GEOLOGY & GEOPHYSICS NEWS

Yale University | Department of Geology and Geophysics Winter 2008

Chairman's Letter

David Bercovici

Greetings, friends of Yale Geology & Geophysics, this is my second year as Chair of our fine department, and it gives me great pleasure to tell you about the many events of the last year. There have been numerous changes, including new faculty, new graduates, expansion in numbers of undergraduate majors, graduate students, and postdoctoral scholars; even the building has seen renovations.

Early in 2007 we ran two simultaneous junior searches, one in mineral physics and geophysics, the other in isotope geochemistry. The searches led to the appointment of four new faculty, two in each of the disciplines. The new assistant professors are geochemists **Hagit Affek** and **Zhengrong Wang**, both of whom started in July 2007, and geophysicists **Kanani Lee** (who starts in July 2008) and **Maureen Long** (who starts in January 2009). Each brings unique talents to the Department, and they will oversee major expansions in isotope geochemistry, mineral physics and seismological research. You can find profiles and a photo of each of them later in this newsletter.

As we add new young faculty, our formerly young faculty are getting older and this year saw the promotions of geophysicist **Jun Korenaga** to Associate Professor, and atmospheric physicist **Steven Sherwood** to Professor. You might recall that Jun Korenaga was the recipient of the James B. Macelwane Medal from the American Geophysical Union in 2006, and Steve Sherwood received the Clarence Leroy Meisinger award from the American Meteorological Society in 2005.

Bob Gordon retired in July of this year but continues as a Senior Research Scientist. Bob was an undergraduate '52 and PhD '55 in engineering; he returned to Yale after a stint at Columbia and has been a professor since 1957. In early November, the Department held a two-day symposium in Bob's honor to highlight the singular contributions he has made in the fields of rock mechanics (including some of the early work that paved the

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Interior Renovations to the Kline Geology Lab

The results of renovations—the auditorium looking toward the podium, and the departmental lounge.

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way for the plate tectonic revolution), and his seminal work in archeometallurgy. Other honorable transitions (albeit temporary, we hope) are that **Derek Briggs**, the Beinecke Professor of Geology and Geophysics, will become the new director of the Peabody Museum in July 2008, and **Jeffrey Park** will succeed Derek as Director of the Yale Institute of Biospheric Studies. Derek will be on leave for the first 6 months of his Directorship, so our own **Jay Ague** will be acting Director of the Museum during that time.

This year members of our G&G community garnered two major honors. First, the Graduate School's highest honor, the Wilbur Lucius Cross Medal, was awarded to **John Suppe** (**G '69**) for his groundbreaking work in structural geology and tectonics; a department reception and the university ceremonies took place in October. Second, **Alexey Fedorov**, Assistant Professor, was Yale's recipient of the David and Lucille Packard Fellowship, which is a great honor for a young faculty member, and will allow him to expand on his extremely timely research into the effects of climate change on El Niño patterns and Gulf Stream circulation.

PhD candidates who enrolled in 2001 and 2002—two of our largest classes in recent years (with 20 total)—are graduating and moving on to prestigious postdoctoral positions such as Cambridge University, California Institute of Technology, and Woods Hole Oceanographic Institution.

The expanded Bateman Postdoctoral Fellowship and Interdepartmental Postdoctoral Fellowship programs are growing success stories. Our cadre of postdoc scholars—currently 23 in number—continues to bring great scientific vitality and diversity to our department. The group is strongly international with people from France, Russia, Japan, Korea, India, Norway, the UK, Australia, Israel, as well as the US and Canada. We now hold a regular "Lunch with the Postdocs" seminar series, one of our best attended regular events. With the addition of new faculty will come even more postdocs and our greatest concern is in fact where to house all of them!

The ranks of undergraduate majors had, for several years, dipped in number, but with the revamping of the undergrad program to include multiple tracks (Amosphere and Oceans; Solid Earth; Environmental Geoscience; and Paleontology and Geobiology) the number of majors has doubled to well over 20 and is climbing. Our undergraduates have even formed a new Geology and Geophysics Club to organize activities, seminars and field trips; we look forward to their expanding role in the life of our department.

For those of you who spent countless hours of your youth in the Kline Geology Lab, you will be happy to know that it has had a major interior face-lift (perhaps Botox treatment is more apt) over the last year. In addition to repainting the hallways, we have completely renovated every teaching room and lab to include new lighting, computer projectors, and (finally) comfortable new furniture. The Departmental Lounge, used for receptions,

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As part of the Global Tectonics class (G&G212b) taught by Mark Brandon and David Evans, undergraduates visited the active Sicilian foldbelt during Spring Recess. Here, some of the Yale group is shown examining Miocene turbidites near Cefalu.

FACULTY NEWS

Meet the New Faculty

Hagit Affek (hagit.affek@yale.edu) is an environmental geochemist who comes to Yale following a postdoc appointment at Caltech working with John Eiler. Her PhD thesis was awarded by the Weizmann Institute of Science, Rehovot, Israel, and her mentor there was Dan Yakir; her topic was "*Isoprene emission from leaves: Physiological role and isotopic composition.*" Hagit is continuing her research into environment problems and is using isotopic chemistry to investigate biosphere-atmosphere interactions. She is particularly interested in studying the role of emissions from the land-based biosphere in determining the chemical composition of the atmosphere. Hagit has been in the Department since July 2007.

Kanani Lee (kanani@physics.nmsu.edu) comes to us from New Mexico State University, where she is an Assistant Professor of Physics. Before starting her position in New Mexico, she was the OK Earl Postdoctoral Fellow at Caltech. Kanani's PhD was awarded by the University of California, Berkeley, where her thesis advisor was Raymond Jeanloz. Her thesis title was *"Exploring planetary interiors: Experiments at extreme conditions."* Kanani will join the Yale faculty in July 2008. She plans to continue her research into the physical properties of Earth's core, in particular electrical and thermal conductivities, heat generation, and composition. She will also continue research into pressure and temperature dependencies of

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afternoon teas, and seminars, has been redesigned and refurnished. The Dana Club room was likewise gutted and fitted with new modern cafe-style furniture. And our flagship auditorium, which over the years had acquired the appearance of a ships hull, was completely gutted and renovated with an elegant new seating, state-of-the-art projection system, and a center piece demonstration table of 2-billion-year-old metaconglomerate from Brazil. Along with these changes will come many additional renovations of research labs for newly hired faculty. While the department office has as a whole been working tirelessly toward these changes, the super-human efforts of our Assistant Business Manager Pam Buonocore in coordinating the renovations are particularly noteworthy and she earns our profound thanks.

What does the immediate future hold in store for our Department? Well, we have been working on several initiatives including a Geobiology Initiative that involves the Departments of G&G, Ecology and Evolutionary Biology, Chemistry, and Astronomy; it's a major initiative and we hope it will grow into several faculty hires and new facilities designed to study the interaction of microbes and the environment, the coevolution of life and Earth, and extremophiles and astrobiology. We have also been firing up a new Climate Institute Initiative that we hope will pull together and expand all the science and engineering research going on in G&G and throughout Yale on the critical problem of climate change and mitigation. I hope to be able to give you positive progress reports on these in the next newsletter.

We plan to expand field experiences for our undergraduates. We have already made some positive moves; last year the Structure and Tectonics class went to Sicily and the class leaders plan a repeat trip this year. The Natural Disasters class is planning a trip to explore the volcanoes, the sites of earthquakes, tsunamis, hurricanes, landslides, and shore waves in Hawaii, in March 2008. And the Department is planning a graduate field trip to New Zealand, in December 2008.

Finally, we are planning a Yale Geology & Geophysics Reunion in the Fall of 2008 so that all our former graduate, undergraduate, and postdoc alumni can join us in order to visit old advisors and teachers and meet the newest faculty, students, and scholars. Keep an eye out for the dates, details, and invitations!

Well, it's been an active year—hence my long letter. Anytime you wish to find out more about the department or even visit, feel free to send an email (david.bercovici@yale.edu) and we will be more than happy to take care of you.

Late Breaking News

Academic Analytics has released rankings for 2007.

- Geology at Yale came in a solid 5th among departments.
- Geophysics sits at the top of the list in its discipline.

To read more go to: *http://www.academicanalytics.com/TopPhysMathSci2006-2007.html*

FACULTY NEWS

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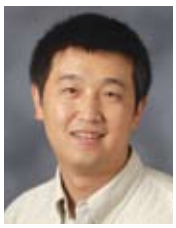
radioactive decay, and constraints of the lower mantle composition. Her principal tool of research will be a laster-heated diamond-anvil cell.

Maureen Long (long@dtm.ciw.edu) is still a postdoc at Carnegie Institution's Department of Terrestrial Magnetism in Washington, D.C. She has accepted Yale's offer and will join the Department in January 2009. Maureen's PhD is from MIT where Rob van der Hilst was her thesis advisor, and her thesis was on "*Anisotropy and deformation in the Earth's mantle: Seismological observations, geodynamical models, and laboratory experiments.*" Maureen states that "a large part of my planned research program for the next several years is the further improvement and extension of the techniques for understanding mantle anisotropy."

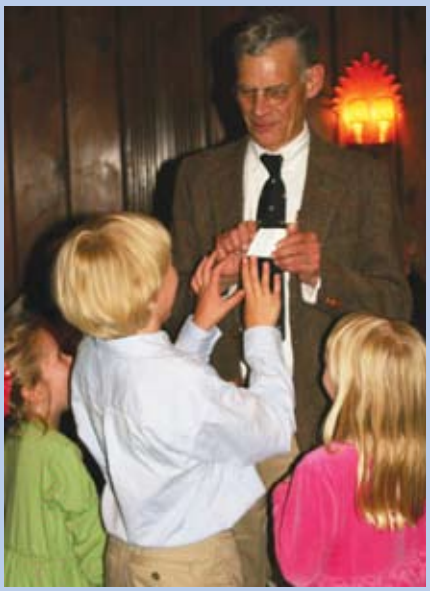


Zhengrong Wang (zhengrong.wang@yale.edu) was previously at Woods Hole Oceanographic Institution as a postdoc in the Deep Ocean Exploration Institute. His PhD is from Caltech in 2005 and was on "*Oxygen isotope studies of the petrogenesis of Hawaiian lavas and a theoretical study on equilibrium thermodynamics of multiply-substituted isotopologues.*" His thesis advisor was John Eiler. Zhengrong plans to expand his research into a study of magnesium and oxygen isotope compositions of various mantle reservoirs in order to potentially constrain mantle dynamics. He also plans to use the new inductively coupled plasma mass spectrometer, when it is finally installed, to investigate Mg isotope fractionations during biomineralization and in hydrothermal systems. Zhengrong joined the Department in July 2007.

A Conference Honoring Robert Gordon on the Occasion of His Retirement

Bob Gordon '52, D. Eng. '55 (robert.gordon@yale.edu) retired from teaching June 30, 2007. But he hasn't retired from his prodigious research program, and most days he can still be found on the second floor of Kline Geology, in either the lab, surrounded by archaeological specimens of metallic objects, or in the big conference room next to his office discussing results of the research.

Bob started his academic career as a metallurgist and is still widely known for his seminal book, *Structure and Properties of Alloys,* coauthored with Phillips and Brick. His first appointment after his doctoral degree from Yale was at the School of Mines, Columbia University, but in 1957 he returned to Yale and joined the still-extant Metallurgy Department. With the demise of metallurgy at Yale, he was appointed Professor of Geophysics and Applied Mechanics in 1960. He was a great addition to the then-expanding Department of Geology, soon to be renamed the Department of Geology and Geophysics. The fit was excellent and Bob's move into geophysics soon produced results of major importance on creep in Earth's mantle. He chaired the department from 1979 to 1983 and at different times filled most of the roles needed to keep the department running.



With grandchildren at retirement conference.

Much as he liked geophysical problems that needed solving, Bob's love for issues metallurgical never waned and in recent years he returned to the field, but this time with a special twist—archaeological metallurgy. When colleagues gathered on November 2 and 3, 2007, to honor Bob, the group was divided into two. On November 2nd, Paul Craddock from the British Museum, David Crossley from the University of Sheffield, Mike Wayman from the University of Alberta, and former graduate student David Killick from the University of Arizona, spoke on research in archaeological metallurgy. On November 3rd, Bob's geophysical colleagues, Hans Weertman from Northwestern University, Don Weidner from the University of New York, Stony Brook, Harve Waff from the University of Oregon, and Shun Karato from Yale, spoke of their research and how Bob's work had influenced them.

FACULTY NEWS

A New Professorship of Geology and Geophysics

In April 2007, **Ron Smith** (ronald.smith@yale.edu) was appointed as the first Damon Wells Professor. **Damon Wells '58**, though not a former major in geology, has been a successful investor in mining and a generous supporter of the Department. Damon funded the very successful Damon Wells Fellowships for students and/or post-docs from Australia, which brought a number of Australians to the department over the approximately 20 years it was active. As part of the Yale's current capital campaign, Damon generously increased the size of the Fellowship endowment to the level of a professorship. We lost the Fellowship but gained a Professorship.

Ruth Blake and students at Fort Hare

Ruth Blake and students.

Ruth Blake (ruth.blake@yale.edu) presented keynote lectures on her research on the stable isotope biogeochemistry of phosphorus at two international meetings: the 17th Goldschmidt Geochemistry meeting held August 19th to 24th at the University of Cologne, Germany; and the 7th international meeting on Applied Isotope Geochemistry (AIG7) held September 10th to 14th at the University of Stellenbosch, South Africa. Following the AIG7 meeting, Ruth was honored with an invitation to conduct a five-city lecture tour of South African Universities, which included visits to the University of the Free State at Bloemfontein, University of Zulu-Natal at Durban, University of Johannesburg, and University of Capetown. A highlight of Ruth's S. Africa lecture tour was a visit to the University of Ft. Hare at Alice, near East London, which is located in the Eastern Cape Province, formed in 1994 out of the "independent Homeland" settlements of Transkei and Ciskei, established under the apartheid system. The Eastern Cape region is birthplace to many prominent South Africans, including Nelson Mandela, Thabo Mbeki, Steve Biko, and Charles Coghlan. The University of Ft. Hare is a

Ruth Blake and Prof. Baojin Zhao, Department of Geology, Faculty of Science and Agriculture, University of Fort Hare, Eastern Cape, South Africa.

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New Director of the Peabody

Derek Briggs

Jay Ague

Effective July 1, 2008, **Derek Briggs** (derek.briggs@yale.edu) will become Director of the Peabody Museum of Natural History. Derek, who is Curator of Invertebrate Paleontology, will actually be on leave and overseas at the time his appointment commences, and **Jay Ague** (jay.ague@yale.edu), Curator of Mineralogy, will step in as Acting Director until the end of 2008. Jay Ague is also involved in another change in activities. After 10 years as co-editor of the *American Journal of Science*, which task he has performed excellently, Jay is stepping down. The search for a new co-editor is being directed by the Chair of the Governing Board of the Journal, Ron Smith.

Recent PhD Theses

The following have defended their PhD theses and/or received their PhD degrees within the last twelve months:

John Vanden Brooks, "The Effects of Varying pO_2 on Vertebrate Development and Evolution," now a postdoc at Arizona State, working with Jon Harrison in the School of Life Sciences. **Walton Green**, "Using Leaf Architectural Data for Phenetic Ecological Comparison of Modern and Fossil Forest Stands," now a postdoc at the Smithsonian, working jointly at the Tropical Research Institution and the Natural History Museum. **Garrett Leahy**, "Structure and Dynamics of a Mid-Mantle Melt Layer: Predictions and Observations of Hydrous Melting above the Transition Zone," now a postdoc at the Woods Hole Oceanographic Institution, working with Mark Behn. **Ian Miller**, "The Taxonomy, Paleoecology and Paleolatitude of the Early Cretaceous (Albian) Winthrop Formation Flora, Washington State, USA," now a postdoc at the Museum of Natural History, Denver, working with Kirk Johnson. **Jerome Neufeld**, "Natural and Forced Convection During Solidification," now the Lloyds of London Fellow, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, working with H. E. Huppert. **Philip Skemer**, "Deformation and Grain-Size Evolution of Orthopyroxene in the Upper Mantle," now a postdoc at the Department of Geology and Geophysics, Brown University, working with Greg Hirth. **Krister Smith**, "Horizontal and Vertical Aspects of Species Diversity in the Fossil Record: Alpha, Beta, and the Temporal Nature of the Richness-Temperature Relation," now a postdoc at the University of Texas. **James Stevenson**, "Partial Melting of Eclogite: Formation of High Mg# Adakitic Melts During Fluid-Induced, High-Pressure Partial Melting of Continental Eclogite, Involving Growth of Peritectic Garnet and Amphibole, Tromso Nappe, Norway," returned home to Australia and is now employed as a financial analyst. **Ben Zaitchik**, "Local Drivers of Aridity in the Middle East and Beyond," now a Research Associate in the Hydrological Sciences Branch of NASA, at Goddard Space Flight Center, Greenbelt, Maryland.

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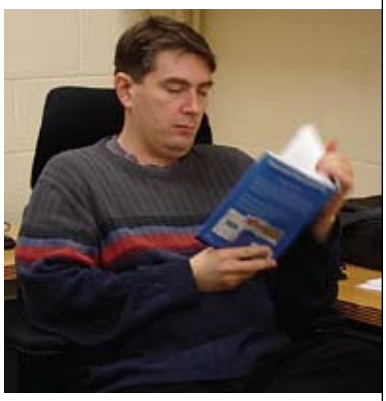
renowned, historically black university, and alma mater to many black South African antiapartheid leaders, and to other Africans, some of whom became leaders in their home countries. Although by far the most remote of the five universities visited by Ruth—located 2 hours drive from the airport—students and faculty at the University Ft. Hare, including Geology Department Chair Baojin Zhao, were most welcoming and enthusiastic. Also in attendance at the Ft. Hare lecture was Yale graduate **Jay Barton '67** who lives in Johannesburg and following retirement now lectures as an adjunct professor in the Geology Department.

FACULTY RESEARCH

Alexey Fedorov *(alexey.fedorov@yale.edu), who joined the department in July of 2004, is working on climate and ocean dynamics in the context of contemporary global warming and past climate changes. In particular, he is interested in the problems of ocean general circulation, especially as they relate to climate, ocean thermal structure, large-scale ocean-atmosphere interactions, and climate predictability. In October 2007, Alexey was awarded a fellowship from the David and Lucile Packard Foundation to continue his studies of the effect of global warming and past climate changes on El Niño.*



Alexey Fedorov at work.

Climate Puzzles: El Niño, Global Warming, and Abrupt Climate Change

by Alexey Fedorov

Earth's climate appears to be moving toward a state unlike any recorded by instrumental data, which means that modern measurements are not sufficient for testing theories and models used for climate prediction. Paleoclimate research, however, has recorded remarkable extremes that may well be similar to climate shifts expected to occur later in this century, or later centuries. For this reason, My research addresses both present and past climate variations.

Projected consequences of global warming are being intensely studied by scientists, and observed changes in global climate have been successfully modeled using comprehensive numerical models of the ocean and the atmosphere. Yet, threshold behavior and rapid changes in the climate system remain poorly understood. Consider, for example, a sudden shutdown of the ocean "conveyor belt"—a component of the ocean circulation system that transports heat to the North Atlantic. Evidence from Greenland ice cores and other sources make it clear that heat delivery was disrupted on multiple occasions in the past, and that some of the changes developed as rapidly as in a few decades. Another example of abrupt climate change is a shift in climate conditions associated with the El Niño-Southern

Oscillation phenomenon (ENSO).

El Niño is the warm phase of a natural oscillation maintained by ocean-atmosphere interactions in the tropical Pacific (Fig. 1b). Strong easterly Trade winds normally pile up water in the Western Pacific (Fig. 1a). In the equatorial Pacific, the wind strength is proportional to the east-west temperature difference. A small relaxation of these winds lets warm water flow eastward, reducing the temperature gradient along the equator. The reduced gradient causes the winds to weaken further, creating a positive feedback and giving rise to El Niño. Negative feedbacks associated with subsurface ocean processes eventually return the system to normal conditions.

El Niño typically occurs every 4 to 5 years and has profound effects on the global atmospheric circulation, temperature, and precipitation patterns. During the last three decades, we have experienced the most intense El Niño episodes in more than a century, and their impacts on many of Earth's natural systems have been devastating. The El Niño events of 1982 and 1997, for example, caused floods in California, droughts in Australia, an increase in the number of hurricanes in the Pacific, severe damage to ecosystems over the entire Pacific Rim, and even unusual epidemics of diseases in developing countries (e.g., McPhaden, 1999). Overall, the total damage to the world economy was estimated in hundreds of billions of dollars.

These episodes lead to several important questions: Is there a connection between global warming and the severity of El Niño? Is the recent predominance of strong El Niño episodes an omen of what to expect as the global temperature continues to rise? Will such exceptional warm events become more severe and long-lasting? And, finally, might the climate system shift toward continuous, semipermanent or permanent, rather than intermittent, El Niño events (imagine El Niño of 1997 persisting for many, many decades)?

Recently obtained temperature records (derived from tropical deep-sea cores) show that the Earth was locked into a permanent El Niño state, between approximately 3 and 5 m.y. ago. What makes this finding so important is that during that time the Earth was experiencing greenhouse conditions similar to today's, including an elevated concentration of CO_2 in the atmosphere and an increased global mean temperature.

One consequence of this climate state was that all major coastal nutrient-rich upwelling regions of the world oceans (such as the one off the coast of California) were apparently absent. The temperatures of these regions were up to 10°C higher than at present, and oceanic ecosystems were severely disrupted. Today, even weak decadal variations in the strength of the California current have detrimental impacts on the ecosystems off the coast of North America.

My studies, based on general circulation climate models, indicate that a potential transition to a permanent El Niño will have many far-reaching consequences for Earth's climate, forcing shifts in global weather patterns in different regions from Australia to India and to North and South America. Even more important, a permanent El Niño will greatly amplify the effect of global warming because uniformly warm temperatures over the huge area of the tropical ocean would lead to increased evaporation from the ocean surface and to higher water vapor content in the atmosphere. Water vapor, in turn, is a potent greenhouse gas.

Numerical experiments suggest

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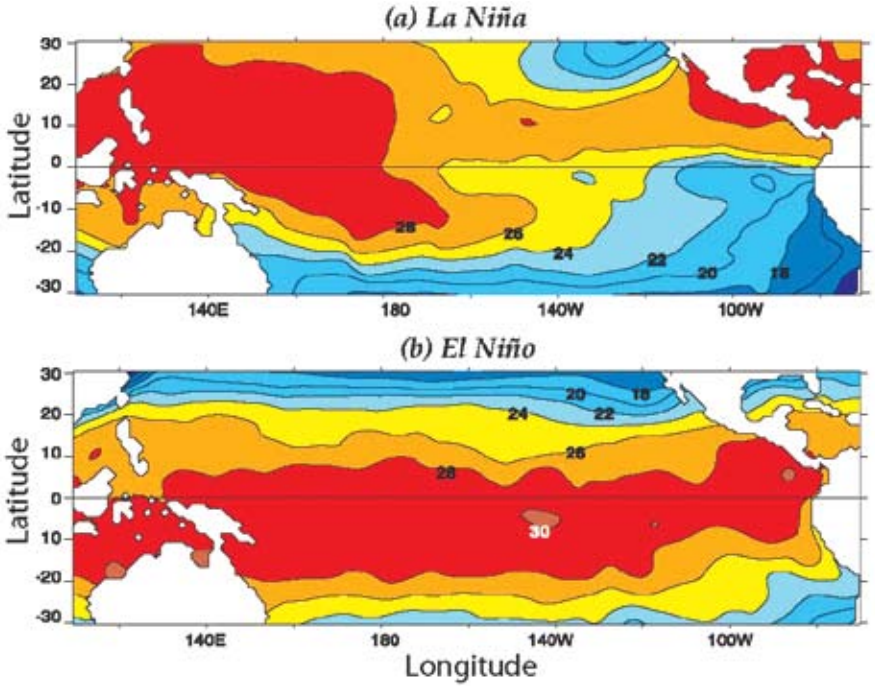


Fig. 1. Typical sea surface temperature patterns (in °C) during different phases of ENSO. El Niño is the warm phase of the oscillation (bottom), La Niña is its cold phase (top). Changes between the two states are associated with profound shifts in the atmospheric circulation both globally and locally. The mean tropical conditions resemble those of a weak La Niña (Fedorov and Philander 2000).

Climate Puzzles *continued from page 7*

that as soon as a certain threshold is reached a permanent El Niño state can occur rapidly, supporting the notion that the climate system is extremely sensitive to external perturbations. Observational data indicate that the mean temperature of the eastern equatorial Pacific—an important index of tropical climate conditions—has increased by about 1°C since the 1960s and 1970s. Models used in the recent climate assessment by the Intergovernmental Panel on Climate Change (IPCC) also show a net tendency, albeit weak, toward El Niño-like conditions. Is it possible that the coupled ocean-atmosphere system is slowly moving to a different climate regime? What are the climate parameters that we should monitor to predict such an occurrence? Although many questions still remain unanswered, our work has provided tentative clues to some of these problems.

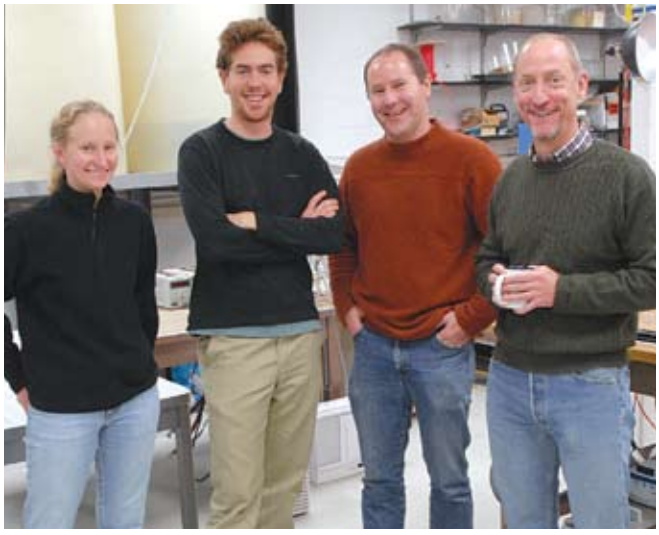
The first goal of future research, is to understand the mechanisms behind a permanent El Niño state, specifically the physical processes that control the thermal structure of the upper ocean and the interactions between the ocean and the atmosphere in a changing climate. It will be possible then to determine how the Earth remained in such a state, and whether it is possible for a permanent El Niño to return as a result of global warming. Deciphering these mechanisms is a challenging problem that depends on the ocean vertical diffusion of heat and a critical interplay between the radiative forcing of clouds and greenhouse gases.

One of the pay-offs coming from this research is an improved understanding of the warm climates of the deep past—from the Cretaceous to the Eocene. A fundamental challenge of climate science is to explain how the high latitudes were ~20°C warmer in the past while the tropics remained at temperatures only slightly higher than today's. The mechanism of a permanent El Niño may be the very key to this paradox.

My colleagues and I use a hierarchy of models of various complexities ranging from mathematical models based on basic physical relationships to comprehensive ocean-atmosphere general circulation models. Extensive numerical simulations are conducted at Yale with Linux supercomputing clusters. We also take advantage of a high-performance supercomputer at the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey. Ultimately, this work will improve our ability to predict the severity and impacts of global warming and prepare for its outcome.

Working with me at Yale on the problems of abrupt climate changes and the physics of El Niño are postdoctoral researchers Jaclyn Brown (PhD, CSIRO Marine and Atmospheric Research, Australia), Chris Brierly (PhD, University of Reading, UK), and Zonghui Liu (PhD, Brown University). Graduate student **Carlos Szembek** studies El Niño predictability, and graduate student **Melanie Parker** (Co-advised with **Steven Sherwood**) investigates the connection between the equatorial Pacific Ocean and the upwelling region off the coast of California. The problem has significant applications because of the importance of the California current system for the climate and ecosystems of North America.

Reference: Fedorov, A.V. and Philander, S.G.H. 2000: Is El Niño changing? *Science* **288**, 1997-2002.



John Wettlaufer Discusses Research into Ice Physics and Geophysics at Yale. (left to right: Melissa Spannuth, PhD candidate, Erik Thomson, PhD c.ndidate, Michael Patterson, Assoc. Research Scientist, John Wettlaufer).

Ice and Fluid Dynamics Research at Yale

by John Wettlaufer (john.wettlaufer@yale.edu)

The distribution of ice throughout the universe and here on Earth has central implications from the nucleation and growth of primordial matter in stellar nebulae to the fate and state of our climate system. Large swaths of our planet are seasonally or perennially covered with snow and ice, and although more than two-thirds of the surface of Earth is covered by water, it is the ice to water conversion, and vice versa, which insures that an important fraction of the globe is habitable today. While changes in the large-scale dynamics of the ice cover capture public interest principally because of their role in global warming and ice-age events, it has long been known that ice is a central agent in the shaping of the past, present, and future climate. Earth's ice cover is an extremely sensitive geophysical variable. Among other

things, the eccentricity, obliquity, and precession index of Earth's orbit, the optical depth of the atmosphere, and the storage of heat in the oceans underlie the present tropical-to-polar difference in mean surface temperature of approximately 50°C. Because water freezes near the middle of this range, it is not difficult to grasp the concept of advancing or retreating ice extent.

John attempting not to break Jerome Neufield's apparatus.

Ice in the Oceans, on Land, and throughout the Atmosphere

What may be less intuitive to the community of Earth and Planetary Scientists is that the microscopic structure of ice underlies much of its important large-scale influences. Much of our research efforts focus on the places where the physics of ice and its geophysical consequences meet. A careful scrutiny of the material has benefits that transcend the environmental questions that may motivate our studies. This is a natural consequence of the fact that ice exhibits the same range of phase transition phenomena common to *all* materials. Hence, under natural and laboratory conditions its study weds a broad range of scientific fields.

Sea ice

Recently it has been difficult to pick up a newspaper or magazine without reading of the great decline of the Arctic sea ice cover as a harbinger of global warming. In particular, the focus is on the minimum summertime sea ice extent that has been *observed* to decrease 20% in 28 years. The girth of the attention is given to claims that this minimum extent is in a spiral toward complete demise, generally referred to as the "tipping point" in the community. These predictions are based on output from Global Climate Models (GCMs), but none of these did, or could have, predicted the unprecedented enormous loss of sea ice in the Pacific sector of the Arctic Basin that occurred in the summer of 2007. Its cause is intimately related to how heat from the warm waters that enter the basin from lower latitudes make their way toward the underside of the ice. A recent study of output from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) coupled GCM's reports that the simulated Northern Hemisphere sea ice covers are very similar to each other and to observations. However, the same models, using the same parameters that capture reasonably well the ice cover during the observed period (28 yrs), when run out to 2100 give 100% variation.

The principal balances that control the large-scale distribution of sea-ice thickness are those between thermal processes that lead to growth and melting and mechanical processes, induced by wind, oceanic and internal stresses, which drive deformation.

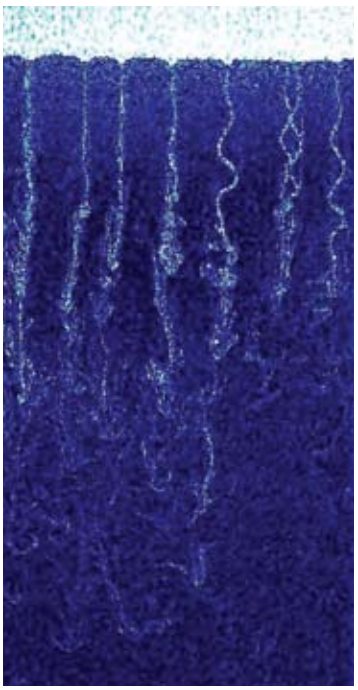


Fig. 1a. An image of an experiment in which a salt solution is solidified into a "mushy layer" (the white material at the top) and the residual buoyancy is focused into a discrete number of plumes, visualized in terms of their salinity and hence ability to refract light. The downward-moving plumes model the dense salty water produced during oceanic freezing.

The GCMs mainly parameterize the thermodynamics of the ice in fashions that most often violate basic conservation laws and they do not have realistic fluid dynamics in their oceanic components. Importantly, however, the ice itself is not like that in your drink. It forms from an impure liquid, the ocean, and hence holds much in common with all multicomponent systems. We treat sea ice as a "mushy layer;" a rigid matrix of pure solid (e.g., ice) bathed in its impurity rich melt (e.g., brine). Mushy layers[1] appear prominently in a wide variety of settings in science and engineering from the casting of metal alloys to the growth of ice from the oceans and the evolution of the Earth's inner core. The mushy layer equations reduce to the most rigorous climatologically based sea ice thermodynamic model under the same approximations employed therein. With Ian Eisenman (Harvard) and Norbert Untersteiner (University of Washington) we have developed simple analytical descriptions of the thermodynamics of the ice cover that show how GCMs exploit the ice-albedo feedback to "control" ice-cover predictions under various climate-forcing scenarios. Sea ice is strongly influenced either by buoyancy, due to the preferential rejection

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Ice Research *continued from page 9*

of impurities, or an external flow. **Jerome Neufeld's** recent thesis[2] explored the combined effect of both buoyancy- and externally driven flows on the evolution of such systems and hence his results underlie how dense brine is delivered to the ocean. The dense brine influences the formation, evolution, and the stability of the Arctic Ocean stratification that traps heat at depth and suppresses the melting of the ice. The fate of the density currents that are produced by growing sea ice are difficult to study in the field and the large-scale models don't treat the fluid dynamics rigorously. Therefore, we make laboratory analogue models of these and other phenomena. **Rachel Berkowitz**,[3] **Jerome Neufeld**, **Michael Patterson,**[4] and **Mathew Wells**[5] have been actively involved in experiments on model sea ice solidification processes, the associated density currents (Fig. 1). We find for example that brine production over the vast shelf regions in the Arctic can influence the nature of the ocean stratification in a manner that may bring the trapped heat to the surface and thereby help melt the ice cover more rapidly.

Premelting, paleoclimate, frost heave, and snowflakes

We now know that melting of *any* material begins at one of its free surfaces at temperatures *below* the bulk melting point (about 0°C for ice). While this *premelting* describes the effects responsible for the persistence of its liquid phase at temperatures well below the normal melting temperature, the phenomena most familiar to the Earth and planetary scientists are *Gibbs-Thomson* and *Colligative effects*. The former is a statement that a solid phase that is convex into its melt phase has a lower freezing point than the bulk, and the latter originates in the lowering of the chemical potential of a solvent in the presence of a solute. These are responsible for the canonical phase architecture of ice and mantle materials with veins, nodes, and trijunctions and the familiar description of "partial melting" in such systems (Fig. 2). While such effects are important in ice, we also focus on the *planar* interfaces of solids. *Interfacial premelting* occurs at the surfaces of all known solids and is characterized by the appearance of an interfacial thin film of liquid that grows in thickness as the bulk melting temperature is approached from below. The effect allows liquid to persist in the solid region of the bulk phase diagram in the absence of solute or curvature. The relationship between the film thickness and the temperature depends on the nature of the interactions in the system. Premelting effects are active within water filled porous media at temperatures below its bulk melting temperature.[6]

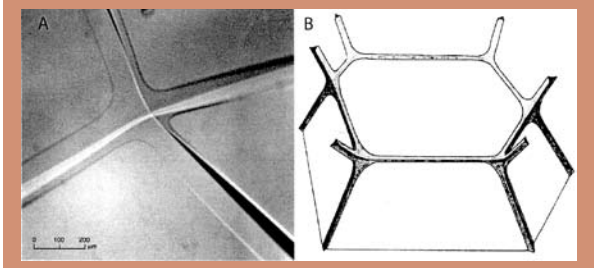

FIG. 2. Left, a photograph of four veins intersecting at a node between four grains in polycrystalline ice near the bulk melting temperature. Right, schematic of the vein/node network [Dash, J.G., A.W. Rempel and J.S. Wettlaufer, *Rev. Mod. Phys.* **78**, 695 (2006)].

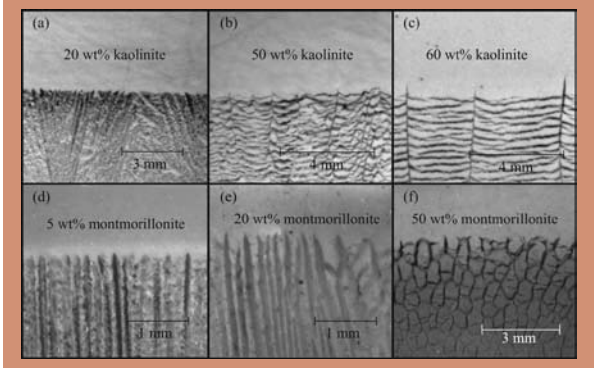

FIG. 3. Colloidal suspensions frozen upward in a cell that is free at its upper end [From Peppin et al., *J. Fluid Mech.* **554**, 147-166 (2006); *Proc. Roy. Soc. Lond. A* **463**, 723-33 (2007)]. Clearly the structure of the ice (dark regions) depends on the conditions of freezing and the particle concentration. While (a) and (d) exhibit ice dendrites that align colloids in (c) and (f) a polygonal structure forms and there are mixed states between the two geometries initiated by sidebranching as shown in (e).

The existence and motion of premelted liquid underpins the postdepositional redistribution of climate proxies (soluble impurities and isotopes) in the ice sheets, thereby compromising the dating of climate events; it flows within "subfreezing" soils to heave up the ground surface and influence geomorphological features in landscapes, and it is central to the morphology of snowflakes. **Erik Thomson's** thesis work[7] explores grain boundary premelting by scattering light off of a carefully prepared ice bicrystal; **Simon Mochrie**[8], **Stephen Peppin**[9] and **Melissa Spannuth**[10] study the basic dynamics of premelted films by examining their collective effects on many particles (Fig. 3) and **Andrew Cahoon**[11] and I have been exploring the connections between surface structure and ice crystal

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1 A long standing collaboration on mushy layers with Herbert Huppert and Grae Worster at University of Cambridge has explored many tendrils of these problems.
2 Leonard X. Bosack and Bette M. Kruger Graduate Student Fellow at Yale, now a Postdoctoral Fellow in the Department of Applied Mathematics & Theoretical Physics, University of Cambridge.
3 A physics undergraduate at Yale now at the BP Institute, University of Cambridge.
4 Associate Research Scientist, Department of Geology & Geophysics.
5 Recently a Postdoctoral Fellow at Yale, now Assistant Professor at the University of Toronto.
6 Premelting has been explored with Greg Dash, University of Washington, for the last 15 years and other collaborators including Alan Rempel, University of Oregon, and Grae Worster, University of Cambridge.
7 Leonard X. Bosack and Bette M. Kruger Graduate Student Fellow, Department of Geology & Geophysics.
8 Professor of Applied Physics and Physics at Yale.
9 Postdoctoral Associate, Department of Geology & Geophysics.
10 National Science Foundation Graduate Student Fellow, Department of Geology & Geophysics.
11 Physics graduate student at Yale, now Assistant Professor at Colby-Sawyer College.

The Yale Center for Earth Observation (YCEO)

History and Activities

In 1992, the YCEO was initiated as one of the first Centers under the umbrella of the Yale Institute for Biospheric Studies. The Director of the Center is **Ronald B. Smith**, Damon Wells Professor of Geology and Geophysics. The Center's mission is to support and coordinate the application of satellite remote sensing to environmental research and monitoring at Yale. To do this, the Center: Maintains software and hardware for image analysis and GIS; Maintains an image archive and provides assistance in accessing other international archives; Supports the teaching of the introductory course "Observing the Earth from Space"; Supports student and faculty research projects in remote sensing; Provides a forum for the design of interdisciplinary research projects.

Geography at Yale

The last twenty years have seen resurgence in the study of geography, i.e., "the study of the earth and its features, inhabitants, and phenomena." As Yale has had no geography department during this growth period, the associated teaching and research activities have been spread across campus in departments such as Anthropology, History, Forestry & Environmental Studies, Epidemiology & Public Health, and Geology and Geophysics. One of the goals of YCEO is to bring these diverse groups together. By supporting a common method of analysis, i.e., remote sensing and GIS, the Center has created a central focus for geographic studies. Only with remote sensing can one keep abreast of the rapid changes occurring on our planet regarding land, ocean, ice, and atmosphere. In spite of the modest size of the Center, it is recognized on and off campus as a world-class organization, with its teaching and research having a significant impact internationally. Dozens of research projects, small and large, are carried out in the Center each year. (See http://www.yale.edu/ceo/).

European Heat Wave of 2003

An example of a YCEO research project is the recent remote sensing study of the European Heat Wave. Especially in eastern France, the late summer of 2003 was more than "two standard deviations" above normal summer temperatures, causing thousands of deaths and providing, some would say, a look into the future of global warming. This heat wave included small-scale features that could only be resolved with satellite remote sensing. This YCEO study was led by **Ben Zaitchik**, a PhD student in G&G.

By August of 2003, a coupled pattern of high temperature and vegetation loss was located over central France, controlled in part by terrain and land-use factors. The anomalies in vegetation index and surface temperature derived from MODIS are shown in Figures 1 and 2. The authors of the study concluded that surface feedbacks, especially in farmland and pastureland, amplified and focused the heat wave into the regions shown.

Fig. 1. Vegetation index anomaly from MODIS in France for August 13–28, 2003, compared with the same dates in 2000–2002 and 2004. Yellow pixels are unchanged while brown pixels have decreased the index by 0.4. (Zaitchik, BF; Macalady, AK; Bonneau, LR; Smith, RB. 2006. Europe's 2003 heat wave: a satellite view of impacts and land-atmosphere feedbacks. *International Journal of Climatology* 26 (6): 743–769).

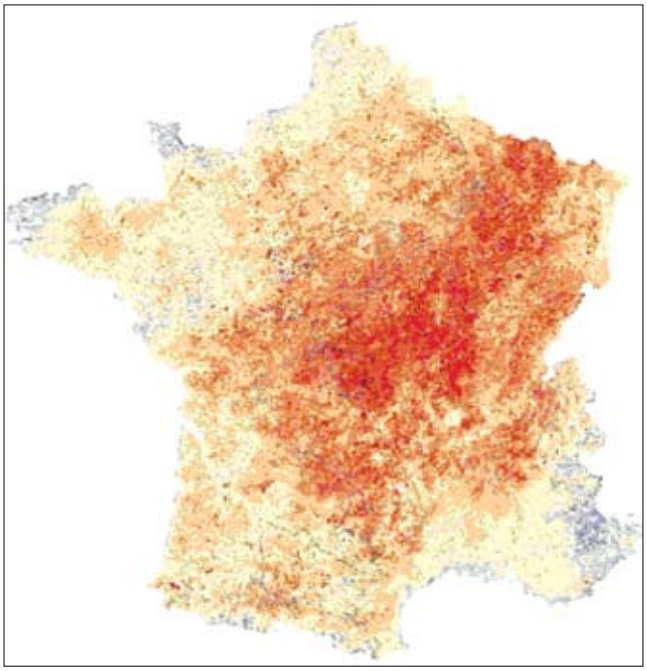

Fig. 2. Similar to Figure 1 but for surface temperature anomaly. Gray areas are slightly cooler, yellow is unchanged, and red is hotter by as much as 20°C.

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Stephen C. Porter '55 G '62 (scporter@u.washington.edu) has been elected an Einstein Professor by the Chinese Academy of Sciences (Academia Sinica), China's foremost scientific organization. He is the first Earth scientist to be so honored. An aim of the Academy in establishing the professorships is to help develop future academic leaders through the interaction of Chinese graduate students and foreign scientists. Porter, who served as Director of the Quaternary Research Center at the University of Washington from 1982 to 1998, first visited China in 1983 as a member of an American scientific delegation concerned with climate-related issues. Since 1985 he and Chinese colleagues have carried out field studies across the loess region of central China from Inner Mongolia to the northeastern Tibetan Plateau. Their research has focused on changes in monsoon climate during the glacial ages.

Craig Schiffries G '80 (cschiffries@geosociety.org) is the first Director of Geosciences Policy for the Geological Society of America (GSA). The new office is located in Washington at 1200 New York Avenue NW. The focus of the office will be directed to public policy and geosciences. Craig brings a lot of experience to his new position, having served as Director of Science Policy for the National Council for Science and Environment for the past five years.

Wilbur Cross Medal to John Suppe

Congratulations to **John Suppe G '69** (suppe@princeton.edu) on the award of Yale's Wilbur Cross Medal, October 9, 2007. The citation for the award read "He is the author or editor of five books, including the highly successful textbook, *Principles of Structural Geology.* He is considered the world leader in the study of fundamental forces that act to deform the upper portion of Earth's crust, concentrating on the role of large earthquakes and the development of new techniques for imaging active faults. He was the first to recognize the large-scale structure of the modern collision zone on the island of Taiwan, one of the most rapidly changing landscapes in the world. Taiwan was unknown to much of the geologic community until Suppe started publishing on the tectonic evolution of the area in the 1980s. That region is now one of the most intensively studied mountain belts in the world."

After receiving his degree from Yale in 1969, John joined the faculty at Princeton and he rose to become the Blair Professor of Geology. But John's life is turning in a new direction. He has resigned from Princeton—though he will retain a close connection—and he will take up the position of Distinguished Chair Research Professor at the National Taiwan University in Taipei, Taiwan. You can read about this move in *Making it Big in Taiwan, Nature*, v. 446, p. 695-697, April 2007.

Christopher Usher '83 (CUsher@lgc.com) (Alumni team, Henley rowing victory this summer, Chris second from the right) was appointed Senior Director of Landmark's DecisionSpace® and Innovative Technologies, effective October 1, 2007. In that role, he is responsible for the ideation, development, portfolio management, marketing and commercialization of all DecisionSpace and Innovative Technologies software.

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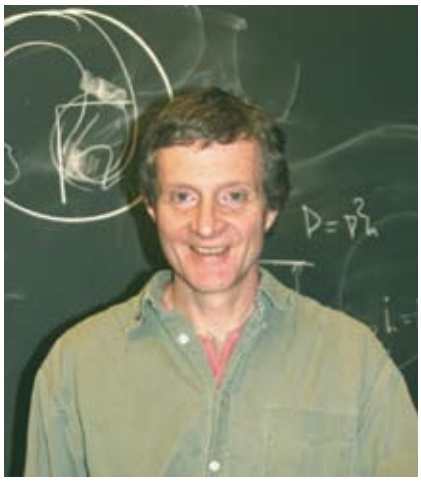

Don Canfield in front of the blackboard in the newly renovated auditorium, Kline Geology Lab, following his lecture on "The evolution of Neoproterozoic ocean chemistry."

On Nov. 28 and 29 **Donald Canfield G '88** (dec@biology.edu.dk) visited the Department and lectured on his recent work. Don is a leading expert on the biogeochemistry of sulfur and its application to the evolution of the global environment. His isotopic research and development of new field and laboratory methods have greatly advanced knowledge of microbial processes in the carbon, sulfur, and iron cycles. His ideas concerning the chemistry of the Proterozoic ocean and the evolution of atmospheric oxygen have been particularly influential in the ongoing debate about this enigmatic period of Earth history.

Don is Professor of Ecology at the University of Southern Denmark and Director of the Nordic Center for Earth Evolution. He was elected in 2007 to the U.S. National Academy of Sciences.

Kirk Johnson G '89 (kirk.johnson@dmns.org) has added a major public outreach component to his busy careers as a paleobotanist, and as Vice-President and Chief Curator, Research and Collections, of the Denver Museum of Science and Technology. Kirk and Sam Bowring of MIT have presented a series of live TV broadcasts to Denver middle schools as part of an EarthTime Project. They call themselves Tick and Tock the Time Guys and the project has now produced a 30-min CD that outlines the steps needed to get a U-Pb date from a zircon. Collaboration with the museum education staff produced supporting posters and bookmarks that are being distributed at national teachers conferences. Kirk says that he and Sam are now embarking on a series of teacher-training exercises for middle and high school students.

Kirk Johnson (right) Sam Bowring (left).

In addition to his TV exposure, Kirk has authored a number of educational books for young adults. The most recent two are "Cruisin' the Fossil Freeway, an epoch tale of a Scientist and an Artist on the Ultimate 5,000-Mile Paleo Road Trip," coauthored with artist Ray Troll, and "Gas Trees and Car Turds: A Kids' Guide to the Roots of Global Warming" coauthored with Mary Ann Bonnell, If you wish, both books can be obtained through the publishers at www.fulcrumbooks.com.

David Applegate '89 (applegate@usgs.gov) is the Senior Science Advisor for earthquake and geologic hazards at the U.S. Geological Survey. In that capacity, he leads the Earthquake Hazards, Global Seismographic Network, and Geomagnetism Programs and coordinates geologic hazards activities across the USGS. He also chairs the National Science and Technology Council's interagency Subcommittee on Disaster Reduction.

Applegate is an adjunct faculty member of the University of Utah's Department of Geology and Geophysics. Prior to joining the USGS in 2004, he spent eight years at the American Geological Institute as Director of Government Affairs and, for the last four years there, as the Editor of *Geotimes*, AGI's newsmagazine of the earth sciences. Before coming to AGI, Applegate served with the U.S. Senate Committee on Energy and Natural Resources as the American Geophysical Union's Congressional Science Fellow and as a professional staff member for the minority.

Congratulations to **Ethan Baxter '95** (efb@bu.edu) on the award of the Geochemical Society's Clarke Medal. After graduating from Yale, Ethan earned a PhD at the University of California, Berkeley, where Don DePaolo was his mentor, then he went on to Caltech for a postdoc spell with Paul Asimow and **Ken Farley '86**

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(farley@gps.caltech.edu). Ethan is currently on the faculty at Boston University.

The Clarke Medal is "Awarded annually by the Geochemical Society to an early-career scientist for a single outstanding contribution to geochemistry or cosmochemistry." The award went to Ethan because "his novel, integrative applications of isotope geochemistry, petrology, and transport theory have provided critical new insights regarding rates of deep crustal processes, forcing reexamination of both conventional petrologic models that assume equilibrium and of conventional interpretations of Ar-Ar geochronology based on closure temperature."

Lee Delattre Steinke **G '98** (leesteinke@comcast.net) is a Senior Geoscientist with Williams Production in Denver. Her husband, Tor, is also a geologist. They welcomed their first child, Tessa Marie Steinke, to the world on March 31, 2007.

Alena Bartoli '01 (ambartoli@gmail.com) sends greetings from the Middle East where she is currently working in college advising and curriculum development at King's Academy, a new coeducational boarding high school on the outskirts of Amman, Jordan. She is pictured here on a recent trip to Saudi Arabia at Addir'iyyah, the ancestral home of

the Sa'ud family. The ruins of the city date back to the early 19th century and are built of mud brick with limestone block foundations. While in Saudi, she wore the *abaya* and *hijab,* traditionally worn by women there, and found them quite comfortable, especially when clothing protected her from the sandstorm which cut short her trip to the ruins.

Matthias Bernet, G '02 (matthias.bernet@aya.yale.edu) has been appointed Assistant Professor at the University of Massachusetts, Amherst. Matthias's research interests are in detrital thermochronology for rates of exhumation and provenance studies, SEM-CL/optical microscopy studies for quartz provenance analysis, and all aspects of diagenesis and sediment petrology.

After receiving his degree from Yale, Matthias spent a year as a Postdoctoral Research Fellow at the University of Canterbury, Christchurch, New Zealand, then a year as a Marie-Curie Postdoctoral Fellow, and a further year as a Lecturer at the Universite Joseph Fourier, Grenoble, France. Most recently he has been an Assistant Professor at SUNY New Paltz; he will move to the University of Massachusetts in January 2008.

Congratulations to **Dana Royer G '02** (droyer@wesleyan.edu) on being the first recipient of the newly established Ebelman Medal of the International Association of Geochemistry. The medal, which is for "A geochemist of particular merit and outstanding promise who is less than 35 years old," was presented at the Goldschmidt Conference in August, in Cologne. Dana is currently an Assistant Professor in the Department of Earth and Environmental Sciences at Wesleyan University, Middletown, CT, where he is continuing his research on the use of plants and plant fossils in the reconstruction of paleo-environments.

Jeff Rahl, G '05 (rahlj@wlu.edu) joined the faculty of Washington and Lee University in Lexington, VA, as an Assistant Professor in 2006. Jeff is continuing his research into the formation, growth, and erosion of mountain belts to which he brings a variety of tools and approaches, including field work, ductile and brittle structural analysis, thermochronology, numerical modeling, and metamorphic petrology. After Jeff received his degree from

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Yale, he was appointed a Turner Postdoctoral Fellow at the University of Michigan, where he worked for a year with Ben van der Pluijm and Todd Ehlers.

George Gaylord Simpson Prize

Walton Green G '06 (walton.green@yale.edu) has assiduously avoided acquiring marketable skills in 12 years spent collecting degrees from universities on two continents. His recently completed doctoral dissertation proposes a new palaeoecological method for analyzing forests based on architectural attributes of the leaves they produce. In addition to plant palaeoecology, leaf architecture, and the graphical display of quantitative information. Walton was a coawardee of the George Gaylord Simpson prize for 2007 for his paper coauthored with Leo Hickey (2005) "Leaf architectural profiles of angiosperm floras across the Cretaceous/Tertiary boundary." *American Journal of Science* 305(10): 983–1013.

Erik A. Sperling (erik.sperling@yale.edu), who is still a graduate student, was a coawardee of the George Gaylord Simpson Prize for his paper, "A Permian-Triassic boundary section at Quinn River Cross, northwestern Nevada, and implications for the cause of the Early Triassic chert gap on the western Pangean margin," *GSA Bulletin*, May/June 2006, v. 118; no. 5/6; p. 733–746.

Student Discovery

Graduate student **Tyler Lyson** has a keen eye for fossils. Growing up in North Dakota he began looking for fossils in the Hell Creek Formation at an early age. His teen-age skills were honed by contacts with professionals working in the region, most particularly **Kirk Johnson G '89**, and in 1999, at age 16, he found three tail bones of a Late Cretaceous hadrosaur. In 2004 he returned as leader of a team to excavate the find and discovered that his hadrosaur was one of the very few ever found on which large, three-dimensional tracts of fossilized skin were present.

Excavations were complete by 2006 and the resulting 10-ton block containing the body and 4-ton block encasing the tail were removed to the North Dakota Heritage Center for final preparation. Tyler is carrying out research on the unusual state of preservation with **Derek Briggs**, and he is working on the paleobiology of the specimen with **Jacques Gauthier**. Eventually the fossil will be housed in a future museum in Tyler's home town of Marmarth, North Dakota.

Tyler at work excavating a fossil, 2005.

In Memoriam

Barbara Tahoe Talbot Washburn died on September 3, 2007. Tahoe Washburn was the wife of **Albert Lincoln (Linc) Washburn G '42**, whose death was announced in our Spring 2007 Newsletter. Linc and Tahoe were a team both in the home and in the field. Tahoe regularly accompanied Linc to the far northern Arctic and in 1999 published a book about their experiences, "Under Polaris: An Arctic Quest," by Tahoe Talbot Washburn, University of Washington Press, 304 p.

Kurt Servos G '54, died in April 2007. Kurt moved from Yale to Stanford, where he taught mineralogy. The Servos family lived in New Jersey, and when Kurt's father died, Kurt returned to run the family business. Apparently running a business was not to his liking, because in 1967 Kurt moved back to the West Coast where he was appointed to a professorship at Menlo College, a position he held until he retired in 1994.

Kurt was a great admirer of the work of the Dutch artist, M.C.Escher, and while Escher was alive (he died in 1972) Kurt corresponded with him and acquired seven of his engravings. Kurt left his Escher collection to the Yale University Art Gallery, raising Yale's collection from two to nine in the process.

George Moore G '60 died October 4, 2007 in a car accident in Oregon. George was a long-time member of the U.S. Geological Survey but in recent years had been appointed Courtesy Professor of Geology in the Department of Geosciences, Oregon State University. Among the many things George is remembered for his coining the word *speleothem*.

Ice Research

continued from page 10

growth morphologies.

Naturally occurring polycrystalline ice provides a compelling confluence of fundamental concepts in, among others, phase transitions, diffusive and advective transport, nonlinear free boundaries and mathematical homogenization, and links our research program to that of many branches of the department and many other departments as well as broad scale issues of interest to members of the society at large.

Annual Departmental Field Trip

Jay Ague explaining the geometry of deformation in the famous Purgatory Conglomerate, Narragansett Basin, Rhode Island. The photo was taken in September 2007 during the annual Departmental field trip to introduce new students and faculty to the geology of Connecticut and Rhode Island.

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Geology and Geophysics Department
Yale University
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New Haven, CT 06520-8109

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