Voyagers on the stern of the U.S. icebreaker *Nathaniel B. Palmer* look northward to the sun peeking over a tabular iceberg, as the research vessel cuts through sea ice and heads toward Antarctica. Aboard the *Palmer* to collect samples of Southern Ocean seawater for geochemical analyses was Dee Breger, who operated the scanning electron microscope facility at Lamont-Doherty for decades. Breger, whose photography of the microscopic world has been widely acclaimed, captured this macroscopic view.

Photo courtesy of Dee Breger, Drexel University

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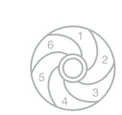
LAMONT-DOHERTY EARTH OBSERVATORY IS RENOWNED IN THE INTERNATIONAL SCIENTIFIC COMMUNITY for its success and innovation in advancing understanding of Earth, for its unique geological and climatological archives and state-of-the-art laboratory facilities, and for the outstanding achievement of its graduates. Observatory scientists observe Earth on a global scale, from its deepest interior to the outer reaches of its atmosphere, on every continent and in every ocean. They decipher the long record of the past, monitor the present, and seek to foresee Earth's future. From global climate change to earthquakes, volcanoes, nonrenewable resources, environmental hazards and beyond, the Observatory's fundamental challenge is to provide a rational basis for the difficult choices faced by humankind in the stewardship of this fragile planet.

G. Michael Purdy
Director, Lamont-Doherty Earth Observatory



1. A low-pressure system off the coast of Greenland
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"We all share one goal: to understand the Earth, and in so doing, to benefit humankind."

WE HAVE EXPERIENCED GREAT SUCCESS OVER THE TWO YEARS SINCE WE published the first in this new series of biennial reports for the Observatory. Our core activity, of course, is understanding the Earth, and we have made notable advances in our understanding of climate, earthquake dynamics, river processes, and many other areas of Earth research–just a small number of which you will find described in this all-too-brief overview.

Our Tree-Ring Laboratory has taken on a five-year challenge to unravel the mysteries of the Asian monsoon with a landmark grant from the National Science Foundation. We have developed important new facilities, including the expansion of the Borehole Research Group to serve the newly established international Integrated Ocean Drilling Program and the very recent acquisition of a new research vessel to replace R/V *Maurice Ewing* in 2006. These are just two examples of Observatory facilities that have significant impact not just on Lamont-Doherty researchers, but also on the international research community. As it always has throughout its illustrious history, Lamont-Doherty continues to play a vital role at the vanguard of global efforts to study our planet.

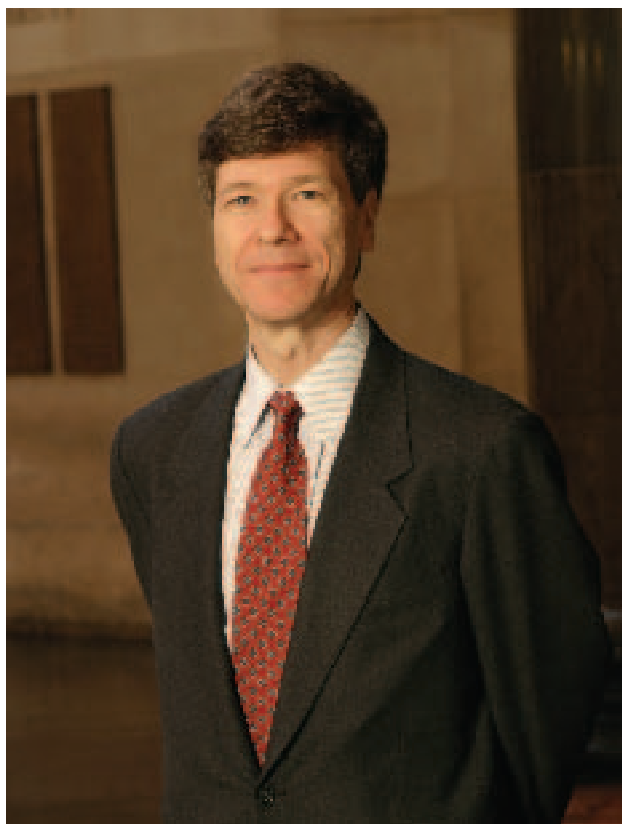
We have made major investments in our future by attracting a substantial new group of research staff and faculty from other universities and institutions to join our team in its quest to build the pre-eminent multidisciplinary earth science research center in the world.

Naturally we are not without challenges. There have been setbacks and there will continue to be significant barriers to be overcome as we build this great institution within the maturing construct of Columbia's Earth Institute. But as carbon dioxide concentrations continue to build in our atmosphere, as populations increase concentrations in coastal areas, as developing nations battle disease and malnutrition, and as water supplies are stressed to meet the increasing demands of the developing world, global decision-makers increasingly will turn to earth scientists for ideas and solutions. I sense a slow but heartening growth in public understanding of the direct relevance that earth science plays in their lives. Our efforts at all levels of education are critical to maintain this trend–from our ever-popular October Open House to our prestigious Ph.D. program.

I hope you enjoy reading this report and the tremendous diversity in intellectual pursuits and research topics, the global reach of our research efforts, and the vast array of research approaches–from real-time observations to laboratory experimentation and theoretical computer modeling. Through all this, do not lose sight of the fact that we all share one goal: to understand the Earth, and in so doing, to benefit humankind. The importance of this goal is gradually being realized. In human history, its priority has never been higher. I hope you will appreciate the essential role that the Observatory is playing in this mighty endeavor.

G. Michael Purdy
Director

"Lamont's recruitment of world-class scientists upholds the long tradition of consummate, unsurpassed expertise in earth sciences."



THIS HAS BEEN A MARVELOUS TWO YEARS OF ACCOMPLISHMENT BY THE scientists of the Lamont-Doherty Earth Observatory. After reading this biennial report, you will agree that, under the dynamic leadership of Dr. G. Michael Purdy, the Observatory's expert research staff has made many leaps forward in our fundamental understanding of Earth processes across all the major disciplines. These include the reconstruction of a history of drought over the last 2000 years from tree-ring records, retrospective prediction of El Niño over the last 148 years, new advances in our understanding of tectonics, and the acquisition of a new research vessel that will surpass our current ability to use acoustic and seismic technologies to better understand Earth processes. In addition, Lamont's recruitment of world-class scientists upholds the long tradition of consummate, unsurpassed expertise in earth sciences.

I am also thrilled by the growing linkages between researchers at the Observatory and elsewhere in the Earth Institute. The other Earth Institute research units at the Lamont-Doherty campus–the International Research Institute for Climate Prediction (IRI), the Center for International Earth Science Information Network (CIESIN), the Center for Hazards and Risk Research, the Center for Rivers and Estuaries, the Center for Nonlinear Earth Systems, and the Tropical Agriculture Program–have especially benefited from an exchange of knowledge and collaboration made possible by their presence on the Lamont campus.

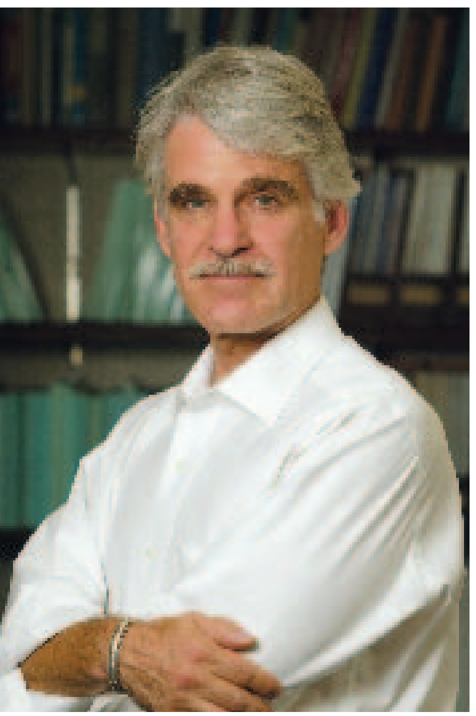
A notable example is the World Bank-sponsored Natural Disaster Hotspots program, which involves scientists from Lamont-Doherty, IRI and CIESIN. As these academic relationships develop and mature, we continue to see the deep intellectual benefits in fostering truly innovative new ways to address complex problems in earth and environmental sciences and to develop practicable solutions to meet the challenges of achieving sustainable development.

The Earth Institute and the Lamont-Doherty Earth Observatory have continued to foster stronger connections as well between the Observatory campus and Columbia's Morningside Heights and Health Sciences campuses, in particular through education programs. A new M.A. degree in Climate and Society is the most recent example, with research scientists at the Observatory and the IRI launching an educational program to train a new generation of professionals well-versed in the application of climate forecast information to critical decisions involving water resources, health, and agriculture. The Ph.D. degree in Sustainable Development is another new educational program that relies on the scientific leadership of Observatory scientists as we strive to train social scientists in the natural sciences that underpin sustainable development.

This is truly an auspicious time for the Observatory, and thus, for the Earth Institute as a whole. I am deeply grateful for the work of our colleagues at Lamont-Doherty, and know that I speak for the entire Earth Institute community when I congratulate the Observatory for its continued excellence.

Jeffrey D. Sachs
Director, The Earth Institute at Columbia University

All organisms are products of the environment in which they exist, or existed. They influence their surrounding environment, and they are influenced by it.



John Marra
Doherty Senior Scholar,
Associate Director,
Biology and Paleo
Environment Division
Credit: Bruce Gilbert

The Biology and Paleo Environment Division (B&PE) comprises a diverse range of scientists—oceanographers, geochemists, biologists, and environmental scientists—whose research is linked by two connected efforts: They seek to understand how today's environment, through its oceans, atmosphere, and land, affects present-day life on Earth, and they use evidence from past life on Earth (fossils) to learn about the history of Earth's past (paleo) environment.

All organisms are products of the environment in which they exist, or existed. They influence their surrounding environment, and they are influenced by it. Organisms are shaped by a variety of factors, ranging from temperatures and the availability of water, nutrients, and light to chemical or physical changes that stress the natural system. Changes in the environment are reflected in the organisms. By studying organisms preserved during ancient times, scientists can reconstruct a picture of how Earth's climate system behaved in the past, shedding light on how the climate system works and how it may change in the future.

To conduct this research, B&PE scientists turn to the Observatory's world-class collections of deep-sea sediments, tree rings, and coral reef samples. Cores of deep-sea sediments contain remnants of ancient microscopic marine life that continually rain down to and pile up on the ocean bottom. They are like tape recordings providing scientists with a chronological archive of oceanic conditions reaching several million years into Earth's history.

Dendrochronologists in our Tree-Ring Laboratory analyze the widths of annual growth rings in long-lived trees, which reflect temperature and precipitation experienced during a growing season. These studies provide accurate and detailed records, stretching back several hundred years, of past climate in particular locations. Like trees, corals also have growth rings, and scientists analyze them to extend records of climate into times before humans began to have such a large impact on the environment.

And while paleo-oceanographers and geologists sift clues from Earth's past, other B&PE scientists monitor the converse: They examine how present-day marine plankton, trees, and other organisms are responding to changing environmental conditions. In particular, they are investigating changes in the amount of solar radiation reaching our planet. Solar variability may be partly or entirely linked to warm-cold oscillations in Earth's climates, such as the Medieval Warming Period (about 800 to 1200 A.D.) and the Little Ice Age (about 1300 to 1890 A.D.), and it is highly likely to trigger similar climate shifts in the future.

The three projects that follow offer recent examples of B&PE research.

Eddies: The ocean, like the atmosphere, has "weather"

IN OUR ATMOSPHERE, SWIRLING HIGH- AND low-pressure air masses form and interact in a fast-paced dynamic that generates our ever-shifting weather. But a similar phenomenon also creates "weather" in our planet's other fluid environment, the oceans. And just as atmospheric weather has profound impacts on those living on the Earth, so does "ocean weather."

In 2000, strong winds surged in the gap between Maui and Hawaii, driving sea surface waters westward on Hawaii's leeward side. Earth's rotation added its spin, and together, these forces created a cyclonic spiral of seawater, 50 to 150 kilometers in diameter, within the overall ocean circulation—a phenomenon known as an eddy.

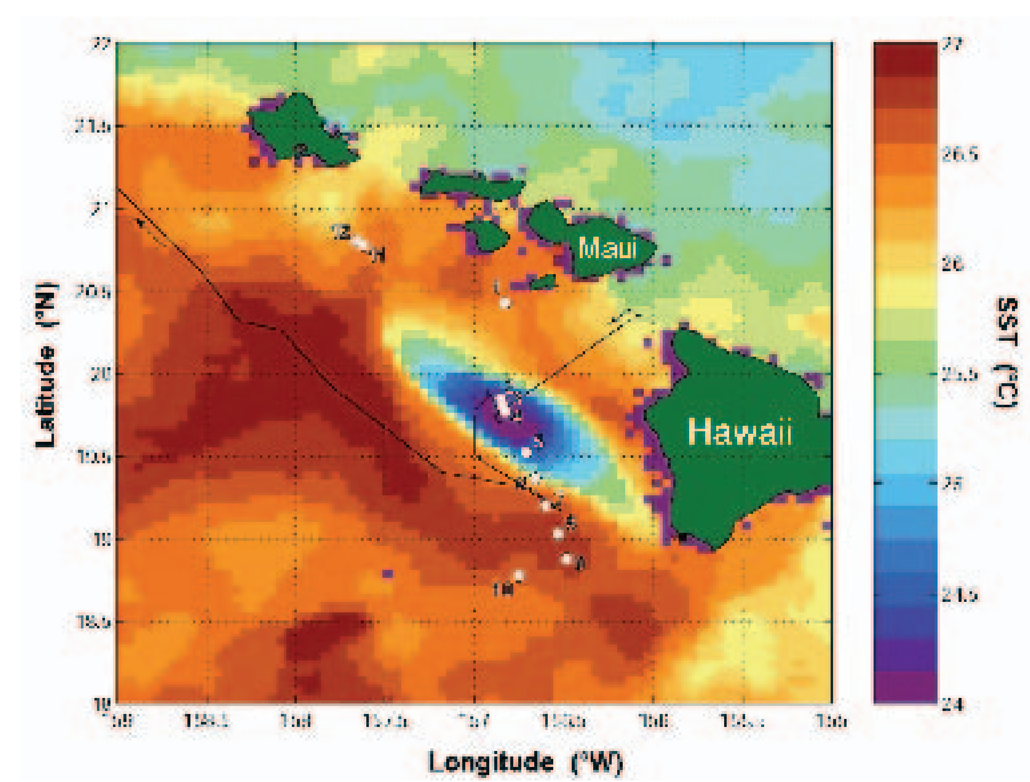
Exploiting the easy access from Hawaii, Lamont-Doherty scientist **Robert Vaillancourt**, along with a multi-institutional team of researchers, deployed a variety of instruments to make a wide range of measurements of the eddy, which, like atmospheric cyclones, was given a name: Haulani.

Analyzing all the data they collected, the team summarized its findings in an article published in 2003 in *Deep-Sea Research*. The researchers found that surface waters in the center of the eddy were cooler, saltier, and denser than waters outside the eddy. The interior waters were also full of nutrients and lush with phytoplankton, the microscopic plants that form the base of the marine food chain.

The research showed that, just as atmospheric cyclones draw air upward in their centers, eddies pump up deep water, containing essential nutrients for phytoplankton, to the sunlit sea surface. That combines all the ingredients (along with carbon from carbon dioxide in the atmosphere and ocean) that are needed for photosynthesis. The result is a hot spot for rapid growth of phytoplankton.

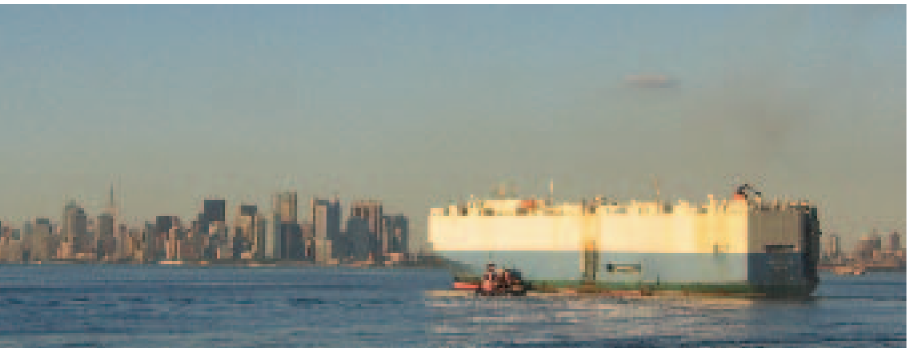
Large "blooms" of phytoplankton draw large amounts of carbon dioxide from the atmosphere, and when the phytoplankton die or are eaten, large amounts of organic carbon sink to the seafloor. Thus, eddies—a common feature throughout the world's oceans—may play a significant role in taking up heat-trapping carbon dioxide from the atmosphere and sequestering it in the deep. In a world of global warming, that makes eddies an important phenomenon to understand.

And just as atmospheric weather has profound impacts on those living on the Earth, so does "ocean" weather.



An image from the GOES-10 satellite of sea surface temperatures on Nov. 17, 2000, shows a cyclonic spiral of seawater, or eddy, 50 to 150 kilometers in diameter west of the Hawaiian Islands. The swirling eddy draws up cooler (bluer) waters from the depths, which contain nutrients that fuel the growth of blooms of phytoplankton.

Credit: R.D. Vaillancourt, J. Marra, M.P. Seki, M.L. Parson, and R.R. Bidigare. "Impact of a Cyclonic Eddy on Phytoplankton Community Structure and Photosynthetic Competency in the Subtropical North Pacific Ocean" in Deep-Sea Research I 50 (2003).



The brown haze near the horizon in the skies over Manhattan is caused by a buildup of man-made particles. The phenomenon, called global dimming, scatters incoming solar radiation back into space, with ramifications for Earth's future climate.
Credit: Philip Stier

Global dimming: Will Earth be drier and cloudier in the future?

AS THE EARTH WARMS, IT ALSO MAY BE GROWING dimmer, according to new research by Lamont-Doherty scientist **Beate Liepert**. Analyzing data collected over four decades by a worldwide network of monitoring stations, Liepert determined that the amount of solar radiation reaching Earth's surface has declined by 4 percent (1.3 percent per decade) between 1961 and 1990.

…the amount of solar radiation reaching Earth's surface has declined by 4 percent (1.3 percent per decade) between 1961 and 1990.

The phenomenon, called "global dimming," is an important and previously unrealized factor affecting future climate. It both increases and mitigates global warming. It could lead to a future world that not only is warmer, but also has less sunshine and rainfall.

Like global warming, global dimming is likely caused by human activities, which–along with heat-trapping greenhouse gases–have sent a surfeit of soot and other air pollutants into the atmosphere. Some of these man-made particles scatter sunlight back into space, reducing the amount of solar radiation hitting Earth's surface. Other particles absorb solar energy, heating up the atmosphere, but not the surface of the Earth itself, Liepert explained. If these aerosol particulates were not reflecting some radiation away, Earth's surface temperatures would be rising even faster or higher than they are.

Aerosol particles also play a critical climate-influencing role in another way: Water condenses around them, initiating the formation of clouds. This process, combined with a warmer atmosphere that can hold more water vapor, has led to an observed thickening of Earth's cloud cover. Clouds can either trap solar radiation (leading to more warming) or reflect more of it back into space (resulting in less heat and light on Earth's surface).

Industrially produced aerosols are different from those that form naturally. They condense water into smaller, less dense cloud droplets that are less likely to sink as rain. That counteracts the effects of global warming, which increases evaporation and precipitation, and could lead to a drier world in the future.

"These new ideas on the effects of aerosols open up many new avenues to explore in the climate change debate," Liepert said.

Arsenic poisoning: LDEO mobilizes to curtail a huge health hazard

AN UNUSUAL TEAM OF EARTH SCIENTISTS AND health scientists from Columbia University has combined to find ways to alleviate what has been called the largest case of mass poisoning in human history.

Until the 1970s, about 250,000 people in Bangladesh died each year by drinking water contaminated with deadly disease-causing microbes. The Bangladeshi government and aid agencies encouraged rural households to dig millions of inexpensive, hand-pumped tube wells, shifting water consumption in poor, rural areas from tainted surface water to groundwater free of microbial pathogens.

Today some 12 million wells supply 97 percent of the drinking water to more than 130 million people in Bangladesh. The well-intentioned campaign contributed to a dramatic reduction of deaths from waterborne infectious disease, but it also had unintended consequences. A large percentage of the groundwater supplies were later found to contain elevated levels of arsenic, an odorless, tasteless, colorless–and toxic–element.

The 1980s and 1990s saw a rise in the number of cases of arsenicosis–a combination of debilitating skin lesions, skin and internal cancers, diabetes, and vascular disease caused by arsenic poisoning. Past exposure to arsenic is likely to double the number of cancer deaths in Bangladesh in the coming decades.

An estimated 50 million people in Bangladesh have been chronically exposed to arsenic, and similarly affected groundwater wells have been installed in Vietnam, India, and other South Asian river delta areas.

To address this health hazard of massive proportion, scientists and students from three of Lamont-Doherty Earth Observatory's divisions (Biology and Paleo Environment, Geochemistry, and Marine Geology and Geophysics) teamed up with colleagues from Bangladesh and Columbia's Mailman School of Public Health, and later with social scientists from Columbia's School of International and Public Affairs. The team, spearheaded by Lamont-Doherty geochemist **Lex van Geen**, began to fan out in early 2000 to test more than 6,000 wells over a 25-square-kilometer area in Bangladesh, and geo-referenced the data set with handheld Global Positioning System (GPS) receivers.

The team found that wells with high and low arsenic levels were interspersed across the landscape. Within the same village, a household with a safe well would often have a less fortunate neighbor meters away whose well tapped into high-arsenic groundwater. The team found that only half the households within the test area owned a safe well, though 90 percent of the people in the area lived within 100 meters of a safe well.

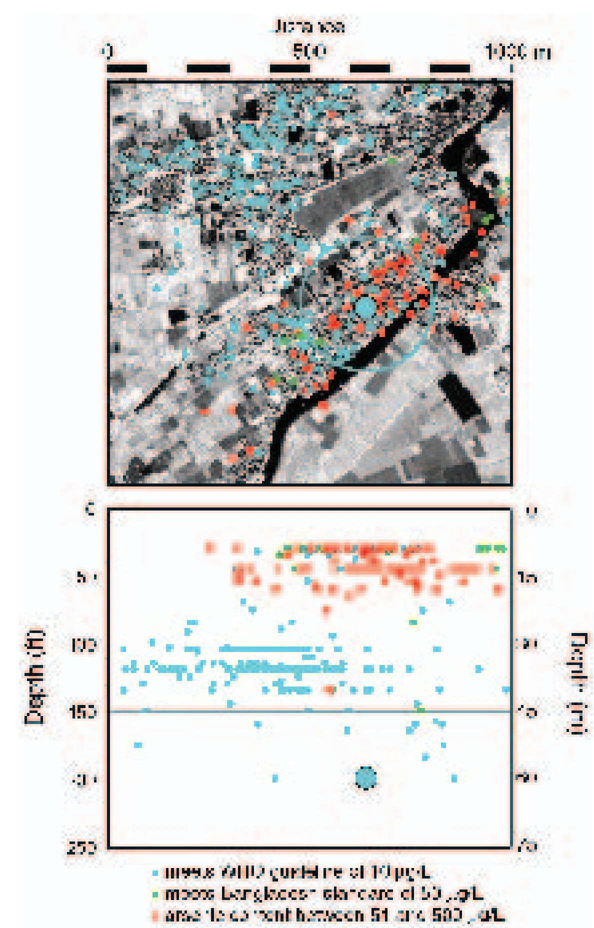
The findings posed a problem: It meant that every well, not just a few, had to be tested in an area to ensure all the wells' safety. But they also offered a solution: The team's observations bore out van Geen's prediction (which initially was widely questioned inside and outside Bangladesh) that communities could mitigate the arsenic crisis by sharing existing nearby wells that are safe, a concept the team coined "well switching."

Lamont-Doherty scientists have gone on to investigate the geological factors that affect arsenic levels in groundwater, finding that deeper wells may prove safe. They are also exploring hydrological and geochemical factors that mobilize arsenic into groundwater.

Careful isotopic dating of groundwater by a Lamont-Doherty team led by **Martin Stute** has cast doubt on a controversial study suggesting that irrigation enhances the release of arsenic, naturally contained in rock or soil, to groundwater. The study showed that, if anything, recharging of aquifers enhanced by irrigation is more likely to reduce arsenic levels in shallow wells.

Another recent Lamont-Doherty study has shown that while irrigation with arsenic-containing groundwater does raise arsenic levels in paddy soil, this does not lead to significant arsenic accumulation in rice grains and therefore does not increase arsenic exposure to people.

Doherty Senior Scientist Lex van Geen holds a needle sampler used to test arsenic levels in groundwater in Bangldesh. Van Geen has led studies to find effective ways to curtail the widespread use of wells containing the toxic element. The health hazard threatens tens of millions of people, especially in developing countries in Asia.
Credit: Brian Mailloux



An image from the IKONOS satellite (top panel) shows locations of individual wells used to supply water to a village in Bangladesh. Red dots are shallow wells that contained high levels of arsenic; blue dots are deeper wells that contained lower levels of the toxic element. The large blue dot in both panels is a recently installed deep communal well to provide safe drinking and cooking water.

Credit: spaceimaging.com

Recently, the purview of our work has expanded, delving to greater depths…and soaring to new heights.

Associate Director and Doherty Senior Scholar Taro Takahashi (left) led the Geochemistry Division for 23 years. He stepped down in 2004 to devote time to scientific research. Associate Director and Doherty Senior Scholar Robert F. Anderson (right) now heads the Division. *Credit: Bruce Gilbert*

For decades Lamont-Doherty geochemists could proudly explain to colleagues, family, and friends that members of our Division study chemical reactions and use chemical tracers to investigate a variety of naturally occurring processes in settings ranging from Earth's mantle to the moon. Recently, the purview of our work has expanded, delving to greater depths by examining reactions involving Earth's core and soaring to new heights by proposing novel theories about the polar ice caps on Mars.

Of course, Lamont geochemists continue to study processes in all of the principal realms of the Earth system: land, ocean, cryosphere, and atmosphere. Given such a diversity of scientific endeavor, it is difficult to cover all aspects of research within the Geochemistry Division in a single report. Here we focus on research activities involving extremes in the spatial spectrum of geochemical research, with illustrations of work on extraterrestrial systems and deep within Earth's interior. These examples complement the studies of processes occurring at Earth's surface described in the 2000-02 biennial report.

Where did Mars' atmosphere go?

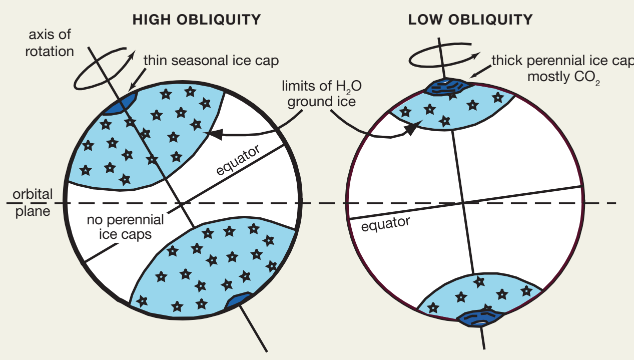
MARS' UNUSUALLY THIN ATMOSPHERE (0.006 bars compared with the Earth's 1.0 bar) has long mystified scientists. Geological evidence of running water on Mars' surface had led scientists to speculate that as much as 1 to 2 bars of carbon dioxide may have been present in Mars' atmosphere 3 billion to 4 billion years ago–enough to produce sufficient greenhouse warming to stabilize liquid water. Today, only a vestige (1 percent) of that atmosphere remains.

What happened to the rest of it? Lamont-Doherty geochemist **John Longhi** has been investigating a provocative theory that Mars' atmosphere may have been transferred chemically to hidden reservoirs deep within the crust.

A combination of two disparate processes may account for this uniquely Martian loss of atmosphere. One process is rotational precession: Over thousands of years, Mars' axis of rotation changes. At one extreme, it rotates around an axis that is almost perpendicular to its orbital path (called periods of low obliquity). Thousands of years later, it rotates around an axis that slants nearly parallel to its orbital path (high obliquity).

During high obliquity, solar energy is spread fairly evenly over the planet, and the polar ice caps, which now are mainly frozen water, either melt or sublime directly into water vapor. Some of this water is believed to sink down into Mars' porous crust to recharge a global aquifer.

During periods of low obliquity, the poles receive little solar heat. They potentially could become cold enough to precipitate much of Mars' atmospheric carbon dioxide into a solid carbon dioxide (dry ice) cap several kilometers thick.



[left] During periods of high obliquity, when Mars' axis of rotation is tipped more toward the sun, solar energy is spread more uniformly over the planet, and polar ice caps melt.

[right] During periods of low obliquity, the poles become cold enough to precipitate carbon dioxide (CO_2) in Mars' atmosphere, creating thick ice caps made of solid CO_2. The thick layers of solid CO_2 insulate the crust, allowing CO_2 at the base of the ice cap to melt. Pressure from the overlying ice cap force the liquid CO_2 back into the crust—effectively transferring CO_2 from the atmosphere into the planet's interior.

Credit: Mars precession and climate, after Kleffer and Zent (1992)

Now the second process, heat flow, would come into play. Dry ice is a much better insulator than water ice. Calculations show that only a kilometer of dry ice (as opposed to 11 kilometers of water ice) is sufficient to trap enough heat from the planet's interior to melt the growing dry-ice cap at its base. Aiding this process is the very low melting point of dry ice–about 60° C lower than that of water ice.

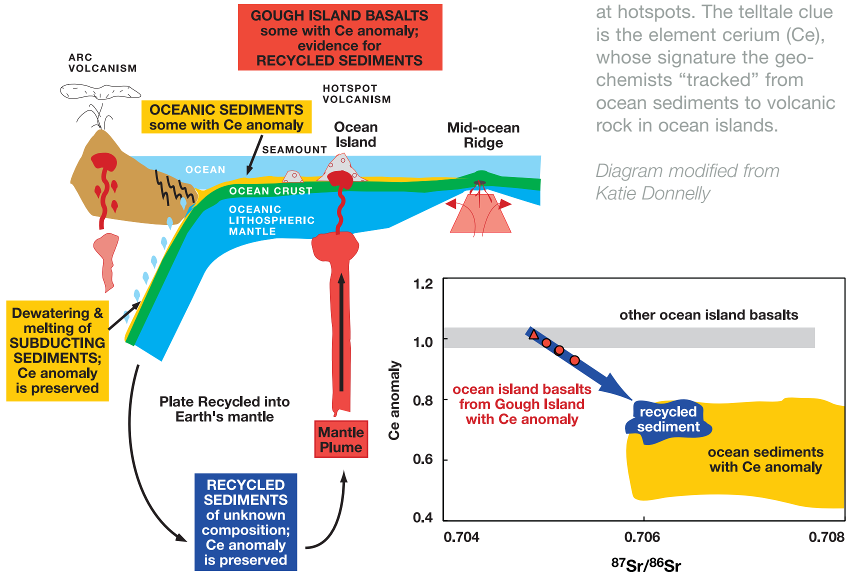
The pressure of the overlying ice cap may drive liquid carbon dioxide at the ice cap's base into the porous Martian crust, forming a liquid carbon dioxide aquifer that coexists with and acidifies the global water aquifer. Acidic groundwater may dissolve rock near the poles, allowing more fluids to percolate into Mars' interior and subsequently flow toward the equator, where the carbon dioxide dissolved in water could precipitate subsurface carbonate. In this way, over geologic time, large quantities of gaseous carbon dioxide may have been transferred from Mars' atmosphere into aquifers as liquid and into subsurface carbonate deposits as solid.

To construct a framework for this theory, Longhi organized the poorly understood liquid-solid-gas chemical interactions of water and carbon dioxide into a coherent grid of pressure and temperature. And using data from the Viking Lander, he has estimated the limits at which water dissolves in carbon dioxide liquid and gas under the unusual conditions of low temperature (-60°C) and pressure (0.006 bars) found on the Martian surface. These interactions and solubility limits provide the basis for predicting the temperatures at which water ice and carbon dioxide ice would condense and the temperatures at which these two types of ice would melt at the base of the polar ice caps.

Recycling material deep within the Earth

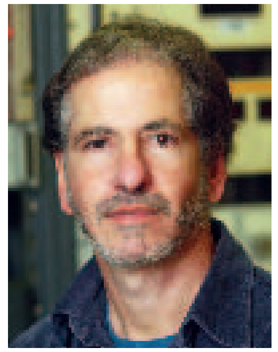
IN THE PAST HALF-CENTURY, EARTH SCIENTISTS have been able to relate dynamic processes occurring near Earth's surface to processes deeper within the planet. Islands such as Hawaii in the Pacific and Gough Island in the South Atlantic, for example, form from upwellings of material from deep within Earth's mantle, called mantle plumes. At mid-ocean ridges, magma rising from Earth's mantle spawns earthquakes and volcanic eruptions that continually create new oceanic crust.

Over millions of years, the oceanic crust spreads outward until it cools and becomes dense enough to sink back down into the mantle (and sometimes as deep as the core-mantle boundary). This occurs at subduction zones, which are often associated with deep trenches on the seafloor.



Lamont-Doherty geochemists Cornelia Class and Steven Goldstein and colleagues offer the first unambiguous evidence that seafloor sediments subducted into the deep mantle may be recycled to Earth's surface in islands formed by mantle plumes at hotspots. The telltale clue is the element cerium (Ce), whose signature the geochemists "tracked" from ocean sediments to volcanic rock in ocean islands.

Diagram modified from Katie Donnelly



[*left*] Conny Class

[*right*] Steve Goldstein

Credit: Bruce Gilbert

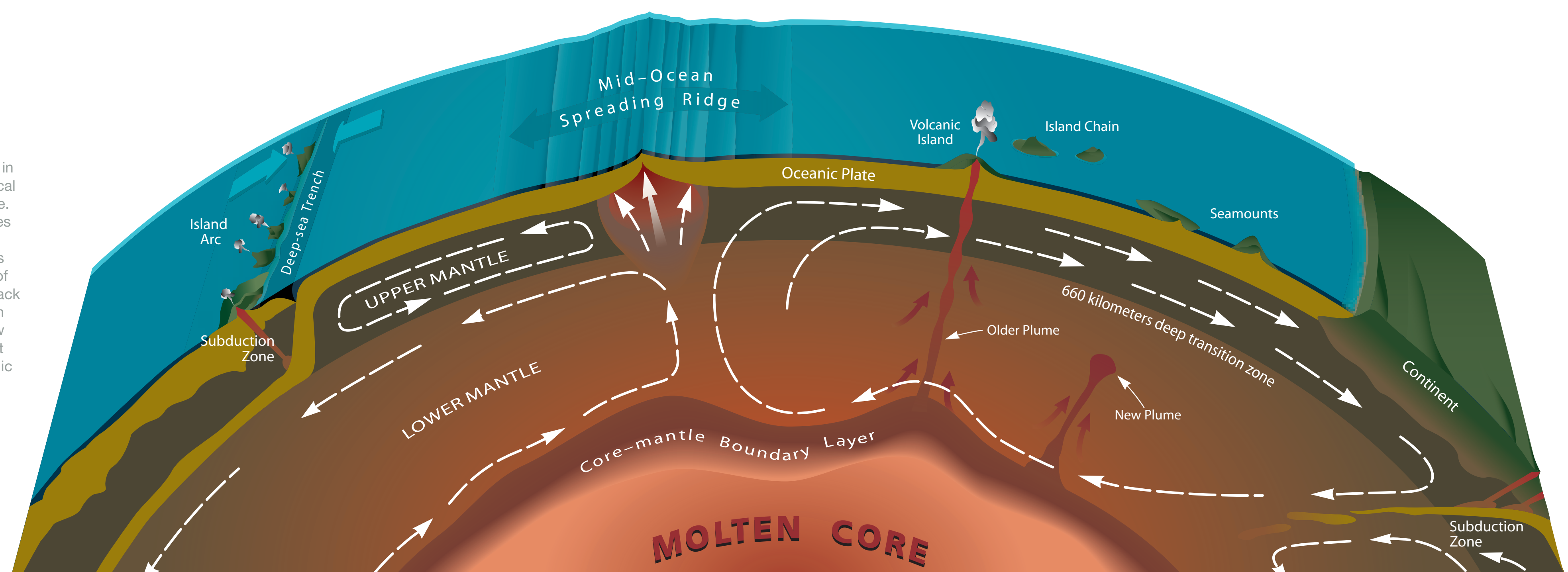
Lamont-Doherty geochemists offer finally unambiguous evidence that ocean sediments subducted into the mantle are recycled to Earth's surface.

In the meantime, however, the ocean crust obtains a veneer of sediments formed from material eroded from the continents and from accumulated skeletons of microscopic marine life that sink to the bottom. By means of subduction, ocean sediments are recycled back into the deep mantle. It is not yet constrained how deep they get subducted and to what extent they come back to Earth's surface.

Until now, all the evidence has been ambiguous. But new research by Lamont-Doherty geochemists **Cornelia Class** and **Steve Goldstein**, along with Anton le Roex from the University of Cape Town in South Africa, found unambiguous evidence that ocean sediments subducted into the mantle indeed return to Earth's surface.

Analyzing volcanic rocks from Gough Island, the scientists found they had unexpected low levels of cerium, a rare earth element. Cerium behaves differently from its rare earth cousins, such as lanthanum and neodymium; it readily oxidizes in oxidizing environments such as seawater and ocean sediments and fractionates from the other rare earth elements. Thus, a relative deficiency of cerium compared with lanthanum and neodymium in volcanic rocks is evidence that these rocks contain material, principally ocean sediments, that could have formed only on Earth's oxygen-rich surface. This distinctive chemical fingerprint, called a "negative cerium anomaly," is preserved as material descends into the mantle and again as it returns to the surface via a mantle plume, the scientists say.

The finding suggests that processes occurring on the Earth's surface affect the evolution of the deep Earth. It re-emphasizes the importance of treating the whole Earth, from core to atmosphere, as an integrated system.



The underlying "flow" of rocks in Earth's mantle drives geological phenomena at Earth's surface. Hot, buoyant mantle rock rises at mid-ocean ridges to form new ocean crust that spreads outward, cools over millions of years, and eventually sinks back into the mantle at subduction zones. In some areas, narrow plumes of mantle rocks erupt at the surface to form volcanic islands and seamounts.

Is Earth's core leaking material to the surface?

LAMONT-DOHERTY PETROLOGIST DAVE WALKER has plunged even deeper than his above-mentioned colleagues—investigating whether Earth's core may be leaking material all the way back to the planet's surface.

Until recently, the border between Earth's mantle and its underlying core seemed to be marked with "one-way" signs: Heavy materials could sink into the core, but there was no apparent means for dense core materials to rise out of it. But some rocks from mantle plumes now seem to contain tantalizing chemical clues suggesting that some material in the rocks originated in Earth's core.

The presence of life on Earth creates some unique conditions, specifically an atmosphere full of oxygen, which reacts chemically with rocks on Earth's surface. When old, cold, dense tectonic plates sink down into Earth's interior, they drag oxygen-rich rocks into the oxygen-deficient mantle. That initiates chemical reactions to "reduce" the oxygen, creating more chemically stable metal oxide compounds. But until now, little thought has been given to the potential for oxidized material to cause chemical reactions at the core-mantle boundary.

Earth's outer core is made of liquid metal. In theory, if oxygen reached this metallic ocean it should react chemically with the metals to form metal oxides (similar to rust). These metal oxides are not as heavy as the metals themselves, which presumably would deter them from taking the trip farther down to the solid inner core. Instead, lighter metal oxides could float into the mantle, where they could be recycled back to Earth's surface, bringing some metal from the core with them.

Investigating such geochemical processes has been stifled by the extraordinary difficulty of experimentally reproducing conditions at the core-mantle boundary, where temperatures reach 4,000°C and pressure surpasses 1 million bars (it's 1 bar at Earth's surface). Walker, however, has developed new strategies to conduct experiments simulating core-mantle conditions.

He places test materials into a cell between a pair of diamond anvils that can reproduce core-boundary pressures without crumbling themselves. Lasers transmitted through the transparent diamonds reproduce core-level temperature.

To observe what happens to materials under these conditions, Walker has used his apparatus in conjunction with synchrotrons at Daresbury Lab in England and the Advanced Light Source at Lawrence Berkeley National Lab in California. Synchrotrons accelerate electrons around a large track at nearly the speed of light to spin off thin X-ray beams directed at experimental material. Different chemical compounds, and different phases of them (solid or liquid), absorb X-rays with different efficiency, providing images that can identify the compounds—similar to the way bones and soft tissue create light-and-dark X-ray images used by doctors.

Liquid iron will not chemically absorb oxygen at low pressure, but will it under high-pressure conditions? Using laser-heated diamond-anvil cells and synchrotron-based X-ray absorptometric imaging, Walker is testing the nature of the liquid iron and oxygen interaction at high pressure.

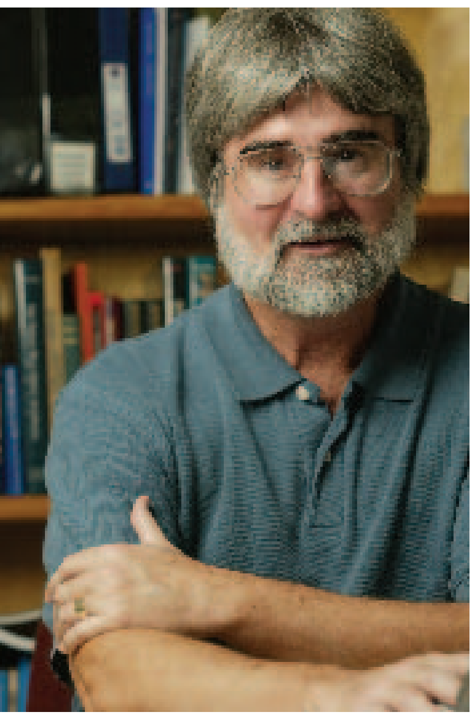
These studies should make it possible to evaluate whether oxidized crust, subducted through the mantle and brought to the core, could then draw metal out of the core, which could rise to add a core flavoring to rocks at Earth's surface. If so, life not only affects the chemistry of Earth's surface, it also has long-term consequences for chemical cycles in the deep interior of our planet.

Dave Walker
Credit: Bruce Gilbert

Lamont-Doherty geochemists Conny Class and Steve Goldstein are investigating whether ocean sediments—accumulated atop seafloor crust that is driven into the mantle in subduction zones—may be recycled back to the surface via volcanoes. Geochemist Dave Walker is investigating whether seafloor crust may be recycled all the way down to Earth's core, precipitating "leaks" of core material all the way back to Earth's surface.

Credit: Jayne Doucette

Success in obtaining these awards can be attributed to the high regard the nation's MG&G community has for Lamont-Doherty's experience and expertise in handling fundamental shipboard observations.



Jeffrey Weissel
Doherty Senior Scholar,
Associate Director,
Marine Geology and
Geophysics Division
Credit: Bruce Gilbert

The Marine Geology and Geophysics Division (MG&G) comprises a diverse and versatile group of scientists whose primary mission is to understand the nature and evolution of the ocean basins and margins. But many in MG&G have exported their techniques and expertise to address scientific questions in terrestrial settings. Today, MG&G researchers are working from pole to pole in all oceans of the world, on most of the continents, in rivers and lakes, and even on the exploration of other planets and moons.

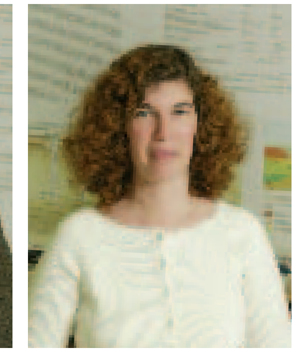
New tools, some pioneered here at the Observatory, such as marine MultiChannel Seismic (MCS) Reflection techniques, now allow researchers to use seismic energy to probe more deeply into the Earth. Multibeam bathymetry mapping and side-looking sonar imaging instruments permit scientists to map larger areas of the seafloor in ever-greater detail.

Although surface ships traditionally have served as the main platforms for MG&G research, satellites and robotic submersibles have started to play vital roles. In July 2004, for example, Lamont-Doherty scientists and colleagues from Scripps Institution of Oceanography and Woods Hole Oceanographic Institution used SeaBED, a WHOI autonomous underwater vehicle, for detailed studies of sites along the mid-Atlantic shelf edge, where naturally occurring natural gas pockets have built up pressure and discharged violently through the seafloor. This recently discovered phenomenon may be linked to submarine landslides and tsunamis.

The acquisition of a new MCS research vessel, the *Western Legend*, in 2004 is an important event for Lamont-Doherty scientists and for the broader national community. The new ship has a vastly increased capacity for towing linear arrays of airguns to generate sound energy. It will enable researchers to image seafloor and sub-seafloor strata with a resolution beyond reach a few years ago.

In 2003, the National Science Foundation announced that Lamont-Doherty, the Joint Oceanographic Institutions, Inc. in Washington, D.C., and Texas A&M University will operate the U.S. non-riser drilling vessel for the next 10 years for the Integrated Ocean Drilling Project (IODP). NSF awarded the Division's Borehole Research Group, led by **David Goldberg**, the contract to provide downhole logging services for IODP. The Borehole Research Group has led efforts to design and deploy new logging tools for use by the wider scientific community. These instruments, inserted into holes drilled into the seafloor, collect a wide range of geophysical measurements for characterizing sub-seafloor rock formations.

Over the past two years, **Suzanne Carbotte**, **Dale Chayes**, **Bill Haxby**, **Bill Ryan**, and their colleagues have also obtained several NSF grants to manage marine geoscience data and make them accessible to the entire community via the Internet. These awards reflect the national MG&G community's high regard for Lamont-Doherty's longstanding expertise in handling fundamental shipboard observations.



MG&G Division Administrator
Sally Odland (left) and
Administrative Assistant
Felicia Taylor (right).
Credit: Bruce Gilbert

LDEO scientist finds new way to locate areas most at risk for large earthquakes

LAMONT-DOHERTY GEOPHYSICIST MLADEN Nedimovic and his collaborators have found a new means to more accurately predict the potential for megathrust earthquakes, the largest and most devastating earthquakes on Earth.

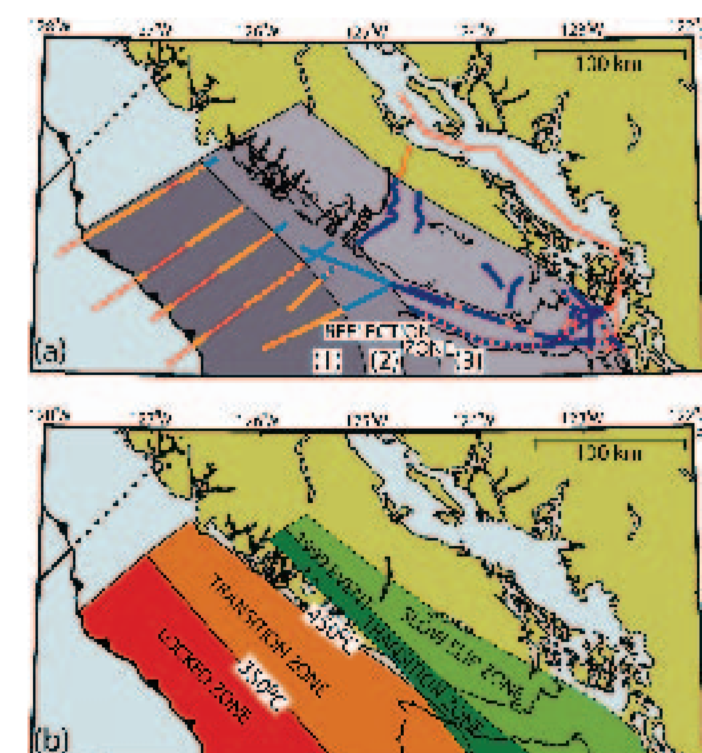
Megathrusts are enormous faults found in areas called subduction zones, where two of Earth's tectonic plates meet in a head-on collision and one thrusts down and underneath the other. Rocks along deeper portions of these megathrusts can be heated enough to become ductile and slide against each other without causing an earthquake. But in shallower and colder portions of megathrusts, the rocks are brittle and the plates often won't slide and become locked. Enormous strain from the locked plates builds up over hundreds of years until the rocks fail or slip suddenly, causing earthquakes with magnitudes of 9 or greater.

To identify and characterize locked zones deep within the Earth, scientists currently rely on thermal and deformation models. But these models contain assumptions that could limit their accuracy.

Nedimovic and colleagues used sound waves reflected off rocks in Earth's interior to create seismic reflection images of the megathrust along the northern Cascadia margin off Vancouver Island, where the Pacific seafloor is being pushed under the North American continent. The images revealed variations in the rock structures that could identify and distinguish the locked zones more directly and accurately than models can.

Previous model estimates had indicated that a 36-mile (60-kilometer) swath of megathrust, reaching some 31 miles (50 kilometers) offshore of Vancouver Island, was locked. Nedimovic's seismic reflection analysis, however, showed that the locked zone is more likely to be a 56-mile (90-kilometer) swath, extending some 20 miles (30 kilometers) closer to land.

If this interpretation is accurate, the Pacific Northwest region, including the populous cities of Seattle, Portland, and Vancouver, faces a greater threat from megathrust earthquake hazards than previously predicted. The occurrence rate for great earthquakes on the Cascadia megathrust is approximately every 200 to 800 years. The last major earthquake beneath the Cascadia margin, in 1700, was a magnitude-9 event that devastated the region.



Lamont-Doherty geophysicist Mladen Nedimovic and collaborators have found a new way to predict more accurately the potential for large, devastating megathrust earthquakes. Using seismic reflection surveys of megafaults (top map) rather than thermal and deformation models (bottom map), they estimated that a "locked" zone where large quakes are generated (No. 1 on the top map, red on the bottom map) is closer to land, increasing the risk to populous Pacific Northwest cities.

LDEO scientists reveal curious structure of lake buried deep beneath Antarctic ice

DEEP IN THE ANTARCTIC INTERIOR, BURIED under thousands of meters (more than 2.5 miles) of ice, lies Lake Vostok, a lake roughly the size of Lake Ontario that has been sealed by ice and isolated from the rest of Earth's environment for hundreds of thousands of years. Scientists have longed to explore the lake's waters for ancient life forms that may no longer exist elsewhere on the planet.

Scientists have longed to explore the lake's waters for ancient life forms that may no longer exist elsewhere on the planet.

In 2004, scientists from Lamont-Doherty and the University of Tokyo discovered that the lake contains a prominent ridge that subdivides the lake into two distinct regions. The finding has significant implications for the kinds of ecosystems scientists could expect to find in the lake and how they should go about exploring them.

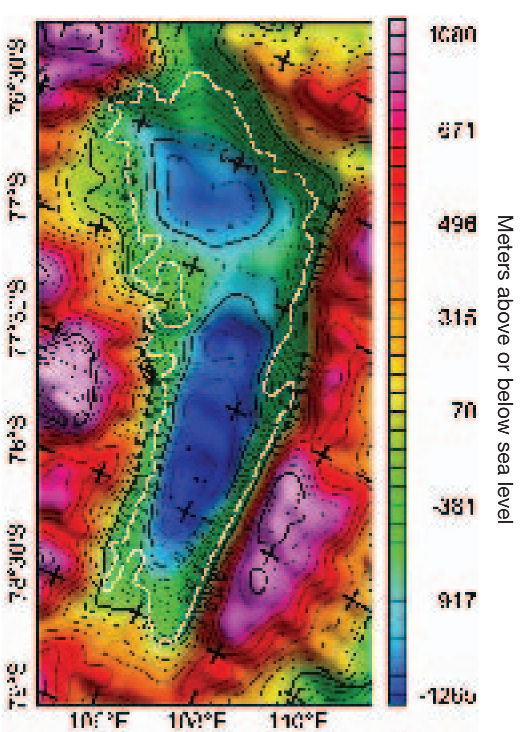
Using laser altimeter, ice-penetrating radar, and gravity measurements collected by aircraft flying over the lake, **Michael Studinger** and **Robin Bell** of Lamont-Doherty and **Anahita Tikku**, then at the University of Tokyo, provided the first comprehensive map of the entire lakebed of Lake Vostok. Contrary to what scientists had assumed, they found that the lake is not a single basin, but rather is divided by a narrow ridge into previously unknown northern and southern sub-basins.

The water over the ridge is relatively shallow (200 meters or 650 feet deep), as compared with the rest of the lake, where the water ranges from roughly 400 meters (1,300 feet) deep in the northern basin to 800 meters (2,600 feet) deep in the southern. "The ridge between the two basins will limit water exchange between the two systems," Studinger said. "Consequently, the chemical and biological composition of these two ecosystems is likely to be different."

The scientists conclude that the arrangement of the two basins, their separation, and the characteristics of the water melting into them all may affect the circulation of water within the lake. For example, if the water in the lake were fresh, then saltier (and denser) water melted from the ice moving onto the top of the northern basin would sink to the bottom of that basin. That would limit the exchange of waters between the two basins and lead to very different conditions, and perhaps different life forms, within each.

Sediments falling to the bottom of the northern and southern basins may also be different. By observing melting and freezing patterns of ice moving over Lake Vostok, scientists believe that the northern basin should contain sediments of rock debris carried from land and deposited into the lake. The southern basin would not have these land deposits, but they would more likely contain sediment deposits that recorded environmental conditions that existed before the ice sheet sealed off the lake.

Scientists hope to explore these preserved clues to ancient life and climate conditions, but first must develop the technology to sample the undisturbed water and sediments deep beneath the ice without introducing contamination from above. The new comprehensive map of Lake Vostok provides essential information to guide further exploration of the lake.



Flying over Lake Vostok in a plane equipped with lasers, altimeters, ice-penetrating radar, and gravity sensors, researchers mapped the hidden lake buried beneath miles of Antarctic ice. They discovered a previously unknown ridge that divides the lake into two basins. The finding has significant implications for how to explore the lake and for the kinds of ecosystems scientists can expect to find in it.
Credit: Michael Studinger/NSF

Listening in the ocean, LDEO scientists hear quakes, whales, and the breakup of polar ice

UNDERWATER ACOUSTIC STUDIES HAVE A LONG and distinguished history at the Observatory, going back to seminal work in the early 1950s by Lamont founder Maurice Ewing and J. Lamar Worzel on the SOFAR channel–a low-velocity layer in the ocean that propagates sound energy efficiently over vast distances. For the past two years, Lamont-Doherty researchers have been "listening" for sound using arrays of hydrophones deployed in the SOFAR channel in the Indian Ocean.

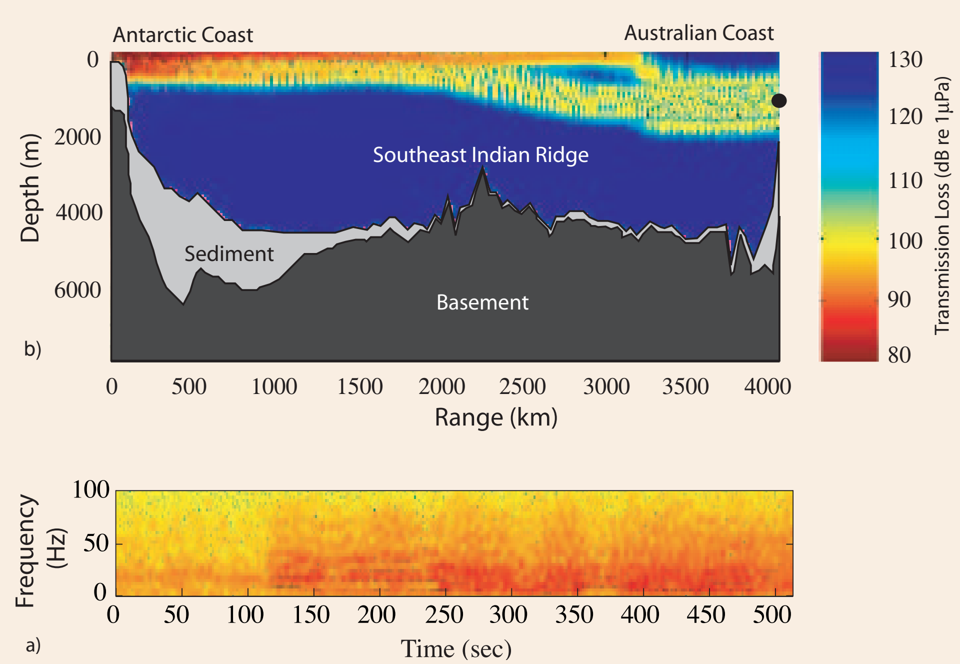
The arrays were designed for monitoring in support of the Comprehensive Test Ban Treaty. With them, scientists can identify the sources of energy generated by explosions in or just above the ocean.

But Lamont-Doherty scientists **Maya Tolstoy** and **Del Bohnenstiehl** also have used the hydrophone systems to isolate a variety of other sounds that they relate to both natural and anthropogenic sources. Data collected from the array have been used to address a diverse set of problems ranging from the seasonal migration of Antarctic blue whales to the earthquake interactions within the diffuse plate boundary zone separating India and Australia.

Most recently, they have been tracking the breakup of Antarctic ice using a set of unusual tremor signals, which are thought to represent resonance within a partially submerged ice mass. They have been able to detect sounds within the Indian Ocean near the equator that originated near the Antarctic coast more than 7,000 kilometers away.

These newly identified tremor signals represent significant but naturally occurring acoustic noise that propagates throughout the oceans. By triangulating these acoustic signals using the listening stations in the Indian Ocean, Bohnenstiehl and Tolstoy were able to locate regions where glacial ice enters the Southern Ocean and in some cases track its movement along the Antarctic margin.

Maya Tolstoy
Credit: Bruce Gilbert



Lamont-Doherty scientists Maya Tolstoy and Del Bohnenstiehl have used hydrophone systems in the oceans, deployed to monitor nuclear weapons tests, to isolate sounds from the breakup of Antarctic ice. Above, a range-dependent sound propagation model shows that despite some transmission loss, a 40-hertz signal originating near the Mertz Glacier and traveling across the South East Indian Ridge was still recorded by a hydrophone moored within the SOFAR channel near southwestern Australia, more than 7,000 kilometers away. Below, spectra of an ice-generated signal over time show that the signal's frequency is concentrated in frequency bands, or harmonics (red colors).

More than ever, the biosphere, in the form of humankind, is adding a new dimension, superimposing powerful stresses on Earth's delicately balanced climate system.

Arnold L. Gordon
Professor of Earth and Environmental Sciences, Associate Director, Ocean and Climate Physics Division
Credit: Bruce Gilbert

Archeaological records have revealed the dire consequences of abrupt and severe climate changes on human civilizations in the past. Today, year-to-year shifts in El Niño and in the great monsoons cause devastation for people in some regions and benefits for others.

Changes in Earth's climate—whether abrupt or slow, global or regional—have been going on throughout the planet's long history, and will continue. These changes are governed by complex interactions involving the atmosphere, the oceans, the cryosphere (ice), and the biosphere (living things).

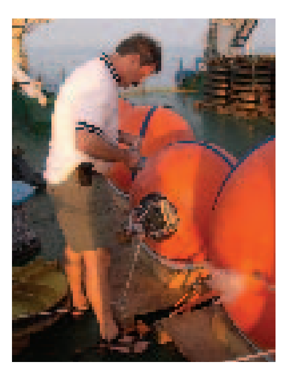
Understanding the natural variability of Earth's climate is complicated enough. But more than ever, the biosphere, in the form of humankind, is adding a new dimension, superimposing powerful stresses on Earth's delicately balanced climate system.

Human-induced changes to land surfaces and to the chemistry of the atmosphere, for example, may make the natural system prone to changes—perhaps relatively rapid ones. High latitudes are especially susceptible to warming that threatens the stability of permafrost fields and glacial and sea ice. Their melting may add fresh water to the oceans, which could lead to shifts in ocean circulation and, in turn, to changes in atmospheric circulation, which may last many centuries. Changes in Earth's hydrological cycle, whereby the oceans and atmosphere circulate water around the planet, could result in excessive rainfall and flooding in some areas, or droughts in others.

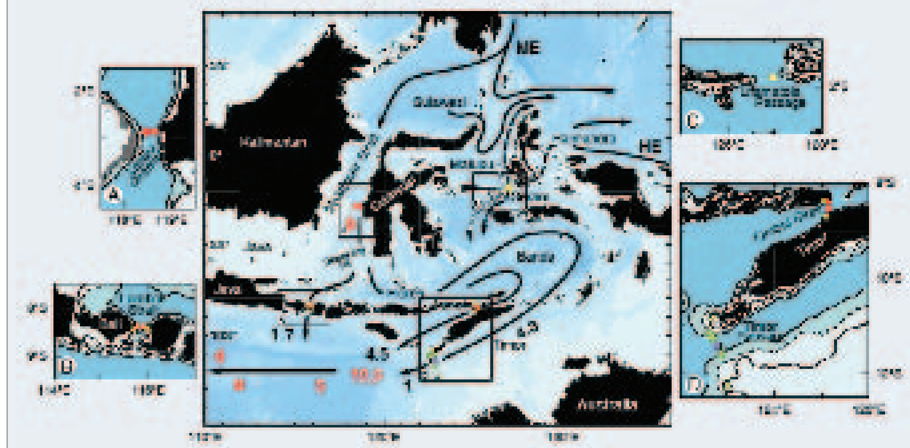
Scientists in the Division of Ocean and Climate Physics (OCP) delve into the mysteries of Earth's climate. They strive to understand the forces and processes that govern climate changes on timescales ranging from years to centuries. They explore how anthropogenic factors may alter the climate dynamic. And they seek to predict future trends in climate variability, an essential tool for planning how to safeguard humankind's future and the well-being of the planet.

To achieve these goals, OCP oceanographers make observations and collect data on expeditions that range from local waters, such as the Hudson River and the U.S. East Coast, to the remote frozen Southern Ocean and the balmy tropical seas of Indonesia. Others analyze data from satellites or records of past climates preserved in deep-sea sediments or glacial ice cores. Still others employ numerical models that simulate the dynamics of the climate system.

Close collaboration between observationalists and modelers, between oceanographers and climatologists, and with scientists from other divisions, notably with Lamont-Doherty geochemists, is a hallmark of the OCP Division and has led to significant advancements in the field of ocean and climate science. The following projects highlight the diversity of OCP researchers.



Crew members and scientists (far right), including Lamont-Doherty researcher Bruce Huber (right) prepare to deploy arrays of bottom-anchored moorings that measure the velocity, temperature, and salinity of waters from surface to depths in the Indonesian Throughflow.
Credit: Arnold Gordon



In 2003, Lamont-Doherty joined a multinational scientific expedition to deploy moored instruments over three years to measure the passage of ocean waters through the Indonesian Throughflow. The complex, island-filled passage is a critical chokepoint in the global ocean circulation system that also plays a fundamental role in the El Niño phenomenon and the Asian monsoon.

Inserts A-D show positions of INSTANT moorings. A) United States Makassar Strait Inflow moorings (red diamond) within Labani Channel. B and D) Sunda moorings in Ombai Strait, Lombok Strait, and Timor Passage: U.S. (red diamonds); France (purple square); Australia (green circles). Green x's represent U.S. shallow pressure gauge array. C) The Netherlands mooring within the main channel of Lifamatola Passage (yellow triangle).

The Indonesian seas: Where the Pacific flows into the Indian Ocean

INVESTIGATIONS OF CLIMATE CHANGE WOULD not be complete without a thorough understanding of the ocean. Like interlocking cogs in an engine, the ocean and atmosphere work together, moving heat and fresh water around the globe, from regions of surplus to regions of deficit, to drive Earth's climate system.

While the atmosphere envelops the globe, the ocean is segmented into individual basins, such as the Atlantic or the Pacific, connected by channels of varying dimensions. As a result, each ocean takes on distinct temperature and salinity properties and circulation characteristics. To equilibrate these differences with their neighbors, they exchange waters.

Atlantic waters, for example, are saltier and therefore denser than the Pacific's, and they sink to the abyss to propel a global system of deep currents that flows throughout the world's oceans. The Indian Ocean, confined to the planet's warm midriff and without access to the Northern Hemisphere, must transfer all its tropical heat to the Southern Ocean surrounding Antarctica. The atmosphere is coupled to these ocean dynamics and responds to them.

Lamont-Doherty oceanographers have long investigated inter-ocean exchanges throughout the world, charting ocean circulations around Antarctica and along the southern rim of Africa. More recently, they have been exploring the flow of Pacific water into the Indian Ocean through the complex, island-filled passages of the tropical Indonesian seas. The exchange of warm waters through this inter-ocean connector, called the Indonesian Throughflow, may play a fundamental role in the El Niño phenomenon and in the timing and strength of the Asian monsoon, whose moisture comes from water evaporating from the Indian Ocean.

In December 2003, oceanographers from Indonesia, France, the Netherlands, United States, and Australia launched the International Nusantara Stratification and Transport (INSTANT) program. Oceanographers **Arnold Gordon** and **Dwi Susanto** represent Lamont-Doherty in this international partnership.

For the first time, scientists will be able to measure unambiguously the magnitude and properties of the inter-ocean transport between the Pacific and Indian Oceans.

The INSTANT field program consists of a three-year deployment of an array of bottom-anchored moorings that will directly measure the velocity, temperature, and salinity of waters in many passageways of the Indonesian Throughflow, from surface to depth. For the first time, scientists will be able to measure unambiguously the magnitude and properties of the inter-ocean transport between the Pacific and Indian Oceans.

The array will also provide unprecedented data elucidating many other complex, fascinating, and previously unresolvable scientific mysteries in this tropical region. The Lamont-Doherty team, for example, is examining how intense tidal action over the rugged seafloor in Indonesian seas mixes Pacific water coursing through them, changing the water's characteristics before it reaches the Indian Ocean.

Antarctic ice shelves: Where ice meets the ocean

BETWEEN AIR AND OCEAN, ICE ALSO PLAYS A crucial role in the Earth's climate dynamics. Our planet's warming atmosphere has led to concern that its ice sheets will melt, sending now-frozen water into the ocean and accelerating the rise of global sea level. Indeed, ice shelves have quickly disintegrated along the Antarctic Peninsula, where air temperatures have risen several degrees during recent decades, and surface melt ponds have penetrated cracks in the ice.

Some ice shelves are melting at their bases 10 to 100 times faster than expected.

Scientists have long known that a warmer atmosphere could carry more moisture poleward, potentially depositing enough snow on Antarctica's vast, sub-freezing interior to more than balance the calving of icebergs. However, this view largely ignored direct melting of the ice shelves that fringe nearly half of the Antarctic continent.

On recent voyages into the relatively inaccessible Amundsen and Bellingshausen Seas, oceanographer **Stan Jacobs** and colleagues found evidence that some ice shelves are melting at their bases 10 to 100 times faster than expected. These results pointed to additional ice sheet vulnerabilities due to climate change.

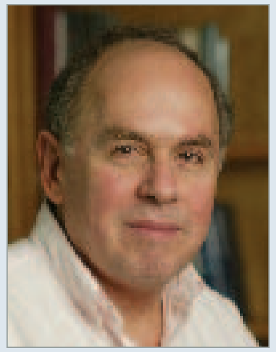
Combining the ocean data with circulation models and satellite measurements, they showed that ice shelves are melting at higher rates near deep "grounding lines," where thick ice streams move off the land and begin to float. Ice melts faster where it lies deeper in the ocean because the freezing point of seawater declines with increasing pressure. Melting rates will also increase as the ocean warms. Together these processes can allow seawater to penetrate deeper under the grounded ice and corrode it.

Furthermore, thinning an ice shelf weakens its frictional contacts with shorelines and embedded islands, and may permit inflowing ice streams to move more rapidly into the sea. Consistent with this idea, recent observations have shown that ice stream velocities have increased where ice shelves have thinned or collapsed entirely.

Lamont oceanographers also reported geochemical evidence for higher ice melting and long-term freshening of the ocean near Antarctica. It remains to be determined whether average melting is high and steady or has recently accelerated.

Jacobs and colleagues have developed plans to return to the Amundsen Sea with an autonomous underwater vehicle, which can make measurements beneath the ice shelves. The ice shelves often extend over deep troughs that were gouged by glaciers grounded on the seafloor during the last ice age. It may be no coincidence that Antarctica's ice is thinning and moving fastest in regions where the warmest deep water gains access to these troughs, and thus to the retreating grounding lines.

In recent years, massive icebergs like this one have calved from Antarctic ice shelves, raising concerns of melting ice sheets and rising sea levels. Lamont-Doherty oceanographer Stan Jacobs found evidence that some ice shelves are melting 10 to 100 times faster than expected at their "grounding lines," where thick ice streams move off land and begin to float in the ocean. *Credit: Josh Landis/National Science Foundation*



Yochanan Kushnir
Credit: Bruce Gilbert

The past two decades of the 20th century brought unprecedented global warming to the planet and striking changes in regional climate.

CICAR: Where past and future climates meet

TO ENHANCE THEIR ABILITY TO PREDICT FUTURE CLIMATE CHANGES, SCIENTISTS can use two approaches: They can reconstruct how the climate system behaved in the past to see what it is capable of, and under what circumstances. They can gain similar understanding by using numerical models that incorporate the known physics that drive the climate system. Merging these two approaches can have a synergistic effect.

Lamont-Doherty Earth Observatory (LDEO) scientists have joined colleagues at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton, N.J., in a unique collaboration between paleoclimatologists and experts in climate dynamics and modeling. LDEO and GFDL scientists are set to explore climate evolution from the medieval period to the modern industrial age and into the future.

In 2003, NOAA established the Cooperative Institute for Climate Applications and Research (CICAR), a collaborative venture between Columbia University and NOAA. CICAR is a recent addition to a nationwide network of a dozen similar partnerships between NOAA laboratories and nearby academic and research institutions that conduct research on Earth's oceans, coasts, atmosphere, and climate, said **Yochanan Kushnir**, Doherty Senior Research Scientist at LDEO and CICAR Director.

Now, under one of CICAR's themes, researchers have begun to study the evolution of Earth's climate during the past 1,000 years and into the greenhouse future, said **Richard Seager**, Doherty Senior Research Scientist. About 1,000 years ago, during an era called the Medieval Warm Period, much of the Earth was as warm as it was in the early 20th century, allowing Vikings to colonize Greenland. But the Vikings abandoned Greenland as Earth's climate later cooled. During the following "Little Ice Age," the Earth was cooler than in the 20th century, and glaciers advanced worldwide. The Little Ice Age ended in the late 19th century to be followed by a warming climate in the 20th century.

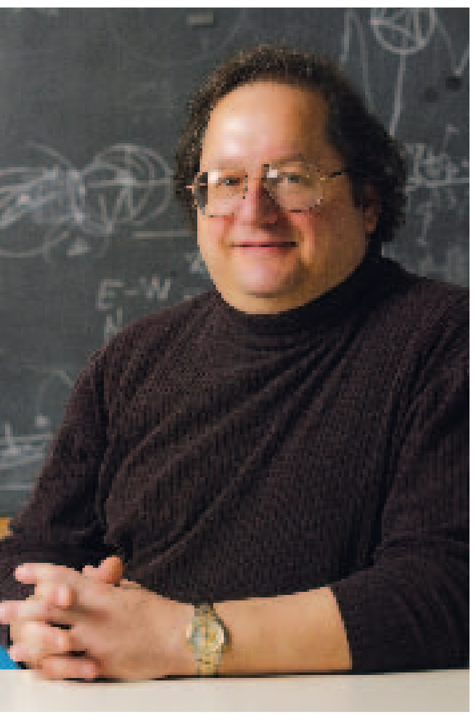
The past two decades of the 20th century brought unprecedented global warming to the planet and striking changes in regional climate. In the past several years, drought has struck the American West. Lamont-Doherty researchers have shown that chronic drought also occurred in the American West during the Medieval Warm Period and once again has become more common in the 150 years since the Little Ice Age ended, including the terrible Dust Bowl drought of the 1930s.

Is the current drought in the West a random event or the beginning of a climate that is more arid than in recent historical experience? A long-term perspective of climate change over the past millennium and knowledge of how the climate system responded in the past to stresses will provide deeper understanding of the character, mechanisms, and consequences of climate changes influenced by human activities, such as fossil fuel burning.

Other important research projects under CICAR are the advancement of El Niño prediction and the unravelling of the perplexing phenomenon of abrupt climate change.

Tree stumps rooted along a river bottom in West Walker River Canyon in Eastern California are evidence that trees once grew in this region during medieval times, when megadroughts dried up the river. The trees were drowned and killed when drought conditions diminished and river levels rose again. Lamont-Doherty climate researchers are working to understand the evolution of climate conditions over the past millennium that have spawned cycles of droughts and their opposite—called pluvials—in North America.
Credit: Scott Stine

An explosion of new geophysical and geological data has given us the ability to probe the Earth with ever-increasing accuracy.



Art Lerner-Lam
Doherty Senior Scientist, Associate Director, Seismology, Geology, and Tectonophysics Division
Credit: Bruce Gilbert

This has been an especially exciting time in the solid-Earth geosciences. An explosion of new geophysical and geological data has given us the ability to probe the Earth with ever-increasing accuracy. New instruments are adding more—and more precise—observations. At the same time, rapidly emerging developments in geophysical theory and computation are advancing understanding of complex geodynamic processes in Earth's crust, mantle, and core.

Using all these tools, staff and students in the Division of Seismology, Geology and Tectonophysics (SG&T) are conducting new integrated explorations of the geodynamic mechanisms underlying plate tectonics, the evolution of the planet, and earthquakes. Beyond our fundamental research, we demonstrate the more immediate impacts of our work by developing the scientific tools needed to reduce the risks of natural disasters and nuclear weapons proliferation. And we continue the long tradition of Lamont-Doherty observational science by coordinating earthquake-monitoring activities in the greater New York area and elsewhere in the Northeast.

We are gaining new insights about brittle and ductile deformation processes in the Earth's crust and lithosphere that lead to faulting, localized strain, and earthquakes. New hyper-accurate maps of seismicity are helping to reveal the morphology of major faults and the interactions among faults in complex plate boundaries. Our Rock Mechanics Laboratory conducts experiments to calibrate the physical properties and processes involved in fundamental, smaller-scale geodynamic factors such as fault friction, deformation in brittle rocks, and fluid flow.

Structural seismologists in the Division analyze global and regional seismic data to refine images of Earth's crust, mantle, and core. By deploying temporary seismograph networks dedicated to specific geodynamic targets, we are able to image heterogeneities in the crust and mantle with very high resolution. We have also developed new capabilities to deploy high-fidelity ocean-bottom seismographs for more than a year, expanding seismological investigations of important and previously inaccessible areas of the globe.

But structure and source seismology provide only snapshots of the current state of the planet. To learn about its history, our geologists interpret the record preserved in structural relationships of rocks and sediments. Recent results have provided new insights on the evolution of the Basin and Range in the western United States and the mechanisms by which Earth's crust is extended, one of the fundamental processes shaping Earth's surface.

Scientists and technicians in Lamont-Doherty's Ocean-Bottom Seismometer Lab have designed and built new-generation, long-term seafloor seismometers that expand seismologists' ability to collect seismic data in remote oceanic regions.
Credit: Daniel Weiss

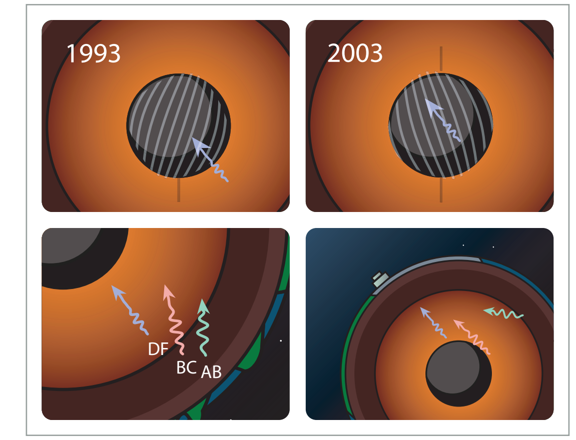
Earthquakes reveal the rotation of Earth's inner core

EARTH'S SOLID INNER CORE IS AN INTRIGUING but difficult target for investigation. Seismologists have to resort to what physicians would call noninvasive procedures: To explore the core's composition and dynamics, they analyze seismic waves that have traveled through it. But the liquid outer core often blocks or refracts some types of seismic waves. Unknown heterogeneities in the mantle and the core-mantle boundary can also affect seismic waves, masking subtle structures in the inner core.

To make progress, seismologists must perform exacting analyses of core-traversing seismic waves in hundreds or thousands of seismogram records. Doing that, Lamont-Doherty seismologists **Xiaodong Song** and **Paul Richards** made an astonishing and controversial finding in 1996: The inner core is rotating faster than the rest of the Earth. This result led to a flurry of research and competing and inconsistent claims.

To strengthen the evidence for rotation, seismologists must find records of seismic waves that were generated by earthquakes that occurred in essentially the same location and that traveled similar pathways through the inner core to the same recording station. These are rare because they also require earthquakes and stations at high latitudes near the poles of the planet. Further, the earthquakes must have occurred several years apart, so that there is time for the inner core's rotation to affect seismic wave travel times.

With a painstaking examination of earthquake records between 1982 and 1998, Richards and his colleague **Anyi Li** found 17 earthquake pairs, or doublets, that occurred in close proximity. Only one of these doublets provided seismic waves with a measurable "core phase," but Li and Richards were able to make an incontrovertible measurement of a change in seismic wave travel time over the years between the two events. This observation rules out the possibility that the rotations of the inner core and the Earth are in lockstep, and confirms the earlier finding that the inner core is rotating eastward, between 0.4° and 1° faster than the rest of the Earth each year.



[*left*] The wave labeled DF travels through the inner core, and for a pair of repeating earthquakes (in 1993 and 2003) DF is observed to travel faster for the later event, compared with the waves BC and AB, which did not travel through the inner core. One explanation for the time change is that between 1993 and 2003 the inner core—which is composed largely of crystalline iron—has rotated, thus bringing the path of DF waves into better alignment with the fastest path through this part of the Earth's deepest interior.

[*right*] Paul Richards
Credit: Ronnie Anderson

A new method to home in on earthquake hypocenters

TO UNDERSTAND EARTHQUAKES, SEISMOLOGISTS investigate faults, the fractures in Earth's crust where rocks slide or rupture suddenly to generate earthquakes. Hypocenters—the precise locations where earthquakes start—are a key measurement. They help elucidate the complex structure and relationships of neighboring faults—the underlying geological architecture that leads to earthquakes.

But surprisingly, pinpointing accurate locations for this most fundamental feature of earthquakes is difficult. Seismographs often are not ideally positioned to record the most scientifically useful earthquake-generated seismic waves. Often seismologists have difficulty interpreting seismic waves traveling through the crust, because they have no information about variations in rock types that the seismic waves are traveling through.

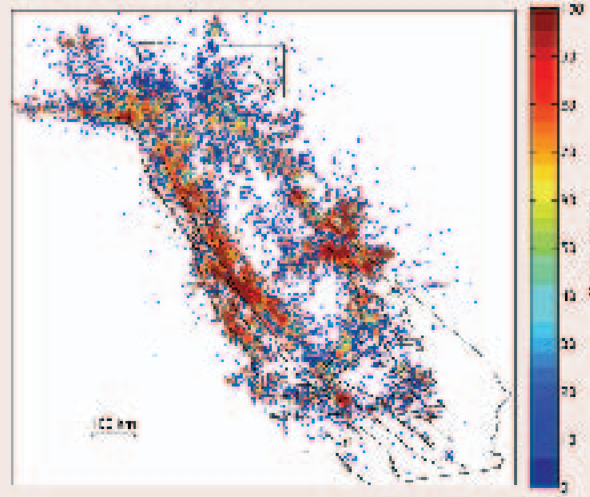
Some, but not all, of these difficulties can be reduced by finding hypocenter clusters that have generated multiple earthquakes. Such clusters produce similar seismic wave signals recorded by the same seismographs.

In an exhaustive study, Lamont-Doherty seismologists **David Schaff** and **Felix Waldhauser** examined 225,000 California earthquakes and 15 million individual seismograms (processing some 26 billion seismic wave measurements). They found that an unexpectedly large number of these earthquakes—90 percent—had seismograms similar to at least one other earthquake recorded at four or more seismic stations. By cross-correlating the waveforms from these "repeated" quakes, the scientists improved their ability to locate earthquake hypocenters by a factor of 10 to 100.

Using this new waveform cross-correlation, or WCC, method, Schaff and Waldhauser developed much more detailed pictures of the San Andreas Fault system around San Francisco. Schaff also processed huge amounts of seismographic data from Chinese networks, and using the WCC method, he believes he has located hypocenters with an accuracy approaching 100 meters. Such precise measurements, leading to finely resolved maps of complex fault systems, advance our abilities to quantify seismic hazards.

In an exhaustive study, Lamont-Doherty seismologists David Schaff and Felix Waldhauser examined 225,000 California earthquakes and 15 million individual seismograms recorded by the Northern California Seismic Network (NCSN). They found that an unexpectedly large number of these earthquakes—90 percent—occurred within a few kilometers of each other and produced similar seismic wave signals recorded at four or more seismic stations (the minimum number required to locate an earthquake's hypocenter). By cross-correlating the waveforms from these "repeated" quakes, the scientists improved their ability to locate earthquake hypocenters by a factor of 10 to 100.

Using this new waveform cross-correlation method, Waldhauser and Schaff are now pinpointing more accurate locations for a large percentage of past California earthquakes—a project funded by the U.S. Geological Survey. Such precise measurements, leading to finely resolved maps of complex fault systems, advance our abilities to quantify seismic hazards.



Casting doubts on old theory explaining the formation of the U.S. West

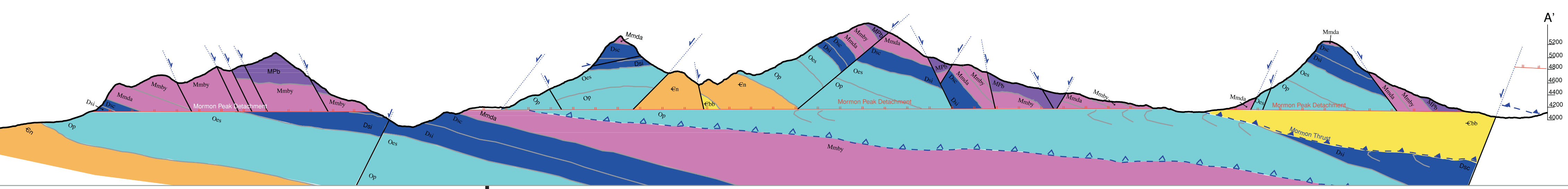
FOR MORE THAN A DECADE, MARK ANDERS, Nicholas Christie-Blick, and colleagues have played the role of dogged skeptics about a widely accepted theory explaining a fundamental Earth-shaping process: how Earth's crust is extended to create the landscape in such places as the Basin and Range province in the western United States. According to widely accepted thinking, massive crustal blocks that lie atop large, gently sloping (so-called low-angle) normal faults slide downward over millions of years—stretching and thinning Earth's upper crust.

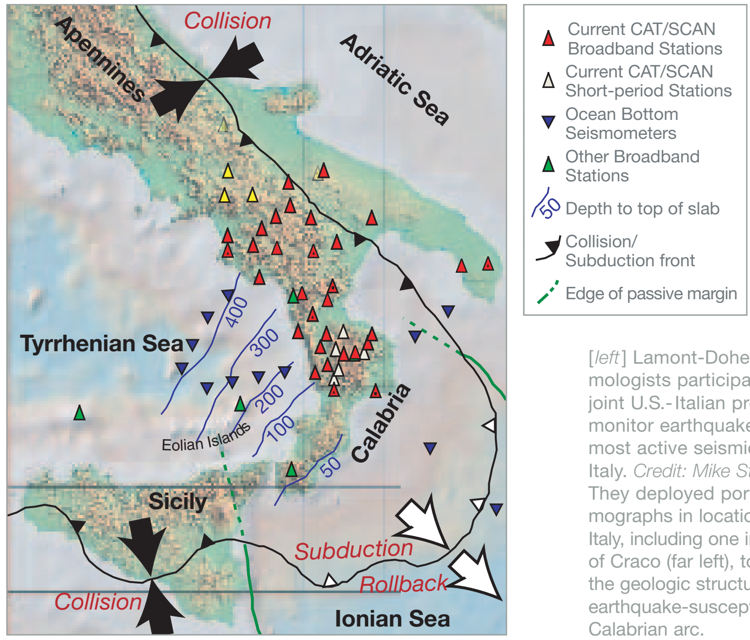
In the mid-1990s, Anders and Christie-Blick re-examined an apparent boundary in seismic images of subsurface rock layers in the Sevier Desert in Utah, which scientists had long interpreted to be a low-angle fault. They analyzed rock specimens cored from just above and below the presumed fault and found no evidence of deformation that would have formed if the rocks ever slid past one another. They concluded that the seismic feature, long believed to be a fault, was not a fault.

More recently, Christie-Blick and graduate student **Byrdie Renik** have investigated another geological icon regarded as definitive evidence for extreme extension: the Eagle Mountain Formation in Death Valley, California. Scientists had found rock fragments from a large igneous rock body, or batholith, which they believed were deposited at an alluvial fan—a common desert landform constructed where floods emerge from a narrow gorge into a broad valley. The maximum extent of alluvial fans is about 20 kilometers, but the rock fragments were found more than 100 kilometers away from the batholith. It was concluded that the extensional movement of crustal blocks accounted for the wider separation of the fragments from their source.

Christie-Blick and Renik took a closer look at the geological evidence. The rock fragments turned out to be well-rounded, not angular as would be expected in alluvial fan deposits. They found a host of other depositional details more closely pointing to an accumulation in rivers channels rather than at alluvial fans. That casts new doubts on published interpretations of how and by how much the crust was extended across the Death Valley region.

Exploring how the landscape in the American West was created, geologist Mark Anders and graduate student Chris Walker have studied the Morman Mountains in Nevada (cross-section below). Scientists had believed that Earth's crust was extended in the area when crustal blocks slid along a low-angle fault. But Anders' and Walkers' early results suggest that the "fault" is really the surface of a huge (100-square-kilometer) landslide, and therefore does not extend the crust at all. *Credit: Chris Walker*





[*left*] Lamont-Doherty seismologists participated in a joint U.S.-Italian project to monitor earthquakes on the most active seismic belt in Italy. *Credit: Mike Steckler.* They deployed portable seismographs in locations across Italy, including one in the town of Craco (far left), to map the geologic structure of the earthquake-susceptible Calabrian arc. *Credit (far left): Bob Greschke*

Lab launches fleet of new-generation seafloor seismometers

OVER THE PAST TWO YEARS, LAMONT-DOHERTY'S new Ocean Bottom Seismology (OBS) Laboratory has reached operational status. The OBS engineering group, led by Spahr Webb, has completed construction of a fleet of 60 ocean-bottom seismometers and has deployed them in the Pacific near the Mariana Islands and in the Tyrrhenian Sea. This low-power, broad-bandwidth design provides high-fidelity recordings of natural seismicity for periods extending beyond one year. This significant advance expands seismic coverage into remote, previously inaccessible oceanic regions representing 70 percent of Earth's surface and provides seismologists with more observations that can elucidate oceanic mantle dynamics. Webb and his group are developing new instrument capabilities that should allow even better fidelity and longer duration. The OBS Lab is part of a national facility that provides and operates these instruments for the wider scientific community.

A renewed emphasis on reducing natural hazard risks

THE SG&T DIVISION INTERACTS CLOSELY WITH the Earth Institute to apply new results from basic studies of earthquakes, landslides, volcanoes, and other hazards to policies that can reduce risks to life, property, and economic prosperity. Over the past few years, SG&T scientists have participated in pilot studies and policy design projects that have provided assistance to partner institutions in other countries, as well as to international development organizations and humanitarian agencies. We have been able to demonstrate that well-founded assessments of exposure to natural hazards can lead to shifts in urban development and investment in infrastructure that lead to safer communities. For example, a Lamont-Doherty seismological team led by **Leonardo Seeber** and **Art Lerner-Lam** has worked with Italian colleagues in the active seismic belt in the Calabria region on the toe of the Italian peninsula to identify areas where earthquake and landslide hazards may be higher than previously suspected.

R/V *Ewing*'s forte is using sound energy to image seafloor and subseafloor strata—not unlike the way CT scans and sonograms are used in medicine to "see" within the human body.

Paul Ljunggren
Senior Staff Associate,
Marine Superintendent
Credit: Bruce Gilbert

In 2002-04, Lamont-Doherty Earth Observatory's signature ship, R/V *Maurice Ewing*, supported 10 research expeditions conducted by dozens of scientists from many institutions—through two oceans (Pacific and Atlantic) and three seas (Caribbean, North, Norwegian), over 60,425 nautical miles, from the coast of Oregon to Norway, and back to the Pacific. Foreign countries visited included Mexico, Costa Rica, Panama, Norway, Barbados, and Bermuda. *Ewing* transited the Panama Canal twice.

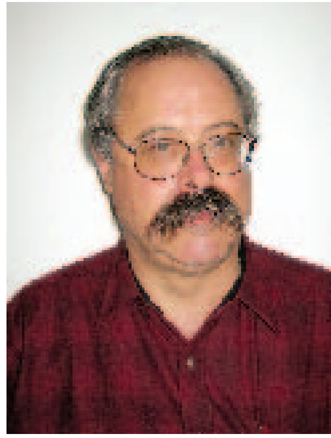
***Ewing*'s forte is its Multichannel Seismic (MCS) capabilities, using sound energy to image seafloor and subseafloor strata—not unlike the way CT scans and sonograms are used in medicine to "see" within the human body. *Ewing* has a 20-airgun array that produces seismic energy and a 480-channel, 6-kilometer-long hydrophone array and acquisition system, which records seismic energy reflected back from rock layers beneath the ocean floor. These features make *Ewing* the only ship in the U.S. academic research fleet capable of performing MCS surveys around the world.**

Not surprisingly, eight of the ship's cruises included seismic research. Lamont-Doherty researchers were principal investigators and chief scientists on two of these. Lamont-Doherty geophysicist **Suzanne Carbotte** led a comprehensive survey of the Juan de Fuca Ridge off the coasts of Washington state and Vancouver, Canada, using *Ewing*'s underway geophysical acquisition systems (magnetics, gravity, swath bathymetry and reflection profiling). They provided the first detailed images of the magma chambers and geological plumbing system that feed the mid-ocean ridge, as well as deeper structures including the Moho, the boundary between the ocean crust and the underlying mantle.

Other cruises dominated by seismic work included investigations of:

- The shallow plumbing system and heat source that drive the formation of the large TAG (Trans Atlantic Geotraverse) hydrothermal vent system and mineral deposit on the Mid-Atlantic Ridge.
- The Støregga submarine slide, a colossal failure of the continental slope off Norway that may have converted solid methane hydrate deposits on the seafloor into large quantities of methane (a greenhouse gas) released into the oceans and/or atmosphere.
- Hess Deep, where transform faulting has exhumed the oceanic crust-mantle transition from its normal position deep in the crust, raising it close to the seafloor.
- The northeastern boundary between the Caribbean and South American tectonic plates, where transcurrent motion across a major strike slip fault is rotating the islands of Aruba, Bonaire, and Curacao.

In 2004, Lamont-Doherty purchased the *Western Legend*, a former commercial seismic exploration ship, with funds provided by the National Science Foundation. The ship will be retrofitted and become the Observatory's new research vessel.
Credit: John Diebold



John Diebold
Research Scientist,
Marine Science Coordinator
Credit: Doug Brusa

In May 2003, Lamont-Doherty scientists **Maya Tolstoy**, **John Diebold**, and **Spahr Webb** made calibrated measurements of *Ewing*'s seismic source levels. These are the first broadband measurements of this kind ever carried out and are crucial to improving our understanding of the impact these and similar seismic sources might have on marine mammals and other sea life.

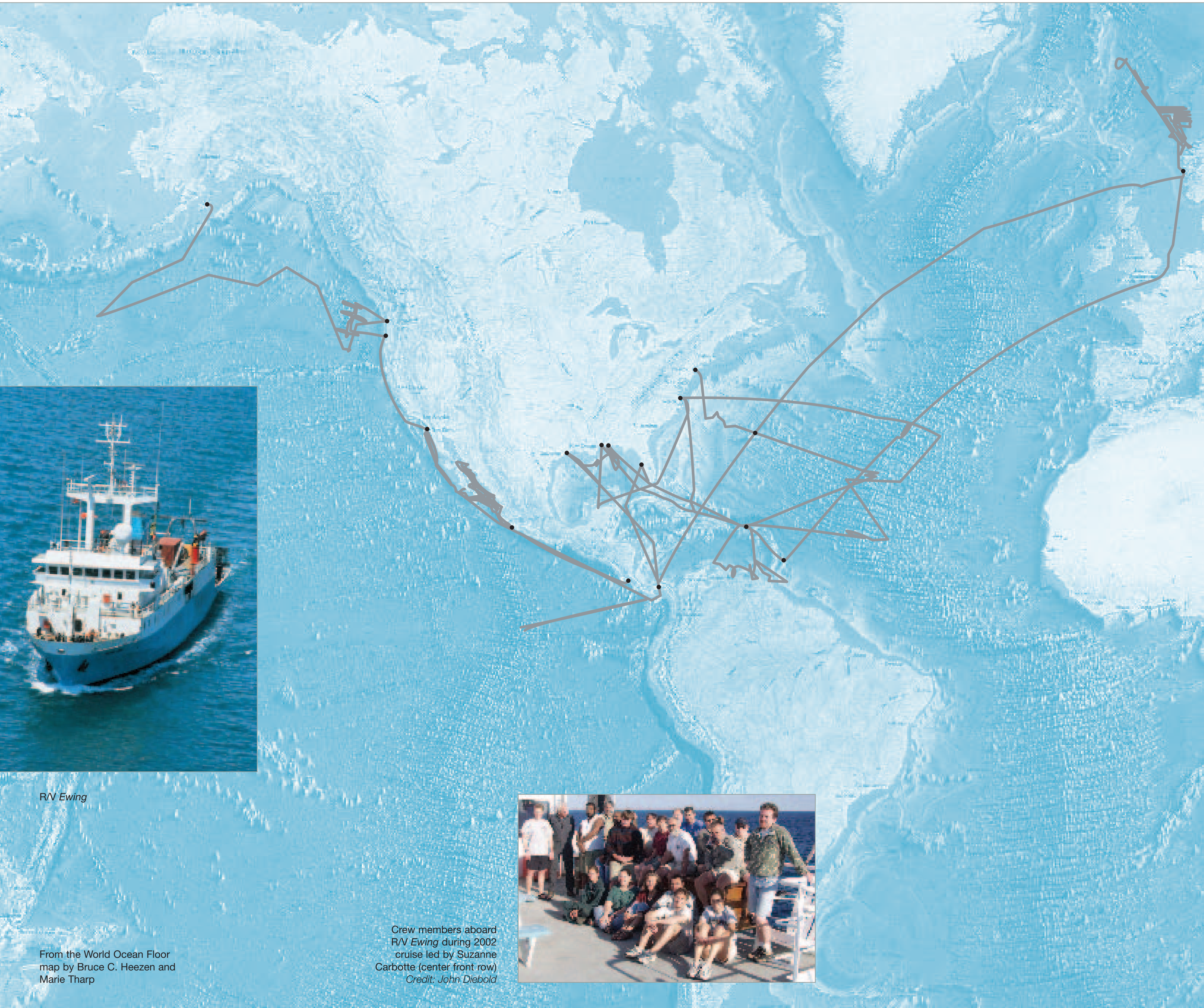
These two years have seen an increase in direct observation and other studies of marine mammals. In June 2003, *Ewing* supported a sperm whale monitoring program in the northern Gulf of Mexico, with scientists from LDEO, Woods Hole Oceanographic Institution, and Texas A&M University. It was jointly funded by the National Science Foundation (NSF), the Office of Naval Research, the U.S. Department of the Interior's Minerals Management Service (which assures that oil and gas operations on outer continental shelf leases are conducted in a manner that reduces risks to the marine environment), and the International Association of Geophysical Contractors, representing companies that conduct geophysical exploration for oil and gas.

During this program, sperm whales were detected visually and by listening for their distinctive underwater vocalizations. Then pods of whales were tracked, using the same methods, and eventually "tagged" with temporary data loggers and tracking devices attached with suction cups. In several cases, the final step was to carefully expose tagged whales to low-level sounds made by oil exploration seismic sources, in an effort to determine their behavioral response.

In September of 2004, NSF provided $20 million to Lamont-Doherty to replace *Ewing*, which has accumulated more than half a million miles in its service to science and exploration of ocean and deep Earth processes. The funding will support the purchase and refitting of a ship from Western Geco Inc., which has operated her for several years as a commercial seismic exploration vessel under the name *Western Legend*. Following a year-long outfitting with modern laboratories and scientific equipment, she will become the world's most capable academic research vessel utilizing acoustic and seismic technologies.

The seismic receiving systems used by *Western Legend* are substantially more sophisticated than the *Ewing*'s. This will greatly improve capabilities of imaging the Earth's deep interior without the need to increase the level of sounds transmitted into the ocean. This is fundamentally important to the research community's ability to make progress in its studies of the Earth's environment while minimizing possible impacts upon marine life.

Following a year-long outfitting with modern laboratories and scientific equipment, the *Western Legend* will become the world's most capable academic research vessel utilizing acoustic and seismic technologies.



R/V Ewing

Crew members aboard R/V *Ewing* during 2002 cruise led by Suzanne Carbotte (center front row) *Credit: John Diebold*

From the World Ocean Floor map by Bruce C. Heezen and Marie Tharp

Schedule for R/V Ewing (July 2002 – June 2004)

CRUISE DATES	PRINCIPAL INVESTIGATOR INSTITUTION	PORTS
2002		
June 14 - July 3	Marie Eble Pacific Marine and Environmental Lab/NOAA	Kodiak, AK Astoria, OR
July 8 - August 7	Suzanne Carbotte Lamont-Doherty Earth Observatory	Astoria, OR Newport, OR
August 12 - September 6	Ingo Pecher/Nathan Bangs University of Texas - Institute of Geophysics	Newport, OR Newport, OR
September 8 - 12	TRANSIT	Newport, OR San Diego, CA
September 16 - October 30	Daniel Lizarralde Georgia Tech	San Diego, CA Manzanillo, Mexico
November 8 - 13	TRANSIT	Manzanillo, Mexico Costa Rica
November 14 - 19	Kevin Brown Scripps Institution of Oceanography	Costa Rica Panama
November 21 - 28	TRANSIT	Panama Norfolk, VA
2003		
April 13 - May 16	Robert Dziak Oregon State University	Norfolk, VA San Juan, PR
May 18 - 23	TRANSIT	San Juan, PR Gulfport, MS
May 27 - June 24	Maya Tolstoy Lamont-Doherty Earth Observatory	Gulfport, MS Galveston, TX
June 28 - July 3	TRANSIT	Galveston, TX Panama
July 6 - 28	Gail Christeson University of Texas - Institute of Geophysics	Panama Panama
August 1 - 20	TRANSIT	Panama Bergen, Norway
August 29 - September 30	Stephen Holbrook University of Wyoming	Bergen, Norway Bergen, Norway
October 4 - 20	TRANSIT	Bergen, Norway Barbados
October 24 - November 9	Robert Sohn Woods Hole Oceanographic Institution	Barbados Bermuda
November 14 - 20	TRANSIT	Bermuda New York
2004		
February 20 - March 1	TRANSIT	Norfolk, VA Mobile, AL
April 7 - 14	TRANSIT	Mobile, AL San Juan, PR
April 18 - June 3	Alan Levander Rice University	San Juan, PR San Juan, PR
June 6 - 11	TRANSIT	San Juan, PR Tampa, FL
June 12 - 21	RUDDER REPAIR	Tampa, FL
June 22 - July 10	TRANSIT	Tampa, FL San Diego, CA

The need for professionals who understand the impacts of climate on society, and vice versa, is acute, and grows ever more so as human activity alters the planet and its atmosphere.

William Menke
Professor and Chairman, Department of Earth and Environmental Sciences
Credit: Bruce Gilbert

The Department of Earth and Environmental Sciences (DEES) occupies a unique position. It takes advantage of facilities and personnel at both the Lamont-Doherty Earth Observatory in Palisades, New York, and at Columbia University's Morningside Heights campus. By enabling student involvement in the Observatory's fertile and varied research endeavors, it enriches students' educational experience and opportunities while simultaneously enhancing the Observatory's research enterprise.

The Department helps students at the undergraduate, master's, and Ph.D. degree levels develop the analytic skills and the critical thinking they need to investigate the complex dynamics of the planet. Earth and environmental research has become increasingly interdisciplinary. Scientists now recognize the meaningful progress that can be attained by making connections between formerly separate fields such as climatology, ecology, oceanography, atmospheric science, geophysics, and geochemistry.

The role of earth and environmental sciences in the public arena has changed, too. The need for sound science to guide decisions on energy policy, environmental change, hazard mitigation, and poverty reduction is vital, as is the need for policymakers who understand that science.

The new Frontiers of Science course, now required for all Columbia undergraduates, exemplifies these new perspectives. "Frontiers" is taught by a team of 15 instructors from five of Columbia's top science departments, including DEES. It tackles the thorny problem of bringing forefront science to an extremely bright but also extremely intellectually diverse group of students, whose majors range from political science to Slavic languages to chemistry. It focuses on four scientific areas–biodiversity, brain physiology, global climate change, and nanophysics–each of which is in the midst of explosive discovery and at the center of public debate. Students are challenged to think like scientists as they critique journal articles, design and carry out experiments, and learn to formulate and articulate scientific analyses.

The Department of Earth and Environmental Sciences administrative staff (left to right): Missy Pinckert, Administrative Aide; Carol Mountain, Program Coordinator, and Mia Leo, Department Administrator
Credit: Bruce Gilbert

Building upon its expertise in climate modeling and climate prediction, the Department this year launched its Climate and Society master's program. The need for professionals who understand the impacts of climate on society, and vice versa, is acute, and grows ever more so as human activity alters the planet and its atmosphere. The 12-month program offers decision-makers clear and reliable guidance on impending climate shocks, as well as practical information and tools to deal with their consequences.

In addition to the Department's 40 regular and adjunct faculty members, another 90 Ph.D.-level research scientists at the Observatory play critical roles in advising and supporting students and directing student research programs. The ratio of Ph.D. scientists to Ph.D. students is more than one to one. The intellectual firepower of this combination is remarkable. Students are full partners in the discovery process and are often the originators of the most revolutionary and paradigm-changing ideas.

The Department's more than 100 graduate students generate an extraordinary level of excitement. They fan out into new territories, ranging from Antarctic glaciers to Icelandic volcanoes to the blue waters of the equatorial Pacific. They bring back new measurements, observations, samples, insights–not to mention fascinating tales. And they break new ground developing laboratory techniques, writing software, and designing new instrumentation.

Members of the Solid Earth System class get a close-up view of the Ramapo Fault on a field trip to Kakiak Park (New York).

Is a career in research for me?

EVEN STUDENTS WHO LOVE SCIENCE OFTEN question whether they really want to pursue a career in research. The Summer Intern Program, jointly sponsored by the Department of Earth and Environmental Sciences, Lamont-Doherty Earth Observatory, and the Earth Institute at Columbia, provides a way for undergraduates to try out research before committing themselves to years of graduate training.

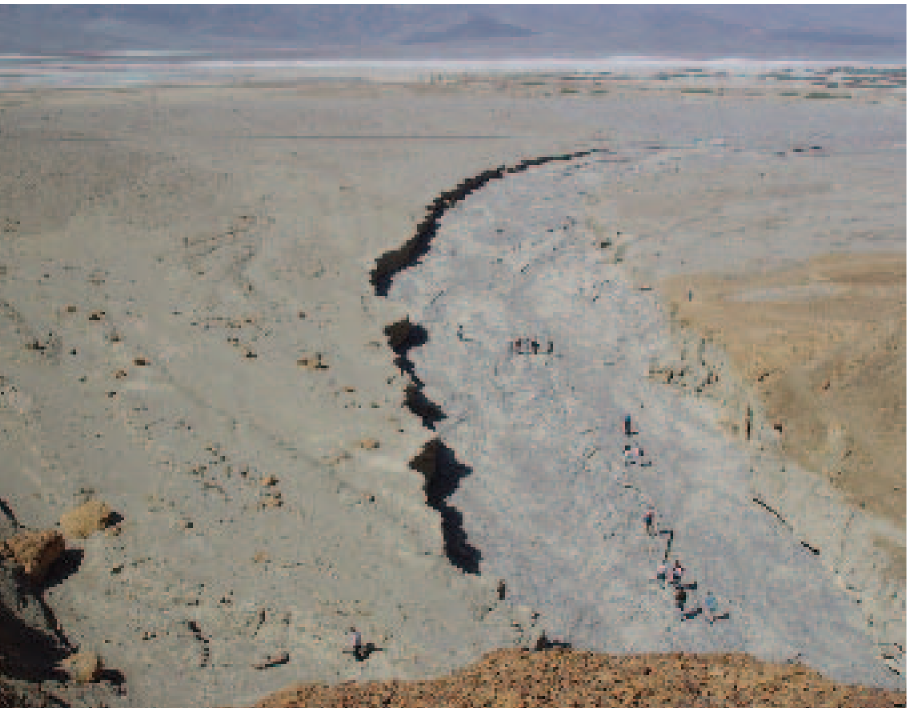
Interns work under the supervision of a Columbia scientist for eight weeks and see a research project through from start to finish. The process includes lab and fieldwork, data analysis, and the development of hypotheses and theories. It culminates in a mini-conference at which each intern presents his or her final results to the Lamont-Doherty community.

The interns are housed in a dormitory on the Barnard College campus, across Broadway from Columbia's main campus in Manhattan. They spend weekdays on the Lamont campus, but take part in the vibrant life of the Morningside Heights community during evenings and weekends.

About 40 percent of our interns go on to graduate school in earth and environmental sciences.

In addition to their individual research projects, the summer interns participate in a well-structured program of workshops and seminars. These are designed to give them an overview of forefront ideas in earth and environmental sciences, a chance to meet the people behind the research, and opportunities to talk about practical issues such as safety, ethics, and job placement.

"About 40 percent of our interns go on to graduate school in earth and environmental sciences," said **Dallas Abbott**, the program's coordinator. "Many of the rest become high school science teachers or enter one of the professions–law, finance, even air traffic control."



Students hike in Gower Gulch during a spring-break field trip to Death Valley, Calif. They explored the relation between alluvial fan sedimentation, erosion, and slippage along an active extensional fault forming the Black Mountains. Pronounced incision of the alluvial fan at this locality is due to diversion into Gower Gulch of the substantially larger Furnace Creek Wash drainage since 1941—testimony to the role of humankind in environmental change.
Credit: Nicholas Christie-Blick.

Death Valley days, or how I spent my spring vacation

THE DEPARTMENT OF EARTH AND ENVIRON-mental Sciences sponsors a student excursion that offers an alternative to the traditional spring break in Daytona Beach–one that is every bit as sunny, but distinctly drier.

Professor **Nick Christie-Blick** leads a group of 20 Columbia undergraduates into Death Valley, a spectacular part of the eastern California desert where they can wander back through more than one billion years of Earth history, in an area of outstanding natural beauty. The notable paucity of trees makes every hill-top a vista point.

The terrain is spectacular, with 11,000-foot-high mountains that rise from a valley floor that is actually several hundred feet below sea level. The valley abounds with earthquake faults, volcanic craters, ancient seabeds, fossiliferous rocks, the remnants of recent floods and landslides–a smorgasbord of effects from a wide range of geological processes.

The weeklong excursion uses a hands-on, trial-and-error approach to learning, which works well even with students with little or no background in geology. Scrambling over landscapes that are off the beaten track and seldom seen by tourists, the students focus on carefully chosen geological vignettes–a valley, hillside, or rock formation that embodies a geological process.

Armed with an array of geological tools, the students make detailed observations, recording them with sketches and notes, and interpreting what they see according to geological principles. Professor Christie-Blick then leads discussions–some of which develop into hot debates–in which students develop hypotheses to explain the geological processes that have shaped the rocks. The idea is to learn firsthand how to apply the scientific method.

The week is physically demanding, especially when the weather is hot. Students need ample supplies of sunscreen and water. They must watch where they walk, because of the often steep terrain, and where the sit, because of the occasional scorpion and rattlesnake. But most students find the experience both exhilarating and eye-opening.

Columbia undergraduates at China Ranch during the 2003 Spring Break Trip to Death Valley (California)
Credit: Nicholas Christie-Blick

"I love blending my background in forest ecology with the wider context of earth science. And I feel like I've just scratched the surface of what I can learn."

How will our forests adapt to climate change?

NEIL PEDERSON GREW UP IN A RURAL COUNTY IN NEW YORK AND SPENT A LOT OF time outside near his family's cabin in the Adirondacks. He earned undergraduate and master's degrees in forestry, seeking to speak for the trees. But when he came to Lamont-Doherty's Tree-Ring Laboratory (TRL), he learned how much the trees could tell us.

Restoring and managing forests, he realized, required looking beyond the trees, and even beyond the forests, to the broader context of the Earth itself.

"There is a 90 percent probability that the Earth's average temperature will rise significantly over the next 100 years," Pederson said. "Such a change in climate will likely have a significant impact on the growth and competitive abilities of trees in forested ecosystems."

The annual growth rings of long-lived trees have traditionally been analyzed to reconstruct past climate conditions, but Pederson has been using them to help predict how climate changes will affect forests in the future. The research circles back again: Trees use heat-trapping carbon dioxide for photosynthesis, so healthy forests could help mitigate climate change.

Pederson first came to the Tree-Ring Laboratory as a technician, but later enrolled as a graduate student. His research has focused on a familiar neck of the woods, the Hudson Valley, one of the most diverse forests in the eastern U.S. The valley's low-lying, warm, moist location between the Catskill, Taconic, Green, and Adirondack Mountains makes it a transition zone where many different southern temperate and northern boreal tree species co-exist at the limits of their ranges.

These attributes make the Hudson Valley an ideal natural laboratory to study how climate changes affect trees and forests. Using tree-ring analyses to study growth trends of several Hudson Valley species over the past century, Pederson has identified several critical factors that forest ecologists hadn't appreciated. Winter temperatures seem to limit tree growth more than summer temperatures, he found. But, counterintuitively, some species located in milder southern regions were more vulnerable to winter temperatures–because more continuous snow cover in northern regions provides a blanket of insulation that prevents freezing soils that would curtail tree growth.

Pederson has also exploited old samples in the TRL's renowned archives to ask new questions: Studying tree rings along the U.S. Eastern Seaboard, he found significant growth increases in trees over the past century. What's more, this growth spurt occurs even in the oldest trees–contrary to the notion that tree growth declines as trees age.

"I love blending my background in forest ecology with the wider context of earth science," Pederson said. "And I feel I've just scratched the surface of what I can learn."

Neil Pederson
Credit: Bruce Gilbert

"I love the interdisciplinary aspects of the work, blending chemistry, microbiology, hydrology, and geology."

Alison Keimowitz
Credit: Bruce Gilbert

Tapping into a well of exciting research

ALISON KEIMOWITZ LOVED THE WAY CHEMISTRY GOT TO THE HEART OF HOW THINGS worked, how the structure and interactions of atoms explained phenomena.

"My chemistry classes in college clarified the world," she said, "though I did spend a lot of time in basement laboratories."

When she contemplated graduate school, she said, "I wanted to stay in touch with the world, and with what the world needed–and get myself out of the basement every now and again."

Keimowitz visited Columbia and met geochemists **Jim Simpson**, **Martin Stute**, and **Lex van Geen**. At the time, the three were part of a large group of Columbia scientists immersed in an ambitious project to learn how, where, and why elevated levels of cancer-causing arsenic were infiltrating shallow aquifers that supplied groundwater to tens of millions of people in Bangladesh.

Here was an atomic-scale, chemical problem with global-scale, societally relevant applications. Keimowitz signed on, joining the effort to explore the factors that affect the mobilization and transport of arsenic in subsurface waters.

Her research has focused on two arsenic-tainted Superfund sites, slated by the federal government for extensive environmental cleanups. One is a capped landfill in Maine, from which two underground leachate plumes are moving through the subsurface, changing the chemistry of groundwater along the way. The plumes create a chemical environment that permits naturally occurring arsenic in surrounding rocks to leach out of the rocks and into the groundwater.

Her other field site is a former industrial plant in southern New Jersey that carelessly stored arsenic-containing herbicides and fungicides. Over five decades, hundreds of tons of waste arsenic were washed into soils, aquifers, groundwater, streams, and rivers that carried arsenic into lakes and estuaries far downstream.

In both cases–involving both naturally and unnaturally occurring arsenic sources–Keimowitz is investigating how arsenic moves through the environment and where it ends up. To understand this multi-faceted, dynamic process, Keimowitz examines samples of groundwater and surrounding rocks and sediments, takes hydrological measurements of groundwater flow, and performs laboratory experiments on materials from the sites. Such knowledge may provide the foundation to remediate arsenic pollution.

One remediation strategy she is investigating involves encouraging microbes in the environment near the landfill to use sulfate in their metabolism to form sulfides. These sulfides can react with arsenic to form arsenic sulfide minerals–thus immobilizing arsenic in a solid phase that doesn't get into groundwater.

"I love the interdisciplinary aspects of the work, blending chemistry, microbiology, hydrology, and geology," she said. The potential benefits to people and the environment are not incidental sources of gratification.

[*far left*] Undergraduate student Elise Baker explores a cave on a field trip to Monsly Park.

[*left*] Summer intern Peggy Hannon takes atmospheric transparency measurements before ascending to 5,000 feet in a hot-air balloon with her advisor Dr. Beate Liepert. Variations in atmospheric transparency are thought to cause dimming of sunlight, which affects the energy budget of the climate system.
Credit: Carmen Alex

Theses Defended (2002 – 04)

CANDIDATE	ADVISOR	DISSERTATION TITLE	DATE OF DEFENSE
Koutavos, Athanasios	J. Lynch-Stieglitz	Sea surface temperature variability in the eastern equatorial Pacific during the last deglaciation: multiproxy geochemical reconstructions.	November 26, 2002
Nagel, Jennifer M.	K. Griffin	The influence of energetic processes on plant success—comparative studies of species from various ecosystem types.	December 13, 2002
Luo, Zhengzhao	A. Del Genio W. Rossow	Investigation of tropical cirrus, their variability, evolution, and relation to the upper-tropospheric water vapor.	December 16, 2002
Liu, Jiping	D. Martinson D. Rind	Sea ice climatology, variations and teleconnections: observational and modeling studies.	February 19, 2003
Vranes, Kevin P.	A. Gordon	The intraseasonal to interannual variability of the Indonesian Throughflow.	April 28, 2003
Shaman, Jeffrey L.	M. Cane	Modeling and forecasting land surface wetness conditions, mosquito abundance, and mosquito-borne disease transmission.	May 9, 2003
Kelley, Maxwell	D. Rind	Water traces and the hydrologic cycle in a GCM.	May 19, 2003
Floyd, Jacqueline S.	J. Mutter	Seismotectonics of mid-ocean ridge propagation.	July 24, 2003
Liu, Li	J. Hansen M. Mishchenko	Optical characteristics of complex aerosol and cloud particles: remote sensing and climatological implications.	October 21, 2003
Cottrell, Elizabeth	D. Walker	Differentiation of the Earth from the bottom up: core lithosphere and crust.	May 7, 2004
Gier, Elizabeth J.	C. Langmuir	The geological implications of the basalts and sediment of the Lucky Strike Segment.	May 11, 2004
Song, Qian	A. Gordon	Modeling the effects of the Indonesian Throughflow on the Indian Ocean.	June 25, 2004
Thresher, Duane E.	D. Rind G. Schmidt	Multi-century simulations of LGM and present-day climate using an accelerated coupled GCM carrying water isotope tracers, with comparisons to ocean sediment/ice cores and observations.	June 30, 2004
Karspeck, Alicia R.	M. Cane	Predictability of ENSO on interannual and decadal timescales.	July 7, 2004
Granville, John P.	P. Richards	Understanding and resolving the systemic differences observed for teleseismic body-wave measurements.	July 9, 2004

A hole at the bottom of the ocean

Lamont-Doherty borehole researchers help lead ambitious new ocean drilling efforts

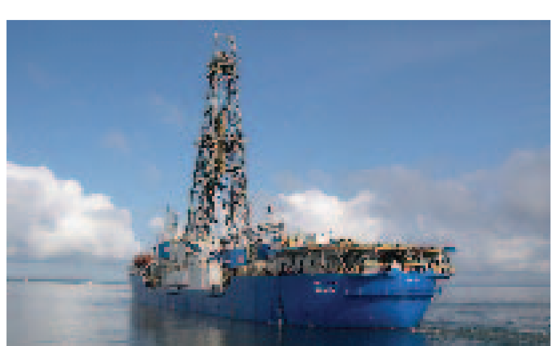
David Goldberg
Doherty Senior Scientist
Credit: Bruce Gilbert

WHEN THE WORLDWIDE OCEANOGRAPHIC COM-munity launched an ambitious, next-generation program in 2003 to drill samples of the seafloor, Lamont-Doherty assumed its customary position at the vanguard. Lamont-Doherty's Borehole Research Group will provide the international ocean drilling program with broad-based science as well as logging services–a research tool that the Lamont group pioneered for use by academic researchers.

Ocean drilling has been an essential means to probe through the layer cake of subseafloor rock strata to learn about the dynamics of the Earth and to reconstruct the history of its changeable climate. Researchers examine oceanic sediment and rock samples cored from the seafloor. But the drilling also creates a hole that offers a portal into the layer cake.

Into these seafloor holes, borehole researchers deploy a variety of electronic instruments that return to the surface within hours with a vast amount of information. As the instruments are drawn up the holes, they measure a wide range of rock properties every 15 centimeters or so, collecting a continuous record of the Earth's deep structure and the climate history preserved in the rocks.

Logging tools employ various acoustic, gamma-ray, and electrical measurement techniques to measure the elemental composition, temperature, magnetic properties, porosity, electrical resistivity, stratigraphy, and other characteristics of rocks. Logging tools penetrate sometimes more than a mile into subseafloor geological formations, providing a treasure trove of clues about the Earth's crust and the myriad processes that shape it. The properties and chronology of seafloor sediments also reveal a record of shifts in ocean temperatures, wind patterns, sea levels, and other climate-induced changes that have occurred over our planet's long history.



With its 202-foot derrick, the drill ship *JOIDES Resolution* (seen here off the coast of Astoria, Ore., in June 2004) has been a workhorse for the international scientific community since 1985.
Credit: Gilles Guerin

THROUGHOUT THE SHORTER HISTORY OF OCEAN drilling, Lamont scientists have always played a leading role. Ocean drilling for basic scientific research began in 1968 with the Deep Sea Drilling Project (DSDP), and it is no coincidence that Maurice Ewing and J. Lamar Worzel, Lamont's first director and associate director, were co-chief scientists leading the first ocean drilling cruise. The two were instrumental in establishing a consortium of oceanographic institutions to muster behind and coordinate an expensive ocean drilling effort–the Joint Oceanographic Institutions for Deep Earth Samples (JOIDES). JOIDES created DSDP and secured a drill ship, *Glomar Challenger*.

Ewing and Worzel's cruise to the Sigsbee Knolls in the Gulf of Mexico was the first of 96 DSDP drilling legs between 1968 and 1983, when DSDP matured into the Ocean Drilling Program (ODP). The new program expanded to include 22 international partners and a new ship, *JOIDES Resolution*, an oil exploration ship converted for scientific research.

During DSDP, scientists focused on studying drilled cores retrieved from the ocean bottom. Logging tools and techniques, originally developed and used by the oil and gas exploration industry, were unfamiliar to many research scientists. But that changed when **Roger Anderson** founded Lamont-Doherty's Borehole Research Group, which incorporated logging into ODP missions and worked hard to demonstrate the advantages of logging.

Log measurements are taken in situ, in contrast to recovered cores whose material can physically expand or change when no longer under high-pressure conditions that exist at depth. Drilling can also shatter or pulverize cores, and often half or more of core samples are lost during the difficult process of retrieval.

Logs provide a continuous record of measurements throughout geological formations, giving scientists the ability to orient "fragments" within an intermittently recovered timeline of rocks and to fill in the missing pieces in it. In the 1990s, the continuous, high-resolution measurements provided by logging proved critical to scientists seeking to reconstruct a detailed, unbroken chronology of climate change in Earth's history.

By 1992, the Borehole Research Group, now led by **David Goldberg**, brought the newest industry technology to bear in the academic community: logging while drilling (LWD). Sensors located in the drill pipe, several feet behind the drill bit, take continuous measurements of rock properties while the hole is being drilled. LWD not only enhances the logging process by adding a while-drilling measurement, it also ensures that information is captured, even if the hole destabilizes during drilling and collapses, which is not an infrequent occurrence, especially in new and challenging drilling target environments such as deeply buried faults and shallow fractured rocks. Today logging is no longer a secondary procedure, but rather is fully integrated into the drilling process.

AFTER 20 YEARS AND MORE THAN 2,900 seafloor holes drilled, ODP was phased out in 2003 and replaced by the Integrated Ocean Drilling Program (IODP), a consortium uniting equipment and expertise from scientists in the United States, Japan, and 15 European nations. Lamont-Doherty's Borehole Research Group is leading an international logging consortium for IODP operations.

The IODP endeavor will include an upgraded U.S. drill ship. It will be joined in 2006 or 2007 by a $500-million, Japanese-built research drill ship, *Chikyu*, which has a drilling system that allows far deeper drilling and that protects against blowouts caused when drill bits penetrate pressurized oil and gas deposits. These two vessels will be complemented by other ships that can drill in the Arctic Ocean and in coastal waters–areas that were too icy and too shallow for the *JOIDES Resolution* to work in.

Those areas also contain the most sensitive records of climate and sea-level change, one of IODP's three major research thrusts. Another thrust is Earth's deep structure and geodynamics, ranging from processes in deep-sea subduction zones that generate earthquakes, volcanoes, and volcanic islands, to the Moho, the boundary between the crust and the underlying mantle. A final research thrust includes explorations of a deep biosphere of microbial life that is potentially thriving in subseafloor regions, and gas hydrates–deposits of frozen, pressurized ice and methane that could be mined as a potential source of new fuel or that could thaw to exacerbate greenhouse warming.

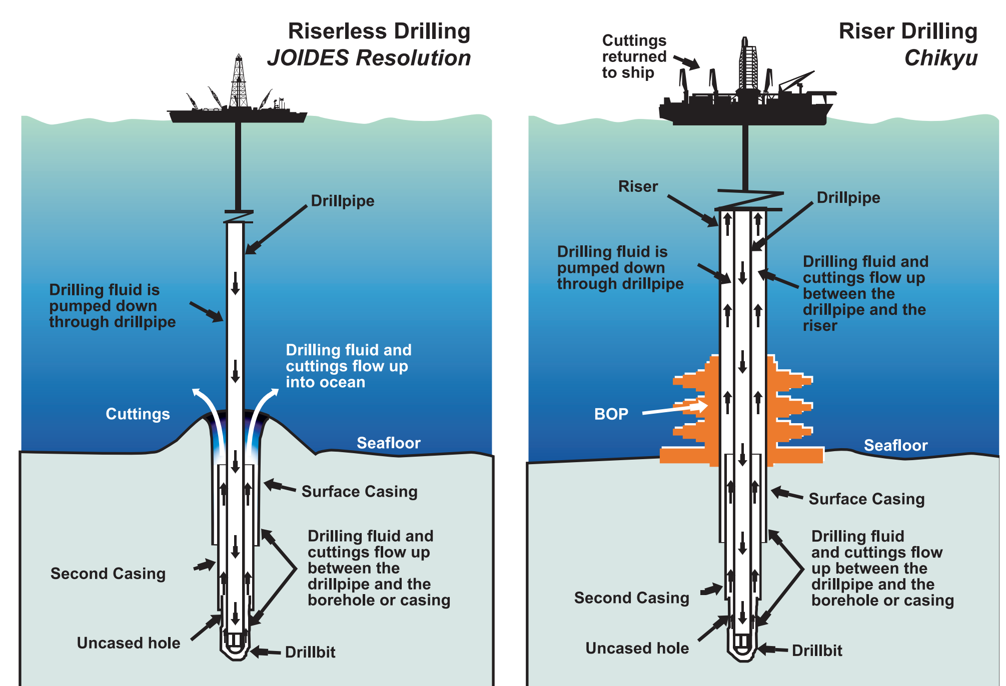
The Integrated Ocean Drilling Program's new 210-meter-long Japanese-built drill ship *Chikyu* ("Earth" in Japanese) is expected to be ready for work in 2006 or 2007.
Credit: Japan Marine Science and Technology Center

The new drilling targets, both shallow and deep, are unstable and difficult to drill in, making core recovery less certain and downhole logging more critical, Goldberg said. The new drilling technology will also create larger holes, with diameters big enough to install modern downhole instruments that can stay in situ for longer periods to monitor temperatures, stresses, fluid flows, and geochemical changes.

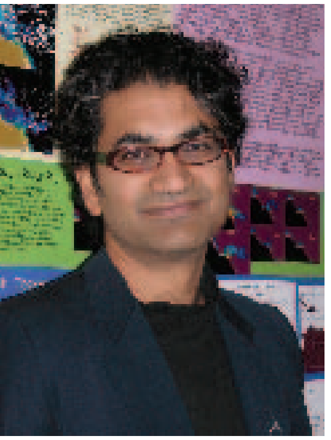
"Considering the complex drilling plans and ambitious scientific objectives proposed for IODP, such advances in logging capabilities and high-quality downhole data will be critical to achieve its goals," Goldberg said. Finally, the Borehole Group will develop accessible methods for integrating and archiving the increased volume of logging data collected by IODP.

"We consider all IODP data acquired by downhole logging to be irreplaceable scientific assets," he said, "and they will be archived in Web-accessible public databases."

Many things are changing on the frontiers of ocean drilling, but one thing hasn't: Lamont-Doherty remains at the forefront.



The new drill ship *Chikyu* will use an outer casing, called a riser. It surrounds the drill pipe and provides return circulation of drilling fluids that maintains pressure balance within the borehole. A blowout preventer (BOP) protects the vessel against blowouts caused when drill bits penetrate pressurized water, oil or gas zones. The drilling system allows far deeper drilling—perhaps up to 7 kilometers below the seafloor.
Credit: Courtesy of Integrated Ocean Drilling Program Management International



Ajit Subramaniam
Credit: Ronnie Anderson

The View from Above

Remote Sensing at Lamont-Doherty Earth Observatory

HUMANS ARE MERELY DOTS ON OUR GREAT planet. To gain perspective on large-scale events that occur over wide areas of Earth's surface, Lamont-Doherty scientists have stepped back, or more accurately, gone aloft. They are using a range of remote sensing instruments aboard aircraft and satellites.

Remote sensing instruments operate in various wavelength bands of the electromagnetic radiation (EMR) spectrum, from visible light across the near, short-wave, and thermal infrared, and on out to microwaves and radio waves. Passive sensors measure radiation such as reflected sunlight or heat emitted from Earth's surface. Active sensors transmit EMR signals that reflect off Earth's surface and are recorded back at the sensor.

Remote sensing techniques offer several advantages: They can be used to study remote or harsh locations that are otherwise difficult to access routinely, or to map large swaths of Earth's surface at a time. For example, sensors aboard Earth-orbiting satellites map our planet's entire surface, both land and ocean, several times a day, every day. Each two-minute scene recorded by such a satellite sensor, which has a resolution of 1 kilometer, would take 11 years for an average ship to survey.

Lamont-Doherty scientists are involved in diverse research programs—on land, over oceans, and in the atmosphere—that employ remote sensing data from airborne and satellite sensors (as well as hand-held spectrophotometers that measure sunlight reflecting off surfaces). We highlight two of the Observatory's remote sensing research programs, which utilize data from opposite ends of the electromagnetic spectrum.

Remote sensing can be used to study remote or harsh locations that are otherwise difficult to access routinely.

Remote Sensing with Light:

Satellites images of ocean color reveal where life and carbon abound

THE OCEAN ISN'T ALWAYS BLUE. IN SOME places, it is green; in others, brown.

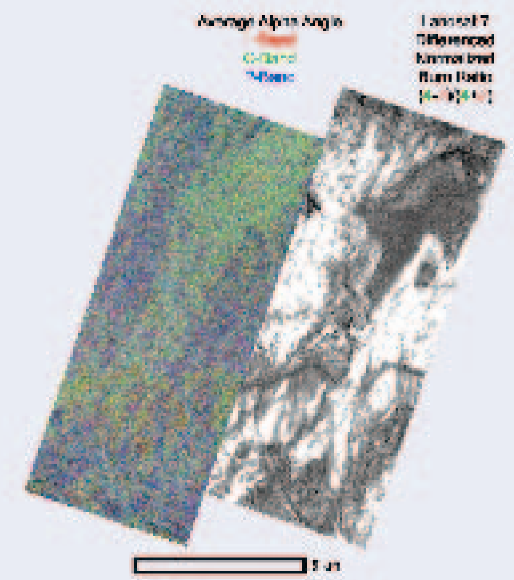
By studying the ocean's color, measured by satellite sensors, **Ajit Subramaniam** and colleagues at Lamont-Doherty are advancing knowledge about where and why single-cell plants at the base of the marine food chain grow. And they are tracking how photosynthetic plants may mitigate global warming–by extracting heat-trapping carbon dioxide from the atmosphere and changing it into carbon taken up by the ocean.

Sunlight entering the ocean is either absorbed by water molecules and materials in the water, or reflected back out of the ocean. Pure water absorbs red light very strongly and scatters blue light, so open ocean waters with little material in them appear deep blue. Phytoplankton contain chlorophyll that strongly absorbs blue and red light, making phytoplankton-filled waters appear green. Waters containing dissolved organic carbon material strongly absorb blue light, making them appear brown.

Using satellite measurements of light leaving the ocean surface at specific wavelengths, Lamont-Doherty scientists have developed algorithms–mathematical equations–to create maps identifying high-concentration areas of phytoplankton, dissolved organic material, and suspended sediments in the sea. By combining maps of phytoplankton, light, and sea surface temperatures–all derived from satellite measurements–the researchers can begin to investigate the locations and factors (light, temperatures, nutrients) that promote phytoplankton growth, as well as where plankton-eating fish may be more plentiful.

Subramaniam is also using ocean color satellite data to map dissolved carbon in waters off the U.S. East Coast. Plants, on land and in the sea, convert carbon dioxide from the atmosphere via photosynthesis into organic carbon. When they die, some carbon dioxide is released back into the air by bacterial decomposition. But a portion may be permanently removed from the atmosphere, thus mitigating global warming. Understanding how carbon is distributed, transformed, and transported through the Earth system enhances our ability to predict climate change and to detect human activities that have environmental impacts.

Chris Small uses a field spectrometer to measure the visible and infrared reflectance of sediment types in chars–giant sand or mud islands that appear, disappear, or move during the annual floods of the Ganges and Brahmaputra Rivers. The measurements are used to calibrate satellite images in a NASA-funded study to map changes in riverbanks and chars over the past 30 years. Such changes displaced an estimated 700,000 people during the 1980s.



A Lamont-Doherty team used new synthetic aperture radar polarimetry-based methods to survey what remained of the Apache-Stigreaves National Forest in Arizona, after a two-week wildfire that burned nearly 500,000 acres in 2002. SAR polarimetry involves several bands of polarized microwave energy, transmitted to and scattered back from the ground. Using SAR, the scientists created burn-severity maps of both the burned area and adjacent unburned forest. The SAR maps (left) matched maps made with conventional optical instruments (right), which, unlike SARs, cannot be used at night or under adverse weather conditions. In the SAR map, the burned forest appears mainly blue; the unburned forest is mainly green. In the conventional map, white represents severely burned; dark gray is unburned.

Remote Sensing with Microwaves:

Mapping natural disasters with Synthetic Aperture Radar technology

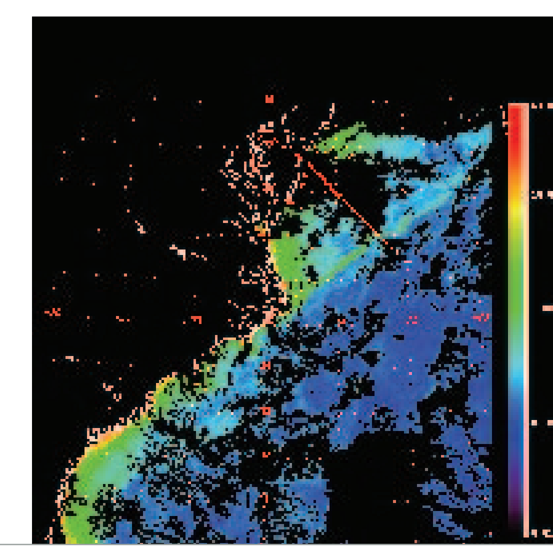
LAMONT-DOHERTY SCIENTISTS HAVE DEMON-strated for the first time the effectiveness of imaging microwave instruments–polarimetric airborne Synthetic Aperture Radars (SARs)–in assessing damage to landscapes from natural hazards and disasters. SAR polarimeters provide disaster response teams with new tools to collect critical information at any time of day and under adverse conditions. Unlike more conventional aerial photography, SARs can be used day or night and can "see" through clouds, smoke, and dust.

SARs on airplanes or satellites transmit short bursts, or "pulses," of microwave energy obliquely downward and record microwave signals scattered back from objects on the ground. The SAR antenna records multiple signals from the objects, as the plane or satellite moves along its flight path. This effectively synthesizes a "large aperture" antenna that generates higher-resolution images of ground targets.

Polarimeters add even more information and detail. They transmit polarized microwaves, which vibrate in either the horizontal or vertical plane. The back-scattered microwaves also vibrate in both planes, providing more data on the nature of the target materials.

Landscape changes caused by landslides, volcanic eruptions, or fires alter the way microwaves are scattered back to SARs, giving scientists the ability to map terrain affected by these hazards. In humid climates, for example, disasters remove or disrupt natural vegetation cover; polarized microwaves bounce once off bare land surface and water, but they bounce many times from more complicated surfaces covered by vegetation, creating a telltale SAR signal.

A Lamont-Doherty research team led by **Jeff Weissel** has successfully used airborne SAR polarimetry to map landscape changes caused by landslides resulting from the 1999 7.6-magnitude Chi-Chi earthquake in Taiwan and by lava flows from a major eruption of the Manam Island volcano, offshore Papua New Guinea, in 1996. In 2002, in the wake of a two-week wildfire that burned nearly 500,000 acres in the Apache-Stigreaves National Forest in Arizona, they used the technique to create burn-severity maps of both the burned area and an adjacent unburned forest. The SAR maps matched those made with conventional optical instruments.



A SeaWiFS satellite image of phytoplankton concentration in the mid-Atlantic and South Atlantic Bights on Oct. 9, 1999, shows a freshwater plume seen as a jet of high chlorophyll extending from the Outer Banks in North Carolina. Red lines show the track of a research cruise that measured in-situ chlorophyll levels. The measurements showed that this jet had extremely high dissolved organic matter absorption and was the runoff after three hurricanes (Dennis, Floyd, and Irene) had passed over North Carolina.

Kerstin Lehnert (left) and Suzanne Carbotte
Credit: Bruce Gilbert

Mining a mother lode of data

LDEO pioneers information technology tools to manage and share vast volumes of scientific data

IN 1952, MARIE THARP AT THE NEWLY FOUNDED Lamont Geological Observatory compiled seafloor sounding data and discovered that the Atlantic Ocean was bisected by a rift valley. Then, she superimposed data on oceanic earthquake locations and found that they aligned with the rift valley.

Thus was born the revolutionary concept of mid-ocean ridges. It was an early lesson of the value of amassing and integrating diverse data sets.

The lesson continued in the 1960s. Lamont scientists acquired first-generation computers to store and display the wealth of bathymetric, seismic, magnetic, gravity and other data collected by its globetrotting ships, and they wrote pioneering software to analyze them.

"We were sitting on the mother lode with all the tools needed to mine it," Lamont-Doherty geophysicist **Dennis Hayes** wrote. "With the data and the means to analyze and synthesize them, we were perfectly positioned to test, validate, define, and refine the simple, elegant, but revolutionary theories of seafloor spreading and plate tectonics."

The term "data management" smacks of dull housekeeping, but Lamont-Doherty has always realized that it provides a critical pathway to exciting discovery.

"These data are extremely expensive to collect and represent a significant part of the legacy of our research," said LDEO geophysicist **Suzanne Carbotte**. "Without data management systems, the data may be lost or inaccessible for uses beyond those of the original researchers."

In the mid-1990s, **Bill Ryan** continued the LDEO data management tradition, creating a database of multibeam sonar seafloor bathymetry collected on RIDGE Program cruises to study mid-ocean ridges. Charles Langmuir and Ryan launched PetDB, a geochemical database in the late 1990s.

At the dawn of the 21st century, Lamont-Doherty is once again pioneering next-generation information technology tools and techniques to preserve, disseminate, and integrate an exploding volume and diversity of geoscience data. The goal, said **Kerstin Lehnert**, Coordinator of Research Administration at LDEO, is to "generate thrilling opportunities for a formerly unimaginable research infrastructure–in which vast amounts of data can be archived; made easily accessible to global and diverse audiences; and linked in ways that reduce barriers of location, time, institution, and discipline."

Over the past decade, rapid advances in instruments that observe, analyze, and model have led to an explosion of incoming information. It has overwhelmed scientists' ability to store their own data, let alone take full advantage of the vast data piling up in other scientists' computers, in widely scattered archives, or in hundreds of scientific publications.

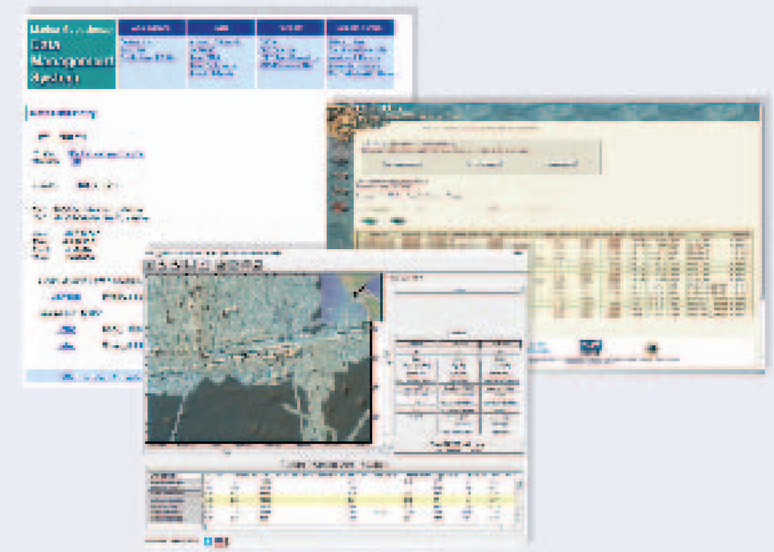
In response, LDEO researchers began to exploit modern advances in digital connectivity and information technology to provide easy access to scientific data, to link data centers around the world, and to offer scientists an archive for their new or previously unarchived data, Lehnert said.

AS A GRADUATE STUDENT, JIAN LIN, NOW A geophysicist at Woods Hole Oceanographic Institution, used to drive to Lamont to peruse data. Today, he, along with colleagues and students, are using PetDB (http://www.petdb.org). The information system now contains geochemical analyses for seafloor igneous rocks compiled from more than 900 scientific papers, reports, dissertations, and even data that were never published in journals because of space limitations. Since 2001, more than 70 papers in major scientific journals have cited PetDB as a source for data.

Lin used PetDB to provide critical data to test a theory that the sources of hotspot plumes lie deep in the mantle. "The database allowed us to compare different hotspots from all over the globe in a consistent way," he said. "You can find something locally, and with the database, you can quickly find out whether the same process applies globally."

In another project, Lin's graduate student compiled geochemical data for rocks collected near the Icelandic hotspot. They indicated that different mantle processes may be at work in different areas around the hotspot.

"A project like that would have taken weeks without PetDB, rather than days," Lin said. "And instead of confirming a hypothesis, it may lead to a surprising discovery."



Lamont-Doherty scientists have created data management systems to provide researchers with easy access to a wide variety of earth sciences data archives. [Clockwise from top] The Marine Geoscience Data Management System *gives research cruise information and field data (shown here, the RAIT02 cruise of R/V* Thomas Washington*);* PetDB *provides access to a global geochemical data set for ocean floor rocks (e.g. radiogenic isotopes for basalts collected during the RAIT02 cruise);* GeoMapApp *offers visualization of bathymetry/topography data, here integrated with data from PetDB (sample locations and compiled chemistry).*

In both cases, Lin said, the database served valuable educational purposes. It efficiently brings a wealth of knowledge to students and to more seasoned scientists, who may have expertise in geophysics but not in geochemistry.

"My research has benefited tremendously, thanks to Lamont's long-term vision of data management," Lin said.

TO BROADEN DATA RESOURCES FOR SOLID Earth geochemistry, PetDB has joined with GEOROC, a geochemistry database run by the Max-Planck Institute for Chemistry in Germany, and NAVDAT, a National Science Foundation (NSF)-funded database for North American volcanic and igneous rocks, to found the EarthChem consortia (www.earthchem.org). One of the consortia's objectives is to better integrate geochemical data with other types of data. Such integration has been seriously hampered by the lack of uniform protocols to name samples consistently and unambiguously.

To address this problem, Lamont-Doherty is developing an online sample registry named SESAR (Solid Earth SAmple Registry at www.geosamples.org). It will provide each sample with a unique serial number, the International Geo Sample Number, or IGSN–similar to a book's ISBN, or International Standard Book Number. The IGSN will dramatically advance interoperability among information systems for sample-based data.

In 2002 and 2003, Lamont-Doherty won four NSF awards to create databases for bathymetry and geophysical data from the Southern Ocean; seismic reflection data; and data for the Ridge 2000 and MARGINS programs (the geoscience community's long-term programs to study the formation, evolution, and eventual destruction of oceanic crust).

These projects are part of the Marine Geoscience Data Management System (DMS) at www.marine-geo.org. The new system provides access to seismic data of the structure of the crust and mantle; tracks of research cruises; seafloor maps made with the most advanced underwater mapping technology; magnetic and gravity data; and photographs and samples of rocks, sediments, and biological communities found on the seafloor obtained with submersibles and other vehicles.

The Marine Geoscience DMS includes a new tool, GeoMapApp (www.geomapapp.org), which gives anyone with Internet access the ability to browse through massive data sets (data mining) and to explore the data visually (data visualization). With GeoMapApp, an individual can select an area from a detailed global topographic map, zoom in to see higher-resolution imagery, generate and download a custom map, and then select from a menu of other complementary data that have been collected in the selected area.

"Until now, scientists would have to know what data existed, who has them, how to get them, and then learn how to manipulate the data," said Carbotte, who heads the DMS team. "We want to provide a tool to allow people to explore global databases without being experts, to explore the data visually, to evaluate relationships between different types of data, and to interact with the data in new ways."

> The goal is to generate thrilling opportunities for a formerly unimaginable research infrastructure–in which vast amounts of data can be archived, made easily accessible, and linked.

Open House 2002
Credit: Rachel Cobb

02

Open House

October 5, 2002

El Niño 2002-2003, Predicting and Preparing
Lamont-Doherty's 2002 Open House took place on Saturday, October 5, 2002. The focus of the Open House was the science and consequences behind El Niño. In addition to the El Niño exhibits, there were exhibits on dinosaurs, volcanoes, the Hudson River, and wild species in urban environments.

Dave Walker hosted a very popular "Mr. Wizard" exhibit, Open House 2002
Credit: Ronnie Anderson

03

Public Lecture Series 2003

March 2, 2003
Exploring the Hudson & Finding Sunken Treasures
Robin E. Bell, Doherty Senior Research Scientist
Lamont-Doherty Earth Observatory

March 30, 2003
Plumbing the Depths: Volcanoes as Windows into the Dynamics of the Deep Earth
Marc Spiegelman, Associate Professor, Earth and Environmental Sciences
Lamont-Doherty Earth Observatory

April 27, 2003
Sponsored by the Lamont-Doherty Alumni Association:
Farms, Plagues, and Climate
Bill Ruddiman, Professor Emeritus, Department of Environmental Sciences, University of Virginia

May 18, 2003
Lamont's Tree-Ring Laboratory
Panel presentation by Gordon Jacoby, Brendan Buckley and Edward Cook
Lamont-Doherty Earth Observatory

June 8, 2003
The R/V Maurice Ewing
Panel presentation by Mike Purdy and Paul Ljunggren
Lamont-Doherty Earth Observatory

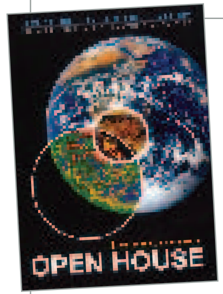
Jardetzky Lecture

September 5, 2003

Awardee: **Alan Levander,**
Rice University, Houston TX

Lecture Title:
Imag(in)ing the Continental Lithosphere

The Jardetzky lecture in geophysics honors the late Wenceslas S. Jardetzky, a renowned researcher and educator whose flourishing scientific career in Europe was halted by World War II and revived after he immigrated to the United States. From 1949 until his death in 1962, he was a research associate at Lamont-Doherty, where he collaborated with Frank Press, former president of the National Academy of Sciences, and Maurice Ewing, Lamont-Doherty's founder, on a well-known and widely used scientific book, "Wave Propagation in Layered Media." The Jardetzky lecture was established in 1992 by Dr. Jardetzky's son Oleg, who is the founder of the Magnetic Resonance Laboratory and professor of molecular pharmacology at Stanford University. In endowing the lectureship, Dr. Jardetzky said he hoped it would "help enrich the outstanding tradition of the Lamont-Doherty Earth Observatory, which provided a much cherished intellectual home to my father after he immigrated to this country."



Open House

October 4, 2003

The Science of Earth
Lamont-Doherty Earth Observatory's 2003 Open House took place on Saturday, October 4, 2003, and, as always, was both well-attended and well-appreciated by the visitors. The theme was The Science of Earth. The dozens of exhibits and lectures included topics such as Global Climate Change and, closer to home, Rockland County Droughts. "Mr. Wizard" (Dave Walker) and "Bathtub Science" (starring Marc Spiegelman) were favorite returning activities for children, as was the new "Plant a Seed, Watch it Grow" activity in the research greenhouse. For the first time this year, visitors included about 200 high school students from around the country who have expressed an interest in studying science at Columbia College.

Visitors at the Tree Ring Lab exhibit, Open House 2003

[*right*] Samir Patel, an Earth and Environmental Journalism student, with young visitors at the "Where are We?" exhibit, Open House 2003.
Credit: Sara Kopcsak

[*far right*] Earth Institute Director Jeffrey Sachs and Lamont Director Michael Purdy with students
Credit: Bruce Gilbert

Earth Institute Lectures

September 16, 2003
The Secret of Lake Vostok, Antarctica
A lecture by Robin E. Bell, Doherty Senior Research Scientist
Sponsored by The Earth Institute at Columbia University

December 3, 2003
Climate and Society
A lecture by Mark Cane
G. Unger Vetlesen Professor, Earth and Climate Sciences
Sponsored by The Earth Institute at Columbia University

2003 Awards

February 2003
Mark Cane
2003 Robert L. and Bettie P. Cody Award in Ocean Sciences from Scripps Institution of Oceanography at the University of California, San Diego

February 24, 2003
Director's Award for Outstanding Research Performance

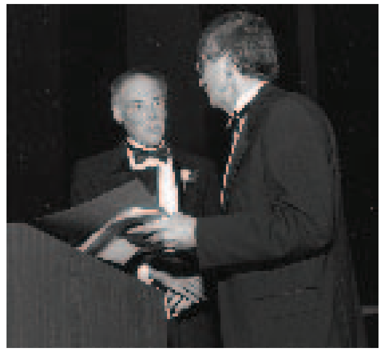
Robert F. Anderson, Geochemistry
As part of the annual merit review process, the Associate Directors of the Research Divisions and the Chairman of the Department of Earth and Environmental Sciences are encouraged to identify and nominate to the Director an individual who has displayed exceptional levels of performance throughout the previous year.

This is a $10,000 cash award. The awardee(s) is selected by the Director in consultation with the Associate Directors.

The award is not necessarily given every year. Except in truly exceptional circumstances, only one award is given.

April 2003
Lamont-Doherty Excellence in Mentoring Award
Robert F. Anderson, Geochemistry
This award recognizes the importance of quality mentoring, which benefits the institution as a whole, its junior members (including graduate students, Postdocs, and Associate Research Scientists), and the mentors themselves. The award recipient receives a $2,000 cash prize and a certificate. The recipient's name is engraved on a plaque that is displayed at the Observatory.

April 2003
Storke-Doherty Lectureship
Nili Harnik, Ocean & Climate Physics
This four-year term award will be made to an individual selected from among the pool of eligible candidates on the basis of outstanding scientific merit and potential. The award is made jointly with the Department of Earth and Environmental Sciences.



[*far left*] Taro Takahashi (right)
2003 Fellow American
Geophysical Union

[*left*] Gerard Bond (left)
2003 Maurice Ewing Medal
American Geophysical Union

03

2003 Awards

Dennis V. Kent
Rutgers University and LDEO
2003 Arthur L. Day Medal (Fall 2003)
Geological Society of America
and **2003 VMSG Medal** (Fall 2003)
Vening Meinesz School of Geodynamics
(picture on next page)

Dee Breger first prize photo: Mongolian Frost Rings, Siberian Pine (sample, Gordon Jacoby).

September 2003

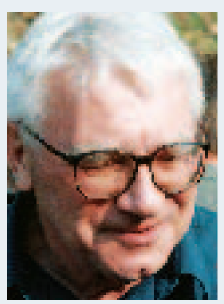
Dee Breger won both first and second prizes in the photography category of the first annual 2003 Science and Engineering Visualization Challenge, a joint project of the National Science Foundation and Science Magazine designed to "encourage recognition of the visual and conceptual beauty of science and engineering" and communicate science to the general public. Two of her micrographs won finalist positions in the 2002 Royal Geographical Society's Photographer of the Year contest and she also won the Whiting Memorial Award of 2002 from the International Society for Philosophical Enquiry.

December 2003

Taro Takahashi
2003 Fellow
American Geophysical Union

December 2003

Gerard Bond
2003 Maurice Ewing Medal
American Geophysical Union



December 2003

George Kukla
2003 Milutin Milankovitch Medal
European Geosciences Union

Bill Thompson
Goodfriend Prize
Graduate student Bill Thompson won the 2003-2004 Goodfriend Prize for his paper "An open-system model for Uranium-series age determinations of fossil corals" (Earth and Planetary Letters 210, 365-381, 2003). The prize is given annually by LDEO and the Department of Earth and Environmental Sciences for an outstanding student paper in Paleoclimatology. Dr. Florentin Maurrasse (PhD '73) established the prize in 2003 in memory of his friend and colleague Glenn A. Goodfriend.
Credit: Sara Kopcsak

04

Gordon Jacoby from the Tree-Ring Lab presenting along with colleagues Ed Cook and Brendan Buckley, May 18, 2003

Earth Institute Lectures

February 3, 2004

The Monitoring of Nuclear Explosions
Why, How and What Do We Learn?
A lecture by Paul Richards
Mellon Professor of Natural Sciences
Sponsored by The Earth Institute at Columbia University

Public Lecture Series 2004

April 4, 2004

Earthquake Prediction
in the Shadow of Chaos
Bruce E. Shaw, Doherty Research Scientist
Lamont-Doherty Earth Observatory

April 18, 2004

Revealing the Deep: Science and Engineering in Deep Ocean Exploration
Sponsored by the Lamont-Doherty Alumni Association
Daniel J. Fornari, Senior Scientist
Woods Hole Oceanographic Institution

May 2, 2004

African Climate Changes
and Human Evolution
Peter B. deMenocal, Associate Professor
Earth and Environmental Sciences
Lamont-Doherty Earth Observatory

May 23, 2004

The Air We Breathe: Air Pollution
and New York City Subways
Steven N. Chillrud,
Doherty Research Scientist
Lamont-Doherty Earth Observatory

C250 Symposium Earth's Future: Taming the Climate

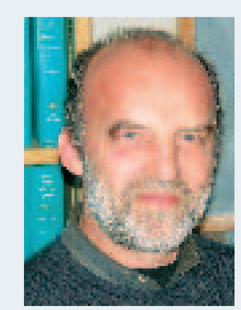
April 22–23, 2004

The Earth's climate is constantly changing, and we know from history that these changes can have dramatic impacts upon the habitability of our planet, and yet we are doing essentially nothing to prepare for this. Why not? What limits our ability to take action to prepare for change, or to try to stop it?

This symposium addressed these questions in cross-disciplinary discussions among climate scientists, political scientists, engineers, economists, and ethicists working together to prioritize the issues and identify the most fundamental barriers. A final panel articulated a set of constructive conclusions helpful for international action.

This symposium was led by G. Michael Purdy, Director of the Lamont-Doherty Earth Observatory; John Mutter, Deputy Director of the Earth Institute at Columbia University, and the planning group consisted of Klaus Lackner, Ewing Worzel Professor of Geophysics, Columbia University; Geoffrey Heal, Paul Garret Professor of Public Policy and Corporate Responsibility, Columbia Business School, and Roberto Lenton, Executive Director, Secretariat for International Affairs and Development, International Research Institute for Climate Prediction, Columbia University. Columbia University, Morningside Campus

2004 Awards

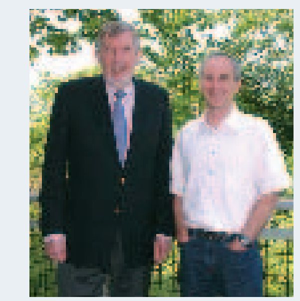


April 2004

Dennis Kent
Elected to National Academy of Sciences
Credit: Sara Kopcsak

April 2004

Kevin L. Griffin
2004 Lamont-Doherty Excellence in Mentoring Award



Lamont Director Mike Purdy with Kevin Griffin

April 2004

Storke-Doherty Lectureship
Del Bohnenstiehl,
Marine Geology & Geophysics

From left to right: Timothy Harwood, Doug Brusa, Sara Kopcsak
Credit: Bruce Gilbert

We are grateful to those who made this growth happen and are encouraged by signs that this growth may continue in the future.

Development

A FINANCIAL REPORT IN THE ADMINISTRATION section of this report (page 49) indicates that giving to Lamont-Doherty (a combination of gifts and private grants and contracts) rose from $1.7 million for the year ending June 30, 2003, to $2.9 million for the year ending June 30, 2004. For 2001, the figure was $1.4 million.

We are grateful to those who made this growth happen and are encouraged by signs that this growth may continue in the future. Gifts to the Observatory come in many forms, but for the purposes of this report we will divide them into three categories. First, and perhaps most welcome, are unrestricted gifts for operating support. Into this category falls the annual fund, which is discussed in greater detail later in this report.

However, chief among our unrestricted donors is the G. Unger Vetlesen Foundation, whose unrivaled support over many years has made a tremendous difference in the Observatory's ability to withstand temporary lapses in government funding, as well as to take advantage of unexpected opportunities to the maximum advantage. The Vetlesen Foundation supports specific areas of the Observatory as well, particularly our climate research activities, and sponsors the Vetlesen Prize, but the impact of its operating support is as great, or greater.

There were also several anonymous donors over the past two years, and although we don't know whether it was one person who made multiple gifts or more than one person, we thank you, whoever you are!

A second kind of support is research support. Typically, this involves salary support for scientists to pursue their research, as well as funding for equipment, travel, and technical support. Again, we have a lead contributor in this category, the Comer Science and Education Foundation, which has supported a number of climate-related projects across the Observatory, especially the work of our renowned researcher Wallace Broecker, Newberry Professor of Earth and Environmental Sciences. Other supporters of our research over the past two years have included Ford Motor Co., Unocal, ExxonMobil, and the Texas Energy Center.

Third, there are a number of gifts that do not fall into either of the above categories, but are gifts earmarked for areas other than specific research projects. This might include the establishment of an endowment to support a researcher or graduate student, or support of a broader area of concern. Into this category fell Florentin Maurrasse, who established the Glenn Goodfriend Fellowship, and the Palisades Geophysical Institute, which provided an endowment, which must be matched, to support engineering innovation.

In addition, Esther Dauch left a bequest that will endow a senior research position in memory of her son, Bruce C. Heezen, who was instrumental in mapping the ocean floor in the early days of the Observatory.

Of course, we are grateful for every gift that comes in to the Observatory, but due to constraints of space and readers' patience, we cannot describe each one. However, following is a list of all individuals, corporations or foundations that made gifts of $100 or more during the 2002-2004 academic years.

$100+ donors

JULY 1, 2002 - JUNE 30, 2004

Anonymous (4)
Dennis Adler
Yash Aggarwal
Charles Amendola
Janet Anderson
Thomas Anderson
BP Foundation
David Black
Morrie and Marianne Brown
Virginia Butters
Steven Cande
Kenneth Ciriacks
Millard F. Coffin
Comer Science and Education Foundation
Rebekah Creshkoff
H. James Dorman
Stephen Eittreim
Wolfgang Elston
Peter Eschweiler
ExxonMobil Foundation
ExxonMobil Upstream Research
Rodger Faill
Herbert and Ethel Feely
W. Arnold Finck
Thomas Fitch
Ford Motor Company
P. Jeffrey Fox
Nestor Granelli
Frank Gumper
John Hall
Gordon Hamilton
Douglas Hammond
Timothy B. Harwood
Heimbold Foundation
David Heit
Thomas Herron
Ki-Iti Horai
Ge Hu
Marc Joseph
Ellen Kappel-Berman
Helmut Katz
Quentin J. Kennedy Foundation
Robert Kovach
Paul Krusic
Naresh Kumar
John Kuo
David Lammlein
Lillian Langseth
Gary Latham
Jean M. Leo
Robert Lifgren
Donald Lovejoy
William Ludwig
John Maguire
Stephen Marshak
William Marshall
Florentin Maurrasse
Arthur McGarr
Andrew and Barbara McIntyre
Mellon Foundation
Morgan Stanley
Noriyuki Nasu
Suzanne O'Connell
Virginia Oversby
Palisades Geophysical Institute, Inc.
Michael Passow
Dee Pederson
Michael Perfit
James Periconi
Edward Potter
Frank and Billie Press
Richard Quittmeyer
James Robertson
William Ryan
Science Museum of Long Island
Joseph Stennett
Sun Microsystems Computer, Inc.
Eric Sundquist
George Sutton
Lisa Tauxe
Texas Energy Center
Leon Thomsen
David Thurber
Seymour Topping
Mary Tremblay
Susan Trumbore
Unocal, Inc.
Peter Van de Water
Harry Van Santford
Richard Wallace
L.A. Weeks
John Wehmiller
Verizon Foundation
G. Unger Vetlesen Foundation
Charles Windisch

Torrey Cliff Society

FOR MANY DONORS, AN OUTRIGHT GIFT IS NOT the best means of achieving their philanthropic or estate planning goals. Carefully planned gifts can offer significant estate tax and income benefits, while at the same time allowing donors to make larger gifts than would be possible otherwise. The Torrey Cliff Society comprises people who have included the Lamont-Doherty Earth Observatory in their estate plans, or who have made life income gift arrangements with Columbia University.

The Society is named for the estate on which Lamont-Doherty is located, which was donated to Columbia in 1948 and which had been named "Torrey Cliff" by its original owners, Thomas and Florence Lamont, for America's famed 19th-century botanist, John Torrey. The Society allows Lamont-Doherty to recognize the generosity of its members, who are inducted each fall just before Open House.

Becoming a member of the Torrey Cliff Society also makes you eligible for membership in Columbia's 1754 Society, the honorary society for alumni and friends who have included the University in their estate plans. Membership has no dues, obligations, or solicitations, but it provides a way for the University to say thanks. The following is a list of Torrey Cliff Society members as of June 30, 2004.

TORREY CLIFF SOCIETY

Nestor C.L. Granelli
Helmut Katz
John Maguire
Rudi Markl
Andrew and Barbara McIntyre
Marie Tharp

Unlike many alumni associations dedicated only to academic degree recipients, the Lamont-Doherty Alumni Association welcomes the participation of former faculty, students, staff, and visiting scientists.

Alumni Association President Jeff Fox

Alumni Association

THE PURPOSE OF THE LAMONT-DOHERTY Alumni Association is to advance the interest and promote the welfare of Lamont-Doherty Earth Observatory, as well as to foster communications and interactions among its alumni. The membership includes past Lamont-Doherty graduate students, postdoctoral fellows, scientists, visiting scholars, and former employees.

The Lamont-Doherty Alumni Association was founded as a result of the Observatory's 50th Anniversary celebrations in 1999. Unlike many alumni associations dedicated only to academic degree recipients, the Lamont-Doherty Alumni Association welcomes the participation of former faculty, students, staff, and visiting scientists. More than 1,200 people have registered as Alumni Association members.

Alumni Association activities are guided by a volunteer board of directors drawn from the membership. The board meets three times a year to give guidance to the Observatory on alumni matters including three principal areas of activity: outreach to friends and alumni, lectures and reunions, and fund-raising.

LAMONT-DOHERTY ALUMNI ASSOCIATION BOARD OF DIRECTORS 2003-2004

President
P. Jeffrey Fox

Directors
H. James Dorman
Stephen Eittreim
W. Arnold Finck
Arthur McGarr
Joyce O'Dowd
Michael Rawson
William B.F. Ryan

Newsletter and Web page

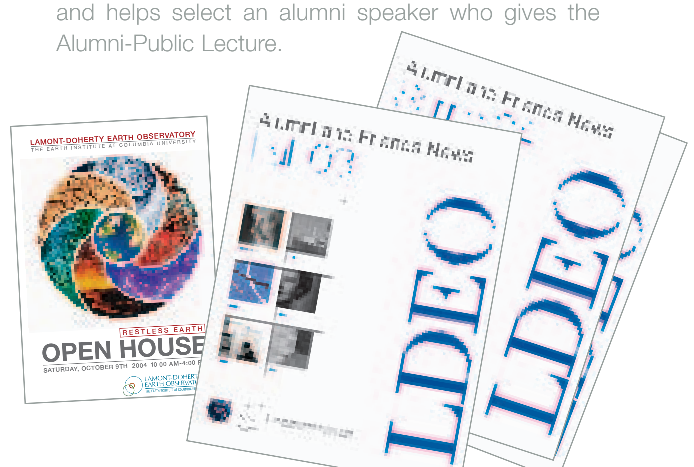
The Alumni Association supports the publication of the LDEO Newsletter for Alumni and Friends. The newsletter is mailed twice a year to alumni and friends and contains updates on what is happening at LDEO, stories about current scientific projects, and profiles of alumni. The association also maintains a Web page where alumni can keep their contact information current, read and contribute "Stories of Lamont," and access newsletters online.

Alumni reunions and Alumni-Public Lectures

After the wonderful reunions of the 50th Anniversary celebrations in 1999, the common refrain was "Let's not wait another 50 years to do this again!" With that in mind, the Alumni Association now organizes and hosts three alumni receptions a year: at the Alumni Association-sponsored Spring Public Lecture at LDEO, during Open House, and at the Fall Meeting of the American Geophysical Union in San Francisco.

Each of the reunions in the past two years has had a good turnout and provided many opportunities for alumni to meet and catch up with each other as well as with current Lamonters.

As a part of the Observatory's Spring Public Lecture Series, the Association sponsors a reception and helps select an alumni speaker who gives the Alumni-Public Lecture.



[*far right*] Newsletter

[*right*] 2003 Open House postcard invitation

Open House 2003 Alumni Association Meeting: (clockwise from top) Lamont Director Mike Purdy with board members Arnold Finck, Bill Ryan, Joyce O'Dowd and Mike Rawson (not pictured: Jeff Fox, Steve Eittreim, Art McGarr, and Jim Dorman).

ALUMNI-PUBLIC LECTURES 2002 – 2004

"Farms, Plagues and Climate"
Bill Ruddiman, PhD 1969
Professor Emeritus, Department of Environmental Sciences, University of Virginia
April 27, 2003

"Revealing the Deep: Science and Engineering in Deep Ocean Exploration"
Daniel Fornari, PhD 1978
Chief Scientist for Deep Submergence, Woods Hole Oceanographic Institution
April 18, 2004

Annual Fund

The Alumni Association sponsors the Annual Fund, a critical source of funding that can be spent on needs for which there is no government support, including communications with alumni and friends. From its start in 2001, contributions by many alumni and friends have made the annual fund a significant contributor to the financial well-being of the Observatory.

Some of our contributors are attendees at our Spring Public Lectures and Open House and wish to help support our public programs. We thank all Annual Fund supporters for their support.

FOLD Dinner attendees, October 8, 2004

Friends of Lamont-Doherty

As the Annual Fund grew in the few years since its creation, it became evident that extra thanks were due to a special group of contributors to the fund. Friends of Lamont-Doherty (FOLD) was created to recognize that group of individuals who have made annual contributions of $500 or more to the Annual Fund.

Members of FOLD receive invitations to Observatory special events including lectures and symposia. A dinner is held annually in their honor at which a presentation is made on a topic of current scientific interest.

2003 – 2004 FOLD MEMBERS

Dennis Adler
Morrie and Marianne Brown
P. Jeffrey Fox
Frank Gumper
Leif Christian Heimbold
Thomas Herron
Ki-Iti Horai
Marc Joseph
Quentin J. Kennedy
Donald W. Lovejoy
Florentin J-M.R. Maurrasse
James J. Periconi, Esq.
Edward E. Potter
James H. Robertson
William B.F. Ryan
Charles C. Windisch

In each case, center and divisional administrators provide the necessary link between scientific activities and the core administrative services required to support these operations.

The Observatory's senior administrative staff. From left to right: Tom Eberhard, Ray Long, Pam Stambaugh, Mary Mokhtari, Ron Schmidt, George Papa, and Dick Greco. *Credit: Bruce Gilbert*

Administration

SINCE LAMONT-DOHERTY EARTH OBSERVATORY is located across the Hudson River north of the main campus on Morningside Heights, the Observatory requires a separate but coordinated administrative staff to maintain effective and efficient operations. Although formally an extension of Columbia University's central operations, the Observatory's administration is able to offer direct, on-site services to the research community on the Lamont campus.

The Observatory's administration is organized around a set of core functions, including Grants and Contracts, Finance and Accounting, Human Resources, Procurement, Facilities Management, Shipping and Traffic and Security. Additional operations encompass a copy center, housing, food service, and a variety of related functions.

Many of these services are provided to the various Earth Institute centers located on the Lamont campus, as well as to the various Lamont-Doherty research divisions. In each case, center and divisional administrators provide the necessary link between scientific activities and the core administrative services required to support these operations. Because these administrators are part of the creative research environment unique to each unit, they are well-placed to provide the appropriate support.

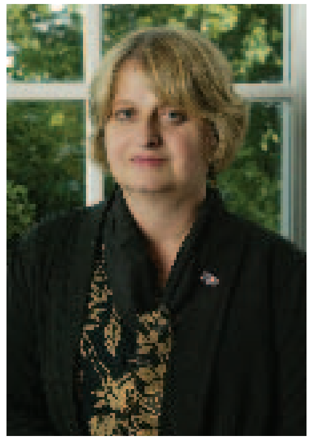
One of the primary responsibilities of administration is to maintain the financial and mandatory requirements of any gift, grant or contract without being overly burdensome or interfering with the institution's primary research activities. Informed individuals will always disagree about just where this balance lies, but we at Lamont-Doherty feel that we are pretty close to the correct mix.

George A. Papa

George Papa came to Lamont-Doherty in December 1993 as Manager of Accounting Services. He quickly familiarized himself with both Lamont and Columbia University procedures and became an invaluable part of the Observatory's administrative team. He was promoted to Assistant Director of Administration and then, before his untimely death in December 2004, to Acting Director. He is sorely missed, and the following pages are dedicated to his memory.

Statement of Changes in Fund Balances for Fiscal Year 2004
July 1, 2002 – June 30, 2004

	Grants	Gifts	Endowment Income	Endowment Principal	Institutional Support	Total FY04	Total FY03
REVENUES							
Government Grants & Contracts							
National Science Foundation	36,697,776					36,697,776	21,845,432
SubContracts	8,243,580					8,243,580	6,977,626
National Oceanic and Atmospheric Administration	1,143,905					1,143,905	1,057,711
National Aeronautics and Space Administration	1,159,823					1,159,823	1,552,145
Defense Threat Reduction Agency	187,455					187,455	0
National Institutes of Health	924,463					924,463	1,616,452
Office of Naval Research	486,359					486,359	408,787
Miscellaneous	891,819					891,819	336,944
U.S. Geological Survey	315,385					315,385	479,531
N.Y. Department of Environmental Conservation	104,974					104,974	5,000
Department of Energy	764,791					764,791	92,500
Private Grants & Contracts	1,148,673					1,148,673	773,995
Gifts		1,086,880		711,709		1,798,589	957,241
Investment Income		4,524	3,658,147			3,662,671	3,485,056
Realized Gain (Loss)				6,412,834		6,412,834	590,475
Change in Unrealized Gain (Loss)				3,623,200		3,623,200	2,628,242
Other Sources				12,238	1,328,690	1,340,928	1,433,425
Total Revenues	**52,069,003**	**1,091,404**	**3,658,147**	**10,759,981**	**1,328,690**	**68,907,225**	**44,240,562**
EXPENDITURES							
Sponsored Research Expenditures	21,329,598					21,329,598	22,472,102
Administrative & Facility Costs	7,674,861				353,154	8,028,015	7,972,575
Marine Expense Recovered by Grants	7,627,256					7,627,256	5,086,599
Marine Recovery in Excess of Expense	(453,469)					(453,469)	1,662,547
Research Support Expenditures		824,208	3,063,397		1,068,447	4,956,052	4,009,861
External Affairs & Fundraising					628,267	628,267	632,422
Ancilliary Services					178,043	178,043	163,337
Plant (Capital) Expenditures					646,321	646,321	863,922
Internal Grants & Seed Funding Expenditures					840,416	840,416	997,743
Total Expenditures	**36,178,246**	**824,208**	**3,063,397**	**0**	**3,714,648**	**43,780,499**	**43,861,108**
TRANSFERS							
Transfer Among Funds		(94,475)	(733,931)	(2,870,267)	2,728,920	(969,753)	(2,193,096)
Budget Adjustments: Close Out Grants						0	119
Grant Carryforwards Adjustments	(55,791)					(55,791)	(149,488)
Total Transfers	**(55,791)**	**(94,475)**	**(733,931)**	**(2,870,267)**	**2,728,920**	**(1,025,544)**	**(2,342,465)**
Net Increase(Decrease) For The Year	15,834,966	172,721	(139,181)	7,889,714	342,962	24,101,182	(1,963,011)
Fund Balance At Beginning of Year	23,675,489	1,974,399	785,669	71,988,384	3,587,625	102,011,566	103,974,577
Fund Balance At Ending of Year	**39,510,455**	**2,147,120**	**646,488**	**79,878,098**	**3,930,587**	**126,112,748**	**102,011,566**

[*left*] Mary Ann Brueckner, Library Specialist

[*right*] Miriam Colwell, Library Assistant

Credit: Bruce Gilbert

Director's Office

Purdy, G. Michael	Director
Alex, Carmen M.	Webmaster
Colwell, Miriam G.	Administrative Assistant
Lehnert, Kerstin A.	Coordinator
Tomsa, Violeta A.	Secretary
Wuerfel, Beverly	Coordinator

Biology and Paleo Environment

Marra, John F.	Associate Director
Hoffer, Karen	Division Administrator

SENIOR SCIENTIFIC STAFF

Bond, Gerard C.	Doherty Senior Scholar
Cook, Edward R.	Doherty Senior Scholar
D'Arrigo, Rosanne D.	Doherty Senior Research Scientist
deMenocal, Peter B.	Associate Professor
Fairbanks, Richard G.	Professor
Griffin, Kevin L.	Associate Professor
Hays, James D.	Professor
Louchouarn, Patrick	Associate Professor
Marra, John F.	Doherty Senior Scholar
Olsen, Paul E.	Arthur D. Storke Memorial Professor
Sambrotto, Raymond N.	Doherty Research Scientist
Van Geen, Alexander F.	Doherty Senior Research Scientist

RESEARCH STAFF

Buckley, Brendan M.	Doherty Associate Research Scientist
Cheng, Zhongqi	Associate Research Scientist
Liepert, Beate G.	Doherty Associate Research Scientist
Subramaniam, Ajit	Doherty Associate Research Scientist
Vaillancourt, Robert D.	Doherty Associate Research Scientist

POSTDOCTORAL STAFF

Barker, Stephen R.	Post Doctoral Research Fellow
Hendy, Erica J.	Post Doctoral Research Scientist
Levi, Camille	Post Doctoral Research Scientist
Wright, William E.	Post Doctoral Research Fellow

GRADUATE STUDENTS

Almasi, Peter F.
Aziz, Zahid
Cao, Li
Chiu, Tzu-chien
Farmer, Emma C.
Giallombardo, Andres
Green, Sarah
Hwang, Sunny H.
Ingram, Sarah J.
Jones, Miriam C.
Ksepka, Daniel T.
Li, Jinbao
Liu, Jun
Machlus, Malka L.
Mihlbachler, Matthew C.
Pederson, Neil
Pol, Diego
Shapiro, Josslyn
Whiteside, Jessica
Xu, Chengyuan

SPECIAL RESEARCH SCIENTIST

Hunkins, Kenneth L.
Jacoby, Gordon C., Jr.
Kukla, George

LDEO ADJUNCTS

Anderson, O. Roger	Adjunct Senior Research Scientist
Burckle, Lloyd H.	Adjunct Senior Research Scientist
Carlut, Julie H.	Adjunct Associate Research Scientist
Chase, Zanna	Adjunct Associate Research Scientist
Cherubini, Paolo	Adjunct Research Scientist
Et-Touhami, Mohammed	Adjunct Associate Research Scientist
Gastrich, Mary D.	Adjunct Research Scientist
Gavrieli, Ittai	Adjunct Associate Research Scientist
Juhl, Andrew R.	Adjunct Associate Research Scientist
Kent, Dennis V.	Adjunct Senior Research Scientist
LeTourneau, Peter M.	Adjunct Associate Research Scientist
Lewis, Marlon R.	Adjunct Senior Research Scientist
Nachin, Baatarbileg	Adjunct Associate Research Scientist
Orwig, David A.	Adjunct Research Scientist
Peteet, Dorothy M.	Adjunct Senior Research Scientist
Ray, Bonnie K.	Adjunct Research Scientist
Rose, Jerome	Adjunct Associate Research Scientist
Rousseau, Denis-Didier	Adjunct Associate Research Scientist
Schuster, William S. F.	Adjunct Senior Research Scientist
Tissue, David T.	Adjunct Associate Research Scientist
Turnbull, Matthew H.	Adjunct Research Scientist
Villalba, Ricardo	Adjunct Associate Research Scientist
Wiles, Gregory C.	Adjunct Associate Research Scientist

STAFF OFFICERS OF RESEARCH

Davi, Nicole K.	Staff Associate
Gavin, Joyce E.	Staff Associate
Lotti, Ramona	Staff Associate
Mortlock, Richard A.	Senior Staff Associate
Wernick, Iddo K.	Staff Associate

SYSTEMS ANALYSTS / PROGRAMMERS

Ho, Cheng-Chuan	Systems Analyst/Programmer
Pistolesi, Linda I.	Web Specialist

SUPPORT STAFF

Anest, Nichole A.	Senior Research Staff Assistant
Baker, Linda D.	Research Staff Assistant
Bitte, Ivars R.	Research Engineer
Curtis, Ashley E.	Research Staff Assistant
Griffith, Heather E.	Research Staff Assistant
Guilfoyle, Carolann R.	Administrative Assistant
Krusic, Paul J.	Research Staff Assistant
Lozefski, George	Research Staff Assistant
Malone, Patricia N.	Senior Research Staff Assistant
Mason, Cedric W.	Research Staff Assistant
Mayernik, Andrea N.	Research Staff Assistant
Mones, Katherine C.	Administrative Assistant
Pederson, Dorothy C.	Senior Research Staff Assistant
Peters, Kenneth	Senior Research Staff Assistant
Rees, Martha	Senior Research Staff Assistant
Sauer, Kirsten L.	Research Staff Assistant

Geochemistry

Anderson, Robert F.	Associate Director
Thompson, Ellen L.	Division Administrator

SENIOR SCIENTIFIC STAFF

Anderson, Robert F.	Doherty Senior Scholar, Adjunct Professor
Broecker, Wallace S.	Newberry Professor
Chillrud, Steven N.	Doherty Research Scientist
Goldstein, Steven L.	Associate Professor
Hemming, Sidney R.	Associate Professor
Longhi, John	Doherty Senior Research Scientist
McGillis, Wade R.	Doherty Research Scientist
Schlosser, Peter	Professor
Simpson, Harry J., Jr	Professor
Smethie, William M., Jr.	Doherty Senior Research Scientist
Takahashi, Taro	Doherty Senior Scholar, Adjunct Professor
Walker, David	Professor

RESEARCH STAFF

Class, Cornelia	Doherty Associate Research Scientist
Ho, David T.	Doherty Associate Research Scientist
Le Bel, Deborah A.	Associate Research Scientist
Schaefer, Joerg M.	Doherty Associate Research Scientist
Winckler, Gisela	Doherty Associate Research Scientist

POSTDOCTORAL STAFF

Donnelly, Kathleen E.	Post Doctoral Research Scientist
Kelly, Meredith A.	Post Doctoral Research Scientist
Matter, Jurg M.	Post Doctoral Research Scientist
Newton, Robert	Post Doctoral Research Scientist
Rinterknecht, Vincent R.	Post Doctoral Research Scientist
Roy, Martin	Post Doctoral Research Scientist
Van de Flierdt, Christina-Maria	Post Doctoral Research Fellow

GRADUATE STUDENTS

Ali, Shahla
Bradtmiller, Louisa I.
Cai, Yue
Cipriani, Anna
Downing, Greg E.
Frantz, Tony
Franzese, Allison M.
Himmel, Dana B.
Jones, Kevin M.
Keimowitz, Alison R.
Piotrowski, Alexander M.
Santella, Nicholas
Schmieder, Paul J.
Simons, Kyla
Soffer, Gad
Spieler, Abigail R.
Stevenson, Elizabeth A.
Thompson, William G.
Wheeler, Kevin T.
Zimmerman, Susan R.H.

SPECIAL RESEARCH SCIENTIST

Biscaye, Pierre E.
Bonatti, Enrico

LDEO ADJUNCTS

Banner, Michael L.	Adjunct Senior Research Scientist
Bopp, Richard F.	Adjunct Senior Research Scientist
Bory, Aloys J.	Adjunct Associate Research Scientist
Brueckner, Hannes K.	Adjunct Senior Research Scientist
Denton, George H.	Adjunct Senior Research Scientist
Ebel, Denton S.	Adjunct Associate Research Scientist
Grousset, Francis E.	Adjunct Senior Research Scientist
Hales, Burke R.	Adjunct Associate Research Scientist
Harlow, George E.	Adjunct Senior Research Scientist
Hemming, N. Gary	Adjunct Associate Research Scientist
Henderson, Gideon M.	Adjunct Associate Research Scientist
Hohmann, Roland	Adjunct Associate Research Scientist
Honisch, Barbel	Adjunct Associate Research Scientist
Kavner, Abby	Adjunct Associate Research Scientist
Langmuir, Charles H.	Adjunct Senior Research Scientist
Liu, Tanzhuo	Adjunct Associate Research Scientist
Mandeville, Charles W.	Adjunct Associate Research Scientist
Mathez, Edmond A.	Adjunct Senior Research Scientist
Rutberg, Randye L.	Adjunct Associate Research Scientist
Shepherd, John G.	Adjunct Senior Research Scientist
Straub, Susanne M.	Adjunct Associate Research Scientist
Stute, Martin	Adjunct Research Scientist
Sweeney, Colm	Adjunct Associate Research Scientist
Tomascak, Paul B.	Adjunct Associate Research Scientist
Torgersen, Thomas L.	Adjunct Research Scientist
Webster, James D.	Adjunct Research Scientist
Zheng, Yan	Adjunct Associate Research Scientist

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Traffic Department. From left to right: E.J. Cocker, Carl Baez, Tom Eberhard, Tony Deloatch, and Isaac Kim. Not pictured: Maurice Mack, Pat Ables, Juan Torres, and Jon Chazen.
Credit: Bruce Gilbert

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Credit: Bruce Gilbert

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Marie Tharp

[*above left*] Marie Tharp, somewhere in Alabama, c. 1930.

"My father had been a soil surveyor for the U.S. government and we moved around quite a lot when I was a child. Here I am using Papa's plane table."

[*above right*] Marie Tharp

IN 1948, ARMED WITH TWO DEGREES IN GEOLogy and math, **Marie Tharp** had a job interview with Maurice Ewing, director of the new Lamont Geological Observatory. "When he heard about my background, he was surprised and didn't know quite what to do with me," Tharp recalled. "Finally he blurted out, 'Can you draft?'"

The first map Tharp drafted indicated that the Atlantic Ocean seafloor was bisected by a rift valley—a finding that Tharp's colleague, **Bruce Heezen**, initially dismissed as "girl talk." But Tharp's finding was true, and it helped launch the plate tectonics revolution, which fundamentally changed our understanding of the Earth. Together, Heezen and Tharp collaborated to create the first-ever global seafloor map, which opened our eyes to a planet that was even more wondrous than we had imagined.

In 2004, Columbia's Earth Institute won a five-year $4.2 million award from the National Science Foundation's ADVANCE Program, which funds programs to help change the chilly institutional climate for women scientists and engineers by defining and implementing approaches that increase their participation and advancement.

A core component of this new program is the establishment of fellowships that provide up to $30,000 of funding for women scientists to conduct research within The Earth Institute for one to three months during their career-building years, said Lamont-Doherty Senior Scientist **Robin Bell**, who heads the program. One of the chief goals of the program is to attract new women to Columbia, and to Lamont-Doherty in particular.

Bell chose to call these Marie Tharp Visiting Fellowships in honor of the young woman scientist who, despite her less-than-warm welcome in 1948, came to mean so much to Lamont-Doherty, to women scientists, and to earth science.

Marie Tharp works on the first map of the Atlantic Ocean floor. In the background, profiles of six east-to-west transects of the Atlantic Ocean floor provided the first evidence of the rift valley that bisects the Mid-Atlantic Ridge—a discovery that helped spur the plate tectonics revolution in the earth sciences.

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