether the management style of NERC fitted it to cope with such a marine board: the Science and Engineering Research Council might well have been more suitable. But in the end reactionary forces prevailed: instead of an executive board, the government decided to set up the interdepartmental Coordinating Committee on Marine Science and Technology (CCMST), a group empowered to give advice, not money.

### The New Committee

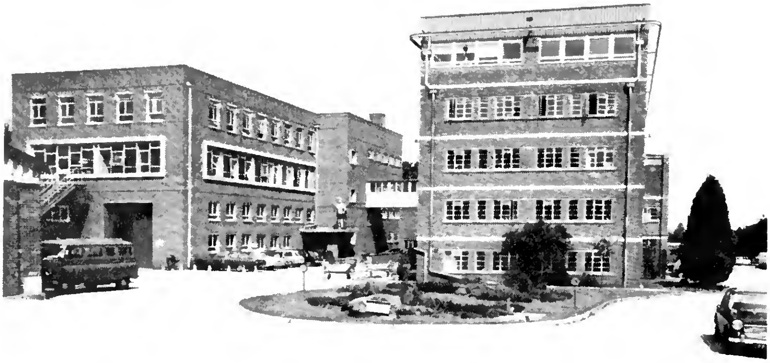
Now, nearly three years after the publication of their Lordships' report, the CCMST has finally been set up and is having meetings. The committee is serviced by NERC, its (part-time) chairman being Sir John Mason, a distinguished cloud physicist who has served as Director-General of the British Meteorological Office and as Treasurer of the Royal Society, and is now chairman of the Joint Scientific Committee for the World Climate Research Program. The committee's twenty members include some individual marine scientists (Sir Anthony Laughton, recently retired from his post as Director of the Institute of Oceanographic Sciences, and Ernest Naylor, University College of North Wales, Bangor), together with some marine technologists, some industrialists, and a dozen representatives of government departments. The aim of CCMST is to formulate a strategy for the whole of UK marine science and technology: they expect this to take until mid-1989, after which, given appropriate funding, the pattern will be set for the 1990s and beyond. They also plan to take care of the UK input into intergovernmental oceanographic affairs—briefing delegates to the Intergovernmental Oceanographic Commission, the International Council for the Exploration of the Sea, and similar bodies.


*The Royal Research Ship* Discovery. *Launched 1962, she will be extended in length from the present 80meters, if funds can be found, and kept in service for another fifteen years. (All photos courtesy of Henry Charnock)*

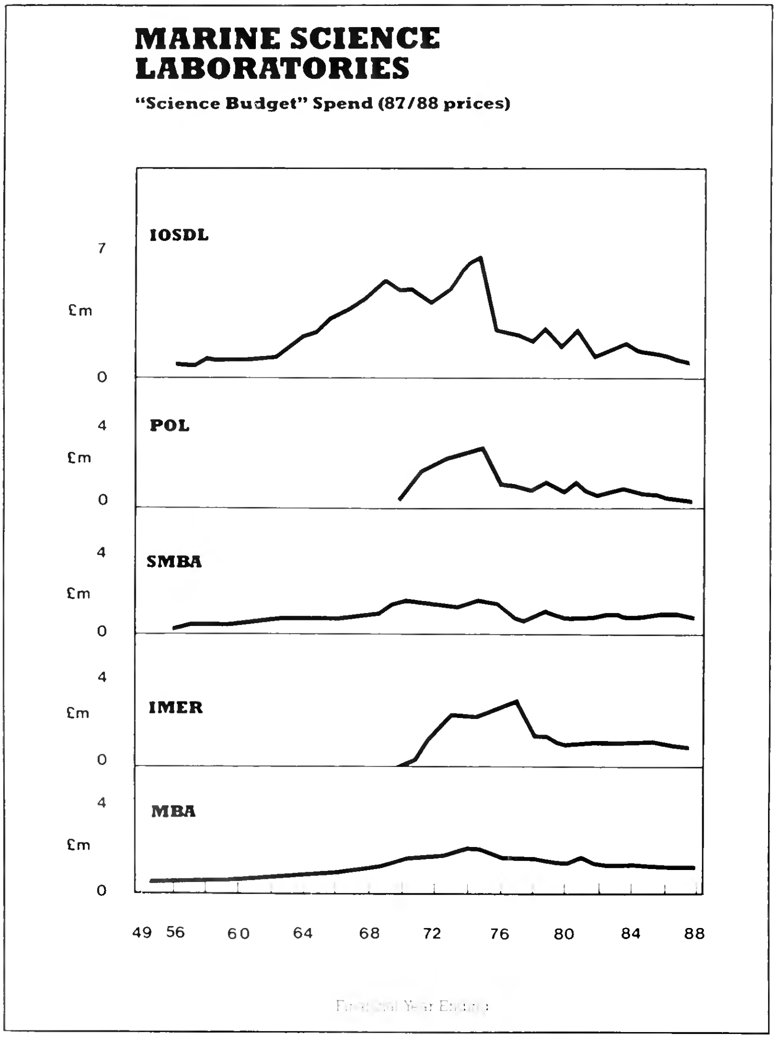

*J. D. Woods, Director of Marine Sciences, Natural Environment Research Council.*

### A Director of Marine Science

In the two years between the decision to form CCMST and its starting work, there were developments within the Natural Environment Research Council, whose Royal Charter requires it to provide the main channel for support of civil marine science in the UK. According to the Lords' report,



*The Institute of Oceanographic Sciences, Deacon Laboratory, in Surrey, England. There are plans to move the Institute to a site near the University of Southampton if funds can be found. Below, funds available to NERC Marine Laboratories, 1955-88, for their own choice of research. Supplementary funds had to be obtained from commissions and contracts from other government departments and outside customers.*



NERC spent £35 million (about $63 million) on marine science in 1984–85. This was about 40 percent of total NERC expenditure, and about half of the total UK government funds for civil marine science and technology. Apart from the about £2.5 million (about $4.5 million, or less than 10 percent of the total) that went to universities and polytechnics, NERC spent almost all its marine science funds through its various institutes. These six facilities are: the Institute of Oceanographic Sciences (IOS); the Institute of Marine Environmental Research (IMER); the Institute for Marine Biochemistry (IMB); the grant-aided Marine Biological Association (MBA) and Scottish Marine Biological Association (SMBA); and the Sea Mammal Research Unit (SMRU), all devoted to marine science. A heterogenous group, these institutes had different historical traditions, organizational structures, and philosophies. All except IMER predated NERC.

Since 1985, the NERC response to financial stringency has been to reduce staff numbers and to bring about increased centralization of scientific policy-making at NERC headquarters. Three new Directors of Science were appointed. One of them a Director of Marine Sciences; his job is to advise council (through a Marine Sciences Committee), and manage the Marine Sciences Research Programme and associated facilities, exercising formal line management of the 600 or so staff in NERC marine institutes.

To fill this important post NERC appointed John D. Woods, Professor of Regional Oceanography at the Institut fur Meereskunde, Kiel, West Germany. Born 1939, John Woods received his Ph.D. in cloud physics (under B. J. Mason at Imperial College) before working at the UK Meteorological Office, and as Professor of Physical Oceanography at the University of Southampton in England. Distinguished for his pioneering experimental work on turbulence and mixing in the upper ocean, he has also made an important contribution to international climate research. His recent work has been on water mass formation and on plankton growth. As Director of Marine Sciences of NERC he has started on a program of rationalization and realignment.

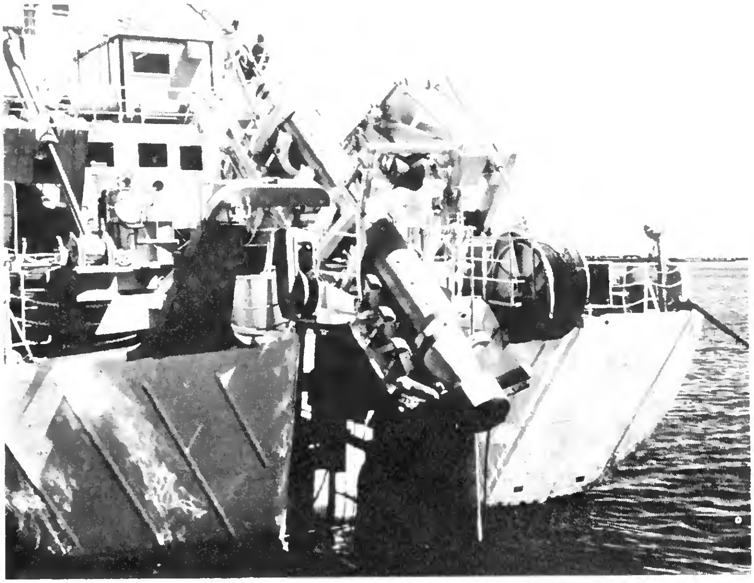
### Changing UK Marine Institutes

In 1985, the establishments of the Institute of Oceanographic Sciences were reduced from three to two, with the closure of the Laboratory in Taunton, Somerset. Some of the scientific staff moved to the laboratory at Bidston in Cheshire, but the group studying marine sedimentation did not survive the move. More recently the Bidston laboratory was administratively separated from IOS, and renamed the Proudman Oceanographic Laboratory—leaving IOS the only site at Wormley, which has been renamed the Institute of Oceanographic Sciences Deacon Laboratory. [Since IOS had been given a Queen's award for the development of the Geological Long-Range Inclined Asdic (GLORIA), it was presumably thought prudent to retain that part of the name.] The two laboratories at Plymouth (MBA and IMER) have been essentially combined into the Plymouth Marine Laboratory, and two in Scotland (SMBA and IMB) are to form the Dunstaffnage Marine Laboratory at Oban. Several of the laboratory directors have retired (they include M. J. Tucker, Sir Anthony Laughton, Sir Eric Denton, and R. I. Currie), with the result there is a new pattern—essentially of a Director-General at NERC headquarters, with less-senior directors implementing his decisions at the various laboratories.

### The Strategy

Clearly, NERC plans will form a major component of the national strategy for UK marine science and technology that is being planned by CCMST. Those plans include computer modelling as a major theme:

> *"Predicting the ocean involves understanding complex interactions requiring an interdisciplinary approach. Eddies, currents, tides, and microscopic animals in the ocean interact in complex ways with each other and with the atmosphere, winds, and man-made substances such as waste. To relate so many variables in time and space, computers must process billions of measurements of temperature, salinity, wind and water speed, and biological activity, gathered throughout the breadth and depth of the ocean. Computers with this power will not exist until the next century, nor will our capability to collect the data. However, foundations laid now are prerequisites for 10-year climate forecasts; the ability to plan for storms, famines, and droughts; and the knowledge to make full use of the ocean's resources. Six key projects depending on recent scientific and technological advances are planned by the Natural Environment Research Council. They will focus the efforts of Britain's 1,000 marine scientists over the next 10 years in Council institutes and in universities towards their goal—to predict the ocean."**


*Deploying the side-scan sonar instrument GLORIA during a cruise.*

These so-called "community research programmes" are to involve groups in universities and polytechnics, as well as the staff of NERC Institutes. They are major projects, some linked to international programs, which typically cost between £5 million and £10 million ($9 million to $18 million) over a five-year period. They constitute the first priority for the funds NERC is granted for its own science. The second priority goes to support laboratory projects (essentially long-term enabling research in NERC institutes) and a few individual research projects that are the privilege of institute scientists of established distinction.

The community laboratory, and individual research projects together constitute

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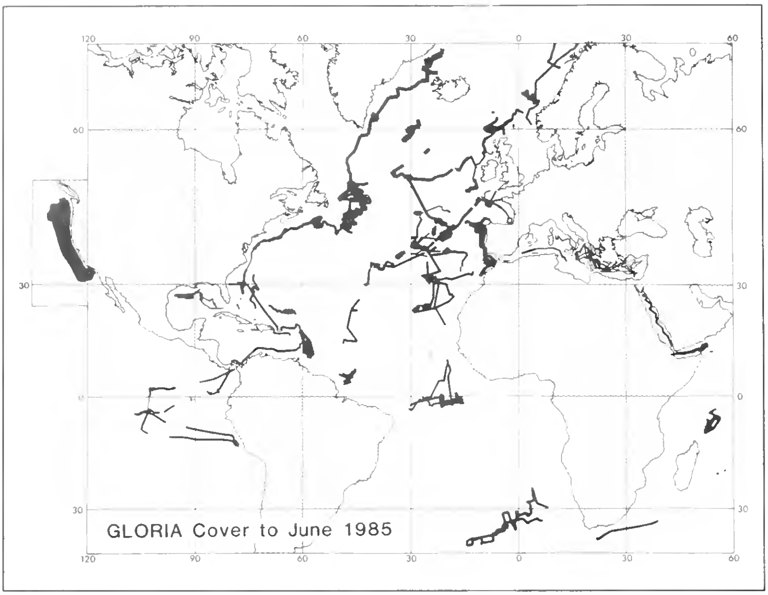
**The Challenge.....to predict the ocean*, NERC, 1987.



the so-called "core program," which the NERC strategy document asserts can be funded without difficulty from existing resources. Nevertheless, it is accepted that active measures (financial and recruitment) must be taken to ensure that UK research is of the first rank: *"The resources needed to revitalize key elements that fall below that level will be sought from NERC, ABRC, or government sources. If no additional resources are available it will be necessary to redistribute existing funds and transfer staff. Only as a last resort will funds needed for support of vulnerable elements be obtained by compulsory retirement of staff in better supported elements."*

It is not yet clear how possible it will be to fully implement the NERC strategy for marine science. In July 1988, NERC announced to its staff that it was being forced to cut some areas of science to cope with its financial difficulty. By April 1989, 160 posts were to be lost, some perhaps by compulsory redundancy. In total, the Marine Sciences Division was to lose almost 20 percent of its establishment of 552, but it was hoped that the areas identified in the strategy as being of high priority would be safeguarded.

UK oceanographers continue to hope that they will be enabled and encouraged to make important contributions to our knowledge of how the ocean works. But in the meantime, they remain concerned for the future of their science.

## 'Protectionist' Monopoly May Grow

# The Coastwise Trade Meets the Exclusive Economic Zone

### by Mark Aspinwall

Although many bemoan what appears to be a prevalence of foreign-flag ships in the transport of U.S. goods, one aspect of that transport remains the exclusive domain of Americans—the coastwise, or cabotage, trade (from the French *caboter*, meaning "to coast"), which refers to the domestic shipment of people and material by water. For almost as long as the United States has been a nation, the cabotage trade has been reserved exclusively for U.S. vessels—those that are built, flagged, crewed, and owned by Americans.

Two recent measures in Congress would change the equation by increasing protection to U.S. ships. One has already been passed into law.

It is a given that any proposed alteration to the coastwise laws draws an extraordinary amount of impassioned breast-beating on both sides of the issue. The reason, quite simply, is that on the "protectionist" side, the policy is seen as the very

*For most of U.S. history, shipment of cargo along the American coast has been the exclusive domain of U.S. flag shipping.*

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*Mark Aspinwall is a member of the professional staff of the Committee on Merchant Marine and Fisheries in the U.S. House of Representatives. The views expressed are solely his own.*

cornerstone of a maritime system designed to foster American shipping for jobs, promotion of trade, and preservation of national security. The merchant marine is often hailed as the "fourth arm of national defense," which will become necessary as a supply line in an emergency. On the "demand" side, the policy is usually decried as anti-consumer, and an outdated concession to inefficient American unions and inefficient transportation companies.

Which, then, is true? Both are.

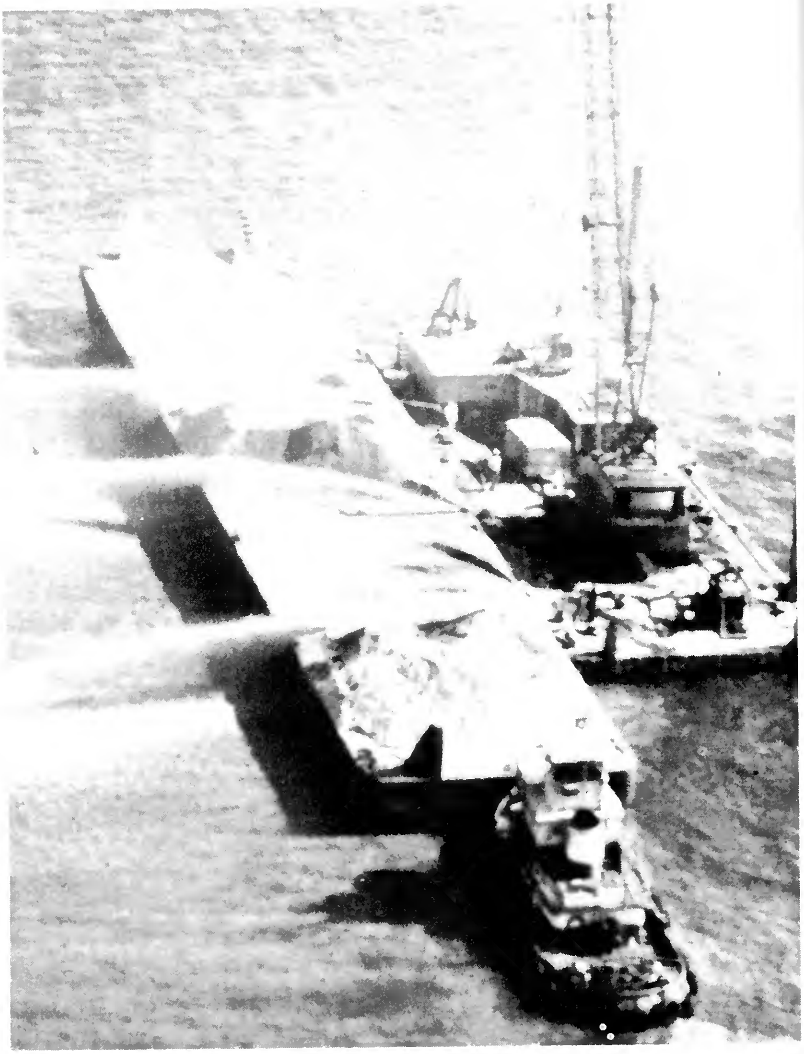
### An 18th-century Policy

The Federal government began supporting the U.S. maritime industry in the very first Congress, two hundred years ago. Early assistance took the form of reduced tariffs on port calls by U.S. ships, and cargo preference rules, whereby certain cargoes on certain routes were reserved for American ships. The oldest cargo preference law barred foreign vessels from merchandise carriage in the cabotage trade; that policy began in the U.S. in 1817, and was modeled after British law dating from the 17th century.

The U.S. Customs Service, in charge of enforcing the cabotage laws, considers them to include the coastwise transportation of merchandise and passengers, towing—in cases where merchandise or passengers are transported—and salvage. The functional scope of U.S. cabotage policy, therefore, is almost entirely based on the concept of transportation.

The geographic scope, or coastwise area, is generally considered to include the navigable internal and territorial waters of the states of the United States, including many of its territories and possessions. The navigable internal waters include those inland water bodies—both fresh and salt—that the Coast Guard has determined are navigable to vessel traffic. The port of Baltimore, for example, is a coastwise point. The territorial sea is a 3-nautical mile-wide band of water around the U.S.

Certain points on the Outer Continental Shelf (OCS) are also within the realm of the coastwise area, and will be treated in more depth below. Therefore, coastwise points include any port or place within U.S. jurisdiction (with some exceptions), as well as some structures and vessels tethered to the OCS.



*Under 1953 legislation even fixed structures operating on the outer continental shelf come under the jurisidcation of American cabotage, or coastwise, law. (Photo courtesy of the Louisiana Department of Natural Resources)*

### The OCS and the EEZ

The Outer Continental Shelf Lands Act of 1953 extended United States law to the subsoil and seabed of the OCS, and to all artificial islands and fixed structures established there for the purpose of exploring, developing, removing, and transporting resources. The OCS is a geological feature which, including the continental slope, extends out to the deep ocean floor.

This statute established the policy that fixed drilling equipment on the OCS was as much a coastwise point as the port of Baltimore. It was a significant extension of U.S. cabotage policy inasmuch as it meant that any ships trading between the offshore rigs and any other coastwise point—namely, a supply port on American soil—must be qualified under American cabotage law. This change was to manifest itself more clearly when the high prices of the oil crisis of the 1970s drove oil companies offshore in the search for new reserves. With the act in place, U.S. shipyards were able to capture a significant market for the construction of service vessels which, of course, were crewed by American sailors.

An amendment to the act was passed into law on September 18, 1978, which changed it by including within federal jurisdiction structures permanently or temporarily attached to the OCS seabed. This change brought anchored vessels, including ships and other floating equipment, within the purview of the cabotage laws, provided they were involved in the recovery of OCS resources.

The 1978 amendment has been interpreted to include such features as marker buoys, which are secured to the seabed temporarily and are used to mark an offshore site that is to be drilled. The significance of such rulings is that the shipment of drill jackets—the frame derrick-like structures that hold the drilling platform—must be performed by coastwise-qualified launch barges if they are brought from the United States to a marker buoy or some other object temporarily affixed to the ocean floor.

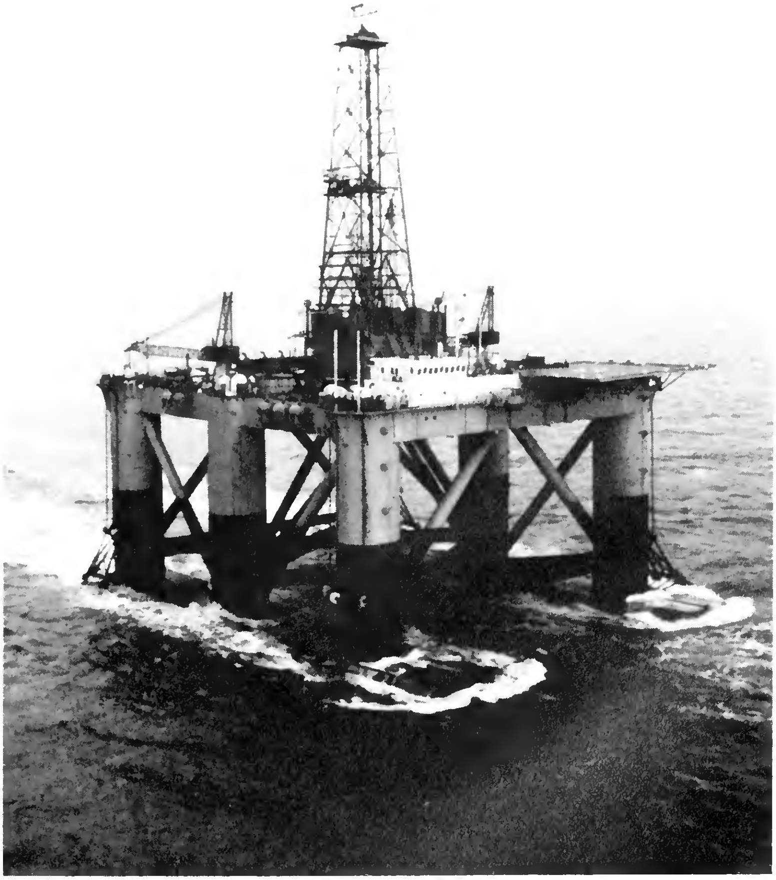
On March 10, 1983, in a significant extension of U.S. control over ocean resource exploitation, President Reagan established, by proclamation, an Exclusive Economic Zone (EEZ) extending out to 200 nautical miles from the baseline from which the territorial sea is measured (*Oceanus*, Vol. 27, No. 4). Unlike the OCS, the EEZ is a constant distance from the coastline. The proclamation was consistent with the terms of the Third United Nations Conference on the Law of the Sea, and it assured U.S. jurisdiction over the resources contained within the waters of the zone and the subsoil and seabed beneath them.

The implications for American control over ocean resources were clear. What was less clear was the part the American maritime industry would play in capturing those resources.

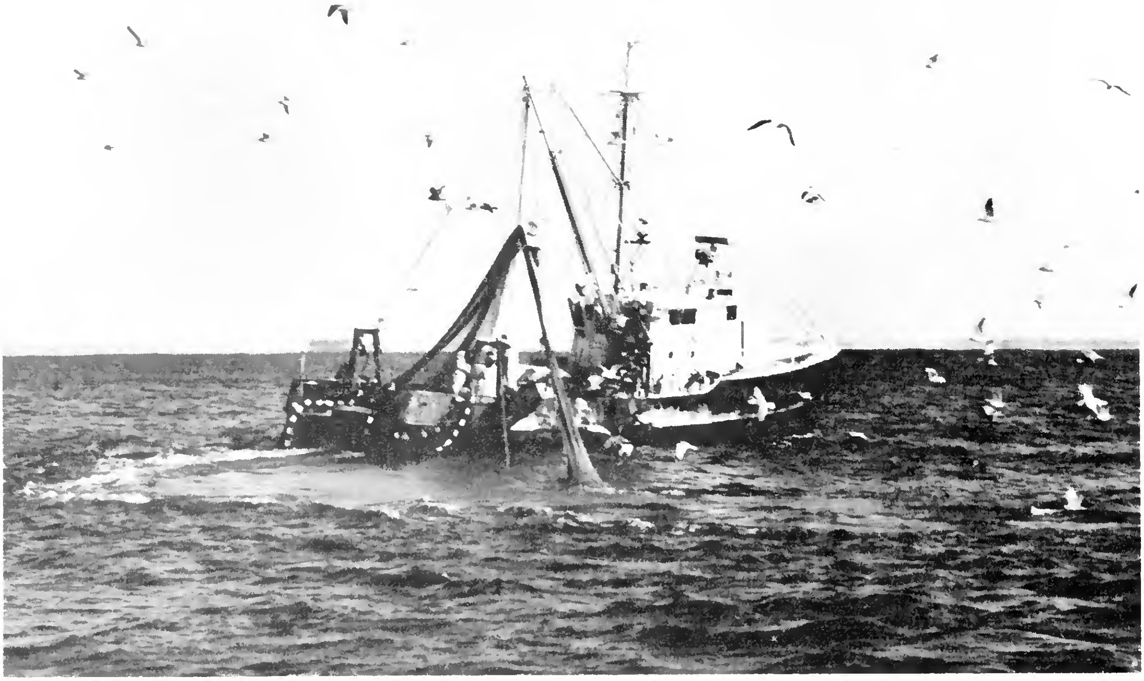
## Legal Complexities

The extent to which structures and vessels within the EEZ qualify as points or places in the United States for the purposes of our cabotage laws has been a growing concern in recent years. Commercial activity of all kinds is on the rise, and the answers are likely to become more important as time passes. Oil and gas extraction, fishing, sand and gravel mining, offshore thermal energy conversion (OTEC), waste disposal, and recreation are among the multitude of EEZ resource uses.

Technological advances and the seaward search for oil and other resources have caused an increase in the number and complexity of ships servicing offshore vessels and installations. There are vessels that assist in the processing of EEZ resources without actually being involved in their transport that are known as "resource processing vessels." Many of



*Under a 1978 amendment to the Outer Continental Shelf Lands Act, the shipment of the supports for drilling platforms, like this self-propelled rig, must be carried out by coastwise-qualified launch barges. (Photo courtesy of the Zapata Corporation)*



*Charter fishing vessels that carry people between two points on the American coast are considered in the cabotage trade and therefore saddled with higher domestic construction and operating costs. (Photo courtesy of Maine Department of Natural Resources)*

these vessels do not fall within the same guidelines as cabotage vessels, and so there is often a high degree of foreign involvement in such activities. Some of these resource processing vessels require services provided by another set of vessels, often not bound by the strict domestic requirements of cabotage law, particularly if they are not engaged in a transportation service. The Customs Service has held that a ship of any nation may engage in offshore service operations, as long as the operation is not a coastwise activity. The question then becomes: when is a service operation a coastwise activity?

The easiest way to answer that question is to refer back to the broad definition of coastwise trade mentioned earlier: it is the transport of material and people between one part of the United States and another. In the case of the EEZ, the "United States" includes resource processing vessels that are tethered to the ocean floor, even temporarily.

The types of vessels that assist in resource processing activities include tugs and barges that transport dredged and mined material as well as waste; crew and supply boats which service offshore oil rigs, OTEC vessels, and fish processors; icebreakers, anchor handlers, diving inspection boats, and geophysical survey boats, among others. In addition, passenger vessels play a role in EEZ service activities, particularly those that undertake diving and charter fishing cruises. Those vessels that are identified as transporting people and material between two coastwise points are in the cabotage trade, and therefore are saddled with higher domestic construction and operating costs.

### "Love Boat" Cruises

One example of how complex the process can become is with cruises to and from the same U.S. port, that may be and are done by ships of any registry. In order for the cruise not to be considered coastwise trade, it must begin and end at the same place, and go outside the 3-mile territorial sea. This is true for cruise ships such as TV's "Love Boat," and for smaller vessels such as scuba-diving boats. Since the net effect of a cruise to nowhere is not the transport of passengers between two distinct places, the coastwise laws do not apply.

The one notable exception to this cruise to nowhere situation is charter fishing boats. If a charter fishing boat begins a trip in one port, steams outside the territorial sea so that the passengers may sportfish, and returns to the original place, the activity is considered coastwise trade. This is because once the fishing lines go over the side, the voyage is designated as coastwise, regardless of whether the trip is outside the territorial sea or not, despite the seeming inconsistency with other passenger service voyages.

This confusing situation reached a milestone of sorts in the sophisticated use of service ships to support oil exploration activities under adverse weather conditions. The Amoco Production Company, in 1985, proposed using two warehouse vessels as floating storage sheds to store supplies in support of offshore drilling operations in the Navarin Basin, off Alaska. The ships consisted of a converted bulker and a converted tanker, both of foreign registry. The benefit of using such vessels is that the equipment and supplies necessary to sustain operations are close to the rig, rather than in port. In a series of rulings, the Customs Service held that the warehouse ships, which themselves could be foreign-flagged, were coastwise points while anchored, and were not coastwise points while drifting. The result was that any movement of supplies from the warehouse ship to the oil rigs could be effected by foreign feeder vessels while the warehouse vessels were *drifting*, but had to be by coastwise-qualified feeder vessels while *anchored*.

### Coastwise Competitiveness

In the 100th Congress, a great deal of attention was focussed on the "competitiveness" of American industry, and ways to protect workers and companies against unfair foreign competition. Naturally, the merchant marine was the subject of some scrutiny consistent with this trend, and within the domestic shipping area, two bills were introduced that would have a significant impact on the present cabotage regime.

The first House bill, House Resolution (H.R.) 82, would require that all valueless material—including sewage sludge, contaminated dredge spoils, and other waste—being moved between coastwise points, or between a coastwise point and the EEZ, be transported on coastwise-qualified vessels. On June 7, 1988, the Senate version of the bill (S. 1988) was signed into law. Representative Mario Biaggi (D-NY) introduced the bill in response to a contract awarded by the City of New York to a Singapore shipyard to build four barges capable of transporting sewage sludge to a deepwater dump site. Though the bill originally applied only to municipal sewage sludge, it was broadened to cover all valueless material.

The measure makes two substantive changes. First, it effectively places matter of no value on the same level as merchandise and passengers for the purposes of U.S. cabotage law. Second, it extends the existing cabotage regime—for the purposes of waste transport only—to the EEZ, without respect to whether the dump site is a "coastwise point" or not. Simply, it defines the entire EEZ as a coastwise point for the purposes of waste disposal.

*Under cabotage laws, only American flag ships like the 207-foot Constitution Service are allowed to service drill rigs off the U.S. coast. (Photo courtesy of WHOI)*

The second bill is H.R. 3106, which recodifies the laws relating to the Federal Maritime Commission and the Maritime Administration. In what is by far the most ambitious restructuring of the coastwise laws ever undertaken, the bill would change the definition of both the coastwise area and coastwise trade. The coastwise area would be enlarged to include resource processing vessels or structures in the EEZ without regard to whether they are actually tethered to the ocean floor or engaged in a transportation service. Therefore, not only would a *drifting* warehouse ship be a "coastwise point" under the provisions of H.R. 3106, but the ship itself would be subject to the domestic construction, crewing, and ownership requirements of the coastwise laws.

Even more significantly, the coastwise trade, defined statutorily for the first time under the term "coastwise commerce," would be expanded to include transportation of valueless material (now covered under the terms of P.L. 100-329, the recently-enacted "sludge bill"), the lodging of any passengers or property that are enroute from one coastwise point to another, and dredging and salvaging.

The latter two activities would be considered coastwise commerce in the EEZ when they are undertaken in conjunction with resource exploration, development, or production. Such a change would be noteworthy in that dredging is not now considered to be a coastwise trade activity (dredges must be U.S.-built, but may be foreign-flagged and crewed); further, salvaging is not currently regulated under the coastwise laws outside the territorial sea, but could be under H.R. 3106. The bill is presently in the Committee on Merchant Marine and Fisheries, and no action is likely to be taken on the issue before the 101st Congress.

### Expanding Federal Authority

In the event of expanding exploitation of EEZ resources, the clear potential exists for a growing employment of support ships such as those mentioned above, and the age-old question of protecting U.S. industry versus allowing free trade in procuring services will present itself to policymakers. U.S. support ship interests have argued that foreign vessels will invade this sector of the maritime industry unless it is reserved to U.S. vessels. In fact, it has been argued that those support services should already be viewed as a type of coastwise trade, and therefore should be reserved to U.S. ships. Conversely, users of these maritime service vessels have a clear interest in maintaining a free market choice in what nationality equipment they will employ.

The upshot of H.R. 3106 and H.R. 82 is that efforts are being made by congressional leaders to encompass maritime services above and beyond the traditional transportation of merchandise and passengers within the realm of coastwise trade, thereby requiring that those vessels be domestically built, owned, and crewed. The hope is that such a policy change would provide more shipyard and seagoing jobs, and add to the security posture of the nation.

The final outcome remains uncertain, although the degree of protection granted will depend on several factors, including the amount of foreign involvement in EEZ activities, the political clout of U.S. maritime service interests, and the regulatory mood in Washington.

*Once the fishing lines go over the side, a trip out of a U.S. port is considered coastwise, even if the voyage extends outside territorial waters. (Photo courtesy of National Marine Fisheries Service)*

# letters

To the Editor:

The statement in "A Brief History of Antarctica" (Volume 31, Number 2, page 28) describing the American expedition commanded by Charles Wilkes as "poorly organized" completely overlooks the significant scientific contributions of America's first scientific expedition. Instead it plays up a court-martial where Wilkes was condemned for being too severe in the punishment of two officers, with 36 and 41 lashes for what Wilkes considered court-martial offenses.

Historians will debate whether the circumstances justified Wilkes's actions. But the record is clear as to the importance of the expedition to the development of American science. Most notable was Wilkes's "Chart of the Antarctic Continent Shewing the Icy Barrier Attached to it." This chart covers more than fifteen hundred nautical miles, from 160 to 100 degrees East longitude with panoramic views of the pack ice and land covered with snow. This documentation, and expedition, was the first to establish that Antarctica is a continent. It would take almost seventy-five years to verify how accurate, for the most part, this chart was. Charts that resulted from his expedition have been used, with little modification, by both the American and British Navies, up until and during World War II.

Wilkes's expedition is best remembered for its collections: more than four thousand zoological specimens, including close to two thousand new species, fifty thousand herbarium specimens with about ten thousand species, and thousands of ethnographic artifacts from the South Pacific, Hawaii, and America's Northwest Coast. In addition, geologist James D. Dana personally oversaw the collection of thousands of geological and coral specimens. It would take fifteen years before the collections were properly accessioned as the first collection for the new Smithsonian Institution's National Museum.

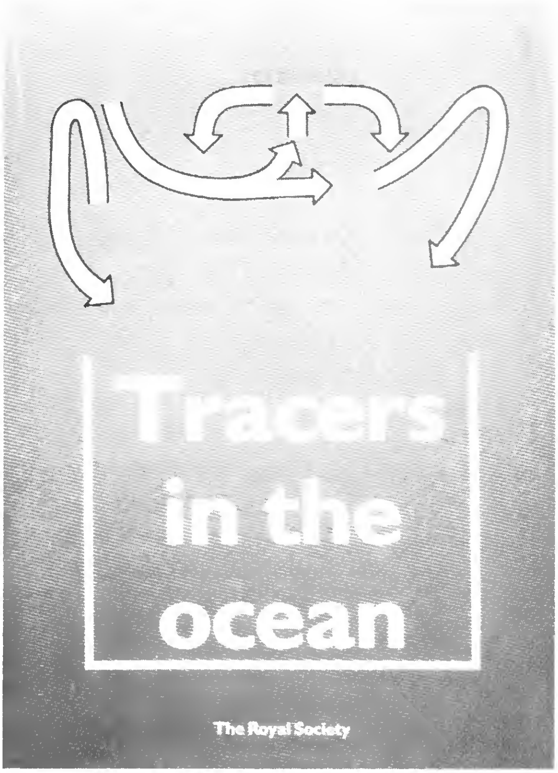
The story of Wilkes's expedition and many of the artifacts, and artwork by the participating naturalists, is being presented in a special traveling exhibition by the Smithsonian entitled "Magnificent Voyagers". The last opportunity to see the Magnificent Voyagers will be at the Peabody Museum of Salem, Massachusetts February 10 through April 20, 1989. I invite you to come see it and decide for yourself the significance of America's first expedition to the Antarctic.

**Rob Moir**
**Curator of Natural History**
**Peabody Museum**
**Salem, Massachusetts**

EDITOR'S REPLY: It is certainly unfortunate that the worth of this expedition was not immediately recognized by the Navy. Nonetheless, Wilkes was court-martialed, a fact I believed suitable to present in a brief history. The intriguing point that, in spite of Wilkes's alleged misconduct, the Royal Geographic Society considered his work worthy of a gold medal, shows that Wilkes received at least some of the recognition he deserved. I look forward to visiting the Smithsonian exhibition.

**Sara L. Ellis**
**Editorial Assistant, *Oceanus***

# book reviews



***Tracers in the Ocean, Proceedings of a Royal Society Discussion Meeting held on 21 and 22 May, 1987.* Organized and edited by Henry Charnock, F.R.S., J. E. Lovelock, F.R.S., P. S. Liss, and M. Whitfield. 1988. Printed for The Royal Society by the University Press: Cambridge, England. 236 pp. + v. £45 in the United Kingdom, £48 overseas.**

This collection of papers reflects a resurgence of interest within the oceanographic community in the distribution and fluxes of minor constituents in the complex chemical soup known as sea water. Like most symposium proceedings, it reflects the current interests of the participants, without striving for completeness or a systematic presentation of its material. However, thanks to its rapid publication, it should serve admirably for some time as a sampler of the current knowledge and thinking in the areas represented.

The opening paper deals with carbon cycle modeling. It illustrates that the dynamics of trace substance transports has become an important topic in itself, rather than just a tool for studying water movements. This work is driven by concerns for how the oceans may influence the climatically significant concentration of $CO_2$ in the atmosphere. It nicely demonstrates the growth in minimal model complexity as the aspiration for modeling detail grows, and suggests that nutrient and alkalinity cycling, and the production of slowly degraded dissolved organic compounds, together with a model for plankton ecology, must be invoked if the oceanic sequestration of carbon dioxide is to be handled with climatically significant precision.

The second paper introduces more explicitly the problem of constructing transport models for which the parameters are defined by a set of constraints based on observed trace substance distributions. Low resolution reservoir budget models are again found inadequate, but after reviewing a number of recent attempts (only marginally successful) to produce well-constrained three-dimensional models, the author concludes on a somewhat optimistic note regarding prospects for further improvement.

In constructing more complete prediction models, accurate representation of processes such as the intensity of gas exchanges at the air-sea interface becomes increasingly significant. A detailed review of tracer-based inferences about the latter process is given, and an evaluation of the implications of the observed global wind distributions for the surface transfer rates of $CO_2$ in the present climate is presented.

Vertical transfer in the water column by incorporation into, or attachment onto, settling particles is important for a wide range of substances, especially for their burial in sediments. An excellent review shows how the study of trace metal scavenging for components such as the lead isotope Pb-210 has allowed the building of models for these processes, applicable to oceanic pollutant and naturally occurring heavy metal cycling. The lucid discussion of this matter is complemented by papers on trace metal chemistry and on the rare-earth elements for cases where natural source distributions provide opportunities for regional transport diagnostics based on observed distributions.

Large-scale variations in the temperature and chemical composition of sea water have traditionally provided the most accessible picture of large-scale water movements, but the determination of rates on this basis depends on an understanding of the sources and sinks for the respective properties. Particularly promising in this respect are several so-called transient tracers, either naturally occurring radioactive ones, or ones recently introduced into the ocean system by human activities. Their use is represented in two papers regarding Atlantic circulation diagnostics based on observed distributions of the radioactive hydrogen isotope, tritium, and its helium isotope daughter, $^3$He. However, little agreement exists as yet regarding how one best approaches the quantitative interpretation problem.

### Artificial Tracers

Yet, in a description of a deliberate release of artificial tracers in the Santa Monica Basin, vertical diffusion in the laterally confined bottom waters was successfully studied. In fact, when one looks for examples of definite quantitative conclusions based on tracer data, and not accessible by other means, the successful cases involve situations that are, at least in a local region, sufficiently homogeneous so that in a generalized sense, one-dimensional models and interpretations are useful approximations. Such is the case in the Santa Monica basin experiment; it also conforms with Carl Wunsch's statement, that the tracer information in his eclectic modeling exercise is mainly useful to constrain the total injection rate of freshly modified surface waters.

One is thus left with the impression that much of the disenchantment of the current mainstream physical oceanographers with transient tracer approaches is due to their fixation on details of motion patterns rather than transport characteristics. The latter are of overriding importance, for instance in the context of problems in climate dynamics and in global geochemical models. The difference in perspective on the part of a modeler oriented towards understanding the global biogeochemical budgets and balances is evident in the discussion of the opening paper.

In conclusion, the statement on the jacket flap that this volume gives, "an up-to-date account of ocean tracers and their potential, and will be of interest to chemists, geologists and geophysicists as well as to oceanographers and climatologists" appears hyperbolic only in the impression of completeness conveyed. It seems that a member of any of the categories listed would find at least a couple of the fourteen contributions worthy of immediate attention, and that a more complete reading would bring to anyone the reward of a broader, if not deeper, understanding of oceanic trace substance transport patterns and mechanisms, as well as of the limits to our present knowledge about them.

**Claes G. H. Rooth**
**Professor of Meteorology and Physical Oceanography**
**Rosentiel School of Marine and Atmospheric Science**
**University of Miami**

# Books Received

## Biology

**Concepts of Ecosystem Ecology** edited by Lawrence R. Pomeroy and James J. Alberts. 1988. Springer-Verlag, Secaucus, NJ 07094. 384 pp. + xii. $72.00.

**The Living Sea** by Jacques Cousteau with James Dugan. 1988 (Second Printing, with New Introduction by J. Cousteau). Nick Lyons Books, New York, NY 10010. 301 pp. $12.95.

**Physiology of Elasmobranch Fishes** edited by Trevor J. Shuttleworth. 1988. Springer-Verlag, Secaucus, NJ 07094. 324 pp. + xii. $130.00.

**The Year of the Crab: Marine Animals in Modern Medicine** by William Sargent. Paperback edition, 1988. W. W. Norton & Company, New York, NY 10110. 191 pp. $7.95.

## Computer Science

**Mathematical Aspects of Scientific Software** edited by J. R. Rice. 1988. Springer-Verlag, Secaucus, NJ 07094. 208 pp. + xii. $21.00.

**Numerical Geology: A Source Guide, Glossary and Selective Bibliography to Geological Uses of Computers and Statistics** by N. M. S. Rock. 1988. Springer-Verlag, Secaucus, NJ 07094. 427 pp. + xii. $39.50.

## Culture of Science

**The Great Devonian Controversy: The Shaping of Scientific Knowledge Among Gentlemanly Specialists** by Martin J. S. Rudwick. 1988. The University of Chicago Press, Chicago, IL 60637. 494 pp. + xxxiv. $19.95.

**The Pasteurization of France** by Bruno Latour, translated by Alan Sheridan and John Law. 1988. Harvard University Press, Cambridge, MA 02138. 273 pp. $30.00.

**Scientific Genius: A Psychology of Science** by Dean K. Simonton. 1988. Cambridge University Press, New Rochelle, NY 10801. 229 pp. + x. $27.95.

**Time's Arrow/Time's Cycle: Myth and Metaphor in the Discovery of Geological Time** by Stephen Jay Gould. Paperback edition, 1988. Harvard University Press, Cambridge, MA 02138. 222 pp. + xvi. $8.95.

## Earth Science

**The Climate of China** by Manfred Domrös and Peng Gongbing. 1988. Springer-Verlag, Secaucus, NJ 07094. 361 pp. + xiv. $130.00.

**Deep Drilling in Crystalline Bedrock, Volume 1** edited by A. Boden and K. G. Eriksson. 1988. Springer-Verlag, Secaucus, NJ 07094. 364 pp. + xiv. $83.50.

**Deep Drilling in Crystalline Bedrock, Volume 2** edited by A. Boden and K. G. Eriksson. 1988. Springer-Verlag, Secaucus, NJ 07094. 538 pp. + xii. $102.00.

**Eh-pH Diagrams for Geochemistry** by Douglas G. Brookins. 1988. Springer-Verlag, Secaucus, NJ 07094. 176 pp. + vii. $89.50.

**Explosion Pipes** by Vladimir A. Milashev. 1988. Springer-Verlag, Secaucus, NJ 07094. 249 pp. + xii. $110.00.

**Neodymium Isotope Chemistry: An Introduction** by Donald J. DePaolo. 1988. Springer-Verlag, Secaucus, NJ 07094. 187 pp. + xii. $49.50.

**Rock and Soil Rheology** edited by N. Cristescu and H. I. Ene. 1988. Springer-Verlag, Secaucus, NJ 07094. 289 pp. + viii. $41.80.

**Structural and Magnetic Phase Transitions in Minerals** edited by S. Ghose, J. M. D. Coey, and E. Salje. 1988. Springer-Verlag, Secaucus, NJ 07094. 244 pp. + xii. $59.50.

**Global Climatic Catastrophes** by M. I. Budyko, G. S. Golitsyn, and Y. A. Izrael. 1988. Springer-Verlag, Secaucus, NJ 07094. 99 pp. + vii. $29.00.

## Environment

**Audubon Wildlife Report 1988/1989** edited by William J. Chandler. 1988. Academic Press, San Diego, CA 92101. 817 pp. + xxx. $24.95.

**Environmental Management of Solid Waste: Dredged Material and Mine Tailings** edited by Wim Salomons and Ulrich Förstner. 1988. Springer-Verlag, Secaucus, NJ 07094. 396 pp. + x. $98.00.

**Great Lakes Coastal Erosion Research Needs: Workshop Summary** edited by Lorelle A. Meadows. 1988. Michigan Sea Grant College Program, Ann Arbor, MI 48109. 63 pp. $5.00.

**Managing Oregon's Ocean Resources** by The Oregon Ocean Resources Management Task Force. 1988. The State of Oregon and The Oregon Department of Land Conservation and Development, Portland, OR 92704. 72 pp. + iv. Free.

## Field Guides

**Cape Cod Field Trips: From Yesterdays Glaciers to Todays Beaches** by Stephen P. Leatherman. 1988. Coastal Publication Series, Laboratory for Coastal Research, The University of Maryland, College Park, MD 20472. 132 pp. + v. $7.00.

**Coral Reefs of Florida** by Gilbert L. Voss. 1988. Pineapple Press, Sarasota, FL 34239. 80 pp. $14.95.

**Seashore Animals of the Southeast: A Guide to Common Shallow-Water Invertebrates of the Southeastern Atlantic Coast** by Edward E. Rupert and Richard S. Fox. 1988. University of South Carolina Press. 429 pp. + viii. $24.95.

## General Reading

**The Japanese Today: Change and Continuity** by Edwin O. Reischauer. 1988. Harvard University Press, Cambridge, MA 02138. 436 pp. $25.00.

**Man on Earth** by John Reader. 1988. University of Texas Press, Austin, TX 78713. 256 pp. $29.95.

**On Human Nature** by Edward O. Wilson. Paperback edition, 1988. Harvard University Press, Cambridge, MA 02138. 260 pp. + xii. $8.95.

**A Whaler and Trader in the Arctic, 1895 to 1944: My Life with the Bowhead** by Arthur J. Allen. 1988 (Second Printing). Alaska Northwest Publishing Company, Anchorage, AK 99501. 213 pp. + xii. $9.95.

## History

**Charles Darwin's *Beagle* Diary** edited by Richard D. Keynes. 1988. Cambridge University Press, New Rochelle, NY 10801. 464 pp. + xxix. $59.50.

## Marine Policy

**North-South Perspectives on Marine Policy** edited by Michael A. Morris. 1988. Westview Press, Boulder, CO 80301. 267 pp. + vii. $28.50.

## Physical Science

**The Acquisition, Calibration, and Analysis of CTD Data** a report of SCOR Working Group 51. 1988. Unesco technical papers in marine science, number 54, Unesco, Paris, France. 94 pp. + vii. Free.

**Exploration of Halley's Comet** edited by M. Grewing, F. Praderie, and R. Reinhard. 1988. Springer-Verlag, Secaucus, NJ 07094. 984 pp. + xxiv. $144.00.

**Fundamentals of Waves and Oscillations** by K. U. Ingard. 1988. Cambridge University Press, New Rochelle, NY 10801. 595 pp. + xiv. $89.50.

**Wave Interactions and Fluid Flows** by Alex D. D. Craik. 1988. Cambridge University Press, New Rochelle, NY 10801. 322 pp. + xii. $24.95.

## Reference

**The Harper Dictionary of Science in Everyday Language** by Herman Schneider and Leo Schneider. 1988. Harper & Row, Publishers, New York, NY 10022. 309 pp. + x. $25.00

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