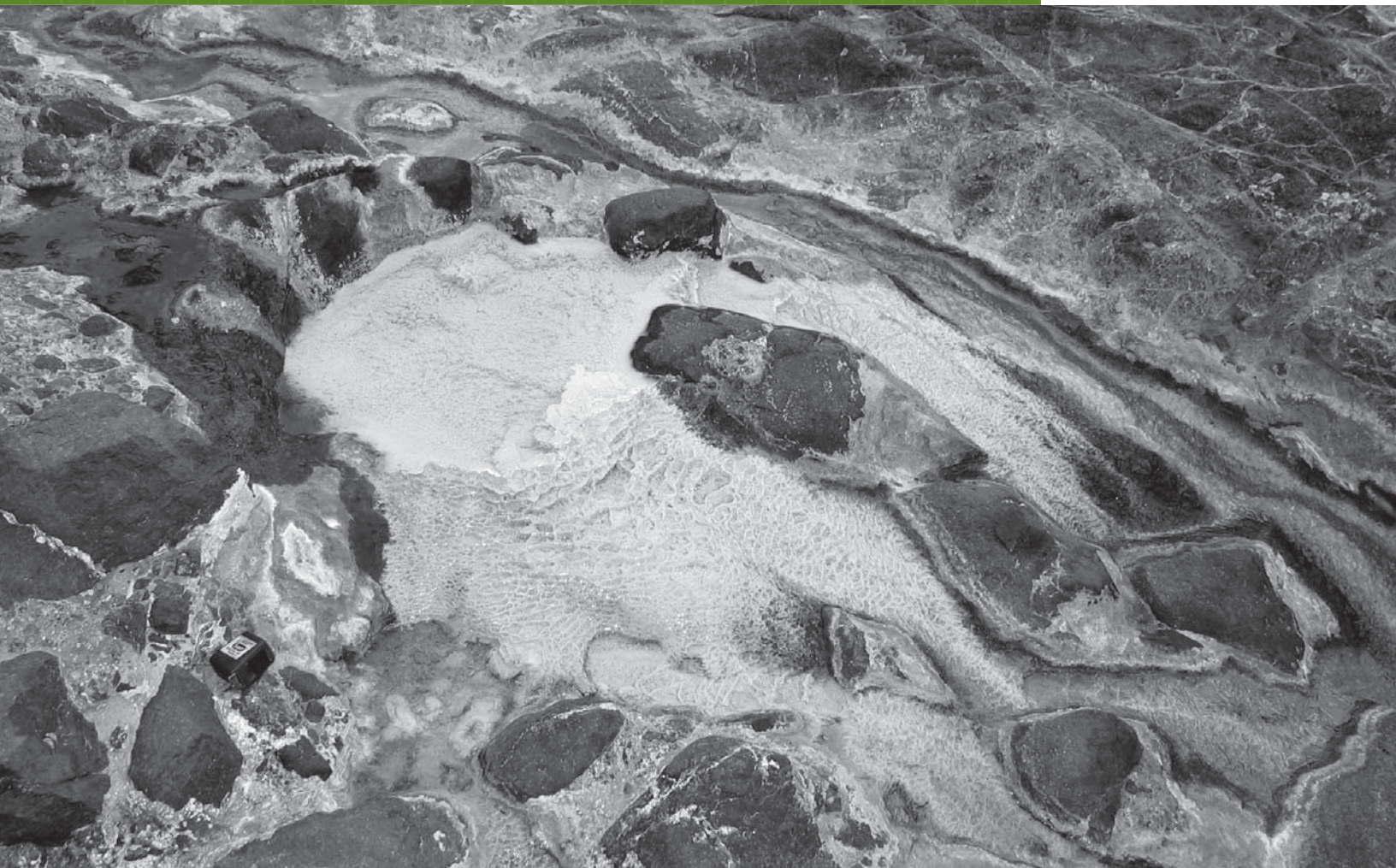


LDEO

ALUMNI AND FRIENDS NEWS

FALL 09

Issue 14



FEATURE ARTICLE

Scientists at Lamont-Doherty
Develop Methods to Transform
CO₂ Emissions into Solid Rock



COLUMBIA UNIVERSITY | EARTH INSTITUTE
Lamont-Doherty Earth Observatory



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Issue 14

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Front cover image: Northern Oman. White deposit of carbonate minerals (travertine) at an alkaline spring in dark mantle peridotite host rocks. The white deposits, composed mainly of the mineral calcite (CaCO₃), form when calcium from the peridotite, dissolved in spring waters, combines with atmospheric CO₂ on the surface.

Photo by: Peter Kelemen





Bruce Gilbert

■ Letter from the Director



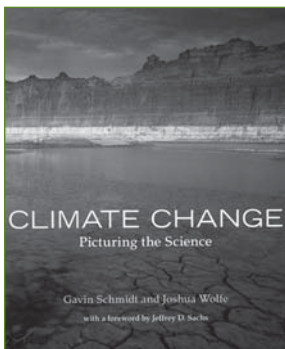
Kim Martineau

Juerg Matter takes part in a carbon sequestration pilot study in Iceland (page 7).



Kim Martineau

Interns Julianne Hegarty and Hannah Moore discuss the mineralogy of ancient rocks with Dallas Abbott (page 3).



Read an excerpt from Peter deMenocal's essay (page 15).

Dear Friends,

As ever, the pace of summer is never as slow as we would expect (or hope for!). Summer interns, federal stimulus proposals, finalizing a number of important new recruitments to our research staff—these are just a few of the activities that have kept us busy at Lamont these past few months. Before autumn slips away, we'd like to tell you a little more about what we have been working on.

Most importantly, the Trustees of Columbia University approved a new LDEO Officer of Research track at their final meeting of the academic year. The new title, "Lamont Research Professor," which will confer many of the benefits given to professors elsewhere at the University, will enable the Observatory to increase substantially its ability to recruit and retain the highest caliber senior researchers. Endowing these prestigious positions will define much of our development efforts in the coming years as we seek to ensure Columbia and Lamont-Doherty's continued legacy as a leader in research and education.

This summer, Lamont had the good fortune to win an internal University selection process for the opportunity to submit proposals to three major new federal stimulus funding infrastructure competitions. Over a period of less than two months, we prepared and submitted proposals requesting approximately 15 million dollars in building construction and renovation funds—all efforts to improve the quality of our research facilities and so enhance the competitiveness of our researchers.

While the economic situation has taken its toll, we hope signs point to an imminent recovery. One of the most difficult decisions we have had to make, as a result of the substantial reductions in income from the Observatory's endowment, was the cancellation of our annual Open House this fall. We have received letters from a number of individuals in the community and feel gratified to hear how much the event means to so many. Maura Muller of Sullivan County wrote to convey her eight-year-old son's enthusiasm after last year's visit. "Your Open House provided the kind of eye-opening, hands-on experience that is necessary for the textbooks to feel real and to help young people put book knowledge into context." This kind of feedback only strengthens our resolve to return to our regular annual cycle for Open House as soon as possible.

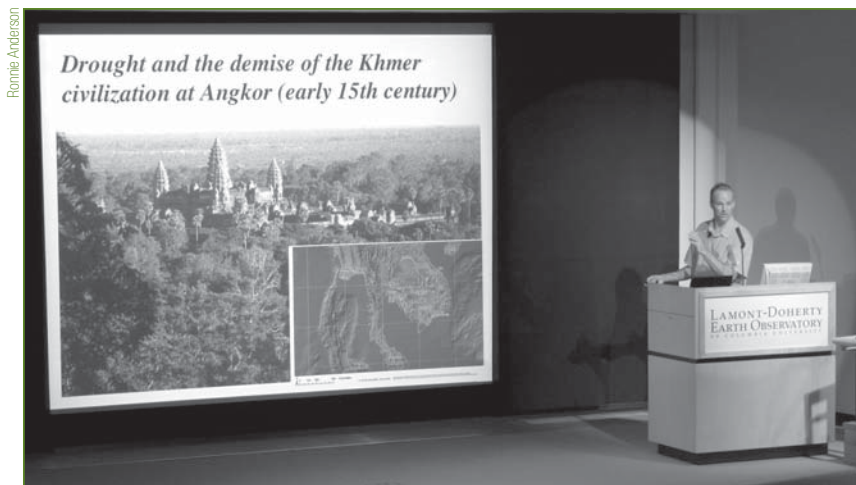
While the economy deteriorated, we maintained our focus on what we do best: generating new knowledge to advance our understanding of the planet and mentoring our exceptional graduate students and postdoctoral investigators. We feature some great alumni achievements in this newsletter. Mohi Kumar, a recent graduate of our earth and environmental science journalism master's program, writes the feature story on Lamont's ongoing research on carbon sequestration. Profiles on alums John Hall, Brenda Ekwurzel, and Kevin Wheeler demonstrate the degree to which our graduates go on to influence the world at large.

If you would like to stay abreast of news from Lamont, I encourage you to sign up on our website for periodic e-newsletters. As always, we value your interest in our science, and we are glad that you remain a valued friend to the Observatory.

Sincerely,

G. Michael Purdy

Spring 2009 Public Lectures



Brendan Buckley shares his findings from the analysis of Asian tree rings.



Michael Studinger answers questions after his talk.



Nicholas Christie-Blick and graduate student Byrdie Renik at the reception following their lecture

Last spring, Lamont-Doherty hosted four weekend lectures open to the public. Topics included a recent expedition to Antarctica to survey a lost mountain range, the way in which tidal marshes serve as recorders of environmental change in the Hudson Valley, continental movement in the western United States, and how the analysis of Asian tree rings helps decipher climate variability and its impact on past civilizations.

If you would like to receive a brochure about the Spring 2010 Public Lectures, send an e-mail to events@LDEO.columbia.edu.

Columbia University Department of Earth & Environmental Sciences
presents the first annual

Arthur D. Storke Memorial Lecture

Estimating Earth's Remaining Mineral Resources: Tectonic Diffusion and Geochemical Cycles

STEPHEN KESLER
Professor of Economic Geology
University of Michigan

May 1, 2009
3:30 p.m.
Monell Auditorium
Reception to follow

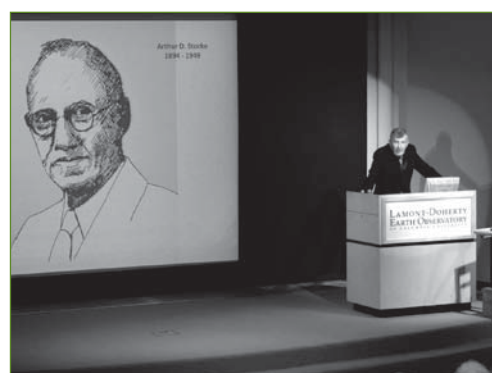
LAMONT-DOHERTY
EARTH OBSERVATORY
THE COLUMBIA UNIVERSITY AT COLUMBIA UNIVERSITY

Arthur D. Storke, a native New Yorker, was born in 1894. By the 1930s, he was an active mining engineer, serving as managing director of a Rhodesian copper mine. During World War II, Storke became Britain's Minerals Advisor for the Allied cause and increased the covert shipment of pitchblende ore out of the Congo—material later used for the development of the atom bomb. Storke met an untimely death in a 1949 plane crash. In his honor, Storke's wife left a bequest to Columbia University to fund the study of Earth's natural resources.

Arthur D. Storke Memorial Lecture



Left: Steve Goldstein (l), chair of the Department of Earth and Environmental Sciences, with Stephen Kesler (r); right: Director Mike Purdy remembers Arthur D. Storke.



In May, Stephen Kesler, professor of economic geology at the University of Michigan, gave the inaugural Arthur D. Storke Memorial Lecture. Kesler's talk focused on methods of predicting Earth's remaining mineral resources.

Update on the R/V *Marcus G. Langseth*



A celebration in Kaohsiung, Taiwan, for the arrival of the R/V *Marcus G. Langseth*

The R/V *Marcus G. Langseth*, a research vessel owned by the National Science Foundation (NSF) and operated by Lamont-Doherty, spent a significant portion of last spring and summer in the waters off Taiwan. Scientists onboard the *Langseth* took part in a joint mapping initiative supported by NSF and the National Science Council of Taiwan as part of the Taiwan Integrated Geodynamics Research (TAIGER) project. Because Taiwan is a subduction zone—its terranes (or crustal fragments) were formed as the Eurasian Plate slid beneath the Philippine Plate—the island is home to frequent on- and off-shore earthquakes. The *Langseth*, with its four 6-km-long streamers, is the only academic research vessel able to perform both deep seismic and wide-swath bathymetric profiling, allowing for both three-dimensional imaging of Earth's interior and depth contour mapping of the seafloor.

Returning to the United States, the ship spent most of September off Washington State surveying the seismic structure of the Juan de Fuca Ridge's northern Endeavour Segment. In October, before heading to the shipyard in November for its biennial maintenance inspection, the *Langseth* will carry out bathymetric mapping in the Gulf of Alaska.

Lamont-Doherty Summer Intern Program 2009

Ronnie Anderson



From left to right: The summer interns at their welcoming reception; Interns Hannah Moore (l) and Peri Sasnett (r) examine fault lineated surfaces.

This past summer, Lamont-Doherty hosted 33 college interns from across the country. Each intern completed an independent research project under the supervision of an LDEO scientist on topics ranging from the formation of mid-ocean ridges to the dating of the Black Sea's submerged shorelines, interplanetary dust particles in the Mediterranean, and the reconstruction of sea surface temperatures. In addition, students attended special lectures, workshops, and fieldtrips.

The Lamont-Doherty Alumni Association Presents:

The Alumni Association Colloquium

FRIDAY, NOVEMBER 20, 2009

SAVE THE DATE

2:45–3:15 p.m., Comer Building, 3rd floor videoconference room

Director Mike Purdy gives “Updates from LDEO”

3:30–5:00 p.m., Monell Auditorium

A Talk by Alumnus Professor Michael Bender (Princeton University)

“Links between CO₂ and Climate throughout Earth History—A Survey”

Light refreshments to follow

Incoming Graduate Students, Fall 2009



Claire Bendersky



Alejandra Borunda



Chen Chen



James De Lanoy



Jordan Garroway



Leonard (Gene) Henry



Ge Jin



Pritwiraj Moulik



Rui Pei



John Templeton



Marc Vankeuren



Stephen Veitch



Hart Webb



Michael Wolovick



Anastasia Yanchilina



Yang Zha

This fall, the Department of Earth and Environmental Sciences welcomes a stellar group of graduate students, 16 promising young scientists whose energy and talents will contribute to the intellectual fabric of the Observatory.

In 2008–2009, **Claire Bendersky** was a Fulbright Fellow studying meteorites at the Muséum national d'Histoire naturelle in Paris. A graduate of Mount Holyoke College, Claire has taken part in projects at the American Museum of Natural History (AMNH), the University of Hawaii, and in La Serena, Chile.

Alejandra Borunda's family voiced surprise when she decided to major in biology—and not writing—at Pomona College. But Alejandra has chosen to combine her passion for both subjects by entering the field of science journalism. This fall she begins a master's degree in earth and environmental science journalism.

At the Ocean University of China, **Chen Chen** received a master's degree in physical oceanography and atmospheric science. Her research approach thus far involves the use of numerical modeling, laboratory experiments, and theoretical work. Chen was a TA this summer at the University of Chicago's Geophysical Fluid Dynamics workshop.

James De Lanoy returns to LDEO after having spent a summer here as an undergraduate research intern studying the flux of CO₂, water, and heat between green roofs and the atmosphere. James holds a dual Bachelor of Science in mathematics and earth science from George Mason University.

Jordan Garroway majored in geological sciences at Cornell and was awarded an internship with the United States Geological Survey. He recently spent the summer as a field research assistant on a project in Argentina, during which the team measured structural features in order to quantify plate movement.

As an undergraduate at Georgia Tech, **Leonard (Gene) Henry** spent the last three years studying Earth's climate systems, reconstructing a flow proxy of the Florida Straits for the past 40,000 years.

Valedictorian of his graduating class at Peking University, **Ge Jin** was active in a seismic research group that collected data in Tibet in the hopes of developing a clearer understanding of the Indian lithosphere currently subducting under southern Tibet.

Pritwiraj Moulik's fascination with geophysics began as a child when he accompanied his father on field surveys for the Oil and Natural Gas Corporation–India. His statistical physics and computational background has led to an interest in modeling earthquake fracture dynamics.

Having received both a BS and MS from Peking University, **Rui Pei** has focused his research on China's early Cretaceous dinosaurs. Rui's fieldwork includes trips to the Gobi Desert and the Shandong Province with researchers from AMNH.

While at UNC–Chapel Hill, **John Templeton** took part in a three-month geology research expedition that brought him to the Owens Valley of Eastern California and to parts of Sierra Nevada. He has also hiked the entire Appalachian Trail.

Marc Vankeuren plans to study extensional tectonics at Lamont—a topic that has intrigued him from the time he was a child growing up on a Navajo reservation surrounded by sandstone cliffs and the plains of volcanic cores.

Stephen Veitch completed a BA in anthropology and history from Carnegie Mellon, but subsequent course work in physics, mathematics, and glacial mechanics convinced him to pursue a graduate degree in glacial seismology.

Hart Webb holds a master's degree in astronomy from Wesleyan, where she wrote her thesis on extragalactic astronomy. She has studied in Tanzania, and has interned at the Jane Goodall Institute.

At Bowdoin College, **Michael Wolovick** had a fellowship to study the surface currents in Maine's Casco Bay, but he lists planetary science and Earth's deep structural and geothermal processes among his other interests.

Anastasia Yanchilina emigrated from Russia as a child and is drawn to the topic of climate change, in part, because of its relevance to issues in current global politics. She has participated in a notable amount of research, including a summer spent at the Woods Hole Oceanographic Institution under the mentorship of Lamont's Jerry McManus.

Yang Zha claims his enthusiasm for geophysics grew from hiking in more than 30 Chinese provinces, where he witnessed his country's astounding glaciers. Having concentrated in physics as an undergraduate, Yang would like to apply physical methods to the study of Earth processes.

Awards 2009



Dale Chayes

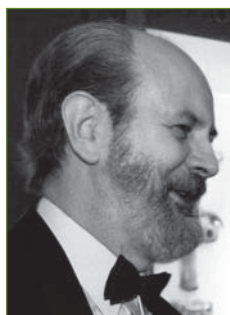


Kim Kastens



Steven L. Goldstein

Wallace Broecker (top, center) with fellow honorees at Cambridge University



Paul Richards



Taro Takahashi



W. Roger Buck



Peter deMenocal



Karen Wovkulich, Jenny Arbuszewski, and Janelle Homburg

Ronnie Anderson

Several Lamont scientists and graduate students have been recognized externally for their insights and contributions to the field of science.

The April issue of the journal *Deep Sea Research II* was dedicated to geochemist **Taro Takahashi** for his research on ocean carbon cycles. Citing Takahashi's pioneering work in carbon cycle dynamics—used by climate modelers everywhere to predict future carbon dioxide levels—the journal's editors also acknowledged Takahashi's legendary “graciousness and humility.”

It is a point of pride when any of our accomplished graduate students receives the Outstanding Student Paper Award at the annual American Geophysical Union (AGU) conference. This spring we learned that the scientific union selected three of our students, **Karen Wovkulich**, **Jenny Arbuszewski**, and **Janelle Homburg**, for this honor!

Cambridge University awarded climatologist **Wallace Broecker** an honorary doctorate in June. The degree was conferred to nine other individuals, including Bill and Melinda Gates, Amartya Sen, and Baroness Williams of Crosby.

At their spring conference in Toronto, AGU presented **Kim Kastens** with the Excellence in Geophysical Education Award. After witnessing many of her Columbia undergraduates struggle to visualize three-dimensional Earth processes, Kastens developed innovative ways to teach spatial concepts and other scientific phenomena to students of different ages.

The Seismological Society of America announced they plan to award **Paul Richards** the Harry Fielding Reid Medal at their 2010 meeting. The award recognizes outstanding contributions in seismology and earthquake engineering.

W. Roger Buck, associate director of Lamont's Marine Geology and Geophysics division, and **Steven L. Goldstein**, geochemist

and chair of the Department of Earth and Environmental Sciences, have been named AGU Fellows. The honor is conferred on only 0.1 percent of AGU's more than 50,000 members.

St. Lawrence University presented several graduates of its geology department with honorary degrees this spring. The list of honorees includes two current Lamont-Doherty researchers (paleoclimatologist **Peter deMenocal** and engineer **Dale Chayes**) and two former researchers (paleoceanographer Miriam Katz and oceanographer Richard Fairbanks).

Lastly, the new **Gary C. Comer Geochemistry Building** won a number of awards in 2009, including the 2009 Lab of the Year prize, cosponsored by *R&D Magazine* and the Scientific Equipment and Furniture Association, and a 2009 Sustainable Design Award, cosponsored by the U.S. Environmental Protection Agency and the Boston Society of Architects.

Sixth Excellence in Mentoring Award

An overwhelming number of undergraduates, PhD students, and early career scientists submitted testimonials in support of **Alexey Kaplan**, the winner of this year's Excellence in Mentoring award. Comments referred not only to Kaplan's endless enthusiasm, generosity, and wit, but also to his exceptional patience and encouragement. One individual stated, "Hardly a week went by in my first years at Lamont when I did not stop by his office with a list of questions. I am afraid I often interrupted him from more pressing matters, but he never indicated as much." Another wrote, "I recall a very snowy day last year when the shuttle was canceled and I was trying to finish our first paper. Alexey schlepped 15 blocks to my neighborhood just to meet me in a coffee shop and discuss some final changes prior to submitting."

The three other nominees, Juerg Matter, Doug Martinson, and Nicholas Christie-Blick, received glowing endorsements as well.



Above: Director Mike Purdy congratulates Alexey Kaplan.
Right: The four nominees (l to r): Juerg Matter, Doug Martinson, Alexey Kaplan, Nicholas Christie-Blick



"In Greek mythology, Mentor was the friend of Odysseus and tutor of Telemachus. His name is proverbial for a faithful and wise adviser."
—Columbia Encyclopedia

Tree Rings, Climate Change, and the Press

By Kevin Krajick, Senior Science Writer, The Earth Institute

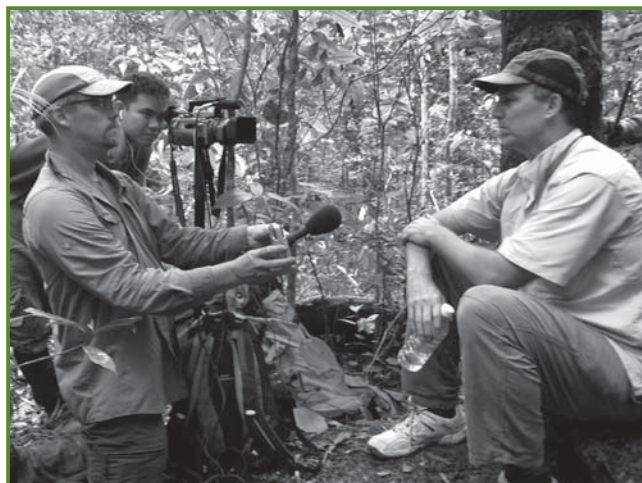
Some of Lamont's most exciting work actually takes place elsewhere: at researchers' far-flung field sites. Often, the location is exotic, the work is nonstop, and the experience is unforgettable. What better way to make science come alive? Our media team has started covering expeditions firsthand and encouraging journalists to come along.

A good opportunity came this February when Brendan Buckley of LDEO's Tree Ring Lab organized a conference on climate change in the Mekong Delta region—a landmark in a five-year project to unravel the workings of the Asian monsoon. Held in the highland city of Dalat, Vietnam, this was followed by an expedition to core ancient *po mu* trees in nearby Bidoup Nuiba National Park.

After we called media across Asia, the conference was covered by the Associated Press, Reuters, *The Economist*, and *Science*. But the real fun was the five-day camping trip to Bidoup Nuiba. This involved strenuous hiking into a mile-high cloud forest to hunt for old *po mu*, a type of pine that survives 1,000

years or more on remote ridge tops. These Methuselahs are not only awesome to encounter; they hold climate records from the days of long-vanished civilizations. Along for the trip were Andrew Nelson, photographer for the *Christian Science Monitor*, and Dinh Hau, cameraman for Associated Press T.V. They kept up, lugged heavy equipment, and—most importantly—came back with the story.

Possibilities for other such trips are endless. In coming months, we have our eyes on places like Iceland (Juerg Matter: a carbon sequestration pilot project); New Zealand (Kevin Griffin: tree respiration and the carbon cycle); Ethiopia (W. Roger Buck: workings of the great African rift); and the Sea



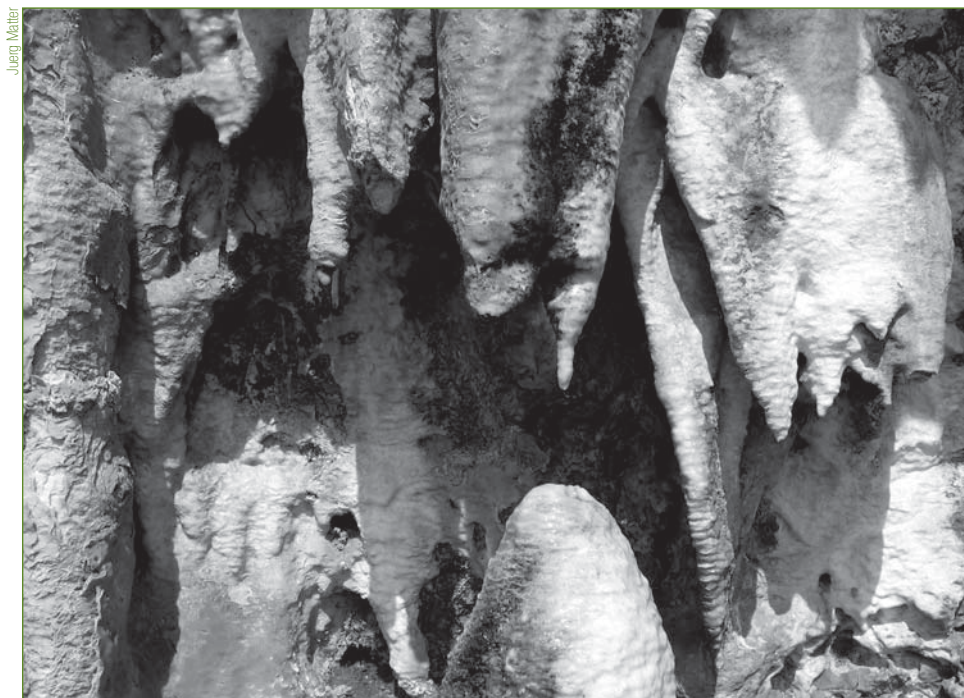
Researcher Brendan Buckley is interviewed by journalists while in Vietnam.

of Marmara (Donna Shillington: imaging of earthquake faults).

To view an audio slideshow on Buckley's Asian tree-ring work, visit the LDEO website: www.LDEO.columbia.edu

Scientists at Lamont-Doherty Develop Methods to Transform CO₂ Emissions into Solid Rock by Mohi Kumar

Scientists studying climate change are projecting increasingly dire scenarios: Alpine glaciers may be gone within the next few centuries; Arctic sea ice is rapidly shrinking and may even disappear. Expect severe droughts, heat waves, flooding, and more intense hurricanes in the near future.



Stalactites composed of calcite (CaCO₃) growing at an alkaline spring within mantle peridotite in northern Oman

Humans emit nearly 30 billion tons of carbon dioxide (CO₂) per year—7 billion tons from the United States alone. These emissions are rapidly altering the environment to the point where some scientists believe that rising temperatures and shifting climate patterns may irreparably damage life on Earth.

While assessments of potential variability are often based on surveys and models of the atmosphere, one solution to future problems may lie underground. Scientists at Lamont-Doherty Earth Observatory are exploring methods to sequester carbon emissions. Unlike typical efforts that involve storing liquid or gaseous CO₂ in saline aquifers or depleted oil wells, which come with inherent risks of leakage, Lamont-based projects

seek to engineer more stable CO₂ repositories. These projects aim to take carbon emissions and transform them into calcium and magnesium carbonates—minerals that are solid, benign, and able to be permanently stored away.

To accomplish this, Lamont geoscientists David Goldberg, Peter Kelemen, and Juerg Matter are studying the chemical reactions involved when calcium- and magnesium-rich silicate rocks are exposed to water that contains dissolved CO₂. When CO₂ is dissolved in water and injected into targeted rocks, chemical processes transform these rocks into solid carbonates, thereby soaking up substantial CO₂ emissions.

But the rate of such reactions, and whether the reactions can be artificially sped up in time

to avert the adverse effects of climate change, is not fully known.

WANTED: DARK ROCKS

To learn more, these scientists are conducting chemical weathering experiments on mafic rocks, which have high concentrations of calcium and magnesium silicates.

Dark-colored, rich in iron and magnesium, but poor in quartz, mafic rocks originate as magmas deep within the earth. Some ooze out as basalts from ocean ridges, rifts, and hot-spot volcanoes such as those on Hawaii; others crystallize within the crust to form rocks known as gabbro and dolerite.

Earth scientists at Lamont searching for mafic rocks need not look far. Stretching nearly 80 kilometers from Staten Island through New York's Rockland County, the Palisades Sill is a 200 million-year-old dolerite rock unit that is quite literally in Lamont's backyard.

During the late 1990s, Goldberg and Lamont geochemist Taro Takahashi wrote a proposal to do a small-scale injection experiment into the sill. With funds from Columbia University's Earth Institute, they hired Matter, then a postdoc, for help with hydrological aspects of the experiment.

The plan was simple: Inject water saturated with dissolved CO₂ into the sill via a borehole. Acidic due to the presence of CO₂, the injected water attacks the surrounding rock, dissolving it. The dissolved particles of the surrounding rock are then free to bond with the water's carbonic acid molecules and so begin to form calcium and magnesium carbonates. These carbonates rain out of the solution as solids, thus sequestering the CO₂.

"It's called a push-pull experiment—we pushed fluid in, and we let it incubate," said Goldberg. "We then pulled the water back out incrementally over time and analyzed its geochemistry." As time passed, the concentration of acid in the water began to wane, suggesting that the dissolved rock was recombining to form new minerals.

But how fast does the CO₂ break down rocks? "That's what we really wanted to know," Matter explained. Preliminary answers show that the reaction was fast enough to observe but slow enough that it could take decades to centuries to

continued on page 8



Left: Veins, composed of carbonate minerals filling cracks in mantle peridotite, form when ground water containing CO₂ combines with the peridotite's magnesium and calcium, essentially prying apart the pre-existing rock. This creates new pathways for fluids bringing CO₂ to react with newly exposed fracture surfaces in a positive feedback process.
Right: Area of the Iceland pilot study: the Hellisheidi power plant near Reykjavik



continued from previous page

dissolve the mafic rocks and form carbonates in that location. Would a more voluminous injection of CO₂ affect the reaction time? The Palisades experiment involved injecting carbonated water, but would the same rate hold for injections of pure compressed CO₂ into rock? “The results made one thing clear,” Matter said. “It was time to scale up the experiment.”

THE BIGGER, THE BETTER

In response, Matter and Goldberg joined forces with scientists at the Pacific Northwest National Laboratory (PNNL). PNNL researchers are surrounded by mafic rocks that blanket more than 150,000 square kilometers of the Columbia River Plateau. After completing surveys of a section of these basalts near the city of Wallula WA, Goldberg, graduate student Natalia Zakharova, Matter, PNNL researchers, and others plan to inject 1,000 tons of compressed CO₂ deep into the nearby ground in late fall 2009.

Matter and his colleagues from Lamont are also involved in a carbon sequestration project in Iceland, in partnership with Reykjavik Energy, University of Iceland, and France's University of Toulouse. Beginning in the winter of 2009–2010,

about 2,000 tons of CO₂, collected from the emissions of a nearby geothermal power plant, will be dissolved in water and injected into shallow basalt over the course of nine months.

Both projects seek to determine the efficacy of larger-scale injections. Though these are important first steps to assuring the public of the viability of carbon sequestration, to seriously counteract the effects of climate change, scientists must think bigger—injecting 2,000 tons of CO₂ here and there is only a minuscule fraction (about one ten-millionth) of the annual amount of CO₂ released by humans.

“We’re emitting gigatons of CO₂ per year,” Goldberg said. “If we want to put a dent in that, we’d need to contemplate very large-scale injections.”

According to Goldberg, the ocean could accommodate such injections. The amount of basalt on the ocean floor is vast, easily accessible from the coast, formed of very porous lavas, and surrounded by very reactive seawater. But perhaps more importantly, overlying the layers of basalts are blankets of microscopic skeletons that fall to the ocean floor as organisms die. These skeletons accumulate and cement together over time, sealing the basalt layers underneath.

“Ocean basalts are exactly what we’re looking for—a wide open injectable reservoir, with a nice impermeable sediment cap,” Goldberg said.

“Even if there’s a little leak, it’s under 3,000 meters of water—it’s not going anywhere. At that depth, the density of CO₂ is greater than that of water, so liquid CO₂ would tend to stay put.” All these traps for the CO₂ give the system time to form mineral carbonates after injection.

THINKING GREEN, AS IN OLIVINE

While Goldberg ponders the ocean's capabilities, Kelemen and Matter are exploring the carbon sequestration potential of peridotites. Peridotites are ultramafic—their composition is almost wholly composed of mafic minerals. Loaded with bright green olivine and dotted with dark pyroxene, peridotites are rocks from Earth's interior that have been thrust to the surface. They also react with CO₂ to form mineral carbonates.

“The rate of reaction depends on temperature and pressure,” explained Kelemen. According to Kelemen's preliminary calculations and experimental data from other laboratories worldwide, peridotite reacts with CO₂ to form carbonates hundreds of times faster than basalt. Nonetheless, natural reactions at Earth's surface may still take millions of years to solidify enough carbon to mitigate climate change.

To quantify the natural rates through which peridotites weather into solid carbonates,



White deposit of carbonate minerals (travertine) at an alkaline spring in northern Oman. The white deposits, composed mainly of the mineral calcite (CaCO_3), form when calcium from the peridotite, dissolved in spring waters, combines with atmospheric CO_2 on the surface.

Kelemen and Matter are conducting fieldwork in Oman. Dotted with alkaline springs that deposit solid carbonate minerals, Oman's ultramafic rocks naturally soak up about 2,000 tons of atmospheric CO_2 per cubic kilometer of peridotite per year. But don't be misled by this seemingly large number, warned Kelemen. "This is 10 million times lower than the rate of human input of CO_2 into the atmosphere."

However, experiments indicate that elevating the rock's temperature to 185°C increases this rate by roughly a million times. If rocks could be preheated, Kelemen estimates that uptakes could reach a few gigatons of CO_2 per cubic kilometer of rock per year. Even at 10 percent of this maximum uptake rate, the process could play a significant role by sequestering 5 percent or 10 percent of anthropogenic emissions per year.

At elevated temperatures and pressures, the reaction of olivine with CO_2 is exothermic—it gives off heat. Through model calculations, Kelemen and Matter found that when peridotite reaches 185°C , the heat released by the reaction of CO_2 and olivine is able to preserve this temperature, sustaining the reaction without the need for additional heat, Matter explained.

But heating rocks on the ground to high temperatures is not an easy task. "You could do it

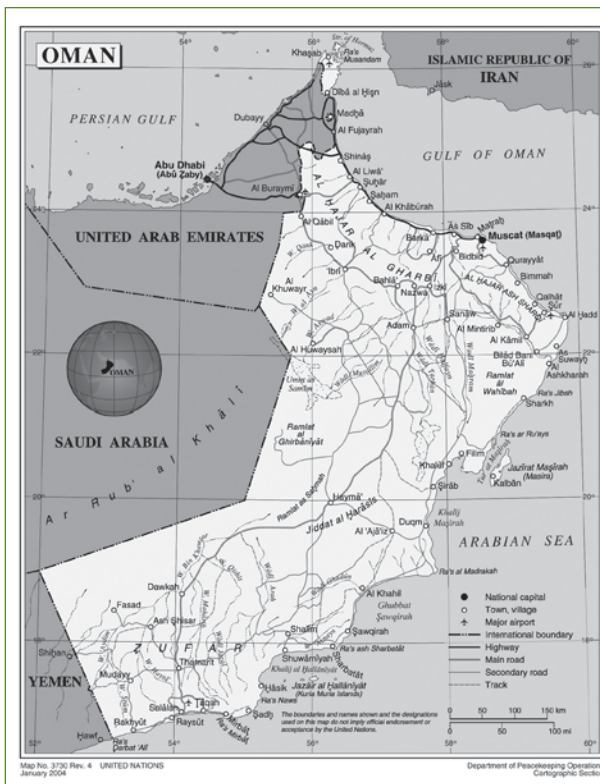
with steam, or you could inject hot CO_2 ," Matter speculated. Or you could find an environment that's already hot. In Northern California, near Mt. Shasta, peridotite rocks at the surface have roots that extend underneath the Mount Shasta volcano. "There you may have rocks that are already at high temperatures near the surface," Kelemen noted.

Although ultramafic rocks like peridotite are rarer on Earth's surface than basalt, a recent report released by Columbia University's Earth Institute and the U.S. Geological Survey shows that in the continental United States alone, almost 16,000 square kilometers of ultramafic rocks may be useful for carbon sequestration.

LOOKING TO THE FUTURE

According to the U.N. Environment Programme's *Year Book 2009*, "The changing climate is pushing many Earth systems towards critical thresholds that will alter regional and global environmental balances and threaten stability at multiple scales." Governments, heeding such warnings, are scrambling to take action, but solutions will require a great deal of basic scientific research.

In response, Lamont has positioned itself at the forefront of the endeavor to develop answers.



But Goldberg, Kelemen, and Matter know that their work represents mere baby steps. For carbon sequestration to succeed, it needs to be conducted on a massive scale and be economically viable. A large part of the expense of sequestration—nearly 85 percent—will involve developing the infrastructure to capture the emissions, explained Goldberg. "A lot of people need to buy into this—government, industry, the public."

Drawbacks abound. Pumping CO_2 into the ocean basalts may prove expensive. And scientists may be unable to speed up the reactivity of peridotites at an acceptable cost. Nonetheless, researchers agree that no single mitigation strategy is enough to stave off the dire climate scenarios predicted. "Sequestration is just one in a portfolio of solutions," Matter explained. "It may contribute to emission reduction, but you still have to increase fuel efficiency and explore renewable energy such as solar and wind."

"We're taught in this society to pick winners and look for the best solution, but in this case that's not the right way to think about it," suggested Kelemen. "We need to pursue a whole lot of options in parallel—if any one strategy solves even just 5 percent of the problem, when all are taken together we might actually succeed."

■ Letter from Steve Cande, Alumni Board President



Steve Cande

Dear Alumni and Friends of Lamont,

Let me begin by introducing you to the newest members of the alumni board: geochemists Robert Kay (PhD '70) and Louisa Bradtmiller (PhD '08). A warm welcome to you both.

I imagine that I am like many of you who do not have a chance to get back to Lamont very often (for me it's distance; I live in Southern California) but would like

to stay more in touch. To this end, I highly recommend spending a couple of hours browsing the Lamont website, which does an excellent job of giving us a feel for the research being done at the Observatory today. If one wants to know the latest findings on climate change or what's beneath all that ice in Antarctica, one can get a rapid education here. There are links to interviews with Wally Broecker on the realities of global warming and a lecture by Robin Bell in which she describes a recent expedition by Lamont scientists to map a mountain range buried deep beneath the East Antarctic ice sheet.

Be sure to check out the alumni section of the website as well. While there, you can join the Lamont-Doherty alumni and friends group on **Facebook**, which is frequently updated with links to national news articles featuring Lamont scientists. Want to network with other Lamont graduates? Join the LDEO alumni group on the professional online networking site **LinkedIn**.

In addition, I found that the Lamont website conveys how important outreach and public education have become to the life of the Observatory, a sea change from my days at Lamont in the early 1970s. Online one can watch any (or all) of the Public Lectures in which Lamont scientists describe their work to a general audience. As media outlets cut back their science reporting, it will become incumbent upon us to communicate our research (and its importance) to nonspecialists. On this topic, I think you will find the following Q & A with alumna Brenda Ekwurzel, staff climate scientist with the Union of Concerned Scientists, particularly compelling.

This year marks Lamont's 60th anniversary. In browsing the website, one is reminded of the remarkable role the Observatory has played in the history of the geological and oceanographic sciences. Founded in 1949 by Doc Ewing and a small group of pioneers who installed seismometers in the cellar and abandoned swimming pool of the Lamont estate, it has evolved into a major education and research institution—an indisputable leader in the quest for insight into the workings of our planet and an important communicator of the challenges we face.

I look forward to catching up with a lot of you at the Lamont annual AGU alumni meeting and reception on December 15.

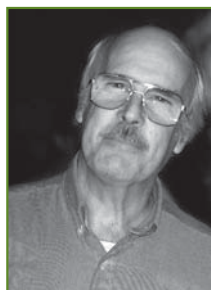
Sincerely,

Steven C. Cande, PhD '77
Alumni Board President

New Alumni Association Board Members



Louisa Bradtmiller



Robert Kay

Louisa Bradtmiller (PhD '08) begins an assistant professorship this fall in the Environmental Studies Department at Macalester College. She spent the last year as a postdoctoral fellow at the Woods Hole Oceanographic

Institution, studying the behavior of uranium-series elements in seawater and ocean sediment. Robert Kay (PhD '70) has been a professor of geological sciences at Cornell University since 1976. His studies concern the formation, modification, and destruction of Earth's crust.

SAVE THE DATE

AGU Alumni Reception

TUESDAY, DECEMBER 15, 2009
6:30–8:30 p.m.

Join us beforehand for the
General Alumni Meeting,
5:30–6:30 p.m.





Alumni Association Board of Directors

President

Steven C. Cande
Scripps Institution of Oceanography
La Jolla CA

Directors

Louisa Bradtmiller
Macalester College
St. Paul MN

Mary Ann Brueckner
Palisades NY

Millard (Mike) Coffin
National Oceanography Centre
Southampton UK

Stephen Eittreim
Palo Alto CA

Emma (Christa) Farmer
Hofstra University
Hempstead NY

W. Arnold Finck
Palisades NY

P. Jeffrey Fox
Texas A&M
College Station TX

Robert Kay
Cornell University
Ithaca NY

Rudi Markl
Rye NY

Arthur McGarr
Palo Alto CA

Gregory Mountain
Rutgers University
New Brunswick NJ

Joyce O'Dowd Wallace
Goshen NY

Michael Rawson
Washington Township NJ

Q & A with Brenda Ekwurzel, PhD '98

Brenda Ekwurzel wrote her PhD thesis on Arctic Ocean isotope geochemistry. As a postdoc at Lawrence Livermore National Laboratory in California, she conducted noble gas hydrology research. She then joined the faculty at the University of Arizona, with appointments in both the Geosciences Department and the Department of Hydrology and Water Resources. Ekwurzel is currently a staff climate scientist with the Union of Concerned Scientists (UCS).

Editor: You held a faculty appointment at the University of Arizona, and you have conducted high-level research. What brought you to Washington to work in policy?

I reached a personal tipping point—I was appalled by the huge gap in understanding between the published science on climate change and public discourse in the U.S. I made the personal calculation that the consequences accruing with each year of inaction warranted my shift into the public arena. I was typical of many scientists who, after writing grant proposals, managing research groups, mentoring students, reviewing papers, and serving on panels, find little time for outreach despite having benefited for years from public tax dollars that funded their careers.

So in 2004 I dramatically changed that time allotment. I took a job as a staff scientist with the UCS in their Washington DC office.

Editor: Nowadays, one often hears the words “climate” and “economy” linked together in public discourse. David Owen recently wrote in *The New Yorker* that “the world’s principal source of man-made greenhouse gases has always been prosperity.... [S]huttered factories don’t spew carbon dioxide.” Is a period of economic crisis the right time to tackle carbon emissions? Or will success in one area preclude success in another?

Well, recessions aren’t a strategy for reducing emissions. There’s this false choice between the economy and the environment that a lot of us have in our heads. We’re now realizing as a country that the oppositional relationship between the economy and the environment is just not true. Many of the solutions to climate change are things that benefit the economy, like fuel-efficient cars that save people money on gas, or people in the Rust Belt going to work building wind turbines.

And a lot of companies like Dow Chemical are reducing emissions and saving money. One program



Herman Farmer

to clean up their emissions costs \$50 million and is yielding \$2 billion in annual savings. That’s helping Dow’s bottom line during this recession.

Part of what we have to realize is that continuing down the same path that relies on conventional coal and oil to drive our economy isn’t a viable economic or environmental option—those sources are limited, they’re hurting our planet, and we need to think long term about how we get to a cleaner economy.

Given the high cost of inaction—adapting to public health threats, sea level rise in coastal cities, etc.—how can we not address global warming now?

Editor: In 2007 you warned (presciently) that ignoring global warming is “as irresponsible as not making payments on a high-interest credit card.” This spring, *New York Times* columnist Thomas Friedman wrote, “[I]t’s now obvious the reason we’re experiencing a simultaneous meltdown in the financial system and the climate system is because we have been mispricing risk in both arenas.” Have we learned any important behavioral lessons from this year’s economic crisis?

If as a nation we had grown our research, development, and deployment of climate-friendly energy options from the moment we had our wake up call during the “energy crisis” of the early 1970s, the U.S. would likely be closer to decoupling economic growth from the kind of energy that

continued on page 12

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harms our climate and consumer budgets. Perhaps now after the recent severe worldwide financial downturn, people may be more aware of risky decisions that can cause personal as well as global harm that may play out in the future, long after the risky behavior has occurred.

Editor: You've expressed optimism that many of the solutions to climate change will have profound benefits for public health and energy security. Can you explain?

The economic and health benefits of reducing our reliance on fossil fuel energy are often overlooked when discussing the cost of deploying solutions to climate change. Take a look at coal. It's dirty. When we burn it, we put particle matter, mercury, and other toxic emissions into the air. My colleagues have calculated that we could avoid using 11 billion tons of coal over the next two decades with smart policies in place. That could save approximately 280,000 lives and avoid 444,000 pollution-related heart attacks.

The national security benefits of weaning our country off of oil are implicit when the U.S. currently imports around 6 million barrels of petroleum products a day from OPEC countries. The Department of Defense is actively looking for fuel alternatives as a majority of their budget is devoted to fuel purchase, transport, and the cost of personnel deployed to escort, protect, and maintain the fuel supply lines.

Editor: Do you get the sense that the Obama administration will make an effective ally in the coming years?

Obama administration officials repeatedly refer to the connection between energy, economy, and climate. That's important, because this isn't just about climate change—it's about our economy and our health and our position in the world.

Editor: If given the chance, what specific policies would you advise Obama to propose?

I would recommend the implementation of a swift and deep declining cap on emissions and new standards to improve energy efficiency in all economic sectors. We need cost-effective solutions to meet our growing energy demands that will simultaneously prevent the worst consequences of climate change. This will require investing in the National Science Foundation and other federal agencies. Examples include NOAA tracking the most vulnerable U.S. locations to improve local planning and preparedness, or the Department of Energy investing in large-scale energy demonstration projects.

Editor: You testified to the Committee on Ways and Means in February of this year. What kind of feedback did you receive from members of Congress?

It was an honor to testify before Congress. The Ways and Means members were preparing climate legislation and wanted to learn more about the science. These members of Congress are typically dealing with finance and tax issues, so a lot of their interest focused on how science informs the question of a carbon tax vs. a cap on emissions. I testified that UCS would prefer a cap, because a tax wouldn't guarantee a given level of emission reductions.

Editor: What is the UCS's strategy in communicating the science of climate change? *New York Times* science writer Andrew Revkin suggested in a February 2009 article that "hyperbole is an ever-present temptation on all sides of the [global warming] debate." How do you convey concern without sacrificing the integrity of the research?

Historically, groups that oppose climate action routinely cherry pick the science and fund campaigns to confuse the public. So it's not a temptation for them, it's really business as usual. Thankfully, that's become a less tenable position, and those front groups have lost a lot of credibility in recent years.

That said, UCS always wants to bring the best science to bear, so we pay special attention to

how we talk about research. UCS has a policy of asking scientists to review our statements to ensure that our efforts to make their research more accessible has not affected its accuracy. This builds trust with congressional staff, who repeatedly return with requests for further evidence.

With the sort of climate science findings that are coming through, there's really no reason to exaggerate.

Editor: Scientists often lament the fact that the nuances in their work are ignored in public discussions. Are nuances simply too difficult to turn into sound bites?

I think what UCS does effectively (and what a lot of scientists are learning to do, too) is to communicate about science in a way that will help people understand the significant points. Metaphors such as "carbon dioxide builds up in the atmosphere like bad credit card debt" are ways to put a picture in people's heads that lets them grasp the concepts and math that scientists are dealing with.

UCS offers a lot of advice on how to communicate with reporters in its book *A Scientist's Guide to Talking with the Media*. Reporters have to communicate with the general public. It's the scientist's job to translate scientific nuance to the reporter. We tell scientists and other experts to distill what they're trying to convey to its essence. You can communicate simply without being simplistic and without abandoning your scientific credibility.

Editor: Have you found your current position rewarding?

To my surprise, I did not abandon what I loved most about my academic life—sharing research discoveries with students and colleagues. Now I share this information with a larger group.

I enjoy the challenge of providing just enough context so the public will grasp cutting-edge research, thereby advancing our collective understanding. It is my hope that whatever decisions policymakers, business leaders, and citizens make, the process will involve more consideration of the scientific evidence.

"This isn't just about climate change—it's about our economy and our health and our position in the world."

Alumni Profile: John K. Hall, PhD '70

After completing a doctorate in marine geophysics at Lamont, John K. Hall immigrated to Jerusalem with his Israeli wife and spent 35 years at the Geological Survey of Israel before retiring in 2005. A self-described “five times over Mayflower Yankee,” Hall has devoted much of his career to mapping the bodies of water in and around the Middle East. In 2000, Hall purchased his own private multi-beam (swath) sonar, which he has used to map the bathymetry of the Mediterranean and the northernmost Gulf of Elat. As vice-chairman of the International Bathymetric Chart of the Mediterranean project, Hall has been a longtime vocal proponent of assembling a 0.1° grid of the Mediterranean and Black Seas.

Hall's instrumental role in obtaining seismic and bathymetric data from these areas, as well as the Red, Dead, Caspian, and Black Seas, Lake Baikal, and the Sea of Galilee (the “puddles” as Hall jokingly refers to them), stems from a spirit of curiosity, determination, and adventure that has similarly marked his latest endeavor: the mapping of the inaccessible Alpha Ridge, located in the central Arctic Ocean.

If the destination is not entirely new for him (Hall conducted his thesis research on Fletcher's Ice Island), his mode of transport certainly is. To reach this nearly impenetrable part of the Arctic, Hall has purchased and equipped a hovercraft, the R/H *Sabvabaa*. As a graduate student, Hall speculated that the Alpha Ridge (which rivals the Himalayas in size) was a fossil spreading ridge—a region once active due to mantle convection. Subsequent findings by others have shown this to be incorrect, but the ridge, which could conceivably reveal the origin of the Arctic's main Amerasia Basin, remains a mystery.

Over the years, another Lamont alumnus, Yngve Kristoffersen (PhD '77), would review Hall's early published seismic records of this area. Something in the data puzzled Kristoffersen, so in 2004 he invited Hall to the University of Bergen to discuss the records. The seismic evidence showed a severely disturbed area some 200 by 600 kilometers, suggesting an intriguing scenario: the possibility that an asteroid hit the Alpha Ridge several million years ago. Hall and Kristoffersen have decided to return to the region to test this hypothesis further. In the process, they also plan to deploy autonomous drifting seismic reflection buoys, along with echo-sounding buoys developed under the Seafloor Soundings in Polar and Remote Regions project.

“To get into an area inaccessible to icebreakers—or reachable by plane only in spring—is pure chutzpah.”

Will Fessenden Jr.



The R/H *Sabvabaa*

“The task is to figure out the real message in the data—a dream challenge for any scientist. So far, we have mostly met shaking heads, which just makes it more fun,” Kristoffersen explained.

Hall and Kristoffersen have outfitted the *Sabvabaa* (the name, in Inupiaq, means “flows swiftly over it”) with the latest technological instruments. The hovercraft, with a 2,200 kg payload, boasts an electromagnetic device for underway ice thickness measurements, a CTD winch that measures the water's salinity and temperature to depths of 500 meters, a light-weight corer, a rock dredge and winch with 3,000 meters of Kevlar rope, a 20 in³ airgun and six-channel streamer, a CHIRP sub-bottom profiler and 12kHz echo sounder, GPS navigation, satellite, marine and aircraft communications, FLIR (infrared) thermal imaging, small computers, and a rooftop solar panel. The team will rely on icebreakers to deposit caches of diesel fuel to keep the hovercraft operational. The craft can travel more than 500 nautical miles with full payload without refueling. Its base for these expeditions is Longyearbyen, Svalbard, at 78°N.

The *Sabvabaa* is highly mobile and economical. While the American icebreaker *Healy* costs \$9,000 an hour, the hovercraft can operate for more than a week on that amount. Over the summers of 2008 and 2009, the *Sabvabaa* completed nine weeklong trips onto the permanent icepack as part of the Norwegian International Polar Year project “Classroom on the Ice,” which paired researchers with high school students. These shorter trips have left Hall and Kristoffersen very optimistic that the hovercraft will be able to tackle the Alpha Ridge. So far, the craft has traveled 6,500 nautical miles on Arctic missions.

Hall's return to his Arctic roots began during a year's sabbatical in 2003 as a Visiting Scholar

at the University of New Hampshire's Center for Coastal and Ocean Mapping (CCOM), headed by multibeam guru Larry Mayer. While there, Hall participated in two of Mayer's cruises aboard the *Healy*, generating maps in support of a future U.S. submission under the United Nations' Law of the Sea. With the Arctic ice cover shrinking, interest in acquiring exploitable marine areas is peaking. (A May 2009 *National Geographic* article entitled “Arctic Landgrab” depicts this international activity and illustrates the areas mapped by CCOM.)

By the time this piece goes to print, Hall will have completed his fourth (and Mayer's fifth) *Healy* cruise, a joint seismic operation with the Canadian icebreaker *Louis S. St-Laurent*. These cruises, to areas Hall traversed on the drifting ice station more than four decades ago, have fortified his belief that the hovercraft, operating without time and financial constraints, offers the best chance to get “boots on the ground.” The *Sabvabaa*, with a crew of two or three, has much of the capability that Lamont's *Vema* had in the 1960s.

When he is not at sea, Hall is on the editorial advisory board of the journal *Hydro International*. He has also coauthored two books—one on the Russian swath mapping of the eastern Mediterranean and another on the geology of the Levant. This past summer, Hall was inducted into the Norwegian Academy of Sciences and Polar Research. Hall views his proactive swath mapping and hovercraft purchase as having been made possible by his grandfather's successful career as head of the American Chicle Company.

In his nominal retirement, Hall can look back on a long (if far from finished) career. To a great extent Hall credits his years at Lamont for shaping the course of his research. “We did an awful lot of pioneering then, and I believe that I have faithfully continued in this tradition.”

Alumni Profile: Kevin Wheeler, PhD '07

These days, Kevin Wheeler, who grew up in the mountains of Virginia and later received his degree at Lamont in experimental petrology, finds himself a long way from home. Since April 2009, Wheeler has lived and worked in Iraq's Red Zone, dividing his time between Baghdad and Erbil, the capital of the Kurdish region. Employed by the Kaizen Company, a subcontractor for the United States Agency for International Development (USAID), he is part of an international team assisting Iraqi ministries implement new initiatives to improve operations. Wheeler's role has been to develop and support internal consulting groups at the Ministry of Electricity, the North Oil Company, the North Refining Company, and the Refined Products Distribution Company.

Before his relocation to Iraq, Wheeler spent time in the Middle East, studying Arabic in Syria for a few months and living briefly in Jordan. The chance to work in Iraq appealed to him because "the country is such an exciting and dynamic place with a lot of opportunity to make a real impact." His group supports the ministries as they identify and pursue organizational improvements. Examples of such activities include creating clearly defined job descriptions, articulating the mission of the organization, implementing IT systems, and improving budget and procurement processes. The challenge is formidable. "Historically, the Iraqi governmental system has been very hierarchical, with a strong resistance to change and little incentive for initiative," Wheeler explained. He stressed that the sea change USAID envisions will take time. "There is no way to force this kind of cultural transformation."

When asked whether Iraqis were receptive to American advice, Wheeler admitted that he and his colleagues must be subtle in their approach. Consultants work hard to ensure that all activities are Iraqi-driven; Iraqi employees identify the problems they would like to rectify and they oversee the entire transition process. Many ministry officials seem to value American support, but Wheeler has come to realize that "they want to act on their own terms, in their own way, and on their own time line." He is heartened by the fact that the leadership at the Ministry of Oil (MoO) has invited Wheeler and his colleagues to expand

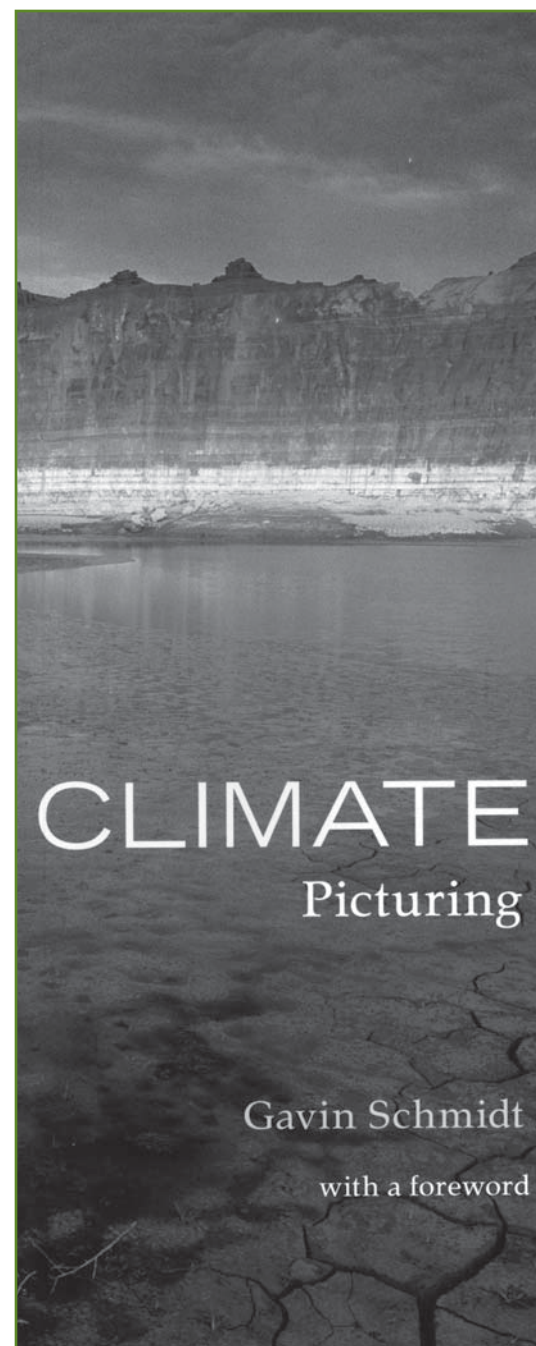


their program. "This shows a serious and real commitment to improving their country," he said. But Wheeler also tempers this optimism. "This commitment is not shared by all Iraqis. And to see that can sober one to the realities facing Iraq along its path to unity and stability."

Wheeler has found his graduate degree beneficial, if not directly applicable. When he interacts with high-level managers in the MoO companies, his comprehensive science background garners respect. And he believes his scientific approach to problem solving and his comfort with drawing conclusions in uncharted territory has been very helpful.

Life inside the compound maintains some degree of normality, but venturing beyond its walls requires convoys with armed security officers. When he is in Baghdad, Wheeler has little interaction with the general population, but security restrictions are less severe when he travels to the Kurdish region. In Erbil he coaches a local youth soccer league that meets six times a week, allowing him to form bonds with local Iraqi citizens.

"Coming out here I expected to encounter a dynamic, even chaotic environment with lots of surprises and little predictability—and that's what I've found," Wheeler said. But he finds little to deter him. Wheeler plans to stay at least until the end of 2010 and, depending on the state of security and the government's trajectory, possibly a whole lot longer.



Climate Change: Picturing the Science
by Gavin Schmidt and Joshua Wolfe
Copyright © 2009 by Gavin Schmidt
and Joshua Wolfe
W.W. Norton & Company, Inc.



"It is simply the best available collection of essays by climate scientists on the nature of human-induced climate change."

—Jeffrey D. Sachs

On Our Bookshelf

Instead of our usual book reviews, what follows is an excerpt from Lamont scientist Peter deMenocal's chapter in the book *Climate Change: Picturing the Science*, an anthology of images and elucidating essays on the science of climate change.

CHAPTER 1

TAKING THE TEMPERATURE OF THE PLANET

By Peter deMenocal

"31 December, 1768: No one can recall such a mild Autumn: the ground is as green as in the Spring, and today I have picked sufficient young nettles, dandelions, and other herbs to cook green cabbage tomorrow, which is New Year's day."

A colorful mix of meteorology and domestic concerns is typical of weather diaries kept by diligent observers for centuries. This example, from the Stockholm Observatory in Sweden, is not unusual, but it does pose problems for those interested in climate change. For instance, exactly how mild was that autumn and how might it compare to the autumn of 2007? To answer such questions and others like them, these qualitative descriptions are not sufficient—quantitative measures are required.

Galileo Galilei developed the first thermometer in the late 1500s. The "thermoscope," as beautiful as it is imprecise, is an elegant, liquid-filled glass cylinder containing several colorful, sealed glass bulbs that rise and sink with changes in temperature as their density relative to the liquid changes. More accurate measurements became available two centuries later, when German physicist Daniel Fahrenheit developed the sealed mercury thermometer in 1714 and the temperature scale that bears his name. As with many scientific advances, this new way of reducing nature to numbers led to a new way of viewing the climate. No longer was the difference between one year and another simply a qualitative change—warmer, cooler, wetter, drier—but a difference that could be reliably quantified. These records gave rise to the statistics of weather and, eventually, to the possibility of detecting subtle changes in climate....

OCEANS, BOREHOLES, AND SATELLITES

... Analyses of ocean temperature are based on millions of measurements made by ships

sailing the world's oceans. Coverage in earlier decades was reasonable along well-traveled shipping lines, but quite sparse in the remoter areas of the ocean. Measurements became more widespread when expanding fleets of commercial and passenger ships began routinely to record the intake temperatures of seawater used to cool their engines. Over the years, their voyages have recorded ocean temperature changes for most regions of the world's oceans. An obvious limitation to this data is that some of the more remote areas (such as the South Pacific) have relatively few ship tracks and their temperature history is not definitive.

In the early days, ocean temperatures were measured by dipping a canvas bucket over the side and taking a thermometer reading on deck. Getting a bucketful of water was a feat by itself, as the ship would usually be moving at full speed and some skill was needed to dip the bucket without being pulled overboard. For a laugh, the old hands used to let the young, inexperienced sailors measure bucket temperatures. They would confidently go to the rail with their bucket wondering what the fuss was about. As the light canvas bucket skimmed the ocean surface, it immediately filled and became an impossibly heavy, jerking weight. The poor deckhand would typically be dragged along the ship's rail, his hands blistering on the rope as he struggled to haul the bucket back to the deck. (Speaking from experience, this lesson is needed precisely once.)

In the last few years, a technological innovation has given us the potential to deal with the sampling problem by allowing us to obtain near-global, real-time measurements of world ocean temperatures, not only for the surface but for the subsurface as well. Since 2000, a global array of three thousand drifting floats [has] been released into the world's oceans to autonomously measure, record, and report (via satellites) ocean temperatures. These Argo floats, named after Jason's oceangoing ship of ancient Greek legend, are about 1 meter (3 feet) long and drift with the ocean currents. Periodically, they sink below the surface by adjusting their buoyancy with an internal bladder, and they record continuous measurements of ocean temperatures to depths of up to 2,000 meters (6,000 feet). They then float back up to the surface and wirelessly report the results to a data center on land. The record from these devices is not yet long enough to

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completely specify the trends, but slowly and surely the gaps in coverage are being filled....

These days, measurements are no longer limited to ground (or belowground) observations. Since 1979, weather satellites orbiting Earth have been measuring a whole spectrum of changes in radiation. An advantage of these satellite-based surface temperature measurements is that they can very nearly measure the entire globe in a few quick orbits. Satellites do not measure temperature directly, but by measuring the radiation at certain wavelengths that emanate from the atmosphere, usually in the microwave band, they can estimate the temperature of different layers of the atmosphere. Microwaves reflect the temperature of vibrating atmospheric oxygen molecules and are measured using Microwave Sounding Unit sensors....

At slightly different wavelengths, these same satellite sensors have been used to show that the stratosphere (at an altitude of around 20 kilometers [12 miles] and higher) has been *cooling* significantly over the same time that the lower atmosphere has been warming. While this might at first seem contradictory, these opposing temperature trends between the upper and lower reaches of the atmosphere are an important fingerprint that identifies the causes of these changes (see Chapter 6 for details).

Curiously, this upper atmospheric cooling means that the sky is, literally, falling. The upper layers are becoming more dense and are therefore contracting, and so the stratosphere and the layers above it are slowly falling closer to earth. Chicken Little might not have approved, but a positive benefit of this change is that it reduces the frictional drag on the satellites, and thus is helpfully prolonging the lifetimes of the very satellites that observe the phenomenon....

LOOKING FURTHER BACK

One of the more challenging questions surrounding the recent record-setting surface temperatures is how unusual the current trends are in the broader long-term context. The challenge is that our observation period is really quite short relative to the long timescales of global climate change. As we have observed, global thermometer readings only extend back 150 years, and ocean temperature and satellite-based records reach back a paltry 50 or 30 years, respectively. As compelling

and consistent as these temperature records are, they are still too short to assess the magnitude of natural variations in temperature over the last several centuries or millennia.

Luckily there are reliable ways to do this using *proxy* records of past climate change. Proxy records are surrogate indicators of past climate change that derive from natural recorders of climate variability, such as tree rings, corals, fossil pollen preserved in lake sediments, ocean sediments, clam shells, and glacier movements. They aren't direct measures of temperature or rainfall, but they are so closely tied to them that changes in the proxy can give a strong clue to changes in climate.

An example of a proxy record is the use of tree rings to reconstruct past changes in temperature or rainfall. Temperature controls the growing season of some tree species in certain locations very closely. These trees lay down visible rings each year, with light, low-density layers reflecting growth in the warm season, and dense, dark layers marking the cessation of growth in the cool season. Since some trees live for hundreds of years and forests of trees represent a broad spectrum of ages, it's possible to take small borings from dozens of trees in a particular location and to build a single composite tree ring record that documents changes in tree growth spanning many hundreds of years.

Tree rings are not the only biological proxy that has annual banding. Corals in the tropical oceans produce a hard calcium carbonate skeleton that is also laid down in annual increments. The carbonate is made of constituents that the corals extract and precipitate from seawater, and these can be analyzed to determine the water temperature in which the coral grew. Some corals grow to be several meters in diameter, and their skeletons can represent a virtual library of many hundreds of years for continuous coral growth in a single spot in the ocean....

The most interesting result from these reconstructions is not the tracking of the warmest year this millennium but the structure of the temperature and rainfall patterns in space and time. These can often be tied to documented changes in human societies and landscapes that are found in art, oral histories, or archeological sites. For instance, cold periods during the fourteenth and seventeenth centuries and even as late as the nineteenth century, sometimes called the Little Ice Age, correspond to occasional Frost

Fairs on the frozen Thames River where the citizens of London would drink, skate, play sports, and socialize. Some of the very long instrumental records also capture these cold periods, such as the "Year without a Summer" in 1816 in the wake of the Tambora volcanic eruption. Going further back in time, drought reconstructions from tree ring records indicate that severe droughts were coincident with the collapse of the classical Mayan cultures in the Yucatán, Mexico, and the disappearance of the Ancestral Pueblo (Anasazi) culture in the American Southwest (see Chapter 7 for more details)....

UNEQUIVOCAL WARMING

The collection of warming indicators discussed in this chapter demonstrates why the 2007 Intergovernmental Panel on Climate Change assessment described recent warming as "unequivocal." Nineteen of the warmest years on record have occurred within the last twenty-five years. The warmest years globally have been 1998 and 2005, with 2002, 2007, and 2003 close behind.... The odds of this sort of clustering, if it occurred only by chance, would be less than one in a billion, which is almost like being the newcomer to a game of roulette and having your ball consistently land in the number 1 pocket, spin after spin. It's exceedingly unlikely that the current warming trend is, well, not a trend.

How does modern warming fit into a broader, Earth history perspective? The last time the Earth was substantially warmer than this for a sustained period was about 3 million years ago, during the early Pliocene, when global temperatures were about 3°C (5.5°F) warmer and geological evidence shows that the Arctic was ice-free, the Greenland Ice Sheet was nearly absent, and sea levels were possibly 20 meters (over 60 feet) higher. Other more recent periods appear to have been slightly warmer, specifically the last interglacial period around 125,000 years ago, when Greenland temperatures might have been 3°C to 5°C (5°F to 9°F) warmer and sea level 4 to 6 meters (20 feet) higher.

The bottom line is that although current warming is not unprecedented in all the Earth history, previous eras that were clearly warmer than today were accompanied by changes (particularly in sea level) that dwarf the variations any modern humans have seen.

In Memoriam

Katherine Vazquez (1974–2009) The LDEO community mourns the untimely loss of Katherine Vazquez, payroll and benefits manager in the Office of Human Resources.

Lamont Research Professors—Securing the Next 60 Years

Now, more than ever, the world needs the kind of research and discovery for which Lamont-Doherty is famous. Yet, as the field of earth sciences has expanded in popularity and importance, recruitment and retention of the best and the brightest has become more challenging. Distinguished researchers, attracted by the security of tenured and salaried positions at universities, increasingly choose traditional faculty professorships over research appointments.

In response, Director G. Michael Purdy spent more than five years shepherding a proposal for a Lamont Research Professorship through the Columbia University system, finally receiving Trustee approval this past summer. The establishment of this new title will sharpen the Observatory's competitive edge, while securing its capacity for new discovery, interdisciplinary cooperation, and the mentorship of young scientists.

Thanks to the early and generous philanthropy of Thomas W. Lamont, the Henry L. and Grace Doherty Foundation, and other donors, the Observatory has thrived during its first 60 years. But the urgency of growing threats to our planet requires greater resources than yesterday's fortunes allow; and the Lamont Research Professor initiative will require greater investment than ever before.

Only by building Lamont-Doherty's endowment will we be able to fund these new professorships and support a world-class faculty. And it is the talent of our senior scientists that attracts the most promising students. The combined strengths of our faculty, postdocs, and students inevitably lead to a flourishing institution and to solutions to the challenges we face as a global community.

For information on how to make a lasting contribution to the field of science by endowing a professorship in your name or that of a loved one, please contact Barbara Charbonnet, acting director of development, at 845-365-8585, or bcharb@LDEO.columbia.edu.



Jerry Paros of Paroscientific Inc. and Quartz Sensors Inc. made a \$1.5 million gift to Lamont-Doherty in 2007 to name the Jerome M. Paros Senior Research Scientist of Observational Geophysics.

Your Support Is Needed

Your support is essential to funding important outreach and research initiatives at Lamont. To make a tax-deductible contribution to Lamont, please visit our website (www.LDEO.columbia.edu) and click on the "support LDEO" icon.

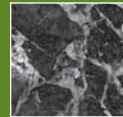
To send a gift by check, make it out to "Lamont-Doherty Earth Observatory" and mail it to: Development Office, LDEO, P.O. Box 1000, Palisades, NY 10964. If you would like to make a restricted gift, planned gift, or a gift of stock, please contact the acting director for development, Barbara Charbonnet, at 845-365-8585.

FROM THE ARCHIVE



The de-commissioning of the R/V *Robert D. Conrad*

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