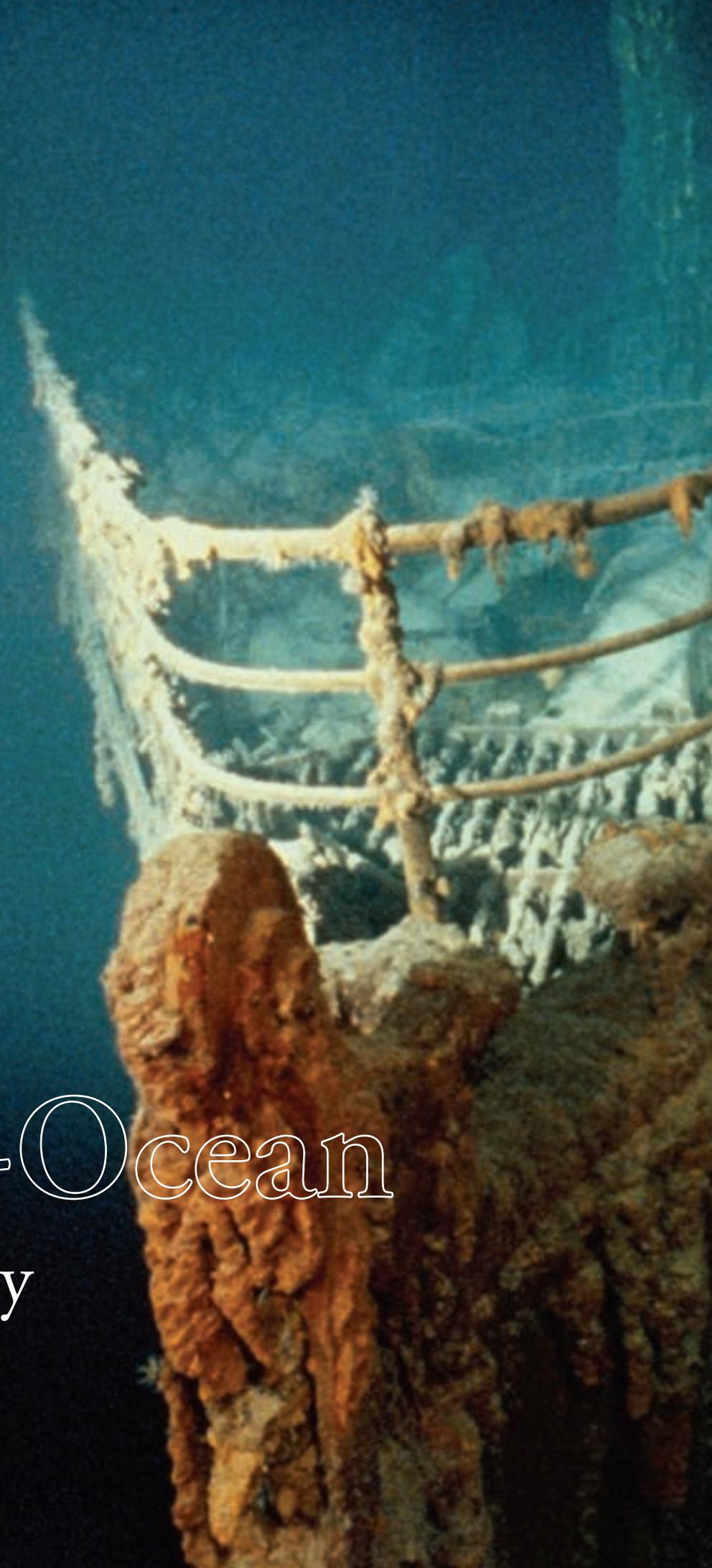
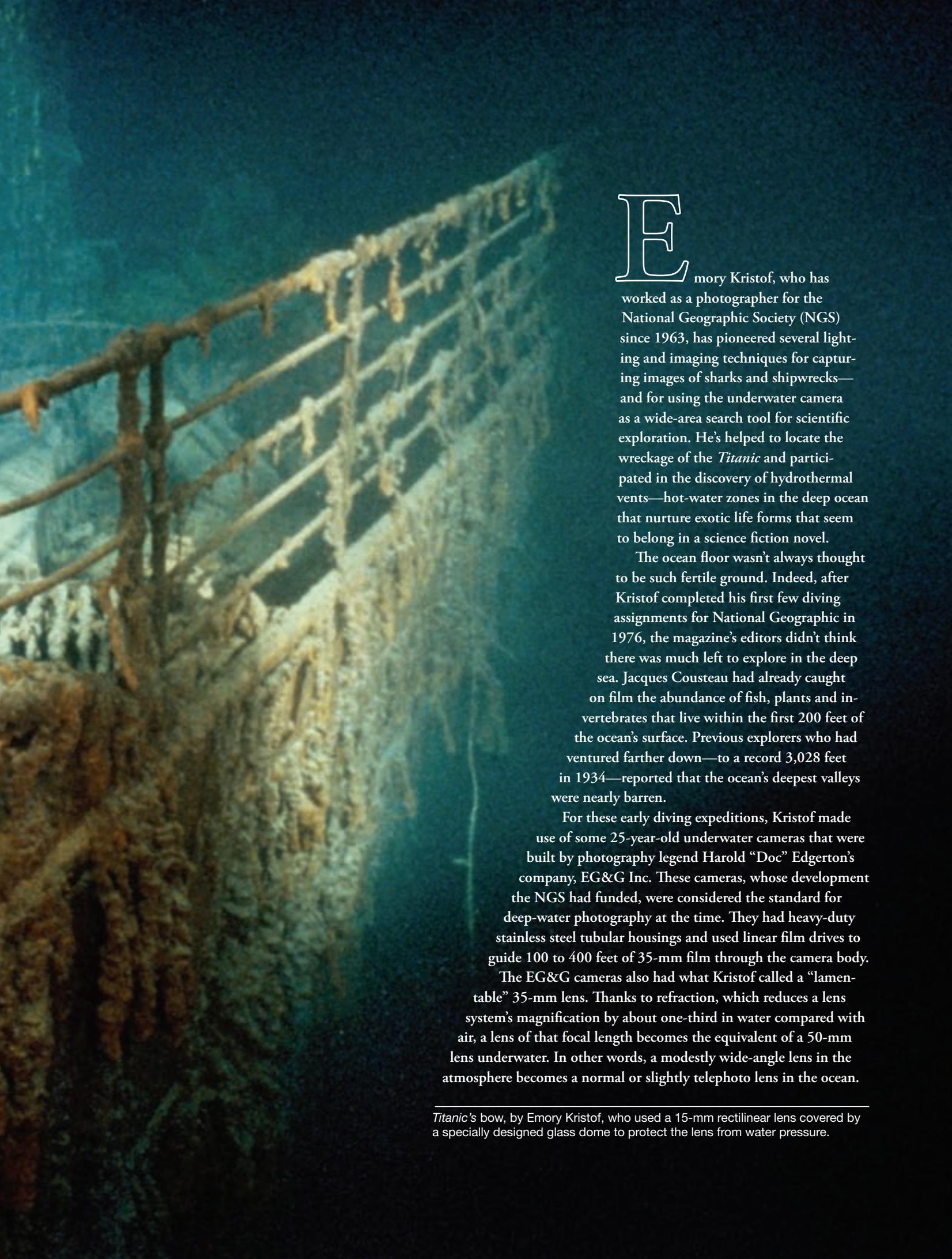


The deep ocean is characterized by extreme pressures, toxic temperatures and total darkness. Using optics, Emory Kristof, one of the National Geographic Society's pioneering undersea photographers, helped develop imaging and video equipment that can operate in these harsh conditions, opening the door to discovery in one of the most fascinating—and inaccessible—places on Earth.

Secrets of Deep-Ocean Photography

Patricia Daukantas





Emory Kristof, who has worked as a photographer for the National Geographic Society (NGS) since 1963, has pioneered several lighting and imaging techniques for capturing images of sharks and shipwrecks—and for using the underwater camera as a wide-area search tool for scientific exploration. He’s helped to locate the wreckage of the *Titanic* and participated in the discovery of hydrothermal vents—hot-water zones in the deep ocean that nurture exotic life forms that seem to belong in a science fiction novel.

The ocean floor wasn’t always thought to be such fertile ground. Indeed, after Kristof completed his first few diving assignments for National Geographic in 1976, the magazine’s editors didn’t think there was much left to explore in the deep sea. Jacques Cousteau had already caught on film the abundance of fish, plants and invertebrates that live within the first 200 feet of the ocean’s surface. Previous explorers who had ventured farther down—to a record 3,028 feet in 1934—reported that the ocean’s deepest valleys were nearly barren.

For these early diving expeditions, Kristof made use of some 25-year-old underwater cameras that were built by photography legend Harold “Doc” Edgerton’s company, EG&G Inc. These cameras, whose development the NGS had funded, were considered the standard for deep-water photography at the time. They had heavy-duty stainless steel tubular housings and used linear film drives to guide 100 to 400 feet of 35-mm film through the camera body.

The EG&G cameras also had what Kristof called a “laminatable” 35-mm lens. Thanks to refraction, which reduces a lens system’s magnification by about one-third in water compared with air, a lens of that focal length becomes the equivalent of a 50-mm lens underwater. In other words, a modestly wide-angle lens in the atmosphere becomes a normal or slightly telephoto lens in the ocean.

Titanic’s bow, by Emory Kristof, who used a 15-mm rectilinear lens covered by a specially designed glass dome to protect the lens from water pressure.

To cover more ocean bottom in each image, Kristof started using camera lenses with shorter focal lengths than the old ones: first a 28-mm, then a 16-mm “fish-eye” lens and finally a 15-mm lens with rectilinear correction.

“The water actually corrected a lot of the barrel distortion that you get in a fish-eye,” Kristof said. A 16-mm fisheye lens, used with 35-mm film, has a 180-degree-diagonal field of view in the atmosphere; however, the image it projects onto flat film suffers from severe barrel distortion, in which horizontal and vertical lines appear to bulge toward the edges of the image. (See figures at top right.)

Under the ocean’s surface, the water acts as a negative lens and counteracts much, though not all, of the fisheye distortion. Short-focal-length lenses thus let Kristof survey a much bigger area than he could with longer lenses—an important consideration when searching for missing ships or uncharted features of the sea bottom.

Early in his diving career, Kristof also realized that photographers and researchers needed a better way to locate what

they had already imaged, so that they could return to an object or area they had found earlier for further examination while still at sea. At that time, divers had to wait until they returned ashore to develop and print their film. This time delay reduced the effectiveness of a search for an unknown target.

By using color slide film, which produces positive instead of negative images, Kristof was able to develop film and look at the results right aboard ship. The NGS photo engineering staff built a special projector through which divers could view the rolls of Kodak Ektachrome slide film as soon as they were developed. Sam Raymond, a former Edgerton student who founded the underwater camera company Benthos Inc., also outfitted one of his company’s cameras with a modified first-generation LED watch, which yielded more precise 24-hour timing than the analog watches used in earlier deep-sea cameras. (The watches were used to

Emory Kristof and National Park Service divers

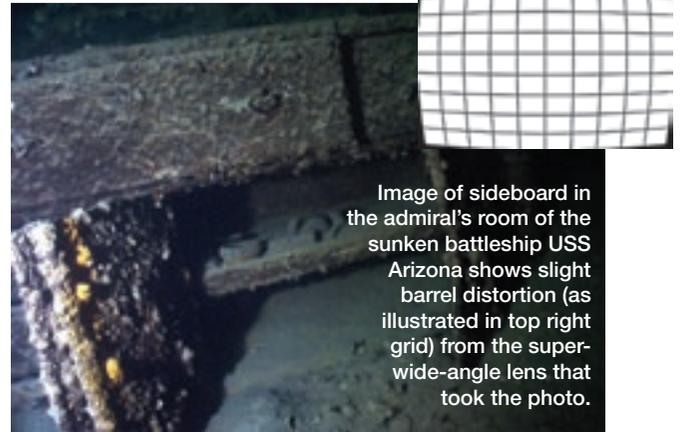


Image of sideboard in the admiral's room of the sunken battleship USS Arizona shows slight barrel distortion (as illustrated in top right grid) from the super-wide-angle lens that took the photo.

determine the location where an image was taken by synchronizing the time of the photograph with coordinates taken by acoustic transponders on the ocean bottom.)

One of the first things that Kristof built at the NGS was a small armored camera designed to photograph the submersible *Alvin* at a depth of 10,000 feet. The camera took the lead photo for famed oceanographer Robert D. Ballard’s 1976 *National Geographic* story on the Cayman trough.

Hot-water vents

In 1977, Kristof joined Ballard’s search for hot-water vents in the Galápagos Rift. Ever since the development of plate tectonics theory in the 1960s, oceanographers and geologists had hypothesized that such hydrothermal vents would crop up wherever large plates of territory were moving apart underwater. Molten rock from Earth’s mantle would rise up through the gaps between the plates, forming underwater ridges and mountains. The cooling rock would crack, providing places where cold ocean water could heat up and rise and fall like geysers on land.

Most oceanographers had thought they could find the vents by measuring heat flow near the ocean floor. However, that method didn’t work because the heat dissipates too quickly. “The bottom of the ocean is a big heat sink,” Kristof said. Even vents issuing water as hot as 800° F would be hard to detect thermally due to rapid heat loss into the surrounding cold water—which is typically about 34° F.

Ballard had the idea to look for the vents using photography. His team, aboard the research vessel *Knorr* from the

Emory Kristof, Richard Cole and Keith Moorehead

A predator fish lunges for its prey amid flecks of “marine snow.”



Woods Hole Oceanographic Institution (WHOI) in Massachusetts, was allocated 15 percent of the expedition's total exploration time to tow a camera sled over the ocean bottom, some 2,500 m or more below sea level. The rest of the exploration time was allocated to geologists and geochemists.

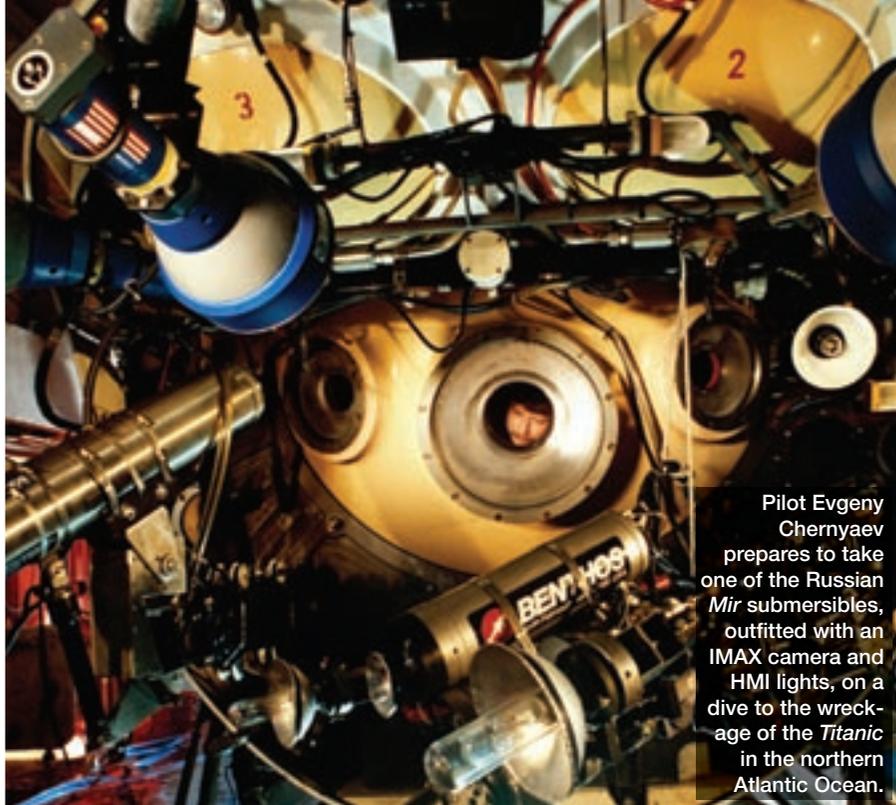
Not only did Ballard's team find what they were looking for, they found—to their great surprise—that the vents were teeming with life. The photos from the team's 35-mm still cameras revealed a throng of white clams where scientists had expected to see barren lava rock. Until the Galápagos expedition, researchers had thought that all deep-ocean animals were scavengers that lived off of dead biomass falling down from shallower waters that sunlight could still penetrate. Photosynthesis—the process by which plants convert solar energy into sustenance—was thought to be a required step in all food chains. Everything on Earth was believed to “eat toward the sun.”

Yet Kristof's photography for Ballard's team documented the existence of a whole ecosystem of brightly colored tube worms, clams, shrimp, fish and other creatures living in the hydrothermal vent. They were all feeding off an entirely different type of food chain that began with never-before-seen microbes that derive their energy from the mineral-rich sulfides spewing from the vents rather than from photosynthesis. In other words, these deep-sea creatures were “eating toward the center of the Earth,” Kristof said. Biologists ultimately classified several hundred new chemosynthetic species living in or near the vents.

“Up until 1977, we had missed over 50 percent of the biomass of the planet,” Kristof said.

Delicate sea animals

Lawrence P. Madin, a marine biologist and director of WHOI's Ocean Life Institute, studies deep-sea jellyfish and other creatures that are fragile and lack bony skeletons or shells. There's no real



Pilot Evgeny Chernyaev prepares to take one of the Russian *Mir* submersibles, outfitted with an IMAX camera and HMI lights, on a dive to the wreck-age of the *Titanic* in the northern Atlantic Ocean.

way to record the existence of such flimsy, gelatinous creatures without imaging technology, he said; their bodies can burst when brought up to a low-pressure environment. “They don't do too well with gravity,” Madin said.

Video imaging allows researchers to study how such creatures interact with their environment and one another. “You really want to know what they look like and how they act,” said Madin. Characteristic postures and swimming methods provide important clues to animal behavior—details that can only be captured with photographic methods. Other methods of studying organisms, such as trawling, will capture some specimens for genetic analysis, but the nets yield mostly dead animals; any creatures that manage to survive don't look anything like they did in the water, according to Madin.

Moreover, approaches such as trawling or the collection of water samples don't reveal what the ocean itself truly looks like. Seawater is filled with so-called “marine snow”: dead bits of plants, animals and other detritus. “That's everywhere in the ocean,” Madin said. Photographic images show the gelatinous animals in their natural, “snowy” surroundings. (See photo on p. 24, bottom left.)

Photography is important to oceanography for another reason: Researchers can assemble pictures into a detailed mosaic of wide-area vistas of the sea floor. Short

of taking all the water out of the ocean, researchers would have no other means of viewing the marine world in that way.

In 1979, Kristof and his collaborators made television history when they filmed a documentary about the deep ocean using a then-new technology called the charge-coupled device (CCD). Conventional tube-based television cameras of the 1970s could be made no narrower than 13½ inches in width; once encased in half-inch-thick steel to withstand deep-ocean pressures, such a camera would have weighed hundreds of pounds, Kristof said.

By contrast, the RCA CCD camera, packaged in a stainless-steel tube by Benthos, was only 4 inches wide, so it could easily ride on *Alvin's* exterior. Kristof's camera work was showcased in the Emmy-winning documentary “Dive to the Edge of Creation;” it was produced by NGS and WQED-TV of Pittsburgh. It was the first TV show filmed by a CCD camera.

Searching for the *Titanic*

By the late 1970s, Ballard and Kristof had set their sights on the “Mount Everest of the ocean”: the *Titanic*. Since 1912, the famous luxury liner had lain at some unknown spot below two miles or more of the North Atlantic. During a 1977 lecture at the NGS, Ballard predicted that the *Titanic's* resting place would be found



Tim Marzoff

Wearing a special viewfinder, photographer Emory Kristof directs the *Pisces VI* submersible, owned by International Underwater Contractors, during an exploration of sharks in Bermuda with biologist Eugenie Clark.

within 10 years. Thanks to imaging technology, he found the lost ship in eight.

Other explorers had hoped to find *Titanic* with sonar or magnetometers. Ballard and Kristof had the idea to use a low-light-level black-and-white TV camera, also known as a silicon-intensified-target (SIT) camera, which was as fast as the film-speed rating ASA 200,000. The SIT camera could scan half an acre at a time in deep ocean water. To carry the camera, Ballard got funding from the Navy to build a camera sled, named *Argo*, that could transmit SIT-camera images to the surface ship in real time.

Kristof was part of the Ballard-led American-French team aboard the *Knorr* that found the *Titanic* on Sept. 1, 1985. The *Argo's* first images from the sunken ship showed a boiler and other wreckage from the debris field between the separated bow and stern of the once-mighty vessel.

A few years after the discovery of the *Titanic*, Kristof joined with Canadian filmmaker Stephen Low to do an IMAX film, "Titanica," on the ship's wreckage. To create dramatic camera angles and lighting effects, they needed two piloted submersibles, and so they hired the Russian subs *Mir I* and *Mir II*.

The IMAX project made heavy use of another of Kristof's innovations: a special type of lighting designed to shine in the

ocean's nether regions where sunlight never does. The previous standard in underwater photography had been incandescent quartz lighting. Seeking greater efficiency, Kristof started using a type of ballasted lamp called HMI, which gets its name from the mercury (Hg) metallicized iodized salts that power it. HMI lights are four or five times more energy-efficient than their incandescent counterparts, so they can brighten the bleakest depths without draining the batteries of a piloted submersible or remote-controlled robot.

HMI lights have a color temperature of 5,600 K, which is close to that of daylight, Kristof said. (Color temperature is a measure of a light source's color.) With a color temperature of around 3,200 to 3,400 K, incandescent lights appear redder than HMI ones. Thanks to Rayleigh scattering, blue light carries farther through water than red light, making HMI more suited to deep-water work. Sometimes, though, Kristof will add a few incandescent lights to his submersible rig in order to highlight objects or animals in the foreground.

For the "Titanica" filming with the relatively slow IMAX cameras and lenses, Kristof and Low arranged eight 1,200-W HMI lights on booms attached to the sides of the *Mir* submersibles to distribute them away from the camera's optical axis. Together the eight lights were equal to

100 kW of incandescent lighting, and Kristof was able to shoot additional still photos with the HMI lights and ASA 1600 film without the need for strobe lights. For some shots, Kristof had one of the submersibles backlight the sunken ship's wreckage while he filmed the debris from the other sub.

Rovers take the pressure

Kristof started experimenting with using remotely operated vehicles (ROVs) in the early 1980s in an effort to find a lower cost alternative to piloted submersibles.

The first ROVs cost \$250,000 or more and were built for oil companies and the military. Chris Nicholson, president of Deep Sea Systems International Inc. of North Falmouth, Mass., thought he could build an underwater robot for a tenth of that cost.

The first mini-rover, which Nicholson's company built shortly after its 1983 founding, was designed to be carried around in a suitcase, yet could dive to 500 feet. "Prior to this, there was no way to do it other than with big equipment and big ships," Nicholson said, adding that, for a small rover, it carried a good-quality camera.

Since that first product, Nicholson has seen the market for camera-carrying marine ROVs expand beyond scientific research. Public-safety workers use the robots to search for lost bodies, inspect ships and piers below the waterline and go thousands of feet into tunnels.

Still, Nicholson noted, the rovers have influenced research by allowing scientists to stay down in the water for days at a time, instead of surfacing every few hours like scuba or submersible divers. "It's changed their whole understanding of the environment and the creatures that live in it, because they could stay down there with remote technology," he said.

The ocean is an unforgiving environment that requires engineers to be conservative and methodical in their approach, Nicholson said. "You need to test everything, because you don't get a second chance."

Nicholson said his engineers don't rely on only one manufacturer's cameras and lenses. Rather, they subject several systems to side-by-side tests on the lab bench to compare their performance.

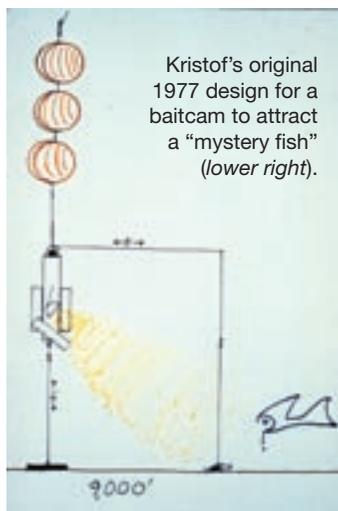
Fiber optics plays an important role in underwater ROV systems by providing multiple high-bandwidth communications channels between shipboard researchers and their camera-toting robots. Nicholson said that some of his company's ROVs have had as many as six single-mode optical fibers inside their umbilical cable, protected by stainless steel buffering tubes.

Ropcams and baitcams

From his animal-photography experience on dry land, Kristof got the idea to use a submersible as a baited blind to hunt deep-sea animals with a camera. That resulted in the 1986 *National Geographic* article "Sharks at 2,000 Feet," with Eugenie Clark, who was a University of Maryland biologist at that time.

"I wanted to treat these animals like those on the Serengeti Plain," Kristof said. Photographers don't look for wildebeest in a Land Rover with lights blazing and a honking horn, he reasoned, so why would oceanographers choose equipment that is disruptive to marine life?

In 1995, Kristof also developed the "ropcam" as an alternative to expensive piloted submersibles. Ropcams are cameras attached to a 5/16-inch polypropylene rope that costs about \$20 for 600 feet. Kristof has dropped baited ropcams down more than two miles into the sea to photograph sharks and other deep-water



subjects for a fraction of the cost of a piloted submersible.

Obviously, animals that are accustomed to constant darkness probably don't appreciate a camera that shines a bright, steady light. However, with ropcams, "I'm sure the flash is so quick that the animals don't really know what it is," Kristof said.

New sea-life inventory

Kristof's next expedition is the Inner Space Speciation Project, a vertical inventory of marine life in the Indonesian archipelago. Several oceanic areas near Indonesia's islands have deep pools—15,000 to 17,000 feet below sea level—surrounded by comparatively shallow waters. Scientists believe that the pools are home to a greater diversity of aquatic animals than

can be found in other locations, including some species that exist nowhere else.

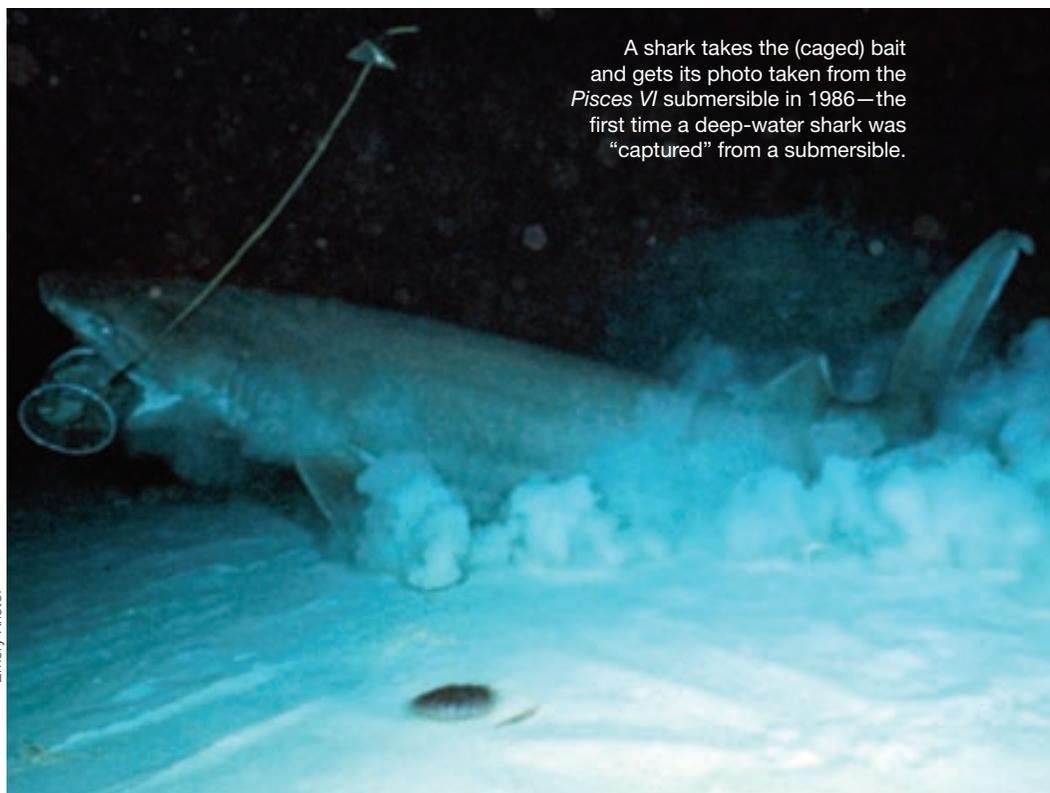
With funding from the National Oceanic and Atmospheric Administration, Kristof is journeying this fall to Indonesia with researchers from the Monterey Bay Aquarium Research Institute in California, the New England Aquarium and WHOI in Massachusetts, and the University of California at Los Angeles. The team is doing a six-week-long survey of the changes in animal populations at increasing depths—an approach that they had previously used to study the Monterey Canyon off California's coast. The researchers are using a combination of deep-water trawling, scuba diving, ROV photography and baited ropcams to compare the populations at three Indonesian locations.

No one knows how many previously undiscovered species will pop out of Indonesia's oceanic depths onto the photographic canvas of Madin, Kristof and their fellow explorers. But the voyage will surely uncover new information about the world's oceans and its inhabitants that will both expand current knowledge and thrill the imagination. ▲

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A shark takes the (caged) bait and gets its photo taken from the *Pisces VI* submersible in 1986—the first time a deep-water shark was “captured” from a submersible.