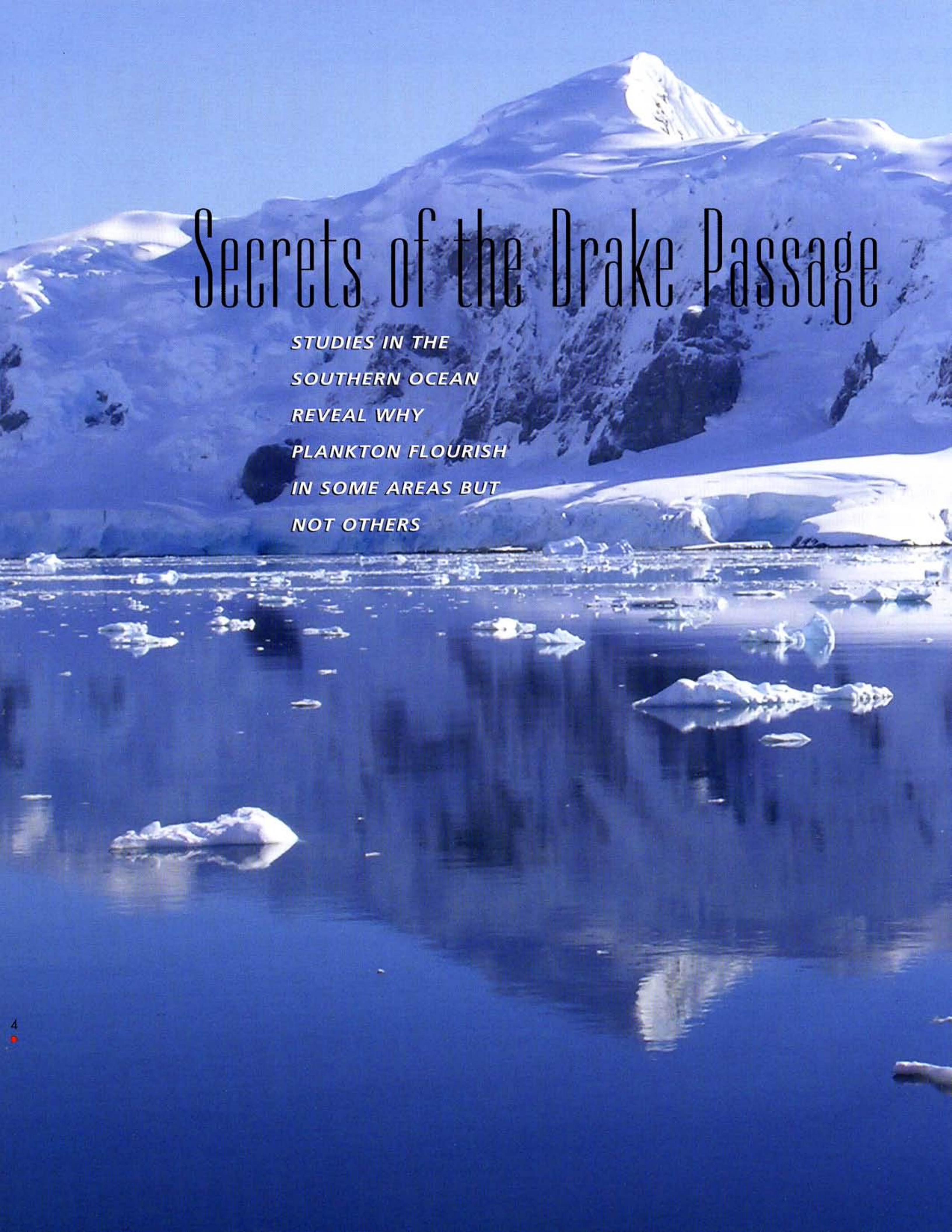
Secrets of the Drake Passage

STUDIES IN THE SOUTHERN OCEAN REVEAL WHY PLANKTON FLOURISH IN SOME AREAS BUT NOT OTHERS



BY CHUCK COLGAN

IF YOU WANT TO KNOW the best places to eat in the oceans, just follow the whales. They're connoisseurs of marine smorgasbords—where pods of large, hungry mammals can fill up on all the plankton and krill they can devour.

One of their favorite dining spots is the Scotia Sea, off the bottom tip of South America just east of the Drake Passage. Of course, whalers knew about this spot one hundred years ago, making South Georgia Island the largest whaling port of its time.

This is surprising because the ocean around Antarctica, for the most part, is rather barren, with low concentrations of plankton except in the summertime, particularly in Scotia Sea surface waters, when the sun shines for up to 24 hours a day and millions of tons of microscopic plant life, called phytoplankton, thrive. The low plankton mass in many regions is attributed to an inadequate supply of dissolved iron.

The days of large-scale, commercial whaling in Antarctic seas are over, but interest in plankton growth in the Southern Ocean has taken on a new twist. When phytoplankton bloom, they absorb carbon through photosynthesis, transferring tons of carbon dioxide from the atmosphere to the oceans. As the phytoplankton are eaten by zooplankton and other marine life, some of the carbon is incorporated into waste products from these animals that sink into deep waters in a process called the "biological pump."

Thus the question has arisen: If you fertilize the Southern Ocean with iron to increase plankton growth, could phytoplankton remove enough carbon from the atmosphere to reduce global climate warming? It's an intriguing idea, possibly with some merit, but as Scripps biological oceanographer Greg Mitchell points out, we simply don't know enough about the factors that regulate the Antarctic marine ecosystem to set about manipulating them safely.

The Southern Ocean is essentially a ring of water that encircles Antarctica. High winds and cyclonic storms blow from west to east around the continent, pushing the ocean in a clockwise circulation pattern. This Antarctic Circumpolar Current (ACC) is an important feature because it is the primary way by which water is exchanged between the Atlantic, Indian, and Pacific Oceans, making it a major component of the worldwide ocean–atmosphere climate system. In essence, it is like a giant kitchen mixer, taking water from each ocean, mixing it, and redistributing it back to each ocean.

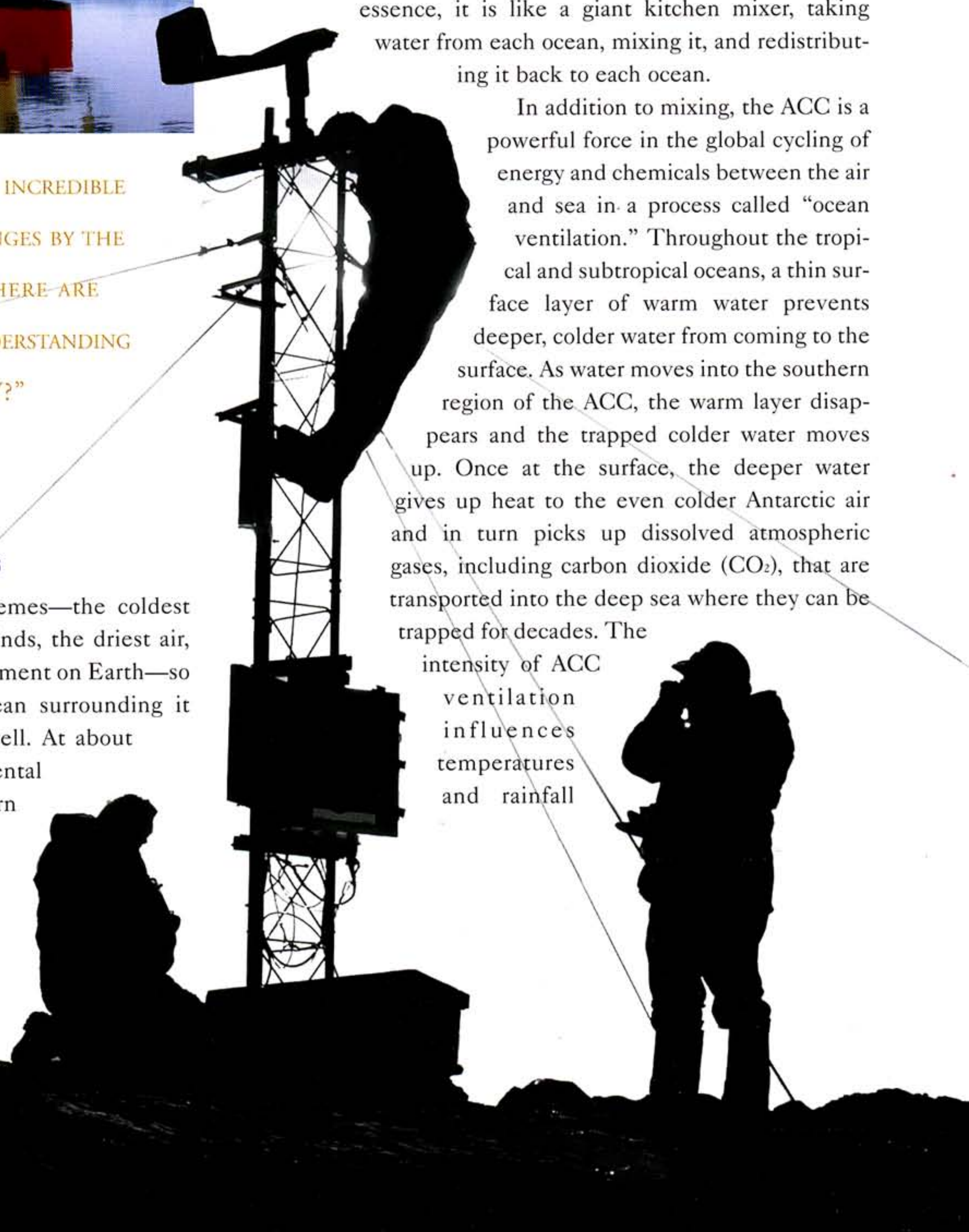
In addition to mixing, the ACC is a powerful force in the global cycling of energy and chemicals between the air and sea in a process called "ocean ventilation." Throughout the tropical and subtropical oceans, a thin surface layer of warm water prevents deeper, colder water from coming to the surface. As water moves into the southern region of the ACC, the warm layer disappears and the trapped colder water moves up. Once at the surface, the deeper water gives up heat to the even colder Antarctic air and in turn picks up dissolved atmospheric gases, including carbon dioxide (CO_2), that are transported into the deep sea where they can be trapped for decades. The intensity of ACC ventilation influences temperatures and rainfall

"THE DRAKE PASSAGE IS AN INCREDIBLE BODY OF WATER THAT CHANGES BY THE MINUTE. THEIR STUDIES HERE ARE OPENING THE DOOR TO UNDERSTANDING THE BIG QUESTION: WHY?"

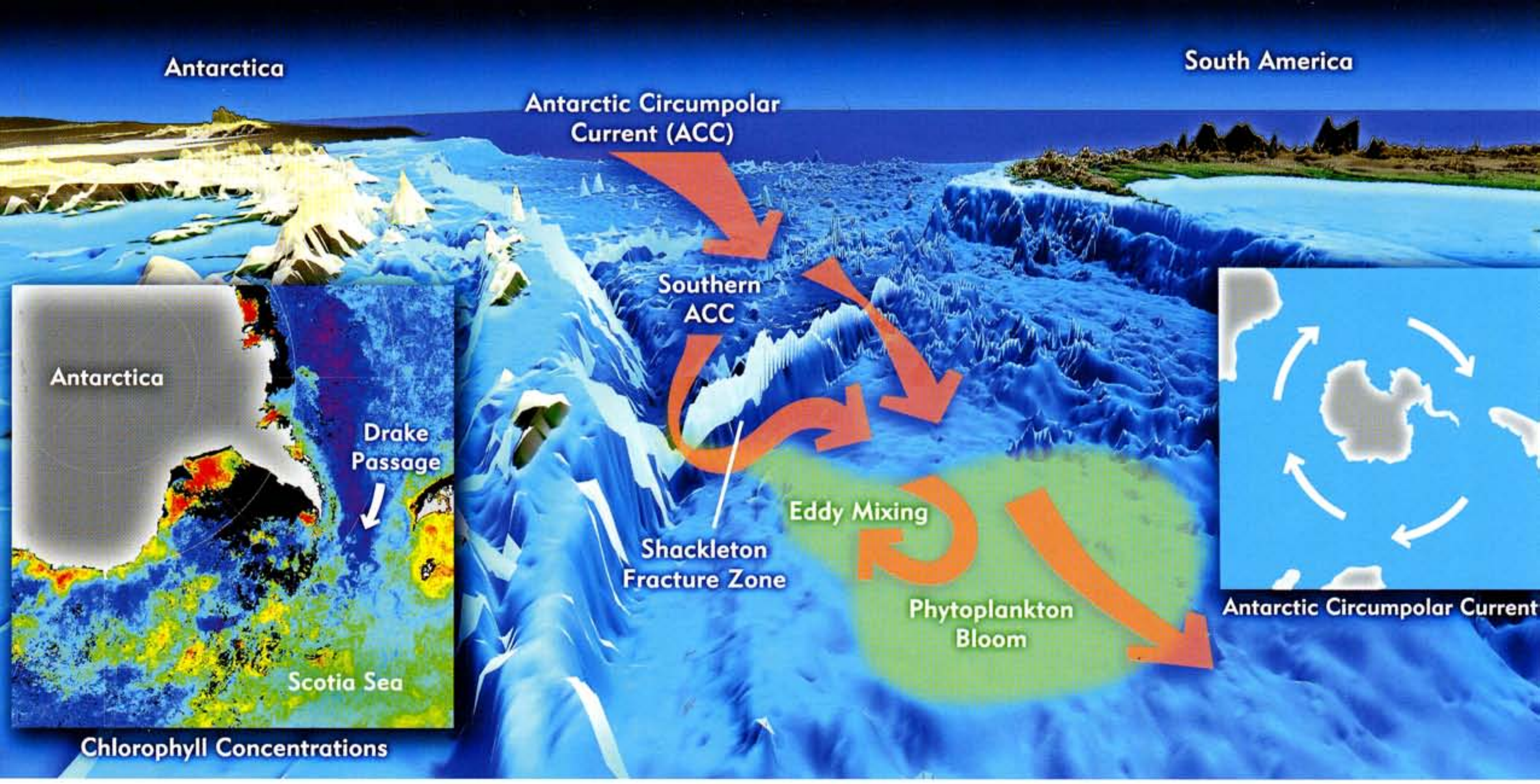
—MICHAEL TERMINEL, CAPTAIN
R/V *LAURENCE M. GOULD*

LAND OF EXTREMES

Antarctica is a land of extremes—the coldest temperatures, the highest winds, the driest air, and the most pristine environment on Earth—so it only follows that the ocean surrounding it would be extraordinary as well. At about twice the area of the continental United States, the Southern Ocean has the longest and fastest ocean currents and contains the coldest and the saltiest ocean waters.



Top left, *Research vessel* Laurence M. Gould *of the National Science Foundation's Office of Polar Programs is specially outfitted for polar conditions.* **Above,** *Members of the expedition repair a weather station on RACER Rocks near Antarctica. The weather station was installed in 1988 by Osmund Holm-Hansen and Greg Mitchell during their RACER project.*



Left inset, *A satellite image of chlorophyll levels in the Antarctic Circumpolar Current (ACC) surface waters shows low productivity (purple and blue) west of the passage and high levels (green, yellow, and red) in the Scotia Sea.* **Center,** *As the ACC narrows as it passes through the Drake Passage between South America and Antarctica, part of the flow is diverted south through a gap in the seafloor ridge, uplifting sediments rich in iron that promote seasonal plankton blooms.* **Right inset,** *The ACC is the only ocean current that flows uninterrupted by continents.*

worldwide and plays a major role in greenhouse warming.

THE BIOLOGICAL CONNECTION

Where the warmer surface waters from the north converge with the colder southern waters is a zone rich in plant nutrients necessary for photosynthesis and phytoplankton growth. There are only a few areas, however, where there are significant phytoplankton blooms—along the edges of the Antarctic continental shelf and near the Scotia Sea. Marine biologists know that continents provide iron via sediments and dust that fertilize plankton growth, but how is iron transported to the faraway Scotia Sea? Mitchell and his research collaborators think they might have an answer.

Oddly, it's possible for oceanographers to study the Southern Ocean's biological production from anywhere in the world, as long as they have an Internet connection. They can log onto databases of images from Earth-orbiting satellites that carry instruments capable of observing the ocean's surface color from space. The bluer the water, the less marine life there is; whereas if phytoplankton are plentiful, the water is green because of the absorption of blue light by pigments, primarily chlorophyll, within the tiny plants. Mitchell is a leader in developing the use of this satellite technology and was the NASA program manager responsible for implementing the first satellite mission for global ocean color scanning, called SeaWiFS, in the early 1990s.

Chris Measures (left) and his University of Hawaii team deploy a water-sampling rosette for trace metal studies.

Over the years, Mitchell has used data from SeaWiFS in his research at Scripps. While studying various time series of images, he became intrigued with the fact that low-chlorophyll water enters the Drake Passage from the west and emerges with high levels of phytoplankton productivity. His hypothesis was that the ocean bottom might hold the clue to what was happening at the surface. In February 2004, during the southern hemisphere's summer, Mitchell and an interdisciplinary group of scientists from Scripps, the University of Massachusetts, Boston, and the University of Hawaii went to the Southern Ocean to get a closer look.

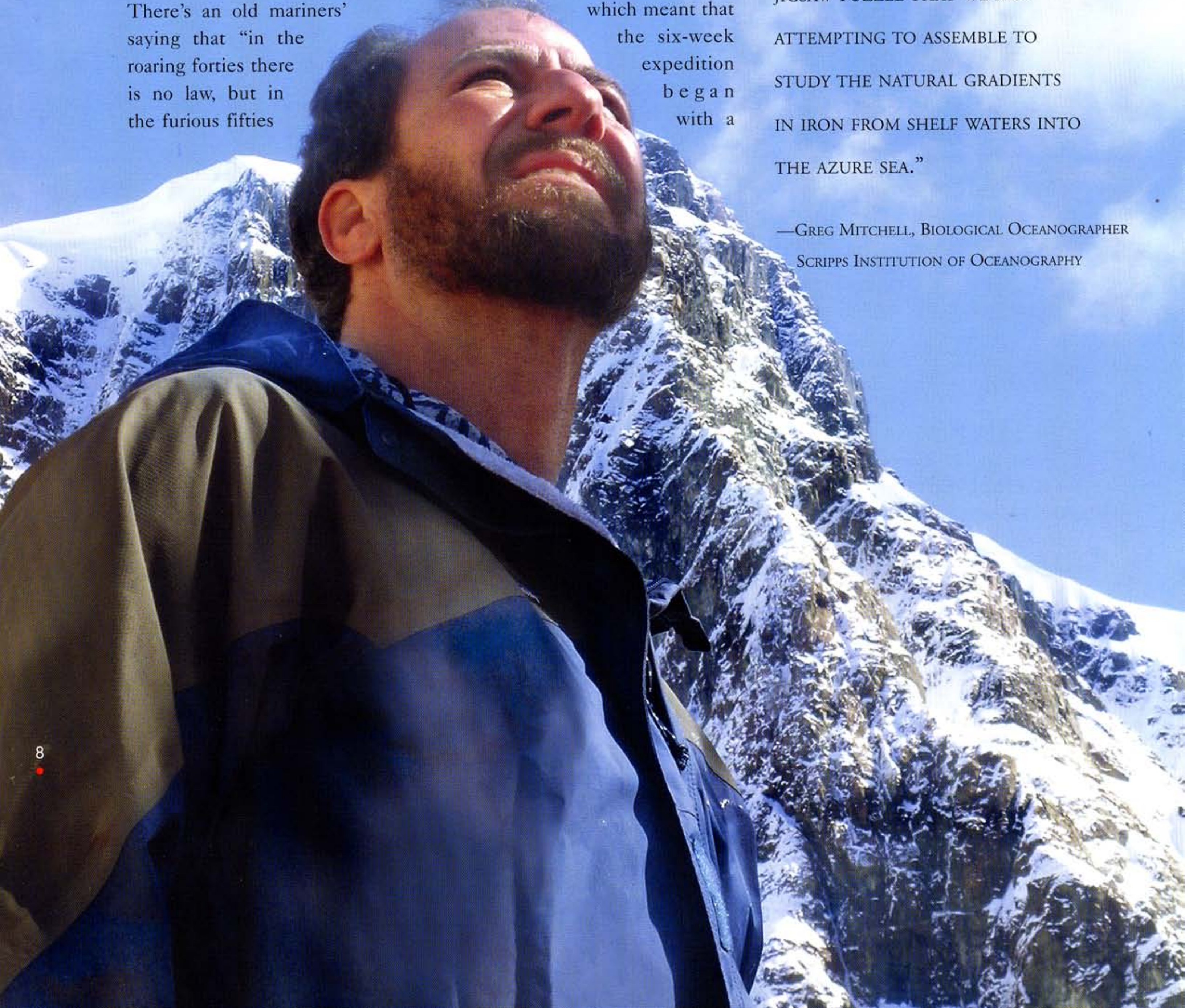
CROSSING THE FURIOUS FIFTIES

The strong winds that blow through the Drake Passage at a latitude of 50° south can make the ocean a hostile environment. There's an old mariners' saying that "in the roaring forties there is no law, but in the furious fifties there is no God." Just sailing into the Southern Ocean is worthy of respect.

Mitchell and the group headed out of Punta Arenas, Chile, onboard the ice-strengthened research vessel *Laurence M. Gould* of the National Science Foundation's Office of Polar Programs. A 76-meter-long (250-foot) ship, *Gould* is capable of multidisciplinary research year-round in the Southern Ocean. It is the support and supply ship for the U.S. research base on the Antarctic Peninsula, which meant that the six-week expedition began with a

"IT WAS MIDNIGHT AND MY BODY AND MIND WERE WEARY AFTER 18 HOURS OF WORK RELATED TO OUR INTENSIVE MAPPING OF A REGION WHERE WE HAD HYPOTHESIZED THAT SHELF WATER WOULD BE FLOWING OFFSHORE. . . . THE DATA WILL BECOME PART OF THE JIGSAW PUZZLE THAT WE ARE ATTEMPTING TO ASSEMBLE TO STUDY THE NATURAL GRADIENTS IN IRON FROM SHELF WATERS INTO THE AZURE SEA."

—GREG MITCHELL, BIOLOGICAL OCEANOGRAPHER
SCRIPPS INSTITUTION OF OCEANOGRAPHY



Greg Mitchell (right) with his research lab group from Scripps (left to right), Rick Reynolds, Nigel Delaney, and Haili Wang.

stop at Palmer Station.

During the next month, they sailed through and around the Drake Passage from west to east, conducting rapid surveys of the chemical, plankton, and hydrographic properties of the surface waters. They also set up a grid of sites for more detailed analysis of water conditions at various depths and collected phytoplankton samples for shipboard incubation experiments. Only a couple of times did the weather turn so bad that the ship had to find shelter behind an island to wait for sustained winds of 50-plus knots to subside.

"What we found was an abrupt change in chlorophyll near the Shackleton Fracture Zone, a prominent ridge in the southern Drake Passage," Mitchell said. "This suggests that the factors regulating phytoplankton biomass change dramatically near the fracture zone."

As part of the investigations, Christopher Measures from the University of Hawaii analyzed the concentration of metals—specifically iron, aluminum, and manganese—in water samples to determine where they came from. If there is a correlation between the amounts of iron and aluminum, then they are likely to be from atmospheric transport of dust from the continents. If the iron and manganese are correlated, it is likely they both came from the seafloor and the adjacent

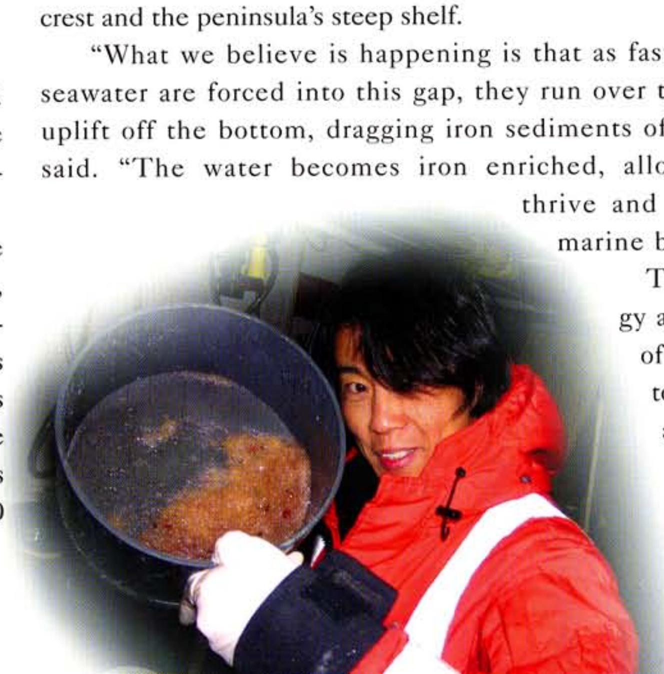
Scripps graduate student Brian Hopkinson prepares a phytoplankton sample for analysis, and biogeochemist Katherine Barbeau takes a break and enjoys the zooplankton samples.

Above, *Huili Wang (left) and Rick Reynolds (right) pack up instruments on the last day of the cruise.* **Below,** *Research associate Yiwu Zhu of the University of Massachusetts, Boston with krill collected with a net tow.*

Antarctic continental shelf. Measures found the latter to be the case, with very little airborne input.

The seafloor in the Southern Ocean is deep, 4,000–5,000 meters (13,000-16,400 feet), over most of its extent with only limited areas of shallower water. At the Drake Passage, the depth rises to less than 1,000 meters (3,280 feet) over the Shackleton Fracture Zone, an underwater mountain ridge about the height of the Rocky Mountains that lies between Cape Horn, Chile, and the Antarctic Peninsula. The passage is the narrowest part of the ACC, about 700 kilometers (435 miles) wide. At its southern end is a gap between the Shackleton ridge crest and the peninsula's steep shelf.

"What we believe is happening is that as fast-moving fronts of deep-seawater are forced into this gap, they run over the continental shelf and uplift off the bottom, dragging iron sediments off the seafloor," Mitchell said. "The water becomes iron enriched, allowing phytoplankton to thrive and creating a hot spot for marine biology."

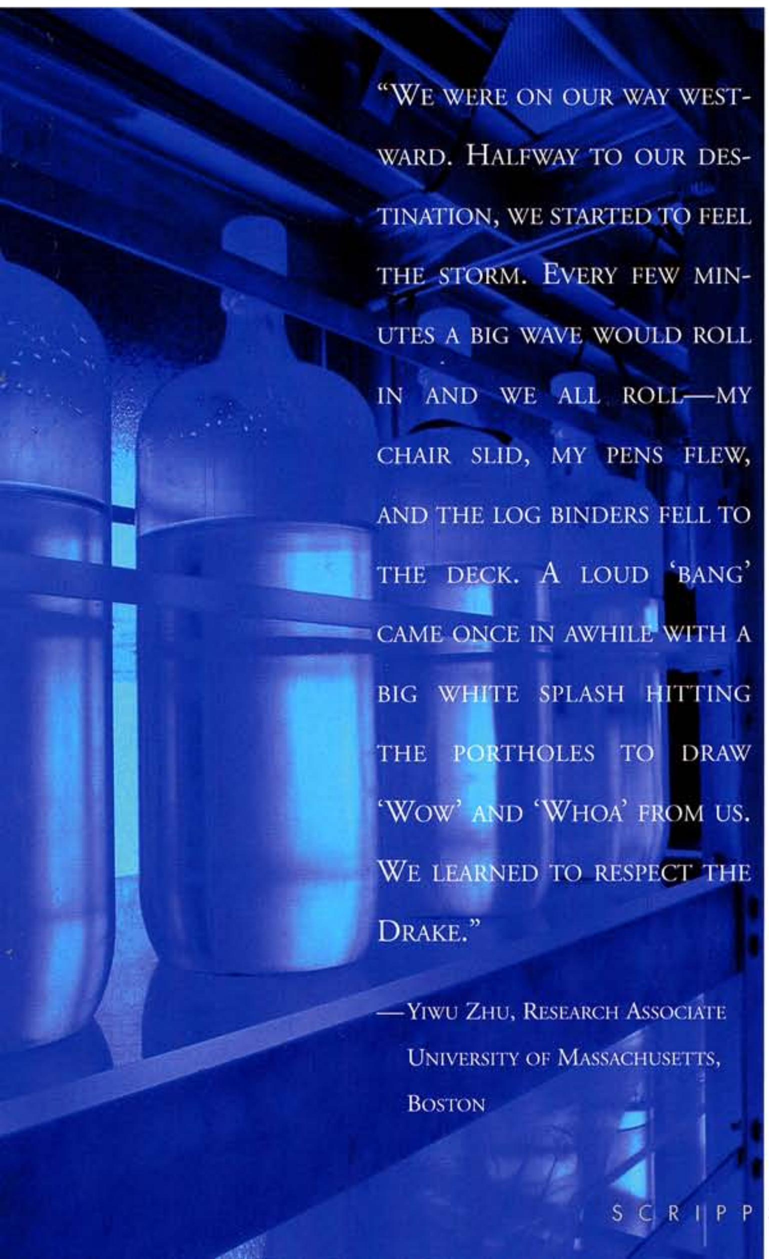


This idea of seafloor geology and the physical dynamics of the currents bringing iron to the surface opens a new area for investigation, not only in Antarctica, but elsewhere in the world's

Top, *Rick Reynolds recovers an instrument for measuring the optical properties of the upper water layers.* **Bottom,** *Bottles in the ship's "Antarctic Tanning Salon" contain water samples enriched with iron that will be used to analyze phytoplankton responses. The artificial light mimics the wavelengths of sunlight.*

oceans as a means to explain natural iron enrichment occurring away from the continental shelves.

Mitchell and his collaborators are funded by the National Science Foundation for a future expedition to the Drake Passage in the winter of 2006 and significantly more detailed studies of this phenomenon. In addition to Mitchell, the group includes Scripps scientists Farooq Azam (bacteria), Katherine Barbeau (trace metals), Sarah Gille (physical oceanography), as well as Osmund Holm-Hansen and Chris Hewes (biology); Meng Zhou (physical oceanography) of the University of Massachusetts, Boston; Matthew Charette (biochemistry) of Woods Hole Oceanographic Institution; and Christopher Measures (trace metals) of the University of Hawaii.



"WE WERE ON OUR WAY WESTWARD. HALFWAY TO OUR DESTINATION, WE STARTED TO FEEL THE STORM. EVERY FEW MINUTES A BIG WAVE WOULD ROLL IN AND WE ALL ROLL—MY CHAIR SLID, MY PENS FLEW, AND THE LOG BINDERS FELL TO THE DECK. A LOUD 'BANG' CAME ONCE IN AWHILE WITH A BIG WHITE SPLASH HITTING THE PORTHOLES TO DRAW 'WOW' AND 'WHOA' FROM US. WE LEARNED TO RESPECT THE DRAKE."

—YIWU ZHU, RESEARCH ASSOCIATE
UNIVERSITY OF MASSACHUSETTS, BOSTON

THE GERITOL™ SOLUTION

One of the most ingenious ideas to emerge from studies of iron and Antarctic biomass abundance is called "the Geritol™" solution to global warming. It involves sprinkling iron dust over large sections of the Southern Ocean to accelerate plankton production, thus priming the biological pump and increasing the ocean's uptake of atmospheric CO_2. John Martin of the Moss Landing Marine Laboratory first promoted this concept in the 1980s, and later said, "Give me a half a tanker of iron, and I will give you an ice age." Just how serious he really was isn't clear, as he died shortly afterward, but the idea has held its ground in some scientific circles. It has also attracted the interest of governments and entrepreneurs who see the potential for carbon "emission trading" opportunities and enhanced marine fisheries.

Several medium-scale ocean experiments have shown that adding iron to the ocean surface can trigger plankton production and increase uptake of CO_2. There is limited evidence, however, that the carbon was effectively transferred by the ocean's biological pump into the deep sea. Whether it will work remains an open question. However, Mitchell said, there are daunting questions about how iron

Mitchell said, there are daunting questions about how iron fertilization might impact ocean food webs and the biological and geophysical cycling of chemicals.

One possible problem could be that as more organic carbon is transported to deeper water, it would lead to the depletion of oxygen and reduce krill populations. Fertilization also could result in a shift in the microbial community toward organisms that produce other greenhouse gases, such as nitrous oxide and methane, which have potential warming capacities even greater than that of CO_2. Or it might upset the balance of nutrients in adjacent oceans and alter the composition of other marine ecosystems.

"Attempting to fix one anthropogenic disaster could lead to new, unanticipated dire consequences," Mitchell said. "It would be much more effective to improve how we produce and use energy rather than try to mitigate the atmospheric CO_2 problem by ignorantly toying with a large ocean ecosystem."

At 4 a.m., Greg Mitchell deploys an instrument provided by NOAA's Global Drifter Program for tracking ocean surface currents.

"In the spirit of the international Antarctic Treaty, we must actively strive to better understand and to protect this unique, beautiful, and important Southern Ocean ecosystem in the interest of all future generations."

—Osmund Holm-Hansen, Marine Biologist
Scripps Institution of Oceanography