2004–2006

BIENNIAL REPORT

LAMONT-DOHERTY
EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

View to the west, up Korridoren Glacier in East Greenland. Meredith Kelly, a postdoctoral research fellow in Geochemistry, is using surface exposure dating techniques on glacial moraines in the region to reconcile an inconsistency between existing ice core and mountain glacier temperature records. *Credit: Meredith Kelly*

LAMONT-DOHERTY EARTH OBSERVATORY IS RENOWNED IN THE INTERNATIONAL SCIENTIFIC COMMUNITY FOR its success and innovation in advancing understanding of the 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

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The profound tragedies of the last two years drive us to find ways to accelerate our progress.

WE STRIVE TO UNDERSTAND HOW OUR EARTH EVOLVES AND CHANGES—how the deep interior is structured to feed global volcanism and trigger earthquakes, how the atmosphere changes with additions of greenhouse gases and aerosols, how the oceans transport heat to control the ever-changing cycles of climate variability. When the changes related to fundamental processes like these occur catastrophically, as they did with the Indian Ocean tsunami and Hurricane Katrina, then the general public is reminded of the importance of earth sciences to the well-being of society.

These profound tragedies of the last two years are poignant reminders of the significance and urgency of the research we do. They drive us to find ways to accelerate our progress.

The ongoing construction of our new Geochemistry laboratory building is one example of how we are doing this. The new facility will enable our Geochemistry Division to be housed together in a single building for the first time in many years. Its superior laboratories and innovative design will provide the capabilities and working environment that our geochemists need to maintain their world leadership and expand our understanding of Earth.

As our planet changes, few areas are impacted as rapidly or as significantly as are the poles. Observatory researchers have during the past two years developed leadership roles in planning for the International Polar Year activities that will begin in 2007, and you will read much about this important initiative throughout this report.

You will also read about our increased dedication to and involvement in earth science education at many different levels; about our increasing level of coordination and cooperation with other departments and units within Columbia University, enabled by the continued growth and effectiveness of The Earth Institute; and about our increasingly active Advisory Board whose dedication to the Observatory is having real impact upon our growth and security.

The past two years have been marked by too many successes to be mentioned in these few introductory comments, but I hope this report effectively conveys the overall level of success and accomplishment that Observatory researchers have achieved. Our growing levels of government funding, successful recruitment of first-class young scientists and acquisition of our new research vessel *Marcus G. Langseth* are all tangible symbols of our leadership—a leadership that we are confident will continue far into the future.

G. Michael Purdy
Director

It is here that the strength of rigorous, cross-disciplinary scientific study to address many of the most pressing issues facing society truly shines through.

AS THE EARTH INSTITUTE ENTERS ITS SECOND DECADE, WE ARE emboldened in our efforts to promote science-based solutions to sustainable development by the many outstanding successes at the Lamont-Doherty Earth Observatory over the past two years. It is here that the strength of rigorous, cross-disciplinary scientific study to address many of the most pressing issues facing society truly shines through.

Nothing illustrates that strength more to me than what happened after a concerned businessman and philanthropist asked himself why he was able to sail through the Arctic Ocean without the aid of an icebreaker. To answer his questions about global warming, Gary Comer turned to Lamont-Doherty and Wally Broecker. From that meeting and eventual friendship grew not only one man's education about climate science but also an enduring legacy of support that is likely to change the nature of what we know about Earth's natural systems.

Certainly, Lamont-Doherty's strengths do not end with its tradition of excellence in climate science. You will read in this report about fundamental breakthroughs made by Observatory scientists in our understanding of earthquakes and mantle formation, of changes in the ocean's biological systems and of the origin of dust storms in China. The fact that all of these studies and many more go on in the same place, with scientists from such diverse backgrounds interacting on a daily basis, is central to the Observatory's continued success and to the principals on which The Earth Institute was founded.

In addition to looking back over the past two years, this report reminds us of the many great things that are sure to grow out of such outstanding work. In the fall, we broke ground on the Geochemistry building made possible in part by the generosity and foresight of Gary Comer. Sadly, Gary passed away shortly after groundbreaking, but his legacy will live on most powerfully in the discoveries that are certain to be made there for decades to come.

In 2006 we also saw the start of refit on the R/V *Marcus G. Langseth*, a ship that will open new avenues of discovery and take scientists physically and intellectually to places they have yet to explore.

Finally, no accounting of Lamont-Doherty's strengths would be complete without acknowledging the strength of leadership that Mike Purdy has shown over the years. That leadership was justifiably recognized recently when he was awarded the 2006 Maurice Ewing Award by the American Geophysical Union. We look forward to many more years with Mike's steady, insightful guidance and many more discoveries by Lamont-Doherty scientists that will push the boundaries of what we know about our planet.

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

CHASING SCIENCE TO THE ENDS OF THE EARTH

IN 1957, KEN HUNKINS, A YOUNG GRADUATE STUDENT THIRSTING TO EXPLORE EARTH'S geographic and scientific frontiers, came to what is now the Lamont-Doherty Earth Observatory. He was promptly dispatched to Station Alpha—a research camp on an ice floe in the Arctic Ocean.

His arrival coincided with the International Geophysical Year (IGY), an extraordinary, coordinated effort involving thousands of scientists from more than 60 countries to focus their scientific efforts on the poorly understood poles and expand on two previous worldwide research programs to explore Earth's polar regions, the International Polar Years of 1882–83 and 1923–33.

"We accumulated a wealth of data on the Arctic Ocean seafloor, currents and marine life, as well as the complex interactions among the ocean, sea ice and atmosphere," Hunkins said. "We gave four dimensions to a unique region of the planet that on most maps, and in most people's minds, was a featureless white expanse over a black hole."

Since then, the Observatory's researchers, spanning the spectrum of earth science disciplines, have never ceased exploring Earth's poles. Between 2004 and 2006, they made fundamental discoveries and have played leadership roles in planning the upcoming International Polar Year (IPY) that begins in March 2007.

Glacial Jolts

While working at Harvard, Lamont-Doherty seismologists Göran Ekström and Meredith Nettles identified a new kind of seismic event caused by the sudden movements of glaciers. Now, they have found that the number of these "glacial earthquakes" has more than doubled in Greenland since 2002, an indication that the glaciers, and the ice sheets that feed them, are sliding more rapidly toward the sea.

Nettles and Ekström analyzed recorded seismic waves that were routinely overlooked because they were not caused by earthquakes. To their surprise, they found about 200 previously undetected long-period seismic events in typically earthquake-free Greenland. The events all occurred in the valleys draining the two-mile-high Greenland Ice Sheet and happened more often in summer.

The scientists theorize that summer melting causes water to seep to the base of glaciers, where it lubricates sudden lurching. "Some of Greenland's glaciers, as large as Manhattan and as tall as the Empire State Building, can move 10 meters in less than a minute, a jolt that is sufficient to generate moderate seismic waves," said Ekström, who joined Lamont-Doherty in 2006.

Glaciers may be responding more rapidly than expected to changing climate conditions, Nettles said, sending more ice and fresh water into the oceans. That, in turn, could amplify climate changes even further and raise global sea levels. Ekström and Nettles are carrying out first-of-its-kind work to monitor for glacial earthquakes in near-real time.

Telltale Chemical Clues

Atop the ice sheets of both Greenland and Antarctica, geochemist Pierre Biscaye is continuing his work to identify dust trapped in layers of ice. The dust is composed of microscopic particles of soil and ground-up rock carried around the globe by winds. Telltale mineral and isotopic signatures give scientists the ability to trace the dust's origins and pathways and to reconstruct atmospheric circulation patterns tens of thousands of years in the past.

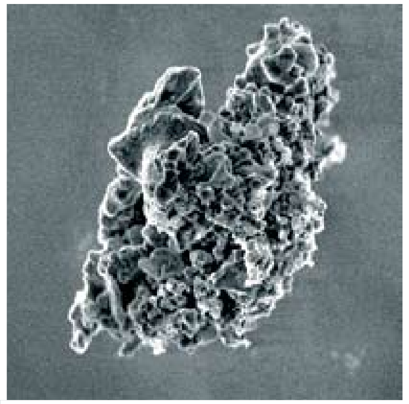
"There are fantastic records of past climate conditions in the ice cores," said Biscaye. "They provide insights into how our climate system works, and they are the best means of testing the accuracy of the models we use to forecast future climate change."

Geochemist Gisela Winckler exploited a vastly different type of dust for climate studies: "stardust." Every year, 40,000 tons of cosmic dust falls to Earth from outer space and becomes embedded in ice sheets. These particles, measuring a few thousandths of a millimeter in diameter, contain an isotope of helium that is rare on Earth but abundant in space. Analyzing Antarctic ice cores, Winckler found that interplanetary dust has fallen to Earth at a constant rate, thus offering a new, high-resolution clock to date extremely ancient ice.

Meanwhile, Lamont-Doherty geochemist Peter Schlosser has tracked chemical compounds in the Arctic Ocean and the Nordic Seas. These chronicle circulation changes, perhaps caused by climate changes, that may act as a trigger for further changes in Earth's climate (see page 15).

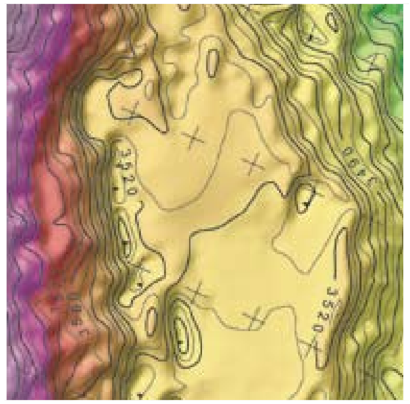
Some of Greenland's glaciers, as large as Manhattan and as thick as the Empire State Building is tall, can move 10 meters in less than a minute, a jolt that is sufficient to generate moderate seismic waves.

[below] Meredith Nettles
Postdoctoral Research Scientist
Credit: Leigh A. Stearns



[left] Cosmic dust particle similar to those found in Antarctic ice cores.
Credit: Scott Messenger, NASA

[right] The Russian Antarctic research station Vostok.
Credit: Michael Studinger

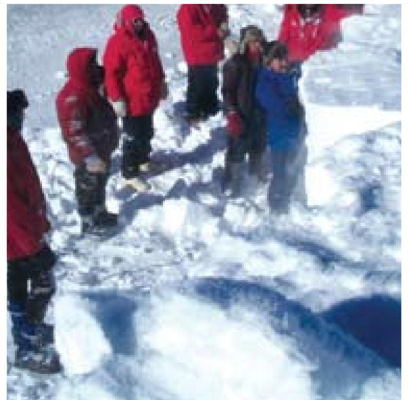


[left] Topographic map of the ice surface above Lake Vostok.
Credit: Michael Studinger

[below] Miles above Lake Vostok lies a flat expanse of featureless ice. During fieldwork in the short Antarctic summer, temperatures range between -30ºC and -40ºC (-22ºF to -40ºF). In 1983, the temperature at Vostok dropped to -89.2ºC (-128.6ºF), the coldest temperature ever recorded on Earth. *Credit: Michael Studinger*

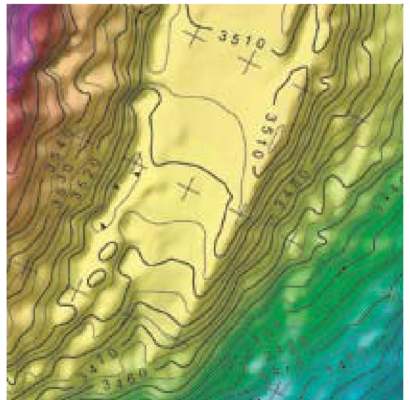
[above] Leigh Stearns from the University of Maine and Andreas Ahlstrøm from the Geological Survey of Denmark and Greenland install a GPS station on Helheim Glacier in East Greenland as part of Meredith Nettles' recent work to monitor glacial earthquakes.
Credit: Gordon S. Hamilton

[right] The U.S. nuclear submarine *Skate* at Ice Station Alpha in 1958.
Credit: Ken Hunkins



[above] Scientists examine a crack in the sea ice near Station Alpha in 1958 that will eventually force the station to be relocated.
Credit: Ken Hunkins

[right] A section of the EPICA ice core sampled by researchers to measure the accumulation of cosmic and terrestrial dust particles in Antarctica.
Credit: Sepp Kipfstuhl, AWI



Exploring Polar Oceans

The seas surrounding Antarctica play a critical role in global ocean circulation and climate. There, the interactions among air, sea and ice form very cold, dense water that sinks and spreads northward, chilling the lower two kilometers of the entire world's ocean. The descent of these large, cold water masses displaces deep waters toward the surface. By this process, the ocean "overturns," with dense polar surface waters taking up greenhouse gases from the atmosphere that can be effectively stored in the deep ocean.

Antarctica's remote, ice-choked waters have largely deterred investigation of this fundamental phenomenon. In 1992 Lamont-Doherty physical oceanographers Arnold Gordon and Bruce Huber engaged in pioneering measurements in the Weddell Sea, as part of Ice Station Weddell, to investigate the complex processes that form the dense bottom water that eventually spreads northward. They began to deploy mooring arrays in the Weddell Sea from 1999 and in the Ross Sea from 2003 (both remain in operation today) to monitor the rate, variability and other properties of cold bottom water as it drains away from formation sites along the margins of Antarctica and into the global ocean.

Some scientists think that rapid climate change could, for example, melt large amounts of sea ice, exposing more ocean surface to the sun and adding fresh water to the system. That, in turn, may leave surface waters too light (warm and fresh) to sink and propel ocean overturning, which could have a wide range of possible climate impacts.

Lakes and Life Beneath the Ice

In 2005 and 2006, Lamont-Doherty biological oceanographer Andrew Juhl conducted fieldwork near Barrow, Alaska, to learn how little-known communities of marine algae thrive in the underside of sea ice and to study their crucial role in the polar ecosystem (see page 9). Exotic life forms may also be living in two large lakes that have been sealed for millions of years beneath two miles of Antarctic ice. In 2006, geophysicists Robin Bell and Michael Studinger, using aerial gravity surveys and satellite laser mapping, described for the first time details of the subglacial lakes 90°E and Sovetskaya.

The scientists believe water in these and other subglacial lakes on the flanks of the ice-covered Gamburtsev Mountains could lubricate the flow of the massive East Antarctic Ice Sheet, which holds enough ice to raise global sea levels by 50 meters. The dynamics of the lakes and the tectonic origins of the mountain range, which are as large as the European Alps and fostered the growth of the massive ice sheet 35 million years ago, remain unknown.

[top] U.S. Coast Guard Cutter *Healey* working its way through Arctic sea ice. *Credit: Henry Dick, National Science Foundation*

[bottom left] Robin Bell, Director of Center for Rivers and Estuaries, Doherty Senior Research Scientist, Marine Geology and Geophysics *Credit: Bruce Gilbert*

[bottom right] Scientists at Ice Station Weddell drifted with the Antarctic sea ice for nearly five months in 1992. *Credit: Arnold Gordon*

Lamont-Doherty Leadership

During the IPY, Bell and Studinger will help lead pioneering expeditions to explore the Gamburtsev Mountains, the last unmapped mountains on Earth. Near the planet's other pole, Schlosser will help lead expeditions deploying innovative technology to investigate ocean conditions in the "Arctic Switchyard," an important region north of Greenland where Arctic waters diverge to head east or west around Greenland.

Schlosser has been involved in planning Arctic research since the early 1990s, when he first detected that large-scale circulation changes were occurring. Most recently, he was a member of the first science steering committee for United States' multiagency Study of Environmental Arctic Change (SEARCH) program and has chaired that group since 2004. Schlosser also helped plan the International Study of Arctic Change program and presently serves on its science steering committee.

For her part, Bell chaired the National Research Council's Polar Research Board, the national coordinating committee for the IPY. She also co-chaired the International Council for Science (ISC) group that developed the first major planning document for the current IPY and continues to serve on the ICS's planning group.

In testimony before Congress in 2006, Bell said, "Although we've made tremendous progress in all science over the past 100 years, the polar regions are still at the frontiers of human knowledge. The maps aren't quite as blank, but the frontiers and unknowns have actually increased, and range from the molecular, to the ecological, to the continental."

A NEW HOME FOR GEOCHEMISTRY

FROM ITS BEGINNINGS IN CRAMPED QUARTERS AT LAMONT HALL, THE GEOCHEMISTRY Division has built a proud tradition of leadership that addresses Earth's many complex and interconnected systems. In recent years, however, the Observatory's sprawling Geochemistry laboratory building, dedicated in the early 1950s, began to prove inadequate for the scientists who study fundamental questions about the structure and function of the planet, from its core to the outer atmosphere.

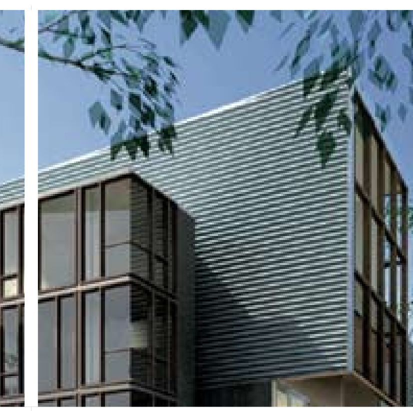
In 2005, Columbia University received an $18 million gift from Gary Comer and the Comer Science and Education Foundation to support construction of a new geochemistry building at Lamont-Doherty—one of the largest donations ever received by the Observatory. The gift reflects the commitment of the founder of the Lands' End clothing-catalog company to efforts that deepen understanding of the effect of human activity on the environment. Support for the project has also included major gifts from Columbia Trustee Gerry Lenfest as well as an anonymous donor and the Ambrose Monell Foundation, and the Observatory's highest priority is raising the remaining $3.9 million needed to complete funding for what is certain to become a cornerstone for scientific research on campus.

Plans call for a two-story, 63,000-square-foot-building that will house Lamont-Doherty's Geochemistry Division, which is currently scattered across the campus. It will contain laboratories designed to meet the best practices described in the EPA's Labs21 program as well as provide much-needed support and office space. Ribbon-cutting is scheduled for November 2007.

Comer's interest in the project grew from a 2001 trip he made through the Northwest Passage on his yacht *Turmoil*. After he was able to complete the trip without the aid of an icebreaker, he became concerned about global warming and he turned to Lamont-Doherty geochemist Wally Broecker for insight. In following years, he accompanied scientists from Lamont-Doherty and other institutions into the field many times.

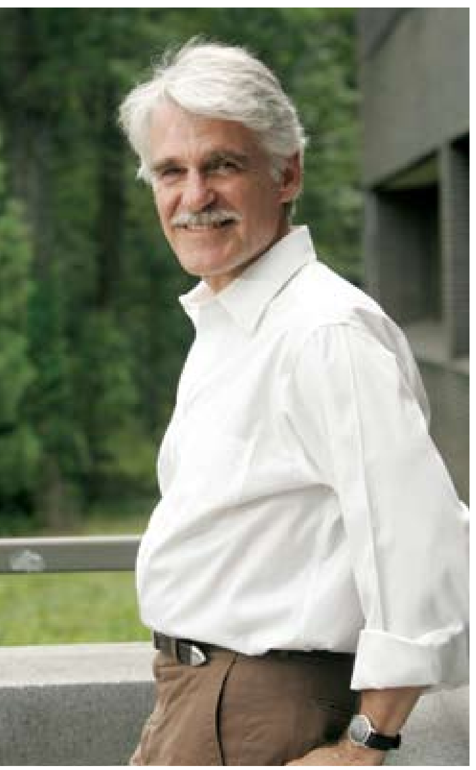
Sadly, Mr. Comer passed away in October 2006 shortly after ground was broken. His legacy will remain, however, not only in the form of the new building, but in the generations of scientists it will help train and the fundamental discoveries it will undoubtedly enable.

Columbia University received an $18 million gift from Gary Comer and the Comer Science and Education Foundation to support construction of a new Geochemistry building at Lamont-Doherty.



[above and left] When the new building opens, it will provide a home for the entire Geochemistry Division and act as a hub of laboratory research for the entire Observatory.
Credit: Payette Associates, Inc.

By studying living organisms or fossil remains, B&PE scientists can make sense of Earth's current environment, how it has changed through time and what may be expected in the future.



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

The Biology and Paleo Environment Division (B&PE) is a diverse group of oceanographers, geologists, geochemists, biologists and environmental scientists who pursue research in two connected efforts. First, we use biology (usually looking at fossils) to uncover clues about Earth's past environment. We also strive to understand how the modern environment—through its oceans, atmosphere and land—affects present-day biology.

All organisms record the environment in which they exist. Ecosystems are shaped by such factors as temperature, water availability, nutrients, light and chemical or physical changes and, hence, shape the creatures that live in them. These organisms, in turn, exert an influence on their surrounding environment. By studying living organisms or fossil remains, B&PE scientists can make sense of Earth's current environment, how it has changed through time and what may be expected in the future as current trends play out.

B&PE scientists turn to a number of primary sources to conduct research on past environments, including deep-sea sediment cores, samples from coral reefs and growth rings of trees. Deep-sea sediment cores are like tape recordings of the past that allow scientists to look at Earth's history over the last several million years. In an example of such research (see page 9) Lamont-Doherty scientist Peter deMenocal and former graduate student Sarah Feakins examined leaf wax from plant material preserved in deep-sea cores to link major climate changes with fundamental evolutionary events in human history.

To extend records of climate and ocean conditions beyond pre-anthropogenic times, scientists study corals, both living and fossilized, whose growth rings preserve a record of ocean conditions in which they grew. Similarly, the width of tree rings, formed as trees grow and lay down wood seasonally, can reflect the temperature and precipitation during each growing season. By studying trees several hundred years old, scientists can establish an accurate record of the climate for many locations. Ed Cook and colleagues in Lamont-Doherty's Tree-Ring Laboratory are in the midst of a five-year project to reconstruct the history of the Asian monsoon, whose rhythms pace and undergird the health and welfare of billions of people (see page 10).

While paleoceanographers and geologists sift the evidence of Earth's past, others in B&PE monitor the converse: They look at modern effects of the environment on marine plankton and trees, for example, to understand how these organisms are responding to changing environmental conditions. Biological oceanographer Andrew Juhl recently joined colleagues in Barrow, Alaska, to explore little-known, but ecologically important, marine algae that live in sea ice (see page 9).

Together, projects such as these help B&PE better understand how Earth's climate has changed in the past—and what we might be able to expect in future climate regimes.

Former DEES graduate student
Sarah Feakins in the Fye Lab at Woods
Hole Oceanographic Institute.
Credit: Robert Nelson, WHOI

Did Climate Shifts Change The Course of Evolution?

In 1995, Lamont-Doherty paleoceanographer Peter deMenocal first reported intriguing evidence that dramatic climate changes on Earth may have governed the course of human evolution. He found that thicker, more abundant layers of soil particles and tiny remnants of grasses—blown out to sea during drier climates—had accumulated in ocean sediments off the African coast around 2.8 million and again about 1.8 million years ago.

Those times coincided with two major events in human evolution recorded by fossils. About 2.8 million years ago, *Australopithecus afarensis* ("Lucy") became extinct and the human family tree diverged into two branches. One million years later, humans' most immediate ancestor, *Homo erectus*, first appeared. Together, the evidence strongly suggested that shifting environmental conditions contributed to the extinction of some human ancestors and also gave other species opportunities to adapt and thrive.

That interpretation remained open, however, because the thicker layers of terrigenous material in the oceans could be explained by stronger winds as well as by drier conditions. So deMenocal, Columbia graduate student Sarah Feakins and Tim Eglinton, a geochemist at Woods Hole Oceanographic Institution, sought a new approach to investigate how African vegetation changed over the last four million years. They measured plant leaf wax preserved in seafloor sediments drilled from the Gulf of Aden, where winds blow dust from Ethiopia, Kenya and Tanzania—the same regions in which scientists have discovered many hominid fossils.

In particular, the team measured and analyzed isotopic carbon compositions of the remnant plant material, allowing them to distinguish between plants that use different chemical pathways in their photosynthesis. To adapt to arid conditions, savannah grasses use the so-called C-4 pathway, which lets them use water more efficiently. Nearly all other trees and shrubs use the C-3 pathway.

Feakins was lead author of a paper published in 2005 in *Geology* that demonstrated northeast Africa did become markedly drier about 3 million years ago and grassland vegetation began to replace woodlands. Fossil records of African antelopes also show that the population of these savannah grass grazers began to expand about 3 million years ago, around the same time that "Lucy" and her cohorts began to decline. The aridification trend appears to have been gradual, culminating in the driest conditions around 1.6 million years ago, when *Homo erectus* emerged.

Collectively, the geochemical and fossil data indicate that major events in human evolution correlated with an increasingly open and more arid African landscape.

Investigating Hidden but Ecologically Critical Species

The vast stretches of sea ice extending over the Arctic Ocean seem totally desolate and lifeless from the surface, but in early spring the underside of the ice comes alive. In 2005 and 2006, Lamont-Doherty biological oceanographer Andrew Juhl conducted fieldwork near Barrow, Alaska, to learn how little-understood communities of marine algae are able to thrive inside sea ice and to study their crucial role in the polar ecosystem.

"Sea ice is a hostile environment—it's cold, and the salinity can be very high—but over time, the algae have successfully adapted," said Juhl. Among their adaptations is the ability to grow with very little light, perhaps one-tenth of that needed by other microscopic marine plants living in liquid water. As a result, ice algae begin to grow as soon as the first tentative rays of sunlight break the long Arctic darkness and begin penetrating through sea ice. That occurs in early spring—several months before plant growth begins in open-ocean regions after the sea ice has melted.

Scientists now think that ice algae greatly extend the growing season in polar regions, providing a significant source of food at the base of the food chain at a critical time when other plant life is inactive. Learning about ice algae has become more crucial now, at a time when a warming climate threatens to reduce sea ice and otherwise disrupt the delicately balanced Arctic ecosystem.

Juhl and Christopher Krembs of the University of Washington deployed instruments to monitor light intensity and the growth of ice algae, along with other sensors to measure currents, water temperatures, chlorophyll and nutrient levels in the water beneath the ice. They have also taken cores of sea ice to

Beyond their ecological importance, ice algae can also help expand our understanding of how organisms adapt to seemingly harsh environments, such as those on other planets.

sample the ice algae as well as other organisms living inside the ice that graze on the algae.

Large masses of ice algae appear to build up and are released into the ocean in periodic pulses. The scientists are investigating whether these pulses are correlated with strong currents or increases in light. One hypothesis is that as the algae collect light for photosynthesis, they may actually absorb enough heat to melt themselves out of the ice.

Beyond their ecological importance, ice algae can also help expand our understanding of how organisms adapt to seemingly harsh environments, such as those on other planets. Juhl and Krembs are examining mucous-like substances produced by ice algae that may help them stick to the ice and modify the structure of internal channels within the ice. Cold-adapted organisms such as ice algae may also produce unusual enzymes or other bioproducts that could prove useful in industrial or biomedical applications.

Reconstructing the History of Asian Monsoons

Two-thirds of the world's population depends on the seasonal rainfall brought by the Asian monsoon. Deviations in monsoon behavior can create floods or droughts that affect billions of people from Arabia to Indonesia. The source of monsoon rains are the oceans surrounding Asia. As the vast Tibetan Plateau absorbs summer heat, the atmosphere above it warms and rises. Cool, moist air—drawn in from the Indian and Pacific Oceans—rushes in and releases its moisture, sometimes with devastating results.

In 2004, the Tree-Ring Laboratory (TRL) embarked on a five-year project, funded by the National Science Foundation, to reconstruct the history of Asian monsoon climate dynamics. When completed, the study will provide an archival record that will help unravel the factors that lead to monsoonal shifts and help predict how the monsoons may change in an era of global warming (see page 11).

Andrew Juhl holds a core of ice extracted from the frozen Chuchi Sea in April 2005. The discoloration in the bottom of the core is caused by algae living inside channels and pores in the ice.
Credit: Christopher Krembs University of Washington

Over the last two years, TRL researchers Edward Cook, Gordon Jacoby, Rosanne D'Arrigo, Brendan Buckley and William Wright have roamed through Asia, identifying and sampling long-lived trees whose annual growth rings reflect temperature and precipitation conditions in the years in which they were formed. Data from this network will allow them to knit together a chronicle of monsoon behavior throughout the continent over the last several hundred years.

The researchers must negotiate often confusing cultural and governmental hurdles to obtain necessary collection permits. "It would be easy to let the impediments become frustrating, if not infuriating," said Wright. "But we have learned the importance of patience and find that crossing the bureaucratic quagmire can be a culturally fascinating experience."

Part of the TRL's mission is to provide formal training in tree-ring techniques in each country where they work and, if possible, to set up tree-ring laboratories. TRL researchers have been closely involved in developing the Laboratory of Tropical Dendrochronology (LTD) at Kasetsart University in Bangkok, Thailand; the Tree-Ring Laboratory at Mongolian National University in Ulan Baatar; and tree-ring facilities at the Institut Teknologi Bandung (ITB) in Bandung, Java, Indonesia, and at the Renewable Natural Resources Research Center in Jakar, Bhutan. They are also helping to develop new tree-ring programs at the University of the Philippines, Los Baños, and at the University of Peradeniya in Kandy, Sri Lanka. TRL scientists also held a three-day workshop in Thailand on dendrochronology in association with the Laboratory of Tropical Dendrochronology, which included participants from Thailand, Laos, Cambodia, Vietnam, Sabah, Sarawak, the Philippines, Sri Lanka, India and Australia.

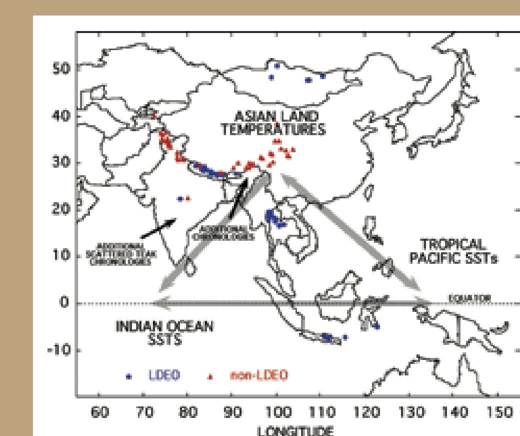
Regional tree-ring scientists from Lanzhou University in China; the Birbal Sahni Institute of Paleobotany in Lucknow, India; and the Indian Institute of Tropical Meteorology in Pune, India, have actively collaborated with Lamont-Doherty scientists, who said their Asian collaborators have taught them much about their region's climate and environment. Regional scientists have also been instrumental in facilitating the collection of tree-ring samples and in some cases have collected samples themselves.

Using this growing wealth of tree-ring data, Lamont-Doherty researchers are investigating how climate-related changes in sea surface temperatures in the Pacific and Indian Oceans and in land temperatures over the Tibetan Plateau may be linked with shifts in the strength of life-giving seasonal precipitation patterns for the entire region.

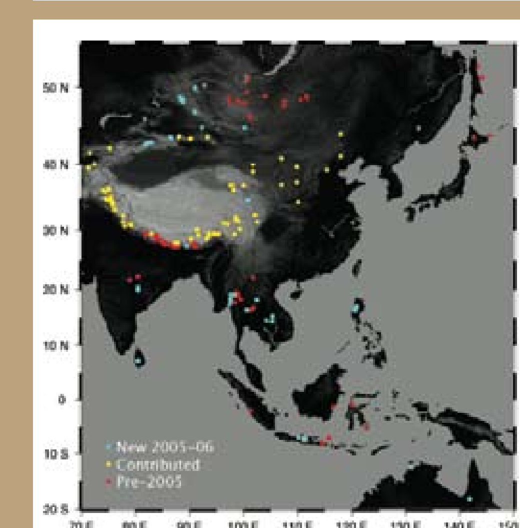
Lamont-Doherty Scientists Investigate the Asian Monsoon

Defining the role of the tropics in driving or modulating notable climate changes over the past 500 years or more requires information from a network of sites and adequate time series. Tree rings are the only data source that provides the required geographic and temporal coverage. The choice of sampling locations is influenced by the location of, and interactions among, three primary features of Asian climate variability that have links to variability in the strength of the monsoon: Indian Ocean sea-surface temperatures (SSTs), tropical Pacific SSTs and land temperatures over the Tibetan Plateau and northern Eurasia [Figure 1]. Scientists from the Tree-Ring Laboratory chose study sites (both new and existing) where the tree growth is influenced by one or more of these features, and their efforts have begun to yield results—with substantial increases in the tree-ring data network for the Asian monsoon region, particularly in the Asian tropics [Figure 2].

Analyses of these new data have already led to publications that have demonstrated links between several study sites and all three monsoon-related features. Other investigations are yielding new climate-sensitive records from Mongolia, the Philippines and Laos, and the results to date suggest bright prospects for the remainder of the research.



[Figure 1] The three primary dynamic environmental features that influence the strength of the Asian monsoon and location of sampling sites in the region.



[Figure 2] Map showing the expanding network of sampling sites throughout Asia. Red dots indicate sites that were available at the start of the project; yellow dots show the origin of data that have been contributed from various additional sources. Blue dots represent those new data and chronologies that have been developed over roughly the past two years of field work.

Geochemists have been heavily engaged during the past year in designing the new building, and we look forward to reporting on the move to the new building in the next biennial report.

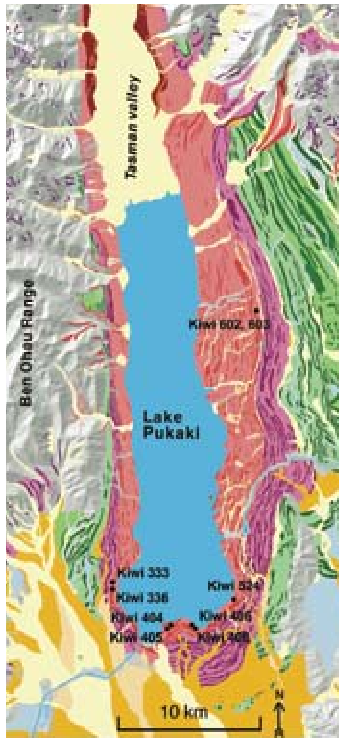
Robert F. Anderson
Associate Director,
Geochemistry Division
Credit: Bruce Gilbert

Scientists in Lamont-Doherty's Geochemistry Division work on a broad spectrum of topics, united by the shared philosophy that geochemical tracers can be exploited to unravel mysteries about the formation of Earth and the operation of its systems. Some of the principal research themes in the Division include:

- Solid-earth dynamics, including the exchange of material between Earth's core, mantle and crust.
- Structure and composition of Earth's lower crust and upper mantle, with a focus on melt transport in the upper mantle, accretion of igneous lower crust at spreading ridges and arcs and the hydration and carbonation of mantle-derived material that has been tectonically exposed at Earth's surface.
- The formation of Earth and its moon, and the transformations that occurred during the earliest phases of their histories.
- The oceans' role in climate, tracing ocean currents that transport heat around the globe and their variability through time, and investigating ocean processes that regulate the concentration of carbon dioxide in the atmosphere, from microscale physics at the air-sea interface to the global-scale meridional overturning ocean circulation.
- Causes and consequences of climate change over longer timescales, ranging from variability over many thousands of years paced by subtle changes in Earth's orbit to abrupt changes, sometimes within the span of a human lifetime, forced by as-yet unidentified mechanisms internal to Earth's climate system.
- Sources and fates of contaminants in the environment, transported both in air and water, with an emphasis on the New York metropolitan region and the Hudson River, but with projects extending worldwide.

Although modeling constitutes an important part of our work, the lion's share of the geochemistry research portfolio is made up of observational and experimental projects. Consequently, the success of our operations relies on maintaining state-of-the-art analytical facilities. These facilities have come under increasing pressure in recent years due to the declining state of the building that houses most of the Division.

Consequently, geochemists were delighted to receive a donation from Gary Comer and the Comer Science and Education Foundation (see page 7) that forms the financial foundation for a major new laboratory building. Geochemists have been heavily engaged during the past year in designing the new building, and we look forward to reporting on the move to the new building in the next biennial report.



Locations around Lake Pukaki in New Zealand where researchers have carried out surface exposure dating studies to examine the timing of the end of the last ice age worldwide.
Courtesy of Joerg Schaefer

View of the Lake Pukaki basin with nearly 30 different lateral and terminal moraine ridges visible around the lake.
Credit: Joerg Schaefer

Cosmogenic "Clock" Dates the Waning of Glaciers and Ice Ages

The forces that have driven Earth's ice ages have so far largely remained a mystery. Now, a new geochemical tool, called surface exposure dating (SED), is offering a transformational breakthrough in scientists' ability to precisely and directly date when glaciers anywhere in the world began to retreat.

As they advance, glaciers act like giant earthmovers, scraping up rocks and loose material to create deposits called moraines. Long Island and Cape Cod, for example, were formed by this process. The moment a glacier starts retreating, material at the top of a moraine is exposed to open sky and bombarded by cosmic rays, and a cosmogenic clock starts ticking.

Highly energetic neutrons in the cosmic rays induce reactions with oxygen and silicon atoms, which are replaced in the crystalline structure of minerals by beryllium-10 (^{10}Be), an isotope basically absent on Earth. Because the isotope accumulates at a known rate and modern detection methods can measure even minute amounts of ^{10}Be, scientists have a powerful geochronometer for determining when the rock surface became exposed.

Joerg Schaefer, head of the cosmogenic dating research group at Lamont-Doherty, led a recent study using ^{10}Be SED to date glacial moraines in the Northern and Southern Hemispheres. His work sought to explore a vexing question: Was the end of the last ice age a global phenomenon, or did changes occur asynchronously in different hemispheres?

The question arises because data from Antarctic ice cores shows that temperatures there began to steadily rise 17,500 years ago, concurrent with a rise in atmospheric carbon dioxide levels. That pattern makes rising greenhouse gases a prime suspect for causing the end of the last ice age worldwide.

Paleoclimate records in the north, however, tell a very different story. Ice cores from Greenland indicate that temperatures shot up dramatically 14,700 years ago—2,800 years after warming began in the south. Records from seafloor sediments also show that North Atlantic Ocean temperatures were cool between 17,500 and 14,700 years ago, another indication that ice-age conditions continued around Greenland.

Schaefer and colleagues sampled the top surfaces of large boulders on moraines in the Sierra Nevada Mountains in North America and the Southern Alps of New Zealand and used the SED method to time glacial retreats at mid-latitudes in both hemispheres. Combining their studies with SED studies by other researchers of six other mid-latitude moraines (three in each hemisphere), they found that—despite various geographic, geological, glaciological and hemispheric differences—the timing of glacial retreat in mid-latitudes was remarkably synchronous at around 17,500 year ago.

That pattern makes rising greenhouse gases a prime suspect for causing the end of the last ice age worldwide.

This result provides strong evidence that the end of the ice age was a global phenomenon in near-synchrony with rising atmospheric carbon dioxide levels and temperatures over Antarctica.

So how to explain the Greenland record?

Schaefer and colleagues offer this hypothesis: Rising global summer temperatures 17,500 years ago initiated the retreat of mid-latitude glaciers and also destabilized great Northern Hemispheric ice sheets. This caused the flow of ice toward the sea to increase and launched armadas of icebergs into the North Atlantic. The influx of such a large volume of fresh water changed the ocean's circulation, almost shutting down a system of currents that transports heat from the tropics to the North Atlantic. As a result, sea ice spread and hyper-cold winters ensued in the arctic, which offset for nearly 3,000 years the warming that was occurring in the rest of the world.

Do Coastal Waters Absorb CO_2, or Add It to the Atmosphere?

In this era of global warming, a key question that must be answered is how much carbon dioxide the oceans can absorb to offset the buildup of atmospheric greenhouse gases. To answer this, scientists have roamed the world's oceans over the last decade, measuring gas exchanges between air and sea. However, critical clues may lie closer to home in coastal waters, where blooms of photosynthetic marine plants use carbon dioxide dissolved in the ocean and draw down more from the atmosphere.

Some research suggests that the thin sliver of ocean around continents may absorb as much as 1 billion tons of atmospheric carbon dioxide per year, roughly half the known uptake of the rest of the open ocean. But Lamont-Doherty geochemist Wade McGillis thinks that estimate is oversimplified.

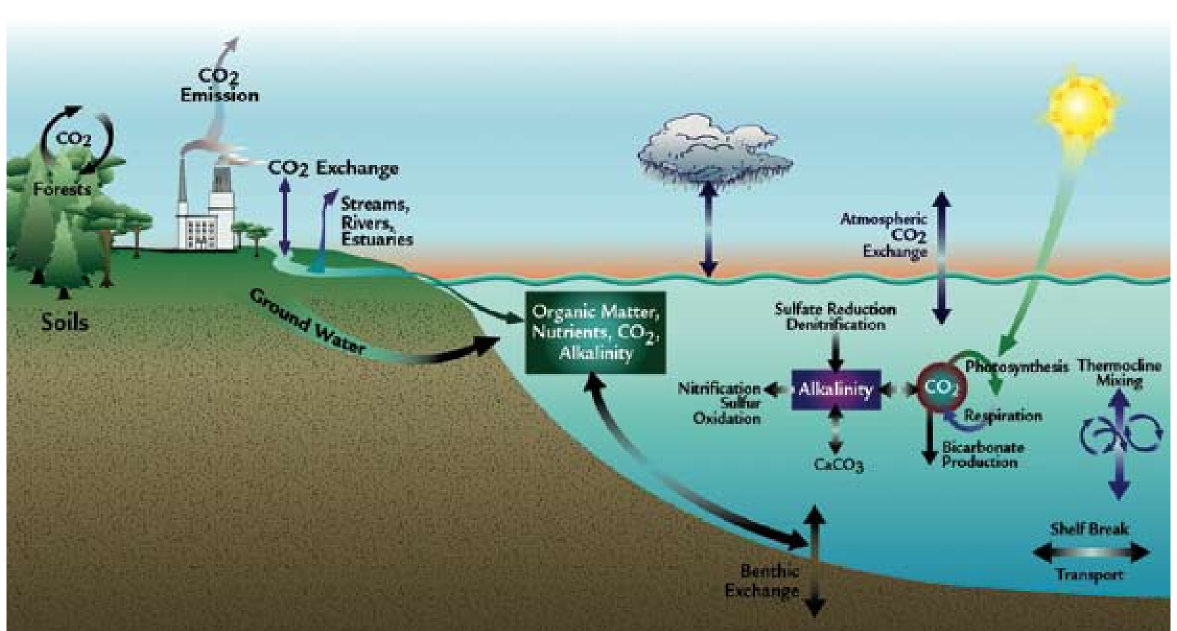
By expanding these pioneering studies to coastal regions worldwide, scientists will be able to determine which areas contribute to or offset increasing greenhouse gas levels in the atmosphere and will gain important insights to better assess global warming issues.

Waves, weather, river inputs, nutrient supplies, tides, currents, marine life populations and other factors vary from one coastal region to another and from season to season. These complex, interacting factors affect the gradient of carbon dioxide in the air and oceans and, consequently, the exchange between them. They also affect the amount of carbon dioxide that is exchanged between the coastal and open oceans. In some places and at certain times, temperature and respiring marine animals that eat marine plants may actually produce more carbon dioxide than the plants take up, making the area a net source, rather than a "sink," of carbon.

Few coastal areas have been observed continuously to sort out what is really happening, however. To remedy this situation, McGillis and collaborators launched an effort to make long-term observations of coastal dynamics. They deployed manually operated and autonomous instruments, designed and built at Lamont-Doherty, to measure air-sea carbon dioxide fluxes at a series of observatories along the East Coast: the Gulf of Maine Ocean Observing System, the Martha's Vineyard Coastal Observatory, the U.S. Army Corps of Engineers Field Research Facility in North Carolina, the South Atlantic Bight Ocean Observing Network off eastern Florida and on the west coast of Florida.

"Through continuous monitoring of CO_2 and related dynamics in the coastal ocean, we can begin to understand which processes govern the rate and magnitude of air-sea CO_2 fluxes," said McGillis.

By expanding these pioneering studies to coastal regions worldwide, scientists will be able to determine which areas contribute to or offset increasing greenhouse gas levels in the atmosphere and will gain important insights to better assess global warming issues.



Ocean margins are a potentially important contributor to the global carbon cycle, although little is known about the spatial and temporal variability of CO_2 in these areas. The major physical and biogeochemical processes controlling CO_2 in coastal waters are photosynthesis, respiration, heat and gas exchange and the mixing of estuarine and marine waters. *Credit: Wade McGillis*

Fresher Oceans Increase Potential for Climate Change

In 1991, Peter Schlosser first reported evidence of dramatic changes in the Greenland Sea that had potentially far-reaching consequences for the world's climate; waters that historically sink there as part of the oceans' global circulation nearly stopped in the 1980s. The search to find out why took Schlosser and collaborators into the Arctic Ocean where they have been working since the late 1980s.

Cold winters in the Nordic seas cool the ocean waters, making them dense enough to sink to the abyss. That helps drive a huge mass of southward-flowing deep water and draws warm surface currents northward from the tropics to replace them. When the warmer waters reach high latitudes, they release a large amount of heat to the atmosphere, tempering winters in the North Atlantic region.

Polar waters had remained largely understudied in the late 1980s, when Schlosser began to trace the penetration of natural and anthropogenic chemical compounds from the ocean surface downward. To determine the rate of sinking in the Greenland Sea, he and his colleagues tracked tritium from nuclear weapons tests in the 1960s, together with its radioactive decay product, helium-3, as well as chlorofluorocarbons (or CFCs, the now-banned chemicals formerly used in aerosols). Working with postdoctoral scientists from Lamont-Doherty and in close collaboration with colleagues from other U.S. and European institutions, Schlosser found that the rate of sinking in the Greenland, Norwegian and Iceland Seas (known as the Nordic Seas) has decreased substantially.

One suspected cause is the increase of fresh water flowing into high-latitude seas. Fresh water is more buoyant than salt water and "floats" above it—acting as a cap that blocks heat exchange between ocean and atmosphere and reduces the sinking of surface waters.

Other researchers found that freshwater levels in the Labrador and Irminger Seas, south of the Nordic Seas, have increased significantly in recent decades. Schlosser and his colleagues, among them Bill Smethie from Lamont-Doherty, headed upstream of the Greenland Sea into the Arctic Ocean, a region they found was also undergoing ocean circulation changes of a magnitude that had not been seen before humans began gathering data there.

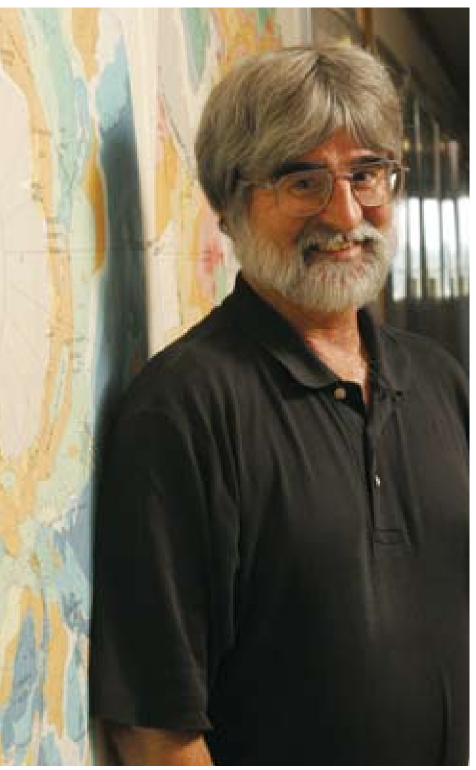
Researchers in Lamont-Doherty's Environmental Tracer Group collected water samples during several cruises into the deep, ice-covered Arctic Ocean including a voyage across the entire Arctic Ocean on the Swedish icebreaker *Oden* in 2005. In the first detailed survey of the interior of the Canadian Basin, they are analyzing tritium, helium-3 isotopes and CFCs to study changes in upper water layers, as well as salinity and nutrients to determine the sources of Arctic fresh water.

Dale Chayes, Guy Mathieu and Richard Perry joined expeditions in 2004 and 2005 on a pilot project to investigate freshwater flow in the "Arctic Switchyard," north of Greenland—so named because Arctic waters diverge there to head around the west coast of Greenland or around the east coast into the Greenland Sea. The researchers sampled waters at several locations from Ellesmere Island north using a through-ice CTD rosette, a new instrument to measure salinity, temperature and depth that was designed and built at Lamont-Doherty.

The research will help answer whether polar seas—perhaps fed by melting sea ice or glaciers and by increased precipitation associated with greenhouse warming—are becoming fresh enough to threaten changes in ocean circulation and climate.

Bob Williams [left] from the Scripps Institution of Oceanography and Richard Perry [right] from the Lamont-Doherty Earth Observatory Instrument Lab deploy a trace gas tight thin hole water sampler through the Arctic sea ice. Water samples taken with the instrument, which was developed at the Lamont-Doherty Instrument Lab, will help improve understanding of ocean circulation in the Arctic Switchyard. *Credit: Dale Chayes*

The past two years have seen major growth at the intersection of marine geoscience and disciplines such as biology, climate studies, natural hazards and the social sciences.



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

The primary mission of scientists in the Marine Geology and Geophysics Division (MG&G) is to advance understanding of the nature and evolution of Earth's ocean basins and continental margins. Nevertheless, the past two years have seen significant growth at the intersection of marine geoscience and disciplines such as biology, climate studies, natural hazards and the social sciences.

When the giant Sumatran earthquake and Indian Ocean tsunami occurred on December 26, 2004, Lamont-Doherty scientists were among the first to respond: in the media with informed commentary; on the Internet with text and graphics describing both the earthquake and the tsunami devastation; and, less than two months later, as part of an NSF-supported rapid-response research team to survey the rupture zone aboard the Japanese research vessel *Natsushima*.

To enhance our research mission, we are taking advantage of several initiatives in NSF's Major Research Equipment and Facilities Construction (MREFC) program. The first involves NSF's decision to retire the D/V *JOIDES Resolution* after more than 20 years of scientific ocean drilling and move to a new, riserless drilling vessel with improved science capabilities. Our Borehole Research Group received a major contract to assist in the design of a new vessel and equipment. A second MREFC project, NSF's Ocean Observatories Initiative (OOI), will include three primary components to make long-term marine observations and investigate oceanic processes at a variety of timescales: global-scale moored buoy systems, a regional-scale seafloor fiber-optic cable system and coastal observatories. Lamont-Doherty investigators in the Ridge 2000 program studying mid-ocean ridge processes, in particular, stand to benefit from the OOI initiative.

With our strong NSF award base for managing geophysical and geochemical data, MG&G expects to keep Lamont-Doherty in the vanguard of the NSF's Cyberinfrastructure Initiative—a program that will streamline the way scientific information is disseminated among individuals, scientific communities and the general public. To this end, the Marine Geoscience Data System group at the Observatory, with major grants over the past two years, was recently provided 10 terabytes of free storage on the San Diego Supercomputer Center (SDSC) Data Central system.

Also on the instrumentation front, investigators Michael Studinger and Robin Bell recently received a Major Research Instrumentation (MRI) grant from the NSF to outfit a ski-equipped airplane with the latest gravity, magnetics, ice-penetrating radar and laser altimeter sensors to be used for studying the polar ice sheets and lithosphere during the International Polar Year.

On the research vessel front, after 15 years in service, R/V *Maurice Ewing* completed its last research expedition for Lamont-Doherty, arriving at Quonset Point, Rhode Island, on March 9, 2005. There she joined the M/V *Western Legend,* recently purchased from WesternGeco, which was just starting its conversion to the R/V *Marcus G. Langseth* as the *Ewing*'s replacement. The *Langseth*, named after one of Lamont's preeminent geophysicists, will have superior capabilities for marine geophysical surveys, including a 1°-by-1° deepwater multibeam system and the ability to tow up to four multi-channel hydrophone arrays, as well as two independently fired seismic sources, each comprising two linear subarrays. The ship is also being equipped with the best available marine mammal observational capabilities and broadband communications.

Space does not allow a comprehensive discussion of the scholarly achievements made by MG&G scientists over the past two years. Instead, a few notable examples have been chosen to highlight the depth, breadth and diversity of research undertaken within the division.

Adjunct associate research scientist Andrea Taramelli collects samples and field photographs of a potential dust source in the western Gobi Desert near the Mongolia-China border.
Credit: Chris Small

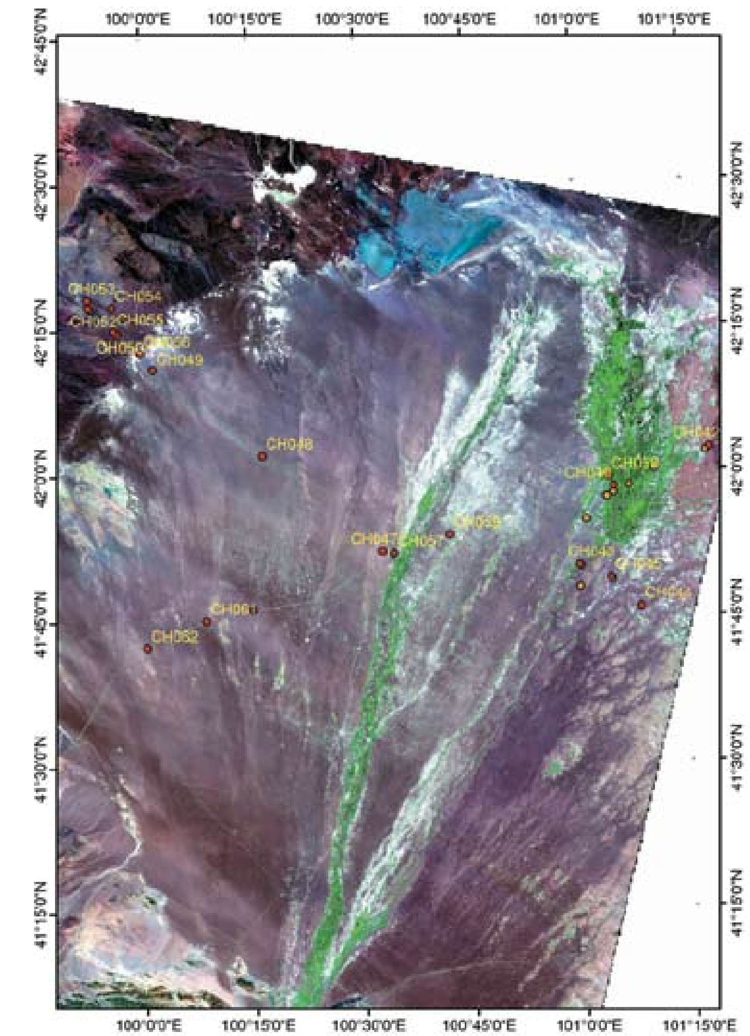
Seeking the Source of China's Growing Dust Pollution Problem

Severe spring dust storms are an unpleasant fact of life and a growing health hazard for millions of people in northern China and neighboring countries. With the summer Olympics scheduled for Beijing in 2008, officials have turned their attention to understanding and mitigating the dust problem for the capital and nearby regions. On behalf of Chinese authorities and with funding from the Italian government, Lamont-Doherty scientists Chris Small, Colin Stark, Andrea Taramelli and Jeffrey Weissel, along with Ph.D. students Dalia Bach and Jon Barbour, have begun using Landsat satellite data to identify potential sources of dust.

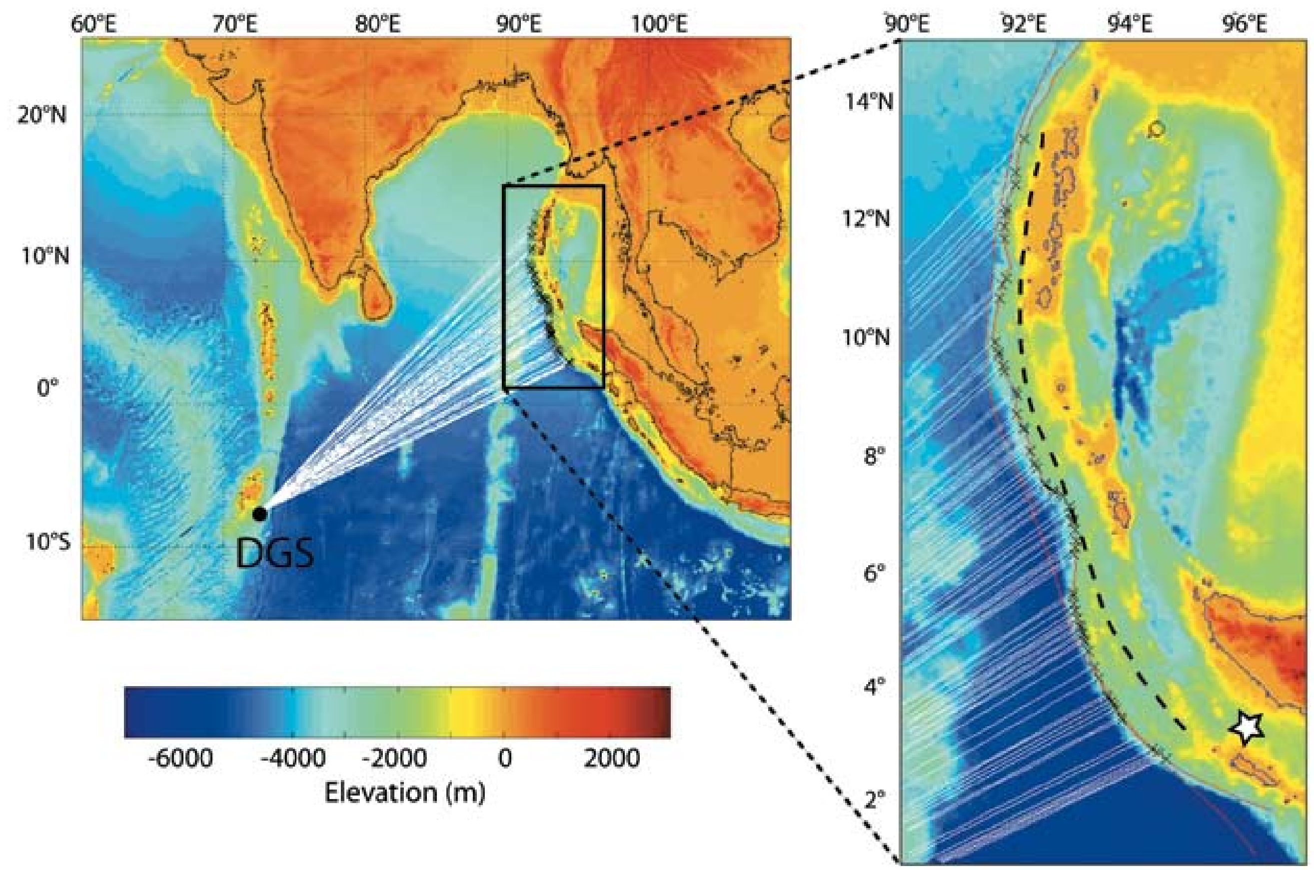
Landsat measures reflected energy across the electromagnetic spectrum, including infrared radiation, which is invisible to human eyes. Different materials on the planet's surface, from soil to plants to water, reflect different electromagnetic wavelength ranges—vegetation, for example, reflects more in the near-infrared than visible wavelengths. This gives scientists the ability to map land cover over broad regions. The Lamont-Doherty team used Landsat images to identify areas that might be sources for windblown dust. To verify their interpretations, Small and Taramelli, together with Chinese colleagues, collected dust samples in 2005 from possible source areas across the Alashan and Gobi Deserts of northern China.

Preliminary results from the study suggest that changing climate and human impacts both have contributed to shifting patterns of dust sources across northern China. Quarries and gravel pits in the hinterland, the result of mining for much-needed building materials, are among several culprits producing the fine dust that plagues the Beijing region each year.

As a result of the research, potential source regions in the remote Gobi Desert that were identified and mapped with satellite imagery are currently being monitored for dust emissions. Meteorologists at the University of Florence are also incorporating the study's findings into computer models of atmospheric dust transport that will provide forecasts for the 2008 Olympics.



False-color Landsat image of an alluvial fan in the Gobi Desert near the China/Mongolia border. Former lake areas, which are thought to be dust emission hot spots, are light-colored. Light streaks trending in the direction of the prevailing winds mark wind-eroded lake sediments transported downwind as dust.
Credit: Chris Small



Maya Tolstoy and DelWayne Bohnenstiehl used acoustic data from hydrophones at Diego Garcia to study the progression of the Great Sumatran Earthquake of 2004 along the Sumatra-Andaman Fault. White star indicates the epicenter of the earthquake determined from short period seismic waves. *Credit: Maya Tolstoy and Del Bohnenstiehl*

Underwater Listening Devices Record Tsunami-causing Quake

Two Lamont-Doherty scientists recently used data from the network of underwater microphones set up to monitor nuclear weapons tests to provide an accurate measure of the timing and length of the seafloor earthquake rupture that spawned the devastating 2004 Indian Ocean tsunami.

Maya Tolstoy and Del Bohnenstiehl analyzed acoustic energy (called tertiary waves or T waves) generated by the magnitude-9.3 earthquake on the seafloor off Sumatra, Indonesia. The waves propagated through the ocean and were recorded on hydrophones near Diego Garcia atoll in the Indian Ocean, more than 1,700 miles from the epicenter. The hydrophones are deployed in the ocean's SOund Fixing And Ranging (SOFAR) channel—a layer in the ocean that propagates sound energy efficiently over vast distances.

The scientists' study revealed that the seafloor ruptured in at least two phases: a fast event at the southern extent of the rupture that slowed markedly and suddenly as it moved north. They also showed the total rupture length measured nearly 750 miles.

Because hydroacoustic listening stations like the one at Diego Garcia operate around the clock and their data is available in real time, Tolstoy and Bohnenstiehl believe they could potentially provide a rapid and accurate source of information on the duration and length of underwater earthquakes. Such information is critical in determining tsunami risks and where to send emergency relief in the first hours of a disaster.

New Subseafloor Images Show How the Ocean Crust Is Formed

A team led by Lamont-Doherty geophysicists recently produced some of the highest quality images ever taken deep beneath the seafloor, revealing that Earth's upper and lower oceanic crust seem to form in two distinct ways. The new images go a long way toward resolving a decade-long debate over whether the ocean crust is formed entirely by magma that accumulates in a single, large pool in the middle of the crust or whether crust is also created from several smaller magma sources at different levels.

Mladen Nedimovic and Suzanne Carbotte, together with colleagues from Woods Hole Oceanographic Institution and Scripps Institution of Oceanography analyzed sound waves reflected off structures several kilometers beneath the seafloor. The subseafloor images they created are the first ever to detect solidified lenses and sills (narrow, lateral intrusions of magma) embedded in the boundary between the mantle and the overlying crust, a region known as the Moho transition zone.

The findings, published in the August 25, 2005, issue of *Nature*, provide evidence that magma helps form the base of oceanic crust. It favors the emerging view that volcanoes at Earth's mid-ocean ridges—where magma rises from deep within Earth and solidifies to become new crust—have complex plumbing systems consisting of many interconnected sills and magma conduits.

Investigating Seafloor Methane as a Potential Risk and Resource

Methane is a potentially significant source of fuel. It is also a greenhouse gas more potent than carbon dioxide that could exacerbate global warming and, under some conditions, can cause submarine landslides and tsunamis. Lamont-Doherty scientists have been heavily involved in mapping the distribution of this important gas beneath the seafloor.

In 2004, Lamont-Doherty scientists Marie-Helene Cormier and Jeffrey Weissel, together with graduate student Kori Newman, joined colleagues from Scripps Institution of Oceanography and Woods Hole Oceanographic Institution aboard the R/V *Cape Hatteras.* They studied sites along the continental shelf edge off Virginia and North Carolina where naturally occurring methane has discharged through the seafloor, forming crater-like features several kilometers long and up to 50 meters deep.

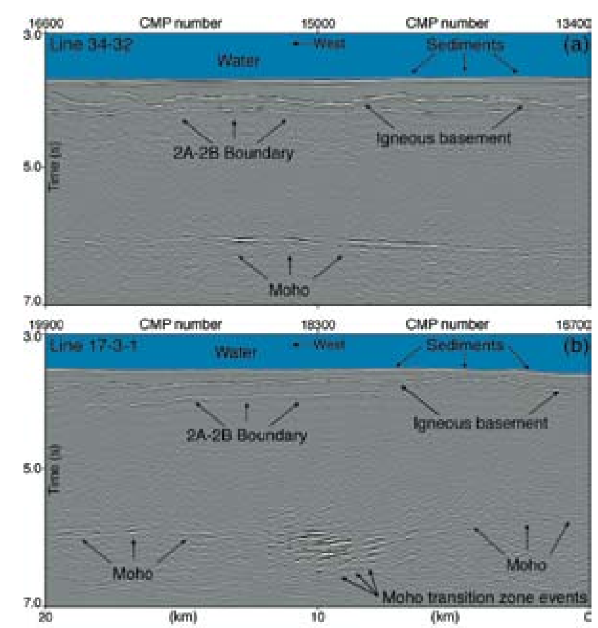
The team measured dissolved methane and other chemicals near the seafloor using an autonomous underwater vehicle and in seafloor sediments using core samples. They found that methane gas, mainly produced by microbes decomposing organic matter, is venting today through the crater walls into the oceans, perhaps acting as a source of atmospheric greenhouse gases.

The high pressure and cold temperatures in sediments beneath the seafloor also turn methane into a solid locked within a cage of ice crystals. Known as methane clathrate or methane hydrates, these deposits are a potentially significant energy resource. In 2005, Gilles Guerin, Alberto Malinverno and Greg Myers of Lamont-Doherty's Borehole Research Group (BRG) participated in an ocean drilling expedition off Canada's Vancouver Island to learn where and how gas hydrates form. They lowered electrical and acoustic instruments, including ones that detect gas hydrates, into drill holes to measure a variety of properties of seafloor rocks and sediments. Later in 2005, the BRG provided downhole logging services in a joint project between the U.S. Department of Energy and industry groups to drill in the Gulf of Mexico and assess the commercial viability of marine gas hydrates.

In 2006, Malinverno, Guerin and Lamont-Doherty geophysicist Jim Cochran sailed aboard the D/V *JOIDES Resolution* to participate in a three-month expedition exploring the resource potential of gas hydrates around the continental margin of India. The project, funded entirely by the Government of India, is part of a cooperative effort involving Lamont-Doherty, the U.S. Geological Survey and the commercial operators of the drill ship.

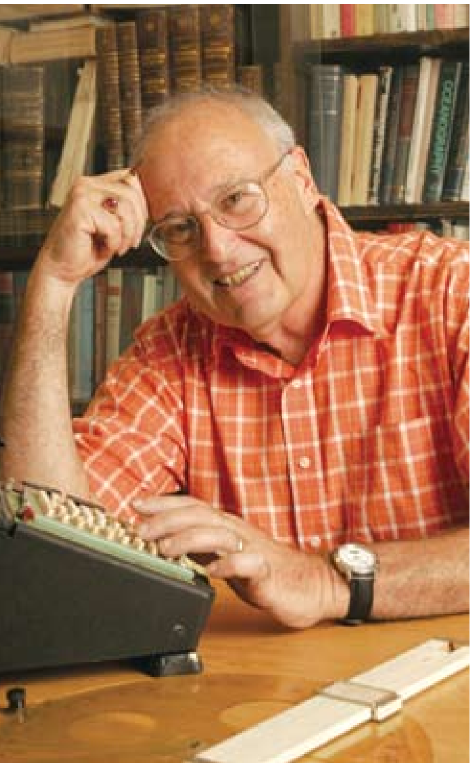
In 2005, Cochran and Malinverno convened a workshop at Lamont-Doherty that focused on the potential threat posed by continued global warming melting gas hydrates in the Arctic permafrost and along the margins of the Arctic Ocean. When temperatures rise or pressure is reduced, methane hydrates can turn back into a gas and release into the environment. Scientists theorize that sudden, massive outbursts of methane in the past sent large amounts of the heat-trapping gas back into the atmosphere and dramatically warmed the planet's climate. The workshop provided an opportunity for scientists from Lamont-Doherty and other research institutions to identify important scientific issues related to gas hydrates along the Beaufort Sea margin and to plan further marine geological and geophysical exploration.

Lamont-Doherty scientists have been heavily involved in mapping the distribution of this intriguing gas beneath the seafloor.



Ocean sediments, the igneous crust and the Moho discontinuity are clearly visible in these seismic reflection images taken near the Juan de Fuca Ridge. Mladen Nedimovic and his colleagues identified the thick Moho transition zone structures at the crust/mantle boundary (visible in b) as solidified magma lenses. This offers evidence that the lower crust may be generated by more than one magma source. *Credit: Mladen Nedimovic*

Changes in Earth's climate—whether abrupt or gradual, global or regional—have been going on throughout the planet's long history and will continue.



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

Understanding the natural variability of Earth's climate is complicated enough, but more than ever, human activities are introducing powerful stresses on Earth's delicately balanced climate system.

Changes in Earth's climate—whether abrupt or gradual, 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, planetary volcanism, the cryosphere (ice), the biosphere (living things) and external forces such as variability of solar radiation and even the occasional asteroid impact.

Over recent decades, it is becoming increasingly apparent that our climate is rapidly changing. The air is warming, more so at high latitudes; ice and permafrost are melting; sea level is rising as warmer sea water expands and ice and glacial melt water reach the ocean; changing patterns of precipitation and evaporation are stressing agricultural and water resources; and droughts and floods seem to be more intense. Increasingly, these recent climate changes are attributed to human activities.

If we can understand our climate system, we can prepare reliable projections of future global and regional climate trends. This will enable informed management of a sustainable society and help safeguard humankind's future as well as the planet's well-being.

Scientists in the Division of Ocean and Climate Physics (OCP) contribute to that mission. They delve into the mysteries of Earth's climate, striving to understand the forces and processes that govern climate changes on timescales ranging from years to centuries. They explore ways in which anthropogenic factors alter the climate system, and they seek to understand the mechanisms underlying climate fluctuations of the last centuries and millennia in order to predict future climate.

To achieve these goals, OCP climatologists investigate patterns of climate changes that occur over time and across geography, employing data obtained from meteorological instrument records of roughly the last 160 years and from Earth-orbiting satellites. They study atmospheric dynamics and also use climate-simulation models, testing the models' validity against direct observations and proxy records of past climates preserved in tree rings, deep-sea sediments or glacial ice cores.

OCP oceanographers examine the role of the ocean in the climate system through seagoing expeditions, sensors deployed on moorings and from remote data obtained from satellites. Their regional studies 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; from the ocean surface to the deepest ocean layers. Scientists in the division are increasingly involved in establishing long-term monitoring strategies to detect changes in sensitive points of the climate-ocean system.

The observationalists and modelers, the oceanographers and climatologists all closely collaborate with each other and with scientists from other divisions of the Observatory. This hallmark of OCP has led to significant advancements in the field of ocean and climate science. The three projects that follow highlight the diversity of our research.

Past and Future Dust Bowls Across the Western U.S.

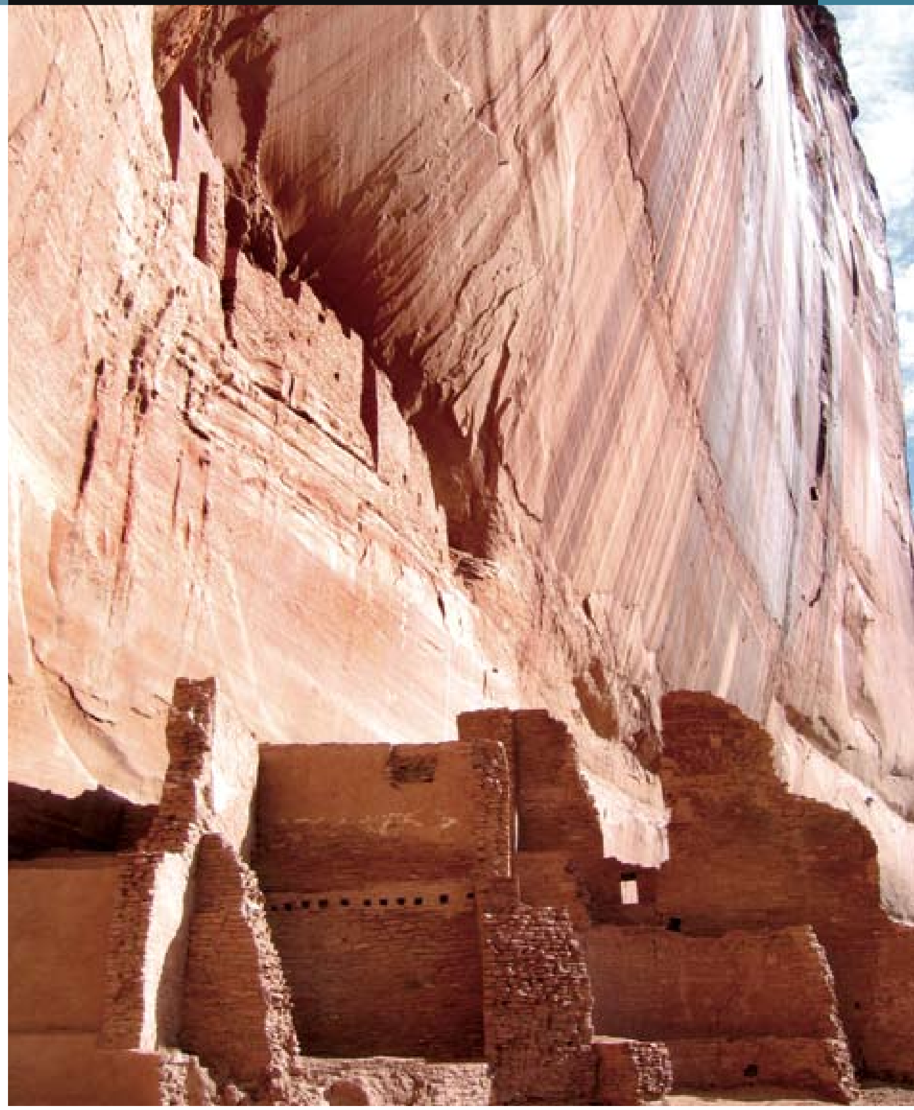
Evidence has mounted over the last several years that a series of "megadroughts" devastated the fauna and Native American societies in the American West between 800 and 1400 A.D. Using a computer model that simulates the dynamics of Earth's climate system and a new atlas of tree-ring data that indicates when and where past droughts occurred, Richard Seager has explored what caused the medieval megadroughts. He is also assessing the risks that aridity in the western United States will return to medieval levels in the modern, warming world.

In 2003, the Lamont-Doherty Tree-Ring Laboratory published the *North American Drought Atlas*, consisting of hundreds of records of the annual growth rings of long-lived trees throughout the continent. By analyzing the width and other characteristics of tree rings, scientists can reconstruct when the trees experienced droughts and how severe the droughts were. The atlas is gridded into maps of summer drought last 2,000 years; from about 800 A.D., the maps contain tree-ring data that and spans the entire continent.

Seager's analysis of the drought atlas revealed that, over the last 1,200 years, the same areas that have experienced drought in modern times—essentially the United States west of the Mississippi, the Canadian prairies and northern Mexico—also experienced megadroughts comparable to the Dust Bowl years.

What marked megadroughts during medieval times, however, was their persistence—they lasted not for years, but for decades on end. Together, the evidence suggests that the same conditions caused both medieval and modern droughts, but the conditions persisted for an unusually long duration in medieval times.

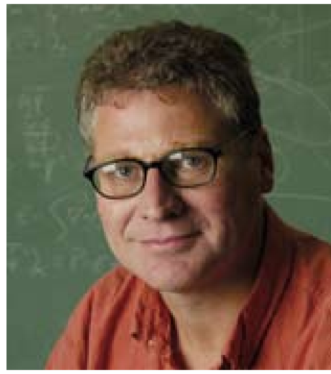
Seagers's climate modeling research indicates that megadroughts occur when water temperatures are colder in the eastern tropical Pacific Ocean (a condition known as La Niña) and, to a secondary degree, when subtropical North Atlantic Ocean waters are warmer. Such conditions appear to have prevailed during medieval times.



To examine the issue more closely, Seager compared global climate conditions that spawned droughts in both medieval and modern times. From dry conditions in mid-latitude South America coupled with wet conditions in northern South America to persistently good Nile River floods at the same time that dry conditions prevailed in East Africa to a strong Indian monsoon, the ocean and atmospheric conditions that accompanied medieval and modern droughts appeared remarkably similar.

So what caused the tropical Pacific Ocean conditions that spawned medieval megadroughts? Seager's research with models of the tropical Pacific atmosphere-ocean system suggests that La Niña-like conditions arose as a response to increased radiation entering the ocean surface—from both high solar irradiance and weak volcanism—during medieval times.

Rising greenhouse gases also increase the radiation entering the ocean surface, a condition that could increase the risk of returning to medieval levels of aridity and megadroughts in the coming years and decades.



[above] Ruins left by the Anasazi people in the southwestern United States may support ideas that a prolonged "megadrought" contributed to the society's collapse.

[bottom] Richard Seager, Doherty Senior Research Scientist, Ocean and Climate Physics Division
Credit: Bruce Gilbert

Scientist Finds a Way to Detect Invisible 'Microbreaking' Waves

For every whitecap on the crest of a wave, a barrier is being broken. Waves breach the 1-millimeter-thick boundary between two fluid media—air and water—mixing the two to create white, foamy bubbles. At the same time, heat, momentum and greenhouse gases, such as carbon dioxide and water vapor, are also exchanged between the ocean and atmosphere.

Countless exchanges like this make the ocean-atmosphere system go around, much the way countless $100 transactions help drive a country's economy. However, measuring the subtle complexities of air-sea interactions is difficult, often impeding scientists' ability to understand the mechanics of fundamental processes that drive ocean, atmosphere and climate dynamics.

The problem seems even more intractable when one considers that for every whitecap in the ocean, there are many smaller waves, centimeters in height, that create what are called "microbreakers." They occur even when strong winds are not creating whitecaps and, like many $100 transactions that add up to billions of dollars, probably make a significant contribution to critical air-sea exchanges worldwide. However, there has been no way to observe this elusive but fundamental phenomenon—until now.

Lamont-Doherty scientist Chris Zappa recently demonstrated that microbreakers disturb the ocean's cool "skin" layer at the air-sea interface, leaving behind a small patch of the sea surface ever so slightly warmer—perhaps 0.5 degrees Celsius—due to mixing from below. Zappa used an infrared imager to detect the temperature difference and indicate where, when and how microbreaking occurs.

In 2005, Zappa deployed an 8-meter boom from the end of the 560-meter pier at the U.S. Army Corps of Engineers' Field Research Facility in Duck, North Carolina. The boom carried an infrared imager, a radiometer to measure sea surface temperatures, a video camera, an altimeter to measure wave heights, an anemometer to measure wind speed, and a device to measure carbon dioxide and water vapor. Together, the instruments captured high-resolution data that made a previously invisible process visible on multiple levels (see figure far right bottom).

Zappa found that these microbreakers were comparable to whitecaps in promoting exchange between the ocean and atmosphere. The groundbreaking results from Zappa's study will improve scientists' ability to understand marine storms, ocean waves, upper ocean circulation and, ultimately, climate change.

> The groundbreaking results will improve scientists' ability to understand and forecast marine storms, ocean waves, upper ocean circulation and, ultimately, climate change.

Closing the Loop on the Ocean's Global Circulation

The world's oceans circulate like a conveyor belt, with waters sinking and spreading across the ocean depths and eventually returning to the surface. Scientists know where and why waters sink—they lose heat at high latitudes and become colder and denser. One of the most basic questions remains unanswered, however: Where and how do the waters eventually surface to complete the loop?

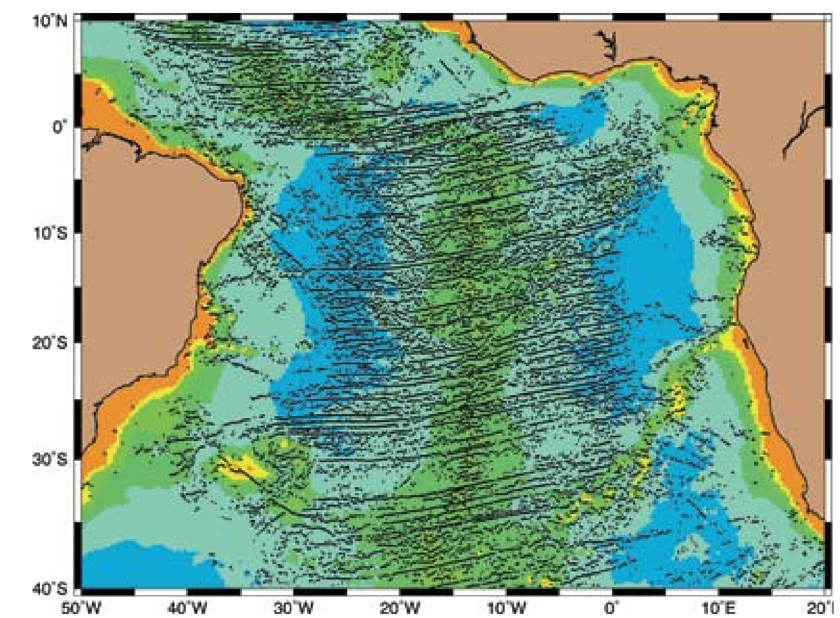
Understanding the fundamental mechanics of ocean circulation has important implications for understanding climate change. The oceans act as a planetary heating and ventilation system, transporting large amounts of warm equatorial waters toward the poles, where they transfer their heat to the atmosphere before sinking and flowing back to lower latitudes.

This has been incorporated into many of the computer simulations that scientists use to understand and forecast changes in Earth's climate. The models are limited, however, because they do not contain detailed information about how deep waters regain heat and upwell to shallower depths.

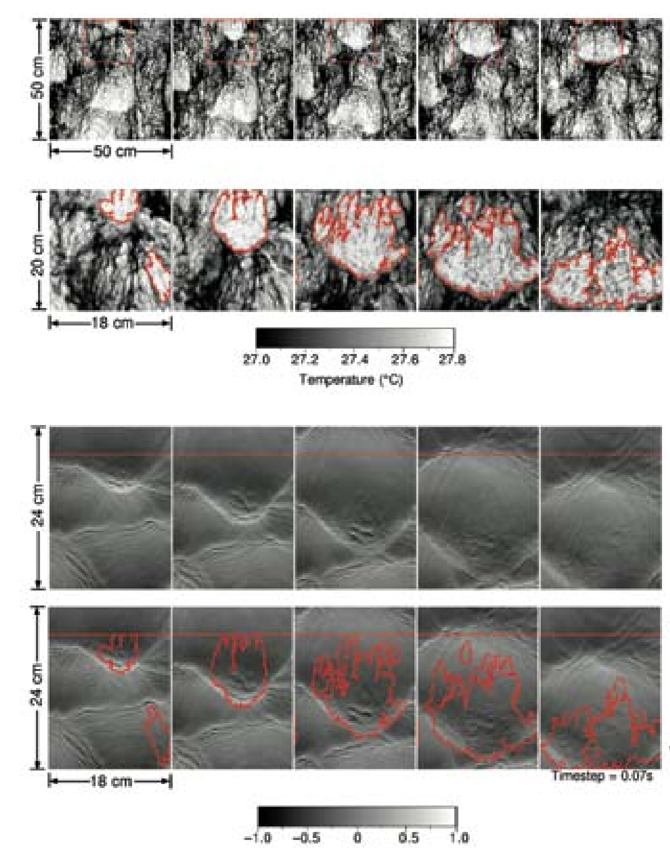
In 1996, scientists observed strong mixing in the deep waters over the western flank of the Mid-Atlantic Ridge in the South Atlantic—the ridge that is part of the contiguous volcanic mountain chain extending throughout the world's oceans. At first, scientists theorized that the mixing was caused by tides forcing waters across submarine topography.

Lamont-Doherty physical oceanographer Andreas Thurnherr recently reanalyzed the data and found that strong currents flow along the thousands of submarine canyons on the flanks of the mid-ocean ridge and that most of the mixing takes places within these canyons. Thurnherr believes that sills found every few tens of kilometers in the canyons cause deeper waters to mix with warmer overlying waters and begin their return to the upper ocean.

To test the theory, Thurnherr joined a research cruise aboard the French research vessel *L'Atalante* in August 2006. He and colleagues deployed instruments to measure water temperature, salinity and current velocities, as well as small-scale fluctuations caused by mixing throughout a canyon on the Mid-Atlantic Ridge. They hope to obtain the first detailed measurements of how waters flow and mix in deep submarine canyons, seeking evidence that deep waters' return journey to the surface starts there.



Thousands of submarine canyons around the world, like those flanking the Mid-Atlantic Ridge, contribute to mixing between surface and bottom waters and that, in turn, helps drive global ocean circulation. *Credit: Andreas Thurnherr*



Infrared (top) and surface slope (bottom) images revealing the temperature and structure of microbreaking waves. *Credit: Chris Zappa*

A goal in the next few years is to capitalize on our progress by building more expertise in global and regional geodynamics.

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

The past two years have seen remarkable advances in the Seismology, Geology and Tectonophysics (SG&T) Division that have consolidated our strengths in observational and theoretical seismology with new directions in the study of crust and mantle deformation.

We are seeing greater interactions between our experimental seismologists, who develop plans for deployments of portable seismometers to illuminate specific tectonic targets, and our tectonophysicists, who study a range of deformation phenomena from brittle fracture to mantle flow and magma transport. The confluence of these investigations is a natural outcome of the need to validate deformation models with seismological and kinematic observations. As a result, we are seeing new interdisciplinary approaches to understanding basic tectonic processes.

In a data-driven science such as ours, this combined approach offers opportunities to generate new insights from regional studies and apply them to global tectonics. One of our goals in the next few years is to capitalize on our progress by building more expertise in global and regional geodynamics.

The SG&T Division also hosts the Lamont Ocean Bottom Seismometer Lab, part of the national OBS Instrument Pool, which supplies the national and international scientific community with unique broadband ocean bottom seismometers capable of very long deployments at sea. Designed by Spahr Webb and managed by newly hired lab chief Andrew Barclay, the latest versions of these instruments are now undergoing final testing before new deployments early in 2007. In addition to their seagoing duties, Barclay, Webb and others are thinking about new ways of improving instrument performance and adding new kinds of transducers.

In the last two years, Lynn Sykes, one of the founders of seismotectonics and a leading force in observational seismology and plate tectonics for more than 40 years, officially retired from our division. Having earned a well-deserved respite from day-to-day duties, Sykes is moving on to other scientific projects, including a new look at seismicity in the northeastern United States.

We are very proud of our tradition of linking experimental and observational work with modeling and theory. The tradition established by Sykes and others will only be strengthened in coming years.

Lynn Sykes
Higgins Professor Emeritus of Earth
and Environmental Sciences
Credit: Bruce Gilbert

Exploring Mantle Dynamics From Planetary and Atomic Perspectives

Two Lamont-Doherty scientists, working from very different perspectives, have joined together to learn how great rifts occur.

The rifts in question are continental in nature—such as the ones that separate Arabia from Africa to create the Red Sea, or Baja California from the rest of Mexico to form the Gulf of California. The scientists' focus is on the mantle, where intense heat and tectonic stresses can deform rock crystals slowly and cause rocks to flow.

Ben Holtzman works from the atomic scale upward, conducting laboratory experiments on samples of rock types found in the mantle. He studies their fundamental physical properties when subjected to heat, pressure and stress and investigates how small amounts of melt material organize into microscopic branching and connecting networks that influence how the rocks deform.

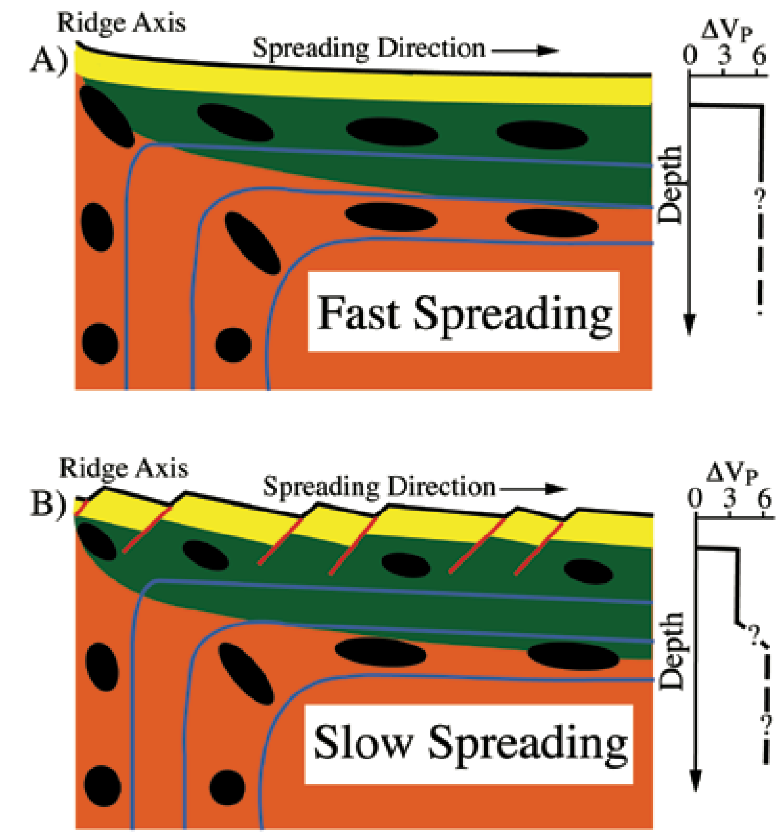
Jim Gaherty and his collaborators take a big-picture, field-based approach, deploying instruments to record earthquake-generated seismic waves that travel through mantle rock in rift zones. Much they way CT scans image internal structures in the body, the seismic waves allow Gaherty to image the crystal "fabric" of mantle rocks 30 to 250 kilometers deep. This offers insights into the distribution of melt in the mantle and the direction of mantle flow underlying the rift zones.

When crystals align during large-scale deformation, that region of the mantle acts like a seismic polarizing filter, causing waves that vibrate in different directions relative to the rock's "fabric" to travel at different speeds. The common assumption is that crystals align in the direction of the mantle flow, but Holtzman's experiments indicate that in some situations the rock fabric may be modified profoundly by the way the melt is distributed.

Holtzman puts very fine powders of rock samples in an apparatus that applies pressure equivalent to about 10 kilometers below the ocean floor and temperatures as high as 1,250 degrees Celsius. The machine simulates conditions at which rocks deform in the mantle, but speeds up to about five hours a process that takes many thousands of years in the Earth. The samples are then quenched to preserve the orientations of the crystals and the distribution patterns of the melted material, which can then be viewed with optical and electron microscopes.

The experiments provide a more detailed and unexpected picture of deformation processes in partially molten mantle rock. Holtzman found that networks of melt-rich bands "anastomose" around lenses of melt-depleted material. On a microscale, the melt-rich bands are weaker than the lenses, so the networks concentrate strain and deformation into them. They act to weaken the rock as a whole, Holtzman theorizes, and on a planetary scale, this process lubricates mantle flow. Holtzman is studying these dynamics in collaboration with Marc Spiegelman and Richard Katz at Lamont-Doherty.

To test whether this melt-enhanced deformation can be detected in Earth, Gaherty's fieldwork has focused on areas where partial melt is likely to exist. He and colleagues are analyzing data from temporary, land-based seismic arrays deployed by colleagues in Ethiopia and Mexico, and in 2005 they deployed 15 ocean-bottom seismometers in the Gulf of California.



Fast-spreading ridges (A) have a high, peaked axis and minimal off-axis faulting. Slow-spreading ridges (B) have axial valleys and off-axis faulting. Studies by Jim Gaherty and his colleagues revealed that seismic P-wave anisotropy (direction-dependent velocity) in the Atlantic is approximately one-half that in the faster-spreading Pacific. This suggests that cooling beneath slow-spreading centers increases brittle deformation in the mantle, limiting viscous deformation.
Credit: Jim Gaherty

[left to right] Won-Young Kim, Doherty Senior Research Scientist, and Mitchell Gold, Staff Associate, Lamont Cooperative Seismic Network
Credit: Bruce Gilbert

Lamont Seismologists Reach Out and Span Bridges

The seismological pioneers who founded Lamont-Doherty relentlessly sought out places to install the modern seismographs they were developing in the late 1940s. They put their instruments first in a hollowed-out space beneath a trapdoor in the Schermerhorn Building on the Columbia campus, then in the empty swimming pool of the Lamont estate and later in a zinc mine in Odgensburg, New Jersey.

Over time, the Observatory added more sites and began to partner with other institutions to establish the Lamont Cooperative Seismographic Network (LCSN). This network monitors seismicity in the northeastern United States to understand the causes of earthquakes and identify areas of high seismic hazard in the region. It also gathers data from earthquakes worldwide.

Earthquakes occur more frequently in the western United States, where the edges of tectonic plates collide. Still, large, so-called intraplate earthquakes, whose sources and causes are less well delineated and understood, have occurred in recent centuries along the East Coast. The region's potential seismic risk looms large because of its population density and aging infrastructure, much of which was built without considering the potential for earthquakes.

Under the direction of Won-Young Kim, the LCSN expanded between 2004 and 2006 to include eight new broadband stations and six new partners. The network now consists of 25 cooperating partners, operating 21 broadband seismographic stations, and an additional 21 short-period stations in New York, New Jersey, Connecticut, Pennsylvania, Delaware, Maryland and Vermont.

Partners include colleges, universities, community colleges, research institutions, secondary schools, museums, a state geological survey, conservation organizations such as the Central Park Conservancy in Manhattan, and one tourist attraction—the Howe Caverns in Cobleskill, New York. The LCSN offers educational opportunities to students and valuable professional development opportunities to station operators. It is also an integral component of the Advanced National Seismic System (ANSS) led by the U.S. Geological Survey.

In an effort to explain the importance of continuing earthquake monitoring and the information products offered by the LCSN and the ANSS, Kim has also reached out to new emergency management partners, especially in New York City. During the 2004 New York City Marathon, Lamont-Doherty seismologists and geodecist Misha Kogan deployed digital accelerographs and global positioning system (GPS) receivers on the Verrazano-Narrows Bridge in a unique experiment to measure the bridge's dynamic response to loading conditions caused by 37,000 runners.

Seismic recording during the marathon showed a prominent spectral peak at 2.8 Hertz, which may correspond to the beating of runners at nearly regular intervals. At the same time, the GPS receivers recorded vertical deflection of the bridge of more than 30 centimeters. The measurements provide important constraints on the structural integrity of this important New York City lifeline.

New Methods Precisely Locate Earthquakes

Three months after the great Sumatra earthquake that triggered the devastating Indian Ocean tsunami, a smaller earthquake in the same region killed 1,300 people, mostly on the Indonesian island of Nias. Were these two earthquakes linked?

The tsunami-generating earthquake in December 2004 released centuries of pent-up strain along the Andaman-Sunda Trench, where the Indian and Australian tectonic plates are grinding against and diving beneath the Eurasian Plate. However, stress alleviated in one region can shift to neighboring areas and increase the potential for earthquake-producing ruptures elsewhere along the 55,000-kilometer-long trench.

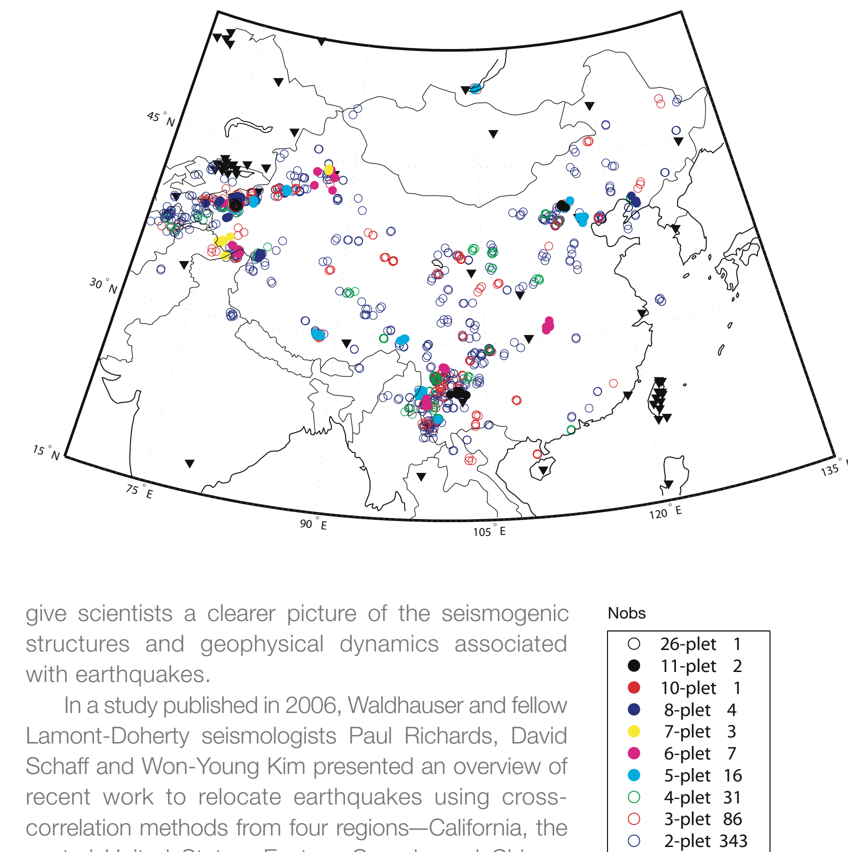
The cascade of aftershocks set in motion by the 2004 earthquake—thousands ranging over time, space and magnitude—offers an opportunity to track how stress is transferred along faults by great quakes. The trail would be harder to follow, however, if scientists did not know exactly where the earthquakes started.

Over the past several years, Felix Waldhauser has been leading an effort to apply new methods that can precisely pinpoint the locations of seismic events. Traditionally, seismologists have estimated the locations of earthquakes or underground explosions one at a time by measuring the arrival time at seismographic recording stations of selected seismic waves generated by an event.

In contrast, the new method involves jointly analyzing numerous neighboring events recorded by several common stations—reducing both measurement and modeling error and increasing location precision. The resulting cross-correlated, high-resolution locations give scientists a clearer picture of the seismogenic structures and geophysical dynamics associated with earthquakes.

In a study published in 2006, Waldhauser and fellow Lamont-Doherty seismologists Paul Richards, David Schaff and Won-Young Kim presented an overview of recent work to relocate earthquakes using cross-correlation methods from four regions—California, the central United States, Eastern Canada and China—representing different tectonic environments and seismic networks. After cumulatively analyzing more than 240,000 events recorded by more than 1,100 stations, they confirmed that the cross-correlation techniques result in locations that are 10 to 100 times more precise than traditional methods.

Since the 1970s, the combination of enormous improvements in the quantity of seismic stations and the quality of seismograms, improved computing power and communication links, and fewer political barriers in many countries (which once impeded the flow of seismological information) have created a much larger, more accessible archive of digital seismograms that can be analyzed using cross-correlation methods to locate seismic events in most places. The new methods enhance seismologists' ability to understand the nature of earthquakes and to analyze associated seismic hazards in places ranging from the San Andreas Fault to the Andaman-Sunda Trench.



David Schaff applied his cross-correlation techniques to approximately 14,000 seismic events in and near China between 1985 and 2000 and found 1,301 earthquakes that were similar (cross-correlation coefficients greater than or equal to 0.8) to at least one other event during the same period.
Credit: David Schaff

GPS antenna installed by Mikhail Kogan and his colleagues on the Verrazano-Narrows Bridge to study the motions imparted on the bridge by more than 37,000 runners in the New York City Marathon.
Credit: Mikhail Kogan

Marcus Langseth developed one of the first instruments to measure heat flux from Earth's interior into the deep ocean basins and compiled the first global heat flow map.

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

Lamont-Doherty's research vessel operations saw tremendous activity and great change between 2004 and 2006.

In spring 2005, R/V *Maurice Ewing* completed a distinguished career of more than 15 years as the seismic vessel of choice and de facto national facility for marine seismic research in the U.S. academic community. *Ewing*'s last scientific cruise was an important and highly successful survey of the Chixculub meteor impact structure, an estimated 180 kilometer-wide, submerged, multi-ringed crater centered on the northern coast of Mexico's Yucatán Peninsula.

Many believe the crater was created by a meteor some 10 to 20 kilometers in diameter that collided with Earth and that was responsible for the mass extinctions that included the demise of the dinosaurs at the Cretaceous-Tertiary, or K/T, boundary. The resulting crater is now completely buried, and its exact size and the total energy transmitted during the impact are unknown and will remain so until the *Ewing* data are fully analyzed.

At the same time, preparations for *Ewing*'s replacement were under way. After extensive negotiations among Lamont-Doherty, the National Science Foundation (NSF) and Western-Geco/Schlumberger, M/V *Western Legend*, a 235-foot, former petroleum exploration vessel, was purchased and delivered to the United States in October 2004. Further negotiations and the funding of a $23 million proposal by NSF allowed the conversion of the *Legend* into what will soon be a powerful, multipurpose, world-ranging oceanographic research vessel, whose strong suit will be the capability to carry out marine geology and geophysics surveys, including 3-D seismic profiling with multiple source and receiving arrays, as well as marine mammal research.

The new ship will be rechristened *Marcus G. Langseth*, in honor of one of the Observatory's most famous geophysicists, who died in 1997. Langseth developed one of the first instruments to measure heat flux from Earth's interior into the deep ocean basins and compiled the first global map of heat flow that was instrumental in establishing the emerging paradigms of plate tectonics and seafloor spreading. He earned his Ph.D. from Columbia University in 1964, and from 1966 to 1975 he led NASA's lunar heat flow experiment, which proved that the moon had lost much of its internal heat long ago and lacked the dynamic Earth's mechanisms for creating new heat.

Langseth also actively served on the Fleet Improvement Committee of the University-National Oceanographic Laboratory System (UNOLS) from 1985 to 1994, which was instrumental in the development of our modern national fleet of research vessels. In the 1990s, he spearheaded the first unclassified scientific missions aboard U.S. Navy nuclear-powered submarines operating beneath the Arctic ice cap, which helped revolutionize understanding of the Arctic Ocean.

In preparation for the demands of operating *Langseth* as the U.S. national facility for academic seismic surveys, Lamont-Doherty's Office of Marine Affairs was reorganized to streamline the management structure and chain of command within the office, which was renamed the Office of Marine Operations in January 2005. A new position, marine engineer and technical coordinator, was created and filled by Albert Walsh.

R/V *Langseth* will complete outfitting in early 2007 and is expected to begin science operations later in the year.

Photo Credit: Carlos Gutierrez

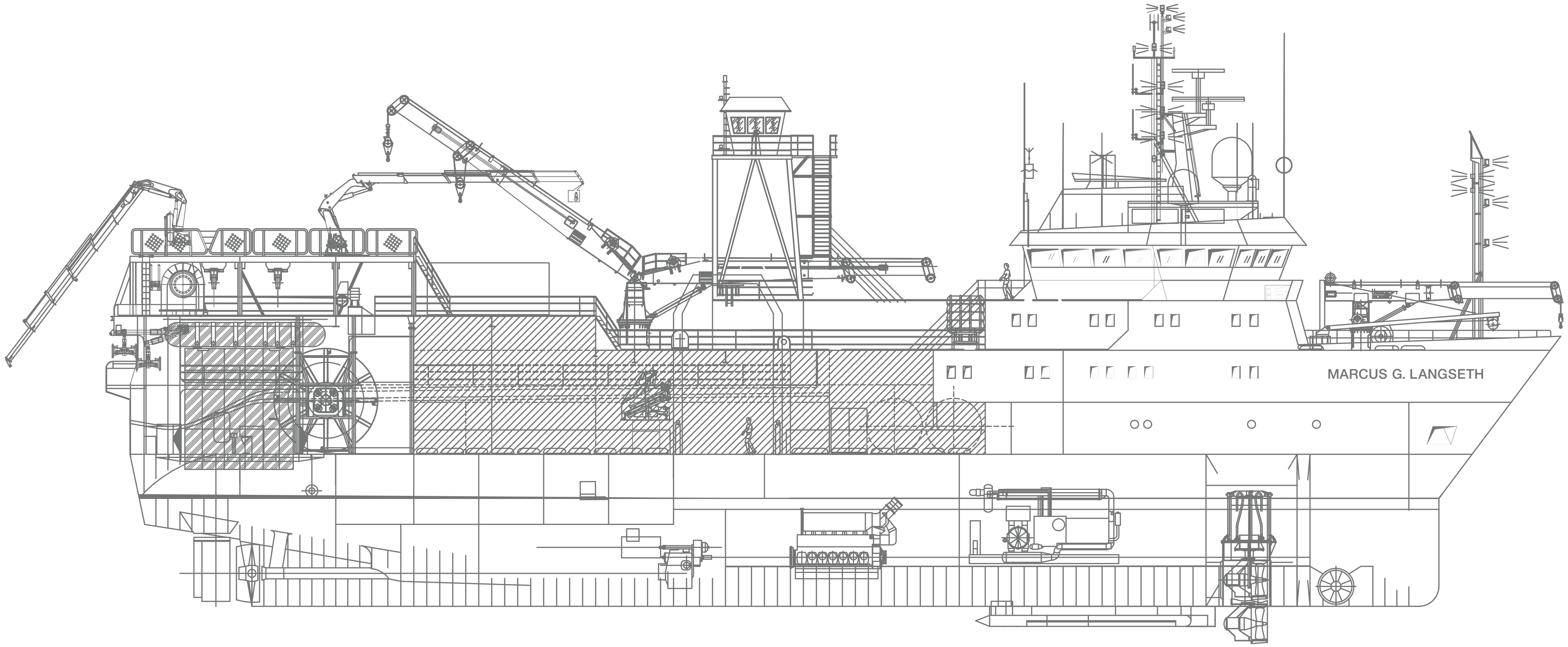
Exploring New Depths

Scientists on the Langseth *will see tremendous improvements in four areas: much larger laboratory spaces; a high-resolution, deep-water, multibeam bathymetric swath mapping system; the ability to tow up to four separated hydrophone arrays; and sophisticated seismic source arrays that can be deployed in many different configurations. When four hydrophone arrays are towed 100 meters abreast of one another and two source arrays, towed 50 meters apart, are alternately triggered, the ship will be able to simultaneously acquire eight reflection seismic profiles separated by 25 meters. This eightfold increase in productivity generates the vast amount of data required for 3-D imaging in a reasonably short time.*

John Diebold
Chief Scientist
Marine Operations
Credit: Bruce Gilbert

R/V *EWING* CRUISE SCHEDULE (2004–2005)

CRUISE	2004	PORTS	AREA	PURPOSE	PIS
EW0402	20 Feb–1 Mar	Norfolk - Mobile	West Atlantic	Transit	
EW0403	7 Apr–14 Apr	Mobile - San Juan	Caribbean	Transit	
EW0404	18 Apr–3 Jun	San Juan - Tampa	SE Caribbean	MCS - OBS	Levander, Rice
EW0405	6 Jun–11 Jun	San Juan - Tampa	GOM	Transit	
	12 Jun–21 Jun	Tampa		Rudder repair	
EW0406	22 Jun–10 Jul	Tampa - San Diego		Transit	
	11 Jul–12 Aug	San Diego		Out of service	
EW0407	6 Aug–17 Aug	San Diego - Newport	SB Channel	Multibeam survey	USGS
EW0408	21 Aug–23 Sep	Newport - Kodiak	SE Alaska	MCS - JPC	Mix-Jaeger/OSU - UF
EW0409	28 Sep–16 Oct	Kodiak - Astoria	G. of Alaska	FOCI	Stabeno/PMEL/NOAA
EW0410	20 Oct–4 Nov	Astoria - San Diego	Blanco FZ	MCS - OBS	Christeson, UTIG
EW0411	7 Nov–17 Nov	San Diego - Puerto Caldera		Transit	
EW0412	21 Nov–22 Dec	Puerto Caldera - Panama	Sandino Basin	MCS	Fulthorpe, UTIG
EW0413	25 Dec–31 Dec	Panama - TBN		Transit	
	2005				
EW0501	7 Jan–20 Feb	Panama - Progreso	Yucatan platform	Chixculub Crater survey	Gulick [UTIG] Barton [Cambridge]
EW0502	01 Mar–04 Mar	Progreso - Jacksonville		Transit and demobilization	
EW0503	06 Mar–09 Mar	Jacksonville - Quonset Point		Transit and demobilization	Diebold LDEO



***MARCUS G. LANGSETH* SPECIFICATIONS**
Built: 1991 Ulstein Norway
Length (LOA): 71.5 m (235 ft)
Beam (molded): 17.0 m (56 ft)
Draft (max): 5.9 m (19.5 ft)
Gross tonnage: 2925

CAPACITY
Ship's crew: 20
Scientific personnel: 35
Fuel capacity: 1340 m^3
Range: 13,500 nautical miles
Speed working: 0–11 knots
Speed cruising: 11 knots

Over the past decade, we have annually graduated an average of nine majors and concentrators in Environmental Science and Earth Science, double the rate of the previous decade, and we look to continue on that upward trend.

Nicholas Christie-Blick
Professor and Chair,
Earth and Environmental
Sciences Department
Credit: Bruce Gilbert

Mark A. Cane
G. Unger Vetlesen
Professor of Earth and
Climate Sciences,
Earth and Environmental
Sciences Department
Associate Chair,
Earth and Environmental
Sciences Department
Credit: Bruce Gilbert

Lamont-Doherty Earth Observatory was born out of Columbia University's Geology Department in 1949, and today's Department of Earth and Environmental Sciences (DEES) has experienced numerous changes over the decades that parallel the evolution of the Observatory.

The years 2004 to 2006 represent the end and beginning of significant chapters in departmental history, with the retirements of Professors James Hays (December 2004) and Lynn Sykes (June 2005)—the first faculty retirements in more than 20 years—and the arrival of petrologist Peter Kelemen from Woods Hole Oceanographic Institution as Arthur D. Storke Memorial Professor and seismologist Göran Ekström from Harvard University.

Hays is a renowned paleoclimatologist and micropaleontologist and is best known for his seminal works testing the astronomical theory of climate change, which demonstrated the role of orbital forcing in pacing the timing of ice ages. An expert on the history of the polar oceans, he also pioneered deep-sea core studies in the most remote seas. As the department's director of undergraduate studies for many years, Hays was instrumental in the development of our major and concentration in environmental science.

Sykes was the Higgins Professor of Earth and Environmental Sciences until his retirement and he played a leading role in the development of plate tectonics in the 1960s with particular reference to seismicity at plate boundaries. He has also been influential in the field of earthquake prediction and in the seismological verification of underground nuclear test bans.

Of the newcomers, Kelemen conducts interdisciplinary research on melting and melt transport in Earth's mantle and the development of Earth's crust. Ekström works in global earthquake seismology, focusing on the details of individual earthquake ruptures and the seismological record of large-scale tectonic deformation. He was also the lead author on a 2003 paper in *Science* that first identified a new class of seismic signals that were linked back to the movement of glaciers in Greenland, a finding that may help monitor the effects of global warming on the ice sheet.

Our challenge looking forward will be to continue to recruit outstanding individuals, particularly at the junior level—to fill the shoes of those responsible for building our institutional reputation, to invest in emerging areas of research and scholarship and to work toward greater diversification with respect to both race and gender. In January 2007, paleoclimatologist Bärbel Hönisch, who completed her Ph.D. in 2002 at the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, will be joining the DEES faculty as an assistant professor.

Three adjunct professors have been appointed in the past two years. Vertebrate paleontologists John Flynn and Mark Norell are based at the American Museum of Natural History. Flynn is a specialist in mammalian paleontology and paleomagnetism. Norell's research is both theoretical and field-based and focuses on the evolution of dinosaurs. Dorothy Peteet, based at the NASA Goddard Institute for Space Studies, is a world-renowned palynologist and paleoclimatologist who maintains a lab at Lamont-Doherty and teaches a popular alternate-year course on wetlands.

DEES continues to invest in undergraduate education at the level of majors and concentrators and, more broadly, in students seeking to fulfill Columbia's science requirement. Over the past decade, we have annually graduated an average of nine majors and concentrators in Environmental Science and Earth Science, double the rate of the previous decade, and we look to continue on that upward trend.

Particularly important to that effort is our summer intern program, expanded in 2003 as a three-year experiment with institutional resources to permit the involvement of many more Columbia and Barnard students than was possible with the long-running Research Experience for Undergraduates program alone. The latter is directed primarily toward students at other institutions.

The annual geological excursion to Death Valley took place for a fifth time in the spring of 2006. It has proven to be immensely popular with first- and second-year undergraduates and highlights the importance of field-based experiences to our program in Earth and Environmental Sciences. Focusing on vignettes drawn from both the contemporary environment and the geological record, the course emphasizes the development of interpretations from the students' own observations.

Frontiers of Science, launched in 2004 as Columbia's latest addition to its famed Core Curriculum, has completed its second full year, with DEES continuing to take responsibility for the 25 percent of the course dealing with global climate change and accounting for by far the largest contingent of instructors of any department.

The course's objective is to communicate the philosophy and intellectual habits of science in the context of selected topics at the forefront of research. The topics change from one term to another, depending in part on the expertise of the lead faculty involved, and they represent vehicles for conveying the essence of scientific inquiry rather than specific content to be learned.

In addition to the DEES segments on climate change, spearheaded by Wally Broecker, the Newberry Professor of Earth and Environmental Sciences, and by Associate Professor Peter deMenocal, topics have included extrasolar planets, astrophysics, human language, brain dynamics, biophysics, the nanoworld and biodiversity. The challenge of communicating such diverse themes to the heterogeneous Columbia College audience is balanced by the shared commitment of those responsible for lectures and sections of the course to the importance of science in a broad education. For a department some distance from the intellectual center of gravity of Columbia's first-year undergraduates, Frontiers of Science is also an opportunity to draw attention to both the excitement and societal relevance of earth and environmental science.

Robina Esther Simpson
Senior Lab Technician 5,
Earth and Environmental
Sciences Department
Credit: Bruce Gilbert

New Master's Program Links Climate Research to Society

The past few years have brought damaging hurricanes, harsh droughts, severe floods, lethal and energy-consuming heat waves and climate-related infectious disease outbreaks throughout the globe—all of which have displaced populations and triggered the need for international assistance. In recent decades, however, new knowledge of Earth's climate system has also revolutionized our ability to understand and predict climate change.

"This new scientific knowledge can offer better ways to respond to the problems and opportunities created by our varying climate, especially as human activity alters it," said Mark Cane, the G. Unger Vetlesen Professor of Earth and Climate Sciences at Columbia. "But decision-makers must understand how to make effective use of this new knowledge and factor climate research into policy decisions and economic strategies."

That need is the driving motivation behind the new Climate and Society master of arts degree program, launched in 2004 and directed by Cane. The innovative, 12-month program brings together students from all over the world to learn the workings of Earth's climate system, assess its socioeconomic impacts and make climate information usable for policy-makers. The students study with Columbia faculty from all across the University,

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

Hans von Storch, director of the Institute of Coastal Research in Geesthacht, Germany, and professor at the Meteorological Institute of the University of Hamburg, presents to students in the master's program.
Credit: Bruce Gilbert

as well as researchers at Earth Institute units, including the International Research Institute for Climate and Society (IRI) and the NASA Goddard Institute for Space Studies (GISS). The rigorous program emphasizes problems of developing countries, where climate hazards often set back the development process.

The program's first graduating class of 18 students in 2005 included Asefaw Getachew from the Malaria and Vector-borne Diseases Control Department in Ethiopia; Kareff May Rafisura, a disaster mitigation professional from the Philippines; and Daniel Dalmat, a middle school science teacher in Stamford, Connecticut, who said the Climate and Society program also informs his classroom. "By illustrating the interconnectedness of science and society to my students," he said, "they understand the subjects better, and they have more enthusiasm for learning."

Investigating How Life on Earth Rebounds from Catastrophes

By the time she was 16, Jessica Whiteside had lived in 19 states, mostly in the southwestern United States. "I spent a lot of time in the back seat of my parents' station wagon, looking at all these great geological features," she said. And reading, and thinking.

Swept along by her father's career as a NASA engineer and her parents' religious beliefs, Whiteside said she "developed a fascination for powerful forces." During those long car trips, she wrestled with reconciling the Biblical story of Genesis with Hopi creation myths and the Big Bang.

Then she was introduced to fossils "and I realized that fossils told stories similar to myths," she said. "But they could be verified." All these powerful forces in her childhood coalesced in Whiteside deciding to work with Columbia paleontologist Paul Olsen. In the 1990s Olsen co-led an ambitious project with Lamont-Doherty paleomagneticist Dennis Kent to sample and date the Newark Supergroup, a series of rock formations along the East Coast that are the remnants of ancient lakebeds formed between 220 million and 180 million years ago at the seams where the supercontinent Pangea began to split into what is now North America, Europe and Africa. The rocks in the Newark Supergroup contain tens of millions of years of climate records and also span the Triassic-Jurassic boundary, when an unknown event wiped out more than half of the life on Earth. Whiteside decided to focus her research on that.

"I'm especially interested in how life rebounds from catastrophic events, how ecological systems rebuild from massive insults, such as mass extinctions and abrupt climate change, and reassemble themselves over time through the advent of key evolutionary adaptations," she said.

To explore these questions, Whiteside investigated geological sites in North America, Morocco, Europe and England using a variety of techniques. She studied microfossils, fish fossils and fossilized pollen from ancient lakebeds to chronicle how and when life changed during this cataclysmic era. She also analyzed carbon isotopes deposited in sediments that indicated big-leafed plant species did not survive past the Triassic-Jurassic boundary, while smaller-leafed plants such as ferns and conifers did.

Together, Whiteside's research suggests that an external source—an asteroid colliding with Earth, perhaps, or massive volcanic outgassing associated with the breakup of Pangea—created a super-greenhouse effect with an initial massive extinction in less than 10,000 years and a massive disruption of Earth's carbon cycle.

Whiteside said she enjoyed the freedom to pursue rigorous scientific questions and took advantage of Lamont-Doherty's continuing smorgasbord of seminars, its "kaleidoscopic toolkit" (ranging from mass spectrometers to cryogenic magnetometers and state-of-the-art microscopes), and its connections with other institutions (including the American Museum of Natural History and Woods Hole Oceanographic Institution). Upon earning her Ph.D. degree, Whiteside became assistant professor of terrestrial environments at Brown University.

Inspired Student Becomes Inspiring Teacher

Beth Katz grew up in Los Angeles but decided to try a new side of the country when she chose a college. The Core Curriculum at Columbia persuaded her to come to New York, and she arrived full of curiosity but undecided about what she wanted to study.

Then in her first year, she signed up for an elective course called "Science and Society," in which faculty members from a variety of disciplines teach the science underlying a broad range of the world's environmental problems. Global warming, the destruction of wetlands and energy consumption demanded more attention than it seemed society was willing to give, she said, so she decided to give them her attention and major in environmental sciences.

Her classes "were small, challenging and extremely relevant," said Katz. "At Columbia, I was always engaged and quite often inspired.

"In addition to a rigorous classroom education, Columbia also provided me with outstanding opportunities to engage in research. I spent the summer after my sophomore year at Lamont-Doherty researching arsenic levels in tree rings from a contaminated site in New Jersey. As an intern, I went into the field to core trees, prepared and analyzed my samples in the lab and generated my own results under the guidance of my advisor, Zhongqi Cheng. In December of 2004, I presented my research at the American Geophysical Union's annual conference in San Francisco."

For her senior thesis, Katz conducted a series of experiments to evaluate different household water filters, whose use in New York City has become popular but whose effectiveness on water quality had so far not been tested. "I had to learn a variety of analytical techniques," she said. "The kitchen in my dorm room started to look like a lab," as hundreds of sampling syringes and bottles, pH and conductivity meters and strips to test chlorine levels vied for space with dishes and utensils. Under the guidance of geochemists Martin Stute at Barnard and Gisela Winckler at Lamont-Doherty, she also used ion chromatography to detect dissolved anion concentrations and an inductively coupled plasma mass spectrometer to investigate trace metal levels.

At Columbia, I was always engaged and quite often inspired. In addition to a rigorous classroom education, Columbia also provided me with outstanding opportunities to engage in research.

Upon graduation in May 2006, Katz joined the Teach for America Program. During an intensive summer training program in Los Angeles, she got her first taste of teaching others about environmental sciences. "It was inspiring to see my students start to tackle problems ranging from global warming to water quality," said Katz. "They reminded me about how curious I was when I started at Columbia."

In the fall of 2006, Katz began teaching environmental sciences at the Environmental Charter High School in Lawndale, California.

Beth Katz on a field trip with her class at the Ballona Wetlands near Los Angeles.

Seeing Through the Sea and Seafloor

Marine seismologists push the envelope to get revealing new images of the ocean crust

Suzanne M. Carbotte
Doherty Research Scientist, Marine Geology and Geophysics
Credit: Bruce Gilbert

In 1937, Maurice Ewing sank a parcel of TNT to the bottom of the ocean to see if he could record the explosive energy as it reflected off layers of rocks beneath the seafloor. Lamont-Doherty's founding director wanted to illuminate the underlying ocean crust with sound—similar to the way physicians today use ultrasound.

Ever since, Lamont-Doherty scientists have led the way in the field of marine seismology. They continually advanced technology and techniques on every one of the Observatory's research ships, which became the flagship vessels in the U.S. academic fleet for marine seismic exploration.

Between 2004 and 2006, Lamont-Doherty marine seismologists Suzanne Carbotte and Mladen Nedimovic, together with their colleagues, broke new ground with exceptionally clear, deep seismic images that revealed intricacies of seafloor and sub-seafloor structures. Their images bring into better focus the geological processes that contribute to the formation and evolution of Earth's crust and that contribute to large earthquakes.

Carbotte led an expedition aboard the R/V *Maurice Ewing* to conduct the first detailed seismic reflection study of the Juan de Fuca Ridge, a volcanic underwater mountain chain where magma erupts to create new seafloor off the U.S. Pacific Northwest coast. The study, published March 2006 in the journal *Geology*, helped resolve a long-standing debate about the mechanisms that produce such a wide variety of different ridge structures and shapes.

Previously, scientists theorized that different shapes represented different phases in an alternating cycle of growth, in which magma rises from a chamber to create new ocean crust and then the chamber dissipates and magmatism wanes. During the non-magmatic episode, the seafloor accommodates the stretching of the ocean plate by tectonic forces: The stretched crust forms cracks, or faults, and slabs of crust slide along these faults and spread outward like falling dominoes, forming a depression.

But the new seismic images showed for the first time that magma chambers exist beneath each segment of the Juan de Fuca Ridge, including those previously assumed to be in a non-magmatic phase. The finding has led to a new theory on how continual, rather than episodic, magma delivery can generate the diversity of ridge shapes seen on the seafloor.

In another study based on these same data and published in August 2005 in *Nature*, Nedimovic, Carbotte and colleagues detected for the first time crystallized lenses of magma embedded in the Moho, the boundary between the mantle and the overlying ocean crust. The finding shed new light on how ocean crust is created (see page 18).

New seismic images are also leading to discoveries at the other end of the Juan de Fuca Plate—where oceanic crust, created at the ridge millions of years ago, is grinding against the North America Plate and bending into a deep submarine trench off the coast of Oregon and Washington. A variety of forces conspire to generate powerful earthquakes in such subduction zones, which extend across most of the edges of continents that border the Pacific Ocean.

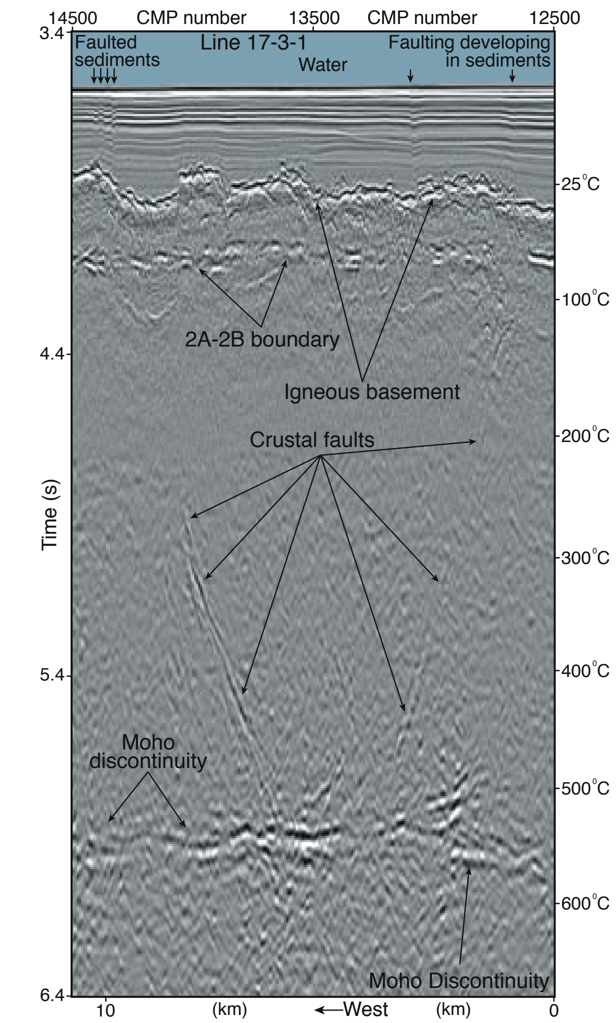
One critical earthquake-generating factor is water, which is carried into Earth with the subducting plate and promotes brittle failure that generates intraslab earthquakes, a type of seismic event unique to subduction zones. Another is the role of overlying sediments. The Juan de Fuca Plate is notorious for having large blankets of sediments on top of it. Nedimovic, Carbotte and former Lamont-Doherty colleague DelWayne Bohnenstiehl were able to obtain seismic images of faults that extend not only through the sedimentary layers, but all the way through the crust down to the Moho, as well.

"This has never been done before," Nedimovic said. "Often, seismic images can be blurry, so you have to guess or interpret fault structures in them. But these are sharp, like a knife. We don't have to guess or interpret. We can clearly see faults extending far down into the crust."

In the Cascadia subduction zone, located at the east end of the Juan de Fuca Plate near many large Pacific Northwest population centers, the Lamont-Doherty team found that these faults continue down to the Moho, but—critically—no farther. This means that seawater, which penetrates along the faults, is stopping at the Moho and not getting deeper into the mantle, which is composed of peridotite rocks that can absorb much more water than crustal rocks.

The plumbing system revealed by the Lamont-Doherty seismologists likely explains why fewer intraslab earthquakes occur in the Cascadia subduction zone, compared to other subduction zones. The limited volume of water that gets embedded and later released in the downgoing Cascadia slab results in fewer intraslab earthquakes and the limited depth that water reaches via faults may limit the magnitudes of earthquakes in this populous region to about 7.

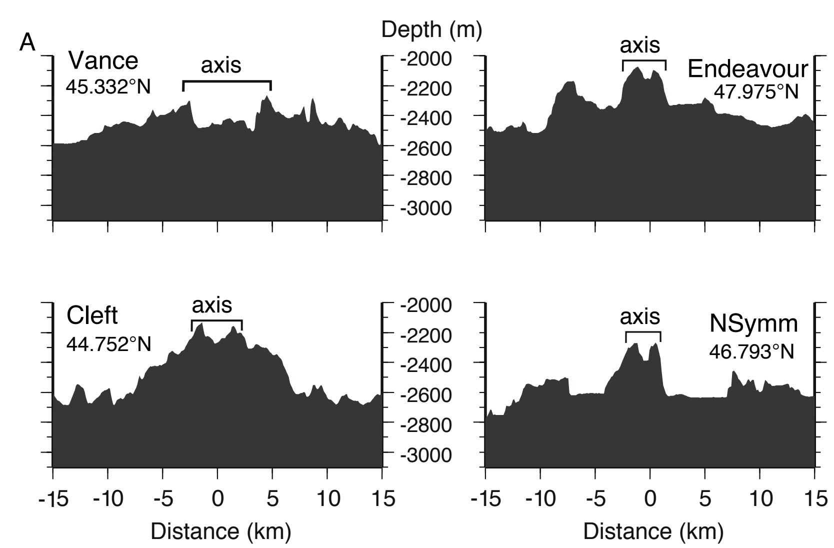
The clearer and more detailed seismic images, Nedimovic and Carbotte say, were due to advances in technology and practices aboard the *Ewing*, which was retired in 2006. Over the years, the *Ewing*'s longer receiving arrays and optimized sound-energy source were used to image structures with increasingly fine detail. Those technologies will be upgraded to provide three-dimensional seismic images when the Observatory's newest ship, R/V *Marcus G. Langseth*, begins operating in 2007, carrying on Lamont-Doherty's traditional leadership in marine seismology.

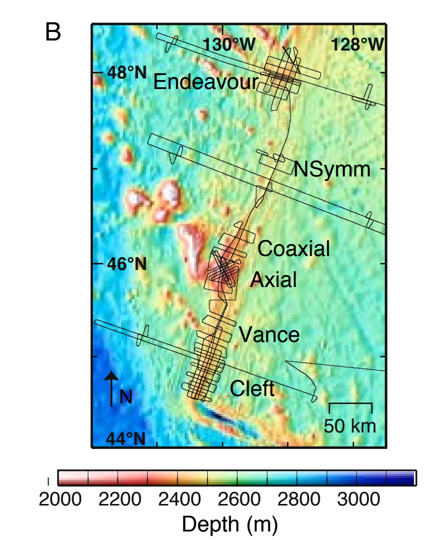


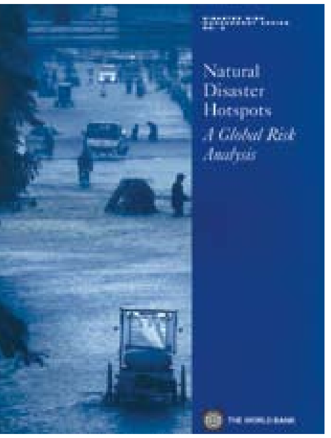
Seismic images near the Juan de Fuca Ridge showing faults that extend through sediments and much of the crust to the Moho.

[left] Cross-axis profiles showing the wide variety ridge structure at adjacent segments of the Juan de Fuca Ridge produced by continual magmatism. *Credit: Suzanne M. Carbotte*

[right] Regional bathymetry of the Juan de Fuca Ridge with seismic survey tracks shown. *Credit: Suzanne M. Carbotte*







Global distribution of economic loss hotspots for all hazards (cyclone, drought, flood, earthquake, volcano and landslide) is assessed in *Natural Disaster Hotspots.*

Hitting All the Hotspots

A global study of natural disasters shifts development and aid strategies

Every so often, a piece of scientific research comes along that opens eyes, breaks barriers and helps shift policy strategies. One such project by Lamont-Doherty seismologist Art Lerner-Lam is not only changing the way world development and aid organizations view the world, it is changing the way they do business. Ultimately, it could help save thousands of lives and millions of dollars.

Lerner-Lam, director of the recently established Center for Hazards and Risk Research (CHRR), co-authored an ambitious effort to systematically and scientifically assess the exposure of regions throughout the globe to earthquakes, floods, droughts, volcanoes, landslides and cyclones. Commissioned by The World Bank, the "Hotspots Project" identified areas that were more exposed to natural hazards and at greater risk to high rates of mortality and economic loss.

"When you look at all of the spots together, you see a phenomenally large exposure to disasters," said Lerner-Lam. "It gave us real insight about how much of the global population and how much economic development is affected by natural disasters."

Perhaps the greater impact of the study was in demonstrating that managing disaster risks is not only a humanitarian issue, but one that should be an integral part of development planning, as well. "Hunger, disease and poverty have been top priorities in the developing world, but the ability of societies to be resilient and withstand natural environmental stresses is an important component, too," said Lerner-Lam. "Natural disasters can be a drag on development."

The study, officially called *Natural Disaster Hotspots: A Global Risk Analysis*, was co-authored by Bob Chen of the Center for International Earth Science Information Network (CIESIN) at Columbia and Maxx Dilley, formerly of Columbia's International Research Institute for Climate and Society (IRI), and included researchers from the World Bank's Hazard Management Unit; the Norwegian Geotechnical Institute; three UN programs (Development, Environment and World Food); as well as other groups.

Lamont-Doherty's role, said Lerner-Lam, was "to bring best available scientific knowledge to bear and coordinate the geophysical studies of the regions." This continues to be an area of ongoing research.

The researchers combined hazard occurrence with population and gross domestic product per unit area to assess each region's potential exposure to human and economic losses. They applied this approach to a map of the world that was gridded into small cells and calculated relative risks for individual regions within countries to multiple, interrelated disasters.

"The Hotspots Project report is a tool to inform strategies on where and how to encourage and target investments in developing countries," said Lerner-Lam. "Building schools that cannot withstand earthquakes in an earthquake-prone area is a potential double disaster. Hotspots has had a very positive and direct impact on World Bank and United Nations development policy because we have been able to quantify the natural hazard risk and provide evidence to support particular development programs."

The report also provides motivation to devote resources to prepare for disasters and to prevent losses, he added. Among the report's key findings are:

- About 19 percent of Earth's land area and 3.4 billion people (more than half the world's population) have relatively highly risk of exposure to at least one hazard.
- One hundred sixty countries have more than one-quarter of their population in areas of high mortality risk from one or more hazards.
- More than one-third of the U.S. population lives in hazard-prone areas.
- More than 90 percent of the populations of Bangladesh, Nepal, the Dominican Republic, Burundi, Haiti, Taiwan, El Salvador and Honduras live in areas of high relative risk of death from two or more hazards.
- Poorer countries in the developing world are more likely to have difficulty absorbing repeated disaster-related losses and costs associated with disaster relief, recovery and reconstruction.

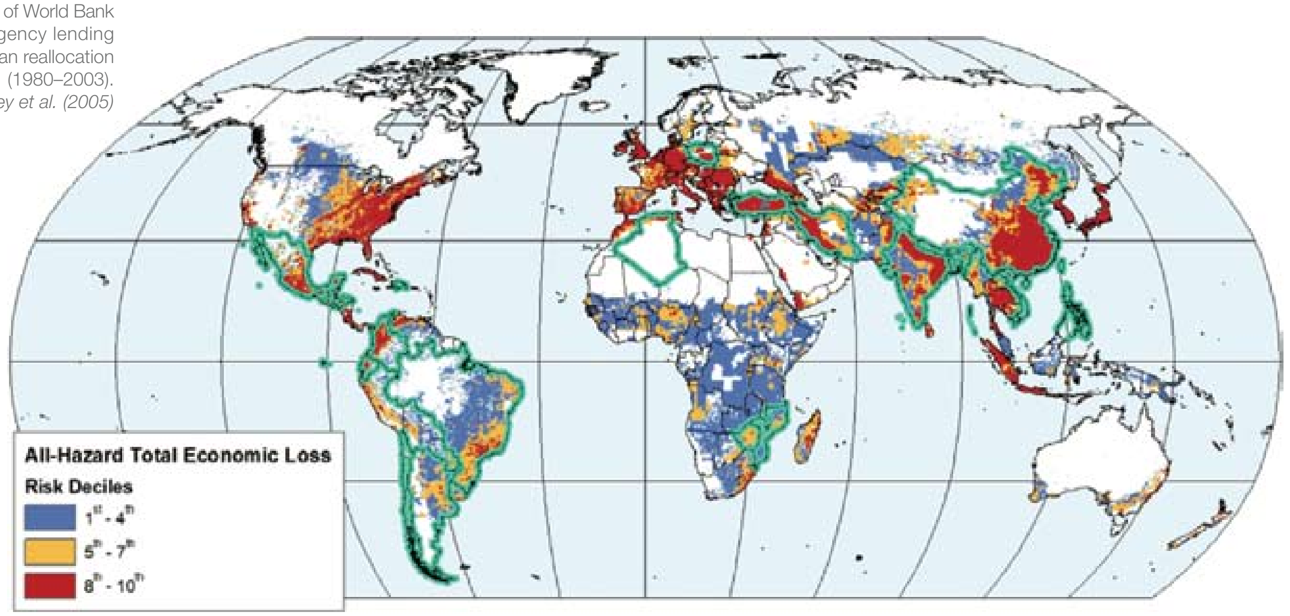
Among the longer-term benefits of the Hotspots Project, said Lerner-Lam, was to motivate social and geophysical scientists to begin talking to each other and talking each other's language.

"We showed that you can link basic geophysical knowledge with disaster assessments that economists, political scientists, social scientists, agronomists and others face every day. Now we see more of these scientists at meetings, and we have deeper conversations with them. There's a hunger for information from both sides. People didn't know what they didn't know. It's no longer a situation where we geophysicists write scientific papers and hope scientists in other fields or practitioners read them; now we write papers together. Our research is connecting in ways it hadn't before and there's a shorter leap between research and its applications."

The Hotspots Project also fostered collaborations with scientists worldwide, which should continue and grow as Lamont-Doherty scientists take global disaster risk assessment research to the next levels.

"Lamont has always attracted an international cast of characters, which is the best way to study the Earth," said Lerner-Lam. "We have a long history of identifying and building collaborations with in-country partners around the world and working with them in country-specific ways. A businessman would call it capacity building. We call it business as usual."

Total economic loss risk hotspots and the top 20 recipients of World Bank emergency lending and loan reallocation (1980–2003). *Credit: Dilley et al. (2005)*



New Orleans in the aftermath of Hurricane Katrina, showing Interstate 10 at West End Boulevard, looking toward Lake Pontchartrain. *Credit: U.S. Coast Guard, Petty Officer 2nd Class Kyle Niemi*

The Hotspots Project report is a tool to inform strategies on where and how to encourage and target investments in developing countries.

At a test site in the Hengill region of southwestern Iceland, Lamont-Doherty researchers are studying the feasibility of storing CO_2 safely and permanently in basaltic formations. *Credit: Juerg Matter*

What to Do With CO_2?

Lamont-Doherty scientists test new method to lock excess greenhouse gas underground

In the grand geological scheme of things, Earth has a balanced carbon budget. Over tens of millions of years, carbon dioxide trapped deep within the rocky bowels of the planet was vented into the atmosphere by volcanoes. Over time, that carbon dioxide either reacted chemically with rocks on Earth's surface and converted into carbonate rocks or the carbon dioxide was taken up by photosynthetic plants and animals that ate them, both of which subsequently decomposed into hydrocarbons that got buried in the Earth.

Since the Industrial Revolution, however, humans began to remove carbon from the planet much faster than natural systems could restore it. In a short time, we have extracted huge quantities of hydrocarbons, in the form of oil and gas, and burned them for fuel, pouring an excess of heat-trapping carbon dioxide into the air in the process. The result is the global warming scenario we now face.

"The world currently emits 25 gigatons [billions of tons] of CO_2 per year; the U.S. approximately 6 gigatons," said Lamont-Doherty scientist Juerg Matter. "We can't expect that we will stop using fossil fuel. That's why we have to take action."

Matter and two Lamont-Doherty colleagues, David Goldberg and Taro Takahashi, have proposed an innovative solution for the manmade problem: Put large quantities of carbon dioxide back into the Earth from whence it came. To keep it there, they aim to convert the carbon-containing gas into carbon-containing rock.

For decades, the oil and gas industry has injected carbon dioxide into oil wells to push out every last drop of oil and left the gas underground. That has led to the idea of putting excess carbon dioxide into underground traps—beneath impermeable cap rock formations or in the spidery pore spaces between rocks—and storing it there.

Despite the appearance of geologic permanence, there are potential leaks. "No traps are perfect," said Goldberg. "Carbon dioxide can migrate up toward the surface and leak back into the atmosphere. Part of the CO_2 will dissolve with residual water into carbonic acid that may help create new pathways to the surface."

Certain types of rocks, however, react differently with carbonic acid and water. Rocks rich in calcium and magnesium form limestone—hard rock that, once formed, stays put. With funding from The Earth Institute at Columbia University, Matter, Goldberg and Takahashi began experiments to determine the feasibility of such a carbon sequestration program. The trio combined an array of required expertise: Takahashi is a geochemist renowned for his research on carbon dioxide; Matter is a hydrologist who studies fluid flow in rock; Goldberg, director of Lamont-Doherty's Borehole Research Group, has a long history of work in measuring rock properties in underground and undersea rock formations.

In laboratory experiments, they studied chemical reactions involving carbon dioxide and different rock types under various conditions. In a test well on the Lamont-Doherty campus, they monitored chemical reactions in underground rocks.

"The key question is: How fast will the chemistry happen?" said Goldberg.

"The reaction should not be too fast so that the gas turns to rock instantly and clogs the reservoir before all the gas can get in," Matter added. "But it must be fast enough so that the gas doesn't persist long enough to leak out."

The research demonstrated that the long-term carbon sequestration concept is viable, and in 2005 Lamont-Doherty joined the Big Sky Partnership, a collaboration involving the U.S. Department of Energy (DOE) and several national laboratories, universities and other government agencies to explore carbon sequestration on a large scale.

In the Big Sky states of Montana, Idaho, Washington, Wyoming and South Dakota, there are an estimated 53,000 square miles of basalt rock deposits that flooded over the landscape in the distant past. These volcanic formations offer a sufficiently deep, drillable, porous reservoir of rocks with the right chemical composition for carbon sequestration. The DOE has already drilled holes near the site in a relatively uninhabited area, which has been well-studied and may be a possible long-term carbon repository.

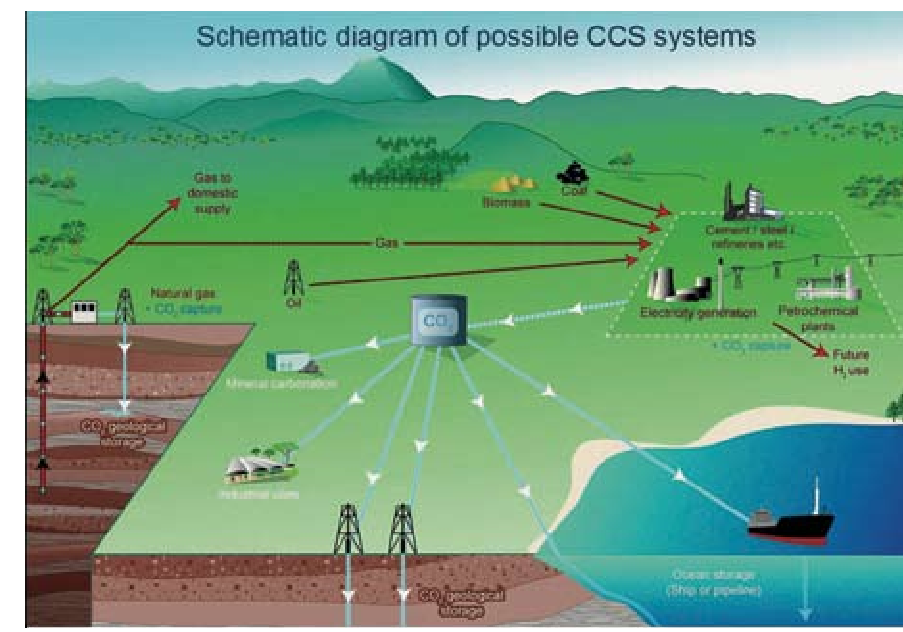
Over the next several years, the Lamont-Doherty scientists will participate in experiments to inject 3,000 tons of carbon dioxide 3,500 feet underground. The scientists will study the reactivity and mineralization of the basalt rock to see how fast it is converted into limestone.

"If only 3 percent of the basalt is suitable for CO_2 sequestration, it could sequester 100 gigatons of CO_2," said Matter.

According to Goldberg, if carbon sequestration works, there are many other places around the world with the right type of potential rock reservoirs, such as the vast Deccan Traps flood basalts in India. Taking the concept a step further, Goldberg, who has long accompanied seagoing drilling expeditions, pointed out that the world's oceans are full of permeable basalt deposits covered by a cap of thousands of meters of water and sediments. "They are far from everyone and have a huge storage capacity," he said.

Indeed, Goldberg has advanced a proposal to the Integrated Ocean Drilling Program (IODP) to explore potential basalt reservoir sites off the U.S. Pacific Northwest coast, which are near shore, have a large sediment cover and are already well-studied. He envisions the possibility of a carbon sequestration industry on the scale of the oil exploration industry, or the latter transforming into the former.

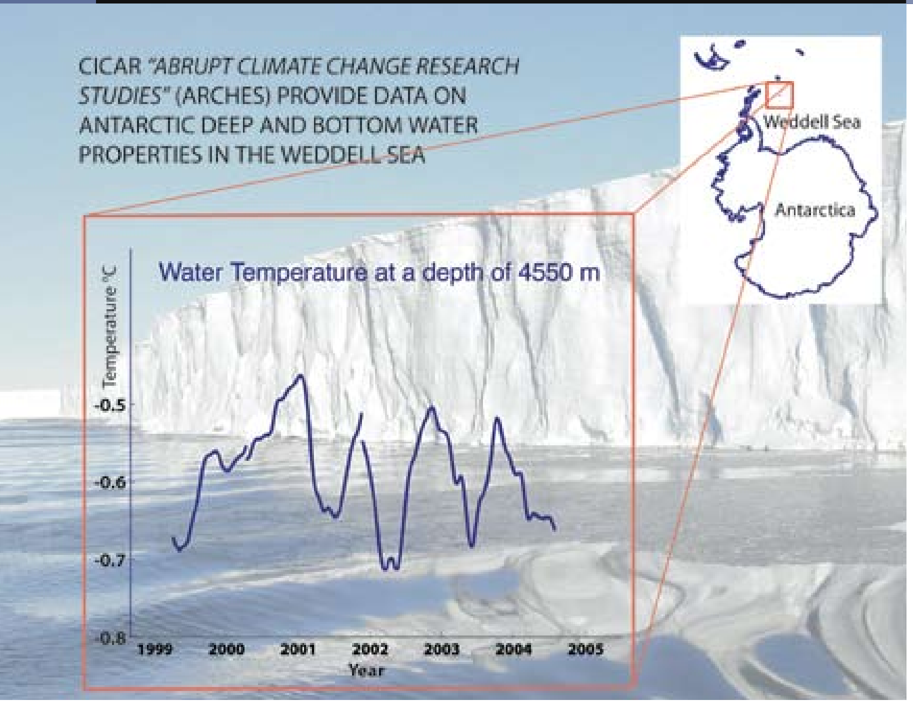
"Carbon sequestration won't provide the entire solution to our greenhouse warming problem," Goldberg said, "but it could be a viable piece."



Credit: Intergovernmental Panel on Climate Change

[left] Wallace Broecker, Newberry Professor of Earth and Environmental Science, at the carbon capture and sequestration (CCS) field study site in Iceland. *Credit: Juerg Matter*

Over the next several years, Lamont-Doherty scientists will participate in experiments to inject 3,000 tons of carbon dioxide 3,500 feet underground.



Water masses that form at the continental margins of Antarctica fill the world's deep oceans. The ARCHES Southern Ocean Modern Observations program maintains instrumented moorings near the South Orkney Plateau in the Northwest Weddell Sea to monitor a major source of Antarctic deep and bottom waters. The six-year record from mooring M3, placed at 4,550 meters, has shown significant seasonal and longer-period variability in the temperature of the Weddell Sea bottom water exiting the gyre.

COOPERATIVE INSTITUTE FOR CLIMATE APPLICATIONS AND RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Cooperative Institute for Climate Applications and Research

The Cooperative Institute for Climate Applications and Research (CICAR) was established in November 2003 as a research partnership between the National Oceanic and Atmospheric Administration and Columbia University. The Institute's research plan is guided by three climate-centered themes: Earth system modeling, modern and paleoclimate observations and climate variability and change applications research.

The NOAA-funded research portfolio at Lamont-Doherty grew out of a clear strategic vision that ocean observations and coupled ocean-atmosphere modeling are fundamental to understanding long-term climate variability and change and to developing climate prediction capabilities. It also emphasizes paleoclimate research as providing climate scenarios broader in context than those revealed in the short instrumental record, thus helping to expand our view of Earth's climate system properties and variability and challenge our conceptual and modeling capability. Columbia scientists worked with NOAA to form programs and set research directions that build on this vision and history of success.

The collaboration between Lamont-Doherty and two of NOAA's other climate-oriented organizations, the Climate Program Office (CPO) and the Geophysical Fluid Dynamics Laboratory (GFDL) lie at the core of CICAR's activities. CICAR's climate research agenda complements the goals of both these organizations. As part of its mission, CICAR also fosters climate-education initiatives to enhance climate education and outreach.

The CICAR research portfolio includes the multi-faceted Abrupt Climate Change Studies (ARCHES) research initiative, which combines paleoclimate research with modern ocean circulation observations and the study of abrupt change climate dynamics through the use of numerical models. Also included are individual, principal investigator–driven initiatives that span several Observatory divisions as well as other units of The Earth Institute at Columbia University.

Since CICAR's founding, a deliberate planning process has developed new research activities to support the NOAA goal to "understand and describe climate variability and change to enhance society's ability to plan and respond." This has lead to the development of the Lamont-Doherty/GFDL project to investigate the climate of the last millennium, in which graduate students and postdoctoral scientists, under the mentorship of senior investigators from both institutions, have conducted research with the common goal of understanding and simulating climate variability over the past 1,000 years and of looking into the greenhouse future. In addition, CICAR launched a University-wide effort to identify and develop applications research to create effective decision-making tools to address North American hydroclimate variability.

In fall 2006, CICAR underwent a comprehensive program review by NOAA. The goal of the review was to evaluate the CICAR research and education programs and its science management. The draft report of the Science Review Committee concluded that CICAR is a valuable member of NOAA's Cooperative Institute community and assigned an overall rating of "outstanding." Encouraged by this support, CICAR will continue to grow and conduct world-class research to improve the nation's capabilities to understand and predict climate variability and change.

ADVANCE Program

When Marie Tharp first suggested that her interpretations of the ocean floor supported the then-revolutionary idea of plate tectonics, her findings were dismissed as "girl talk." This was during the 1950s, a time when a woman scientist was an anomaly at the Lamont-Doherty and in science.

Lamont-Doherty has come a long way since then. In 2004 the Observatory became host of The Earth Institute ADVANCE program, a five-year, $4.2 million NSF-funded initiative led by Robin Bell to increase recruitment, retention and advancement of women scientists at Columbia.

Women now make up nearly 20 percent of the research staff and over half of the graduate students at Lamont-Doherty. This number decreases, however, the higher one looks among the scientific ranks. In an effort to attract more emerging and established leaders, ADVANCE created the Marie Tharp Fellowship, which enables women scientists to come to Lamont-Doherty for up to three months with a $30,000 stipend. This also provides Observatory scientists the opportunity to work with such emerging leaders as Lisa Curran, a 2006 Fellow who was recently awarded a five-year MacArthur "genius grant" for her work to mitigate deforestation and enhance conservation in the tropics.

A 2005 ADVANCE survey found women at Lamont-Doherty were less likely than men to travel to professional meetings or spend time in the field due in part to the cost of child care. As a result, ADVANCE developed a program to help women defray these costs and encourage professional travel.

ADVANCE is also exploring the growing body of social and behavioral research linked to diversity. In 2005, the program launched "The Science of Diversity" lecture series, which has already attracted such leaders in the field as Valerie Purdue-Vaughns, a psychologist from Yale University, and Harriet Zuckerman, a widely recognized sociologist from the Mellon Foundation.

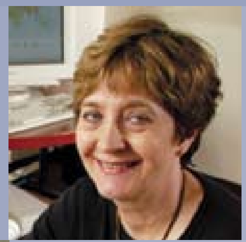
In 2007 ADVANCE will be evaluated to measure the effectiveness of its initiatives and to help the principal investigators develop a plan to institutionalize successful programs. By creating an inclusive environment, Lamont-Doherty will not only improve the work environment for all its employees, but it will also become a more competitive research institution. Marie Tharp would be proud.

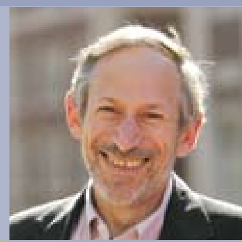
The mission of the Earth Institute ADVANCE program is to increase the recruitment, retention and advancement of women scientists and engineers at Columbia University.

ADVANCE
AT THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

ADVANCE Co-PIs, Fellows and Staff


Robin Bell
ADVANCE Co-PI
Credit: Bruce Gilbert


Roberta Balstad
ADVANCE Co-PI
Credit: Bruce Gilbert


Mark Cane
ADVANCE Co-PI
Credit: Bruce Gilbert


Patricia Culligan
ADVANCE Co-PI

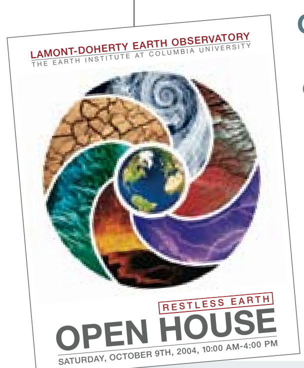

John C. Mutter
ADVANCE Co-PI
Credit: Bruce Gilbert


Stephanie Pfirman
ADVANCE Co-PI
Credit: Bruce Gilbert


Natalie Mahowald
Marie Tharp Fellow


Jennifer Laird
Assistant Director

04



Open House 2004

October 9, 2004

Restless Earth

September 18, 2004

Columbia's 250th Celebration Community Day

2004 Awards

November 9, 2004

Vetlesen Award
Professor W. Richard Peltier and Professor Sir Nicholas Shackleton

November 2004

The Ford Award to Taro Takahashi
The Ford Motor Company honors a carbon cycle pioneer by presenting the Ford Award to Taro Takahashi "in recognition of [his] contribution to understanding what happens to industrial carbon dioxide."

December 2004

Peter Kelemen received the Bowen Medal from the Volcanology, Geochemistry and Petrology Section of the American Geophysical Union at its annual meeting in San Francisco.

05

Jardetzky Lecture

May 12, 2005

Recent Insights Into the Anthropogenic Perturbation of the Global Carbon Cycle
Nicholas Gruber, University of California, Los Angeles

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, who later became president of the National Academy of Sciences, and Maurice Ewing, Lamont-Doherty's founding director, on a well-known and widely used scientific book, *Elastic Waves in Layered Media*. The Jardetzky lecture was established in 1992 by Jardetzky's son Oleg.

Spring 2005 Public Lectures

April 17, 2005

The Science Behind *Aliens of the Deep*
Maya Tolstoy, Doherty Research Scientist

May 1, 2005

A Natural History of the Palisades
Professor Mark Anders and Neil Pederson, Tree-Ring Laboratory

May 15, 2005

Deep Time: The History of Our Planet Revealed
P. Jeffrey Fox, Director of Science Services, Integrated Ocean Drilling Program

This talk sponsored by the Lamont-Doherty Alumni Association.

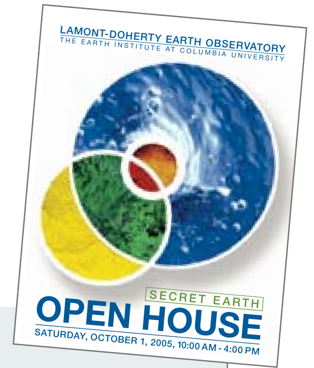
May 22, 2005

Blindsided: How Science Can Help the Developing World Avoid Another Tsunami Tragedy
Art Lerner-Lam, Director, Center for Hazards and Risk Research

Open House 2005

October 1, 2005

Secret Earth



2005 Awards

Lamont-Doherty Excellence in Mentoring Award, Marc Spiegelman, Seismology, Geology and Tectonophysics

The Lamont-Doherty Excellence in Mentoring Award recognizes the importance of quality mentoring, which benefits the institution as a whole, its junior members (including graduate students, postdoctoral fellows 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.

Glenn A. Goodfriend Award, Sarah Feakins
The prize is given annually by LDEO and the Department of Earth and Environmental Sciences for an outstanding student paper in paleoclimatology. Florentin Maurrasse (PhD '73) established the prize in 2003 in memory of his friend and colleague Glenn A. Goodfriend.

Sarah Feakins and G. Michael Purdy
Credit: Doug Brusa

September 2005

Bob Anderson awarded the Huntsman Foundation's Award on the 25th anniversary of the founding of the award at the ceremonies in Halifax, Nova Scotia.

December 2005

Arnold Gordon awarded an honorary D.Sc. by the University of Cape Town.

December 2005

Dennis V. Kent recognized by the Institut de Physique du Globe de Paris, France, with its highest honorary degree, becoming one of its few Doctors Honoris Causa.

06

Spring 2006 Public Lectures

March 26, 2006

Is the Earth's Core Leaking?
David Walker, Professor, Earth and Environmental Sciences

April 9, 2006

Climate Change Problem: A Permanent Underground Carbon Storage Solution?
Juerg Matter, Doherty Associate Research Scientist

April 30, 2006

The 100th Anniversary of the San Francisco Earthquake of 1906: What Have We Learned Since Then About the Earthquake Process and Prospects for Earthquake Prediction?
Lynn Sykes, Higgins Professor Emeritus

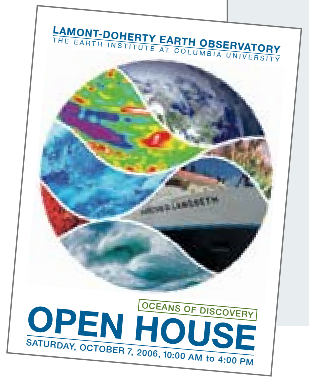
May 21, 2006

The Katrina Disaster: A Poor World Tragedy in a Rich Country
John Mutter, Professor of Earth and Environmental Sciences Department; Deputy Director/Associate Vice Provost, The Earth Institute at Columbia University

Open House 2006

October 7, 2006

Oceans of Discovery



2006 Awards

Storke Doherty Lectureship Award
Tina van de Flierdt, Geochemistry
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.

January 2006

Paul Richards awarded the 2006 Leo Szilard Lectureship Award by the American Physical Society "for work applying his expertise in geophysics to seismic detection of nuclear explosions."

April 2006

Dennis V. Kent received the Petrus Peregrinus Medal by the European Geosciences Union for outstanding scientific contributions in the field of magnetism.

April 2006

G. Michael Purdy named to receive the W. Maurice Ewing Medal at the American Geophysical Union's fall meeting.

May 2006

Robin Bell receives an Honorary Doctor of Science degree from Middlebury College.

June 2006

Gordon Jacoby received a Life Achievement Award and **Ed Cook an Outstanding Service Award** at the 7th International Tree-Ring Conference in Beijing.

[top to bottom]
1. Open House 2005. *Credit: Bruce Gilbert*
2. AGU 2006 Award Ceremony. *Credit: Doug Brusa*
3. David Walker at the Public Letures Spring 2006 *Credit: Ronnie Anderson*
4. Open House 2006. *Credit: Bruce Gilbert*

[left to right] Sarah Huard, Stacey Vassallo, Ronnie Anderson, Doug Brusa

Your contributions help ensure Lamont-Doherty's continued tradition of excellence in research, education and outreach.

Development Office

In 2005 and 2006 charitable gifts from individuals and foundations totaled $5.1 million, with an additional $21 million in gifts and pledges for the new Geochemistry laboratory building and for Lamont-Doherty's endowment. This latter figure includes an $18-million gift—one of the largest ever received by the Observatory—from Gary Comer and the Comer Science and Education Foundation for the new laboratory building (see page 7). Columbia Trustee Gerry Lenfest also gave $2 million to support the project as well as an additional $750,000 to purchase a new mass spectrometer. A very generous anonymous donor contributed $500,000 toward construction, and we were also grateful to receive a gift of $100,000 from the Ambrose Monell Foundation for the project.

Another milestone for Lamont-Doherty in 2005 was the establishment of the Jerome M. Paros–Palisades Geophysical Institute Fund for Engineering Innovation in Geoscience Research. The fund, which was made possible by a $550,000 gift from Jerome M. Paros matching an earlier gift from the Palisades Geophysical Institute, supports the development of new technologies and the application of existing technologies to aid Lamont-Doherty researchers in their studies of Earth.

In both 2005 and 2006, Lamont was awarded grants from the Brinson Foundation to fund the work of postdoctoral fellows in the Seismology, Geology and Tectonophysics Division and to establish the Earth Microbiology Laboratory at Lamont-Doherty.

We continue to benefit from the thoughtful generosity of the G. Unger Vetlesen Foundation. The Foundation provides critical unrestricted support, which in 2005 and 2006 allowed Director Mike Purdy the flexibility to fund priority projects across a range of disciplines. Funding from the Vetlesen Foundation also supports Lamont-Doherty's climate center programs and makes possible a large part of the Observatory's extensive and growing climate research activities.

In 2005, to recognize the leadership support of our longtime friends and supporters, the Observatory established the Founders' Circle and was delighted to welcome George Rowe of the Vetlesen Foundation and Walter Brown of the Henry L. and Grace Doherty Foundation as inaugural members. Membership in the Founders' Circle is a recognition reserved for our most generous benefactors whose contributions have made a transforming impact on the Observatory.

It is also our pleasure to acknowledge in this report the impact of our newly reconstituted Advisory Board. Since its inaugural meeting in January 2005, the Board has grown to 17 members and is thriving under the leadership of its chair, Quentin Kennedy. The Advisory Board is charged with promoting the best interests and mission of Lamont-Doherty, advising the director on a broad range of issues and supporting the Observatory through personal financial donations as well as by providing contacts and contributing time, talent and effort.

Lastly, we would like to thank each person, foundation and corporation who chose to make a gift to Lamont-Doherty. Your contributions help ensure Lamont-Doherty's continued tradition of excellence in research, education and outreach.

$250 + Donors

JULY 1, 2004 THROUGH JUNE 30, 2006

Dennis M. Adler and Robin Aronow
Charles Amendola
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American Geophysical Union
Anonymous (2)
Aquanautix
William and Jeannemarie Baker
Black Rock Forest Consortium
David G. Black Jr.
Bonshow, Inc.
The Brinson Foundation
Richard E. Byrd
ChevronTexaco
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Comer Science and Education Foundation
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Verizon Foundation
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The Wallace Marital Trust
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Jill C. Weinberg
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Friends of Lamont-Doherty

Friends of Lamont-Doherty (FOLD) recognizes donors who contribute annual gifts of $500 or more to Lamont-Doherty, including unrestricted gifts that give the director unparalleled ability to direct support to research areas most in need or to fund special projects. In addition to the knowledge that their leadership gifts enable the continued advancement of research by Lamont-Doherty scientists and students, members of FOLD receive special invitations to Observatory events, trips and tours.

Torrey Cliff Society

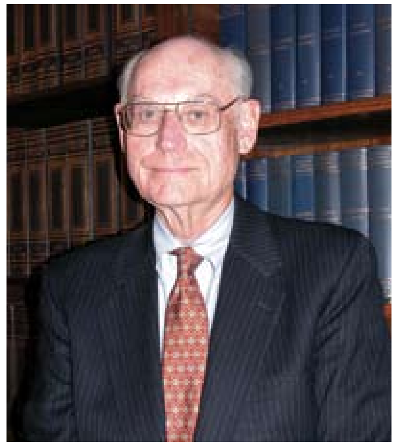
For many donors, carefully planned gifts can offer significant estate and income tax benefits, while at the same time allowing individuals or families to make a much larger impact than would be otherwise possible. The Torrey Cliff Society is composed of people who have included the Lamont-Doherty Earth Observatory in their estate plans or who have life income gift arrangements with Columbia University.

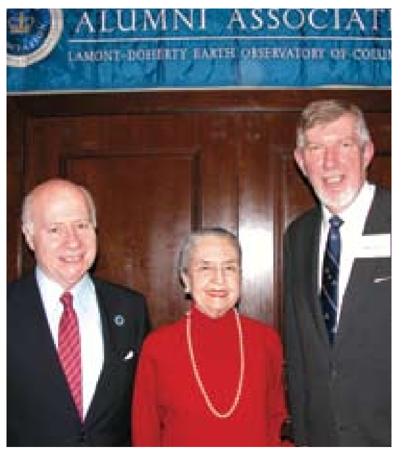
The Society is named for the estate on which Lamont-Doherty is located, which was donated to Columbia in 1948 and which had been named by its original owners, Thomas and Florence Lamont, for America's famed, 19th century botanist, John Torrey. The Society enables Lamont-Doherty to recognize its members, who are inducted each fall just before Open House, in a way that relates their generosity to the Observatory's proud history of scientific advancement.

Becoming a member of the Torrey Cliff Society also confers 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 Lamont-Doherty and the University to extend their gratitude.

TORREY CLIFF SOCIETY MEMBERS AS OF JUNE 30, 2006

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





[top left] Quentin Kennedy, Chair of Advisory Board
[top right] P. Jeffrey Fox, President of Alumni Association
[bottom] Lamont AGU Reception.
Credit: Doug Brusa

LDEO ADVISORY BOARD

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G. Michael Purdy, Director
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LAMONT-DOHERTY ALUMNI ASSOCIATION BOARD OF DIRECTORS 2005–2006

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P. Jeffrey Fox

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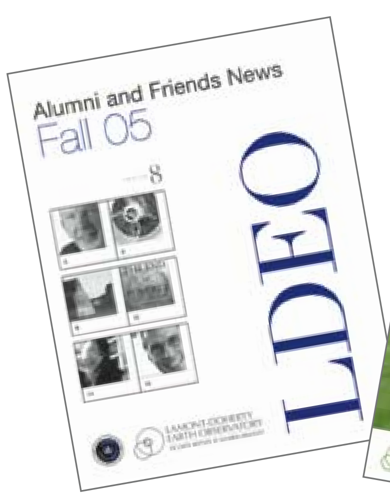

Alumni Association

It is impossible to know precisely how many members there are, but thousands of people are part of a certain extended family. Its members studied at, worked at or, in some cases, were briefly a part of Lamont-Doherty. What they share is a respect and affection for the place and its legacy, and, no matter how many years removed from the campus, they still consider themselves "Lamonters."

Lamont-Doherty alumni are not often ones to stand on ceremony or establish highly structured bureaucracies. Informal reunions and grapevine communications had been going on for decades without any formal alumni association until, on the Observatory's 50th anniversary in 1999, a slightly more formal alumni group was founded in order to assure steady and continuing alumni activity. The Lamont-Doherty Alumni Association has been active and thriving ever since.

Under the leadership of founding president Terry Edgar and his successor Jeff Fox, an Alumni Association Board was formed that works with Observatory staff on all matters relating to alumni. The board is composed of both academic and staff alumni, and it sponsors three reunions each year: two at Lamont-Doherty (Alumni Public Lecture Day in the spring and Open House in the fall) as well as an international reunion at the December meeting of the American Geophysical Union in San Francisco.

Although many Lamont-Doherty alumni choose to support the Observatory and its alumni activities with financial contributions, there is no specific fee for membership in the association. All those who self-identify as alumni are encouraged to join the mailing list by contacting alumni@LDEO.columbia.edu.

THE PURPOSE OF LAMONT-DOHERTY ALUMNI ASSOCIATION

The purpose of the Lamont-Doherty Alumni Association is to advance the interest and promote the welfare of the 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.

Open House 2006 Alumni Association Meeting: [clockwise from top] Emma (Christa) Farmer, W. Arnold Finck, P. Jeffrey Fox, Mike Purdy, H. James Dorman, Joyce O'Dowd Wallace, Mary Ann Brueckner, William Ryan, Michael Rawson (not pictured: Steven Cande, Stephen Eittreim, Arthur McGarr)
Credit: Bruce Gilbert

Lamont administration is routinely used by Columbia as a test site for new programs and initiatives due to the complexity of our programs and the strength of our staff.

1st Row [left to right] Edith Miller, Victoria Nazario, Maribel Respo and Karen Hoffer
2nd Row [left to right] Raymond Long, Thomas Eberhard, Patrick O'Reilly and Richard Greco
Credit: Bruce Gilbert

Central Administration

The primary responsibility of the Lamont-Doherty Earth Observatory's administration is to ensure compliance with the terms and conditions of our funding while also facilitating the day-to-day work of our research scientists. To achieve this goal, Lamont-Doherty has created a multi-tiered administrative management structure that provides the checks and balances necessary to ensure appropriate stewardship of sponsored projects, endowments, gifts and other institutional funding. Although formally an extension of Columbia University's central operations, the Observatory's administration offers direct, on-site services to the research community on the Lamont Campus.

Lamont-Doherty's central administrative departments are responsible for a core set of activities including grants and contracts management, finance and accounting, purchasing, human resources, facilities management and engineering, shipping and traffic, and campus safety and security. Administrators also manage a range of ancillary services including a copy center, food services and campus housing operations. In addition to these central departments and activities, each of the five research divisions and Earth Institute programs located on the Lamont Campus has an administrator and an administrative assistant who provide day-to-day support to scientists.

Because of the complexity of our programs and the strength of our staff Lamont-Doherty Administration is routinely used by Columbia as a test site for new programs and initiatives. We are proud to provide quality services to the Observatory's scientific community and to be regarded as administrative leaders within the University.

STATEMENT OF ACTIVITIES (in 1,000s)

Sources of Revenue	**2004–05**	**2005–06**	
National Science Foundation	27,291	17,698	(1)
National Oceanic and Atmospheric Administration	6,196	6,877	
National Aeronautics and Space Administraiton	2,555	2,704	
Nationional Institute of Enviromental Health and Safety	919	1,016	
Office of Naval Research	548	555	
U.S. Geologic Survey	351	666	
Department of Energy	317	152	
Department of Defense	218	58	
Department of State	165	13	
Department of the Air Force	163	177	
New York State	142	228	
Government Funds via Subcontracts with Other Institutions	8,457	8,621	
Miscellaneous Federal Funds	12	99	
Total Government Grants	**47,335**	**38,864**	
Private Grants	1,459	1,046	
Gifts	1,074	1,525	
Endowment Income	3,987	4,217	
Miscellenaeous	120	1,546	
Indirect Sources	657	515	
Total Sources	**54,633**	**47,713**	
Uses of Revenue			
Research Expenses	27,878	27,490	
Instruction and Research Support	3,838	3,257	
General and Financial Administration	3,346	3,503	
Operation and Maintenance of Plant	3,329	3,903	
Equipment	6,542	1275	
Other Instruction-related	1,788	(1,313)	(2)
Information Technology	818	614	
External Affairs and Fundraising	681	710	
Debt Service	382	389	
Indirect Uses	4,374	5,506	
Total Government Grants	**52,976**	**44,884**	
Net Operating Gain/(Loss)	**1,657**	**2,829**	
Capital Expenses	(590)	(635)	
Transfers from Endowment	48	77	
Subtotal Non-Operating Expenses	(542)	(558)	
Beginning Fund Balance	6,665	7,727	(3)
Ending Fund Balance	7,780	9,998	

NOTES:

(1) FY05 NSF revenues include $5.4M for the purchase of the *Langseth* and $4.5M ship operations costs that are not in the FY06 amount due to the conversion and reflagging project. Since the conversion of the *Langseth* is not an operating activity the FY06 cost of $9.37M is not included in this Statement of Activities.
(2) Other Instruction-related—recoveries for FY05 cruises are reflected in FY06. In addition, a credit of $1.4M from the sale of seismic equipment from the *Ewing* is included in the FY06 amount.
(3) An account with a balance of $53K was incorrectly included in the FY05 ending fund balances, and the account was moved to IRI. This correction reduced the FY06 beginning fund balance by an equal amount.

William H. Menke

Director's Office

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Tomsa, Violeta	Administrative Assistant

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Eisenberger, Peter	Professor
Fairbanks, Richard G.	Professor
Griffin, Kevin L.	Associate Professor
Hays, James D.	Professor
Liepert, Beate G.	Doherty Research Scientist
Louchouarn, Patrick	Associate Professor
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Olsen, Paul E.	Arthur D. Storke Memorial Professor
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Van Geen, Alexander F.	Doherty Senior Research Scientist

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Juhl, Andrew	Doherty Associate Research Scientist
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Wright, William E.	Doherty Associate Research Scientist

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O'Mullan, Gregory	Post Doctoral Research Scientist

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Kirkwood, Gemma
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Levy, Jennifer
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Teneva, Lida
Whiteside, Jessica

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Jacoby, Gordon C., Jr.
Kukla, George

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Gastrich, Mary D.	Adjunct Research Scientist
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Rainforth, Emma	Adjunct Associate Research Scientist
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Rousseau, Denis-Didier	Adjunct Research Scientist
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Wiles, Gregory C.	Adjunct Associate Research Scientist

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Lotti, Ramona	Staff Associate
Mortlock, Richard A.	Senior Staff Associate

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Pistolesi, Linda I.	Web Specialist

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Sakulich, John	Senior Research Staff Assistant

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Tozer, Catherine	Division Administrator

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Chillrud, Steven N.	Doherty Research Scientist
Goldstein, Steven L.	Professor
Hemming, Sidney R.	Associate Professor
Hoenisch, Barbel	Adjunct Associate Research Scientist
Kelemen, Peter	Arthur D. Storke Memorial 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

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Kenna, Timothy	Doherty Associate Research Scientist
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Straub, Susanne M.	Associate Research Scientist
Van de Flierdt, Christina-Maria	Doherty Associate Research Scientist
Winckler, Gisela	Doherty Associate Research Scientist

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Kaplan, Michael	Postdoctoral Research Scientist
Keimowitz, Alison R.	Postdoctoral Research Scientist
Kelly, Meredith A.	Postdoctoral Research Fellow
Machlus, Malka	Postdoctoral Research Scientist
Pahnke, Katherina	Postdoctoral Research Fellow
Taber, Hersum	Postdocotoral Research Fellow
Zimmerman, Susan R.H.	Postdoctoral Research Scientist

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Buono, Antonio
Cai, Yue
Cipriani, Anna
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Schmieder, Paul J.
Simons, Kyla
Spieler, Abigail R.
Van Tongeren, Jill
Wall, Anna
Wheeler, Kevin T.
Wovkulich, Karen
Zylberberg, David

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Bonatti, Enrico

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Bory, Aloys J.	Adjunct Associate Research Scientist
Brueckner, Hannes K.	Adjunct Senior Research Scientist
Chaky, Damon	Postdoctoral 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
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
Rinterknecht, Vincent	Adjunvt Associate Research Scientist
Rutberg, Randye L.	Adjunct Associate Research Scientist
Shepherd, John G.	Adjunct Senior 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
Turk, Daniella	Adjunct Associate Research Scientist
Webster, James D.	Adjunct Research Scientist
Zellmer, Georg	Adjunct Associate Research Scientist
Zheng, Yan	Adjunct Research Scientist

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Ross, James M.	Staff Associate
Schwartz, Roseanne	Staff Associate

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Benedetto, Karen	Administrative Assistant
Bent, Jonathan	Research Staff Assistant
Catanzaro, Patricia H.	Draftsman
Clark, Elizabeth H.	Senior Research Staff Assistant
Criscione, Deborah C.	Administrative Assistant
Criscitiello, Alison	Laboratory Technician
Dachille, Anthony	Senior Research Staff Assistant
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[Bottom right]
Traffic Department: (left-right) Standing: Pat Ables and Jonathan Chazen
Sitting: Carl Baez, Thomas Eberhard, Robert Daly and Antonio Deloatch
Not Pictured: Maurice Mack and Juan Torres
Credit: Bruce Gilbert

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Credit: Bruce Gilbert

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McCarthy, Kevin	Utility - Temporary
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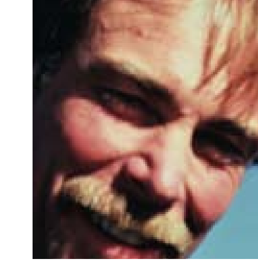
Front Row [left to right]: Gerard Carroll, Eric Soto, Monica Calungcagin and Rick Trubiroha
Back Row [left to right]: Charles Jones, Kevin Sullivan, Bruce Baez, Dick Greco and Lenny Sullivan (not pictured: Joe Casilli, Herb Muench, Jackie Murray, Ray Slavin and Doug Yano)
Credit: Bruce Gilbert



Over the past two years, our community lost three of its giants: Gerard Bond, Marie Tharp and William Haxby.

Gerard Bond (1940–2005). *Credit: Raymond Bradley*

Marie Tharp (1920–2006). *Credit: Bruce Gilbert*

William Haxby (1949–2006). *Credit: Miriam Colwell*

EVERY SO OFTEN SCIENTISTS COME ALONG WHO VIEW THE WORLD with a fresh, creative perspective and, by doing so, fundamentally change our view of the world. Lamont-Doherty seems to attract more than its share of scientists like that. Over the past two years, our community lost three such intellectual giants: Gerard Bond, Marie Tharp and William Haxby.

Bond, who died in June 2005, was trained as a classic geologist and spent the first half of his career studying continental rock formations, tectonics and geologic history. In the late 1980s, seeking a new way to study banding patterns in continental rocks, he tested geologic techniques on a deep-sea sediment core in the Lamont-Doherty Deep-Sea Sample Repository. The test revealed distinct, narrow bands that seemed to match a cyclic record of abrupt changes in past air temperatures called Dansgaard/Oeschger cycles.

"I had never heard of Dansgaard/Oeschger cycles, but by the early 1990s, I had shifted my research from rocks to deep-sea mud," said Bond. "Fortunately, in North Atlantic deep-sea cores … I saw something familiar."

What he found were tiny, iron-stained quartz grains that he knew originated from rock formations in eastern Canada. They had been frozen into moving glaciers and floated out to sea with vast armadas of icebergs. As the icebergs melted, the grains fell to the seafloor.

Bond showed that the timing of these iceberg armadas coincided with rapidly warming and cooling climate fluctuations that occurred every 1,400 to 1,500 years. He painstakingly traced these cycles forward from 100,000 years ago through Earth's most recent ice age and found that they also punctuated the past 10,000 years, when ice sheets no longer covered the planet. These fluctuations are now known as Bond cycles.

Bond and his colleagues then analyzed the effect of cosmic rays on deep-sea cores. Their research turned up evidence for a theory—still being explored—that small changes in the sun's sunspot activity and radiation output could be driving these dramatic and abrupt 1,500-year cycles of climate change.

"Gerard brought his expertise into a entirely new field and changed the way people thought about that field" said Jerry McManus, Bond's former graduate student who is now a paleoceanographer at Woods Hole Oceanographic Institution.

Few people changed the field of earth sciences or our understanding of our planet as dramatically as Marie Tharp, who died in August 2006. She blazed two trails into unexplored territories: As a scientist, she created the first maps that revealed the previously hidden and unknown seafloor; as a woman, she also provided a pioneering role model for women in the earth sciences.

Tharp joined the Columbia staff in 1948, a year before Lamont was founded by Maurice Ewing, who hired her more for her drafting abilities than her master's degrees in geology and math. For the next several years, she and her colleague Bruce Heezen systematically and meticulously plotted seafloor sounding data, point by point, to create seafloor maps of unprecedented detail and accuracy.

Through her work, Tharp revealed the first evidence that the Mid-Atlantic Ridge was bisected by a rift valley, a discovery that Heezen initially dismissed as "girl talk" because it shook the pervading belief that continental drift was scientific heresy. Soon after, Tharp and Heezen provided the first comprehensive look at one of Earth's most dramatic geological features—the globe-encircling, 40,000 mile–long mid-ocean ridge system.

Over the course of 30 years, Tharp and Heezen collected thousands of soundings to create the first global ocean floor map, giving the first visual image of the spectacular seascape that, until then, had remained beyond human view. Soon after, the mid-ocean ridge system was discovered to be the site of seafloor spreading, which helped support the growing belief that continents drift across the face of the Earth.

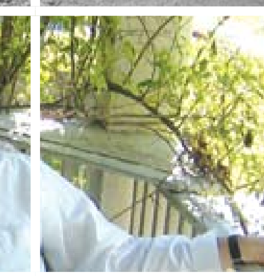
Tharp and Heezen's World Ocean Floor map, published in 1977, was historic and heroic, but it necessarily contained gaps and educated guesses in places where ships never collected soundings. Six years later, William Haxby, who died in January 2006, made a spectacular leap in seafloor map-making.

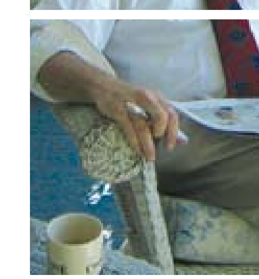
In a flash of insight, he gathered measurements of tiny height variations over the ocean surface that had been recorded by the Seasat satellite. These variations are caused by massive features such as submarine mountains, which attract water toward them, creating mounds of water on the surface above them. By contrast, features such as trenches and canyons leave miniscule dips in the sea surface.

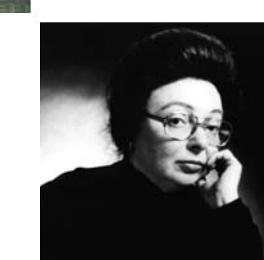
Haxby devised a computer program to convert the massive amounts of data into an exquisite topographic map that displayed the seafloor as if the oceans had been drained away. The data spanned the entire ocean, including places where ships had never traveled and guided oceanographic expeditions for decades to come.

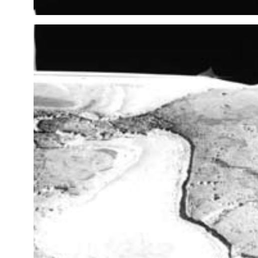
Haxby was an early pioneer in using computers to visualize Earth. In the 1990s, he and Lincoln Pratson transformed bathymetric data collected by NOAA into visually and scientifically stunning images of the U.S. continental slope. Most recently, he created a software application called GeoMapApp (http://www.marine-geo.org/geomapapp) that enables people to view seafloor images on virtually any computer.

Kevin Vranes, who earned a Ph.D. at Lamont-Doherty in 2003 and is now a visiting fellow at the University of Colorado, wrote in a tribute to Haxby: "Every day I would … trudge up the hill to the Oceanography building, open the door, and there to greet me, starting at me, unavoidable, was Bill Haxby's map. It is hung dead center of the hallway that all entering the Oceanography building by the main entrance must walk toward. … Passing the map many times every day, it held a very stark message to me: 'Great and original things have been done in this place. … You're here to try to be great, too.'"









Credit [top to bottom]: *Rusty Lotti Bond, Lamont Archive, Rusty Lotti Bond, Miriam Colwell, Steve Sagala*

A GPS station on the Helheim Glacier in East Greenland placed by Meredith Nettles and her colleagues to monitor movement of the glacier during the summer of 2006.
Credit: Meredith Nettles

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The R/V *Marcus G. Langseth* is a 235 ft, 2578 gross ton research vessel which is owned by the National Science Foundation and operated by Lamont-Doherty Earth Observatory.

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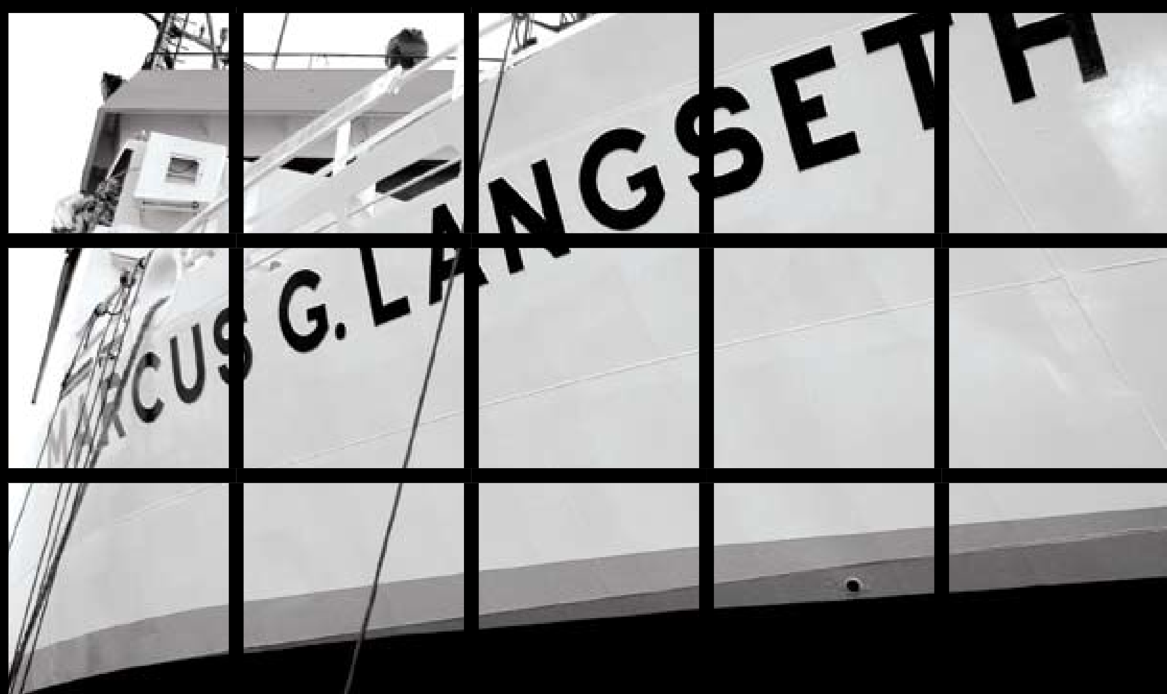

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