Instruments Cast Fresh Eyes on the Sea

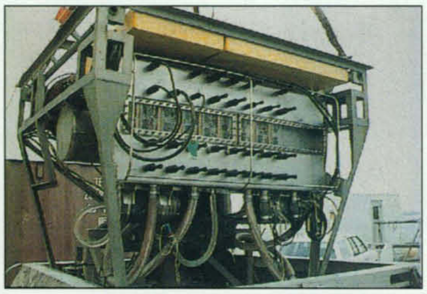
NEWS

From roving sensors to fixed offshore observatories, a raft of innovations is opening up new horizons in ocean research

MONTEREY BAY, CALIFORNIA—Below deck on the research vessel *Point Lobos*, pilot Stuart Stratton fires hydraulic thrusters to nudge *Ventana*, a tethered robot, within arm's length of a steep canyon wall some 1000 meters below the surface. Colleague Paul Tucker twists a joystick to guide *Ventana*'s arm to the rock face—a jagged gray cliff on the shipboard monitor—then gently plucks a salami-sized seismometer from its rocky cleft to retrieve its data recorder. For an encore, the team inserts a new seismometer in the same borehole, near a hazardous fault that cuts offshore between Monterey and Santa Cruz.

Scientists from the Monterey Bay Aquarium Research Institute (MBARI) perform such ballets nearly every day with the remotely operated vehicle (ROV) *Ventana*. The former oil-exploration craft has opened new research vistas within Monterey Canyon, where shallow coastal waters plunge into deep ocean. *Ventana*'s sensors probe canyon features that were inaccessible just a decade ago: cold hydrocarbon seeps, a sea floor contorted from centuries of earthquakes, and bizarre creatures such as the tadpolelike larvaceans—filter feeders enshrouded by nets of mucus.

But *Ventana*, MBARI researchers say, is just a foretaste of the coming era of robotic oceanography. Last March, the institute celebrated the first expedition of a $32 million tandem: the research vessel *Western Flyer* and its state-of-the-art ROV, *Tiburon*. The twin-hulled, 36-meter *Western Flyer* gives a more stable platform for deploying an ROV than the round-bottomed *Point Lobos*, which churns even the hardiest stomachs. And *Tiburon*'s all-electric design, far quieter than *Ventana*'s hydraulic systems, lets the robot "sneak up on things" with exquisite control at depths of up to 4000 meters, says marine geologist Marcia McNutt, president of MBARI. "We're getting to the point where there is little justification for manned submersibles," McNutt says. "ROVs and autonomous underwater vehicles [AUVs] are the wave of the future in ocean science."



Sea lion. The LEO-15 ocean observatory, ready to be lifted overboard off the New Jersey coast.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Other oceanographic institutions around the world are catching that same wave. Fleets of robotic sensors drift in the oceans' midwaters, periodically bobbing up to beam their data to satellites. AUVs, set loose for hours to months at a time, crawl on the sea floor or skim through the water along preprogrammed paths. And fixed observatories monitor currents, salinity, and other tracers of the ebbs and flows of coastal ecosystems. Although some researchers say that federal funding falls short of the long-term buy-in that new oceanographic tools require, "the technology today unquestionably is driving the science," says Michael Reeve of the National Science Foundation (NSF) in Arlington, Virginia. "There is incredible complexity and variability in the ocean that we have only recently begun to see."

Sea legs for new devices. To open that view, instrument designers are drawing on advances in areas such as microelectronics. New chip and sensor technologies have shrunk instrument packages while increasing their capacity to store huge amounts of data—creating, in McNutt's words, "high-powered brains with low-power requirements." And materials such as Teflon-coated titanium, rugged glass spheres, and dense plastics have enabled engineers to devise better ways to cope with the sea's corrosiveness and crushing pressures. As a result, many oceanographers no longer need to wait a year to go out on a ship or schedule a costly manned submersible dive. The sea, while still daunting, is now much more accessible.

One futuristic vision, imagined in 1989 by the late oceanographer Henry Stommel of the Woods Hole Oceanographic Institution (WHOI) in Massachusetts, already is coming to pass. Stommel dreamed of a fleet of 1000 undersea craft that would wander the globe for years, steering with adjustable wings and ballast. The devices would upload data to satellites several times a day and receive new instructions. Many of those attributes now exist in drifting sensors called PALACEs (Profiling Autonomous Lagrangian Circulation Explorers), first deployed in 1990 by oceanographer Russ Davis of The Scripps Institution of Oceanography in La Jolla, California. Resembling small compressed-gas cylinders, PALACEs regularly record temperature and salinity in the upper 2000 meters of the ocean. They ascend and descend through the water on timed cycles, when pumps adjust the volume of oil between internal reservoirs and inflatable bladders.

Roving recorders. Gliders can spend months in the open ocean, tracing circulation patterns.

CLAYTON JONES, IWRC

"These floats allow us to get a large number of [sensors] into the ocean relatively inexpensively," says Davis. Hundreds of PALACEs are tracing circulation patterns in the Atlantic, Pacific, and Indian Oceans, relaying data to satellites when they pop to the surface. They also track basin-scale events, such as the annual sinking of cold water in the North Atlantic—part of a "conveyor belt" of heat exchange between the tropics and high latitudes (see story on p. 156). PALACEs have even revealed a new current in the Labrador Sea.

Although today's floats drift with currents, teams led by Davis and two others—Charles Eriksen of the University of Washington, Seattle, and Douglas Webb of Webb Research Corp. in East Falmouth, Massachusetts—are designing steerable gliders for coastal and open-ocean research. Some of the gliders propel themselves by tapping energy from the temperature differential between shallow and deep waters. Scientists could send such devices to specific regions to monitor hydrothermal vents, plankton blooms, and other phenomena, thus fulfilling Stommel's prophecy a decade or two ahead of time.

Swimming lessons. MBARI scientists test *Tiburon*, their snazzy new ROV.

GREG PIO/MBARI

Gliders could roam the waters indefinitely, but the robotic subs called AUVs are already making shorter forays, exploring the sea floor and water column without the expense and potential danger of putting scientists into heavy submersibles. However, the going price of AUVs—about $50,000 for small units to more than 10 times that for fully loaded, Cadillac-class vehicles—means their inventors have hesitated to send them on unsupervised journeys where they might vanish or get damaged. "We're still like a father who has given his son his first car," says WHOI engineer Chris von Alt. "We're willing to let them drive around the block but not much farther."

Cost is not the only factor holding back AUVs. Accurate navigation is the "Achilles heel" for today's vehicles, especially in deep water, says James Bellingham of the Massachusetts Institute of Technology, a leader in AUV development. "Full autonomy is the exciting research frontier, but we're not there yet," he says. Docking systems, still being refined, would extend the range of AUVs by providing fresh charges of power away from the ship. Even so, the Odyssey IIb AUVs developed by Bellingham's group have collected data during 18 field deployments in the last several years, including a recent study of how cold surface waters mix with deeper water in the Labrador Sea (*Science*, 17 April, p. 375). This spring, the vehicles also measured how sound scatters off the Mediterranean sea floor—a U.S. Navy–funded project for locating mines and other buried objects.

Oceanographers can also gather data using observatories that stay put and study what the currents bring. Beneath the swells some 9 kilometers off the coast of Tuckerton, New Jersey, is the Long-Term Ecosystem Observatory, also known as LEO-15. According to project director Fred Grassle of Rutgers University in New Brunswick, New Jersey, the remotely controlled observatory—a truncated stainless-steel pyramid that sits in water 15 meters deep—is the first of its kind. A cable from shore powers a suite of biological, chemical, and physical sensors, as well as a winch to ferry instruments up and down. Within a year, small AUVs called REMUS (remote environmental monitoring units), created at WHOI, will dock at LEO-15 and periodically scout the nearby sea floor. "We want to know everything about a 100-kilometer-square area of generic continental shelf," Grassle says. "This observatory is doing the kind of research we haven't been able to do until now," he adds, because moving platforms and randomly timed surveys miss fine-scale details.

Deployed in August 1996, LEO-15 has tracked seasonal upwellings near the coast. Cold, nutrient-rich water rises during the summer every time sustained winds blow from the southwest and push warm surface water offshore. Gyres of upwelled nutrients form on the lee sides of sea-floor mounds; LEO-15 watches how and under what conditions these gyres trigger plankton blooms. During storms that stir this nutrient pot even more, LEO-15 continues to make observations—a valuable resource when the seas are too risky for boat surveys, Grassle says.

Another pioneering nearshore observatory is Aquarius, an undersea lab in the Florida Keys National Marine Sanctuary. Teams of scientists spend up to a week inside the lab at a depth of 20 meters, studying nearby coral reefs. "Some of the most exciting research has come from staying in place and making long-term observations," says G. Michael Purdy, director of NSF's Division of Ocean Sciences.

Funding tide is turning. Despite the promising new instruments, a disquieting undercurrent is rippling through the oceanographic community. Researchers see a waning of long-term commitments by federal agencies to fund instrumentation, says Scripps Institution of Oceanography director Charles Kennel. A federal infusion of $24 million, announced in Monterey last month at the National Ocean Conference by Vice President Al Gore, will help a few projects (including LEO-15 and Aquarius) during the next several years but won't meet the field's larger needs, researchers at the conference agreed.

Although oceans pose research challenges similar to those of space, Kennel maintains, federal agencies approach the two frontiers

Sensing the Sea Without Breaking the Bank

NASA may have pioneered the trend toward "faster, cheaper, better" with its Discovery space missions, but ocean scientists faced with budget cuts for new instrumentation (see main text) have adopted that mantra, too. Innovative tools at relatively low cost are surfacing throughout the United States, as researchers develop technology that their colleagues elsewhere can adapt and use.

One example of oceanography on the cheap is the $5000 "OsmoAnalyzer," a compact device that, from a buoy, measures concentrations of dissolved nitrate for up to 3 months. The instrument requires little power, as osmotic pressure pumps seawater droplets into a detection chamber every 15 minutes. Newer models will test for phosphate, iron, and other nutrients. "Everyone is clamoring for in situ chemical instrumentation, because samples change quickly when removed from their environment," says OsmoAnalyzer developer Hans Jannasch of the Monterey Bay Aquarium Research Institute (MBARI). A companion tool, the "OsmoSampler," slowly draws a year's worth of water samples into a single tube a millimeter wide and up to 2 kilometers long, allowing researchers to gauge chemical changes at one site over time without returning to collect many separate batches. Ultraslow collection rates prevent the samples from diffusing into each other.

JOHNS HOPKINS UNIVERSITY

Also in the pennies-per-kilobyte category is a sensor for spotting harmful algae blooms in their earliest stages. MBARI molecular biologist Chris Scholin and colleagues at Saigene Corp. in Redmond, Washington, have devised a $7500 "dipstick" test that identifies RNA sequences unique to each toxic species. In a small water sample, detergents and heat break open cells. Fluorescent molecules latch onto particular phytoplankton RNA strands to identify killer species. Last May the probe spotted a nascent diatom bloom near Santa Cruz, California. The same diatom had killed hundreds of Monterey Bay seabirds in 1991; this time health officials were able to track the bloom down the coast, where it apparently killed birds and sickened sea lions. Although researchers still don't know what drives these blooms, says Scholin, "early warnings can go a long way toward mitigating potential problems."

World in a bottle. New holographic camera maps a microscopic universe (including this diatom, *left*) in a small cylinder of ocean water.

Two new devices across the continent aren't quite as low budget, but they've opened research windows as effectively as high-priced ROVs. University of Maryland scientists use the $150,000 "ScanFish," a towed, batlike fin crammed with instruments, to monitor the Chesapeake Bay's ecology (see p. 196). And a team at Johns Hopkins University and the University of Rhode Island (URI), Narragansett, has developed a submersible "holocamera" that uses holography to image all particles in a cylinder of water about the size of a can of spray paint. The camera yields precise three-dimensional positions and velocities for hundreds of thousands of particles. "Holography is the only tool that gives us both of those measures at scales from centimeters to microns," says URI's Percy Donaghay. A better grasp of how plankton and other particles move in response to small-scale turbulence, he says, will help researchers understand the base of the sea's vast food web.

–R.I.

far differently. "At NASA, there is a close understanding of the relationship between technology development and the ability to do science in the future," says Kennel, a former associate director at NASA. "I don't see a similar strategy in ocean technology." Marine geophysicist Fred Spiess of Scripps, who has developed instrumentation since the early 1950s, goes further: There is "no question," he contends, that funding is being squeezed to the point where ocean science suffers.

"Funding ocean instrumentation is a really tough job," says Mel Briscoe, director of the Processes and Prediction Division at the Office of Naval Research (ONR). "A normal 2- or 3-year proposal will barely get you started, and both the funder and the scientist have to be prepared for a long series of failures." Of the agencies that fund most instrumentation development—ONR, NSF, and the National Oceanic and Atmospheric Administration—the Navy has traditionally been the most willing to provide long-term support, says MBARI's McNutt. ONR, Briscoe maintains, is "perhaps singular" in its willingness to fund risky proposals and to encourage technology transfer from military applications to the research community.

Since the end of the Cold War, however, ONR's support for new instrumentation has dwindled, McNutt and others contend. Last year ONR spent $102 million on basic ocean science, compared to $98 million in 1990. "In inflated dollars, our budgets are smaller," Briscoe acknowledges. As a result, he says, "I don't think we are seeing as much instrumentation development." Briscoe adds that ONR'S funding emphasis shifted away from the open ocean to the coastal zone as the Navy's priorities changed at the end of the Cold War. Although ONR still supports AUV programs, nearshore observatories, and other select technologies, says Robert Gagosian, director of WHOI, researchers in fields such as acoustics and deep-sea research may feel left out to dry.

Despite its own flat budget for instrumentation, NSF is trying to fill the gap, says H. Lawrence Clark, who directs the agency's Oceanographic Technology and Interdisciplinary Coordination Program. Clark's program provides $4.5 million a year—about one-third of the agency's budget for ocean technology—as dashes of "venture capital" for projects that might otherwise fall through the cracks. And MBARI thrives because of its founder, the late electronics pioneer David Packard, whose gifts of more than $200 million endowed big-ticket items such as the *Western Flyer* and *Tiburon*.

The notion that private patronage is becoming more important in keeping ocean technology afloat makes Gagosian, for one, uncomfortable. "If we don't succeed in funding the instrumentation we need now with federal support, we will miss a window of opportunity unique to our generation," he says. "We have learned the scientific questions to ask, but we may lose the technical experts. They'll leave oceanography and go where the challenges are." **–ROBERT IRION**

Robert Irion is a science writer in Santa Cruz, California.

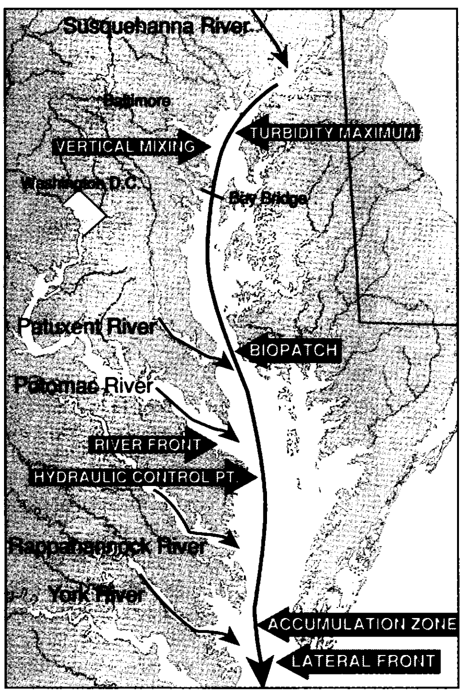
Stirring Up the Chesapeake's Cradle of Life

NEWS

Scientists are teasing out how the bay's currents and crannies create lavish nurseries for fish

Some say the best beachcombing spot along the Chesapeake Bay lies at the tip of its Eastern Shore, just north of where the bay spills into the Atlantic Ocean. Now that corner of the Chesapeake is drawing notice for a reason other than the fishing lures and driftwood that litter the sand there. Last year, Raleigh Hood, a biological modeler at the University of Maryland's (UMD's) Horn Point lab in Cambridge, proposed that everything from flotsam to plankton should be pulled together, like soap scum in a draining bathtub, by a 16-kilometer-wide eddy near the bay's mouth. At first Hood's colleagues were skeptical—his prediction, after all, relied on an error-prone mathematical model. Then last year, Hood says, scientists began tracking scads of jellyfish and anchovy larvae "right smack dab in the middle" of that part of the bay.

Hood and others now suspect that the eddy creates oases of tiny plants and animals that nourish fish and crustaceans. "It took some observations to wake us up," says Bill Boicourt, a UMD physical oceanographer. The area has joined a list of probable ecological hot spots in the Chesapeake now being studied in a 6-year, $3 million National Science Foundation (NSF) project called Trophic Interactions in Estuarine Systems (TIES). The project is testing the idea that an estuary's physics—its bumps and crevices and complex flows of fresh and salt water—largely explain why fishery yields in the Chesapeake and other bays are so much higher than in lakes and the open ocean. "People talk about it all the time," says estuarine ecologist John Day of Louisiana State University in Baton Rouge. "But careful documentation is lacking."



Mixing it up. At several spots in the Chesapeake Bay, swirling currents and unique topography create unusually rich ecosystems.

SOURCE: UMD

TIES has already changed how scientists view estuaries. So far, the group has documented the forces that sustain one of the bay's nutrient mixing areas, termed convergence zones, and even discovered the unexpected new zone near the bay's mouth. Figuring out why the Chesapeake teems with seafood may have a practical payoff, too. It could help agencies make better fishery-management decisions, such as where to dredge channels and how to clamp down on the surfeit of nitrogen and phosphorus running into the bay—nutrients that, at high levels, can fuel phytoplankton blooms that deplete the water's oxygen and kill fish.

The project, part of NSF's Land Margins Ecosystem Research program (see sidebar), traces its roots to studies in the 1960s that hinted at the importance of mixing zones such as turbidity maxima, where fresh river water collides with tide-driven brackish water, whipping up sediments chock-full of zooplankton and detritus. "There's 10 times, 100 times the ambient concentration of food, and that's where you're able to outgrow the competitors," UMD's Mike Roman says. But studies on turbidity maxima in the San Francisco Bay and the St. Lawrence River, for instance, focused mainly on the food pyramid's base, such as plankton and fish larvae, says microbial ecologist Tim Hollibaugh of the University of Georgia, Athens. TIES, launched in 1995, is moving the science up the food chain by exploring how local flow patterns caused by